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CAUSES AND CONTROL COUNTERMEASURES OF EUTROPHICATION IN CHAOHU LAKE, CHINA

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ABSTRACT: Chaohu Lake, located in the central Anhui Province, is one of the five largest fresh lakes in China. Now it is one of the three most eutrophication lakes in China. The deterioration of its water quality has influenced the sustainable development of society, economy and environment of Hefei City, the capital of Anhui Province. A series of measures have been carried out to control its eutrophication, but it is still serious. On the basis of the lake water quality data from 1984 to 2003, the causes of the eutrophication of Chaohu Lake are analyzed. Studies indicated that the suitable natural conditions and human activities played a crucial role in the process of the eutrophication of Chaohu Lake. A great amount of industrial, agricultural and domestic sewage discharged into the lake is the main cause of eutrophication in the lake. Land use, soil erosion and shoreline collapse destroyed the watershed eco-environment and the terrestrial ecosystem of Chaohu Lake. And the building of Yuxi Gate extends the sluggish of the nutritious substance and speeds up the process of the eutrophication. From the view of systematic engineering and watershed ecology, a series of the countermeasures have been put forward to control the eutrophication.
KEY WORDS: causes of eutrophication; eutrophication control; non-engineering measures; watershed management; Chaohu Lake

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1 INTRODUCTION

Chaohu Lake, located in the central Anhui Province of China, has multiple functions of flood control, water supply, irrigation, transportation, fishery and tourism. It is famous for its beautiful landscape and historic sites. For thousands of years the lake has created its special brilliant civilization in Chinese history, being regarded as a bright pearl of the Jianghuai Plain (the plain between the Changjiang (Yangtze) River and the Huaihe River). In the last decades, however, the pollution of the lake by the anthropogenic sources was becoming increasingly serious due to the rapid growth of economy and population in the basin and artificial regulation of the water flow. Therefore, nutritive matters such as nitrogen and phosphorous are greatly accumulated in Chaohu Lake. Water quality in the lake has been deteriorated and eutrophication of the lake has been formed to be feature of the lake, which results in adversely affects on the industrial and agricultural development, tourism and especially the drinking water supply for Hefei City and Chaohu City. At present, Chaohu Lake has become one of the three most eurtophication lakes in China attracting more and more attention in the world-wide-concern.

By far, a series of measures have been taken by national and local government to control the eutrophication process in Chaohu Lake. Anhui provincial government has started to control the eutrophication of Chaohu Lake since 1984. And the treatment of the eutrophication of Chaohu Lake was appointed by the government of China as a major project in 1995–2000. But the entrophication of Chaohu Lake is still serious. Causes or mechanisms of the eutrophication formation should be understood well enough (RYDING and RAST, 1992; PHILIPS, 1999). Lake eutrophication control countermeasures without such understanding lead to not only insufficient effects but also a harmful state (PEI and MA, 2002). There are some reports on the mechanisms of lake eutrophication, but the formation mechanisms are not well understood (QIN, 2002). As a typical nation-wide case study of lake eutrophication, comprehensive researches on Chaohu Lake has been carried out for more than 20 years (TU *et*

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al., 1990; JIN, 1990; XU, 1997; WANG and HU,1994; ZHANG *et al*., 1999). But it is still unknown in the causes of the eutrophication in Chaohu Lake well (YIN and ZHANG, 2003). We must first study the causes of the eutrophication in Chaohu Lake thoroughly before taking further countermeasures, so as to control the eutrophication in Chaohu Lake more effectively.

2 MATERIALS AND METHODS

2.1 Study Area

Chaohu Lake is located in the central area of Anhui Province, China, 15km from Hefei City, the capital of Anhui Province. The geographic coordination of its water area is 31°25′28″-31°43′28″ N, 117°16′54″-117°51′46″E. It is between two famous rivers of China, namely the Changjiang (Yangtze) River and the Huaihe River, and belongs to the right shore water system of the Changjiang River. The main characteristics of the lake are described in Table 1.

