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A Pragmatic Framework for Urban River System Plan in Plain River Network Area of China

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Abstract

As an essential ecological infrastructure and landscape in urban area, urban river system is frequently managed and engineered. This paper develops a pragmatic framework which includes a series of basic steps for urban river system planning based on several practices in Yangtz River Delta (YRD) of China. The planning steps include on-site investigation and monitoring, analysis of the current river system, estimation of urban demand on river system goods and services, analysis of the compatibility of services for each river, design of the enhancement projects and evaluation of the feasibility and post-effects. The framework is used in Taicang city as a case study.

Keywords: urban river system plan; river enhancement; river network area; network connectivity; Taicang city

1. Introduction

People have intervened in the natural course and behavior of rivers since before recorded history - to manage the water resources, to protect against flooding or to make passage along or across rivers easier through engineering works. The process is represented as planned human intervention in the course, characteristics or flow of a river with the intention of producing some defined benefit.

However, human intervention sometimes inadvertently modifies the course or characteristics of a river, and river systems worldwide are greatly changed and heavily degraded by a broad range of human uses. Floodgates, sluice gates, dams, pumping stations, culverts, and weirs are densely constructed on rivers for particular goal which result in negative effects recognized more recently [1]. For example, several predictable and negative effects of canalization have been specified as loss of wetlands and extremely slow rate of recovery from an almost invariably, straightened stream. Consequently, increasing attention has been focused on river uses, alteration, restoration, management and planning. These efforts seek to

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improve important goods and services provided by flowing water, and awareness is increasing to adopt a holistic catchment perspective and integrated river management.

While current studies mostly focused on natural rivers and their watersheds or basins, urban river system management are rarely considered at an administrative region scale, which is of importance due to the shifting trends of urban demands. For example, river greenways are frequently established as urban open space, in particular rivers have the dual-edged anthropocentric benefits of ensuring the quantity and quality of water resources and of providing an attractive setting in which to perform non-motorized forms of activity [2]. Actually, increasing attention has been paid to the issues on river system enhancement by scientists, administrators as well as managers and initiatives, and optimal river system plans and management are being launched in the cities of YRD. Both planning and water agencies need more scientific methods to make the plan.

Urban river system plan which represents a targeted approach to improve the holistic river system as well as single rivers is a master plan for the key water bodies including rivers, lakes, channels and adopted by the city officials. It is regarded as a subset of urban landscape plan and an implementation tool in integrated water resources planning, and a means of achieving the protection, improvement and sustainable use of the water environment. It seeks to regulate relationships between river ecosystems and the urban environment, and generally contain projects to be implemented on rivers to ensure sustainable water uses, reliable water supplies, better water quality, environmental stewardship, efficient urban development, protection of agriculture, and a strong economy.

Despite the contributions of existing studies on landscape connectivity focused on natural rivers and river corridors [3,4], few of them have investigated the structures of river system quantitatively. Many recent investigations have demonstrated the central role that channel network analysis can now play [5,6]. Rivers within a densely populated urban area may belong to one or more watersheds depending on their location, and are usually characterized by particular structure and function instead of natural characteristics as Holton [7], which can be measured by indices of network connectivity based on graph theory. Connection patterns of urban river system networks need to be better understood by engineers and urban planners during planning process.

This paper develops a pragmatic process for urban river system planning. The process includes on-site investigation and monitoring; analysis of the collected data; estimation of the demands on river system goods and services; analysis of the compatibility of services for each river; design of the enhancement projects; and evaluation of the feasibility and post-effects. It is elucidated in Taicang city, YRD of China.

2. Planning Process

The planning process for urban river system planning in the urban area of YRD includes steps as follows: on-site investigation and hydrological monitoring; analyzing the data; inquiring into the requirements on river system by urban as well as ecosystem; determining the sequences of demands; allocating the demands to urban river system; designing corresponding projects; and evaluating the feasibility and post-effects of the projects.

