RESEARCH ARTICLE

Characteristics of water purification pattern of Caofeidian freshwater reservoir

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Abstract: Caofeidian freshwater reservoir is nearly to the lower reaches of Shuanglong River area, which is located on the coast of Bohai Sea. However, the two sides of the Shuanglong River are the agricultural production and cultivation and aquaculture areas, that resulting in serious agricultural non-point source pollution. In this paper, we introduce a water purification pattern of freshwater reservoir based on floodplain wetland and ecological ditch. We set up floodplain wetlands to purify water with Shuanglong River floodplain and the reservoir surrounding idle beach, and lay out ecological ditch to purify rice paddy fields drainage with rice paddy ditch. Calculated, the water purification system of floodplain wetland could reduce the storage of pollutants, including 450 tons of COD, 18 tons of total nitrogen, 3.6 tons of total phosphorus annually, and reduce the water evaporation of 14,000 m^3 annually. Paddy field ecological ditch strengthen the water purification pattern, can effectively remove the storage of pollutants with 4 tons of total nitrogen, 0.8 tons of total phosphorus annually, and conserve 1,000 m^3 water nearly. It could improve the water quality of the storage river by the water purification pattern of Caofeidian freshwater reservoir, which also has environmental and economic benefits and provide inspiration for the construction of similar freshwater reservoirs.

Keywords: Caofeidian, freshwater reservoir, floodplain wetland, ecological ditch, water purification pattern

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1 Introduction

Caofeidian freshwater reservoir is located on the coast of Bohai Sea, and its water supply is mainly composed of two parts: the runoff of Shuanglong River and the paddy fields drainage. Shuanglong River has distinctive seasonal characteristics. The two sides of the river are the agricultural production and cultivation and aquaculture areas, which results in serious agricultural non-point source pollution, which leads to serious water pollution of the reservoir.

The sewage has been effectively purified by constructing environmental remediation projects in Shuanglong River, which is able to enhance the water quality of reservoir water supply security. Beside the Shuanglong River, floodplain wetlands were set up to purify water using Shuanglong River floodplain and the reservoir surrounding idle beach, and ecological ditches were laid out to purify paddy fields drainage using rice paddy ditches.

Wetland technology in sewage purification research and application is of a wide range[1–7]. In this paper, we introduce a water purification pattern of freshwater reservoir based on floodplain wetland and ecological ditch to provide inspiration for the construction of similar freshwater reservoirs.

2 Study Area

2.1 Natural Environment

Caofeidian freshwater reservoir is the original seven farm plain reservoirs in Tanghai County, which is located on the coast of Bohai Sea (39°14'95"N, 118°19'50"E), and is near the lower reaches of Shuanglong River (Figure 1). The reservoir is 30 km away from Caofeidian industrial zone, but only 100 meters away from the water supply pipeline of Caofeidian industrial zone. The reservoir is a substantially rectangular region, north-south length is about 1,720 m, 4,387 m long from east to west, with a total storage capacity of 23.65 million m^3.

The water supply of the reservoir is mainly composed of two parts: the runoff of Shuanglong River and the paddy fields drainage. According to the calculations and analyses, the annual runoff of Shuangyong River (26.14 million m^3) and the available amount of paddy fields drainage (11.14 million m^3) are 37.28 million m^3. So it can meet 23.65 million m^3 of wa-

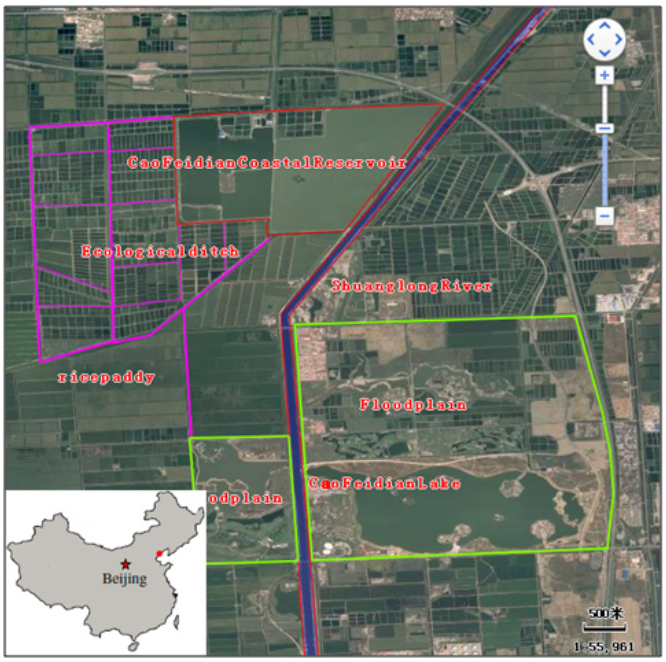

Figure 1. Study site.

ter storage requirements of the freshwater reservoir in normal years.