The watershed area of Chaohu Lake is 13 350km^2. There are 33 tributary rivers in the watershed of the Chaohu Lake. The main tributaries are: the Hangbu River and the Fengle River (they mixed before entering Chaohu Lake and formed a new river called the Xinhe River), the Paihe River, the Shiwuli River, the Nanfei River, the Zhegao River, the Baishishan River and the Yuxi River. The Yuxi River is the only outflow river (linking Chaohu Lake and the Changjiang River). The distance from the Changjiang River to the mouth of Chaohu Lake is 60.4km. Chaohu Lake has been changed from a swallow-spit lake into a semi-closed lake since the Chaohu Gate and Yuxi Gate were built in 1962 (Fig. 1).

2.2 Data Collection

In the water area of Chaohu Lake, there are 12 normal sampling sites and two automatic monitoring stations (Fig. 1). Of 12 sampling sites, 5 sites are set near the mouth area of main tributaries. Samples were taken from each site using water samples every month. All the samples were stored in a dark refrigerator (temperature 0-4℃). The 30 indexes including physical, chemical and biological indicators were measured or tested.

Table 1 Main characteristics of Chaohu Lake

Surface area(km^2)	Length(km)	Maximum width(km)	Length of shoreline(km)	Average volume($\times 10^9$m^3)	Maximum depth(m)	Mean depth(m)
770	54.5	21.0	184.66	2.07	6.78	3.0

Eutrophication is a process whereby water bodies receive excess nutrients especially nitrogen and phosphorous, causing an accelerated growth of algal (CARSON, 1977; OECD, 1982; SEIP, 1994; NICHOLLS, 1999;

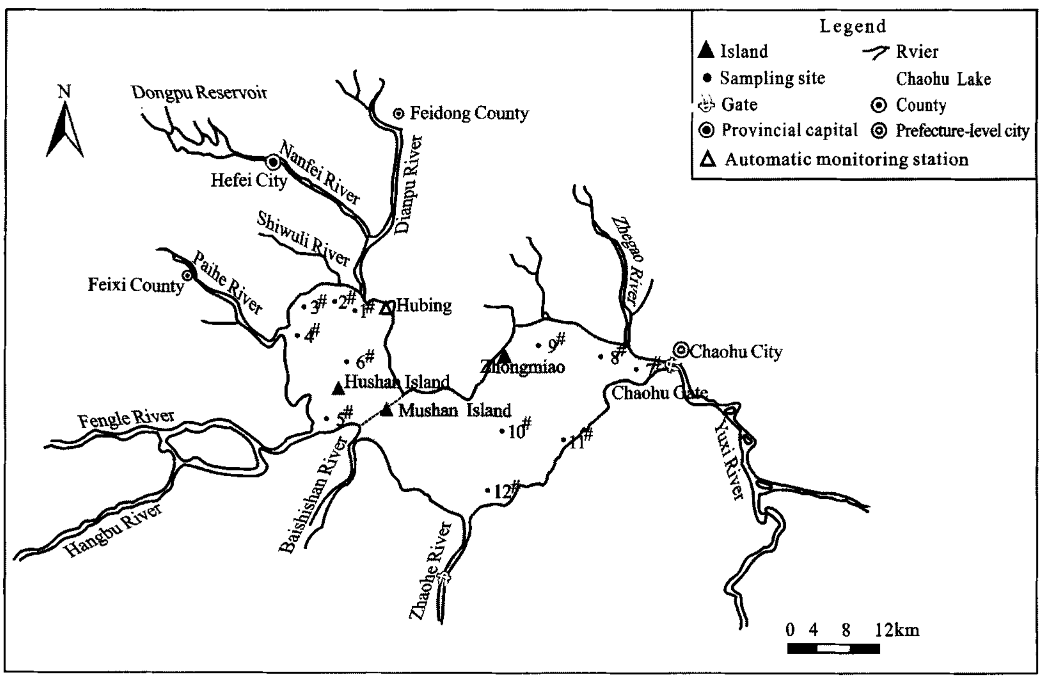

Fig. 1 Watershed of Chaohu Lake

LAU and LANEB, 2002). In this research total phosphorous (TP), total nitrogen(TN), COD_{Mn} and Chlarophyll-a (Chla) are chosen to describe the eutrophication status of the lake environment.

According to Grade Ⅲ of "The Environmental Quality Standards for Surface Water in China" (GB3838-2002), the variation of each indicator from 1984 to 2003 was described. There is no standard for Chla in GB3838-2002, so a table of trophic status index (TSI) was constructed to evaluate the spatial eutrophication distribution of Chaohu Lake (Table 2).

