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Application of constructed wetlands treatment technique for stormwater runoff pollution control

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Abstract: In order to improve the pollution control effect of nitrogen, phosphorus and heavy metals in stormwater runoff by using the constructed wetlands, factors such as medium, plants, pretreatments, etc. that may influence the removal efficiency are discussed based on the current studies. The pollution control effect can be enhanced by the improvement of the design methods, the components and management of constructed wetlands. The design methods aimed at controlling the stormwater runoff should be based on the hydrological data accumulated for years. The development of novel medium and the selection of plants (i. e., flood-tolerant and economical) should be considered in advance. The management of constructed wetlands should be enhanced and the database of the stormwater in wetlands should be built. The discussion above should be effective in improving the pollution control effect in stormwater runoff by applying constructed wetlands.

Key words: stormwater runoff; constructed wetlands; improvement methods

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In developed countries, the point source pollution was already effectively controlled. Non-point source pollution has become one of the main factors that influence the water quality. For example, about 60% of river pollution and 50% of lake pollution are related to the non-point source pollution in the United States[1]. About 40% to 80% BOD load in secondary sewage treatment plants comes from stormwater runoff[1-2]. Stormwater runoff pollution is serious in our country as well. Rapid urbanization has led to the increase in impervious areas, making most of the rainfall hard to infiltrate. Many kinds of pollutants on urban road surfaces are dissolved and washed away by the road runoff. Finally, runoff with pollutants is discharged into the receiving water bodies[3-4], resulting in eutrophication. In Taihu lake and Dianchi lake, non-point source pollution has become one of the main reasons for the eutrophication[5].

Stormwater runoff pollution has the characteristics of discontinuity transportation. Pollution loads in short periods is high during the rainy season[6]. Therefore, decentralized and ecological treatment methods should be chosen for urban runoff pollution control. Constructed wetlands is one of the decentralized and ecological land treatment methods, which was developed in the late 1970s. Now, constructed wetlands have become effective treatment technology for stormwater runoff pollution with low maintenance cost, energy consumption and simple operation.

In order to improve pollution control efficiency of constructed wetlands, the current removal effects of pollutants in stormwater runoff is analyzed, factors influencing the effect are also discussed, some directions and effective measures for improving removal rate of pollutants in stormwater runoff are given in this study.

1 Pollution Removal Efficiency in Constructed Wetlands for Stormwater Runoff Treatment

Nitrogen and phosphorus are the principal pollutants in stormwater runoff that can cause eutrophication and affect dissolved oxygen levels of receiving water. Heavy metals in stormwater are toxic to the aquatic organisms. Therefore, it is necessary to understand the removal ability of constructed wetlands in nitrogen, phosphorus and heavy metals, further for treatment performance improvement.

1.1 Nutrient removal

Generally, nitrification and denitrification are considered as the main ways of nitrogen removal in the constructed wetlands for stormwater runoff treatment. Phosphorus removal routes are mainly dependent on several aspects such as microorganisms, plants absorption and media bed absorption[7]. Also, rainfall characteristics and some other factors would influence nitrogen and phosphorus removal in constructed wetlands. The stormwater runoff of 48 000 m^2 catchments consisting of houses, streets, gardens, and street parking areas is treated by constructed wetlands in Port Jackson (Sydney) with the

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size of 700 m^2. The results show that the average removal efficiency of NO_x, TN, TKN and TP are 22%, 16%, 9% and 12%, respectively[4]. The reports of constructed wetlands treating stormwater runoff from residential and road areas in Kalmar, SE Sweden show that the average nitrogen removal rate is 173 kg/(ha · a) and increasing with time, while the average phosphorous removal rate is 12.1 kg/(ha · a) and decreasing with time[8]. Tanner et al.[9] found that phosphorus accumulation in constructed wetlands is 115 to 128 g/m^2 and the phosphorus removal efficiency decreased obviously after 5 years' operation.

Nitrogen removal rate is low because the hydraulic retention time is too short to accomplish nitrification and denitrification process. Due to the variations in phosphorus removal effects, some studies are carried out for the mechanisms of phosphorus removal in constructed wetlands. It is reported that phosphorus removal is mainly dependent on the reaction with Fe^{2+}, Fe^{3+}, Al^{3+}, Ca^{2+}. Therefore, phosphorus removal efficiency is associated with metal types in the constructed wetlands[10-11]. When the concentrations of Fe and Al in stormwater runoff are high, precipitation and adsorption are considered as the main phosphorus removal mechanisms[12]. Low removal efficiency of phosphorus that maybe result in adsorption saturation of mediums[13]. Therefore, medium cleaning regularly is beneficial for phosphorus removal.

