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The Water Quality of Lake Taihu and Its Protection*

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Abstract: *Lake Taihu, the third largest fresh water lake in China, with a surface area of 2 338 km², is located in the Changjiang River Delta, the most advanced economic zone in China. During the last two decades, the rapid economic development of local agriculture and industry both in the urban and rural areas of the region has made great advances. Great quantieis of pollutants have been discharged into the lake, its nutrient content has increased continuously, and phytoplankton blooms have occurred in some areas. Water quality protection in Lake Taihu is very important because of its close relation with economical development and people's daily life. It is urgent to have comprehensive pollution control in Lake Taihu. Based on water quality monitoring data in Lake Taihu from 1987 to 1994, the dynamic variations of water quality and eutrophication trends have been analyzed, showing obvious spatial and temporal variations. The main water quality factors were compared with the standard for drinking water and indicate considerable change with the seasons. Some basic strategies to protect water quality and prevent eutrophication are discussed.*

Keywords: *Lake Taihu, Water quality protection, Eutrophication, Dynamic variation.*

1. Introduction

Lake Taihu is one of the five famous and third largest freshwater lakes in China. The surface area of lake is 2 338 km^2, its maximum depth is 4.0m, the mean depth is 2.0m, and the total water storage is 52×10^8 m^3. It is a typical saucer-like shallow lake in its depth and shape.

Lake Taihu is the water collecting and distributing area of the Taihu catchment. There are more than 200 rivers entering Lake Taihu at present. Due to the catchment's topographic feature that it is high in the west and southwest while low in the northeast and southeast, the lake usually receives its inflow from the west and southwest and discharges to the northeast and southeast. However, because of changes of the seasons, the wind direction and the precipitation some rivers often change their flowing direction. The water renewal in Lake Taihu takes 308 days and the water exchange rate is 1.18.

The Lake Taihu Basin is located on the northern border of the subtropical broad left forest region, is belong to the south-east monsoon climate area. The rainy season always appears in summer and typhoons and rainstorms have considerable impact on the area.

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Lake Taihu Basin is famous for its natural condition and advantageous économic development with the highest population density and an intensive agriculture. Lake Taihu is not only the water source for industry and livelihood, cities and countryside, but also an aquatic farm and a famous scenic spot, authorized to be one of the special nation tourism zones recently. Along with population growth and economic development, human activities have exerted more and more influence and pressure on the ecological environment, and a large number of pollutants have been discharged into the lake, leading to an increase in lake nutrients and a deterioration of its ecology environment for many years. Investigation and research on eutrophication evaluation have been carried out for a long time on this lake (Carlson, 1977; Jφrgensen, 1980; Huang, 1993).