The following expression was used to calculate the lake eutrophicaion levels for each of the indicators:

$$TSI_i=(TSI_{k-1}+((C_i-S_{i,k-1})/(S_{i,k}-S_{i,k-1}))(TSI_k-TSI_{k-1})) \quad (1)$$

where C_i is the measured concentration of the ith indicator (i=TP, TN, COD_{Mn} and Chla), TSI_k and TSI_{k-1} are the kth and($k-1$)th scales of the ith indicator, $S_{i,k}$ and $S_{i,k-1}$ are the evaluation standards of kth and ($k-1$)th scales of the ith indicator. TSI_i is the trophic status index of the ith indicator.

$$TSI=(TSI_{TP}W_{TP}+TSI_{TN}W_{TN}+TSI_{COD}W_{COD}+TSI_{Chla}W_{Chla}) \quad (2)$$

where TSI_{TP}, SI_{TN}, TSI_{COD} and TSI_{Chla} are the eutrophication levels for TP, TN, COD_{Mn} and Chla; W_{TP}, W_{TN}, W_{COD} and W_{Chla} are the weighting factors for indicators respectively (assumed as 1/4 for each indicator in this paper).

Table 2 Eutrophication evaluation standards for Chaohu Lake*

TSI	Eutrophication level	TP (mg/L)	TN (mg/L)	COD_{Mn} (mg/L)	Chla (mg/m^3)
50	Mesotrophic	0.023	1.0	1.8	4.1
60	Upper-mesotrophic	0.050	1.5	3.6	10.0
70	Eutrophic	0.110	2.0	7.1	20.0
80	Hypertrophic	0.250	3.0	14.0	40.0
90	Dystrophic	0.550	4.6	27.0	100.0
100	Extremely dystrophic	1.200	10.0	54.0	200.0

Note: * Consulting the trophic status index and evaluation standards for lake eutrophication of OECD (1982) and Japan Environmental Institute (AIZAKI *et al.*, 1981), and for Taihu Lake eutrophication in China (JIN, 1990)

3 RESULTS AND DISCUSSION

3.1 Eutrophication Trends and Distribution

The pollution situation of the water area in Chaohu Lake from 1984 to 2003 were described in Fig. 2 to Fig. 5.

From Fig. 2 to Fig. 5 we can know that the water quality of Chaohu Lake can not be met Grade Ⅲ. The concentration of TP and TN exceeds the standards highly. From 1984 to 2003 the average concentration of TP was 0.253mg/L, exceeding the standard 4.06 times. The concentration of TN was 2.88mg/L, exceeding the standard 1.88 times. The mean concentration of COD_{Mn} was 5.41mg/L, which can meet Grade Ⅲ of the standard, but the highest concentration of COD_{Mn} was 8.13mg/L, exceeding the standard 0.355 times.

The distribution of eutrophication level in Chaohu Lake in 2003 was showed in Table 3.

According to Table 2 and Table 3, of the 12 normal monitoring sites, one site (1#) is in dystrophic status, five sites(2#–6#) are in hypertrophic status, and the other six sites(7#–12#) are in eutrophic status.

As we all know, the unusual increase of plankton and emergence of water bloom are main symbols of the eutrophication. Now there are 117 species of algae in Chaohu Lake, of which more than 90% are composed of Cyanophyta, Bacillariophyta, Chlorophyta and Euglenophyta (TU *et al.*, 1990). *Microcgstics aexuginoss* and *Aphanizpmenon flos-aquae* are dominant species. *Aphanizpmenon flos-aquae* grows in winter and spring, and *Microcgstics aexuginoss* grows in the summer and autumn. The algae in Chaohu Lake have grown from 0.5m to 1.5m under the water surface, and have covered all the lake.

