Study on the Clogging and Regulation Measures of Bioretention Facilities in Sponge City

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Abstract: Bioretention facilities play an important role in regulating runoff, purifying water quality and preventing urban waterlogging. However, clogging is the common and restrict problem after long-term operation of these facilities, which affects the effective operation and ecological benefits. Clogging causes and influence factors of bioretention facilities were summarized in this work. And corresponding regulation measures of bioretention facilities in sponge city were studied systematically from five aspects: source control, operation design, media optimization, vegetation selection, and management. A series of optimization measures were recommended, such as apply novel snowmelt agents, add pre-treatment process, improve filter materials, optimize plant species, update damaged cover and vegetation, and build a dynamic monitoring system. This work could provide alternative strategies for the long-term operation of bioretention facilities, which play a vital role in regulating runoff, purifying water quality and improving the construction of sponge city.

1 INTRODUCTION

Bioretention facility is one of the representative measures of low-impact development and sponge city construction, which can alleviate runoff pollution, purify water quality, reduce the amount of surface runoff and peak flow (Skorobogatov 2020). Bioretention facilities mainly include bioretention zone, rain garden, flower bed, biofilter trench and ecological tree pond. Rainwater runoff contains a variety of pollutants such as suspended solids (SS), nitrogen and phosphorus, pathogenic bacteria, heavy metals, snowmelt agents, pesticides and herbicides (Zhang 2019). During the long-term operation, bioretention facilities face some problems such as excessive erosion, pollutants accumulation, media clogging and plant death. And clogging has become one of the most common and vital problems in the operation process of bioretention facilities (Tang 2017, Costello 2020, William 2019).

At present, many researches have focused on the percolation performance, filler composition, plant selection, model simulation and so on (Jiang 2019, Andrew 2021). Li put forward improvement and management suggestions for the construction problems of bioretention facilities, such as inconsistent construction with drawings and poor drainage (Li 2020). However, researches on the causing and influence factors of clogging and their regulation methods of bioretention facilities are still scattered. In this paper, the reasons and factors of clogging that affected the operation of bioretention facilities were systematically summarized, and the regulation measures to optimize were comprehensively proposed, which could provide a reference for the actual operation of green stormwater infrastructure in sponge city.

2 CLOGGING CAUSES

After long-time operation of bioretention facilities, media clogging is one of the common problems and

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the water quality can't meet the design requirements. Permeability is used to characterize the clogging degree of bioretention facilities (Ding 2019). In the field investigation of bioretention facilities after operation for 4 years, it was found that clogging problem existed in 40% of the time during the operation of the facilities (Coustumer 2012). The causes and processes of clogging are complex and simultaneous, which can be mainly divided into physical clogging, chemical clogging and biological clogging.

Physical clogging SS is the representative reason of physical clogging, causing inorganic and organic clogging (Conley 2020). Researches showed that the main reason for inorganic clogging was suspended particles with a particle size above 5 μm, and most of them were inorganic minerals (e.g. quartz, feldspar and other non-expansive minerals), which could permeate with rainwater runoff and easily be trapped on the surface of medium due to filtration (Kandra 2017). SS with particle size during 0.22 μm -5 μm could lead to organic clogging (Kandra 2017).

Chemical clogging When rainwater runoff with complex composition entered bioretention facilities, it would cause changes in pH value, the contents of carbonate and other chemical components of water, resulting in precipitation of salt, iron and calcium ions, and then forming chemical clogging (Wang 2012, Raham 2020). Studies found that TDS of runoff in grassland and congested road surface was pretty high, including bicarbonate and calcium ions, leading to the risk of chemical clogging (Raham 2020). Kakuturu also found that NaCl could affect permeability of facility and plant health, resulting in clogging of bioretention system (Kakuturu 2015).

Biological clogging Under suitable conditions, microorganisms in the facility could multiply rapidly and form biofilms, which blocked the pores of filler and reduced the water conductivity of aquifers (Liu 2017). Organic matters such as humus and fulvic acid-like terrestrial organic matters, as well as proteins were their original sources. Besides microorganisms themselves, extracellular polymers (EPS) secreted by microorganisms could also lead to biological clogging. When the content of TOC in runoff was higher than 25 mg/L, it was beneficial to the large-scale reproduction of microorganisms and secretion of EPS, resulting in a high risk of biological clogging (Chris 2013).

