The Construction of Neighborhood Unit System of Flood Control and Drainage Based on Landscape Infrastructure

Guan Shaoping and Zhang Xi

1 Introduction

In recent years, the flood and water logging happened in many cities of china have caused huge loss for the nation. Many former researches have analyzed the causes of flood and water logging in cities. Such as climate change led to the frequent occurrence of extreme weather; consequently the frequentness and intensity of downpour have a huge upsurge; the functions of nature have been restricted markedly due to the destruction of the nature from the rapid development of cities; the engineering infrastructures cannot meet with the demand of cities rapid expansion; and the unsuitable location and unreasonable overall arrangement of a city, the sedimentation of waterways, inconsiderate design, the bad emergency management [1]. These researches also discussed the corresponding countermeasures against these causes. Such as controlling the urban heat island effect, protecting the climate environment, increasing water seepage area to reduce the speed of runoff, improving the standard and capability of engineering infrastructure of flood control and drainage, adjusting the city layout to evade flood disaster, dredging river system to improve the ability of flood discharge, perfecting the design to enrich the flood control and drainage facilities, updating the management to improve operating efficiency [1]. But dams and pipelines are still the most important and directive way to control flood and drainage according to the construction pattern and operation mode of cities in china. We can see from the surveys of causes

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for flood and the response measures of Beijing, Guangzhou, Xian and Kunming in recent years that the main problem is still the drainage pipelines cannot meet the rapid development of cities and the main response measures are still increasing the number of drainage network or improving the design standards of drainage network [2].

The mode that control flood and drainage by means of gray infrastructure has increasingly revealed its limitation even destructiveness in the background of the city expansion and climate change. Some scholars have concluded a few problems about just the drainage mode by means of pipelines [3]: First, the pipelines are sealed, centralized and frail. Urban drainage pipe network is a centralized and closed transport system that were designed according to a standard. So, it cannot respond resiliently to the excessive rainfall because the flow rate and flow has its limits in unit time and the rainwater has to run too long distance in the pipes. In addition, the system will lose efficacy even paralysis when one or some of them were blocked or damaged. So, the pipeline mode has high stiffness and fragility. Second, the construction and maintenance will cost too much. The drainage pipelines in the city are usually up to hundreds or thousands of kilometers, for which the high costs always have to pay. Furthermore, the drainage pipelines frequently been blocked and destroyed, their structure model also led to the difficulty and high cost to manage and maintain them. Third, single function and enormous waste. The drainage pipelines are merely for drainage and function only in case of rainfall; along with unreasonable design and construction, it will cause massive waste inevitably. Again, it goes against water usage. We drain the rainwater out of city by massive pipelines promptly. At the same time we exploit underground water and divert water from outside the city to solve the shortage of urban water use by gigantic water conservancy project. These ways have brought huge resource waste and environment disruption. At last, this drainage model will cause pollution. It will bring massive water pollution because the water flow throughout the city will catch mass pollutants and the pipelines in the moist and dark environment will create massive bacterium. It will led to water pollution seriously and the destruction of the ecological environment. So, it not only cannot control flood and drainage effectively but also led to huge costs of ecology, economy and society just by improving the capability of the traditional gray infrastructures with some ways such as adding quantity, upgrading technology and raising standards.

The limits and drawbacks of drainage pipelines also existing in city's various kinds of hard engineering facility systems in different forms and contents. We can find a problem from the development process of infrastructure in modern city that the infrastructure constantly pursues high standard technical model. The design of these infrastructure systems aimed to ensure that they can achieve a single goal most efficiently by means of engineering. People consider more about the technical requirements of infrastructures and make them more standard. The main goal of most of the roads is to passage, the cutoff and engineered of massive rivers in cities is to meet with flood control standard. This kind of infrastructure has formed its own unique way to control natural environments and urban physical energy cycle, the intimate relationship between them and nature is disappearing. The main function of this kind of infrastructure is usually to exclude other weak functions in a strength position even at the cost of destroy these functions [4, 5, 6]. So, this kind of infrastructure model actually is a way of "from crisis to crisis" [7] to solve problems.

So, it is very urgent to explore new approaches to get rid of the single mode that manage flood mainly by means of dams and drainage pipelines. This paper proposes the neighborhood unit mode of flood control and drainage aiming to take advantage of nature and artificial nature to deal with urban flooding and keep away disturbance and destruction of ecological system from the engineering infrastructures. Meanwhile, this mode will enhance the city resiliency, create economic, social and cultural benefits to promote the urban sustainable development.

2 Methods

This paper explains the feasibility of neighborhood unit mode of flood control and drainage by Combining qualitative and quantitative methods in three steps. Firstly, aim at the limitations and problems of traditional model which control flood by dams and drainage by pipelines, we propose the conception of neighborhood unit model of flood control and drainage based on landscape infrastructure which combines the idea of "landscape infrastructure" and "neighborhood unit". Secondly, the four key elements of neighborhood unit mode of flood control and drainage including a certain amount of rainwater storage and retention area, the balanced distribution of rainwater storage and retention areas, the connection of rainwater storage and retention areas and the construction of landscape infrastructures of neighborhood unit system of flood control and drainage will be used to analysis four cases qualitatively by dividing them into positive and negative group and then illustrate the feasibility of this mode in practice. At last, build the functional relationship model between the rainfall and water drainage by pipelines base on 3 h rainfall in 1998 in Wuhan as an indicator, and then take Yanxi Lake and East Lake in Wuhan as example to get the relation curves between the rainfall and water drainage by pipelines under different water storage and retention conditions, then validate the effectiveness of neighborhood unit model of flood control and drainage through the comparison of these curves.