3.2 Main Reasons for Eutrophication Formation

3.2.1 Natural conditions

The reasons for the eutrophication of Chaohu Lake are very complicated (BELER *et al.*, 1996; DOKULIL *et al.*, 2000). Firstly, the climate of the region is suitable. It belongs to subtropics monsoon climate zone. The annual mean temperature is 15–16℃. The mean annual precipitation is 1100mm. The mean annual wind velocity is 2.82m/s, from April to October the average wind velocity is only 2.60m/s. So the lake water flow induced by wind is very slow. Secondly, Chaohu Lake belongs to shallow lake. The average depth is only 3m. The slow

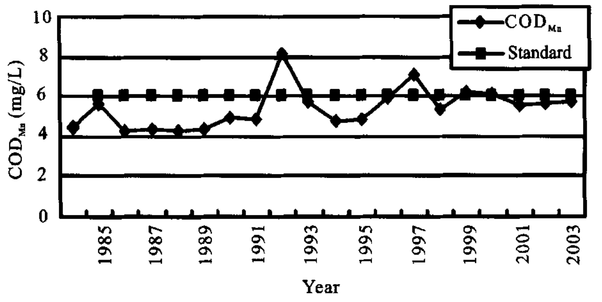

Fig. 2 Variation of COD_{Mn} in Chaohu Lake in 1984–2003

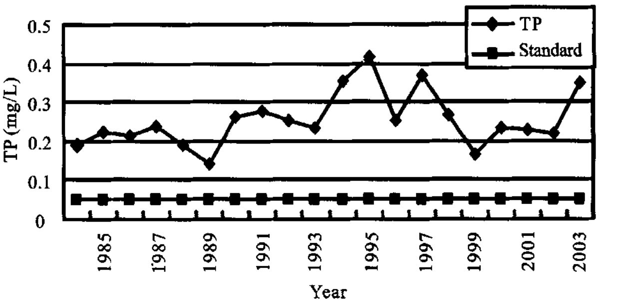

Fig. 3 Variation of TP in Chaohu Lake in 1984–2003

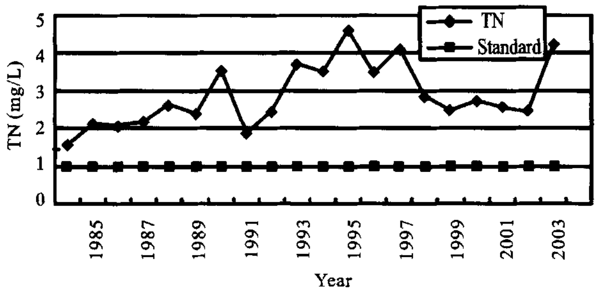

Fig. 4 Variation of TN in Chaohu Lake in 1984–2003

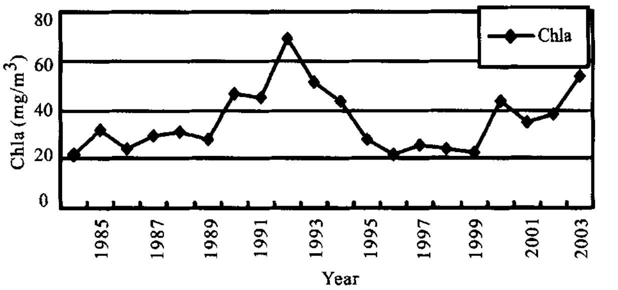

Fig.5 Variation of Chla in Chaohu Lake in 1984–2003

Table 3 Distribution of eutrophication in Chaohu Lake

Sampling site	1#	2#	3#	4#	5#	6#	7#	8#	9#	10#	11#	12#
TSI	80.9	79.3	76.1	74.4	74.2	73.7	65.8	66.7	67.6	66.4	68.7	66.7

flowing (the lake flow in non-flood period is induced by wind mainly, and the flow velocity is very small), the shallowness of the lake, the good sunlight, the rich oxygen in the water body and so on all provided a good condition for the growth and reproduction of the algae.

In addition, there is an area of 500km^2 phosphate mines in the north and northwest parts of Chaohu Lake watershed. And phosphate in soil natural background is high. It is very easy to move in the lake for the dissolved phosphates and to increase phosphorus concentration in Chaohu Lake.