1.2 Heavy metal removal

Some possible ways, such as precipitation, microorganism assimilation, plants absorption and physical chemistry characteristics of mediums, etc. would influence heavy metal removal in the constructed wetlands. Different removal efficiency of heavy metal is shown in different studies. The result of a constructed wetland applied to treat road stormwater runoff shows that 40% to 90% metals are removed[14]. Vymazal[15] found that the removal efficiencies of Pb, Ni, Cd in a constructed wetland for stormwater runoff treatment were 98%, 92% and 77%, respectively. The average removal efficiencies of Cr, Cu, Pb, Ni and Zn are 64%, 65%, 65%, 22%, and 52%, respectively, whereas the removal efficiencies of Fe and Mn are negative (−84% and −294%, respectively) reported in a constructed wetland treating stormwater runoff with six rainfall events[16]. More export of Fe and Mn from the wetlands can be explained by the resuspension of bottom sediments with Fe and Mn during high-flow events [8].

Also, the removal efficiencies of metals would be related to performance of constructed wetlands. The concentration of stormwater inflow, hydraulic loading rate, detention time, storm intensity, runoff volume, and wetland size are all functioned to influence heavy metal removal efficiency[4]. Additionally, some benthic macroinvertebrate communities also released metals into the overlying water, affecting the removal efficiency of metals[17].

2 Effect of Factors on Pollutant Removal in Constructed Wetlands for Stormwater Runoff Treatment

2.1 Mediums

The medium is one of the most important factors which contribute to remove pollutants in the constructed wetlands. At present, wastes, such as construction waste, solid waste, coal cinder, etc. are becoming hotspots used as mediums. In addition, sand and gravel materials are popular. NH_4^+ removal rate is nearly 100% in some constructed wetlands with zeolite filters, better than 42.25% to 69.9% in the constructed wetlands with gravel filters when treating stormwater runoff[18]. Additionally, zeolite could be completely reproduced through the digestive bacteria, without chemical regeneration. Therefore, constructed wetlands with zeolite as the medium can endure high concentrations of ammonia nitrogen in stormwater runoff.

The removal efficiency of phosphorus in stormwater runoff is affected by the types of mediums used in the constructed wetlands. More phosphorus would be removed in the constructed wetlands using the medium with high ion exchange position. However, the removal rate of TP would be sharply decreased when the mediums are saturated.

2.2 Aquatic plants

Aquatic plants are the main components of constructed wetlands for stormwater runoff treatment. Pollutants can be absorbed by the aquatic plants in the constructed wetlands. It is reported that pollutant removal efficiency in constructed wetlands with a plant system is better than that in the constructed wetlands without plants. Also, pollutant removal efficiency is different in the constructed wetlands with different plants. For example, pollutants removal efficiency in the constructed wetland with reed is better than that with calamus[19]. In order to achieve high removal efficiency of pollutants, plants should be harvested periodically when the plants are mature.

Additionally, dissolved oxygen (DO) released from the aquatic plants in the constructed wetlands affects the removal effect of organic matter in stormwater runoff. Therefore, the density of plants is related to (chemical oxygen demand) COD removal directly. With the increase of the plant density, COD removal efficiency would increase in the constructed wetlands[19].

2.3 Pretreatment

Optimal design of the constructed wetlands will reduce the pollution of stormwater runoff efficiently and prolong the lifetime of the wetlands. Generally, a pre-sedimenta-

tion tank is popular in reducing the first flush of pollutants in the stormwater runoff into the main wetlands. For example, bypass oil separators, silt traps and spillage containment facilities could be installed prior to the constructed wetlands when highway runoff is treated[20].

It is suggested that the maximum removal efficiency of pollutants appeared to occur when the sedimentation pond surface area is 2% to 3% of the drainage catchment area in the US and Europe[20]. Therefore, it is necessary to design pretreatment facilities on specific sites to treat different types of pollutant produced from stormwater runoff.

2.4 Other factors

Some other factors are likely to influence the operation of constructed wetlands for stormwater runoff treatment, such as ecological sensitivity, site protection and sensitivity of ground waters, and so on. Therefore, it is necessary to evaluate the environmental deterioration after the stormwater runoff is treated by the constructed wetlands, for further assessing the environmental restoration after the wetlands operation to provide the optimal operation modes.

3 Discussions

Stormwater runoff pollution is one of the most important non-point source pollution. Control and management of stormwater runoff pollution are the main contents in the regional water quality improvement program. Organic pollutants, nitrogen, phosphorus and heavy metals can be removed by the constructed wetlands when the stormwater runoff is treated. However, mediums, plants, pretreatment and other factors can affect the efficiency of pollutants removal in the constructed wetlands. To strengthen the purification effect of constructed wetlands, the following aspects should be further considered.

3.1 Establishing design manual based on runoff pollution control

Generally, in the engineering application of the constructed wetlands for stormwater runoff control, design and construction of the constructed wetlands are unrelated to pollutant removal efficiency. Pollutant removal in the constructed wetlands for stormwater runoff control is usually as an additional value.