3 Idea Formation

The circulation of rainfall, evaporation, runoff and infiltration could be regarded as the natural hydrological cycling. Certain percentage of evaporation and transpiration is for the formation of rainfall in the future. Certain percentage of infiltration is for the replenishing groundwater. Certain percentage of runoff may also be used as a supplemental source of water for rivers continuity. They are the "natural pathway" of rainfall. The rapid development of cities had replaced the original water bodies in cities and led to a large amount of nature ground covered by cement, as a result, large areas of impermeable land surface and "concrete forest" has interrupted this natural cycling and most of the rainfall has no way out but to form runoff and converged to flood [8]. Accordingly, on the surface, the forming of flood in cities is due to inadequate and poor management of the engineering infrastructures such as dams and drainage pipelines, but neglecting and even ignoring the "natural pathway" of rainfall is the internal reason [8].

The expanding of city size always stays ahead of the updating of the flood control and drainage ability of engineering infrastructure such as dams and pipelines, as a result, the overburdened drainage pipelines can only operate overloaded, along with the intrinsic limitations of dams and drainage pipelines, over-dependent on them cannot solve the problem of the flood disaster in cities fundamentally. To solve the problem effectively, we should go back to the root of the issue and find solution by recovering the "natural pathway" of rainfall. But city as human activities gathered area is an artificial subsystem which exerts huge destruction to the existing eco-systems of natural water system. So, it is difficult to repair the "natural pathway" of rainfall [8]. But cities have not completely away from nature, this article seeks to build a flood control and drainage model which according with natural hydrological cycling and create multiple benefits by using nature and even artificial nature resources and combing the engineering infrastructure of urban stormwater management.

This research would benefit from the urban planning philosophy of "neighborhood unit" and "landscape infrastructure".

Neighborhood Unit It was proposed by the American planner Perry in early twentieth Century to adapt the planning structure changes in modern city because of the development of automobile traffic, which has changed the conventions that residential structure subservient to roads and square themselves which result in traffic congestion. It unified the planning of the residential area in a bigger realm, making the neighborhood unit as a cell to live in. The scale of neighborhood unit refers to the service radius of a primary school, and the complement public utilities in the neighborhood unit are built for the daily life of the dwellers, so the daily needs of dwellers in neighborhood unit can be satisfied internally, then the most of the traffic can also be digested internally to avoid the great pressure from massive traffic leading to accidents [9]. Draw lesson from this thought we can look the city as a huge region for flood control and drainage and dividing this region into several "neighborhood units" of flood control and drainage based on its own basic conditions, each "neighborhood unit" is a "cell" of the huge region. The "neighborhood unit" here refers to the infrastructure unit which centered on a couple of flood storage and retention areas such as lakes, reservoirs, wetlands and artificial rain carrier and the city region they served. The rainfall inner each neighborhood unit should being digested in the unit to avoid too much rainwater drains into drainage pipelines within a short time led to flood.

Landscape Infrastructure It is a new term emerged in America academia recently. It was been first proposed by Garry Strang in 1996 [10]. As a new term, it does not mean to a new type of infrastructure but an idea or a strategy of planning. Combine with the ideology of landscape urbanism [11], we can interpret the idea that landscape refers to the complexes constituted by land and the space and matter on the land. It is the marks on the land engraved by complex nature process and human activity; all ecological processes necessarily pass through it [12]. So it is the carrier of all nature process and human activity. In that sense, landscape is not only the scenery and symbol to interpret the interaction between human and nature but also the space and environment human lived in and an ecological system. Therefore, it has multi- attribute and functions of ecology, material space, language [13] and aesthetics and so on. Whether the animate green infrastructures based on natural conditions or the abiotic gray infrastructures based on artificial technology and materials are all the elements of landscape or landscape itself. So these infrastructures should possess the multi- attribute and functions of landscape and to support and participate in the ecological process and results of the nature, society, economy and culture of city. We can conclude based on the analysis above that landscape infrastructure is the organic whole combined landscape with infrastructure which can be built by using landscape design methods to improve the comprehensive functions of urban infrastructure and led it to become both infrastructure and landscape with multiple values of environment, economy, society and culture and so on [6].

Based on the functions and features of landscape infrastructure and followed by the planning theory of neighborhood unit, we connect the neighborhood units of flood control drainage which are mainly consist of lakes, rivers, and green system around them, to become a huge system like the connective tissue (Figs. 1 and 3). Aiming at this huge system of infrastructure, using landscape design methods to give it more comprehensive functions beside flood control and drainage. Similar to the connective tissue that widely distributed in the human body, the huge system widely distributed in the city and plays an important role in connection, supporting, nutrition, protection and other functions, thus it will becomes a system combined landscape with infrastructure of flood control and drainage and creates the multiple values for environment, economy, society and culture. This is the neighborhood unit system of flood control and drainage based on landscape infrastructure.

