**Constructive wetland technology and its application in water quality control of south lake system**

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**Abstract.** Constructed wetland technology is widely used. It has significant effect in the removal of eutrophication factor N, P. From the wetland development and cleansing mechanism of The paper introduces the constructed wetland technology in the use of water treatment of lake form the development of the constructed wetland and the derergency mechanism. The paper especially introduces its application in water quality control of south lake system. In order to analyze the total phosphorus load, it analyze the annual water diversion by the water balance. It discusses the design points of the constructed wetland used in the south lake system. Finally, the outlook of the research in the constructed wetlands and it’s application in eutrophic lake pollution control.

1. **Introduction**

Constructive wetland is an artificial system that simulates the structure and function of natural wetland. It uses the physical, chemical and biological triple functions provided by matrix, aquatic plants and microorganisms to realize the treatment of sewage. It has many advantages such as: low investment, stable treatment effect, low operating cost, simple operation and so on. Therefore, the constructive wetland technology has broad application prospects in the sewage treatment and water quality control.

2. **Development Status of Constructive Wetland and Its Decontamination Mechanism**

2.1 Development status of constructive wetland

Constructive wetland originated in the 1950s and gradually evolved into the main unit of sewage treatment after the 1970s. At least 6,000 constructive wetland systems in Europe and over 1,000 constructive wetland systems in the United States are currently operating. The number of constructive wetland systems is increasing in South America, Australia, New Zealand, Asia and Africa[1]. However, China did not begin research on constructive wetland until the "seventh five-year" period. According to relevant surveys, before 2006, there were more than 200 constructive wetland systems with an area of 100 m\(^2\) to 8000 m\(^2\) in China[1]. The using of constructive wetlands to control agricultural non-point source pollution can produce better economic and environmental benefits in China.
2.2 Decontamination Mechanism of Constructed Wetland

Constructed wetland remove dissolved organic matter by microorganisms living in it. And particulate organic matter is quickly removed by precipitation and filtration. Microorganism removes dissolved organic matter primarily through aerobic and anaerobic degradation. The degrade of heterotrophic bacteria produces carbon dioxide. The degrade of facultative anaerobes and obligate anaerobic bacteria produce methanol, fatty acids, hydrogen, carbon dioxide. Anaerobic degradation of sulfate-reducing bacteria and methanogens produce methane, carbon dioxide, hydrogen sulfide [2].

A part of the inorganic nitrogen in the sewage can be absorbed by the plant and removed by the harvesting of the plant, while the organic nitrogen is mainly removed by ammoniation, nitrification and denitrification. First, the organic nitrogen in the sewage releases ammonia nitrogen through the ammoniation of the wetland microorganisms; secondly, the ammonia nitrogen is converted into nitrite nitrogen by the action of nitrous acid bacteria, and then further oxidized to nitrate nitrogen; finally, under non-oxidative conditions and by the action of denitrification bacteria, the nitrate nitrogen is reduced to nitrogen or nitrogen dioxide by the action of denitrification bacteria, which escapes from the system, thereby achieving the purpose of removing nitrogen.

Plants in constructed wetlands assimilate phosphorus in wastewater, producing organic components such as ATP, DNA, and RNA, and removing phosphorus from the system by harvesting the plants. Studies have shown that matrix adsorption and precipitation play the most important role in the removal or fixation of phosphorus in constructed wetlands[3].

3. Application of Constructed Wetland Technology in Controlling Exogenous Pollution of Lakes

3.1 The possibility of applying constructed wetland technology in eutrophication lakes restorations

Agricultural non-point source pollution is one of the main factors for the formation of eutrophic lakes in China. The agricultural non-point source pollution is scattered, the amount of sewage is large, and the content of N and P in the sewage is high. It is easy to cause eutrophication of the lake by directly discharging into the lake. It is difficult to solve this problem in general treatment technology. Constructed wetland has significant effects in removing N and P which are eutrophication factors, and has the advantages of small investment, simple construction, low operation and management costs, and significant ecological benefits. Therefore, it is possible to consider the application of constructed wetland technology to eutrophic lake treatment.