Most of the constructed wetlands are constructed to reduce the peak flow and delay peak time of runoff. There are no design criteria and methods of constructed wetlands for the purpose of pollution control. In the United States, Canada and Europe, the volume of constructed wetlands is designed to afford 13 mm depth runoff produced from the impervious surface in the catchments. Some other reports suggested that the constructed wetlands surface area can be calculated by 1.5% to 3% of the catchment area. Usually, the runoff volume is proportional to the impermeable surface area of the catchments when the depth of stormwater runoff is less than 25.4 mm. The catchments with more impervious surfaces will produce more runoff than the catchments with a less impervious surface. Therefore, a fixed design method of the constructed wetlands might not be appropriate. It is necessary to establish the constructed wetland design method and construction scheme for the stormwater runoff pollution control and runoff volume reduction, simultaneously. In the areas with stringent requirements on runoff pollution control, the design criteria and methods of constructed wetlands for the purpose of runoff pollution control should be established.

3.2 Improving design methods based on hydrological data

Compared with the urban sewage and industrial wastewater, the stormwater runoff is much different in hydrological and chemical quality and so on. The purifying effect of the constructed wetlands for stormwater treatment is related to the runoff source, speed, volume and the rainfall frequency and so on. Furthermore, the other factors, such as detention time, circulation and distribution of the rainfall, seasons, the change of weather and soil permeability, can affect the purifying function of the constructed wetlands. Hydrological data collected is the key factor to determine the degradation mechanism of pollutants in the stormwater runoff by applying the constructed wetlands. It is necessary to build the constructed wetlands based on the local years' rainfall statistics. Different design methods should be developed in different areas because of different hydrological data.

3.3 Strengthening management and setting up databases

Maintenance and reconstruction are two major management problems of the constructed wetlands, which can influence the runoff pollution control. Maintenance of the constructed wetlands is related to the service time and operation costs. Parameter optimization, optimal operation mode, maintenance costs reduction, service life increase, stable pollutants removal efficiency, etc. are necessary to be considered for operation and maintenance of the constructed wetlands. In order to prolong the lifetime of the constructed wetlands, the following points should be considered in constructed wetlands establishment for stormwater runoff treatment. 1) How to rebuild; 2) How to handle the mediums and plants; 3) Local natural environment restoration.

On the other hand, the wetland databases establishment is useful in investigating the problems and the modified methods for constructed wetland construction and operation, providing basic data for runoff pollution control. At

present, the research of constructed wetland is still based on the black box theory and the model method is less applied during the constructed wetlands construction and operation. Therefore, it is necessary to establish the wetland databases to get first-hand statistical information for building the prediction model of pollutant removal, for further instructing the construction and operation of the constructed wetlands for stormwater runoff treatment.

3.4 Modifying components

3.4.1 Developing novel mediums

In the future, to solve the problem of stormwater runoff pollution is the development direction of the constructed wetlands. It is important to remove pollutants efficiently in single stage wetland under the condition of limited land. Therefore, novel mediums used in the constructed wetlands is an effective method to solve the problem. Waste resources recovery as mediums is one of the study trends. However, the adsorption effect of many materials is not very clear and the adsorption saturation time of mediums is not identical. Therefore, novel ecological adsorption materials which could be used as mediums in constructed wetlands should be developed.

3.4.2 Selecting flood-tolerate and economic plants

Pollutants in the stormwater runoff can be absorbed by plants in the constructed wetlands. Owing to the characteristics of stormwater runoff, plants planted in the constructed wetlands should be flood-tolerant varieties. Also, the plants chosen should be of normal growth in the dry season. On the other hand, harvest period of plants could influence the effect of runoff pollution control. It was reported that short harvest periods of crops is effective in pollutant removal in stormwater runoff because more pollutants can be absorbed by plants in growing periods. Therefore, economic plants can be chosen to solve utilization of the harvest plants. Flood-tolerant and economic plants can be selected in constructed wetlands for stormwater runoff treatment.

4 Conclusion

Constructed wetlands have become the main ecological engineering methods to control stormwater runoff pollution. Nutrients and heavy metals can be removed in the constructed wetlands. Selection of mediums, plants, and some other factors can significantly influence the removal efficiency of pollutants in stormwater runoff. However, at the beginning of design, runoff pollution control by the constructed wetlands is not taken into consideration and regarded as an additional value. To improve the pollutant removal efficiency, the design methods of constructed wetlands should be aimed at stormwater runoff pollution control and should be based on hydrological data collected for years. Novel mediums selected, flood-tolerant and economical plants chosen, effective management and database establishment are necessary.

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人工湿地技术在暴雨径流处理中的应用

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摘要: 针对人工湿地对氮磷和重金属的去除现状,讨论了影响人工湿地处理效果的因素,如填料、植物、前处理等,提出需要从设计方法、水文资料统计、人工湿地组成部分及人工湿地的管理等方面入手改进人工湿地的处理效果. 采用以径流污染控制和削减为目的的设计方法、以多年水文资料为根本的设计思路,以新型填料研发、耐淹及经济植物选择为应用前提,强化暴雨湿地管理,建立暴雨湿地数据库,是改进暴雨湿地净化效果的有效途径.

关键词: 暴雨径流; 人工湿地; 改进方法
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