Chapter 2
Evaluation of Water Eutrophication on Taihu Lake-Connected Channels in Yixing City

Abstract Taihu Lake is one of the five largest freshwater lakes in China. The gross economy of the basin has an important contribution to the whole country. Meanwhile, it is the main source of drinking water for 40 million residents of the region. Hence, it is significant to take up research on water pollution prevention. In order to approach deeply the countermeasures for controlling eutrophication of the lake, 10 channels connected to Taihu Lake in Yixing were chosen to test the degree of eutrophication based on the Carlson trophic state index (TSI). By employing techniques to measure chlorophyll "a" and other chemical indicators such as nitrogen and phosphorus in water body of the channels, TSI was computed using formula, TSI = 10 (2.46 + ln Chla/ln 2.5). The results indicated that TSI, between 53.77 and 70.03, and chlorophyll "a" were suitable parameters to indicate the degree of eutrophication, as well as the content of TP. Through the measurement and evaluation, it was found that all the 10 channels were eutrophic, and the major cause was possibly the higher quantity of P in the channels. The location and land use type of these channels indicated that eutrophication, although a natural process over time, was often accelerated by human activities. Human beings influence the lake by increasing the concentration of plant nutrients, primarily phosphorous. These nutrients can enter the waterway through agricultural land, sewage, or wastewater and cause over enrichment.

Keywords Carlson trophic state index · Eutrophication · Taihu Lake · Chlorophyll · Evaluation · Lake-connected channel

Taihu Lake is one of the five largest freshwater lakes in China. The gross economy of the lake basin has significant contribution to the national economy. It is located at 119°31′–120°03′E and 31°07′–31°7′N and covers 2300 km^2, vastly situated/falling in Jiangsu Province (see Fig. 2.1). It is the main source of drinking water for 40 million residents of surrounding area and neighboring Shanghai and Zhejiang (Qin 2009). However, due to excess consumption of resources for the regional economic development, the eco-environment has been drastically deteriorated. From 80s in the last century, the water quality of Taihu Lake has descended one grade in every 10 year, and now, it has become a typical area of lacking quality water (Zhang et al. 2009). Although the government has given importance/attention

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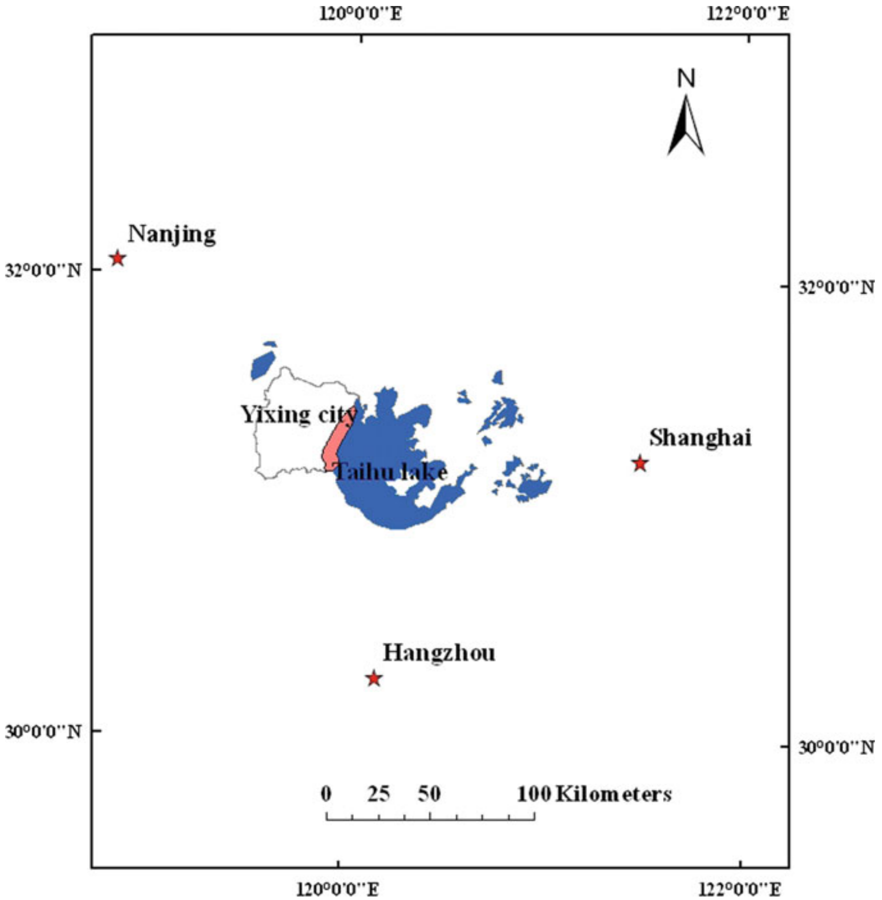


