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Research Status in China and Abroad and Development Trend Analysis of City Rainfall Runoff Pollution Load

Boyang Sun [1], Xiaohua Yang [1 +] and Meishui Li [1]

[1] State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China

Abstract. With the rapid development of urbanization and substantial increase of impervious surface area, compared with the natural area, urban rainfall runoff characteristics have undergone great changes, including changes of runoff hydrological processes and increase of pollution load, which has brought greatly negative impact on urban flood and waterlogging control, water environment protection and water resources utilization. This article analyzes the migration action and regulation of bioretention system. Briefly describes the method of controlling water pollution load and its hydrodynamic principle.

Keyword: rainfall runoff, pollution load, hydrodynamic, bioretention system

1. Introduction

The urban rainfall runoff pollution problem has attracted high attention both at home and abroad at present, and scientific findings show that under the action of the bioretention system, the change rules of urban rainfall runoff pollution load, effective prevention and control of urban rainfall runoff pollution and effective utilization of rainwater resources have become the hot issues and frontier issues in the field of international water environment protection researches at present [1]-[3]. The following paragraphs respectively introduce the research status at home and abroad and development trend analysis on the migration action and regulation and control mechanism of the bioretention system on urban rainfall runoff pollution load.

2. Research on Migration Action of Bioretention System on Urban Rainfall Runoff Pollution Load

Bioretention system, firstly put into use in Prince George’s County, Maryland, US in 1990s, is the optimal management method to replace the traditional control method of rainfall runoff [4]. Under the action of the bioretention system, the migration of urban rainfall runoff pollution load is mainly defined through two processes: water migration and pollutant migration. In terms of water migration, the research mainly focuses on the percolation rate and hydrological model. Emerson et al. [5], based on four-year research data, pointed out that the percolation change of bioretention system is small, and will keep stable at least for several years. Meanwhile, the percolation changes with the season. Coustumer et al. [6] also studied the soil water permeability, structure and change process of operating parameters of the bioretention system and more. In the Guide Rule of US Designed Bioretention System, the runoff curve number method (SCS method) and WinSLAMM model are recommended for the evaluation of runoff under different bioretention areas, but the National Resource Protection Authority raises that the curve number method is inapplicable for the rainfall less than 1.3cm. Dussaillant et al. [7] integrated the Richards equation and surface water balance equation, and developed the numerical model for the water quantity evaluation of bioretention system, and used it for the simulation of water quantity in non-snowy seasons. Due to the bioretention system, Heasom et

+ Corresponding author. Tel.: +86-010-58801757; fax: +86-010-58801757.
E-mail address: xiaohuayang@bnu.edu.cn.

al. [8] improved the water quantity prediction model of the bioretention system by introducing the concepts of permeable basin and impermeable sub-basin, and similar model has been introduced in the latest version of SWMM modeling software environment development [9]. However, the model cannot automatically optimize its structure, and shall be combined with other optimization methods. The uncertainty of rainfall is not considered; therefore the simulation precision and reliability still need to be improved. Due to the shortage of SWMM on the simulation results of uncertain rainfall distribution, Zhang et al. [10] developed the analysis percentage expression method (APE) to study the gathering efficiency of storm rainfall by the bioretention system, and predict the surface depression water storage and reservoir of the bioretention system at the last rainfall period. In China, Shenzhen Water Supplies Bureau conducted outdoor observation and simulation of water quantity output process of the bioretention system, and adopted Green-Ampt hydrologic model and Penman equation to calculate the evaporation capacity of the system. The results show that the bioretention system can reduce the peak flow discharge. Jia et al. [1] combined SWMM and BMPDSS models, and carried out simulation research on the rainfall runoff of the bioretention system in Olympic Community, Beijing. The applicant of this Project has constructed the experimental devices for simulation and structural optimization of bioretention system under the main rainfall conditions, and has obtained some valuable data [11]-[13]. At present, researches on the impact of bioretention system on urban rainfall runoff water quantity are still scattered and unsystematic, and the generation and confluence process of urban rainfall runoff under compound uncertain conditions is seldom considered, which needs to be further improved [14].

