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Stormwater Management in Sponge Scenic Area: A Case Study of the Yesanpo Scenic Area, Baoding, China

Yanbo JIANG[1] and Anchen QIN
College of Landscape Architecture and Tourism, Hebei Agricultural University, Baoding 071001, Hebei, China

Abstract. Under the background of intensified global climate change, seasonal flood disasters and increasing water consumption are two major challenges to the development of scenic spots. In order to address the conflict between frequent flood disasters and water scarcity, and to mitigate the adverse impacts of climate change, this paper explores strategies of stormwater management in scenic areas. Taking Yesanpo Scenic Area as an example, based on topographic data and hydrometeorological data, this paper uses the SCS-CN model and ArcGIS to simulate the inundation area caused by the design rainfall depth of 2% rainfall frequency in the study area. On this basis, according to the volume capture ratio of the annual rainfall of 85%, green stormwater infrastructure is planned, improving the scenic area's ability to resist floods that occur once in fifty years and make use of stormwater resources to achieve safe, healthy, and sustainable development.

Keywords. Sponge Scenic Area, stormwater management, green stormwater infrastructure, Yesanpo Scenic Area

1. Introduction

In recent years, global climate change has resulted in a series of problems such as rising sea levels, urban heat islands, and imbalanced water resources, leading to frequent natural disasters such as tsunamis and severe rainstorms [1, 2]. As one of disaster-prone areas, scenic spots often suffer from dangerous events such as mudslides, landslides, and collapses, causing enormous threats to life safety and economic losses. In July 2012, a torrential rainstorm caused flash floods in the Yesanpo Scenic Area, Laishui County, Baoding City, Hebei Province, resulting in significant damage to infrastructure and the deaths of 30 people [3]. In addition, frequent extreme weather events have resulted in increased frequency and intensity of floods and droughts, further exacerbating the uneven distribution of water resources between rainy and dry seasons and leading to a dilemma of water shortages in the dry season and floods in the rainy season. Meanwhile, with the development and construction of scenic spots, the demand for water supply in these areas has been on the rise.

The sponge scenic spots aim to achieve an organic integration of natural ecological systems and artificial systems, fundamentally solving the contradiction between flooding

[1] Corresponding Author, Yanbo JIANG, College of Landscape Architecture and Tourism, Hebei Agricultural University, Baoding 071001, China; Email: jiangyanbo_jyb@126.com.

caused by seasonal rainfall in scenic areas and water shortages during droughts. To achieve this goal, it is necessary to scientifically manage the stormwater in the scenic area through the green stormwater infrastructure, which transforms stormwater into reusable water resources. This not only comprehensively enhances the flood control and drainage capacity of scenic spots, but also improves the utilization of rainwater resources, thus increasing ecological and economic benefits. Currently, research on a green stormwater infrastructure mainly focuses on categorization and utility. Based on the different demands of runoff treatment, green stormwater infrastructure can be divided into two types: water retention type and hydraulic type. Water retention type facilities include biological facilities and engineering facilities [4], which aim to solve the problem of soil erosion caused by the destruction of hydrological circulation in scenic areas. Biological facilities mainly consist of vegetation such as trees and grass, while engineering facilities include horizontal terraces, terraced fields, fish-scale pits, ponds, etc. These facilities can increase soil moisture infiltration, delay the formation of runoff, reduce flood peaks, and even prevent flooding under certain conditions. Hydraulic type facilities aim to solve problems in the hydrological cycle process in the scenic area. According to the principle of multi-level control from source to end, they can be divided into three types: source, process, and end [5], including permeable pavements, rain gardens, stormwater wetlands, etc. As research progresses, the study of green stormwater infrastructure has shifted from initial external factors such as volume and location to internal factors such as their control effects on runoff. For example, in terms of the application of permeable materials, Zhang [6] analyzed the use of different permeable materials in scenic area roads and summarized the role of permeable roads in restoring and promoting drainage and water purification. Tang [7] found through relevant experiments that the rain garden's ability to retain runoff is more than 20 times its own area. Wang [8] found through small-scale experimental setups that the sunken green space has a significant effect on retaining road runoff, with an average runoff reduction rate of 46.58% for a rainfall recurrence period of 5 years and a phosphorus particle removal rate of over 90% in the runoff.