(a) On-Site investigation. The first step is to make on-site investigation to identify current conditions of key rivers and channel types and the characteristics of the river system. The investigation content includes physical condition of the rivers and river canals (names, width, depth and bank types), vegetation (species, clearance and distribution confines) and engineering works (weirs, culverts, sluices and dams). Apart from those data, the characteristic of stream flow is also investigated by applying historical survey data, and water quantity and quality monitoring data through diversion of clean water.

(b) Analysis of monitoring data through water diversion. Diversion of water is a water resource reallocation method adopted to improve river water quality through maximum use of outer clean freshwater resources and engineering operation of gates and pumps and river tidal dynamics to facilitate an oriented and orderly movement of the water body of main rivers in river-net and water project controlled region. The Yangtze River is usually diverted to the local river system which speeds up water exchange within water bodies on the premise of flood controlling; industrial and domestic water demand as well as navigation and protection of water environment of critical areas are guaranteed. Real time monitoring of water level, flow rate, water quantity and quality during the diversion process can provide accurate data to determine the profile size of river through calculating the ratio of the total flow to tributary flow at each crossing point and variation of water quantity and quality. It is helpful in developing comprehensive functions and benefits of water engineering facilities, understanding the unsuitability of current river system, and providing suitable dimensions of length, top width, bed width and depth for each river.

(c) Estimation of urban demands on river system goods and services. The demands on river system goods and ecosystem services are key elements considered in an urban river system plan. The demands vary with social development, and show an overall transferring trend of dominant services from flood control, fresh water supply to purification and recreation. Recreational service is getting more consideration nowadays and the pattern of recreational function is in relation to the scale of human populations and their demands on ecosystem services [8,9].

Urban demands on river system goods and services are determined and estimated according to population growth, urban plan, land use plan, climate variability, regulatory requirements, temporal and spatial scales, social and environmental effects etc.. Some of the demands such as water demand, water supply, storage capacity for stormwater and water quality, water flow and water level can be quantified by using specific methods while others can only be described qualitatively.

(d) Determination of the sequence of the functions for the multi-purpose rivers. This step is to identify the interrelationships among functions, rank their respective significance and obtain the priority function for the multi-purpose rivers. The order of the required services will be ranked according to their significance. Services are determined and ranked on the premise that the more important services are normally functioned before less important services. Services of drinking water supply and storage regulation are often remained as of most importance, whereas ecological services also need to be considered with the best possible way. In essence, ranking for demands on river ecosystem services is to seek the equilibrium between supply of the whole services of river system and the demand of mankind.

(e) Allocation of the demands. The estimated demands are allotted to each water body in this step. Each river will be utilized as one-purpose, multi-purpose or no-purpose after the allocation. Meanwhile, since each river flows across the whole urban, town or village, where the urban scale rivers are large rivers flowing across the whole city from and to other regions, plan for urban rivers should be in accordance with the upscale river plan and management which may include these rivers in integrated watershed management or basin management plans. Legislative requirements for these rivers should also be consistent with plans for integrated basin management which pertaining to all aspects of river utilization.

(f) Design of river system projects. This step is to design corresponding river system engineering projects which are based on the results and data obtained from previous steps to construct urban river system plan. The required services as well as the monitoring data of stream-flow, water quality and water surface ratio are put into consideration to determine the size of key rivers and streams. Enhancement projects usually include bank stabilization; channel reconfiguration (such as deepening, widening etc.); dam removal or retrofit; fish passage; channel reconnection; flow modification; in-stream habitat improvement; storm-water management; water quality improvement; riparian management; stream modification for runoff conveyance; wetland drainage; river channelization; aesthetics, and recreation.

River system network connectivity is used to evaluate the performance of the planned river system structure before the plan is implemented which can avoid inappropriate projects.