4 Construction

Considering the description of the basic concept of the model in Sect. 3. The construction of the model would be described in four steps including the principles, elements, structure and performance.

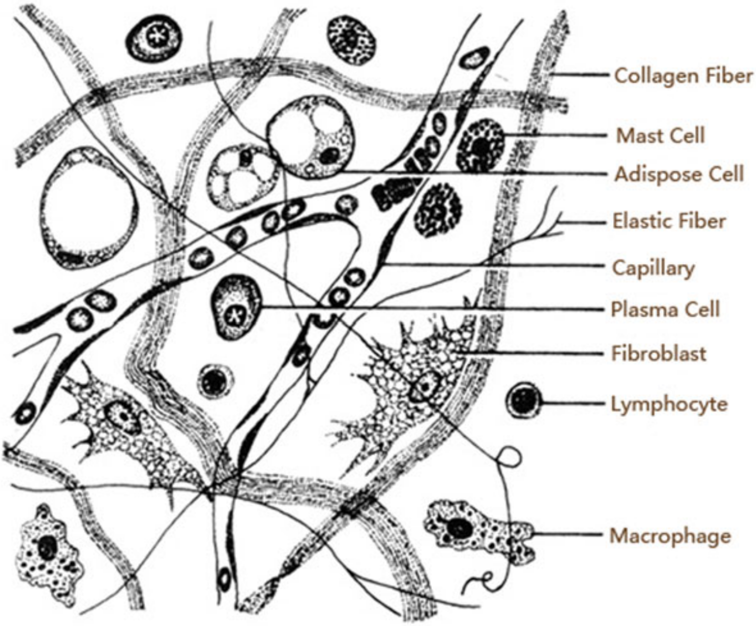

Fig. 1 A diagram of connective tissue (Source: http://baike.baidu.com/view/178915.htm)

4.1 Principles

- The neighborhood unit model of flood control and drainage mainly use nature, artificial nature and part of engineering infrastructures as supplementary to manage rainwater.
- The neighborhood unit model of flood control and drainage recover the "natural pathway" of rainfall according to natural hydrological cycling.
- The neighborhood units should been evenly distributed in the whole city.
- It makes sure the interconnection between neighborhood units and the interconnection among neighborhood units, the river system and drainage pipelines in the city.
- It combines with landscape design to build resilient and sustainable infrastructure which has multi-benefits of ecology, society, economy and culture.

4.2 Elements

There are three main constituent elements of neighborhood unit system of flood control and drainage. They are neighborhood unit, interconnection infrastructure and the operating system.

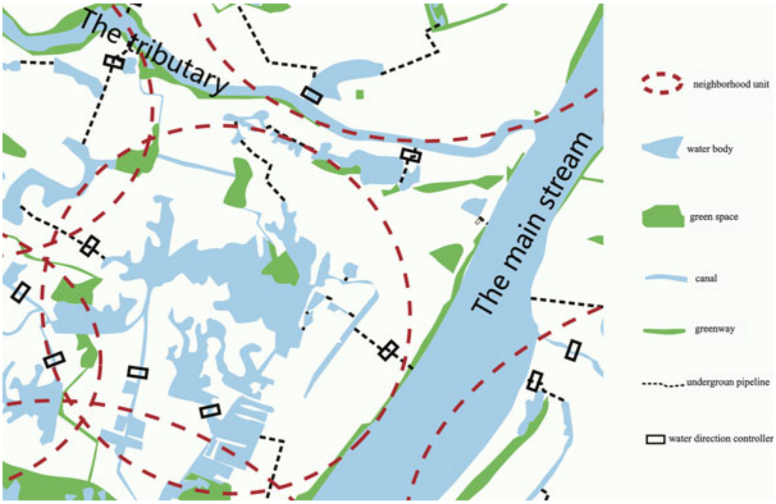

Fig. 2 A conceptual diagram of neighborhood unit of flood control and drainage (Created by myself)

Neighborhood unit. It is the basic unit to construct the neighborhood unit system of flood control and drainage (Fig. 2). It consists of the infrastructure unit which centered on a couple of flood storage and retention areas such as lakes, reservoirs, wetlands and artificial rain carrier and the city region they served. The infrastructure unit of flood control and drainage consists of varies natural and artificial natural water bodies, green space and part of the engineering infrastructure which have the function to regulate rainwater. The scale of each "neighborhood unit" is determined by the regulation ability of the infrastructure unit of flood control and drainage and turban geography.

Interconnection infrastructure. It refers to channels, ditches, pipelines and greenways which have the function of connection (Fig. 2). The interconnection infrastructure should manage to adopt a natural friendly form, and minimize the compositive impact on environment through landscape design if it bound to have engineering process.

Operating system contains the infrastructures and equipments to monitor and regulate the distribution and flow direction of water (Fig. 2).

4.3 Structure

The basic structure of neighborhood unit system of flood control and drainage include the internal structure of a neighborhood unit and the structure of the whole system.