The existing green stormwater facilities are developed based on the theory of sponge cities and are used to address the problem of stormwater in urban areas [9, 10]. However, their limitations in managing stormwater in sponge scenic areas include the following: Firstly, in terms of adaptability to terrain and landform, the existing facilities are more suitable for areas with flat terrain, while scenic areas typically have complex terrain with high and low undulations that these facilities cannot completely adapt to. Secondly, in terms of functionality, the existing facilities mainly address urban waterlogging and urban non-point source pollution issues, while facilities in sponge scenic areas need to consider the requirements of flood prevention and disaster reduction as well as soil and water conservation. Thirdly, in terms of landscape design, the existing facilities are more concerned with their control effectiveness on stormwater, with insufficient consideration for landscape design elements, resulting in more prominent municipal facility marks. Meanwhile, existing research on green rainwater facilities usually ignores the site's inherent ability to absorb runoff [11]. Unlike urban areas, scenic areas have a large number of land-use types, such as grasslands and forests, with strong runoff absorption capabilities. Therefore, when deploying green stormwater facilities in scenic areas, it is necessary to fully consider the characteristics of the site and adopt more suitable research methods based on relevant research references.

This paper takes the Yesanpo Scenic Area as an example and uses the SCS-CN hydrological model and ArcGIS spatial analysis tool to simulate the inundation area caused by a 50-year rainfall event in the study area. Based on this, green stormwater infrastructure is planned according to the volume capture ratio of the annual rainfall of 85% in the study area, aiming to improve the flood control and disaster reduction capability of Yesanpo Scenic Area, promote the reuse of rainwater resources, and meet the increasing water demands of the scenic area, laying a solid foundation for its sustainable development.

2. Materials and Methods

2.1. Study Area

This paper selects Bailixia scenic spot and Juma River scenic spot in Yesanpo Scenic Area as the research object, with an area of 217.34 km^2, located in the northwest of Laishui County, Baoding, Hebei Province, from 115°18’52” to 115°30’60” East longitude and 39°34’51” to 39°45’43” North latitude. The Yesanpo Scenic Area mentioned below refers to Bailixia scenic spot and Juma River scenic spot.

2.2. Data Sources

This study contains various types of data, of which the core data mainly digital elevation model data, meteorological data, land-use type data and administrative division data, the DEM data (spatial resolution: 30 m×30 m), the administrative boundary map and the land-use type map of the Yesanpo Scenic Area in 2018 provided by Hebei Urban and Rural Planning Design Institute, the CN based on the National Engineering Handbook Hydrology Chapters. eCognition software is used to interpret remote sensing images. The land use types in the study area are divided into water construction land, grassland, forest land, water body, transportation land, cultivated land and unused land, as shown in Figure 1.

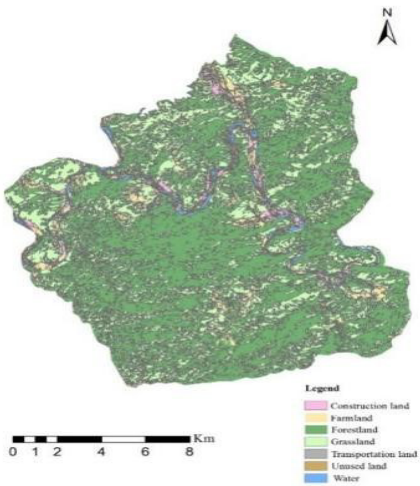

Figure 1. Land-use type distribution map.