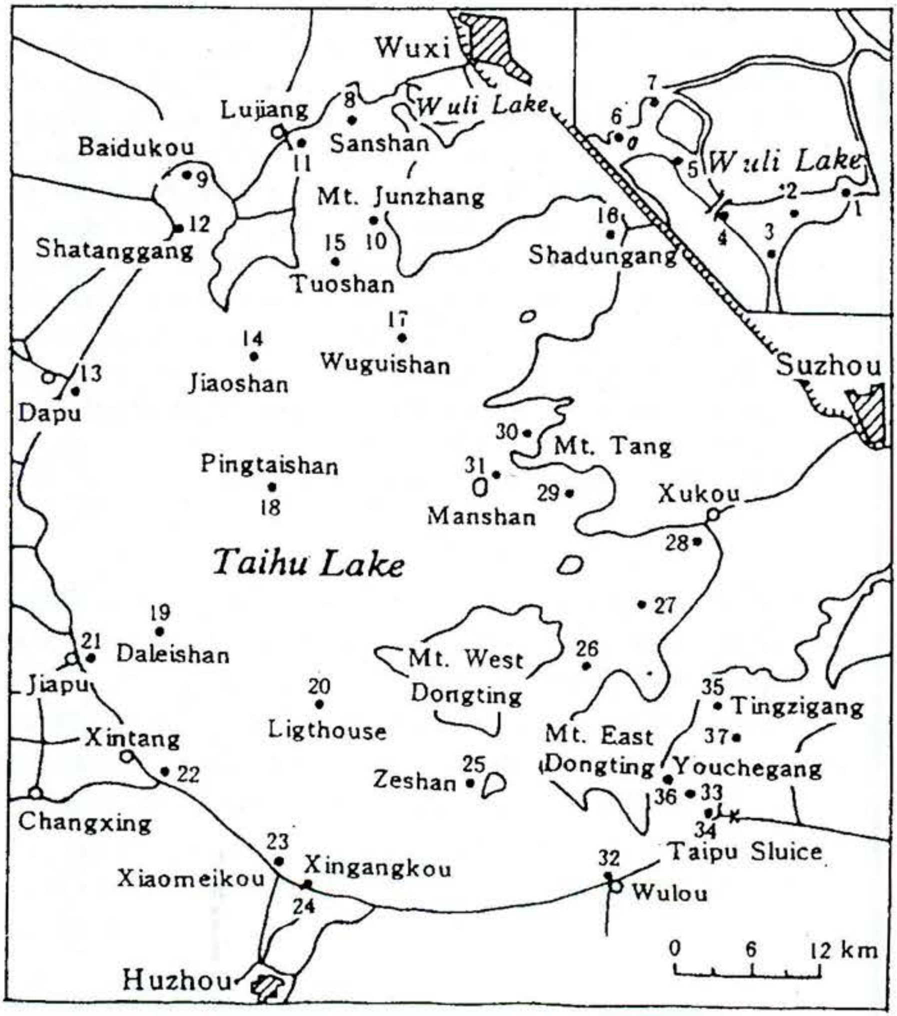

Fig. 1 Locations of monitoring stations in Lake Taihu (1987-1988)

2. Materials and Methods

The water samples were collected at 23 stations in Lake Taihu every two month since 1988 to 1994, during May, 1987 to March 1988 there are six times the water samples were collected at 37 station on Lake Taihu (Figure 1), in which some samples also obtained from 141 rivers around the lake in May, July 1987 and March, 1988 synchronously. Water depth, water temperature, current direction and velocity were determined at same time.

The water quality was monitored on every two month, including conductivity, SD, SS, pH, DO, COD_{Mn}, BOD_5, NH_4^+-N, NO_2^--N, NO_3^--N, TN, PO_4^{3-}, TP, Chlorophyll-a, algae biomass and primary productivity etc. analysis of results by statistics and spearman rank correlation coefficient method.

3. Results and Discussion

3.1 Water Quality Evaluation.

Lake Taihu serves as a source for drinking water, irrigation, aquatic production, navigation and tourism. The results of the analysis of the various water quality parameters were compared with the standards given by the Chinese National Environment Protection Bureau (CNEPB) for drinking water (Table 1).

Tab.1 Results of water quality surveys in Lake Taihu (1987-1988)

	Appar. Rate (%)	Min $mg \cdot L^{-1}$	Max $mg \cdot L^{-1}$	Average $mg \cdot L^{-1}$	Number exceeding	Exceeding rate(%)
PH	-	6.40	8.99	7.71	4	2.5
DO	-	0.69	14.20	9.00	6	3.6
COD_{Mn}	100.0	1.39	6.82	3.16	7	4.2
BOD_5	99.0	0	6.99	1.69	3	1.9
NO_3^--N	100.0	0.007	5.80	1.04	0	0.0
NO_2^--N	99.4	0	0.460	0.028	6	3.6
NH_3	86.7	0	0.102	0.0082	10	6.3
KN	100.0	0.02	5.832	1.112	70	41.7
TP	76.0	0	0.608	0.0579	68	40.0
TOC	93.2	0	15.90	7.84	41	23.3
PHN	6.1	0	0.0146	0.0002	1	0.6
CN	24.0	0	0.004	0.0006	0	0.0
As	10.2	0	0.004	0.00018	0	0.0
Hg	4.2	0	0.00075	9×10^{-6}	1	0.6
Cr^{6+}	9.5	0	0.002	0.00014	0	0.0
Cd	44.7	0	0.0015	0.00014	0	0.0
Pb	100.0	0.002	0.018	0.0075	0	0.0
Cu	100.0	0.003	0.022	0.0092	0	0.0
E. coli	100.0	$20\ L^{-1}$	$240000\ L^{-1}$		10	7.1
Total bacteria	100.0	$5\ L^{-1}$	$17400\ L^{-1}$		1	0.7

