Study on Planning an Ecological Stormwater Regulation System Based on Low Impact Development Mode: A Case Study in China

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Abstract: This paper sets Chaihu Town, Zhongxiang City of Hubei Province as an example, analyzing the ecological and hydrological conditions of Chaihu Town, applying LID (low impact development) mode and putting forward the ecological stormwater regulation system planning strategy which adapts to the development of small towns. The main conclusions are as follows: (1) The “three-low” development mode is put forward, which means low impact, low cost and low carbon, using this construction mode to minimize the ecological impact, relying on natural green space and water to achieve the function of rainstorm regulation; (2) Through the analysis and calculation of the local amount of precipitation, this paper scientifically calculates the required area of storage water and green space, taking the roads as trunks, green spaces as stems, water as veins, and building the green infrastructure system; (3) The author has been repairing and integrating the original drainage ditches of the planning area, replacing traditional rain drainage pipes, establishing “two-loop” water network system which aims at the detention and purification of rainwater, maximizing ecological benefit, economic benefit and landscape benefit.

Key words: LID, ecological stormwater regulation system, drainage network.

1. Introduction

In recent years, flooding has become a new challenge to large cities in China, which causes the paralysis of basic city functions and great inconvenience in public life. As for the reasons of this phenomenon, on one hand, the large areas of impervious surface have been constructed in the conventional city development mode, which results in the increased surface runoff within a shortened time, and thus brings great pressure to stormwater regulation [1], on the other hand, the municipal drainage systems in most cities are constructed following the principle of “fast and efficient engineering drainage”, which demands the rainfall be discharged to the receiving waters through the drainage pipe network in a short time, leaving the urban drainage facilities overburdened and much rain resource wasted [2].

The conventional stormwater regulation system planning mainly focuses on end treatment, the negative effects (such as natural water deterioration, reduced regulation and storage capacity, increased cost in construction and development because of the large number of rainwater drainage pipe laid) of which are gradually revealed in the process of urbanization. Many experts and scholars began to put forward concepts and methods for an ecologically sustainable stormwater regulation, and the LID (low impact development) is one of them.

Liu [3] has selected a pervious parking lot and an extensive green roof as the study area and stated that LID owns flood control ability, pollution prevention and removal ability. Mo and Yu [4] explored a new way of stormwater utilization through landscape architecture, structuring a three-level ecological stormwater regulation system which contains green space and water system. Zhao and Li [1] summarized.
the widely used advanced concepts, techniques and practices of stormwater management in the world to provide guidance to Chinese rain water utilization and management. The LID idea has been developed to many other ideas like the LIUDD (low impact urban design and development) in New Zealand, the WSUD (water sensitive urban design) in Australia, the SUDS (sustainable urban drainage systems) in UK, etc.

The planning for ecological stormwater regulation based on LID mode can achieve the interception, storage, infiltration and evaporation of rainwater with distributed, diverse, small-scaled and localized technology by simulating the hydrology situation before the site is developed. By maximizing protection for the hydrological regime of the site being developed, the ecological planning can reduce human impact on natural surroundings, restrict the flood within the precipitation area as far as possible, make better use of rainwater and reduce cost for rainwater treatment [3].

In this article, the author integrated the latest concept of ecological stormwater management into urban planning process and provided the LID mode to the small town construction practice. This study stated that an ecologically sustainable stormwater regulation system shall be constructed alongside the preservation of existing farmland, grassland, forests, rivers and other natural elements. The LID mode, which combines macro strategy with micro engineering management, is a small-scaled and gradual development and construction mode which is especially suitable for small towns with good ecological environments.

