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THE MECHANISMS OF EUTROPHICATION AND A PROPOSITION FOR THE IMPROVEMENT OF WEST LAKE, HANGZHOU

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Abstract

The mechanism of eutrophication in West Lake was studied, and the main factors underlying it were discussed. Based on the results of our discussions, three proposals are made for measurements to improve water quality. These are the effective utilization of drawn water, dredging of bottom mud, and the introduction of activities to promote citizen awareness of the problem.

Key words: Eutrophication, Mitigation, Counter measure, Blooming, West Lake

Introduction

Characteristics and Present State of West Lake

The West Lake, which is adjacent to Hangzhou City, is a famous sightseeing spot mentioned in famous old Chinese poems. It is approximately 200 km south-west of Shanghai and is located 120° 16' East and 30° 15' North. The total surface area of the lake is 6.03 km^2, although the actual water area is 5.66 km^2 due to banks which cross the lake. The lake's shape is almost square, being 3.3 km from north to south and 2.8 km from east to west. The lake basin is very shallow and flat having a 1.62m maximum depth and a 1.51m mean depth.

West Lake is divided into five smaller lakes (Wai Lake, Beili Lake, Xiaonan Lake, Yue Lake and Xili Lake) by artificial banks, the main basin being Wai Lake which has the largest area. In Yue Lake which is fed from a spring in the northwestern part of the lake, there are copious aquatic weeds, and nets to prevent an invasion of grass bisect the lake. The transparency of this lake is the highest among those in West Lake.

Hangzhou City adjacent to West Lake has one million inhabitants and many tourists, and domestic waste the main sources of the water pollution in this lake. At present, however, the domestic water, except for a small portion, does not flow into the lake directly owing to the establishment of a sewerage system. However, there are many tea fields in the catchment area, and the outflows of fertilizer from these fields remains a source of eutrophication in the lake. The following factors merit prior consideration so that measures may be taken in the future. Inflows of nutrients from urbanareas as a surface source, the release of nutrients from bottom mud of the lake, and water drawn from the Qiantang River to achive the purification of West Lake.

According to a report by Li (1996) on the present water quality of West Lake, the annual mean

values of the transparency of West Lake ranges from 42.7cm to 83.3cm, and Beili Lake has the lowest (42.7cm) among the five lakes. The main basin, Wai Lake, is second lowest at 48.6cm. Shaonan Lake drawing from the Qiantang River has the highest transparency of 83.3cm.

The relationship between the transparency (SD) and the amount of suspended solid (SS) is shown by the following equation:

$$\ln(SD) = 6.75 - 0.834 \ln(SS)$$

A characteristic of West Lake was found to be that the water transparency for the same amount of the SS in West Lake is lower than that of the water drawn water from the Qiantang River. For example, in the water of the Qiantang River the transparency for the 45 mg/L of SS is 75cm, while that of the same amount of SS in West Lake is only about 35cm. It is suggested that the difference is due to the occurrence of phytoplankton in West Lake. Thus, restraining the occurrence of phytoplankton is most important for the restoration of transparency in West Lake.

The COD values in West Lake range from 4.54 to 10.07 mg/L, and Beili Lake (10.07 mg/L) and Wai Lake (8.01 mg/L) show the high levels among the eutrophic lakes. The concentrations of total phosphorus and total nitrogen in West Lake as a standard of the eutrophic state range from 0.085 to 0.156 mg/L and from 2.2 to 2.5 mg/L, respectively. These are all high levels.

As a result, the amounts of chlorophyll-a in the lake range from 45.8 to 266 mg/m^2, and the difference among the five smaller lakes is very large. It is suggested that the difference is affected by the retention time of water and the concentration of total phosphorus in each lake. The maximum concentrations of COD and chlorophyll-a appear in October, and the dominant phytoplankton is blue-green algae.

Progress of eutrophication in West Lake

As a place of scenic beauty, West Lake has been the site of human activity for over 2000 years. Consequently, the sedimentation and the eutrophication of the lake water have progressed. However, there are few long-term scientific data on West Lake.

According to the report, "Introduction to the scientific studies of West Lake, Hangzhou", about the condition of West Lake after 1909 by Pei (1996), the origin of West Lake is a lagoon, and the lake water was brackish in early times. After that, the amount of fresh water gradually increased over time.