The results of this evaluation of water quality for drinking water standards change with the seasons. The average water quality in 1987-1988 was near the standard state, but after September every year it deteriorated and by March was worst (Table 2). Generally speaking, water quality in Lake Taihu is slightly pollution, however, major pollutant such as nitrogen, phosphorus, related nutrients, organic substances and eutrophication are already serious. This change in water quality apparently took place over the recent thirty five years. Heavy metal pollution almost does not exist.

Tab.2 The spatial distribution and evaluation of surface water quality in Lake Taihu

Year	Month	Type percentage of area (%)					Mean water quality	Main pollutant
		I	II	III	IV	V		
1987	May	0	28.3	43.5	28.0	0.2	III (3.0)	TP, TOC, KN, NH_3
	July	8.3	43.7	40.0	6.8	1.2	II-III(2.48)	KN, TOC, TP
	September	7.5	24.6	56.3	10.7	0.9	II-III(2.72)	TOC, KN, COD
	December	0.4	0.6	20.1	78.91	0.8	III-IV(3.78)	KN, TP, TOC
1988	March	0	0.0	0.0	87.8	12.2	IV-V(4.12)	KN, TOC, TP
1987-1988		0	0.0	81.2	18.4	0.4	III (3.19)	KN, TP, TOC, NH_3