The internal structure of a neighborhood unit is to take several flood storage and retention areas as core and then connect them with the natural and artificial natural water bodies and green spaces in the unit through channels, ditches and drainage pipelines to form a internal water circulation system.

The structure of the whole system is to connect the water storage and retention areas in each neighborhood unit and connect them with the river system and drainage pipelines in the city to form a huge network system like the connective tissue.

The construction of neighborhood unit model of flood control and drainage is according to the following steps.

The first step is the ascertainment of the neighborhood unit. We need analysis the geological environment of the city thoroughly, by means of the geographic information technology (such as GIS) and according to the existing waters (such as mountain, rivers, lakes, ponds and reservoirs) and the green space around them to designate many flood storage and retention areas and their scopes, and then calculate the max secure storage capacity of each flood storage and retention area. Then we suppose the seepage and storage capacity of the hard paving areas is 0. According to the hard paving area scope that each flood storage and retention area served in condition of a certain max rainfall (such as the 3 h rainfall once in a century), we can designate many neighborhood units of flood control and drainage in the city.

We suppose the drainage facilities in each area of the city are the same, so the districts without covering by neighborhood units in the city are just those lacks of flood storage and retention areas. They are all vulnerable to the hazard of flood and water logging. So we need combine with the requirements of urban economy and culture etc. to build up the artificial nature flood storage and retention areas in the future urban renewal planning of these districts to satisfy their demand for storage and retention flood, and then, forming many neighborhood units of flood control and drainage in these districts. The flood storage and retention areas in these districts should be equally distributed to avoid constructing giant flood storage and retention areas based on design flood storage capacity of these districts. So we need evenly distribute the design flood storage capacity of these districts. We can choose some fairly suitable areas to build flood storage and retention areas based on the geographical and construction condition.

The factors which influence the storage capacity of a flood storage and retention area in the detailed flood storage area design are: the water area, the water depth, the area and structure of green around the water bodies. The variation of these factors will influence the storage capacity of the flood storage and retention area and then the ascertainment of neighborhood unit, so we should regulate these factors based on the conditions of geography, construction, ecology and culture.

The second step is the connection of the neighborhood units. The flood storage and retention areas inside neighborhood unit or among the neighborhood units connected with each other through waterways, the flood storage areas which cannot connected with each other through waterways due to the geological environment could be connected with each other by means of underground pipelines to form the

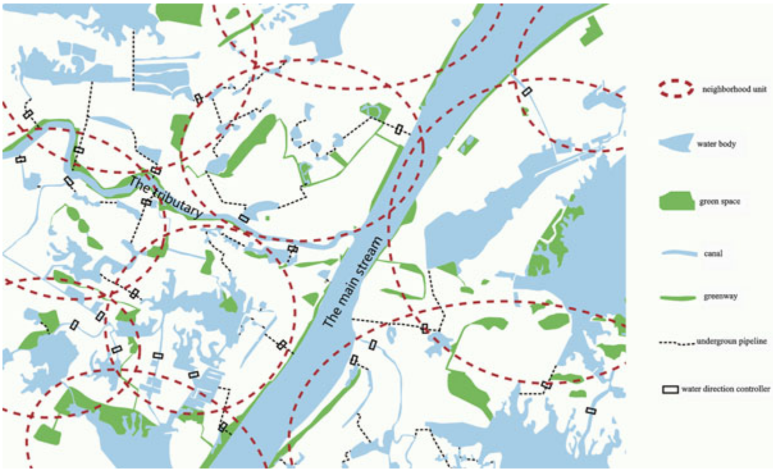

Fig. 3 A conceptual diagram of neighborhood unit system of flood control and drainage (Created by myself)

water network system and ensure the dynamic balance of water in the city. Furthermore, the flood storage and retention areas are connected with each other through greenways to ensure the integrality of the park system, so the park system with the function to detain and seep water would form the landscape infrastructure throughout the city (Fig. 3).

The last step is the regulation and usage of the system. We regulate and use the rainfall through a series of effective measures. There are control facilities such as flood gates and pump stations between each two flood storage and retention areas and among the flood storage and retention areas, river system and drainage pipelines to regulate the water flow direction, and then it builds hydrological monitoring network to act on these water direction controllers based on the system. These control facilities and hydrological monitoring network form a intelligent control system to control and monitor the flood in the whole system.

In addition, the construction of the system from beginning to the end should combine with landscape planning and design, to build the connective and supportive frameworks for the system to the urban organism from the aspects of ecology, society, economy and culture at the same time of meeting the function requirement of flood control and drainage.

So, the whole city is a huge neighborhood unit system of flood control and drainage based on landscape infrastructure.

5 Assessing

5.1 Case Study

First case: the polder system in Dutch (Fig. 4). The Dutch drained water out of shallow seas and lakes to get land around ten centuries AD. They made the land no longer be intruded by the sea with dams and culverts and then dig some water bodies and ditches to collect and store the rainfall, water in the ditches can replenish the periphery land during the drought and been drained to the periphery water bodies during the rainy season. These ditches interwoven with each other to a network and form a massive system with water seepage, storage and drainage. This system has great ability to control and regulate flood. Its wetland environment creates the diversity of ecological landscape.

