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Integrated Water System Planning in Urban Area

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Abstract Nowadays, especially in urban areas, the declining or even vanishing of water system almost unavoidable costs for the urbanization. Based on analysing special characteristics of the urban hydrologic cycle, this paper described the urbanization and its influence on water cycle of Xuzhou city, and then put forward an integrated planning model of water system in urban areas. Our responsibility is making the urban water system resilience parallel to the urbanization.
Keywords urbanization, water cycle, integrated planning, Xuzhou city

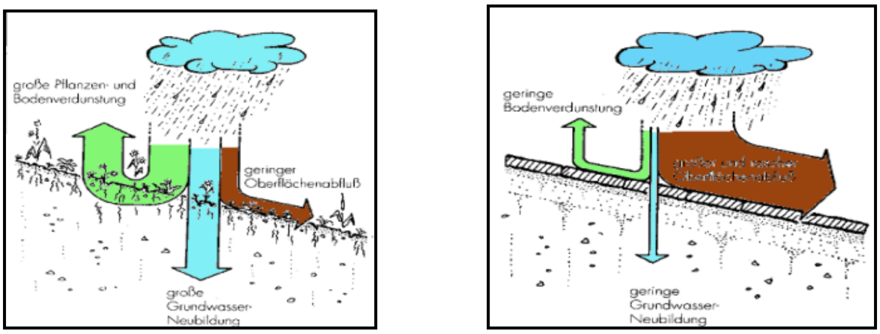
Introduction

According to a UN Report (UNDESA 2008), the world's urban population account for half the total population (6.7 billion), and China is now on its way to become urbanized. From 1980 to 2013, China's urban population has increased from 19.4% to 53.4% of its total population. The accelerating process of urbanization has disturbed and damaged the urban water system as well as the hydrologic cycle in river basins. The resulting water resource shortages, frequent flood disasters, water pollution, destruction of river ecosystem, and other problems often arise concurrently, gravely subjecting the cities and river basins to the urban syndrome (Cottingham et al. 2003). In reality, the water shortage, pollution and floods reflect only the surface of the problem, while the blockage in the original water cycle caused by the increasing impermeable surfaces, the imbalance of the precipitation – runoff – evaporation – infiltration ratios once in harmony with local geographic and climatic conditions, and the destruction and degradation of the urban cycle in urban water system are the core of the problem. So it is very clear that water problems in urban areas can be solved at root only through restoring the functions of urban hydrologic cycle and ensuring a smooth process of natural water cycle in cities. The proposed integrated water system planning in this paper tried to integrate all the space entities within the city capable of collecting and storing rain water and prolonging the period of rain water detention into a network system, coordinate the rapid expansion of cities and the natural water cycle as far as possible, and finally realize the water cycle restoration in step with the urbanization.

Urbanization and water cycle

Before the emergence of cities on a large scale, humans usually lived close to water. In their settlements as the embryos of cities, the rain water could evaporate, infiltrate the soil, and flow along the natural channels freely. Later, the natural rain water channels have been artificially blocked by the increasing impermeable surfaces (fig. 1), which is regarded as the most significant impediment and damage to the water cycle caused by urbanization.

As shown in fig.1, until the beginning of the large-scale urban construction, the rain water channels in the regions encompassing cities were in the natural state: in terms of atmospheric precipitation, the amount of water evaporating into the air is normally larger than that of water infiltrating the ground, and the latter is larger than the amount of surface runoff (fig.1a). The clouds in the air as well as rivers on the surface and ground water in a region are all adequately compensated with rainfall so that the local natural water cycle can be sustained. The often-criticized problem regarding a city's drainage accompanying the process of urbanization nowadays is at bottom caused by the expanding hardened surfaces. With the expansion of hardened surfaces and the shrinking of surface water bodies, the natural rain water channels in a city have been blocked, preventing the enough supplements to the clouds in the air as well as rivers on the surface and ground water. With no access into either the air or the earth, the rain water could just flow randomly along the hardened surfaces, converge on the surface at unprecedented high speeds (fig. 1b), and surge into the usually overloaded man-made drainage pipes. When the drainage pipes can’t endure, inundation and nonpoint source pollution could occur in urban areas.



(a) Before urbanization *(b) After urbanization*

Fig. 1 *Water cycle in urban area*

The increase in runoff coefficient and the acceleration of convergence of rain water are the direct causes of inundation in urban areas. Therefore, the urban drainage problem can only be solved by means of changing the runoff coefficient and prolonging the period of rain water detention into in urban areas. Integrating all the rain water channels into a network system through expansion, transformation, and effective utilization of the spaces capable of collecting and storing rain water was an effective method which the proposed integrated planning of urban water cycle spaces relied on.

The urbanization and its influence on water cycle in Xuzhou city

The urbanization in Xuzhou

The past four decades (1983 – 2013) has witnessed significant growth of the economy, urban population, and construction land of Xuzhou. The GDP has soared from 2 to 240 billions yuan. The urban population has increased sharply from 0.78 to 2.49 billion. And the area of urban construction land has nearly doubled from 311 to 755 hectare (fig.2), which accounted for 10% and 24% of the total area of used land respectively. Overall the urbanization of Xuzhou has shifted from the early stage to middle stage.