2.3. Methodology

2.3.1. SCS Model

The SCS model, with a simple structure and few parameters, was developed by the Soil and Water Conservation Bureau of the U.S. Department of Agriculture in 1954. It is mainly used to study the impact of soil type and soil moisture on rainwater runoff. This model has obvious advantages in the case of limited hydrological data [12]. The principle of the model is based on the assumption of the water balance equation relationship, and the calculation method is as follows:

$$Q = \frac{(P-I_a)^2}{P+S-I_a} \quad P \geq I_a \tag{1}$$

$$S = \frac{25400}{\mathrm{CN}} - 254 \tag{2}$$

where Q is the direct runoff (mm), P is the total rainfall (mm), I_a is the initial rainfall (mm), S is the potential maximum infiltration, and I_a equals 0.2S [13]. *CN* is an empirical dimensionless parameter (0-100), representing the hydrological performance of different land cover types. The larger its value is, the stronger its runoff capacity is.

2.3.2. Calculation Method of Design Rainfall Depth Corresponding to the Volume Capture Ratio of Annual Rainfall

This ratio is the concentrated embodiment of Sponge Scenic Spot. The design rainfall depth corresponding to the volume capture ratio of annual rainfall is an important parameter for calculating the scale of rainwater facilities in Sponge Scenic Spot. The method to obtain this parameter is as follows [14]. Select daily rainfall data in the recent 30 years, eliminate the rainfall events less than or equal to 2 mm, sort them according to ascending order, and count the ratio of the total amount less than a certain rainfall value to the total rainfall value. The rainfall corresponding to this ratio is the design rainfall.

2.3.3. Calculation Method of Detention and Retention Volume of Stormwater Facilities

(1) Volume calculation

The detention and retention volume of rainwater facilities shall generally meet the index requirements of "volume per unit area". The designed detention and retention capacity is generally calculated by the volume method, as shown in equation (3) [14],

$$V = 10H\varphi F \tag{3}$$

V is regulated storage capacity, m^3; H is design rainfall, mm; φ is comprehensive rainfall runoff coefficient; F is catchment area, hm^2.

(2) Permeability calculation

For infiltration facilities with water storage space on the top or inside, such as bio-retention facilities, infiltration ponds, infiltration wells, etc., the scale shall be calculated according to equation (4) [15].

$$\begin{aligned} W_S &= A_S \times \Delta h \\ W_S &= A_S \times (h1 - h2) \end{aligned} \tag{4}$$

where W_S is design infiltration capacity of infiltration facilities, m^3; A_S is effective penetration area, m^2; Δh is effective water storage depth (m); $\Delta h = h1 - h2$, *h1* is elevation of water storage surface, *h2* is ground level of infiltration facilities.

3. Result

3.1. Simulation of Inundation Area in Yesanpo Scenic Area

In view of the special underlying surface of the scenic area, based on the design rainfall depth corresponding to 2% rainfall frequency, this paper simulates the stormwater flooding in the study area. The simulated inundation area is the area that exceeds the runoff absorption capacity of the study area itself. And the green stormwater infrastructure in this study retains the water volume in the flooded area generated by the 50-year return period stormwater, so as to ensure the safety of the scenic area.

According to the SCS model user manual, Curve Number (CN) is an important parameter of the model. Through the soil detection of the Yesanpo Scenic Spot by the Urban and Rural Planning and Design Institute of Hebei Province, it can be concluded that brown soil is widely distributed in this area. By consulting the National Irrigation Engineering Manual of U. S [16] and considering the land-use types, we can acquire the CN of the land-use types in this study: the CN value of transportation land is 98, the CN value of construction land is 85, the CN value of grassland is 64, the CN value of forest land is 55, the CN value of cultivated land is 78, and the CN value of unused land is 86.

With the help of ArcGIS, the inundation area of different land-use types in 12 sub-basins can be calculated. The results show that the inundation area of the Yesanpo Scenic Area caused by the extreme daily rainfall of a 50-year return period is 3331683.38 m^2, the total runoff generated in the flooded area can be calculated, and the result is 176002.59 m^3, as shown in Table 1.

Table 1. Statistics of runoff in the inundated areas.