Fig. 2.1 Location of Taihu

to control the water pollution and taken many measures, mainly focusing on the point source pollution such as industrial wastewater decontamination and lake water cleaning, the water quality of Taihu Lake is still exasperate and the situation of water pollution is austere. The affair of blue-green algae bloom occurred in May 2007 alarmed the people and the government to realize the risk and hazards of eutrophication (Zhang et al. 2010; Zhu et al. 2008).

2.1 Introduction

The causes of water body pollution and eutrophication problem are complicated and multiple (Daniel et al. 1998; Heiskary 1985). With the rapid development of industry and the excess consumption of pesticide for agriculture, large amount of pollutants and nutrients such as nitrogen and phosphorus were drained into the lake and surrounding channels. These materials cause an overgrowth of algae and further deterioration of water environment, including oxygen depletion, which resulted in severe eutrophication (Chai et al. 2006a, b; Hu et al. 2010; Kennedy 2001; Zhang et al. 2007a, b).

Totally, 43 km of Taihu Lake water body is located in Yixing city, Jiangsu Province and now there are mainly 14 Taihu Lake-connected channels, whose water quality is rather different (see Figs. 2.2 and 2.3). It is obvious that the trophic state of these channels will have a certain effect on water quality of Taihu Lake (Qin 2009). Up to now this field has not been touched.

Hence, it is necessary and significant to evaluate the trophic state of these channels for water pollution treatment in the basin.

The trophic state is defined as the total weight of biomass in a given water body at the time of measurement. Various methods have been adopted for the classification of lakes and to indicate their trophic status (Chai et al. 2006a, b; Harper 1992). The most commonly and widely used method is based on productivity, while the frequently used biomass-related trophic state index (TSI) is that of Carlson (1977). This index requires a minimum data and is generally easy to

Fig. 2.2 One of the Taihu Lake-connected channels in Yixing (Photograph taken by Jianfeng Zhang)

Fig. 2.3 Another channel connected with Taihu Lake in Yixing (Photograph taken by Jianfeng Zhang)

understand, but the traditional nutrient-related trophic state categories are ideal for use in volunteer programmes.

Carlson's index uses a log transformation of Secchi disk values as a measure of algal biomass on a scale from 0 to 110. Each increase of ten units on the scale represents doubling of algal biomass. Because chlorophyll "a" and total phosphorus are usually closely correlated with Secchi disk measurements, these parameters can also be assigned TSI values (Carlson 1980). The Carlson TSI is useful for comparing lakes within a region and for assessing changes in trophic status over time. Ranges of TSI values are often grouped into trophic state classifications. The range between 40 and 50 is usually associated with mesotrophy (moderate productivity). Index values greater than 50 are associated with eutrophy (high productivity). Values less than 40 are associated with oligotrophy (low productivity).

In this test, 10 channels were chosen in Yixing to analyze their trophic state based on Carlson TSI. Here the method of Secchi disk was not employed instead of chlorophyll determination considering the available experimental conditions. Moreover, land use system along these channels was investigated, in order to analyze and find the influencing factors on the trophic state for specific channel.

2.2 Materials and Methods

2.2.1 Study Area Description

The selected 10 channels connected with Taihu Lake were located in Yixing (see Fig. 2.4). Water samples were started collecting in the beginning of August 2010 and continued through September and October in the year (see Figs. 2.5, 2.6 and 2.7).