The shallow lakes in the lowlands are characterized by the ease with which they become eutrophicated due to inflowing nutrients from the watershed area and by the release of nutrients from the bottom mud accumulated over time. Furthermore, as human activities increased, the eutrophication of the lakes worsened by inflowing domestic water into the lake. There was little

waste, however, either quantitatively or qualitatively, related to daily life before the development of modern industry, and this did not lead to serious eutrophication. Rathe it was considered a good thing because it increased the production of fish in such lakes, which then became a food source for the local population. It is suggested, however, that the increase in the concentration of nutrients, phosphorus and nitrogen, and of the amount of sedimentation in the lakes laid the groundwork for the artificial eutrophication which progressed rapidly later.

Chan (1955) reported that there are few plankton and nutrients in West Lake. The Environmental Section of Hangzhou City and Hangzhou University carried out surveys on the eutrophication of West Lake from 1979 to 1982. These studies show that the eutrophication of West Lake reached a peak in about 1970. It is thought that the main cause for eutrophication is human drainage inflow.

In 1985, the study of the eutrophication of lakes was taken up nationwide as a top priority of the Chinese Science Committee. Their findings also supported previous data on the eutrophication of West Lake. After that, drawing water from the Qiangtnag River as a purifying countermeasure was realized, and the state of the lake has somewhat improved. However, improvement of the lake fell below expectations, and the transparencies, being measure of improvement, remain disappointingly low (1996).

The present Japan- China Joint Project was planned to radically improve the present state of West Lake. However, it has proven very difficult to find new measures more effective than those already tried.

At present, the target values of the renovation of West Lake, which are shown as numerical values are 60 cm for transparency, 2 mg/L for total nitrogen, and 0.08 mg/L for total phosphorus. While the Chinese national standard of transparency for lakes is 80 cm, that of West Lake has been set realistically lower. The improvement by drawing water from the Qiangtang River was expected to yield a transparency of 90 cm. However, in the present situation, since the inflowing water is itself turbid, reaching the established goal of transparency will be difficult.

The characteristics of mechanisms in the eutrophication of West Lake

The water budget, the COD balance and the nutrient balances are shown in Figures 1 and 2. The sources of loading are as follows:

1) Domestic water: They are accommodated into the sewerage system from the main urban region, but it is necessary to know more about the untreated regions.
2) Industrial drainage: In the area involved, there is little drainage except that from some sightseeing facilities.
3) Agricultural drainage: The area of the tea fields totals about 11% of the catchment area. It is necessary to know the fertilizer levels. According to the record of 1993, the concentration of nitrate nitrogen in inflows ranged from 4.38 to 6.61 mg/L, and even in the upper stream it was

from 2.79 to 2.87 mg/L.

4) Livestock drainage: It is necessary to determine the breeding numbers of livestock and the methods of drainage treatment.
5) Amount of the fish catch and fish culture in the lake: Annual amount of the fish catch in West Lake from 1985 to 1993 ranged from 227 to 296 tons, and the main species of fish was a kind of carp. The numbers of stocked fishes from 1985 to 1993 ranged from 680,000 to 1,270,000 have, and leveled off at 700,000 since 1991.
6) Loading from the urban area: The amount of direct inflow from the roads and ditches following a rainfall remains unknown.
7) Loading from tourism: No data exists on direct loading from tourists, but human waste on the island is regularly transported elsewhere.
8) Loading from forests: The loading amount from forests is calculated from the water quality and the flux of inflows. In the West Lake region, as it is not calculated by the unit amounts from each source, it can not be distinguished from the loadings of agriculture origin.
9) Loading from precipitation: This is not measured directly in the watershed area of West Lake.
10) Loading by drawing water from outside the watershed of the lake: The annual amount of water drawn from the Qiangtang River is 13.4 x 10^6 tons, but the period in which it is drawn is limited. The concentration of nitrate nitrogen in the drawn water was 1.39 mg/L in our study.