In terms of pollutant migration, the research mainly focuses on the pollutant removal, retention rate and model. Paus et al. [15] have studied the hydrologic properties and pollutant removal property of the bioretention system for 8 years, and the research results indicate the bioretention system can provide the infiltration for 6 years and the metal removal effect for 25 years, and the retention rate of the bioretention system for TSS is high and stable [16]. The monitoring results of the bioretention system by University of Virginia indicate the newly built bioretention system has the removal capacity of TSS 86%, COD 97% and grease 67% [4]. According to the experimental simulation conclusion of bioretention column, the removal rates of machine oil, diesel, petroleum and heavy metal are larger than 90% [17], [18]. The operation results of the bioretention system for over a year in Park College, Maryland University indicate that the removal rate of TP in urban rainfall runoff can reach 72% ~ 76% [19]. The removal rates of major pollutants is shown in Fig. 1. As the picture shows, though the average total phosphorus retention rate can reach over 70%, the phosphorus retention rate of the bioretention system is generally unstable [19], [20]. The removal rate of the bioretention system for nitrogen is greatly variable due to the influence of soil oxidation reduction environment, concentration of organic matters and retention time, and complicated migration and transformation mechanism of nitrogen in soil and water [21], [22]. Li Liqing et al. [23] studied the removal mechanism of effects of bioretention system for the nitrogen in different states, and the result indicates the removal effects of the bioretention system for the nitrogen existing in different states are also different. The nitrogen states at the effluence place mainly include organic nitrogen and nitric nitrogen. At present, the nitrogen removal mechanism of the bioretention system is still under the "black box" state. Read et al. [24] investigated the influence of 20 kinds of Australian plants on the removal capacity of the bioretention system, and the results indicate the removal capacity of each kind of plant for total phosphorus and total nitrogen greatly varies. The Project Applicant analyzed the enrichment and removal effects of four kinds of herbaceous plants for zinc, and the removal rate of zinc in different bioretention media and under different inlet concentration of rainfall runoff is 84.65%~91.12%. Soberg et al. [25] studied the influence of temperature and salinity on the removal effects of bioretention system for heavy metal and sediment, and the research results indicate the existence of salt is adverse to the removal of heavy metal by the system. Under the joint action of salty condition and high-temperature condition, the removal effect of the system will be poorer. Li et al. [18] developed the one-dimensional simulation models of the bioretention system for TSS, heavy metal and other elements, and the simulation results are relatively consistent with the contents measured in test. Recently, Quinn et al. [26] have studied the removal mechanism of the bioretention system through sustainable water drainage system. The research mainly focuses on the pollutant accumulation and migration process in upper root areas of the organic soil stratum and sand storage stratum. The results indicate that lead can be accumulated on the upper layer of the system, while copper is mainly reserved in the stratum with the soil depth of over 50cm. The research on the accumulation and migration process of urban rainfall runoff pollution under the action of bioretention system still needs to be improved. In China, the Applicant of this Project, based on indoor simulation experiment, got the following conclusions (Fig. 2): the removal rate of the bioretention system for ammonia nitrogen in Beijing is 96%, the removal rate for nitrite nitrogen is 37%, and the removal rate for total nitrogen is 83% [27], [28]. Meanwhile, the Applicant of this Project has conducted the research and comprehensive evaluation on the migration rules of the rainfall runoff pollution under the action of the bioretention system by combining SWMM model and intelligent dynamic neural network model from the bioretention system in the experimental areas in Beijing (campus of Beijing Normal University and Olympic Community), and has proposed feasible suggestions [12], [28]. In terms of research on the pollutant removal capacity of the bioretention system, a great number of experiments have been carried out abroad, while the research is in the start-up stage in China. The researches on the change rules of migration of urban rainfall runoff pollution under the action of bioretention system both at home and abroad are unsystematic. There are numerous experimental researches, while the number of model researches is rather small. The migration change process of urban rainfall runoff pollution under complicated uncertain conditions is seldom considered, and the researches on this aspect need to be improved.