Watershed	Inundation area (m^2)	Direct surface runoff Q (mm)	Runoff V(m^3)
1	362039.87	40.65	19717.83
2	524728.68	37.57	24712.62
3	424671.24	36.78	20620.34
4	293298.12	39.89	16699.52
5	229139.16	37.57	13608.13
6	75615.92	38.35	7899.63
7	368914.05	39.89	19715.8
8	401757.33	35.2	19140.16
9	264273.83	39.9	15541.76
10	209280.43	35.2	12365.79
11	97766.04	33.59	3483.78
12	80198.71	31.14	2497.23
Total	3331683.38	445.73	176002.59

3.2. Design Rainfall Depth Based on Volume Capture Ratio of Annual Rainfall of 85%

According to the requirements of the Guidelines for low-impact development and construction, the volume capture ratio of the annual rainfall of the Yesanpo Scenic Area shall be higher than 85%. Based on the measured daily rainfall data in the study area from 1990 to 2020, it is calculated that the design rainfall depth corresponding to the volume capture ratio of the annual rainfall of 85% is 37.8 mm.

3.3. Stormwater Management in the Yesanpo Sponge Scenic Area

(1) Infiltration facility planning

Permeable pavement, which has good permeability, is an effective stormwater control facility that can regulate runoff. Its structural styles are diverse, and the basic structure from top to bottom is a surface layer, filter layer, base layer, cushion layer, and subgrade [17]. In order to improve the rainwater infiltration rate of scenic road surfaces, permeable materials such as permeable bricks, permeable asphalt, and permeable concrete can be selected according to regional characteristics. To enhance the landscape of the facility, permeable materials can be combined with rainwater collection facilities to create a rainwater landscape with flood control functions. For example, a row of rainwater collection bowls with varying heights can be arranged above the permeable pavement, and facilities with runoff storage functions can be arranged below the permeable pavement, as shown in Figure 2.

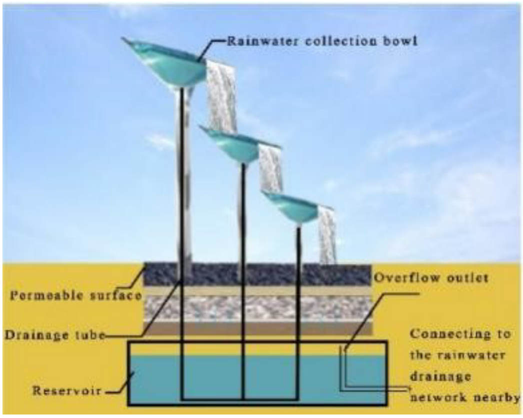

Figure 2. Sectional drawing of infiltration and circulation facility.

Within the core scenic area of the Yesanpo Scenic Spot, there are mainly 6 walking trails, 8 roadways and 3 bicycle lanes, with a total area of 820800 m^2. In order to increase the permeability of the site, the above road surface will be paved with permeable materials. According to equation (3), the comprehensive runoff coefficient of the study area is 0.6. The storage capacity of the above-mentioned infiltration facilities is 18615.74 m^3.

(2) Transmission and purification facility planning

The vegetation filter strip is mainly composed of trees, shrubs, and herbaceous plants, and it is usually located between the pollution source and the water body. Through the functions of adsorption and degradation, it can effectively intercept surface runoff, retain sediment, and reduce pollutant content. To enhance the functionality of the traditional vegetation filter strip, this paper proposes a gentle slope vegetation filter strip, which adds a certain degree of slope on the two sides of the traditional flat vegetation filter strip, and increases the zoning of dry and wet vegetation areas, as shown in Figure 3.

Grassed swale is often used as a transitional facility for runoff flowing into the next rainwater and flood control facility while reducing pollutants in runoff through precipitation, retention, adsorption, and other means. In order to adapt to the terrain changes in the sponge scenic area and reduce the transmission rate of runoff, the line expression of the grassed swale can be further enriched, such as by creating a curved grassed swale, as shown in Figure 4.