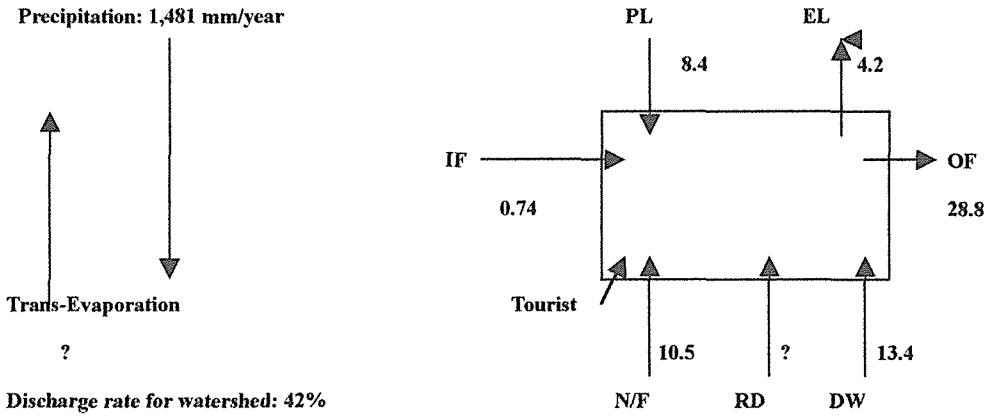
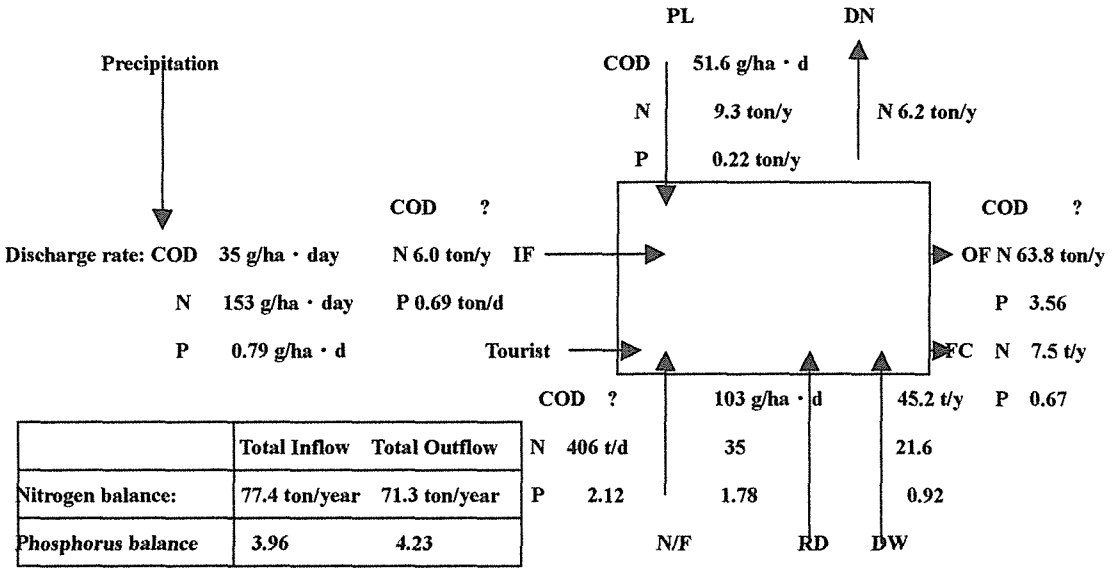


Figure 1. The water balance in West Lake. PL: precipitation into lake, EL: evaporation from lake, IF: inflow of drainage, OF: outflow from lake, N/F: inflow from forest and field, RD: inflow from roadside ditches, DW: water drawn from the Qiangtang River. (x 10^6 m^3/year)

The total amount of inflow: 33.04 x 10^6 m^3/year

The total amount of outflow: 33.0 x 10^6 m^3/year



	Total Inflow	Total Outflow
Nitrogen balance:	77.4 ton/year	71.3 ton/year
Phosphorus balance	3.96	4.23

Figure 2. The COD, nitrogen and phosphorus balance in West Lake. PL, IF, OF N/F, RD and DW the same as in Figure 1. DN: Denitrification; FC: Fish catch.

Characteristics of the ecosystem of West Lake

Natural lakes are formed with a balance between the ecosystem of the limnetic zone, in which the planktonic bio-community is the main component, and the littoral zone, which is composed mainly of aquatic plants and attached microorganisms. As eutrophication progresses, the role of the littoral zone increases and the complex relationship between aquatic plants is restored, acting as a buffer against stresses such as the load caused by the inflow of materials from the outside environment. Through this process, a new ecosystem is formed to maintain overall balance in the material cycles in the lake. One example of this is the phenomenon of water blooming seen in artificially eutrophicated lakes, characterized by the "blue powder" due to blue-green algae blooms peculiar to the summer season mostly in temperate lakes.