2. Characteristics: Crisscross Ditches and Dense Water Network

2.1 General Description

Chaihu Town of Zhongxiang City lies on the Jianghan Plain and is located by the side of Hanjiang River in the south of Zhongxiang (Fig. 1). In 1960s, due to the construction of the Danjiangkou Reservoir, 49,000 people from Zhechuan, Henan were moved to Zhongxiang City, making Chaihu Town the largest centralized resettlement for reservoir immigrants. Located by the Hanjiang River and scattered with a large number of tributaries and lakes, Chaihu Town is known as the “water pocket”, which is afflicted by a severe problem of flood drainage in every rainy season. Since the establishment of the town in 1968, a total number of four major floods were recorded, which caused huge loss to people lives and properties. Therefore, a scientific and effective planning of stormwater regulation system is the top priority of Chaihu Town’s construction.

2.2 Ecological Background

The current ecological environment of Chaihu Town is in good condition. Covering an area of 496 ha, most Chaihu land are farmland, forests, wetland and water system. Through the elevation analysis chart and the slope analysis chart, the overall terrain in Chaihu Town is flat with an elevation range of 37.5~48.5 m, while the north is higher than the south and the east is higher than the west. In most cases, the slope is below 3%, which is suitable for development and construction. However, this kind of flat terrain is prone to problems of water logging and difficult drainage.

2.3 Current Situation of Water System and Ditches

In order to solve the problems of flood control in Chaihu Town, many drainage ditches were built in the past. Currently, in the transverse direction, there are the 3rd branch ditch, the 4th branch ditch, the 5th branch ditch and the 1/6 ditch; In the longitudinal direction, there are Dongyigan Branch Ditch, Donghu’er Branch Ditch, 11th branch ditch, Sujiahe River and Wanjiahe River. In addition, the east main ditch runs through the southeast (Fig. 2). A portion of the 5th branch ditch lies under the Jianghan Avenue as a culvert. At present, all the sanitary sewage and rainwater of Chaihu Town area are discharged along the plate-covered ditches into the main ditches in the
east and west, before merging into Hanjiang River. In addition, the water network in the town area is dense. Other than the ditches for irrigation, there are also many lakes and ponds. Therefore, the overall hydrological situation of the town is characterized by “crisscross ditches and dense water network”.

However, most of the ditches are in a deserted condition due to lack of repair and maintenance. With the development and construction of Chaihu Town, the existing network of channels and ditches has been unable to meet the needs of future development. The core issue of this planning is to establish the drainage system which can meet the demands of Chaihu Town’s development and construction alongside the protection and utilization of the existing ecological environment of “canals, ponds, farmlands and forests”.

3. Capacity Analysis of Ecological Stormwater Regulation System

3.1 Runoff Coefficient

Rainwater runoff is mainly affected by the change of rainfall and underlying surfaces [5]. The underlying surfaces in Chaihu Town mainly include building
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Fig. 2 Current water system.
roofs, greenbelts, roads, water surface and squares. Green roofs, sunken lawn and permeable pavement can be used in the LID mode to reduce rainwater runoff. By using permeable pavement in areas such as sidewalks, bicycle lanes, public squares, parking lots, park roads, roadsides and central isolation belts, the
runoff flows into rivers via the sunken lawn, reducing 90% of the rainwater runoff. By planting vegetation on the roofs as runoff damper and purification, 60% of the rainwater runoff can be reduced (Table 1).

After obtaining the single runoff coefficient for each underlying surface, the comprehensive runoff coefficient can be calculated by the formula:

$$\psi = \sum \psi_i \cdot \left( \frac{S_i}{S} \right)$$

where, $\psi_i$ is the single runoff coefficient of $i$ category surface; $S_i/S$ is the ratio of $i$ category surface against the total area. By using LID mode in Chaihu Town area, the rainwater runoff can be reduced effectively through measures of interception and infiltration, and the comprehensive runoff coefficient can be reduced to 0.473 (Table 2).