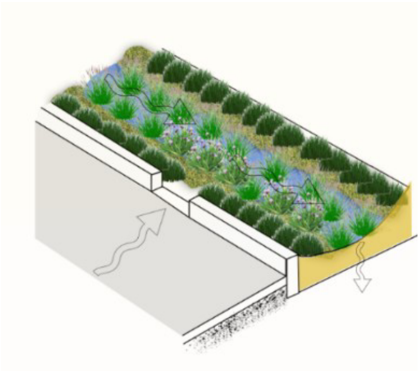

Figure 3. Schematic diagram of sunken vegetation buffer zone.

Figure 4. Schematic diagram of the curved grassed swale.

The potential runoff line is the natural transmission corridor of surface runoff, which plays an important role in dispersing runoff, reducing flood peaks and storing water sources. According to DEM data, the flow direction and volume of runoff in Yesanpo Scenic Spot are simulated with ArcGIS software. Through comprehensive analysis of the river network, the distribution of potential runoff lines, that is, the distribution of natural potential runoff transmission corridor, is obtained. The analysis shows that there are two potential runoff transmission corridors in the Yesanpo Scenic Area, including 39 primary corridors with a total length of 60570.85 m, and 19 secondary corridors with a total length of 38446.73 m. The minimum width threshold for the corridor is 7 meters-12 meters. In this study, the width of the first-level corridor was set to 7 meters, the width of the second-level corridor was also set to 7 meters, and the depth of the corridor was 0.2 meters. According to equation (4), the net storage capacity of the transmission and purification facilities was calculated to be 138624.61 m^3.

(3) Savings facility planning

Rainwater barrels are usually placed next to buildings, connected to the building's rain gutters, to store and utilize runoff from the building's roof. To enhance the aesthetics of this facility, spray-painted designs can be added to the barrel's body, such as condensing local historical and cultural elements of the scenic area into spray-painted patterns for display on the barrel's body. Resistant plants can be planted at the barrel cover position, and the barrel body style can be enriched from texture, material, and shape perspectives. For example, transparent materials can be used to design the barrel body. When combined with spray-painted patterns, the changing water level inside the barrel can form a dynamic water flow landscape, as shown in Figure 5.

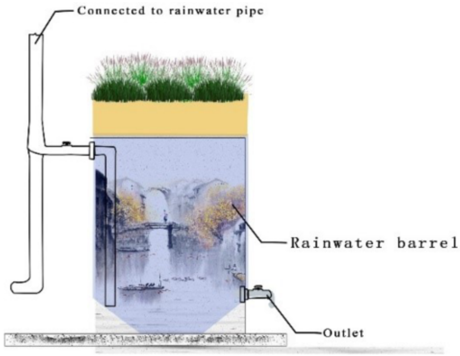

Figure 5. Landscape design drawing of rainwater barrel.

A reservoir is an end-of-pipe runoff control facility. Traditional reservoirs are mostly reinforced concrete structures. With the development of environmentally friendly materials, PP (polypropylene) materials have gradually been used to improve these facilities. PP module storage tank mainly consists of PP modules, geotextiles, and protective layers. To enhance the landscape of the facility, natural lawns or flowers can be planted on top of it, allowing it to blend in better with the surrounding environment and atmosphere of the scenic area. At the same time, entertainment and leisure facilities such as observation platforms and chairs can be set up above the facility, as shown in Figure 6.

Figure 6. Landscape design drawing of the modular storage tank.

A rainwater wetland is a type of constructed wetland designed to treat stormwater pollution and regulate stormwater volume. To enhance the functionality of this facility, this paper proposes to divide it into two functional spaces: a purification zone and a storage and observation zone, separated by emergent plants, as shown in Figure 7. In the purification zone, submerged or floating plants with purification function and water resistance are planted to form a plant community, with a sand and gravel filter layer at the bottom to reduce flow velocity and suspended particles in the stormwater. The emergent plant belt used to separate the spaces can further slow down the flow velocity. After preliminary purification in the purification zone and secondary purification in the emergent plant belt, the stormwater enters the storage and observation zone, which can be used to supplement the green maintenance and irrigation needs of the scenic area. At the same time, this facility can form a scenic waterscape for visitors to engage in water-related activities and leisure.

