Relationship between Hydrodynamic Conditions and Water Quality in Landscape Water Body

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Relationship between Hydrodynamic Conditions and Water Quality in Landscape Water Body

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Abstract. The urban landscape water usually lacks necessary water cycle and water speed is closed to zero, which easily lead to eutrophication in water system and deterioration of water quality. Therefore, understanding the impact of water circulation on the water quality is of great significance. With that significance, this research has been done to investigate the relationship between hydrodynamic conditions and water quality of urban landscape water based on adopted water quality indexes such as chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP) and nitrogen-ammonia (NH₃-N). Moreover, MIKE 21 model is used to simulate the hydrodynamics and water quality under different cases in an urban landscape lake. The results of simulation show that water circulation system could effectively improve current speeds, reduce the proportion of stagnation area, and solve the problem of water quality deterioration caused by reclaimed water in the lake.

1. Introduction
Landscape water is indispensable to the city and serves to discharge flood waters, receive contaminants, provide scenery and support ecological systems. Most landscape waters are closed, with insufficient water mobility, weak hydrodynamic conditions, and fragile self-purification [1]. To relieve water shortages, unconventional water resources, such as reclaimed water, are used to recharge landscape water, but reclaimed water has high nitrogen and phosphorus concentrations, adding to the difficulty of guaranteeing the receiving water quality [2]. In order to keep and maintain landscape water quality, a hydrodynamic analysis is needed because: (1) good hydrodynamic condition increases the transport of oxygen from atmosphere to water and increases the concentration of dissolved oxygen; (2) the flow resuspends organic detritus deposited at the bottom, prolonging the organic detritus residence time, and enabling more complete aerobic degradation; (3) hydraulic structures or pumps that increase water flow enhance recreation and promote the overall ecological environment [3, 4].

In this paper, an urban landscape lake was selected to investigate the relationship between hydrodynamics and water quality, and MIKE 21 model was used to simulate the hydrodynamics and water quality under different cases.
2. Materials and Methods

2.1. Study Area
In this study, the artificial landscape Lake (Figure 1) was used to simulate and predict water quality trends under different conditions. The lake has a surface area of 420,000 m$^2$, a maximum depth of 4 m, and a volume of 1,470,000 m$^3$. Reclaimed water will be used to recharge the lake and offset losses from evaporation and leakage (Table 1). Without external forcing, the wind-driven current is the only source of water mixing. COD, TN, TP and NH3-N are the primary water quality control targets.

![Figure 1. Study area](image)

Table 1. Water quality in the study area

| water quality item | artificial lake | reclaimed water |
|--------------------|-----------------|-----------------|
| NH3-N(mg/l)        | 0.53            | 8               |
| TN(mg/l)           | 1.54            | 15              |
| TP(mg/l)           | 0.08            | 0.5             |
| COD(mg/l)          | 74              | 50              |

*No criteria.

2.2. Water Quality Sampling and Analysis
Water samples in the landscape Lake were collected daily from May 12 to June 24, 2014. The pH and DO were measured immediately in situ using a HACH HQ30d probe. The COD, TN, TP and NH3-N were analysed following the Water and Wastewater Monitoring and Analysis Method (China 2002). The atmospheric data were collected by the Tianjin Meteorological Bureau.

2.3. Model Description and Application
MIKE 21 is a two-dimensional mathematical model developed by DHI Water & Environment and could be used whenever stratification is neglected [5]. In this paper, MIKE 21 was used to simulate hydrodynamics and water quality, and to forecast water quality in the landscape Lake.

The water environment model is composed of the hydrodynamic model and advection/dispersion models [6]. The control equations of the hydrodynamic model are the 2-D shallow water equations in Cartesian coordinates:

\[
\frac{\partial h}{\partial t} + \frac{\partial h u}{\partial x} + \frac{\partial h v}{\partial y} = h S
\]

\[
\frac{\partial h u}{\partial t} + \frac{\partial h u^2}{\partial x} + \frac{\partial h u v}{\partial y} = f v h - g h \frac{\partial \eta}{\partial x} - h \frac{\partial p}{\partial x} - \frac{gh^2}{2 \rho_0} \frac{\partial \rho}{\partial x} + \frac{\tau_{s x}}{\rho_0} - \frac{\tau_{sl}}{\rho_0} - \frac{1}{\rho} \left( \frac{\partial h}{\partial x} \frac{\partial S}{\partial x} + \frac{\partial h}{\partial x} \frac{\partial T_x}{\partial x} \right) + \frac{\partial}{\partial x} \left( h T_{sx} \right) + \frac{\partial}{\partial x} \left( h T_{sy} \right) + h u S
\]
Equation (1) is the continuity equation, and equations (2) and (3) are the momentum equations in the x and y directions, respectively.

