Innovative design of the biological wastewater treatment system

J Liu1,5, X L Qin2, N She3, L Y Wu1 and Z W Bu4

1Ecological Technology Institute of Construction Engineering, Shenzhen University, Shenzhen, China
2College of Civil and Transportation Engineering, Shenzhen University, Shenzhen, China
3Guangdong Great China Technology Co., Ltd., Guangdong, China
4Shenzhen Cenpoint Architects & Engineers Co., Ltd., Shenzhen, China

E-mail: liujian@szu.edu.cn

Abstract. A biological wastewater treatment system (BWTS), which composed of a 400 m² biological wastewater treatment facility (BWTF) and a 100 m² wetland landscaping lake, was designed to further treat the water quality of the recycling pond of an ecological sediment treatment plant of the Qingxi River in Qingxi Town, Dongguan City, Guangdong Province, China. BWTS was designed to treat the water of Class B of the Discharge standard of pollutants for municipal wastewater treatment plant (GB18918-2002) in the recycling pond into Class IV water of the Surface Water Environmental Quality Standard (GB3838-2002). The treatment capacity of BWTF was designed according to 1200 m³/d. The hydraulic load is 3m³/d, volume load is 42 g (BOD)/(m³·d), and hydraulic retention time is 4 h. The inflow and outflow of BWTF were designed as the gravity flow without any power supply. The BWTF consists of active filtration facilities and plants with specific functions. The facility is capable of effectively filtering contaminants, especially with a very high removal efficiency of phosphorus (P) and nitrogen (N). The BWTF has five innovative outlet control systems that will be used to further reduce the nitrogen content to prevent algae growth. At the same time, the system can also remove pathogenic bacteria, heavy metals and hydrocarbons from the water, increase oxygen content in the water and reduce BOD. The wetland landscaping lake was designed to further treat the water quality and recycling use. The surplus water is discharged into the Qingxi River by a pipe. As compared with traditional wetland treatment, BWTS has the advantages of less land occupation, high efficiency, low operation and maintenance costs. The structure of the BWTF is similar to the raingarden, however, they have different medium mixture ratio and inflow & outflow layouts. The water of the recycling pond is transferred to the BWTF through three underground pipes with a diameter of 150 mm, then the flow goes through the layers of protection, medium and gravel, and enters the nearby wetland landscaping lake by five outlet control manholes, an open canal and an underground pipe.

1. Introduction
China is one of the 13 countries with the world's poorest water resources. The shortage of water resources has seriously restricted China's social and economic development. Recycling urban sewage and realizing "sewage resource utilization" is an effective way to solve the shortage of water resources [1]. Constructed wetland has become one of the better wastewater treatment technologies due to its...
good treatment effect, strong nitrogen and phosphorus removal capacity, low cost and strong adaptability to load changes [2]. Constructed wetland is a kind of artificially constructed and supervised ground similar to that of marshes. It uses the triple synergy of physical, chemical and biological in natural ecosystems to achieve purification of sewage. The wetland system mainly consists of various Water-permeable matrix, aquatic plants, water bodies, lower animals in wetlands, and aerobic or anaerobic microbial populations [3].

According to the requirements of the “Dongguan Municipal Water Pollution Prevention Action Plan Implementation Plan”, the Qingxi Town Government plans to remove all the contaminated sediments from the Qingxi River at the end of 2019, restore the river ecology, and realize the sediment resources. The total length of the Qingxi River is about 16.9 km, and the amount of dredging works is about 248,000 m³. In order to solve the pollution problems of the Qingxi River, reduce and recycle the Qingxi River sediment, through on-the-spot investigation, it is found that there is a general shortage of river channel over-flow section, the flood control standard of dikes is low; the sewer pipelines are imperfect, and the collection rate of sewer in the Qingxi River basin is low, some sewage is directly discharged into the river; the urban non-point source pollution control measures are serious; the initial rainwater runoff is directly discharged to the adjacent receiving water body without treatment; the endogenous pollution is serious, long-term siltation in the river to form a polluted sediment; all kinds of pollution are released into the river, polluting the water quality of the river; the water quality of the main river is very poor, and there is a lack of cleaning water supply. To this end, the Qingxi River’s sediment was sampled and analyzed, and the content of each component in the river’s sediment was analyzed. According to the site investigation and the Qingxi River sediment test report, not only the organic matter content in the sediment of some river sections is high, but also the contents of the heavy metals are higher than national standard. In order to reduce the amount of the contaminated sediment treatment and utilization, an ecological technology of sediment treatment was developed based on zero emission & 4R (Reduce, Recycle, Reuse, and Revolution) concept, centrifugal solid-liquid separation technology and high speed suspended solid settlement technology by gravity and polymeric flocculants. The polluted sediment can be accurately divided into gravel, sand, silt and clay by four-stage treatment process. The dewatered clay is made into the mixture soil of the sponge city facilities, permeable bricks or other building materials, gravel and sand are directly used as concrete aggregate, and the silts are used for backfill and planting soil. The treatment efficiency of the ecological sediment treatment technology is more than three times of the traditional sediment settlement treatment process used in China, and there is no secondary pollution and cost savings.