The Second case: the Emerald Necklace in Boston. The Emerald Necklace park system in Boston connects the original Parks, marshlands and drainage ditches. The green system extending 16 km chained 9 park systems [14] (Fig. 5). With decades of construction, the river corridors have penetrated in the whole city and became the nature flood storage areas. Its long linear system have reduced flood in storm period, frostless period and flood period effectively. It bettered the water quality of river and the ecological quality of periphery environment, provide rich outdoor activity spaces for citizen, too.

Third case: Guangzhou is in the Pearl River network area and crisscrossed by rivers and waterways, but many waterways have disappeared or be severely deposited and then the phenomenon of dirty, smelly and unrest was very striking in the last 20 or 30 years because of rapid development of urban area. The water logging in the city was serious whenever the rain storms. Guangzhou has been involved in

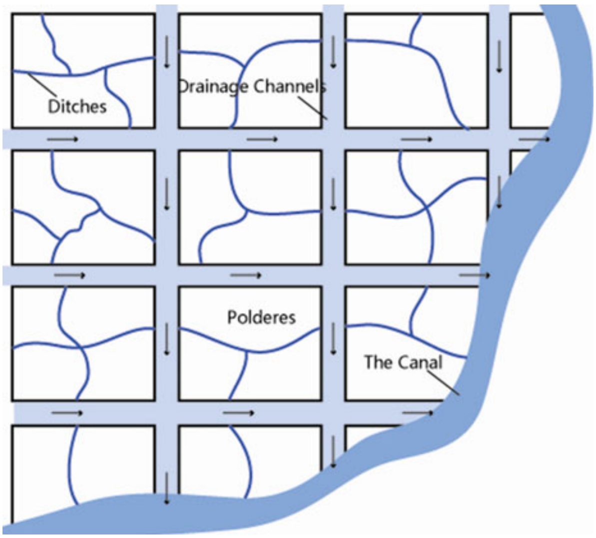

Fig. 4 The diagram of polder in Dutch (Created by myself)

Fig. 5 The Emerald Necklace in Boston (Source: http://www.jx216.com)

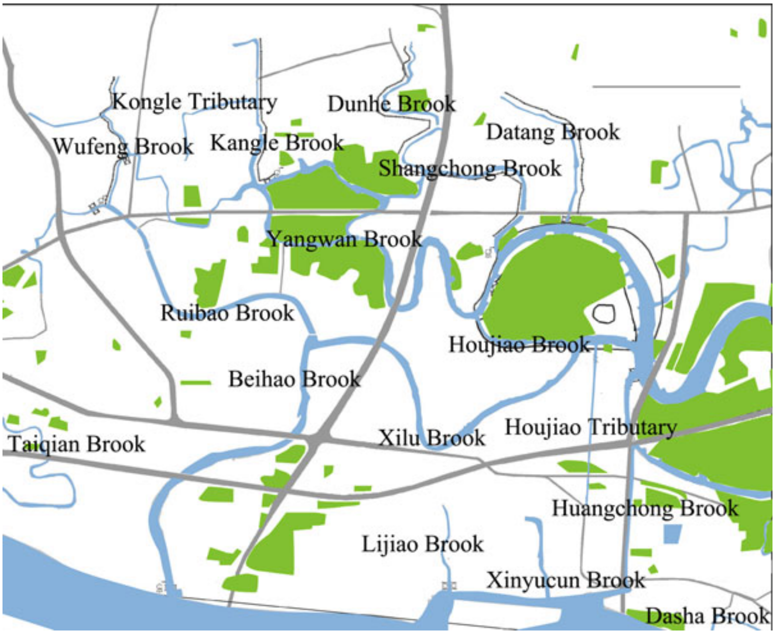

Fig. 6 An analytical diagram of the system of water and green in Guangzhou Haizhu (Redrawing of the map of Haizhu)

the harness of waterways, now the condition has significantly changed through high standard comprehensive harnesses that pull down the buildings along banks, clean up, dredge and connects of the rivers. Figure 6 is the situation of the harness of waterways in Haizhu district. We can know from this figure that the water network has been dredged and connected, the water quality has improved significantly after harness, but the problem that water logging whenever rain storms still haven't

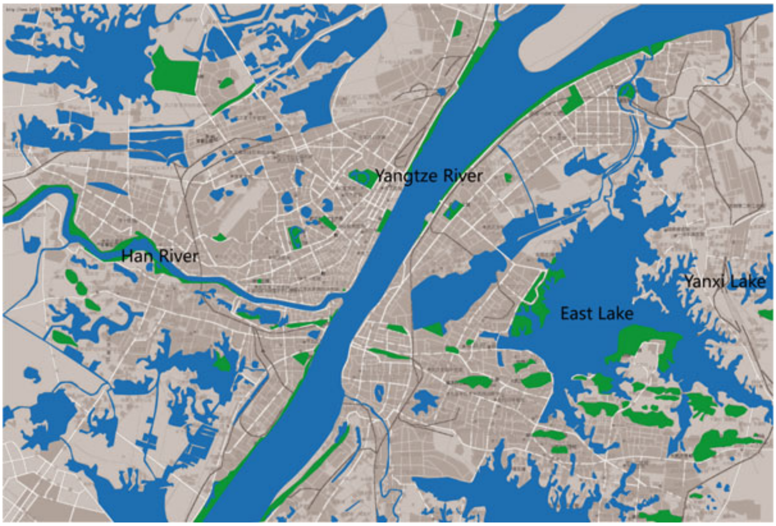

Fig. 7 An analytical diagram of the system of water and green in Wuhan (Redrawing of the map of Wuhan)

improved significantly. One reason is that the large amount of hard ground in the city prevent rainfall from seepage nearby, this lead to huge water logging on the ground surface, another reason is the flood storage and retention capacity is weak because of the narrow waterways and little green space along the banks.

