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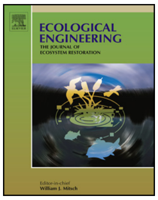

Experimental study and simulation of water quality purification of urban surface runoff using non-vegetated bioswales

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ABSTRACT

Road runoff pollutants are widely recognized as major causes of receiving water pollution. Bioswale serves as an effective storm-water natural purification and disposal technology, which presents important practical value in controlling runoff pollution and stormwater utilization. Multiple bioswale cells with different media are designed and built. Artificial stormwater is synthesized on the basis of the investigated and measured data on the surface runoff pollution in Northwest China, which is used to study the purification effect of bioswale on runoff pollutants from four aspects. Results show that different factors significantly affect water purification process. The removal rate of nitrogen decreases with the increase of inflow concentration for most of media; however, which is contrary for phosphorus and mostly greater than 90%. Blast furnace slag has the best removal of nitrogen, phosphorus and heavy mental Zn under low inflow concentration. The correlation models between the purification effects of total nitrogen, total phosphorus and COD and their influencing factors are established using the multivariate regression method. The Nash–Suttcliffe simulation efficiency coefficients of the models are greater than 0.6.

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1. Introduction

Urban non-point source pollution is a new problem that has emerged along with rapid urbanization. The pollutants in storm runoff (such as nitrogen, phosphorus, heavy metals, and organic substances) will predominantly undergo the processes of accumulation, scouring, and transport before entering receiving waters (Egodawatta et al., 2007). Urban non-point source pollution becomes increasingly complex with the influence of rainfall, runoff, weather, and other parameters, for instance surface characteristics of land utilization. The increased retention time of runoff pollutants and water-saturated conditions, as determined by design configurations and rainfall size, intensity, and interval, were found to significantly affect overall nutrient and herbicide removal (Vaze and Chiew, 2002; Yang et al., 2013).

Bioretention facilities as typical comprehensive management measures of low impact development, which effectively control situ infiltration (runoff pollutants, controlling peak flow, and runoff volume), have been found effective in removing a variety of pollutants from storm water (Li and Davis, 2009). These measures are terrestrial-based (upland as opposed to wetland) water quality and water quantity control techniques that utilize the chemical, biological, and physical properties of plants, microbes, and soils to remove pollutants from storm water runoff; they are designed to drain within hours (Prince George's County, 2007).

After choosing appropriate plants and packing media, Monash University used PVC pipes with a diameter of 375 mm and finished more than 800 small experiments to obtain the following pollutant removal rates: TSS: 95%; TP: 85%; TN: 50%; Zn, Pb, Cd; 90%; Cu: 60% (Wang, 2011a,b). Davis (2006) concluded that TP removal rate for urban storm water runoff can reach 70%–85% on the basis of laboratory soil bin test; although bioretention is highly effective in removing particulate phosphorus, it is not as successful when employed to deal with dissolved phosphorus. Storm water nitrogen exists in a number of chemical forms (Taylor et al., 2005); research results show that dissolved organic nitrogen and nitrate leached from bioretention cells only exhibit a 9% net reduction in overall TN concentration. Laboratory and field studies have shown that the creation of a saturated zone at the bottom of bioretention systems can promote conditions for favorable denitrification to increase nitrogen removal (Zinger et al., 2013; Brown and Hunt, 2011). The removal rates for Cu, Cd, Pb, and Zn generally increase with the

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use of bioretention systems and reach an average of over 60%. The particle state of heavy metals is usually removed by utilizing a filtered intercept, and dissolved metals are eliminated mainly by adsorption. Studies have shown that bioretention systems exhibit good removal effect on heavy metals in particle state; in certain instances, the removal effect on dissolved heavy metals is not ideal, and more than 90% of heavy metals are removed within 25 cm of the filler surfaces of bioretention facilities (Turer, 2001; Muthanna et al., 2007; Myung et al., 2012). On the basis of their analysis of urban runoff water quality in Beijing, Che et al. (2003) pointed out that COD in early runoff from pavements and linoleum roofs usually reaches thousands of mg/L; moreover, the amounts of COD, SS, synthetic detergent, phenol, oil, and heavy metal lead in road surface and roof runoff are beyond the artificial recharge groundwater quality standard in Beijing. It will cause groundwater pollution if stromwater is directly recharged or discharged into the underground, therefore effective measures must be employed to control early-stage rainfall.

As a typical bioretention facility, bioswale (also called biological filter/groove) shows great promise as a technology for minimizing the migration of the aforementioned pollutants (Roy-Poirier et al., 2010). Runoff infiltration rate and pollutant removal efficiency can vary among different media components and various districts. On the basis of the hydrology/geology in Northwest China, a pilot-scale bioswale experiment and theoretical analysis are carried out in this study, to fulfill the following the objectives: (1) to study the effects of such factors as water pollutant concentration, running interval time, media types, and bioswale width on the purification of bioswales and (2) to establish the correlation between bioswale pollutant removal rate and significant factors through regression analysis. The present study serves as the basis for future design improvements pertaining to media characteristics.