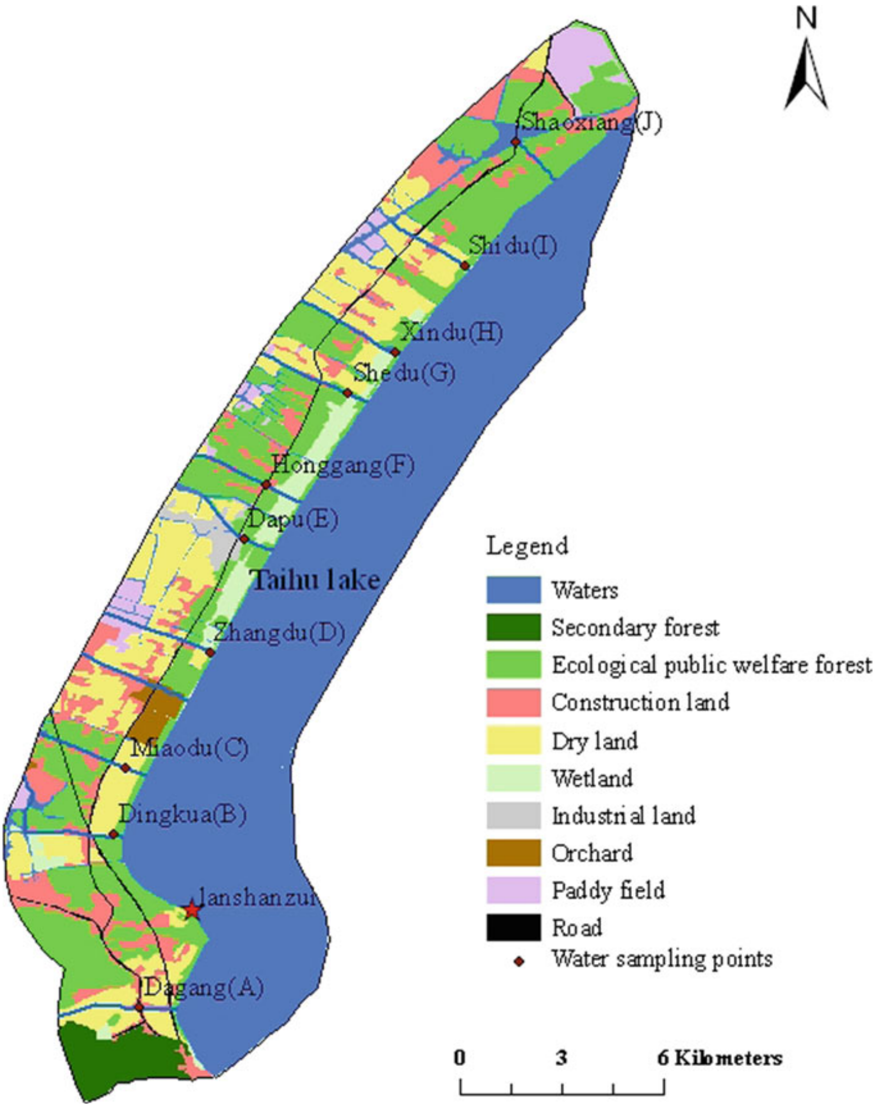


Fig. 2.4 Sampling sites at Taihu Lake-connected channels in Yixing

Fig. 2.5 One of the sampling channels in Yixing (Photograph taken by Ying Wang)

Fig. 2.6 One of the water quality monitor points in Yixing (Photograph taken by Ying Wang)

Fig. 2.7 Water samples collect in Yixing (Photograph taken by Ying Wang)

During the process, the global positioning system (GPS) was used to find the location of the 10 sampling sites. All of these 10 sites were located in the lacustrine zone. Their features are shown in Table 2.1.

2.2.2 *Determination of Parameters*

For each channel, water samples were taken by using an Alpha style horizontal sampler starting 1 m below the surface and continuing at 2 m intervals to the channel bottom. Approximately, 500 ml of water was collected at each sampling depth. At each site, water samples were mixed and brought to laboratory for analysis. A 250 ml portion of each water sample was filtered through a glass fiber filter, and the filter was frozen for chlorophyll analysis. The filters were ground with a tissue grinder in a solution of aqueous acetone, poured into conical tubes, and centrifuged at 500xG for 25 min. The supernatant was analyzed for chlorophyll "a" (Chla). Then, Chla concentration was measured by reading absorbance at 665 nm and 750 nm using a spectrophotometer (Unico UV-2000, Shanghai, China). A 100 ml portion of each sample was acidified to pH 2 with 6 N HCl and frozen for total nutrient determinations. A 25 ml portion of each acidified and unfiltered water sample was digested for total Kjeldahl N (TKN) and TP by using H_2SO_4 with mercuric sulfate as a catalyst. Total nitrogen (TN) was measured by the alkaline