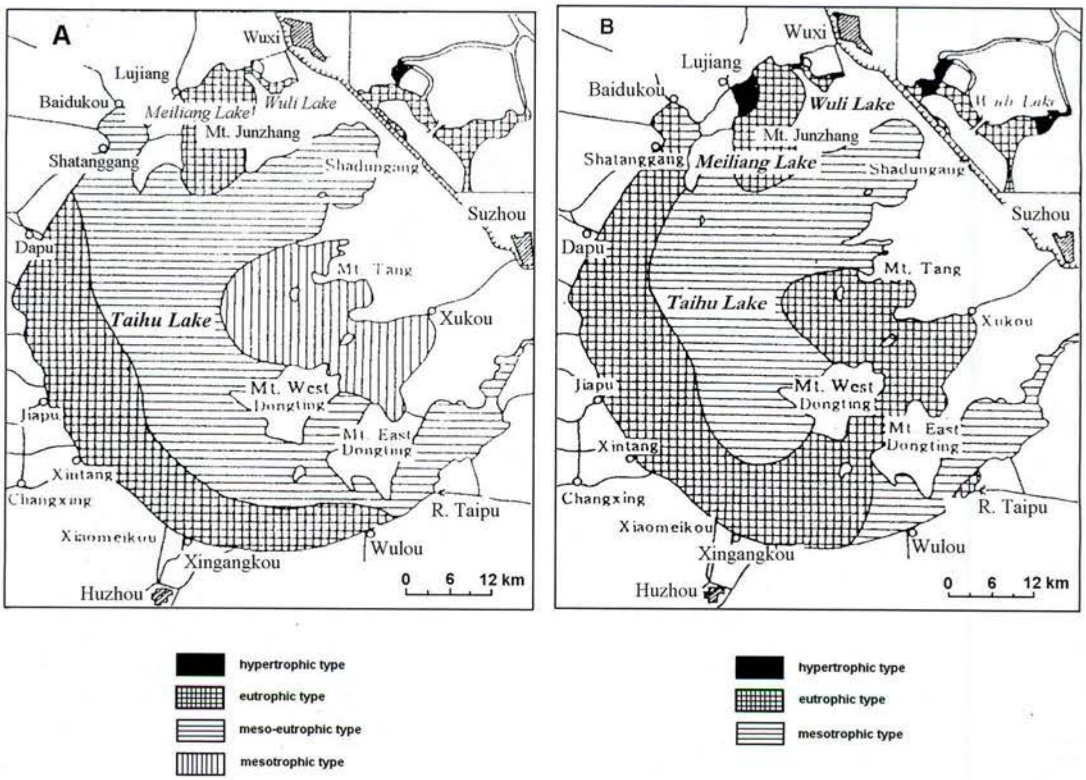

Fig. 2 The geographical distribution of eutrophic state in Lake Taihu. A: July 1987, B: March 1988

3.2 Evaluation of Eutrophic Status in Lake Taihu

According to the data collected in the period of May 1987 through March 1988, and based on data obtained from 37 sampling locations and application of the total score for ten indexes, the average value based on ten indexes was computed. So the type of eutrophication for a given water area is matched with TSIm. The geographical distribution of eutrophic types in different seasons is shown in Figure 2.

3.3 The Trend of Water Quality and Nutritional Degree of Lake Taihu

The variations of total nitrogen (TN), total phosphorus (TP), chlorophyll-a (Chl-*a*), chemical oxygen demand (COD_{Mn}) and biological oxygen demand (BOD_5) in different areas of Lake Taihu are shown in Figure 3. In Lake Wuli, TN and TP increased by 23.6 % and 62.1 from 1988 to 1989 respectively, and increased by 83 % and 100 % from 1991 to 1993 respectively, chl-*a* increased by 340.6% from 1988 to 1990. Lake Wuli is already a serious eutrophied water body. In Meiliang Bay, TP increased by 46.5 % from 1988 to 1990. TN in Meiliang Bay has already been higher than eutrophication standard, so it can be place in the eutrophicated grouping too. Sudden blooming of plankton in July, 1990 (Tab. 3) greatly affected the drinking water supply and caused an enormous loss of RMB 130 million. The water of the central lake body belonged to the middle-degree category of eutrophication. Along the lake shores, because of the pollution discharge from nearby areas, BOD_5 had an increasing trend (r_s=0.886) during the year. This indicated that pollution discharge along the shores were increased year by year. Organic pollution in main tributaries and the outlet of the lake was increasing, and the lake shore areas were classified as a eutrophied water body.

Tab. 3 Algae concentration near the inlet pipe of the Meiyuan Water Supply Plant in July 1990

Depth (m)	0.0	1.0	3.0	4.0	Ave.
Cell numb.10^8 L^{-1}	13.2	4.8	5.7	6.5	7.6
Biomass($mg \cdot L^{-1}$)	10.8	43.8	48.5	50.6	38.4

Meanwhile, recent monitoring in Lake Taihu shows that the all cell numbers and coverage areas of algae have conspicuously increased. The biomass of phytoplankton in Lake Taihu has increased rapidly in the past thirty-five years, especially since the 1980's. In the 1980's the average count of algal cells reached 9 200 cells$\cdot l^{-1}$ and 28.4 million cells$\cdot l^{-1}$ in 1991, a hundred times more than that in 1960's. The composition of dominant species has changed. The ratio of blue-green and green algal species exceeded diatoms, and now formed the dominant species. The change in the zooplankton community has been characterized by a reduction of the number of species and an increase of individuals. There were 91 species belong to different genera of zooplankton in 1991. The peak quantity was 1 184 ind$\cdot l^{-1}$ in western part of Lake Taihu. The composition and biomass of benthos and macrophtes were also under-going a significant change. All these phenomena show that the level of eutrophication in Lake Taihu is getting more serious, and the areas affected are becoming enlarged.