Forth case: Wuhan located in intersection of the Yangtze River and the Han River and known as the reputation of hundreds lakes city. Nevertheless it has been damaged by flood and water logging frequently. The water surface area in Wuhan is 2,117.6 km^2, the coverage of water bodies is 26.1 % and the water surface area ratio is topped in China [15] (Fig. 7). Why still flood here with such enormous nature flood storage areas exist? We can know from Fig. 4 that there are much water bodies in Wuhan but the degree of breakage is quite high and uneven distribution, what's more, the green space shortage in central Wuhan is critical. Here is a simple analysis about the water breakage degree in Wuhan:

The index we take is: the density of splashes(C), the water breakage degree will higher when C is bigger, otherwise it will lower (Table 1).

$$C_i = n_i / A_i$$

Where, C_i = the breakage degree of I, n_i = the patch number of I, A_i = the area of I, in km^2.

We can know from Fig. 7 and Table 1 that the lakes in Wuhan are innumerable but uneven distributed; there is little green in the city even along shores; lakes lack of connectivity and the breakage degree of water bodies is high. These have caused the problem that massive water bodies cannot form a connected huge water system to equalize the digest capacity of flood in the city's different areas just like polder

Table 1 The breakage degree of lakes in Wuhan

i	n_i	$A_i(km^2)$	C_i
Lakes	166	803.17	0.2

system in Dutch. What's more, the green coverage ratio in Wuhan is very low, so the districts with little water bodies will vulnerable to flood in case of rain storms. Therefore, Wuhan will have great flood hazard even the nature storage condition here is good and municipal facilities here are complete.

We can draw inspiration from the first case and second case: firstly, we should take full advantage of the nature service function of the ecological infrastructure (such as nature water body and green), this could play an important role in flood control and drainage, and what's more, it would produce ecological, economical and cultural values. Secondly, the breakage and solitary of flood storage areas will seriously weaken the function of flood control. Strengthening the connection of them to form bigger scale network system and disperse the partial flood pressure that attribute to the disproportion of rainfall through system balance function, its flood control and drainage capacity will be enhanced largely. Lastly, the areas of seepage and storage that are distributed in balance would promote the digest capacity of flood nearby and alleviate the flood disaster caused by the flood control and the disproportion of drainage capacity.

5.2 Performance Analysis

5.2.1 Model Deduction

After the rainfall, as a result of the surface coverage difference, some of the water seep into earth, some evaporate into air, some are detained in the low ground and the rest drained through the drainage pipelines. The factor of evaporation and the amount of water seepage in hard construction areas are been neglected in this article, so we can get the functional relationship between the total volume of rainfall and the water storage and the water drainage as follows:

$$V = Q_{drainage} + Q_{retention} \tag{1}$$

Reference [16] provides that the rain flow formula is:

$$Qy = \Psi qF \tag{2}$$

Where, Qy = rainwater design discharge, in L/s; Ψ = runoff coefficient, assign a value of 0.9; q = design rainwater intensity, in L/hm^2; F = drainage catchment area, in hm^2. From Formula 2 we can get that:

$$Q_{drainage} = Qy \times T(60/1,000) = 0.9qF \times 60T/1,000 = 54qFT/1,000 \quad (3)$$

$$Q_{retention} = D_{river} + D_{plant} \quad (4)$$

Where, $Q_{drainage}$ = the amount of water from drainage pipelines, in t; T = duration of rainfall, in min; $Q_{retention}$ = the amount of water be retained, in t; D_{river} = the amount of water be stored by rivers, in t; D_{plant} = the amount of water be retained by plants, in t.

The study supposes that the designed rainstorm intensity of drainage pipelines in Wuhan is according to 10 years 3 h downpour. It discusses the functional relationship between 3 h' V and $Q_{drainage}$ of in 1998 in the case of the $Q_{retention}$ vary in Yanxi Lake zone and two lakes zone which consist of Yanxi Lake zone and East Lake zone.