3.2 Key points of Constructed Wetland Design in eutrophication lakes restorations

The constructed wetland system can be divided into three main types: surface flow wetland, horizontal subsurface wetland and vertical flow wetland according to the difference of water flow state. Surface flow wetland has some features of low cost, low hydraulic load and great effect by season; horizontal subsurface wetland has better effect on removal of organic matter and heavy metals such as BOD and COD, and is few affected by seasonal influence; vertical flow wetland is better than the former two, but its construction requirements are high and it has not been widely used [3]. Which type of wetland to use is decided by the local pollution sources, the amount of sewage, and the investment amount of the project in a specific engineering practice.

Aquatic plants are an integral part of the constructed wetland system and are the basis for the survival of many peri-cluster organisms. They can absorb and intercept the organic matter in the sewage and provide a living environment for the microorganisms. In the selection of aquatic plants, it is necessary to investigate the aquatic plant species in the local lakes, and try to use local aquatic plants to avoid species invasion.

In constructed wetland systems, the matrix plays the most important role in the removal of phosphorus and provides a carrier and medium for the survival of aquatic organisms and microorganisms. Yuan Donghai et al. studied the mechanism of seven kinds of matrix materials for purifying phosphorus in sewage. The results show that slag and coal ash have good removal effect on
phosphorus, followed by vermiculite, yellow cinnamon soil and lower loess, and the zeolite and sand is the poorest[4]. According to Zhu Xizhen et al., the constructed wetland of coal-ash matrix has better removal effect on organic pollutants, and the removal rates of COD and BOD are 71%–88% and 80%–89%[5]. In constructed wetland designs, the matrix can be configured based on the major contaminants in the sewage and the local material supply.

4. Application of constructed wetland in water quality control of Nanhu Lake system

The Nanhu Water System Project is located in the southeast of Shuangliu County, 1 km away from Chengdu City. The total planned land area is 17 km$^2$. The Nanhu Water System is the core of the Nanhu area planning. In the Nanhu water system, six artificial lakes are planned, with a total lake area of 376 m$^2$ and a total water storage capacity of 16.87 million m$^3$.

4.1 Analysis of exogenous pollution in Nanhu Lake system

The annual average water intake of the Nanhu Lake system can be calculated by the water balance calculation. Average annual total phosphorus load in the Nanhu lake system can be obtained by the calculation model of the intake water pollution load index.

4.1.1 Analysis of water balance in Nanhu Lake

According to the water circulation movement characteristics and operation scheduling mode of the Nanhu water system, the water balance equation of Nanhu can be established:

$$\Delta W = R_i + P + Q - E - R_o$$

Where: $E$ is the amount of water evaporating from the lake; $R_i$ is the runoff of surface water into the lake; $R_o$ is the runoff flow from the lake; $Q$ is the amount of other forms of lake water inflow; $P$ is the total amount of precipitation on the lake; $\Delta W$ is the change of water storage in the lake during a certain period of time.

(1) The amount of water intake into the lake

There is no large-scale development in the area, which is a natural lake basin. Therefore, the scope of the catchment area and the way and direction of runoff and runoff input are basically the same as those of ordinary natural lakes. When the lake is formed, the amount of water shortage has the amount of water replenished by the old south main channel that passes through the area. Based on the above situation, the surface water input items are divided into two parts: one is the runoff input of the actual catchment area outside the lake, and the other is the input of the water intake of the old south main channel.

① Annual average amount of water that surface runoff flows into Nanhu

The rainfall area of the Nanhu Lake system is 15.04 km$^2$. The total lake surface area of the lake system under normal water level is 3.759 million m$^2$. The rainfall area of each lake and the corresponding lake area under normal water level are shown in Table 1. The area of the runoff yield is 11.281 million m$^2$, and the average annual runoff depth of the area is 450 mm. Therefore, the annual average amount of water that runoff flows into the Nanhu Lake system is 5,078,500 m$^3$.

| Table 1. Characteristic parameter table of lake system watershed |
|---------------------------------------------------------------|
| **Controlling catchment area (km$^2$)** | **Lake surface area under normal water storage level (Ten thousand m$^2$)** |
| Lake A | 3.55 | 100 |
| Lake AT | 1.47 | 51.9 |
| Lake B11 | 2.54 | 26.8 |
| Lake B12 | 3.93 | 104 |
| Lake B2 | 2.88 | 87.6 |
| Lake C | 0.67 | 5.6 |
| total | 15.04 | 275.9 |

② Average annual rainfall on the lake
The average annual rainfall of the lake system can be calculated using the average annual rainfall measured by the Shuangliu County Meteorological Bureau and the lake area under the normal water level. The average annual rainfall measured by the Shuangliu County Meteorological Bureau is 902.7 mm, and the lake area under the normal water level of the lake system is 3.759 million m$^2$. The average annual rainfall of the lake system is 3,393,200 m$^3$.