(g) Connectivity computation. The rivers, streams and lakes, mostly excavated by human in plain areas form a circuit network river system which is distinguished with closed circuits instead of connected lines, and has a loop instead of a branch network topology. A circuit river network is mostly bi-directed, representing that the water flow from one vertex to another or in a reverse. A number of topological measures of network structure have been developed based on elementary concepts of graph theory including indices α, β, and g in addition to basic indices of profile metrics including length, width, slope, and curve degree of a river [10].

Index g is the ratio of the connected lines to the maximum possible connecting lines, showing the network connectivity which can be represented as:

$$g = \frac{m}{3(n - 2p)} \quad (n \geq 3, n \in N) \qquad (1)$$

In equation (1), m is the number of edges (river reach); n is the number of vertices /nodes (river crossing); p is the number of sub-networks. The value of g ranges from 0 to 1.0, where 0 means that there is no edge in the network but isolated vertices, and 1.0 means that every node possesses an edge connecting to other node. The larger the value of g, the better the connectivity of the network.

Index a is used to calculate the degree of the circuits of the joints in the network and can offer alternative route for material flow. The "flow" in the network can reflect the network's functioning condition, improve the structure and enhance the function of river system network. It is the ratio of the numbers of circuits that existing in the network to the maximum possible number of circuits within the network, i.e.

$$a = \frac{m - n + p}{2n - 5p} \quad (n \geq 3, n \in N) \qquad (2)$$

In equation (2), m, n and p have the same meaning as in equation (1). Value of α index ranges from 0 to 1.0, indicating to what extent rivers are connected as circuits, while 0 means that there is no circuit and 1.0 means that there are maximum circuits in the network. The higher the value of α is, the higher the circuitry degree of the network is.

(h) Establishment of adjustment measures. Adjustment measures including regulations and protocols (e.g., appropriate monitoring implementation) are presented. The requirements for enlargement of sluice-ways and the compulsory raising of their gates for the passage of floods, a reduction in the number and width of the piers of bridges are still used within an urban river system plan to meet human needs while pollution directly to rivers and the substitution of movable weirs for solid weirs are strictly prohibited. Accidental obstructions, brought down by floods, such as trunks of trees, boulders and accumulations of gravel, must be periodically removed. But flood control measures as the removal of obstructions, whether natural or artificial, from the bed of a river furnishes a simple and efficient means of increasing the discharging capacity of its channel, and consequently, of lowering the height of floods upstream is not appropriate for the densely populated and highly urbanized region of YRD due to the high degree of artificial river system.

(i) Evaluation of feasibility and post-effect. This step is to evaluate the feasibility and post-effect of the planned projects. To make sure that the plan is technically, environmentally and financially practical, the feasibility is evaluated by consultation among agencies, stakeholders and community as well as through Environment Impact Assessment (EIA). In fact, legislation in China also requires an environmental impact assessment before implementation of river projects. In order to understand both direct and less obvious implications of change, the post-effects of the plan need to be evaluated. Detailed project information, including enhancement practices appropriate in a certain environmental context and resilience of structures, are required for post-evaluation and future interagency coordination during the implementation process, where enough survey and monitor are conducted.