Table 2.1 Sites description for sampling plots

Sampling sites	Latitude N	Longitude E	Above sea level (m)	Site description
Dagangkou (A1)	31.1897	119.8974	11	Village, commune habitat
A2	31.1897	119.8981	8	Entrance to the lake
A3	31.1894	119.9055	9	Entrance to the lake
Dingkuagang (B1)	31.2354	119.8901	5	Fallow land
B2	31.2354	119.8905	4	Abandoned land
B3	31.2349	119.8925	2	Abandoned land
Miaodugang (C1)	31.2613	119.8937	13	Garden
C2	31.2608	119.8954	10	Garden
C3	31.2746	119.9019	8	Garden
Zhangdugang (D1)	31.2823	119.9066	23	Forested land
D2	31.2824	119.9065	0	Wetland
D3	31.2840	119.9161	1	Wetland
Dapugang (E1)	31.2838	119.9160	1	Farmland
E2	31.2881	119.9213	3	Farmland
E3	31.3048	119.9264	4	Fallow land
Honggangdong (F1)	31.3279	119.9309	5	Watercourse
F3	31.3277	119.9316	4	Industrial zone
F3	31.3280	119.9315	4	Entrance
Shedugang (G1)	31.3335	119.9456	5	Poplar plantation
G2	31.3342	119.9431	5	Poplar plantation
G3	31.3373	119.9366	1	Bridge
Xindugang (H1)	31.3683	119.9558	3	Wetland
H2	31.3632	119.9652	6	Wetland
H3	31.3626	119.9658	3	Wetland; entrance
Shidugang (I1)	31.3855	119.9844	4	Entrance to the lake
I2	31.3862	119.9835	4	Entrance to the lake
I3	31.3870	119.9826	7	Entrance to the lake
Shaoxinggang (J1)	31.4190	119.9972	6	Poplar plantation
J2	31.4253	120.0125	2	Paddy field
J3	31.4236	120.0098	2	Paddy field

potassium persulfate digestion-UV spectrophotometric method. TP was analyzed by the ammonium molybdate method. All the above methods were described in detail by Huang (1999).

Data analysis was done based on SPSS version16.

2.2.3 Computation Carlson Trophic State Index

Considering the actual state of Taihu Lake, the formula to calculate Carlson TSI was modified as (Zhang and Li 2007):

$$\mathrm{TSI} = 10(2.46 + \ln \mathrm{Chla} / \ln 2.5)$$

where, TSI = Carlson TSI, ln = natural logarithm.

2.3 Results

2.3.1 TN, TP, and Chlorophyll a (Chla)

TN, TP and Chla in waters collected from different channels were analyzed and the results were shown in Figs. 2.8, 2.9 and 2.10.

All the three parameters are closely concerned with water trophic state. In general, bigger the quantity, higher is the trophic state, although the relation varies among the state and the indicator. However, for each channel, the values of parameters changed greatly. For example, TN for channel A was the highest, while for channel A, TP, and Chla were not so high.

According to the results depicted in Fig. 2.8, the highest value of TN was 4.32 mg L^{-1} in channel A, while the lowest value of TN was 1.98 mg L^{-1} in channel C. It is well known that TN is one of the crucial factors leading to eutrophication. For channel A, around the sampling site there are local people living and water samples were collected from the entrance of the channel. Usually, local residents throw garbage everywhere and living rubbishes are discharged into the