The ecosystem of West Lake is characterized by the lack of a littoral zone and the blooming of blue-green algae, which is caused by the eutrophication of the lake. It characteristics are listed in the following.

1) Morphological characteristics

a. The lake was originally an inland-sea lake, but at present state is a freshwater lake. This lake has undergone numerous artificial alterations.

b. The lake is shallow on the whole, and has thick sediment.

c. The inflows and outflow are not large, and the retention time is long.

d. The currents of the lake water are affected by the artificial banks, which divide it into three parts.

2) Physical and chemical characteristics

a. There is large nutrient loading from the inflows, including underground water.

b. There is significant release of nutrients from the bottom and re-suspension of bottom mud.

c. The shores of the lake are nearly all artificial embankments.

d. The transparency is low in all seasons because of the large amounts of suspended solids (SS).

e. The lake is a typical artificial eutrophic lake.

3) Characteristics as an ecosystem

a. Limnetic ecosystems are present in a much large proportion of the lake, with few littoral zones except in a park in the inner part of Yue Lake and in Beili Lake, where aquatic plants grow densely. Yue Lake has many submerged plants and Beili Lake has many emergent plants and lotuses.

b. The phytoplankton in summer is made up of blue-green algae, mainly *Microcystis* spp.

c. There is little zooplankton, with particularly low levels of *Crudocera*.

d. The benthic animals include *Chironomid* midges and *Tubificidae*, but their densities are low.

e. The standing stock of fishes is unknown, but it is estimated that the amount of fish stock in the lake is more than four times that of Lake Suwa, an eutrophic lake in Japan, based on the amount of culture and catch. The possibility has been pointed out that the amount of great stress on other aquatic animal microorganisms.

f. Despite the large standing stock of the blue-green algae, Microcystis, as a primary producer, the standing stocks of zooplankton as the primary and secondary consummers are very small indicating the poor material flow system in the ecosystem.

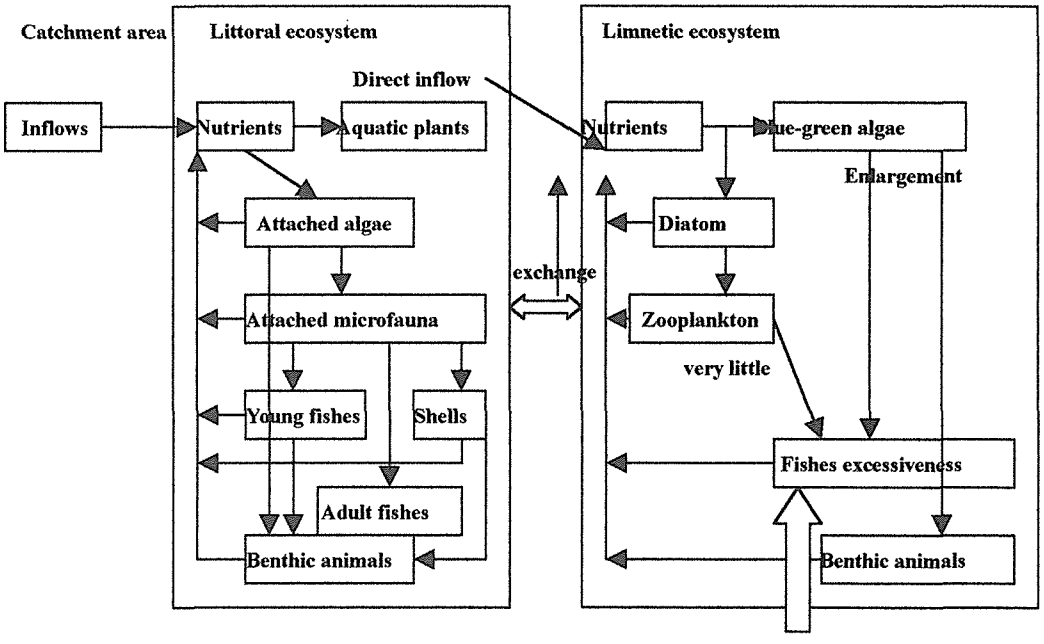


Figure 5. The structure of the ecosystem in West Lake.