Figure 1. The water quality treatment process flow chart.

In the process of ecological sediment treatment, the water quality of the recycling pond is Class B of Discharge standard of pollutants for municipal wastewater treatment plant (GB18918-2002) [4]. Although it can be directly discharged into the Qingxi River according to the present water quality requirements of Dongguan City, it cannot be directly used, and the resource utilization of water is not realized. In order to optimize the process, the biological wastewater treatment system (BWTS) was designed to further treat the water in the recycling pond to meet the Class IV of Surface Water Environmental Quality Standard (GB3838-2002), which is required by the national sponge city.
construction. The treated water can be recycled to wash the sediment, and the excess water can be directly discharged into the Qingxi River at high water quality. The water quality treatment process flow chart is shown in figure 1.

2. Innovative design
The BWTS consists of an BWTF with an area of 400m² and a wetland landscape lake with an area of 100 m². The whole system is designed as the gravity flow by using different elevations of the connection pipelines and facilities. The BWTS layout is shown in figure 2.

![Figure 2. BWTS layout.](image)

2.1. Biological wastewater treatment facility
To easily constructed, the BWTF is designed as rectangle in plane, the length and width are 25 m and 16 m respectively. The walls adopt brick-concrete structure, and the composite waterproof geomembrane was laid on the bottom for anti-seepage treatment. The depth of the BWTF is 1.875 m. The gravel layer at the bottom is 60 cm thick and the upper mixing soil layer is 60 cm thick. A 3 mm permeable geotextile is placed between the gravel layer and the mixing soil layer to prevent the mixing soil from infiltrating into the gravel layer. The BWTF is used to treat suspended solid (SS), phosphorus (P), Nitrogen (N) and heavy metals in the recycling pond through adsorption, attraction, ion exchange and biodegradation through high-efficiency filter medium (mixing soil). The removal process of total nitrogen (TN) and ammonia nitrogen in the BWTF is very complicated, mainly including volatilization, ammoniation, nitrification, denitrification, plant absorption, anaerobic ammoniation, etc. [5,6]. Finally, the water is collected by the plotted pipes in the gravel layer and discharged into the nearby open canal. BWTF considers the different water hydraulic loads, the water level changes will affect the drain time and infiltration rate etc., so the outflow controller is set in the water well to accurately control the flow rate and ensure the water treatment efficiency of BWTF.

In the gravel filter layer of BWTF, the specification range is 25-50 mm. The organic matter content of the mixing soil should be controlled within the range of 8%-10%; the mixing soil mainly contains coco peat, water plant residuals and course sand, and ratio is about 2:3:5 in volume. The saturated water conductivity is 200 cm/h.

The plants on the mixing soil layer in the BWTF are mainly local aquatic plants such as Calamus,
Thalia dealbata Fraser, Cyperus alternifolius, Lycoris, Lythrum salicaria, Pennisetum. The section of BWTF is shown in figure 3.

2.2. Wetland landscape lake

The wetland landscape lake with a foot shape in plane is laid out between BWTF and the Qingxi River. The outflow of the open canal of BWTF is discharged into the wetland landscaping lake by a PVC pipe with a diameter of 300 mm. The lake area is 100 m² and the maximum depth is 1.5 m. The bottom of the lake is laid out by 1 mm waterproof geomembrane for anti-seepage treatment. The bottom soil is the original soil layer and no further treatment is required. A discharge pipe with a diameter of 300 mm is placed at a height of 1.5 m from the bottom of the lake. When the water coming from the BWTF exceeds the volume of the lake, it is discharged into the Qingxi River by the discharge pipe. In order to facilitate the maintenance, a 300 mm diameter emptying pipe is also arranged at the bottom of the lake.