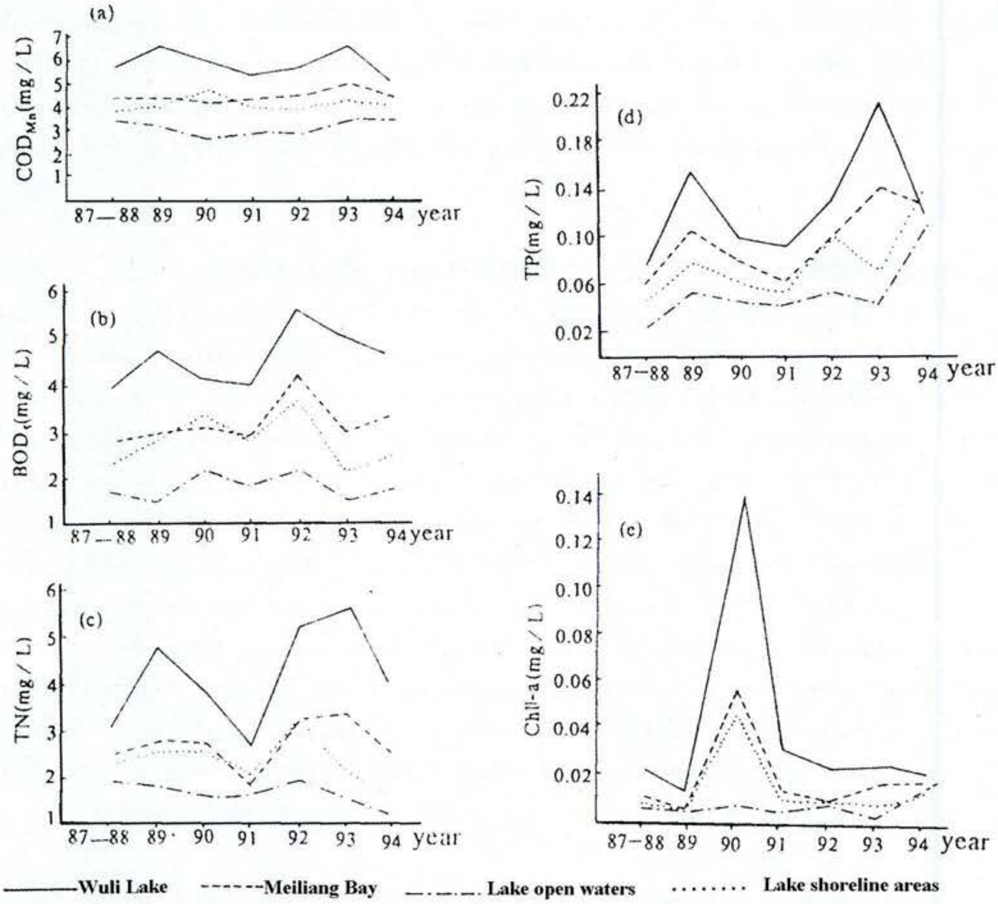

Fig. 3 Yearly variations of COD_{Mn} (a), BOD_5 (b), TN (c), TP (d) and Chll-*a* (e) in different districts

In order to quantitative measurement the trend of water quality change, use the spearman rank correlation coefficient method, the formulation as follows:

$$T_s = 1 - \frac{6\sum_{i=1}^{N} d_i^{\,2}}{N^3 - N};\ \ d_i = x_i - y_i$$

where d_i is difference between X_i and Y_i; X_i is the rank of the period 1 to N according to the concentration from small to large; Y_i is the rank according to the time. If T_s >Wp, the trend of change is obvious, here Wp is a critical value.