3) Annual average water diversion of the south main channel

Through years of average adjustment calculations, it can be seen that the average annual water diversion of the Nangan Canal is 819,000 m$^3$.

Then, the average annual lake intake in Nanhu is the sum of the above three items, namely:

$$507.85 + 339.32 + 81.90 = 929,070,000\text{m}^3$$

2) Consumption of water

At this stage, the water consumption of Nanhu Lake only includes the loss of lake surface evaporation and the leakage loss of the lake system.

1) Annual water evaporation quantity from the lake surface

The lake surface evaporation quantity can be calculated by the lake surface area and the annual average water surface evaporation quantity. The annual average water surface evaporation can be converted by the average annual evaporation which can use Shuangliu County Meteorological Bureau's measured average annual evaporation of 931.3 mm. The project is located in the western part of the Sichuan Basin and belongs to the subtropical humid monsoon climate. According to the Hydrological Calculation Code for Water Resources and Hydropower Engineering (SL278-2002), the water surface evaporation conversion coefficient is $a=0.9$, and the average annual water surface evaporation is $931.3 \times 0.9 = 838.17$ mm. Then, the average evaporation quantity of the lake in the Nanhu Lake system is 3,150,700 m$^3$.

2) Annual seepage quantity of Lake system

The hydrogeological conditions of the Nanhu Lake System are good according to the engineering geological section of the Chengdu Nanhu Headquarters Economic and Creative Industry Development Land Consolidation Project - Lake System Engineering Feasibility Study Report. The lake bed is a non-seepage layer, and the groundwater surface is close to the reservoir surface. The seepage quantity of Lake system is approximately 1% of the normal storage volume of the reservoir. The annual seepage quantity of the lake system is 1,975,600 m$^3$ from the results of years average adjustment calculation.

The change in the annual storage of the lake

According to the principle of water balance, the multi-year average of changes in lake water storage should be zero.

Annual flow of the lake

According to the above data and water balance model, the runoff output from the Nanhu Lake system is:

$$Ro = Ri + P + Q - E$$

Run the equation: $Ro = 4,152,500\text{ m}^3$

4.1.2 Calculation of total phosphorus load in Nanhu Lake

1) Pollution load in the water diversion

The point source pollution in Nanhu is mainly from the pollutants carried in the diversion channel of the old South Canal. Field investigations were carried out on the Nanhu Lake system from the old south canal diversion channel section, and the typical channel section was selected to monitor the pollutant content. The calculation model of the diversion pollution load index is:

$$P_i = Q \times C_i$$

Where, $P_i$ is the load of a load indicator; $Q$ is the discharge of sewage; $C_i$ is the concentration of a certain load indicator.

Through the distribution of sample points and the detection concentration analysis, the total phosphorus concentration in the Nangan Canal sample was 0.095 mg/L. The annual average water
diversion of the Nanhu Lake system is analyzed by water balance, and the amount is known to be 819,000 m$^3$. Then:

\[
\text{Annual average total phosphorus load in water} = \text{sample total phosphorus concentration} \times \text{annual average water intake} = 0.095 \text{ mg/L} \times 81.90 \text{ million m}^3 = 77.81 \text{ kg}
\]

(2) Atmospheric deposition

The atmospheric sediments on the lake surface were measured and collected by an atmospheric sediment trap. Through analysis, the average condition of atmospheric deposition in Nanhu Lake in Chengdu is 246.80 mg/d·m$^2$ in the nearshore area and 85.12 mg/d·m$^2$ in the central area. Based on this calculation, the average annual atmospheric deposition of the Nanhu Lake in Chengdu is 17,704.9 kg, of which the total phosphorus (0.17% of the total sediment particles) is 296.73 kg/a, and the lake area is 3,759,900 m$^2$.