### 3.2 Water Storage Surface Area

The water regulation quantity can be considered as the difference between the water quantity discharged smoothly by drainage system without causing water ponding and the water quantity which can be discharged by existing drainage network, that is, the difference between rainwater quantity at storm recurrence period $P = 3$ and the rainwater quantity at $P = 1$. Considering that except for a small part of the rainwater being absorbed by the green space, the rest is gathered by the municipal rainwater network, the incoming flow duration to the regulation pond which can be taken as the flow duration within the rainwater ditched from the other end of the drainage network. The water quantity to be regulated for each square kilometer is 30,000 m$^3$ to 55,000 m$^3$, taking 0.3–0.5 m as the water depth and the water regulation and storage surface area 6~11 ha.

#### 3.3 Calculation of Rainwater Quantity

Rainstorm intensity formula of Jingmen City is adopted for the calculation of rainwater quantity:

$$q = \frac{895.33(1+0.8541lgP)}{t^{0.526}} \left( \text{L/s}\cdot\text{ha} \right)$$

where:
- $P$ is the recurrence period, 1 year herein with;
- $t$—rainfall duration $t = t_1 + t_2$;
- $t_1$—surface water gathering time, 12min;
- $t_2$—flow duration within the ditches;

Designed rainstorm water quantity $Q = \Phi F q$, $\Phi$ is runoff coefficient which is taken as 0.48 as runoff coefficient and $F$ is the water gathering area.

### 4. Ecological Planning for Stormwater Regulation System

The core concept of the planning for ecological stormwater regulation system is to manage municipal rainwater discharge and reduce the impact on ecological environment by human development through a serious of diversified, miniaturized, localized and cost-effective measures [4]. “Low impact” is manifest in two aspects: One is to reduce the impact on the macro environment in which the

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Application of LID mode.</th>
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<tbody>
<tr>
<td>Category</td>
<td>Low impact development</td>
</tr>
<tr>
<td>Building</td>
<td>Green roof</td>
</tr>
<tr>
<td>Greenspace</td>
<td>Sunken lawn</td>
</tr>
<tr>
<td>Road</td>
<td>Permeable pavement for non-motor vehicle lanes and greenbelts</td>
</tr>
<tr>
<td>Square</td>
<td>Permeable bricks</td>
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</tbody>
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<tr>
<th>Table 2</th>
<th>Rainwater runoff coefficient under LID mode.</th>
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</thead>
<tbody>
<tr>
<td>Category</td>
<td>Building roof</td>
</tr>
<tr>
<td>Construction ratio</td>
<td>56.7%</td>
</tr>
<tr>
<td>Runoff coefficient</td>
<td>0.65</td>
</tr>
<tr>
<td>Comprehensive runoff coefficient</td>
<td>0.473</td>
</tr>
</tbody>
</table>

Note: Use 0.48 as runoff coefficient $\Phi$. 
planned area is located; And the other aspect is to reduce the impact on internal environment.

4.1 Overall Planning for Ecological Stormwater Regulation System

With regard to the connection between the town water network and ditches, several important water ditches are retained, such as the Dongyizhi Main Ditch, the 3rd branch ditch, the 4th branch ditch, the 5th branch ditch and the 1/6 ditch. Repairing and dredging irrigation networks on the farmland via constructing farmland water conservancy.

4.2 Ecological Planning for Stormwater Regulation System within the Town

4.2.1 Water Network of “Two Circles and Five Catchments”

Based on the existing 3rd branch ditch, the 4th branch ditch, the 5th branch ditch, the 1/6 branch ditch, Wanjihahe River, Dongyigan Branch Ditch, the planning has improved the water system landscape environment. Based on the current water system, the planning has added small amounts of water system and water scenic park, avoiding major excavation and major construction and protecting the existing ecological environment (Fig. 3) to construct annular water scenic system and form a water network of “two circles and five catchments”:

(1) Two circles. “Two circles” means outer water circle and inner water circle. The function of the outer circle is to receive and drain the rainwater, and to avoid the impact on the inner side by the water from the outside; the function of the inner circle is to receive and drain the rainwater in the area. Both circles are interconnected;

(2) Five catchments. “Five catchments” refers to water parks with green space and water surface which can serve as water gathering area for rainfall flood regulation and storage system. Sunken lawn is planned in each water gathering area, through which runoff flows into rivers.