3.2.2 Pollutants discharged into lake

A great amount of industrial wastewater and domestic sewage were discharged into the lake. There were more than 3000 industrial enterprises in the watershed of the lake. The annual discharge amounts of industrial wastewater were 142.0 $\times 10^6$t, while the domestic sewage reached 161.39$\times 10^6$t, of which 71.5% was from Hefei City. By 2003, there were about 8.77$\times 10^6$, people living in the watershed of Chaohu Lake, of which about 5.20$\times 10^6$ were engaged in agricultural production. Around Chaohu Lake there were all farmlands, and the use of chemical fertilizer and agricultural chemicals are increasing year by year. The annual average amount of chemical fertilizer reached 5360kg/ha. The forest coverage can only reached 15.5% in the watershed of the lake in 2000 lower than the average (25.6%) of that of Anhui Province in 2000. The area of soil erosion reached 1773km^2 in 1999, being 19% of the total area of the watershed. The eco-environment in the watershed of Chaohu Lake was heavily destroyed. The non-point sources were becoming the main sources of nitrogen and phosphorus in the lake.

About 68.5% of TP, 76.9% of TN flowed into the lake through rivers. Nanfei River, Fengle-Hangfu River and Paihe River account for 77.14% of TP, 78.97% of TN and 74.96% of COD of the total amount. While 26.9% of TP, 36.4% of TN, and 40.1% of COD from Nanfei River flowed into the lake, therefore, the mouth of Nanfei River was in dystrophic condition.

And the terrestrial ecosystem of Chaohu Lake is in a dangerous situation now. The length of the lake shoreline is 184.66km, of which 64.4km were collapsing shores and 95.76km were in silting situation. About 500$\times 10^3$m^3 of soil in every year was brought into the lake due to the shoreline collapse, thus resulting in the silt up of the lake, and destroying the landscape and wetland ecosystem. Consequently, such functions almost lost as the ability of corridor, filter and barrier for material, energy and information exchange of aquatic-terrestrial interaction. The biological diversity of the lake was reduced and the risk of the lake eutrophication was increased.

3.2.3 Risk of eutrophication

Closing Chaohu Lake extended the detention of the nutritious substance and speeded up the deterioration of aquatic eco-environment in the lake. Since the Yuxi Gate was built, the water flowing into Chaohu Lake from the Changjiang River has reduced from $1360\times10^6 m^3$ to $160\times10^6 m^3$ each year, thus making the ratio of water flowing into Chaohu Lake from the watershed to that from the Changjiang River through the Yuxi Gate decline from 1:0.45 to 1:0.05. So Chaohu Lake almost lost the ability to exchange water flow naturally. Its self-purification ability was much weakened, and the cycle time of water exchange was lengthened. It is advantageous to the accumulation of nitrogen and phosphorous and other nutrient matter in the lake. At the same time, the water level in winter is higher than before. The macro-aquatic plant cannot sprout and grow, and the species of aquatic plant are fewer and trend to be simplified. There were few competitors that can compete nutrient matters with algae in the ecosystem. Thus, it would lead to the eutrophication in Chaohu Lake.

3.3 Problem Analysis

In the process of controlling eutrophication in Chaohu Lake, some of the measures were proved to be effective, such as setting up sewage treatment plants (cutting down COD 16 000t/a, TP 260t/a, TN 3600t/a), cutting off all major industrial pollution sources to meet national discharge standards (cutting down COD 19 800t/a, TP 230t/a, TN 2500t/a), and banning the use of detergents that contain phosphorous (cutting down TP 255t). So from 1998 to 2002 the concentration of TP, TN, COD_{Mn} and Chla was cut down (the average concentration was 0.222mg/L, 2.62mg/L, 5.73mg/L and $32.5mg/m^3$ respectively), while from 1991 to 1997 they were 0.308mg/L, 3.40mg/L, 5.91mg/L and $40.5mg/m^3$ respectively. But in 2003 TP, TN and Chla increased again (the concentration was 0.349mg/L, 4.24mg/L and $53.3mg/m^3$). So there still were some problems in controlling eutrophication in Chaohu Lake. In this research, some problems were summed up as follows: 1) As a national total amount control index, COD was well controlled. While entrophication index TP and TN were not well controlled. 2) The industrial pollution sources were not stable. According to the investigation taken in 2003, there were 50%–60% industrial enterprises can not meet national or local discharge standards all the time. 3) The construction of sewage treatment plants and discharge pipes were not enough. And the reduction for nitrogen and phosphorus was not so effective in sewage treatment plant. 4) Nonpoint pollution sources were not paid enough attention to. And 40.3% of TP and 33.1% of TN was from non-point pollution sources, but the treatment for non-point sources still in trial period. 5) The treatment for inflow rivers was not satisfied. Especially the Nanfei River, which brings 26.9% of TP, 36.4% of TN to Chaohu Lakes, was not well treated.