Reference [16] provides that the designed rainstorm intensity formula of Wuhan is $q = 983(1 + 0.65lgP)/(T + 4)^{0.56}$, where, P = the design recurrence interval; t = the duration of rainfall, in min. So the design rainfall intensity q = 87 ($L/hm^2 \cdot s$). If the recurrence interval is 10 years, the duration of rainfall is 3 h. In the real circumstance, the drainage pipeline would not meet with the requirement of rainstorm intensity because of blocking, deformation and other influential factors. So we set an adjustment coefficient $\alpha(0 \leq \alpha \leq 1)$. Meanwhile, it need time that the rain water flow into the rivers and lakes, so we also set an adjustment coefficient for the water storage, $\beta(0 \leq \beta \leq 1)$. We suppose β equal to 0.3, as in [17], the capability of water storage capacity of woodland is 5,461.22 t/hm^2, shrub land is 5,092 t/hm^2, and the grassland is 5,203.23 t/hm^2. So we can conclude Eqs. (1), (3) and (4) into:

$$V = Q_{drainage} + Q_{retention} = [\alpha 54qFT/1,000] + 0.3(D_{river} + 5,464.22A_1 + 5,092.63A_2 + 5,203.23A_3) \quad (5)$$

Where, V = volume of rainfall, in m^3; D = the storage capacity of lake, in m^3; A_1, A_2 and A_3 respectively refers to the area of woodland, the complex of woodland, shrub land and grassland, grassland, in hm^2.

We had known the design rainfall intensity (q) and the design rainfall duration (T), so we can conclude Eq. (5) into:

$$V = 845.64\alpha F + 0.3(D_{river} + 5,464.22A_1 + 5,092.63A_2 + 5,203.23A_3) \quad (6)$$

5.2.2 Empirical Research

Equation (6) is the mathematical model of this research, and then we apply this model to Yanxi Lake and East Lake in Wuhan province. Yanxi Lake located the acreage of Yanxi Lake is 1,333.3 hm^2, the catchment area is 6,830 hm^2; the acreage of East Lake is 3,300 hm^2, the catchment area is 12,170 hm^2 [18]. The storage capacity of Yanxi lake (D_y) is 29,897,500 m^3, the storage capacity of East lake (D_d) is 68,709,200 m^3 [19].

We should definite some key concepts before we begin with the empirical research. Yanxi Lake zone (Z_y) refers to the lake area of Yanxi Lake and the land area in the catchment area of Yanxi Lake. East Lake zone (Z_d) refers to the lake area of East Lake and the land area in the catchment area of East Lake. Two lakes zone refers to the zone consist of Yanxi Lake zone and East Lake zone. The area of Z_y (A_y) refers to the sum of the area of Yanxi Lake and the area of land area in the catchment area of Yanxi Lake. The area of Z_d (A_d) refers to the sum of the area of East Lake and the area of land area in the catchment area of East Lake. The catchment area of Yanxi Lake (C_y) refers to the precipitation area which rain water flowing into the same valley including Yanxi Lake. The catchment area of East Lake (C_d) refers to the precipitation area which rain water flowing into the same valley including East Lake. The catchment area of design drainage pipeline in Yanxi Lake (F_y) equals to the catchment area of Yanxi Lake. The catchment area of design drainage pipeline in East Lake (F_d) equals to the catchment area of East Lake. The green space of Yanxi Lake Park (G_y) refers to the green space of park if we build a park centered on Yanxi Lake. The green space of East Lake Park (G_d) refers to the green space of park if we build a park centered on East Lake. Yanxi Lake Park (P_y) refers to the area includes the green space of Yanxi Lake Park and Yanxi Lake. East Lake Park (P_d) refers to the area includes the green space of East Lake Park and East Lake.

The catchment area of a lake is the area surrounded by watershed borderline and cross-sections. So, $F_y = G_y = A_y; F_d = G_d = A_d.$

There were four steps in this research. First, we suppose the rainstorm in Yanxi Lake zone can be digested only through drainage pipelines, we regard the 3 h maximum rainfall in 1998 in Wuhan as the 3 h rainfall in 1998 in Yanxi Lake zone which is 159 mm [20]. So we can conclude the following result based on Eq. (6):

$$V = 10859700 > 5775721.2\alpha$$

The relationship between the volume of rainfall and the amount of rainwater drained by pipelines shown in Fig. 8 curve I.

Second, we suppose Yanxi Lake could store water in Yanxi Lake zone. So we can conclude the following result based on Eq. (6):

$$V = 10859700 \geq 8969250 + 5775721.2\alpha$$

The relationship between the volume of rainfall and the amount of rainwater drained by pipelines shown in Fig. 8 curve II.

Again, we suppose to build a park centered on Yanxi Lake, the area of the green space of the park equal to the area of the lake, so the area of Yanxi Lake Park is the double of the area of Yanxi Lake. The green structure in the park is according to the structure of green space of parks in Shanghai [21]. The area proportion of woodland landscape is 59.09 %, the area proportion of the complex of woodland landscape, shrub land landscape and grassland landscape is 28.79 %, and the area proportion of the grassland landscape is 12.12 %.