3 INFLUENCE FACTORS OF CLOGGING

3.1 Structure and Operation Mode

The structural characteristics of bioretention facilities (e.g. submerged area, layered packing) and the operation mode (e.g. wet-dry alternation, up-flow mode) have vital influence on the clogging of the facilities. Studies showed that high initial permeability of facility, small thickness of media layer, setting of submerged area and large particle matters could aggravate the clogging of bioretention facilities (Chen 2013, Read 2008). Many studies demonstrated that dry-wet alternation can significantly improve the oxygen supply conditions, improve the removal of pollutants, enhance permeability of the system, and thus effectively control the clogging of facility (Jiang 2017, Pan 2020). In addition, it was found that the structure of layered media effectively prolonged the time of clogging, forming the aerobic-anaerobic conditions and promoting denitrification to increase nitrogen removal (Chen 2013, Li 2014). However, some studies showed that the mixed packing may enhance the connectivity of pore space and improve hydraulic conductivity of the facility compared with the layered media (Lefevre 2015). Zhang et al (Zhang 2019) indicated that up-flow and mixed-flow bioretention facility could delay the clogging time by extending the path of runoff and hydraulic retention time.

3.2 Media and Filler

Media is one of the important factors that affect the pollution control and clogging problem in the bioretention facilities. The characteristics of the media, such as the degree of compaction, the thickness of the filter layer and whether to add carbon source, could all influence the permeability of the bioretention system (Tian 2018, Qiu 2017). Media compaction could increase the bulk density, limit the penetration of plant roots, and lead to a significant decrease in media permeability (Tian 2018). Study founded that sandy soil could bear compaction while its infiltration rate decreased significantly after compaction. As for clay soil, its compaction and water saturation had both low permeability (Qiu 2017). In addition, many studies indicated that adding organic matters into filler composition not only provided carbon source for denitrification, but also provided carriers for microorganisms, promoting the proliferation of microorganisms, thus significantly reducing the bulk density of media (Li 2019, Mu 2020). Additives such as organic compost, biochar, sawdust, straw, agricultural wastes could improve the penetration rate and water holding capacity of media. For example, adding biochar into media had a good performance in hydrological effect and nitrogen removal in the bioretention system (Mu 2020).

3.3 Vegetation

Vegetation played an irreplaceable role in bioretention facilities, but the influence of vegetation on clogging of bioretention system was complex and controversial (Yu 2019, Knowles 2011, Hua 2014). Some researchers pointed out that vegetation could delay the clogging of the facility, on one hand, vegetation could slow down the flow velocity of runoff and reduce SS. On the other hand, the growth of plant roots could promote the reproduction of microbial communities and affected the activity of rhizosphere microorganism, which were beneficial to the degradation of pollutants, maintenance of infiltration rate and prevention of clogging. Results showed that plants in bioretention facilities, especially those with thick and deep taproot, played an important role in maintaining the permeability of facilities (Yu 2019).

However, some researchers believed that plants contributed to more organic matters, thus accelerating the clogging of the system. Kadlec (Knowles 2011) found that 5%-15% of plant residues was difficult to degrade, which was easy to cause clogging. Hua (Hua 2014) indicated that plants played different roles in the whole clogging process of bioretention facility. In the early stage, plant roots restricted water flow, while in the later stage, growing roots opened new pore spaces to improve permeability. Therefore, it is necessary to consider the combination of vegetation in order to improve the efficiency of pollutant removal and alleviate the clogging of bioretention system.

3.4 Microorganism

The pores in the bioretention system could easily be blocked by the propagation of microorganisms in bioretention facilities. Studies pointed out that microorganisms such as algae and bacteria would accumulate on the surface of the bioretention media, and the reproduction of microorganisms greatly reduced the permeability coefficient of the system (Hua 2014). With the proliferation of microorganisms, the pore volume in the media gradually decreased. Microorganisms and their metabolites could block the gaps in the bioretention facility and reduce the permeability coefficient of system. The specific growth rate of microorganisms, substrate concentration and initial concentration of soil microorganisms all could limit permeability reduction. Robert confirmed that the development of clogging was highly related to the total biological oxygen demand and the cumulative mass density load of SS.