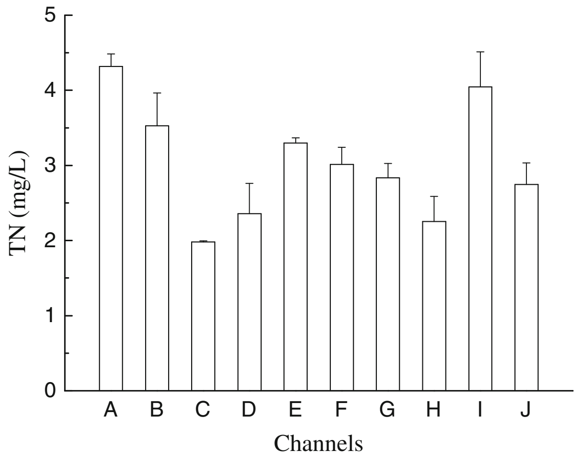


Fig. 2.8 Values of TN in different channels

Fig. 2.9 Values of TP in different channels

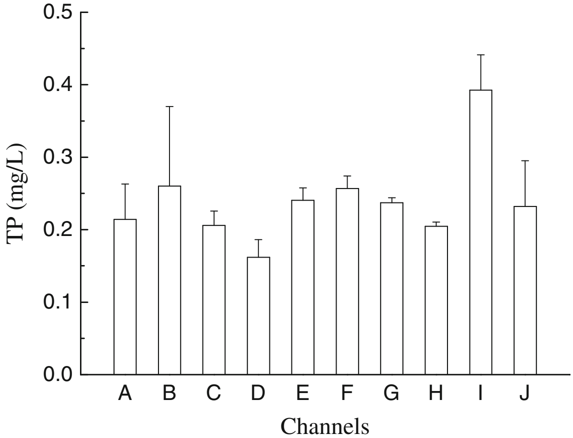
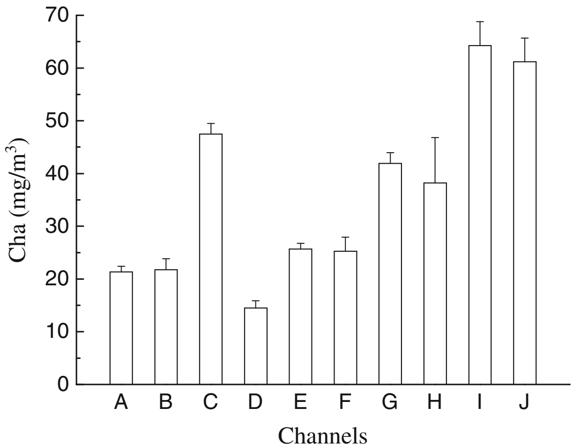


Fig. 2.10 Values of Chla in different channels



channel. Hence, it is understood that the highest value of TN occurred here. On the other hand, for channel C, the land use type is garden under the conditions of little chemical fertilizer application. Furthermore, the altitude of the sampling site is little high, which means that there are few sediments.

The highest TP value of 0.39 mg L^{-1} was recorded in channel I, while the lowest value of 0.16 mg L^{-1} was recoded in channel D (Fig. 2.9). It is clear that mostly P comes from soils due to soil erosion goes to channels. As given in Table 2.1, the sample site of channel I is at the entrance and the upper reaches of the channel are farm land which implies that more fertilizers and pesticides were applied. So sediments gradually increase at the entrance. In channel D, the land use patterns are forest land and wetland, soil and water erosion is prevented to a greater extent, moreover, part of P is taken up by aquatic plants in wetland.

In Fig. 2.10, it can be seen that the highest value of Chla is 64.26 mg M^{-3} was recoded in channel I, while the lowest value of 14.48 mg M^{-3} was in channel D. Obviously, the result is similar with TP. Previous research has also demonstrated strong relationship between P and Chla in lakes (Heiskary 1985).

2.3.2 Carlson Trophic State Index

Values of Chla from specific channels were put into the formula: TSI = 10 (2.46 + ln Chla/ln 2.5) and the results are presented in Table 2.2.

The data in Table 2.2 showed that the values of TSI were different for each channel. The highest is 70.03 for channel I, while the lowest is 53.77 for channel D. No doubt the result is similar to TP and Chla (Dillon and Rigler 1974).

A lake is usually classified as being in one of three possible classes: oligotrophic, mesotrophic, or eutrophic. Lakes with extreme trophic indices may also be considered hyperoligotrophic or hypereutrophic. Table 2.3 demonstrates how the index values translated into trophic classes (Carlson 1980; James et al. 2009).

According to data in Table 2.3, these channels fell into Eutrophic state in view of TSI, although there was more or less a little difference among the channels. Oligotrophic lakes generally host very little or no aquatic vegetation and are relatively clear, while eutrophic lakes tend to host large quantities of organisms, including algal blooms. Each trophic class supports different types of fish and other organisms, as well. If the algal biomass in a lake or other water body reaches too high a concentration (say <80 TSI), massive fish die-off may occur as decomposing biomass deoxygenates the water.

The data in Table 2.3 showed that, when TSI is 50–70, TP is 24–96 (μg L^{-1}). However, the Fig. 2.8, indicated that the content of TP is too high, which means that the main cause of eutrophication is TP for these channels in Yixing.