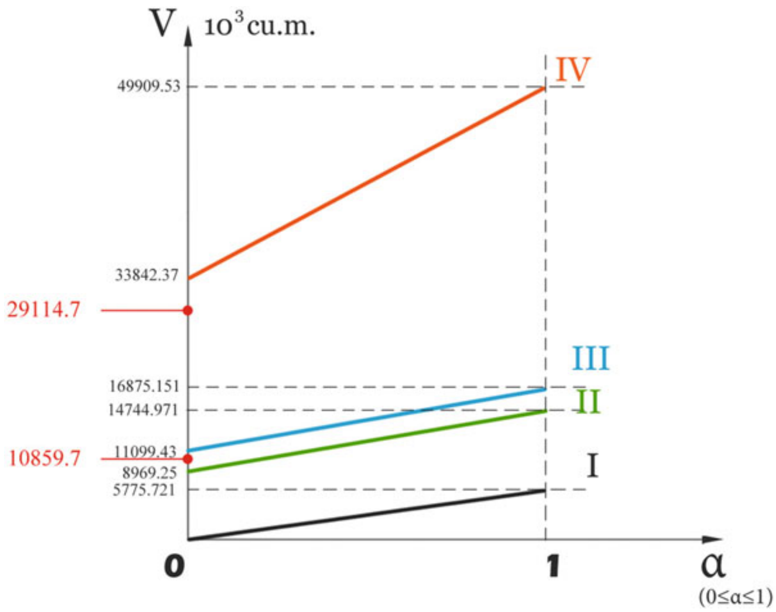

Fig. 8 The relationship between the volume of rainfall and the amount of rainwater drained by pipelines

So we can conclude the following result based on Eq. (6):

$$V = 10859700 < 11099430 \ + \ 5775721.2\alpha$$

The relationship between the volume of rainfall and the amount of rainwater drained by pipelines shown in Fig. 8 curve III.

The above analysis is based on the premise that Yanxi Lake is isolated and without connection with other lakes (Fig. 8). At last, we assume that Yanxi Lake connected with East Lake, there were a lake park in East lake zone, the area of the green space of East Lake Park is 1,333.3 hm^2. The rainfall intensity is uneven in space and time, so we suppose the 3 h maximum rainfall in East Lake zone is 150 mm, the 3 h maximum rainfall in Yanxi Lake zone is still 159 mm, we can conclude the following result based on Eq. (6):

$$V = 10859700 \ + 18255000 = 29114700 < 33842370 \ + 16067160\alpha$$

The relationship between the volume of rainfall and the amount of rainwater drained by pipelines shown in Fig. 8 curve IV.

5.2.3 Results Analysis

We could know from curve I in Fig. 8 that its highest point hasn't reached to the volume of 3 h rainfall in 1998 in Yanxi Lake zone which is $10{,}859.7 \times 10^3$ m^3. We could know from curve II that its highest point has surpassed the volume of 3 h rainfall in 1998 in Yanxi Lake zone. We could know from curve III that its lowest point is surpassed the volume of 3 h rainfall in 1998 in Yanxi Lake zone. We could know from curve IV that its lowest point has far surpassed the volume of 3 h rainfall in 1998 in two lakes zone which is $29{,}114.7 \times 10^3$ m^3. Therefore, Yanxi Lake zone cannot drain all rainwater of 3 h in 1998 in Yanxi Lake zone through drainage pipelines only. It can digest the rainwater of 3 h in 1998 in Yanxi Lake zone through the storage of Yanxi Lake and the drainage of pipelines when Yanxi Lake could store water. It can digest the rainwater of 3 h in 1998 in Yanxi Lake zone through the storage and retention of Yanxi Lake Park without drainage pipelines when Yanxi Lake Park store water as landscape infrastructure. When connected it with East Lake, the water will achieve to a dynamic balance in the whole district, but the range and intensity of precipitation are not changed, so the ability to resist the flood in the district will be reinforced because the amount of rainfall is distributed equally. Thus the two lakes zone can digest the rainwater of 3 h in 1998 through the storage and retention of Yanxi Lake Park and East Lake Park and the balancing action when connection them with each other without drainage pipelines. The analysis above clearly presents a certain amount of flood storage and retention areas which consist of water bodies and green spaces, the balanced distribution of flood storage and retention areas and the connection between them. They are precisely the key points of neighborhood unit model of flood control and drainage and show the effectiveness of this model.

6 Conclusion

The neighborhood unit model of flood control and drainage based on landscape infrastructure play a positive role in flood control and drainage of city, the construction of resilient city and the healthy development of ecological city. Firstly, it follows the rainwater natural circulation and use natural condition combine with part artificial infrastructure to decentralized and centralized manage rainwater through the dividing and connection of neighborhood units. It could reduce the flood in cities and improves water protection and utilization efficiency. Secondly, it combines landscape with infrastructure. On the one hand, it emphasis the coexistence and cooperation of human and nature and the construction of flood control and drainage infrastructure using natural conditions to reduce the construction of dams and pipelines. Therefore, it reduces the interference and destruction to natural environment and the wasting of resources. On the other hand, this model integrates the water network, green network and engineering infrastructure based on the neighborhood unit system of flood control and drainage. Thus, it increases the diversity of urban area, and promotes the capacity of urban area in coping with uncertainty and nonlinear external impacts, with these, it could increase the ability of self-organization and actualize the coordinated development of people and environment [22]. Lastly, it exerts landscape design idea on the infrastructure system of neighborhood unit model of flood control and drainage to build multifunctional and multiform urban open spaces and cultural and living facilities. It embodies multi-benefits such as promote social justice and people's physical and mental health level, cope with crisis and post-disaster reconstruction. In a word, whenever at normal or emergency situation, neighborhood unit system of flood control and drainage could make city more resilient and promote the sustainable development of the city.

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