4 REGULATION MEASURES

4.1 Source Control

As a result of steel and chemical production activities, atmospheric deposition, tire wear, exhaust emissions and the use of pesticides, herbicides, deicing agents, etc. A large number of pollutants would enter the bioretention facilities with rainwater runoff, including SS, TN, TP, metal ions, and organic pollutants, etc. Many researchers indicated that the spatial and temporal distribution of rainfall runoff, pollutant concentration, underlying surface types and rainfall characteristics including intensity, duration and frequency, had great influence on clogging of bioretention facilities (Jiang 2017, Read 2008). For example, higher concentration of influent and higher rainfall intensity could more easily lead to clogging of bioretention facility (Jiang 2017). For reducing the influence of 54rainwater runoff on clogging, environmentally friendly chemicals such as biological pesticides, biological attractants, and snowmelt agents should be used to reduce the accumulation and improve their own degradation. Different clean deicers should be rationally selected according to road conditions, temperature, design of pretreatment diversion should be carried out.

4.2 Operation Design

In order to prevent the clogging and accumulation of pollutants in the bioretention facilities, it is necessary to take into account their structural characteristics and functions. Factors such as rainfall recurrence period, pretreatment process, operation mode, pollutant load, hydraulic retention time, and design of submergence zone were suggested (Coustumer 2012, Li 2019). For example, appropriate dry period was conducive to the ventilation of substrate and rapid degradation of organic matter. It was found that the permeability and hydraulic conductivity of the facility could be improved and the clogging problem could be alleviated by setting the submergence zone (Tian 2018). The addition of pretreatment facilities such as pre-ponds and vortex ponds would remove large particles in runoff ahead of time, slowed down the flow rate and prevented the snowmelt from entering directly into the infiltration area in winter (Chris 2013). For serious pollution and salinization of soil caused by rainwater runoff areas, measures should be taken to discard the flow and salt drainage.

4.3 Media Optimization

In order to alleviate clogging, measures of media optimization mainly include three aspects: combination and proportion of fillers, organic carbon source addition, and filling mode (Tian 2018, Qiu 2017, Li 2019), shown as Table 1. It is often necessary to improve the ratio of fillers or to add additives. The selection of the fillers should follow the principles of easy to obtain, moderate cost, local applicability, and have good permeability, large specific surface area and good decontamination ability, such as zeolites, vermiculites, fly ash, perlite, aluminum sludge and river sediments. New functional fillers like reed, biochar and recycled aggregates were also recommended to improve the permeability of facilities (Tian 2018, Qiu 2017). Proper addition of carbon sources can increase the permeability of bioretention facilities and effectively alleviate their clogging. However, it was also pointed out that excessive addition of carbon source could increase the background value of phosphorus, leading to release of phosphate and worsening water quality (Li 2019). Therefore, the dosage of organic matter should be strictly controlled, and the US design manual recommended that the content of organic matter in the packing should not exceed 5%.

Table 1: Media optimization for bioretention facilities.

Measures	Composition
combination and proportion of filler	sand and fly ash
	aluminum sludge and zeolite
	sand, perlite, vermiculite
	volcanic rock, spongy iron
	vermiculite, zeolite, sand
organic carbon source addition	biochar, activated carbon
	recycled building aggregates
	compost, newspaper, sawdust, straw
filling mode	layered packing
	mixed packing

4.4 Vegetation Selection

In general, vegetation in bioretention facilities should be reasonably allocated according to their cold and drought tolerance, soil permeability and type, facility scale and structure, and runoff water quality (Mu 2020, Yu 2019). The following aspects should be paid attention to when selecting vegetation in different bioretention facilities: (i) local species should be the main species, the remaining species could be matched reasonably, and the plants with strong adaptability should be selected preferably; (ii) plants with well-developed roots, large stems and leaves that can penetrate through soil layer, strong cold-resistance and drought-resistance, strong purification ability are preferred; (iii) plants that can accumulate pollutants such as heavy metals are preferred; (iv) plants with large biomass and short growth cycle are selected; (v) low maintenance cost, certain economic value and landscape effect, and the diversity of plant landscape in different seasons should be considered.