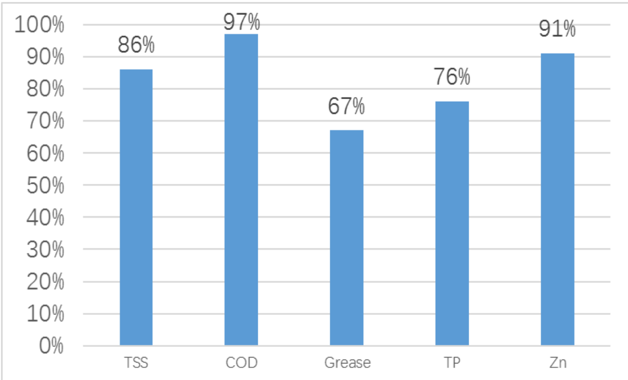

Fig. 1: Removal rates of major pollutants

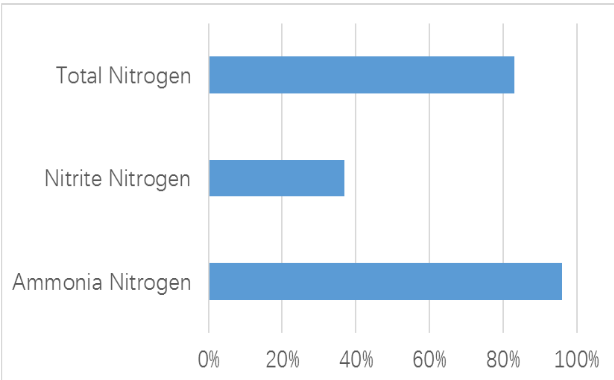

Fig. 2: Removal rates of study area in Beijing

3. Research on Regulation and Control Mechanism of Bioretention System on Urban Rainfall Runoff Pollution Load

The bioretention system, as the typical representative of optimal management measures of urban rainfall runoff pollution, has fast become one of the most effective control measures of urban rainfall runoff pollution with the broadest application in US and other developed countries [14]. It emphasizes the ecological design in combination with plants, water body and other natural conditions [29]. The transitional zones of grass planting ditches at the water inlet, depression, plants, soil, closed conduits, overflow outlet and every other part of the system can play the roles of removal of pollutants, reduction of rainfall runoff and supplementation of ground water. The optimization of structure and layout of the bioretention system is of profound theoretic significance and actual application value [20]. On the bioretention system, as the optimal management method to replace the traditional rainfall runoff pollution control methods, researches on the site design, experimental detection and model simulation of the bioretention system have been conducted in USA, Britain, Australia, New Zealand and other countries.

In terms of structural optimization of bioretention system: the results of field monitoring in Prince George's County, Maryland, US show the regulation and control of the bioretention system after the optimal design of surface runoff can reach the American rainfall discharge standards, and has better removal control effects compared with other BMP [30]. The design dimension standard of the bioretention system is still controversial. Wisconsin also provides some design guide rules, including guide rules for the Owner to select the position, shape, area, depth and plants of the bioretention system. The Applicant of this Project also investigated the influence of 31 plants in Beijing area on the removal effects of 7 pollutants including ammonic nitrogen, nitrite nitrogen, total phosphorous and heavy metal (copper, cadmium, lead and zinc), and has carried out 5 years of experiments, monitoring and simulation researches and established the set pair analysis evaluation model for the structural optimization of the bioretention system. The results indicate that the bioretention system plays an extremely role on the regulation and control of urban rainfall runoff pollution load. The comprehensive pollutant removal effects in Cheqian and Matang areas are excellent [11]-[13]. Zhang et al. [10] proposed the plant species and carbon-containing submerged area will affect the removal capacity of the bioretention system for heavy metal, and has respectively carried out the simulation of the environment with two plant species and the environment with three plant species for 20 months. The result indicates that plants grow well in the carbon-containing areas, and the removal effects for heavy metal are even excellent. The experiment was carried out at room temperature; therefore it still needs to be carried out in field environment. 5% of water treatment residue was added in the bioretention system, and a kind of bioretention system with strong phosphorous removal effect was applied. The research results show the system has striking removal effects on total suspended solids, total phosphorous and particulate phosphorous are obvious, while the removal efficiency of dissolved phosphorous and organic phosphorous are unstable, and decrease with the attenuation of the medium of the bioretention system. Li et al. [23] compared the improvement effects of the bioretention system in different design structures on highway water quality and quantity. The results indicate: in terms of water quantity, the bioretention system with internal water-bearing stratum structure and that without internal water-bearing stratum structure play the roles of peak shifting and retention, but the system with internal water-bearing stratum has better effects. In terms of water quality, the pollutant removal effects of the bioretention system without internal water-bearing stratum are unstable, but the system with internal water-bearing stratum can obviously remove multiple kinds of pollutants. With the promotion and application of optimal management measures of bioretention system for control of urban rainfall runoff pollution both at home and abroad, researches on the regulation and control mode of urban rainfall runoff pollution load and theoretic methods are increasingly valued.

In terms of layout optimization of bioretention system: Harrell et al. [31] established the decision model for determination of the optimal design parameters and spatial position of the bioretention system. Lee et al. [32], with the minimum total cost of pollution prevention as the objective function and in consideration of conditions of water quantity, water quality, land and other factors, established the BMPs regulation and control model for the optimal allocation of distributed bioretention system. Tang Ying [33], with the latest SUSTAIN system developed by EPA as the tool for management and control planning of urban rainfall runoff, carried out rating evaluation on eight BMPs including bioretention system, retention pond, green roof, grass planting ditch, vegetation transition zone, permeable pavement, infiltration ditch and rainwater tank in terms of water quality and quantity control effects, ecological efficiency, cost input and the like. The results indicate the comprehensive control effect of the bioretention system for urban rainfall runoff pollution load is the best. Wang Long [34] pointed out that the simulation models with consideration of the optimal management measures of the bioretention system at home and abroad mainly include: BMPDSS, SUSTAIN, SWMM and more, and also analyzed the characteristics, adaptability and limits of the above-mentioned models, pointed out that these models are still imperfect in the regulation and control of non-point source pollution load of urban rainfall runoff by the bioretention system and intelligent decision-making analysis process in combination with expert suggestions and knowledge experiences. It’s difficult to handle uncertain information, and corresponding theoretic regulation and control method still need to be established. Qi

