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Tracer study of the hydraulic performance of constructed wetlands planted with three different aquatic plant species

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ABSTRACT

The species, density and distribution of aquatic plant affects the hydraulic performance of surface flow constructed wetlands, and further affects the purification of wastewater. In this study, Tracer tests were conducted in three free surface flow constructed wetlands planted with different species of aquatic plants, i.e. *Artemisia selengensis*, *Juncus effusus* and *Iris sibirica*. These tests were repeated three times in each wetland. The optimal hydraulic indicators measuring the hydraulic performance were measured using a significance test and representative analysis. The results showed that the constructed wetland planted with *Juncus effusus*, characterized by thinner stalks and a higher planting density, was significantly better than those planted with *Artemisia selengensis* and *Iris sibirica* in both the effective volume ratio e and moment index I_{moment}. There was no significant difference between the wetland planted with *Artemisia selengensis* and the one planted with *Iris sibirica* in any of the analyzed hydraulic indicators. The results showed that the wetland planted with *Juncus effusus* exhibited the maximum values of effective volume rate e, moment index $I_{moment,}$ short circuiting index t_{10} and mixing index t_{90}/t_{10} and had the minimum of number of tanks in the TIS model N. Therefore, the *Juncus effusus* wetland displayed the best hydraulic performance and the most abundant flow mixture among the tested wetlands. The results also revealed that the degree of plug flow or completely mixed flow in a constructed wetland should not be used as a criterion for evaluating hydraulic performance. N and λ were not recommended as the measurement indicators. The effective volume ratio e, moment index I_{moment}, short circuiting index t_{10} and mixing index t_{90}/t_{10} were selected as the optimal indicators for measuring the flow conditions in free water surface flow constructed wetlands.

1. Introduction

Free water surface flow constructed wetlands (FWSF CWs) have very important applications in agricultural non-point source pollution (Ham et al., 2010; Persson, 2000; Persson and Wittgren, 2003; Tournebize et al., 2016). Because of their physical, chemical, biological and eco-friendly properties, FWSF CWs have the advantages of low cost and simple operation; they also display obvious superiority in the ecological purification of drainage and non-point source runoff (Jenkins and Greenway, 2005). Many studies of FWSF CWs have been conducted around the world, examining sewage, agricultural drainage, industrial wastewater, and rain runoff (Vymazal, 2013).

Unlike the adsorption of substrate materials and biological membranes used to purify wastewater in subsurface flow constructed wetlands (SSF CWs), the species selection and planting form of aquatic plants significantly affect the ability of FWSF CWs to purify sewage (Bojcevska and Tonderski, 2007; Toscano et al., 2015; Zhang et al., 2014). In addition to particle settling and sediment adsorption, plant absorption is a major factor that affects the sewage purification of FWSF CWs. Furthermore, aquatic plants exert an important impact on the internal water flow in FWSF CWs (Holland et al., 2004; Jadhav and Buchberger, 1995; Kadlec, 1990). The effect of the stem resistance of aquatic plants on flow conditions should not be neglected as it further affects particle settling. Aquatic plants affect the hydraulic performance by changing the flow path and the hydraulic performance is closely linked to the purification abilities of CWs (Zhang et al., 2012). Therefore, it is necessary to study the effects of different types of aquatic plants on the hydraulic performance of FWSF CWs.

This study evaluated three FWSF CWs planted with different locally dominant species of aquatic plants. Tracer tests of each wetland were repeated three times and the hydraulic indicators were calculated based on the tracer data. The hydraulic performances of

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the three wetlands were analyzed according to the indicators, and the plant species that most improved the hydraulic performance was determined. In addition, with significance testing and stability analysis, the hydraulic indicators that most accurately reflect the hydraulic performance of a FWSF CW were acquired.

2. Materials and methods

2.1. Site description and wetland features

The test zone is located in the Jiangxi Province Center Station of Irrigation Experiment, which is located in the Ganfu Plain of the Poyang Lake basin, Jiangxi, China. The geographical coordinates are 115°49′E–116°46′E and 28°24′N–29°46′N (Fig. 1). The climate is a typical subtropical, humid and monsoon climate with abundant rainfall. The annual temperature is 18.1 °C, and the annual rainfall is 1685 mm.

Tracer tests were conducted in the three wetlands, which were planted with *Artemisia selengensis*, *Juncus effusus* and *Iris sibirica*. *Artemisia selengensis* has the highest economic value, *Juncus effusus* has the finest stem and the highest density, and *Iris sibirica* has strong climate adaptability. The wetlands were designed with parallel arrangements. The size of each wetland was 14.0 m × 6.5 m (L × W), and the design water depth was 0.2 m (Fig. 2).