Phosphorus is often regarded as the main culprit in cases of eutrophication in lakes subjected to point source pollution from sewage. The concentration of algae and the trophic state of lakes correspond well to phosphorus levels in water

Table 2.2 Values of TSI for target channels

Channels	TSI(Chla)
Dagangkou (A)	57.98
Dingkuagang (B)	58.20
Miaodugang (C)	66.72
Zhangdugang (D)	53.77
Dapugang (E)	60.02
Honggangdong (F)	59.83
Shedugang (G)	65.36
Xindugang (H)	64.36
Shidugang (I)	70.03
Shaoxianggang (J)	69.49

Table 2.3 Trophic classification based on TSI, Chla, TN, and TP

TSI	Chla/(mg m^{-3})	TP/(μg L^{-1})	TN/(mg L^{-1})	Trophic class
<30–40	0–2.6	0–12	0.05–0.16	Oligotrophic
40–50	2.6–20	12–24	0.16–0.31	Mesotrophic
50–70	20–56	24–96	0.31–1.20	Eutrophic
70–100+	56–155+	96–384+	1.20–9.10+	Hypereutrophic

(Dong et al. 2008; Smith 1982). Studies conducted in the experimental Lake Area in Ontario have shown a relationship between the addition of phosphorus and the rate of eutrophication. Humankind has increased the rate of phosphorus cycling on earth by four times, mainly due to agricultural fertilizer production and application (APIS 2005). The controls of point sources of phosphorus have resulted in rapid control of eutrophication, mainly due to land use changes (Zhang et al. 2008).

2.4 Discussion

The results indicated that all the 10 Taihu Lake-connected channels are eutrophic based on the values of TSI. It is understood that around these channels are farmlands, e.g., paddy and garden of cash trees and vegetables, in addition to villages and industrial zone (Table 2.1). In this case, non-point source pollution is getting serious. Of the causes of eutrophication for these channels land use system is crucial and vital.

In order to promote plant growth and to increase agricultural production, local people often apply many nitrogenous and phosphate fertilizers. This encourage/facilitate run-off when rainfall or irrigation occurs. The way of N, P outflow includes: (1) enters the ground water along with the surface runoff; (2) forms the subsurface current (in soil), carrying on the transversal motion through the soil, then goes into the ground water body; (3) infiltrates through the soil to the ground water. The first 2 ways are primary cause leading to water eutrophication (Horne and Goldman 1994). Recent research indicated that the phosphorus can be dissolved or absorbed in soil particles and move through soil subsurface current, then enter the river, the lake or the bay. But for nitrogen, its seepage ability is strong, can infiltrate and pollute the ground water (James et al. 2005). For nitrogen and phosphorus, during the process of adsorption and desorption in soil, some part dissolves in the water, another part with the soil particle deposition, becomes bottom sediments in the lake or the river.

In addition, excessive application of domestic animal excrement in farmland also will cause the nutrients outflow along with the surface runoff, thus pollute the water body.

Human activities also can accelerate the rate at which nutrients enter ecosystems. Runoff from agriculture, pollution from septic, sewers, and other human-related activities increase the flux of both inorganic nutrients and organic substances into terrestrial and aquatic ecosystems (Harper 1992).

However, it must be pointed out that during the period of sample collection, the rainfall is lower than in normal years. Moreover, these channels are small, i.e., the volume of water flow is low. Thus, the content of TN and TP is getting high (Allan and Castillo 2007).

2.5 Conclusions

The techniques to measure Chlorophyll "a" and other chemical indicators such as nitrogen and phosphorus in water bodies of the Taihu Lake-connected channels were employed. The results showed that Chlorophyll "a" is one of the suitable parameters to indicate the degree of eutrophication based on Carlson TSI, and it is closely related to the content of TP. Through the measurement and evaluation, it is found that all the 10 channels are eutrophic. The major cause of eutrophication is possibly due to higher P content in waters. Based on the location and land use type of these channels, it can be inferred that although eutrophication is a natural process over time, it is often accelerated by human activities termed as cultural eutrophication. Humans influence the lake by increasing the concentration of plant nutrients, primarily phosphorous. These nutrients can enter the waterway through agricultural land, sewage, or wastewater which can cause over enrichment.

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