Haijun [35], based on the pollutant intercepting and emission reduction efficiency, economic efficiency and utilization efficiency of LID (low impact development) measures for the bioretention system, established the efficiency identification method and comprehensive efficiency evaluation method system of LID measures through analytic hierarchy process soft law and linear normalization model. Segaran et al. [36] studied the water quality improvement potential of the bioretention system in water sensitive urban design, and the research shows that the bioretention system that covers 10% of the park area might cause the nitrogen reduction by 62%. The article studies the parks in different scales, and analyzes the application potential of bioretention system in urban planning and design. Therefore, the researches on the regulation and control of urban rainfall runoff pollution load by the bioretention system at home and abroad are still in the exploratory stage. At present, in terms of regulation and control of urban rainfall runoff pollution load through the selection of the structure, size and spatial position of the bioretention system, the minimum cost is mainly used as the objective function, while theoretic methods for multi-objective intelligent optimization and intelligent decision-making analysis in synchronous consideration of the reduction of the rainfall runoff pollution load, peak flow reduction (synchronous supplementation of underground water), cost reduction, optimal environmental and economic efficiency and other aspects still need to be further improved.

4. Conclusion

In conclusion, the study on the migration mechanism and intelligent regulation and control effects of the bioretention system as the optimal typical representative management measures on urban rainfall runoff pollution load is the great requirement of fulfilling international sustainable development and new “ecological drainage” rainwater resource management concept and water ecology civilization construction, also the frontier and hot issue in international academic research. It is of great necessity to study relevant theoretic methods, while the current researches on this aspect are still imperfect:

(1) The researches on the bioretention system and combination of migration process and regulation and control mechanism of urban rainfall runoff pollution load are still imperfect. Since the “bioretention system – urban rainfall runoff – pollution load migration – regulation and control” is a completed nonlinear compound uncertain system, it’s in urgent need to carry out the theoretic methods and system innovation to disclose the migration and regulation and control mechanism of the bioretention system for urban rainfall runoff pollution load.

(2) In terms of the migration simulation of urban rainfall runoff pollution load by the bioretention system, though there are numerous researches on the pollutant removal mechanism of the bioretention system both at home and abroad, researches on the mechanism combined with the migration of urban rainfall runoff pollution load are in shortage. Due to expression and quantitative simulation of the surface accumulation of urban rainfall runoff pollutants, runoff erosion, urban rainfall runoff producing and confluence process and pollutant migration process under the action of the bioretention system under compound uncertain system, are still imperfect, and the model and theoretic researches on this aspect are in urgent need to disclose the impact mechanism of the bioretention system in the whole migration process of urban rainfall runoff pollution load.

(3) In terms of regulation and control theory of the bioretention system on migration of urban rainfall runoff pollution load, researches on how to determine the optimal operating parameters of the bioretention system and explore the optimal functions of the system, how to determine the size and spatial position of the bioretention system and explore the optimal regulation and control effects of the bioretention system, as well as researches on the comprehensive evaluation and regulation and control of migration of urban rainfall runoff pollution load by the bioretention system are still in the exploratory stage, and theory and method innovation on this aspect are in urgent need.

(4) In terms of the regulation and control model of migration of urban rainfall runoff pollution load by the bioretention system, the structural design of the bioretention system and the selection of plant and soil types are mainly on the basis of experiences, and therefore quantitative methods are in shortage. The water quantity and quality simulation regulation and control of urban rainfall runoff under the action of the bioretention system are still with great uncertainty. At present, the regulation and control model for comprehensive evaluation and optimization of the migration of urban rainfall runoff pollution load under the

action of the bioretention system that integrates the improvement of rainwater runoff, reduction of runoff pollution, increase of environmental efficiency and optimization of regulation and control scheme and in combination with the characteristics of the compound uncertain system has not been established at present.

(5) Only a few researches have been carried out on the comprehensive regulation and control of migration of urban rainfall runoff pollution load under the action of existing bioretention system, which mainly focus on the simple application or introduction of water quantity and quality simulation evaluation results of the bioretention system. Many researches on the important theoretic construction issue of reasonable generation and optimization under the multilayer uncertain system to achieve optimal effects of urban rainfall runoff water quantity and quality under the action of the bioretention system have been carried out, while the researches on the quantitative regulation and control mode under compound uncertain system and its comprehensive integrated application system are rather rare.

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