The influence of urbanization on hydrological processes

(1) Rainfall

The results of the analysis of the trend in the average annual precipitation data over the nearly five decades (1963-2011) from three precipitation stations of Xuzhou were as follows: (1) Over the twenty years from the mid 1960’s to mid 1980’s, the urbanization has slowed down, and the average annual precipitation was generally below the average over the past five decades. But since the mid 1980’s, the urbanization has developed rapidly, and the precipitation was higher than the average over the past five decades; (2) the average annual precipitation kept rising while the suburban average annual precipitation kept declining, with the rise in the urban precipitation exceeding the decline in the suburban precipitation.

(2) Annual runoff

Based on SWAT, the hydrological modeling for the influence of land-use change on the amount of runoff in the context of urbanization indicated that the expansion of impermeable surface led to larger amount of runoff and higher runoff coefficient. During 1983-2013, the area of construction land has doubled, and the runoff coefficient of median water years has risen from 0.85 to 0.89, thus subjecting the city to a higher risk of storm water.

(3) Storm runoff

According to the storm intensity equation for Xuzhou and the storm data from the three precipitation stations, the one-hour rainfalls in the storm return periods of 1 a, 2 a, 3 a, 5 a, and 10 a respectively were calculated, and the hydrological modeling based on SCS was performed to analyze the storm runoff in different return periods and over different underlying surfaces in the process of urbanization. The results suggested that over the four decades, under the same soil moisture conditions, the amounts of storm runoff in the 5 storm return periods exhibited an increasing trend. And the longer the return period was, the higher the runoff coefficients were, which meant that the runoff increased with the rainfall. As the storm return period went up, the rise in runoff coefficient inclined to moderate.

(4) Groundwater

As the urbanization accelerated, the surface water became so insufficient that the ground water acted as an important water source of Xuzhou. The annual ground water extraction in Xuzhou was about 183 million cubic meters. In the total water supply for the urban area, the ground water to surface water ratio was as high as 1.6: 1. The total amount of ground water extraction from the main groundwater source in the urban area reached 9.22 million cubic meters. The cone of depression caused by over-exploitation amounted to 176.4 km^2, and the water level in the center dropt from 17m in 1980 to -6.20 m in 2006. The long-term serious over exploitation has resulted in the drop in groundwater levels, degradation of water quality, karst-generated collapse and other environmental and hydro-geological problems.Moreover, as the major coal mine of Jiangsu, Xuzhou coal mine has a production capacity of over 15 million tons per year. More than 45 million cubic meters of mine inflows in total are discharged in the city every year. In 2003, the total mining subsidence area reached 12670 hm^2. The seasonal and perennial waters due to the large amounts of mine inflows, and subsidence have damaged the channels for ground water cycle and given rise to significant waste of water resource and continuous environmental degradation.

The implementation of integrated planning

Potential integration spaces

According to their size, the available accumulation spaces can be classified from such three scales as point (site), line, and plane. Point (site) scale spaces include the green roofs in residential areas, industrial parks, and commercial districts, concave green spaces, rain-fed gardens, shallow trenches in vegetation, green parking lots, small rain-fed wetland, small water landscapes, etc. Linear scale spaces are green streets, green roads, etc. And planar scale spaces are the ecological waterfront landscapes near the rivers within the city, ecological corridors, eco-parks, natural reserve, large rain-fed wetlands, reservoirs, lakes, etc (Tan 1999).

The integrated planning of urban water system was designed to create a soft network system (fig. 2) of various small and separate spaces covering the hardened surfaces of the whole city for rainwater through establishing the point, linear and planar scale spaces mentioned above and interconnecting their channels. The cases (Sieker et al. 2006) of rainwater management in commercial districts indicated that only 10% space of the whole was enough for the collection and storage of rainwater in the whole districts. In accordance with the existing construction standards, however, the green area should be larger than 10% of the whole whether in residential area, industrial parks or commercial districts. In this sense, the accumulation spaces will not impede the restoration of natural channels for rain water in cities.

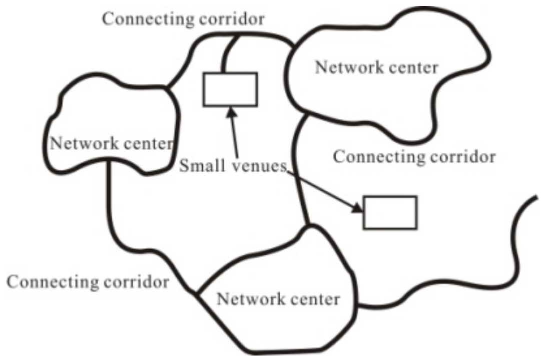


Fig.2 *Spatial structure of integrated planning for urban water system*

The effect of integrated planning

Based on the built-up area of Xuzhou as the research area, the planning of green space network was made, and the change in the amount of its annual runoff before and after the construction of the green space network was analyzed via hydrological modeling.Based on the green space network planning, the area of green land increased 29.21 km^2, new green area and networked green space system makes the regulation and storage capacity of runoff greatly enhanced. The hydrological simulation results showed that, after the greed space network was established, the estimation of the urban annual runoff depth exhibited a relatively large reduction of 25 mm, or 10.4%. This demonstrated that the integrated urban water cycle system planning was able to effectively enhance the infiltration of rain water and thus cut the amount of urban rainwater runoff and promote healthier and more effective development of urban water cycle.

Conclusion

(1) Impervious surface expansion during the urbanization broke the natural water cycle process that is the direct cause of city water problems, and integrated planning for rainwater accumulation space is the basic way to solve the problems.
(2) The integrated planning of urban water system was designed to create a soft network system covering the hardened and impervious surfaces through establishing the point, linear and planar scale of green spaces and their interconnecting channels that would make the rain find their paths of returning water cycle.

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