The water quality model uses the advection-dispersion equation (4) and assuming the degradation processes satisfy the first order reaction mechanism

\[
\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x_i} + v \frac{\partial C}{\partial y_i} = D_x \frac{\partial^2 C}{\partial x_i^2} + D_y \frac{\partial^2 C}{\partial y_i^2} \quad (4)
\]

\[
\frac{\partial C}{\partial t} = -KC \quad (5)
\]

3. Results and Discussion

The study area was sensitive to the environmental conditions, there was no natural inflows or outflows, and rainfall cannot replace water lost by evaporation and leakage. Therefore, reclaimed water would be added to maintain the water level. The reclaimed water will flow into the lake from two points: z1, in the northern part of the lake, and z2 in the southern part of the lake (Figure 1). Compared with the lake water, the reclaimed water had higher concentrations of nitrogen and phosphorus (Table 1). The reclaimed water was equivalent to point source pollution, and easily cause accumulations of nitrogen and phosphorus and subsequent eutrophication. Two canals (north canal and south canal) were planned to build along the lake, and one part of the lake water would flow from point x1, through the north canal and return to the lake at points x2, x3, x4, x5, x6, and the other part of the water would flow from source x10, through the south canal and return to the lake at points x7, x8, x9 (Figure 1). The lake and the water canals would form water circulation system to improve the water hydrodynamic condition. The velocity of the inlet point x2, x3, x4, x5, x6, x7, x8, x9 was 0.0288 m/s, 0.0817 m/s, 0.2655 m/s, 0.1745 m/s, 0.2120 m/s, 0.0648 m/s, 0.1763 m/s, 0.0827 m/s, respectively. And the recirculation system flow rate was 0.81m$^3$/s.

3.1. Model Calibration

Measurements of water quality and velocity from May 12, 2015 to June 30, 2015 and relevant meteorological parameters were used to calibrate the model. The simulation agreed with the observed values within 10%. These results indicated that the MIKE 21 model was properly calibrated and could be used to study the principal water quality characteristics.

3.2. Water Quality Simulation

In this study, the artificial landscape Lake (Figure 1) was used to simulate and predict water quality trends under different conditions. The flow field distribution in the lake was shown in Figure 2. The average current speed was 0.0034 m/s if only by wind (Figure 2a), while the average current speed was 0.008 m/s if the water circulation system built (Figure 2b).
In this article, the influences of circulation system and reclaimed water recharging system on the lake water quality were simulated. Case 1 had only recharging system but no circulation system; and case 2 had both circulation and recharging systems. The two cases simulated the water quality for July 2016. The calculated concentrations of COD, TN, TP and NH3-N in the north, mid, south of the lake were shown in Figure 3a-h.
In Case 1, the reclaimed water was added to the lake from the points z1 and z2, about 29500 m$^3$/d. Figure 3a-d showed the water quality for Case 1. The reclaimed water and the lake water COD concentrations was not significantly different, and the relative volume of reclaimed water was small (approximately 3%), so the change of COD was small. The concentrations of TN, NH3-N, and TP in the reclaimed water were approximately 15, 6 and 10 times larger than in lake, respectively, therefore, the changes in those concentrations were readily observed. The calculated concentrations at the north part were strongly affected by the addition of reclaimed water, because the north part of the lake was narrow with poor dispersion. The south and mid part were rather open and had strong convective...
diffusion, so the pollutant concentrations were lower than the north part. When the simulation completed, the concentrations of COD, TN, NH3-N, TP were 73.5 mg/l, 1.8mg/l, 0.68mg/l and 0.088mg/l, respectively. These results show that if the lake was recharged with reclaimed water (without a circulation system), nitrogen and phosphorus would accumulate and led to eutrophication.

Case 2 included both the circulation and recharging systems. The circulation system, which was favourable for the dilution and diffusion of pollutant, rapidly mixed the recharge water throughout the lake. And through the continuous renew of water-air interface, the DO content was increased and the self-purification ability was strengthened. The water quality was consistent at all three parts (Figure. 3e-h). Variation at the north part was smaller than in Case 1. After the simulation completed, the concentrations of COD, TN, NH3-N, TP were 47 mg/l, 0.115 mg/l, 0.5 mg/l and 0.07 mg/l, respectively. Compared with Case1, the concentrations had decreased by 37%, 35%, 27% and 20%, respectively.

4. Conclusions
This paper presented the relationship between hydrodynamics and water quality of urban landscape water. MIKE 21 model was used to simulate the hydrodynamics and water quality under different cases in an urban landscape lake. The simulation result showed that a water circulation system could effectively improve current speed and solve the problem of water quality deterioration caused by reclaimed water added to offset water losses from evaporation and leakage in the lake. And based on the mechanism of relationship of hydrodynamic and water quality, the Olympic forest park in Beijing and the living water garden in Chengdu have already achieved the expected outcomes. Therefore, a circulation system could effectively maintain water quality and eliminate the risk of water eutrophication when reclaimed water was used to recharge the lake.

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