5 MAINTENANCE AND MONITORING

At present, the design and construction standards of sponge city construction in China are established, but the operation and maintenance of bioretention facilities still lack (Yin 2021, Yang 2020, Mu 2020). In order to ensure the treatment effect of bioretention facilities, prevent clogging and achieve long-term stability of facilities, the following measures are recommended: (i) regular inspection and dredge of garbage and sediment in the spillway, and regular cleaning of the sand deposit; (ii) regular vegetation maintenance according to the condition of plants growth and soil humidity; (iii) to clean or replace the surface fillers regularly and slow down the growth of microorganisms; (iv) to take plant anti-freezing measures and appropriate cover in the packed bed to slow down the freezing rate in winter. In addition, it should be monitored throughout the whole process according to the runoff process, realizing dynamic monitoring and intelligent management through the on-line monitoring, digital information platform and wireless network (Yang 2020).

6 CONCLUSION

As a representative measure in construction of sponge city, bioretention facilities faced clogging after long-term operation and maintenance, therefore, it was of guiding significance to analyse the reasons and influence factors of clogging in facilities and put forward corresponding solutions. This paper sorted out the control measures and suggestions from combination of source reduction, process optimization and operation management, providing reference for long-term stability and operation for green storm water infrastructure in sponge city:

(i) The causes and processes of clogging were complex and simultaneous, including physical clogging, chemical clogging and biological clogging, which mainly caused by SS, inorganic ions, TOC, microorganisms and their EPS.

(ii) Utilization of environment-friendly chemicals, optimization of structure by pretreatment process, modified fillers, reasonable planting of vegetation, maintenance and monitoring system were suggested to improve facility performance and alleviate clogging.

(iii) Combination of plant, microorganism, pollutant migration mechanism to solve the problem of clogging; prediction and model simulation of clogging time; as well as monitoring methods and equipment of clogging need further development.

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REFERENCES

Andrew T R, Nabiul A A, Winston R J, et al. (2021). Conventional and amended bioretention soil media for targeted pollutant treatment: a critical review to guide the state of the practice. J. Water Research, 189, 116648.

Chen X L, Peltier E, Sturm B S M, et al. (2013). Nitrogen removal and nitrifying and denitrifying bacteria quantification in a stormwater bioretention system. J. Water Research, 4(147), 1691-1700.

Chris D, Andrea B, Jennifer D. (2013). Bioretention: assessing effects of winter salt and aggregate application on plant health, media clogging and effluent quality. J. Water Quality Research Journal of Canada, 48, 387-399.

Conley G, Beck N, Riihimaki C A, et al. (2020). Quantifying clogging patterns of infiltration systems to improve urban stormwater pollution reduction estimates. J. Water Research X, 7, 100049.

Costello D M, Hartung E W, Stoll J T, et al. (2020). Bioretention cell age and construction style influence stormwater pollutant dynamics. J. Science of the Total Environment, 712, 135597.

Coustumer S L, Fletcher T D, Deletic A, et al. (2012). The influence of design parameters on clogging of stormwater biofilters: a large-scale column study. J. Water Research, 46, 6743-6752.

Ding B, Rezanezhan F, Gharedaghloo B, et al. (2019). Bioretention cells under cold climate conditions: Effects of freezing and thawing on water infiltration, soil structure, and nutrient removal. J. Science of the Total Environment, 649, 749-759.

Jiang C, Li J, Li H. (2017). Advances in studies on bioretention systems for purifying runoff nutrients. J. Journal of Hydroelectic Engineering, 36(8), 65-77.

Jiang C, Li J, Li H, Li Y. (2019). Remediation and accumulation characteristics of dissolved pollutants for stormwater in improved bioretention basins. J. Science of the Total Environment, 685, 763-771.

Hua G F, Zhao Z W, Kong J, et al. (2014). Effects of plant roots on the hydraulic performance during the clogging process in mesocosm vertical flow constructed wetlands. J. Environmental Science and Pollution Research, 21(22), 13017-13026.

Kakuturu S P, Clark S E. (2015). Clogging mechanism of stormwater filter media by NaCl as a deicing salt. J. Environmental Engineering Science, 2(32), 142-152.