The reservoir area belongs to the eastern monsoon region which is warm and humid zone with semi-humid, mild climate and four distinct seasons. The average annual temperature of the region is 10.8°C, the coldest monthly average temperature is -5.9°C (January), the hottest monthly average temperature is 25.3°C (July). The average annual rainfall of 635.7 mm, up to 1,184.5 mm (1964), the lowest annual rainfall is only 335.3 mm (1968). The annual rainfall is generally concentrated in July to August, with an average of 407 mm, accounting for 64% of annual rainfall. The average annual surface evaporation of the project area is 1,050 mm.

A total of nine flows of Luanhe river and canal pass through Caofeidian District, finally flow into the Bohai Sea. Shuanglong River in Caofeidian District is 37 km long, and the basin area is 256 km^2. Shuanglong River has distinctive seasonal characteristics, resulting in the maximum runoff is generally in June to September (flood season).

Reservoir area includes six serious water shortage regions in North China, where the per capita possession of water resources is 380 m^3, lower than the internationally recognized water crisis protection limit of 500 m^3. The annual water storage of Caofeidian industrial zone will be 360 million m^3 after the completion of the planned project. Water has become one of the main factors restricting the local economic and social development. It is a very urgent and long-term major issue to solve the water shortage problem.

2.2 Question

The water of Caofeidian freshwater reservoir mainly from Shuanglong River, where water quality is V class (GB3838-2002, CHN), unable to meet requirements (GB5749-85, CHN). The agricultural production and aquaculture lead to serious river water pollution in the downstream of Shuanglong River, because of large scale of aquaculture, large loss of fertilizer and lack of governance means. At the same time, a large number of nitrogen and phosphorus and other organic pollutants entry into the reservoir through the rice paddy ditch due to the soil erosion. Therefore, how to solve the problem of non-point source pollution of river water is becoming the key to improve the water quality guarantee of Caofeidian freshwater reservoir.

Practice has proved that the construction of freshwater reservoir, cutting flood water and purificating water for reuse is an effective way to solve the current water shortage problem.

3 Water Purification Pattern

Sewage purification technology in wetland has been recognized all over the world[8–13]. Its research and application is of a wide range[4,5,7,14]. The results show that different plants have different effects on sewage purification[15–22] (Table 1). Meanwhile, they exist between floodplain wetlands and subsurface flow constructed wetlands[1,3,24,28,29] (Table 2).

In this paper, a water quality purification pattern of floodplain wetland is introduced to treat Shuanglong River runoff water, which is the surface flow wetland and subsurface flow wetland. And an ecological ditch purification pattern, using rice paddy ditch, is introduced to purify paddy fields drainage[30–33]. Then a reservoir water purification pattern is constructed: floodplain wetland and ecological ditch (Figure 2).

3.1 A Floodplain Wetland Purification Pattern

The local government has implemented about 20,000 mu (1 mu equal to 666.7 m^2) for the construction of Caofeidian wetland park, including 5,000 mu of the lake area, 12,000 mu of surface flow wetland and 3,000 mu of subsurface wetlands. The total possession of water storage capacity is about 20 million m^3.

Surface flow wetland system (Figure 3a) is surrounded by an embankment with certain height to maintain certain thickness of the water layer (usually 10∼30 cm). And combination plants were planted in wetlands (Phragmites communis/-Typha angustifolia, Zizania caduciflora, Hydrilla verticillata). The flow of water in the wetland surface was pushed forward, in the process of flow, the sewage is purified through physical, chemical and biological reactions, with the biofilm of soil, plants and plant roots[34–36].

Subsurface wetland is a subsurface flow constructed wetland, which is designed to receive surface streams (Figure 3b). The substrate is laid according to the needs of different pollutants (phosphorus contaminants)[3,24,25,29,38], and different types of purified plants are planted.

The sewage is purified under the combined effects of the matrix, plants and microbial physical, chemical and biological through the pattern of surface flow wetland + subsurface

Table 1. Summary of water purification effects of wetland plants (%).