(3) Input by atmospheric precipitation

Through analysis, the total precipitation phosphorus content in the Nanhu catchment area is 0.0462 mg/L. The annual average receiving rainfall of the Nanhu Lake system is 3,393,200 m$^3$. Then: annual average atmospheric precipitation input total phosphorus load = total phosphorus concentration in precipitation × annual average atmospheric precipitation = 0.0462 mg/L × 3,393,200 m$^3$ = 156.77 kg/a.

(4) Non-point source pollutant load in the Nanhu Basin

The non-point source pollution in the Nanhu water system is mainly from farmland and its formation of surface runoff.

Referring to related research, the pollutant output load model is:

\[ Q = R \times C_i \]

In the formula, Q is the annual load of a certain load index; R is the annual runoff; C$_i$ is the concentration of a certain load indicator.

Through background investigation, the average value of total phosphorus content of surface runoff is 0.37 mg/L; the average annual runoff of Nanhu Lake system is 5.078 million m$^3$ calculated by water balance, then: annual total phosphorus load = annual average runoff × total phosphorus concentration = 5,078,500 m$^3$ × 0.37 mg/L = 1879.03 kg.

(5) Total amount of external pollution load in Nanhu Lake

According to the above analysis, the annual average total phosphorus pollution load of Nanhu Lake is 2410.33 kg, as shown in Table 2 below.

| Total phosphorus pollution source         | Load (kg) |
|-------------------------------------------|-----------|
| South Main Canal Diversion Load           | 77.81     |
| Wet and dry sediment load                 |           |
| Atmospheric subsidence load               | 296.73    |
| Atmospheric precipitation load            | 156.77    |
| Non-point runoff load                     | 1879.03   |
| Total                                     | 2410.33   |

4.2 Design of constructed wetland system

The hydration treatment is carried out by using a horizontal subsurface flow constructed wetland treatment system in low tail area of the lake. The horizontal submerged artificial wetland treatment system has good moisture retention, and the phosphorus removal rate can reach 60-70%, which is less affected by the season.

4.2.1 Hydraulic retention time

The hydraulic retention time of the constructed wetland is:
Where t is the hydraulic retention time; V is the wetland volume; ε is the wetland porosity; Q is the average flow. In order to ensure the effect of denitrification in the subsurface wetland, the hydraulic retention time is 2~4d.

4.2.2 Water level control
Considering the normal growth of plant roots and ensuring the nitrification effect, the depth of the system is 1~2 m, from the water surface to the depth is about 0.8 m, the sunlight can penetrate, the photosynthesis is strong, the dissolved oxygen is sufficient to show aerobic state, and the organic pollution in the sewages such as COD, NH3-N, TP, etc can be processed. Below this depth, the deposited sludge achieves anaerobic fermentation and decomposition, reducing sludge production. In order to improve the hydraulic retention time, the section is designed to push flow through the reasonable arrangement of the retaining wall, as shown in Figure 1.

4.2.3 Plants and planting
To form a good biological chain, local aquatic herbs such as reeds and lotus are chosen. Aquatic plants are selected based on conditions such as temperature, light, mixing, and pretreatment. Because the growth of aquatic plants is faster, the initial planting density should not be too large. The planting density of reeds is 5 clusters/m², and the planting density of lotus is 1 plant/3 m². The filter material can be selected from natural river sand, ceramsite, coal gangue, fluorite sand and other filter materials, and placed in appropriate areas for easy maintenance.

5. Conclusion
The constructed wetland technology is in a stage of rapid development. The water quality problem of lakes in China is significant, and the most important one is the eutrophication of lakes. The constructed wetland technology has a good prospect in the treatment of eutrophic lakes. The research on the decontamination mechanism of constructed wetlands is relatively backward, and the kinetic model of the movement and transformation of pollutants in wetlands has not been established. Therefore, in-depth study of the transformation mechanism of pollutants in wetland systems, optimization of hydraulic models and explanation of kinetic models will be beneficial to improve the level of research on constructed wetlands in China, and it should also have far-reaching significance for constructed wetland technology.

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