In the ecosystem of West Lake, the nutrient load from the watershed area flows directly into the limnetic ecosystem due to the lack of littoral ecosystems (left side of Figure). In the limnetic ecosystem, the inflows of nutrients are utilized directly by blue-green algae, and the standing stock of this alga is enlarged. However, because there is little zooplankton to use this phytoplankton, the material cycles of the ecosystem do not function normally. The large stock of fishes in the lake another cause of the decreased standing stock of zooplankton, and is one of the factors in the obstruction of the material cycle system in the lake ecosystem.

g. Due to the lack of littoral ecosystems, the ability of the lake to absorb impacts from the terestrial areas is poor. Moreover, places are not secured for the reproduction of limnetic bio-communities.

The mechanism of nutrients loading in the lake

In West Lake the release of nutrients from bottom mud is the major factor in the loading of the inner lake. It is supposed that the water quality is affected by mixing actions produced naturally, such as by the wind, or artificially by boats. However, the shallowness of the lake helps preserve the aerobic state of the lake and control the release of phosphorus. At present the problem rather the release of nitrogen from decomposing organic matter in the bottom mud.

The inner load of nutrients in West Lake appears to come from the following:

1) Release from the bottom mud of the lake
2) Re-suspension of bottom mud (According to observations in the autumn of 1996, the precipitation speed of the re-suspended matter is high)
3) The decomposition of fish feces
4) The direct load by tourists, and the waste water from the islands in West Lake
5) The retention of nutrients produced by the decomposition of aquatic weeds

Factors in the eutrophication of West Lake

The factors in the eutrophication in West Lake are summarized below.

1. Morphologically, it is shallow.
   1) There is a great supply of suspension solids from the bottom, and a large nutrient load due to the decomposition of organic matter in the water.
   2) The release of nutrients from bottom mud measured per unit of water is particularly large.
2. Because the littoral zone is along artificial embankments, the ability of this zone to purify water is weak.
3. The composition of bio-communities in the ecosystem of West Lake is not in quantitative balance.
   1) Blue-green algae, the dominant producer in summer, grows to excessive levels.
   2) The standing stock of low-level consumers, which control the primary producer, is too small.

3) It is possible that the large standing stock of fishes controls the dynamics of low-level consumers.

4) Littoral ecosystems, which play the role of maintaining the limnetic ecosystem, are lacking.

4. The load of nutrients from the watershed

1) Load of nitrogen components from agricultural fields.

2) Drainage from urban areas.

3) Drainage from the tourist facilities.

4) Direct load on the surface of lake by precipitation.

5) Import of nutrients in water drawn from the Qiangtang River.

It is necessary that the measures adopted for the purification of West Lake be ones which can eliminate or mitigate the above factors.

Proposed measures to prevent the eutrophication of West Lake

The result of a simulation study by Ookubo (1997) suggests that two purge measures would be effective. One is the effective utilization water drawn from the Qiangtang River, and the other one is the removal of bottom mud by dredging. In the following, the pros and cons as well as remaining issues related to these two proposals are discussed. The target value for improvements was a water transparency of 60 cm in the summer in Wai Lake, the largest part of West Lake.

(1) Effective utilization of water drawn from the Qiangtang River

It is necessary that water from the Qiangtang River be drawn continuously at the rate of 2 ton/sec. From June to September, which it is the time of the early blooms of blue-green algae. If this is done, it can be expected that chlorophyll-a amounts will be held down to 2/3 of their present maximum values. Moreover, since the SS level in the lake will depend on the SS content of the water from the Qiantang River, it is predicted that SS will decrease to about 40 mg/L at the time when the drawn water has affected the entire lake. This will in turn reduce algal growth, so that transparency will become higher than 80 cm. Furthermore, if the SS content of the Qiangtang River could be decreased and to the nutrient content improved, even greater improvement of the water quality in Wai Lake could be expected.

To do this, water from the Qiangtang River would have to be introduced temporarily into a pond which acts as a bio-filter, with some type of device to decrease muddiness, before being introduced into Shaonang Lake. It is calculated that a retention time in the bio-filter pond of three to six hours would be necessary, and that the volume of the pond would have to be 20,000 to 40,000m^3. Furthermore, it is important that the surface of this bio-filter pond be covered with mainly emerged plants to increase its effectiveness as a bio-filter.