2. Materials and methods

2.1. Experiment device

In 2013, two groups of pilot-scale bioswales were designed and built in the outdoor field of the Xi'an University of Technology. These groups included a set of 10 bioswales measuring 0.5 m wide (bioswales 1–5 were permeable, whereas bioswales 6–10 featured anti-seepage properties). Each groove featured the following specifications: length 2.0 m × width 0.5 m × depth 1.05 m. Another set comprised 8 bioswales measuring 1.0 m wide (bioswales East1 (E1)–East2(E2) and West1(W1)–West2 (W2) were permeable, whereas bioswales East3 (E3)–East4(E4) and West3 (W3)–West4 (W4) featured anti-seepage properties). Each groove of the bioswales featured the following specifications: length 2.5 m × width 1.0 m × depth 1.05 m. In addition to bioswale #6, other sets showed similar structures, except for the special packing layer (Li et al., 2010). Bioswale #6 showed a filter ditch without planting soil layer that contained a mixture of sand, planting soil, and humus (Zhang et al., 2008). The device structures are shown in Fig. 1 and Table 1. Experimental device photographs are shown in Fig. 2.

Certain bioswales were selected in this study for the purification effect experiment. Bioswales #8–#10 were used to analyze the effect of various media on bioswale water purification. Bioswale #10 was used to determine the influence of running time interval on purification. Bioswales #6–#10 were utilized to study the effect of water concentration on purification. The ditch widths of bioswales #7–#10, #W3, #W4, #E3, and #E4 were employed to determine their influence on the purification of bioswales.

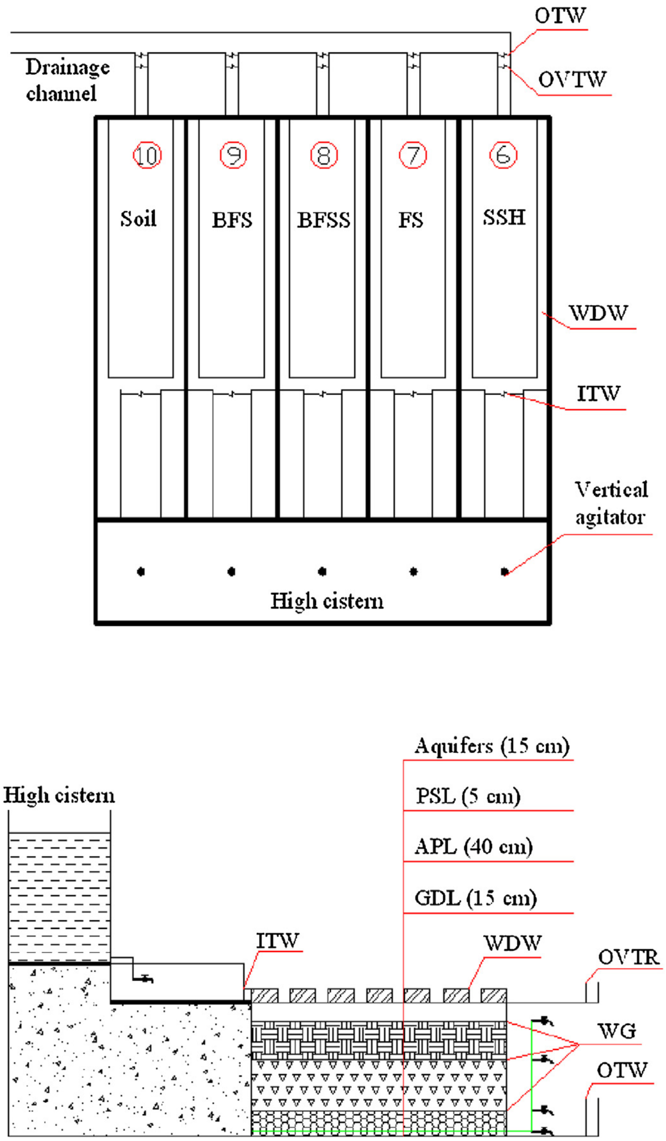

Fig. 1. Floor and section plan of bioswale pilot plant (0.5 m wide). Construction includes an aquifer, covering layer and planting soil layer(PSL), artificial packing layer (APL), rice stone layer, and gravel drainage layer (GDL) from top to bottom in each bioswale. WDW for water distribution weir, ITW for inflow triangle weir, OTW for outflow triangle weir, OVTW for over triangle weir, WG for waterproof geotextile. Screened sizes of blast furnace slag, rice stones, and gravels are 0.6–1.5, 0.3–0.6, and 1.5–3 cm, respectively.

2.2. Monitoring and analysis method

The purpose of this test was to investigate the purification effect of bioswales through physical and chemical tests in the absence of plants. Simulated stormwater was artificially synthesized, and tap water was used to wet the bioswale beds before each test. Because the pilot-scale bioswales were constructed above the ground, it was difficult to collect the surface runoff as inflow water. Meanwhile, for actual rainfall events, many conditions are uncontrolled, such as water volume, pollutant concentration, rainfall pattern, and so on, therefore it is difficult to compare the influence of certain single factor on the purification effect under the comprehensive factors. In this test, the experimental influent concentrations of pollutants were determined through comparing the results of water quality assessment on urban road surface runoff in Xi'an (Li et al., 2012; Yuan, 2011; Lin, 2011; Wang, 2011a,b; Chen, 2012). Therefore, main pollutant concentrations of synthesized stormwater are close to

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