According to the rank correlation coefficient examination, the change trend of chl-*a*, TP, TN, BOD_5, COD_{Mn} all are increased obviously. Compared with that of 1993 and 1989, Chl-*a* increased

50%, exceed the middle nutritional elevel; TP in- creased 26.8 % which 1.8 times the water quality III class standard; TN increased 35.6 %, 2.6 times KN water quality III class standard; BOD_5 increased 23.3 %; COD_{Mn} increased 10.5 %, 1.08 times the water quality III class standard. It was indicated that the water quality was getting worse from 1989 to 1993. The nutritive index formation by chl-*a*, TP, TN, COD_{Mn} four parameters average value has been exceed 50 since 1988 (Fig.4). Among those, that of Lake wuli increased 10.35 % from 1987 to 1994, Meiliang Bay increased 15.25 %, Lake shoreline areas increased 15 %, lake open waters increased 19.2 %. All above indicted that the water quality of 1 700 km^2 open lake waters' nutritive index is increasing quicker than that of the 640 km^2 shoreline area, showing the seriousness of eutrophication degree in Lake Taihu.

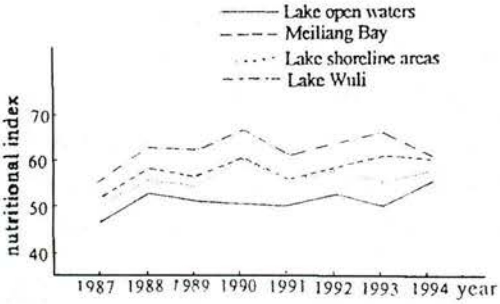

Fig. 4 Nutritional index and yearly variation in different lake districts

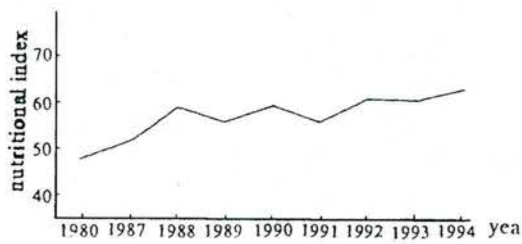

Fig. 5 Mark of nutritive states and yearly trend variation

The nutritive index of whole lake (average by 23 point samples) is increased obviously between 1980 to 1994 (Fig. 5), it is from 47.6 to 63.1, and the increasing amplitude is about 32.56 %. The nutritional degree was monitored from meso-oligotrophic - middle nutritive - meso eutrophic lake.

3.4 Study on Lake Taihu Water Quality Protection.

Water quality protection in Lake Taihu is a very important need which has close relations with economic development and people's daily life. It is very urgent to have comprehensive pollution control in Lake Taihu. The basic strategies to protect Lake Taihu and prevent eutrophication are as follows:

(1) Establish an organization for Lake Taihu water quality protection as soon as possible. The Lake Taihu catchment is 36 500 km^2, its environment and ecological factors are quite complicated, therefore, it is necessary to have an integrated authorization organization. The provinces and municipality in Lake Taihu Basin should realize the seriousness of the pollution of Lake Taihu, and should work together to invest capable man- power to form a Lake Taihu water resource protection committee, which has to organize and co-ordinate the pollution control in Lake Taihu.

(2) Set up and complete planning for Lake Taihu environmental protection. The Lake Taihu Basin

covers seven cities, 35 counties basin and 989 township (towns) with a population of 33 million. A master plan, with a phased programme and practical implementation schemes should be worked out. A developmental strategy which can coordinate the development of the economy, society and environment also should be repaired. By means of various incentive, constrained and coordinated measures including policy, planning, technology, engineering, economy, administration and legislation. The balance of the "resource, environment and sustainability" can be kept at a desirable level, so as to maintain the good circulation of Lake Taihu's natural ecological system by reasonable resource use, reuse and various manmade ecological systems. The ability to control environmental pollution depends on the economic and technical capacities as well as on environmental consciousness of the while society and of its management. There is a possibility that through the adjustment of economic social development strategies and the reform of economic-environmental policy and management system, correct policies and counter measure for the following items should be given high priority: (a) integrated and coordinated local development plans, (b) reasonable layout of industries and energy production, (c) technical progress of proposed new projects and old enterprises and (d) pollution control of main cities, towns, and natural resources protection. Thereby the objective can be reached, which is to alleviate the conflicts between economic-social development and environmental protection, and to avoid the occurrence of a vicious circulation of lake's ecosystem.