The problems with this plan whether or not it will be possible to secure a place to establish a

pond which acts as a bio-filter, and whether the increased concentration of chloride caused by water drawn from the Qiangtang River would affect the ecosystem of the lake; that is, it is that the freshwater ecosystem of the present lake shift to a brackish-water ecosystem as the chlorinization progresses ?

The present freshwater ecosystem would obviously shift toward a brackish-water ecosystem as the brackishness progressed. Natural brackish ecosystems are characterized by a diversity of bio-communities, and it has been commented that West Lake was also a brackish lake at one period in history. However, the effect that this would have on the present fish community should be fully investigated beforehand.

That the chlorinization of a lake has a large impact on the aquatic plants is known from the example of Lake Sinjiko in Japan. In the case of West Lake, aquatic plants are rich in the inner part of Yue Lake, and in this area, it is highly likely that underground water from the watershed area is flowing in. Thus, a plan which incorporates the following would be desirable. First, Yue Lake should be separated from Wai Lake, and the water from Yue Lake, including that collected from other watershed areas, should flow out via Beili Lake. Both Yue Lake and Beili Lake should be left as freshwater lake.

Although an improvement in transparency can be attained by decreasing the nutrient content in the lake water, the improvement of the lake as an ecosystem requires the quantitative restoration of balance among bio-communities.

Lake Suwa is a eutrophic lake in Japan with a standing stock of fishes per unit area among the highest of the lakes of Japan. It is calculated that the maximum fish catch is about 600 tons a year, compared to a fish catch in West Lake of about 300 tons at present. The lake volume of Lake Suwa is about 56 million m^3, against about 8.5 million m^3 in West Lake. While a simple comparison is not possible, because the main fish species in the lakes are different, it is supposed that the adjustment of the standing stock of fishes is an important problem in West Lake. Careful examination of methods to maintain an appropriate standing stock of fish in West Lake, and to make up for any decrease in fish catch caused by this with fish from other culture ponds, will be necessary in the future.

Our proposal is outlined in Figure 3, and issues which should be examined in the future are listed below.

1) The pros and cons of changing West Lake to a brackish lake.
2) If water is continuously drawn from the Qiangtang River (from June to September), the resulting changes in concentration of chlorine in West Lake should be estimated.
3) The possibility of the developing a bio-filter pond for water before entering Shaonang Lake, and the selection of aquatic plants to be grown in the new pond.
4) The possibility of diverting into Yue Lake the inflows from the watershed, and of separating Yue Lake and Beili Lake from the main West Lake.

5) The pros and cons of holding down the standing stock of fishes and the possibility of developing some lakes to compensate for the lower fish yield.
6) The effects of culturing freshwater pears.

(2) The restraint for the release of nutrients from bottom mud

This is done by dredging bottom mud which releases the nutrients. To do this work effectively, the bottom mud of the whole lake must be removed in a short time, within one or two years.

The dredging has two purposes. One is the elimination of the mud, which is rich in nutrients, and thereby decreases the nutrient release. The other is to reduce the concentration of nutrients in the lake water by increasing the water volume of the lake. It will be necessary to decrease the release of nutrients from the bottom mud by 40% in order to have an impact equal to that of drawing water from the Qiangtang River. While dredging 30-40 cm off the bottom surface is the goal, the possibility of attaining the target effect is low even if this much bottom mud is removed. To reduce the concentration of nutrients in the lake water to the desired level, it would be necessary to increase water volume by 40%. In the West Lake, with an average depth of 1.5m, this would mean dredging 60 cm from the entire lake bottom. The amount of mud as dredged would reach 34 million m^3, so the major problem would be to secure a place to dispose of this mud.

A negative result of the increase in depth would be a promotion of phytoplankton growth due to the increased the retention time of the lake water. Thus, although dredging the bottom mud is a fundamental measure, there will be serious difficulties with its implementation.

One possible method would be to improve water quality in only one relatively small portion of the lake, such as in Shaonang Lake and Xili Lake only, but this would still not solve the problem of the disposal of mud. Dredging would be taken up as one means of improving water quality, but questions have been raised as to judging the effectiveness of dredging. It is a method better suited to small ponds or stagnant reservoirs. In the case of West Lake, the lake is shallow and re-suspension of bottom mud would lead to a decrease in transparency and the release of nutrients, thereby promoting the growth of algae. Due consideration is therefore necessary before adopting the method of dredging.