A certain amount of submerged plants, emergent plants and floating plants are planted in the wetland landscape lake. The soil on the bottom and banks is 200mm thick. The aquatic plants in the wetland landscape lake not only have landscape benefits, but also play a very positive role in the purification of water.

The aquatic plants mainly include Calamus, iris, Nephrolepis auriculata, Wedelia calendulacea, Miscanthus sinensis, Cyperus alternifolius. By planting these plants, the ammonia nitrogen in the water can be greatly reduced, the nutrients in the water can be absorbed, the eutrophication in the water can be avoided, and the odour in the water can be removed. The section of the wetland landscape lake is shown in figure 4.

3. Parameter determination and water flowing process

3.1. Parameter determination

BWTS treatment capacity is designed to be 1200 m³/d, hydraulic load 3 m³/d, volume load 42 g BOD (m³/d), hydraulic retention time 4 h. The wetland landscape lake slope is designed according to the wetland.

The diameters of 3 PVC inlet pipes are set as 150 mm, the water head is 0.5 m, and the length of each inlet pipe is 1.8 m. The resistance coefficient λ is 0.025, the discharge of each inlet pipe is
computed by the following formulas, \( Q = 0.004629 \text{ m}^3/\text{s} = 400 \text{ m}^3/\text{d} \), and the total discharge of 3 inlet pipes is 1200 m\(^3\)/d.

\[
Q = \mu_c \alpha \sqrt{2GH} \quad (1)
\]

\[
\mu_c = \frac{1}{\sqrt{1 + \lambda_i/d + \sum \xi}} \quad (2)
\]

\[
\xi = 0.5, \quad \mu_c = 0.0703 \quad (3)
\]

where \( Q \) is design discharge, m\(^3\)/d; \( a \) is pipe section area, m\(^2\); \( H \) is water pressure, m; \( G \) is acceleration of gravity, m/s\(^2\).

According to the *Technical specification of constructed wetlands for wastewater treatment engineering* (HJ 2005-2010), the surface hydraulic load (refers to the amount of sewage per square meter of facility that can be received per unit of time) is 3 m\(^3\)/m\(^2\)·d by the following formula:

\[
q = \frac{Q}{A} \quad (4)
\]

where \( q \) is surface hydraulic load, m\(^3\)/m\(^2\)·d; \( Q \) is design discharge, m\(^3\)/d; \( A \) is facility area, m\(^2\); The hydraulic retention time (refers to the average residence time of sewage in the facility) is 4h by the following formula:

\[
t = \frac{V \varepsilon}{Q} \quad (5)
\]

where \( t \) is hydraulic retention time; \( V \) is the volume of the facility matrix in its natural state, including the matrix entity and its openings, closed gaps, m\(^3\); \( \varepsilon \) is porosity, %; \( Q \) is design discharge, m\(^3\)/d.

![Water distribution pipes and the inlet wells in BWTF.](image)

**Figure 5.** Water distribution pipes and the inlet wells in BWTF.

### 3.2. Water flowing process

The water in the recycling pond passes through three inlet PVC pipes with a diameter of 150 mm and
flows into the three inlet wells in the facility with a water head of 0.5 m. In order to control the flow, an inspection well with a size of 0.8 m×2.6 m is installed, and a water control valve is added to each inlet pipe. The three inlet wells are distributed in the facility, which facilitates the arrangement of the water distribution pipes to improve the uniformity of the water distribution and the functionality of the facilities. The layout of the water distribution pipes and the inlet wells is shown in figure 5.

The water in each inlet well flows into two plotted distribution pipes through two connection pipes with a diameter of 110 mm. The diameter of each distribution pipe is 75 mm. The energy dissipation gravels are arranged under the water distribution pipes to prevent the erosion of the mixing soil layer. The selection criteria for the energy dissipation gravels are the same as those for the gravels layer, but the sizes are different. The treated and purified water by the mixing soils and gravels in the facility flows into the outlet wells through five PVC plotted pipelines with the diameter of 200 mm. The outlet control device is set in each outlet well to control the outflow volume. The layout of the plotted pipelines and outlet wells is shown in figure 6.