3. Case Study

3.1. Study Area and Its Current River System

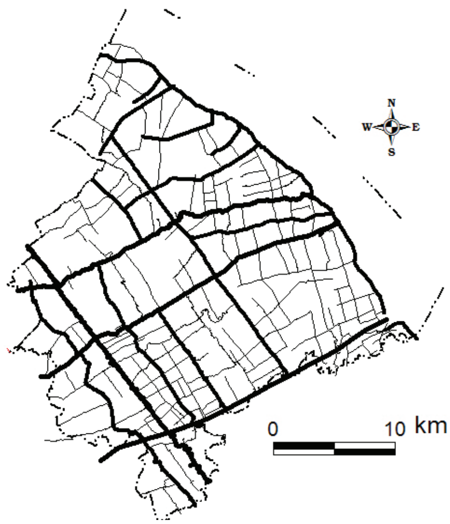
Taicang city, a total of 823 km^2 area, is located in YRD neighboring Shanghai where Yangtze River flows to the East China Sea, and is a historical city with almost 4000 years. Though historical, it is modern and developed with 70% of urbanization rate. It is a river-net area and the key river density is 2.44 km/km2. The interior water surface area is 112 km^2, while external water surface area (Yangtze) is 173.9 km^2 according to A GIS river system network data file (1:50000) as well as a digital river system map and onsite investigation. Current river system consists of 4 region-scale rivers, 12 urban-scale rivers, 143 town-scale rivers and 1321 key village-scale rivers with total length about 100 km, 176 km, 422 km and 1312 km respectively, apart from numerous other small streams, channels and canals according to investigation and survey. Key river system which includes region, urban and important town-scale rivers is shown in Figure 1. It can be found that current rivers are crisscrossed, and paralleled or vertical to Yangtze which forms a circuit network. The values of the γ and α are 0.44 and 0.16 respectively, implying that river system network has a relatively high connectivity but low circuit degree [11].

Onsite investigation also found that numerous drainage and pumping stations, sluices, lock and dams, and channels and canals, apart from 50 km embankment and eleven lock and dams on the Yangtze River were constructed on Taicang's river system. The access to water and waterfront for citizens is uneasy due to high rise flood wall and vertical revetment and embankment. As a result of this man-made process, the rivers were channelized, canalized and in relatively high artificial degree, leading to deteriorated structure and functions, which caused considerable attention from local water agency, and a plan was made in 2005.

3.2. Planning Results

The planned key river system is shown in Figure 2. Main recommended projects include: eight rivers and river reaches newly excavated to link the segmented rivers; fifty-four rivers deepened by removing the silt, and widened simultaneously; all key rivers embanked and vegetated by a specified width and pattern; twelve interior sluices enlarged; six interior sluices newly built; nine exterior sluices enlarged; one sluice newly built along Yangtze to hasten the linkage and water exchange between Yangtze and inner river system, and two water plants and eight sewage plants newly established. Apart from the above projects, a detailed water landscape pattern is designed as "three patches, four belts and six dots", where three patches are important landscape area, four belts include four key rivers, and six dots are six artificial lakes. The river open space could be considered to be local facilities under city management, protecting the river corridors that many municipalities manage. Many small navigable canals are diverted to other uses due to decreased navigation demand.

Total length of key rivers is to increase 16.64 km from 445.63 km to 462.27 km, and river width is to increase 17.85 m averagely after the implementation of the plan which is expected to an increased surface water ratio. The river density will be greatly increased by comparing Figure 1 to Figure 2, and the spatial uneven distribution of river system network will be improved. The values of the γ and α of the planned key river system are 0.57 and 0.35 respectively. The connectivity will be improved at 23% and the circuitry will be improved at 50%, implying that functioning condition, which affects the supply of water ecosystem goods and service will be improved after the implementation of the plan.



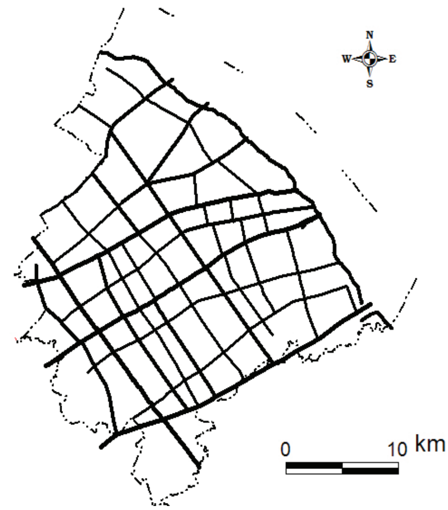


Figure 1. Taicang's current key river system (left)
Figure 2. Taicang's planned key river system (right) — key rivers

4. Discussions

(a)Sufficient communication across local water, urban, land and environment agencies is needed when river system plan is made in an urban context. This collaboration will contribute to forming a river system plan and meeting the strategic needs of urban development and landscape pattern.