(3) The human side of lake conservation

That two means for the restoration of the lake mentioned above are a concrete measure physical, but winning over the regional population to the goals of the project is also important. For this purpose, it is necessary to first establish goals for the quality purge that are easy for local residents to understand.

Lake Suwa in Japan may be given as a concrete example of this. "A Lake Suwa in which it is possible to swim" becomes the slogan of local residents. Although a scientific target value is a prerequisite, a phrase which will be embraced by citizens to help them feel a more personal stake in the goals of the plan is also necessary for its success.

It is clear from results in various other area that continuation of the recreation promotion movement started at West Lake in 1996 will lead to increased concern for the environment, and thus an improved overall living environmental including purification of the lake water. Several examples of activities to raise environmental awareness in Japan are given below. It is hoped that these as examples will help in the development of a program unique to the conditions of West Lake which will given the cooperation of local citizens.

1) Establishment of an Environment Day (exhibits, presentations, lectures)
2) Community activities to clean the shores of lakes and rivers
3) Recreational walks around the lake
4) Nature watching activities
5) Measurement of water quality against biological and chemical measures
6) Publication of a supplementary school textbook (the ecosystem of West Lake, water purification)

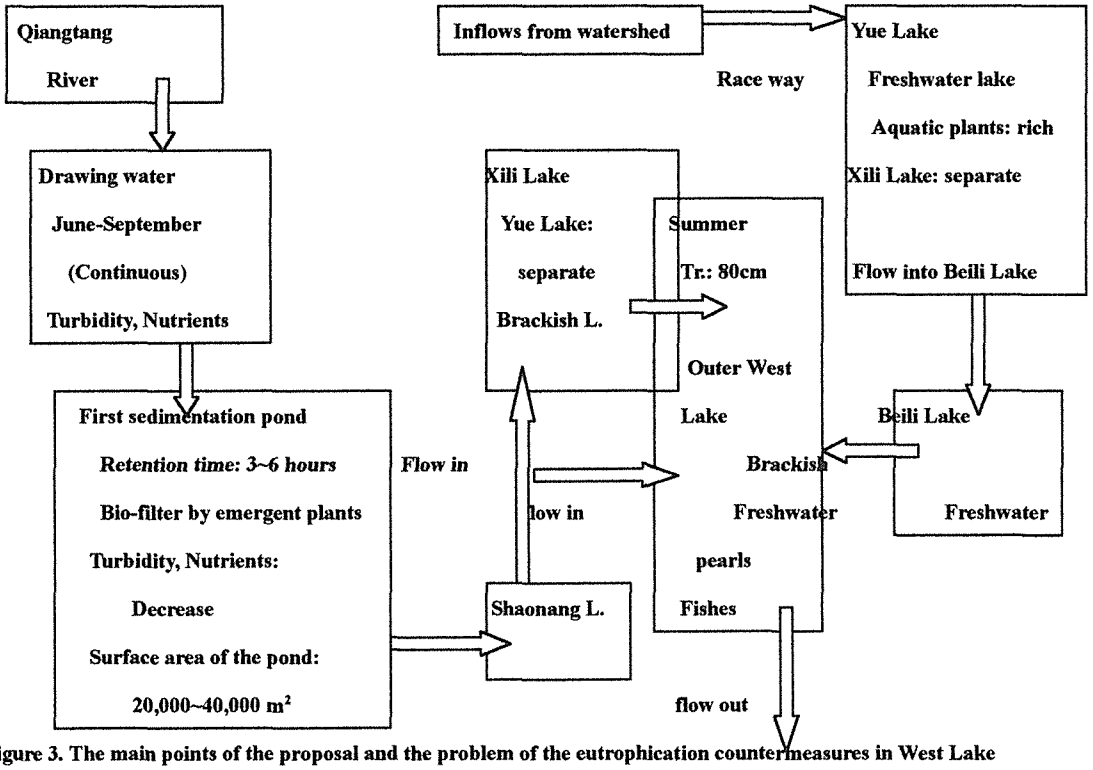


Figure 3. The main points of the proposal and the problem of the eutrophication countermeasures in West Lake

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