Figure 6. Plotted pipes in the gravel layer.
Figure 7 presents the schematic of the triple stage outlet to be used for the BWTF. The tertiary outlet is intended to equalize the effective infiltration rate from the bottom of the BWTF. Using falling head measurements, it is possible to observe the infiltration rate into the surrounding soils, which will vary between treatments. The tertiary outlet corrects for this by using different apertures computed to compensate so the effective flow rates through the bottom are nearly identical for each treatment. The secondary lower outlet allows for raising and lowering the elevation of the saturated zone. During the dry season, this would be raised to promote water storage to reduce drought stress. This will also improve N retention. In the wet season, it would be lowered to provide more detention storage for flow regulation. Its drain time would be modulated in response to media hydraulic conductivity by setting the proper aperture. Likewise, the primary upper outlet would be adjusted to respond to changes in media hydraulic properties. In this case, the elevation would be adjusted to provide similar drain times and infiltration rates when the surface is ponded and flows can also pass through the upper outlet. This provides for adaptive management in bioretention systems. It also provides for identical flow retention times, thus eliminating that variable from affecting the results [7].

![Figure 7. Plotted pipes in the gravel layer.](image)

The water treated by BWTF is discharged into the nearby open canal. The outflow water quality of BWTF is nearly Class IV of *Surface Water Environmental Quality Standard* (GB3838-2002).

The open canal is separated from the BWTF by a wall with a width of 1 m, a length of 25 m and a depth of 1 m. It also adopts a brick-concrete structure and is provided with a waterproof geomembrane for waterproofing. A slope of 0.5% is set at the bottom of the open channel, so that the water body treated by BWTF is collected into the wetland landscape lake under the action of gravity energy. The water of the open canal flows into the wetland landscape lake through an underground pipe with a diameter of 300mm for further water quality treatment. The water quality of the lake is Class IV of *Surface Water Environmental Quality Standard* (GB3838-2002).

The water quality measurement indicators include chemical oxygen demand (COD), total nitrogen (TN), ammonia nitrogen and total phosphorus (TP) in this system.

4. Conclusions
The innovative design of BWTS is discussed the principle and process of urban sewage discharge
standard Class B wastewater treatment as surface water environmental quality standard V types of water, and it has been successfully used to the sediment treatment of the Qingxi River in Dongguan, Guangdong, China. The treatment capacity of BWTS was designed according to 1200 m³/d. It can effectively remove nitrogen (N) and phosphorus (P) from wastewater and reduce BOD and COD indicators. The system has the characteristics of less land occupation, high sewage treatment efficiency, long service life and low operation and maintenance costs. The system realizes the recycling of Class B wastewater, which will promote the research process of urban sewage resource utilization. It can be set in the end of sewage treatment. By rationally designing the landscape of BWTS, it can improve its ornamental performance. It can also be used as a leisure and entertainment place, which not only treats sewage but also meets the needs of citizens.

References
[1] Schindler D W, Hecky R E, Findlay D L et al 2008 Eutrophication of lakes cannot be controlled by reducing nitrogen input: results of a 37-year whole-ecosystem experiment Proc. Natl. Acad. Sci USA 105 11254-8
[2] O’Hogain S 2003 The design, operation and performance of a municipal hybrid reed bed treatment system Water Sci. Technol. 48 119-26
[3] Jun Y and Yubo C 2006 Constructed Wetland Wastewater Treatment Technology (Beijing: Chemical Industry Press) pp 7-52
[4] Jun Y and Yubo C 2006 Discharge standard of pollutants for municipal wastewater treatment plant (GB18918-2002) (Beijing, China: Ministry of Ecology and Environment) pp 12-6
[5] Vymazal J 2007 Removal of nutrient in various types of constructed wetland Science of the Total Environment 380 48-65
[6] Mengxuan T, Juan W and Yanran D 2016 Treatment of domestic wastewater by Hybrid vertical constructed wetland Chin. J. Environ. Eng. 10 1017-22
[7] Lucas W C, She N and Liu J 2012 Advanced LID experimental array Crossing Boundaries, 2012 World Water & Environmental Resources Congress (Shenzhen University, Guangdong Province) pp 203-12