Based on the analysis above on the capacity of rainfall flood ecological regulation and storage system, the regulation and storage water surface area is planned as 6~11 ha. Therefore, the regulated water surface ratio is no more than 10% of the total land area.

4.2.2 Rainwater Drainage System of Grass Ditch and Drainage Pipe

Large amounts of water networks are retained. Rainwater pipe will not be buried along main roads, and ditches will serve as the main drainage facilities in the town area. The ditches will be drenched and protected to make them interconnected and grass will be planted on the bank slope to create ecological ditches. When rainwater runs on the grass ditches, large quantity of water will infiltrate into the grassland and the pollutants in the water can be removed by the plant system and the filler. In addition, as the grass ditches have a certain regulation and storage capacity, the peak flow can be reduced, and the impact of the city flood can also be reduced [7]. The drainage ditches adopt the standards of 20-year flood protection, and the cross section is trapezoid. For the main drainage ditch cross section, the bottom width is 16~20 m, water depth is 2.5~3 m and margin is 0.5 m. For the secondary drainage ditch cross section, the bottom width is 8~10 m, water depth is 2.4~2.8 m and margin is 0.5 m.

Since the north of the town is a newly established industrial zone, considering that the industrial drainage is more than the drainage of sanitary sewage, the drainage system here is mainly of traditional type.

4.2.3 Drainage Ditches as Landscape Corridor

Chaihu Town is a small town with unique water characteristics on the Jianghan Plain. LID mode has another advantage over the traditional rainwater discharge technology, that is, the decentralized and small scale application of LID can be combined with the landscape construction, which can not only reduce the construction cost, but also increase the added value of the surrounding land by improving the scenic
environment quality.

In the planning for ecological stormwater regulation system, the drainage water system and scenic system are combined, making the waterside space an attractive and vibrant public space, which ensures good scenic quality in both high water period and low water period. The water network of “two circles and five catchments” can be not only an ecological corridor, but also a scenic corridor.

The outer water circle can be a display of country landscape and farmland landscape, establishing an integrated natural ecological system. For the cross section arrangement, the gentle slope pavement will be used except for the highway area where rigid pavement will be used. Local plant such as rice, reed and green bristle grass will be used for plantation.

The inner water circle can be a display of city scenery and green landscape, establishing a slow pace system consisting of walking and bicycling, and forge an inner water circle of green and low-carbon. For the cross section arrangement, the gentle slope pavement will be used. Local plant such as calamus, reed and lotus will be used for plantation.

The five water parks can reproduce the waterside town scenery of Chaihu Town, as well as the wetland landscape. Combining with the surrounding large public buildings such as the memorial hall building, museum, folk architecture, theater and commercial complex, the water parks can bring to the public a variety of leisure experiences [8].

5. Conclusions

Using the LID mode and based on the current hydrology situation of Chaihu Town, this article established a sustainable ecological system for stormwater regulation and put forward the “three-low” development mode. Compared to the theoretical study, this article integrated the LID concept into the planning practice, constructing “two circles and five attachments” water network which has not only ecological value but also scenic value. Based on the current situation of Chaihu Town and the analysis of the amount precipitation, the planning adopts the rainwater gathering and discharging system of grass ditch + rainwater pipe + regulation system. Compared to the traditional planning of rainwater system, the length of drainage pipeline is greatly reduced. The ecological stormwater regulation system based on the LID mode has both ecological and economic advantages since it not only regulates rainfall flood and protects hydrology environment, but also reduces construction cost.

For the future study, the LID mode should have more statistic support to display the advantages compared to the traditional rainfall flood control system. For the future planning practice, the application of the LID mode should adjust to the local condition, especially to the hydrology condition.

Therefore, the ecological stormwater regulation system based on the LID mode has unique ecological, landscape and economic benefits, which can meet the development requirements of small towns and have a good application prospect.

References