Kandra H S, Mccarthy D, Fletcher T D, et al. (2017). Assessment of clogging phenomena in granular filter media used for stormwater treatment. J. Journal of Hydrology, 512(4), 518-527.

Knowles P, Dotro G, Nivala J, et al. (2011). Clogging in subsurface-flow treatment wetlands: occurrence and contributing factors. J. Ecological Engineering, 37(2), 99-112.

Lefevre G H, Paus K H, Natarajan P, et al. (2015). Review of dissolved pollutants in urban storm water and their removal and fate in bioretention cells. J. Journal of Environmental Engineering, 1(141), 1-23.

Li C, He L, Zhou J, et al. (2020). Common problems and solution in construction of bioretention facility. J. China Water & Wastewater, 36(20), 105-112.

Li C, Tan X. (2019). Influence of filter media on construction of bioretention facilities in typical regions of southern china. J. China Water & Wastewater, 35(15), 128-133.

Li L, Davis A P. (2014). Urban stormwater runoff nitrogen composition and fate in bioretention systems. J. Environmental Science & Technology, 6(48), 3403-3410.

Liu L. (2017). Biodegradation of polycyclic aromatic hydrocarbons accumulated in bioretention soils using genetically engineered bacterium. J. Journal of Tsinghua University, 10, 201-218.

Mu Y, Wang J, Zheng H, et al. (2020). Study on the plant optimization of biological detention facilities in the north saline soil area. J. Environmental Science & Technology, 43(7), 111-116.

Pan W, Luo L, Wang S, et al. (2020). Seasonal changes in the decontamination effect of the biological retention system with improved filler. J. Chinese Journal of Environmental Engineering, 2020, 10, 12030.

Qiu F, Dai Y, Lu C, et al. (2017). Media amendment and structure modification to enhance pollutants removal in bioretention system. J. China Water & Wastewater, 7(33), 157-162.

Raham M Y A, Nachabe M H, Ergas S J. (2020). Biochar amendment of stormwater bioretention systems for nitrogen and Escherichia coli removal: Effect of hydraulic loading rates and antecedent dry periods. J. Bioresource Technology, 310, 123428.

Read J, Wevill T. (2008). Variation among plant species in pollutant removal from stormwater in biofiltration system. J. Water Research, 42, 893-902.

Skorobogatov A, He J, Chu A, Valeo C, et al. (2020). The impact of media, plants and their interactions on bioretention performance: a review. J. Science of the Total Environment, 715, 136918.

Tang P, Yu B, Zhou Y, et al. (2017). Clogging development and hydraulic performance of the horizontal subsurface flow stormwater constructed wetlands: a laboratory study. J. Environmental Science and Pollution Research, 10(24), 9210-9219.

Tian J, Jin J, Chiu P C, et al. (2018). A pilot-scale, bi-layer bioretention system with biochar and zero-valent iron for enhanced nitrate removal from stormwater. J. Water Research, 12, 111-124.

Wang M, Zhang D, Wang Z, et al. (2012). Long-term performance of bioretention systems in storm runoff management under climate change and life-cycle condition. J. Sustainable Cities and Society, 102598.

William R, Asce S M, Gardoni P, et al. 2019. Reliability-based approach to investigating long-term clogging in green stormwater infrastructure. J. Journal of Sustainable Water Built Environment, 5(1), 04018015.

Yang S, Chen T, Zhou Z, et al. (2020). Construction method of monitoring network for runoff index evaluation in sponge city. J. Chinese Journal of Environmental Engineering, 11(14), 3225-3233.

Yin D, Chen Y, Jia H, et al. (2021). Sponge city practice in China: a review of construction, assessment, operational and maintenance. J. Journal of Cleaner Production, 280, 124963.

Yu X, Chen Y, Ren P, et al. (2019). Selection and comprehensive assessment of plants in bioretention system. J. Chinese Journal of Environmental Engineering, 13(7), 1634-1644.

Zhang W, Sang M, Che W, et al. (2019). Nutrient removal from urban stormwater runoff by an up-flow and mixed -flow bioretention system. J. Environmental Science and Pollution Research, 10(26), 1-9.