(b)Scaling issues need to be considered during the planning process. In urban scale, only those rivers at region-, urban- and town-scale are regarded as key rivers and involved in the plan. The lower scale rivers are subjected to the management of their upper river basins, and should be in accordance with its plan. For example, no project can be planned on Yangtze since it is projected and managed by the Yangtze River Management Committee at watershed scale.

(c)The required functions of river system by human society and water ecosystem are important indicators to the urban river system planning. Though the debate about whether nature can be reconstituted, recreated, or rehabilitated is still existing [12,13], not all rivers can be restored. Chin et al. [14] categorized channel segments in northern part of Fountain Hills into these six channel types: near-natural, adjusting-but could recover, adjusting-unable to recover naturally, channelized-channel altered, channelized-engineered and channelized-culverted. On-site investigation showed that majority of rivers belong to the last four channel types that are unable to be recovered in Taicang city as well as in other cities in YRD which implies that restoration projects are not appropriate for these channels.

5. Conclusion

A methodological framework for urban river system planning is proposed, and it includes on-site investigation to identify the current condition of river network, survey of the historical stream flow data, estimation of the demands on river system goods and services, setting the functions for each river, design of the enhancement engineering projects and evaluation of the feasibility and post-effect of the projects.

The case study in Taicang city shows that it can be used to help construct urban river system planning.

It is known that river system network structure shapes water flows on a network, but further studies still need to be done on the interactions among river system structure, functions and their services.

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References

[1] Dynesius M., Nilsson C. Fragmentation and flow regulation of river systems in the northern third of the world. *Science,* 1994; 266: 753-762.

[2] Coutts C. Greenway accessibility and physical-activity behavior. *Environment and Planning B: Planning and Desig*n, 2008; 35(3): 552-563.

[3] Freeman R. E., Ray R. O. Landscape ecology practice by small scale river conservation groups. *Landscape and Urban Planning*, 2001; 56:171-184.

[4] Tischendorf L., Fahrig L. How should we measure landscape connectivity? Landscape Ecology 2000;15: 633-641.

[5] Brierley G., Fryirs K., Outhet D., Massey C. Application of the river styles framework as a basis for river management in New South Wales, Australia. *Applied Geography,* 2002;22: 91-122.

[6] Montgomery D. R., MacDonald L. H.. Diagnostic approach to stream channel assessment and monitoring. *Journal of the American Water Resources Association,* 2002; 38: 1-16.

[7] Yang K., Yuan W., Zhao J., Xu. S.Y.. Stream structure characteristics and its urbanization responses to tidal river system. *Acta Geographica Sinica*, 2004; 59 (4), 557-564.

[8] Matthew A. W., Berrens R. P. Value of instream recreation in the Sonoran Desert. *Journal of Water Resources Planning and Management,* 2006; 132(1):53-60.

[9] Loomis J. Quantifying recreation use values from removing dams and restoring free-flowing rivers: A contingent behavior travel cost demand model for the Lower Snake River. *Water Resources Research*, 2002; 38, 1066.

[10] Liu M.S., Zhang M.J.. *Landscape Ecology: Principles and Methods*. Publishing house of chemical industry, Beijing; 2004.

[11] Xu H., Xu X. Y., Cui G. B.. Application of landscape spatial structure analysis to urban river system planning. *Advances in Water Science*, 2007; 18(1): 108-113.

[12] Gregory K. J. Urban channel adjustments in a management context: an Australian example. *Environmental Management*, 2002; 29: 620-633.

[13] Gregory K. J. The human role in changing river channels. *Geomorphology*, 2006; 79: 172-191.

[14] Chin A., Gregory K.J. Managing urban river channel adjustments. *Geomorphology*, 2005; 69 (1-4): 28-45.