(3) To control the total quantity of pollutants entering the lake. Now economic development in this area shows the growth of "over-fulfilling and jumping". A lot of economic and technological development zones have been set up. The quantity of waste water is interrelated to economic growth, and the coefficient of elasticity is 40 %. It means: if the GNP grows 100 %, meanwhile, the quantity of waste water increases 40 %. so the economic development is this area with structural change and growth speeding will continue to accumulated the environmental pollution in Lake Taihu. To tackle the pollution problems has become more complex and arduous. Therefore, in order to limit the input of nitrogen and phosphorous, the prime objective is to reduce the nutrient loading carried by rivers that enters Lake Taihu. Due to this pollution is by non-point sources, including inflow rivers, it is much more serious than that by point sources, and it is essential to control this pollution pathway. In order to reduce non-point pollution, the most efficient measure of stopping the continuous expansion of pollution is to set up a sewage treatment project and enhance the standard of drainage water. Now due to the economic power and resources conditions, the sewage treatment plants should be set up preferentially close to cities around the lake, especially in those situated around the upper reaches such as Huzhou, Changxing and Yixing. The waste of large scale animal husbandry, fowl and fish farms should be controlled. Innovated technologies of using fertilizers and pesticides, reform of the farming system, afforestation, control of pollution from navigation and tourism must all be undertaken as soon as possible.

(4) To continue to do researches and experiments on water ecology projects, reduce the nutrient load from internal sources.

In 1991, the amount of nitrogen in the Lake water was 1.7 times more, and the amount of phosphorous was 3.5 times more than that in 1980. Therefore, it is important to alleviate the impact of interal nutrient loading on Lake Taihu.

Some water plants such as water hyacith can grow in the eutrophic areas to utilize the nutrients and absorb detritus. From 1991 to 1995, Some ecological engineering (biological, chemical and physical experiments) were carried out in several pumping regions of the drinking water plants around Meiliang Bay of Lake Taihu, and some good results were obtained. The ecological engineering not only protected the quality of the water supply, but also took nutrients out of the lake by removing the water plants, and also restraining the growth of algae. Reducing internal loading through ecological engineering and developing means to collect the algae is worth consideration.

(5) To adjust the industrial structure and its geographical distribution.

First it should be considered vitally to develop high technology industry and tertiary industry in this area, then control and move gradually the polluting factories, especially the heavy polluting factories to appropriate industrial zones together. In addition, when the development zones have been set up, it is important to pay concern to the environmental protection, perform feasibility studies of the new projects and evaluate the environmental influence.

(6) Use appropriate legislation to strengthen the public consciousness for environmental protection.

It is very important to draw up authoritative laws and policies and to strengthen public consciousness for environment protection. If the mangers of enterprise and relevant authority sections have no solid appreciation of environmental protection, it would be very difficult for them to pursue the environmental policies. Also the public with a low level of education will not understand the real harm of pollution. So it is very important to popularize the knowledge of environmental problems. The public's consciousness and supervision will give the vital go ahead for environment protection. In order to reduce the phosphorous concentration below 0.03 mg L^{-1} in Lake Taihu, appropriate policies and legislation should be established. The laws and regulations have to be in agreement with the practical water quality protection in the Lake Taihu water areas and should be worked out in the localities. Those which have been confirmed as appropriate through practice could turn gradually into regional laws and regulations so as to guarantee their validity in this lake basin. In addition to control the use of detergents, to gradually expand use non-phosphorus detergents by implementing certain measures.

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