The inflow of each wetland was provided by a pump that extracted wastewater from paddy field drainage. The water inflow rate varied among the three wetlands, because the fixed water source position and pump power and the varying wetland locations resulted in the different water head losses as the water was delivered. Some of the basic parameters are shown in Table 1. In this study, the three wetlands were designed to treat the drainage from paddy field after a rainfall event. The average daily maximum flow rate from drainage zone during 1980–2012 is 726.7 m^3/d; it is a drainage depth of 84.6 mm in an area of 8560 m^2. When the three wetlands were used to treat the high-flow drainage, the average hydraulic loading rate to each wetland was 2.66 $m^3/(m^2\ d)$.

Before the tests, the plant density of each wetland was surveyed using the diagonal method (Fig. 2), with a quadrat size of 1.1 m × 1.1 m. *Juncus effusus* grew very densely and was distributed in agglomerated clusters. Therefore, the average density was deduced from the number of stems, which was obtained by multiplying the number of middle clusters and the number of stems in each middle cluster. The results of the plant investigations of these three wetlands are shown in Table 2.

2.2. Test operation and data collection

Tracer tests were performed three times in each wetland to meet the repetition requirement. The inactive tracer, Rhodamine WT, was selected in this study. The tracer's label was 106053 FWT 25, and its mass concentration was 2.5%. Rhodamine WT has the properties of non-toxic, strong fluorescence, low background concentration in the environment, difficulty to be degraded and adsorbed and suitability for short-term tests in one week (Lin et al., 2003). An YSI-600 OMS multiparameter water quality sonde and an YSI-6103 probe were used to monitor the tracer concentration. The YSI-6130 probe can be set to automatically record the concentration, conductivity and temperature of a solution with a specified time step. Before the tests, the probe should be calibrated using the standard solution of Rhodanmine WT dissolved in deionized water, and the corresponding concentration were 0, 100 and 200 μg/L. The time step was set to one minute in this study. Based on the volume of water in the wetlands and the instrument's range, 10 g of tracer fluid was added to the inflow during each test; thus the mass of pure Rhodamine substance was 0.25 g. The predetermined amount of tracer solution was injected into the inflow instantaneously while the water level was held stable at 0.2 m. The YSI-600 OMS monitoring instrument was placed at the outlet to allow real-time monitoring of the concentration changes. When the tracer curve dropped to a stable value near the background concentration, the test was stopped. To prevent water seepage between adjacent wetlands, the water depths of the tested wetland and the adjacent wetlands were maintained at the same level throughout the test process.

2.3. Analytical methods

The residence time distribution (RTD) curve is the basic tool for analyzing hydraulic performance. Under the condition of ideal plug flow, the inflow uniformly flows through the wetland cross sec-

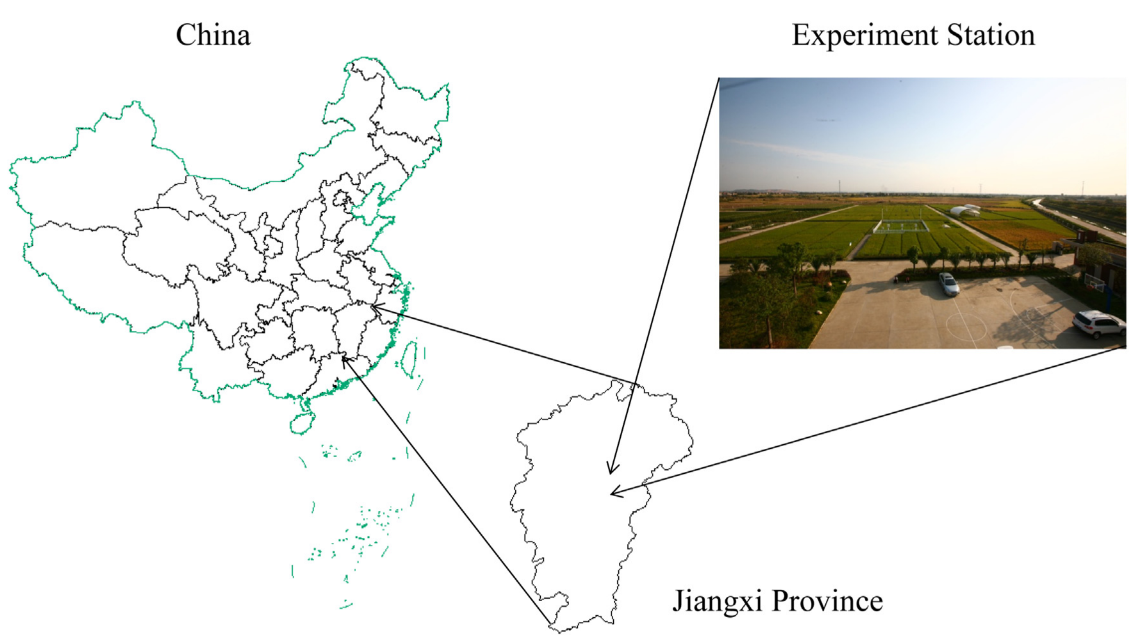

Fig. 1. Location of the Jiangxi Province Center Station of Irrigation Experiment.