No.	Plant type	Pollutant type			References
		COD	TN	TP	
1	Phragrnitas communis	47.0～66.0	64.5	25.0～29.0	Peng Juwei *et al* .,2010[17]; Chen Junmin *et al* ., 2006[12]
2	Phragrnitas communis / Typha angustifolia	13.0～40.0	35.0～52.0	27.0～38.0	Zhou Linfei *et al* ., 2014[18]
3	Phragrnitas communis / zizania latifolia / Acorus calamus	43.2～48.9	52.2	45.3～73.5	Wan Jinbao *et al* ., 2010[23]; Lu Shaoyong *et al* ., 2006[15]
4	Scirpus validus / Phragrnitas communis / Canna glauca	81.0～83.0	68.0～85.0	57.0～70.0	Zhang Wenyi, 2012[24]; Wei Cheng, 2008[25]
5	Scirpus validus / Phragrnitas communis / Iris wilsonii / Pontederia cordata	30.0～64.4	25.0～72.8	23.0～60.0	Liao Weimin et al., 2011[26]; Guo Xiao *et al* ., 2010[14]
6	Zizania latifolia / Hydrilla verticillata / Hydrocharis dubia	28.0	45.0	32.0	Guo Xiao *et al* ., 2010[14]
7	Acorus calamus / Canna glauca / Scirpus validus / Oenanthe javanica	37.0～66.8	35.0～83.4	32.0～64.9	Deng Futang et al., 2006[27]
8	Hymenocallis Americana / Phragrnitas communis / Canna glauca / Vetiveria zizanioides /Acorus calamus / Cyperus alternifolius	65.0～87.0	57.0～90.0	28.0～53.0	Zhao Jiangang *et al* ., 2006[3]

wetland. Where the chemical oxygen demand (COD), total phosphorus (TP), total nitrogen (TN), algae, oil and other significant removal are efficient (COD 40.6%～94.2%; TN 52.2%～72.25%; TP 23%～74%)[25,35,37,38].

In this paper, river water quality (COD 50 mg/L, TN 2.0 mg/L, TP 0.4 mg/L) is calculated. The removal rate of COD, nitrogen and phosphorus are 30%. The pattern can reduce the storage of pollutants, 450 tons of COD, 18 tons of total nitrogen, 3.6 tons of total phosphorus each year. 1,000 mu of phragmites communis wetlands is contained in surface wetlands, the evaporation is 0.2 mm/h (Relative to the ground 1.05 mm/h), the reduction of evaporation is 14,000 m^3 annually.

Table 2. Summary of water purification effect of wetland type (%).

No.	Wetland type	Pollutant type			References
		COD	TN	TP	
1	Surface wetland	50～60	30～50	35～70	Zhao Jiangang *et al* ., 2006[3]; Zhang Wenyin *et al* ., 2012[24]
2	Subsurface wetland	55～75	40～70	70～80	Zhao Jiangang *et al* ., 2006[3]; Liu Bingwei *et al* .,2016[30]; Zhang Wenyin *et al* ., 2012[24]

3.2 Ecological Ditch Purification Pattern

On both sides of the rice paddy ditch bank slope, there are structures plant revetment with the willow and phragmites communis, calamus and others. On the ditch bank slope, the slope dyke layer was constructed by the ecological bag and ecological grid[39]. Compared with the local rice paddy ditch ecological water purification base material[40]. A water purification pattern for paddy field ecological ditch was constructed based on plant revetment, ecological slope and water purification base material[33,41–43] (Figure 3c). The results showed that the removal rate of nitrogen and phosphorus pollution of

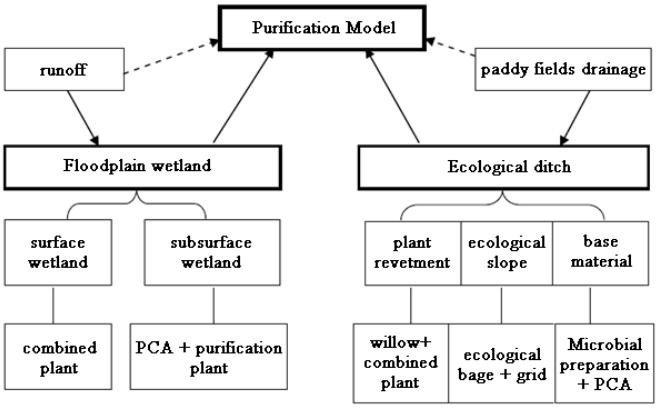

Figure 2. Governance pattern.

agricultural non-point source reached 48% ～ 64% and 41% ～ 70%[44–46].