3.4 Comprehensive Countermeasures

3.4.1 Enhancing monitoring, research and watershed management

In Chaohu Lake the base for eutrophication counter measures was integrated watershed management. The environment of lakes can be preserved basically with comprehensive environment protection programs and development plans for the whole watershed (JORGENSEN and VOLLENWEIDER, 1989; HAVENS *et al.*, 2001). The lake can only be managed efficiently when the information on which management decisions can be based is available. Therefore, it is an absolute necessity to establish and enhance monitoring and research systems.

3.4.2 Combining treatment of point with non-point pollution sources

Nowadays the non-point source pollution is drawing greatest concern, because of its growing contribution to lake water quality deterioration and of difficulty in its control (WELCH *et al.*, 1992; VERA and LASZLO, 2001). So in addition to making sure for the treatment of the point pollution sources, we should reduce the use of fertilizers and pesticides in agriculture, control soil and water erosion and take Hefei City and Nanfei River as major control areas.

3.4.3 Combining pollution treatment engineering with ecological restoration

Pollution sources are obviously the direct reasons for the lake eutrophication, so controlling pollution sources has been regarded as the preliminary step in the eutrophication control. Lake is an alive water body, so ecological restoration measures must be taken at the same time to make the lake ecosystem restored to normal cycle and eutrophication would be controlled basically.

3.4.4 Combining measures of water area with watershed

Lake is only a part of a big ecosystem in the whole lake drainage basin. From the point of the view of systematic engineering and watershed ecology, we should take some eco-technologies to build and resume the aquatic ecosystem in the water area, recon struct the natural vegetation of shoreline to recover the biological diversity and ecosystem in littoral zone, plant trees and develop eco-agriculture in land area and so on to recover watershed ecosystem.

3.4.5 Combining engineering with non-engineering measures

Non-engineering measures to manage lake include the measures of administration, legislation, economy, education and dissemination, etc. Non-engineering measures can ensure the pollution treatment of Chaohu Lake. So we can conclude that non-engineering measures play a key role in the treatment for the eutrophication of Chaohu Lake.

3.4.6 Public participation

One of the biggest challenges in the near future is the adjustment of the life style in order to make a safe and sound environment for future generations. Public participation on environmental aspects is of great importance. Even if the government impose strict rules and regulations for the protection of Chaohu Lake, the greatly success still depends on public attitude. The future environment will be shaped by the participation of them on environmental management at all levels. Only can everyone consider to do something for the lake, the eutrophication of Chaohu Lake would be solved in the near future.

4 CONCLUSIONS AND SUGGESTIONS

The water quality of Chaohu Lake can not meet Grade Ⅲ of GB3838-2002 now. The main pollutants are nitrogen, phosphorus and organic pollutants. From 1984 to 1990 the concentration of TP, TN, and COD_{Mn} were slowly increased, from 1991 to 1997 they were quickly increased, from 1998 to 2002 they slowed down and kept stable, but by 2003 TP and TN concentration were once again increased. According to TSI, of the 12 normal monitoring sites, one site was in dystrophic status, five sites were in hypertrophic status, and the other six sites were in eutrophic status in 2003.

The reasons of the eutrophication of Chaohu Lake are very complicated. Besides the suitable natural conditions, a great amount of industrial, agricultural and domestic sewage were discharged into the lake, and the building of Yuxi Gate extended the detention of the nutritious substance and speeded up the process of the lake eutrophication, which are also the main reasons for the eutrophication of Chaohu Lake.

Since 1984 a series of measures have been taken in Chaohu Lake. But TP and TN in the lake were not well controlled. Non-point pollution sources are not paid enough attention to. And the treatment for inflow tributaries was not satisfied.

Lake is a part of the whole watershed system, and it is an alive water body. The directions for controlling the eutrophication in Chaohu Lake must firstly be indicated, which are to strengthen watershed environmental monitoring and science research on integrated management and to make appropriate strategies for the future of the lake based on natural rules, systematic engineering and watershed ecology. A series of engineering measures will be taken in the pollution control and watershed ecosystem restoration, which still included non-engineering measures and to put all engineering measures into reality.

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