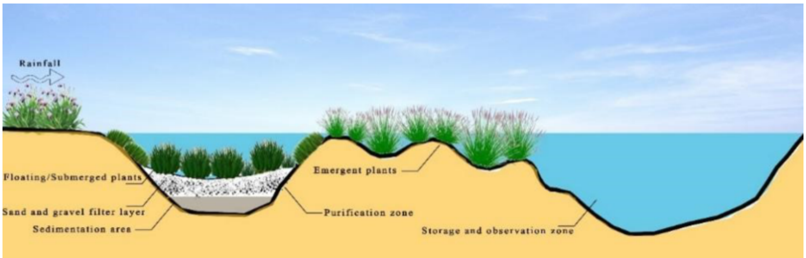

Figure 7. Sectional drawing of a stormwater wetland.

According to the overall planning of Yesanpo Scenic Spot has planned Guoge Zhuang Village, Zishikou Village, Shangzhuang Village, Sanpo Town, and Nanyu Village as the key tourist service villages, among which Guoge Zhuang Village is planned to have 1,250 beds, Zishikou Village is planned to have 4,950 beds, Shangzhuang Village is planned to have 1,100 beds, Sanpo Town is planned to have 7,100 beds, and Nanyu Village is planned to have 1,100 beds, as well as supporting the construction of tourism service facilities such as catering, accommodation, shopping, health care, etc. The above-mentioned places have a large number of tourists and a significant daily demand for water. Therefore, green rainwater facilities such as rainwater barrels and cisterns can be installed to store and utilize runoff. The storage capacity of savings utilization facilities is shown in Table 2.

Table 2. Storage and utilization facility storage table.

Main facilities	Individual facility capacity (m^3)	Number	Stormwater regulation volume (m^3)
Stormwater wetland	6340	1	6340
Rain barrel	1.5	5460	8190
Modular storage tank	180	28	5040
Total			19570

4. Conclusion and Discussion

The following conclusions are obtained:

(1) According to *Guidelines for Low-impact Development and Construction* standards, the design rainfall depth corresponding to the volume capture ratio of the annual rainfall of 85% in the Yesanpo Scenic Area is 38.6 mm.

(2) According to the SCS model, the inundation area of the Yesanpo Scenic Area under the design rainfall depth of a return period of one hundred years is 3331683.38 m^2. The total runoff volume generated by the 12 sub-basins is 176002.59 m^3. The inundation area is mainly concentrated in the construction land, grassland and cultivated land on both sides of the Juma River.

(3) Appropriate green stormwater infrastructure was chosen for the Yesanpo Scenic Area, which includes permeable pavement, a sunken vegetative buffer zone, a curved

grassed swale, rainwater barrels, and modular storage tanks. On the basis of optimizing the function of the facilities, the landscape design was enhanced to achieve the integration of the functional and aesthetic aspects of the rainwater facilities in the scenic area. The above rainwater facilities have a total storage capacity of 176810.35 m^3, which can handle the runoff generated by the maximum design rainfall of more than 2% frequency. While ensuring the safety of the 50-year return period of rain and flood in the study area, the effective utilization of rainwater resources is promoted.

The green stormwater infrastructure proposed in this paper is more reflected in the theoretical construction level. The layout and construction of sponge facilities should further consider the planning and construction needs of the Yesanpo Scenic Area to make the stormwater facilities more suitable for local economic and social development. In addition, the green rainwater facilities should also rely on the policy publicity, legal guidance and demonstration role of relevant departments, so that a multisectoral cooperation mechanism can be established, and the green rainwater facilities can play their role better in flood control and effective reuse of rainwater.

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