In this article, according to the current situation of existing paddy field planting area and ditch, the ecological ditch is 10 km long. The paddy fields drainage are 5 million m^3, the water quality of total nitrogen is 2.0 mg/L, total phosphorus is 0.4 mg/L. The removal rate of nitrogen and phosphorus pollution is 40% and 40% respectively. And then, the system will remove the storage of pollutants total nitrogen 4 tons, total phosphorus 0.8 tons effectively each year. At the same time, it can add 50 mu of woodland on both sides of ecological ditch. The average moisture content of forest land is 20 m^3 [47], and it can conserve nearly 1,000 m^3 water each year.

There is a total result of the reservoir water purification pattern in Table 3. The system will remove the storage of pollutants for the COD 450 tons, total nitrogen (TN) 4 tons, total phosphorus (TP) 0.8 tons, and it can conserve water 15,000 m^3 nearly each year.

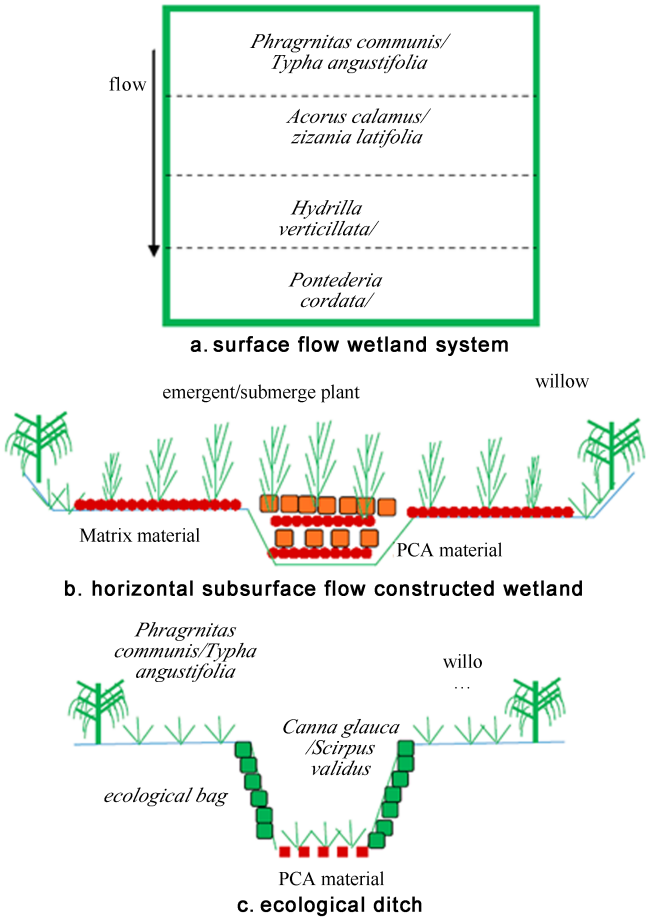

Figure 3. Water purification pattern.

4 Conclusions

(1) Caofeidian freshwater reservoir is located on the coast of Bohai Sea. And the water supply is mainly composed of two parts: the runoff of Shuanglong River and the paddy fields drainage.

(2) The agricultural production and aquaculture lead to serious water pollution in the downstream of Shuanglong River, because of large scale of aquaculture, large loss of fertilizer and lack of governance means. At the same time, a large number of nitrogen and phosphorus and other organic pollutants entry into the reservoir through the rice paddy ditch due to the soil erosion.

(3) The Caofeidian freshwater reservoir water purification pattern is introduced: floodplain wetland + ecological ditch.

Table 3. Total result of the reservoir water purification pattern.

No.	Wetland type	Pollutant type (ton)			Remove rate (%)	Conservate water (m^3)
		COD	TN	TP		
1	floodplain wetland	450	18	3.6	30	14,000
2	ecological ditch	/	4	0.8	40	1,000
3	total	450	22	4.4	>30	15,000

(4) A floodplain wetland water quality purification pattern is introduced to treat Shuanglong River runoff water, which is the surface flow and subsurface. Calculated, it can reduce the storage of pollutants COD 450 tons, 18 tons of total nitrogen, 3.6 tons of total phosphorus, and reduce the water evaporation of 14,000 m^3 annually.

(5) A water purification pattern for paddy field ecological ditch is introduced based on plant revetment, leach slope and water purification base material. Calculated, it can remove the storage of pollutants total nitrogen 4 tons, 0.8 tons of total phosphorus effectively annually, and 1,000 m^3 water is conserved.

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