# THE EFFECTS OF URBANIZATION ON CATCHMENT STORAGE CAPACITY – A CONCEPTUAL MODEL IN PLAIN CATCHMENT IN YANGTZ RIVER DELTA

**SONG S.**[1], **XU Y.P.**[1] **and YANG L.**[1]

[1]School of Geographic and Oceanographic Science, Nanjing University, Nanjing, China
E-mail: ssong@hydrology.uni-kiel.de

## ABSTRACT

Drainage networks and underlying surface in Yangtze river delta area have been significantly changed due to the rapid urbanization and adversely affects the hydrological processes. In this study we took the Qinhuai River Basin in Yangtz River delta as study area, analyzed the total catchment storage capacity and its temporal variation from 1980s to 2010s, based on a conceptual model involving four modules: river network, lakes/reservoir, wetland and forest. The data source is TM images from 1980s and 2010s, thematic maps, digital elevation model, and hydrological data from gauge stations. The main findings of this study is, 1) the current storage capacity of Qinhuai river catchment decreased by 13.45%, from 207.39*106 m3 to 179.49*106 m3 during the study period; 2) the lake/reservoir storage is the most sensitive module to the urbanization, while the river network module serves as the biggest contributor to the total catchment storage capacity. More efforts should be made in the protection and restoration of the low-level rivers, forest and wetlands to optimize the catchment storage capacity. The results of the study would provide support in policy formulating and intervention strategies, and at the same time, opening new challenges for the evaluation of the hydrological process in high urbanized area.

**Keywords:** Storage capacity, urbanization, conceptual model, Qinhuai River basin

## 1. Introduction

Humans have extensively altered river systems in last few decades to meet the water, energy, and transportation needs (Nilsson *et al*., 2005), and the unfavorable hydrological effects of urbanization and its countermeasures are primarily studied. However, attempts to measure and estimate catchment storage and storage changes due to urbanization are seldom addressed in the hydrological effects research, compared with the water runoff and flood process (McNamara *et al*., 2011). The main reason might be the temporal and spatial heterogeneity of the storage capacity, which is impossible to estimate at the point scale and extrapolate to the catchment scale (Seyfried *et al*., 2009; Soulsby *et al*., 2008; Spence, 2007). In this study, we proposed a conceptual model integrated the four storage modules - river, lake/reservior, wetland and ecological land - to estimate the catchment scale water storage capacity. The highly urbanized Qinhuai river basin in Yangtz River Delta was taken as study area, to evaluate the impacts of urbanization on the water storage dynamics, and to reveal the most sensitive storage module. The results would help improve the understanding of the controlling mechanisms of each storage module and their mutual influence on each other and on catchment storage capacity.

## 2. Material and methods

### 2.1. Study area

Qinhuai River basin encompasses Nanjing and Jurong cities and is located between 118º39´ to 119 º 19´E and 31 º 34´ to 32 º 10´N, in south-west of Jiangsu province in China. Draining an area of 2631 km2, the main Qinhuai River flows 110 km across the urban area of Nanjing before emptying into Yangtze River. This area has been undergoing significant underlying surface change during last decades due to the development of urbanization caused by economic growth. The urban land use expanded by 8 times and reached to 158.81 km2 in this area from 1980s to 2010s, while the area of forest decreased by 73.52% from 242.26 km2 to 64.15 km2. The river length and river density decreased by nearly one third, although the river surface ratio increased by one quarter in the last 30 years. The river complexity decreased by around 35%, which leads to the stability of river network decreased by 27.88%.

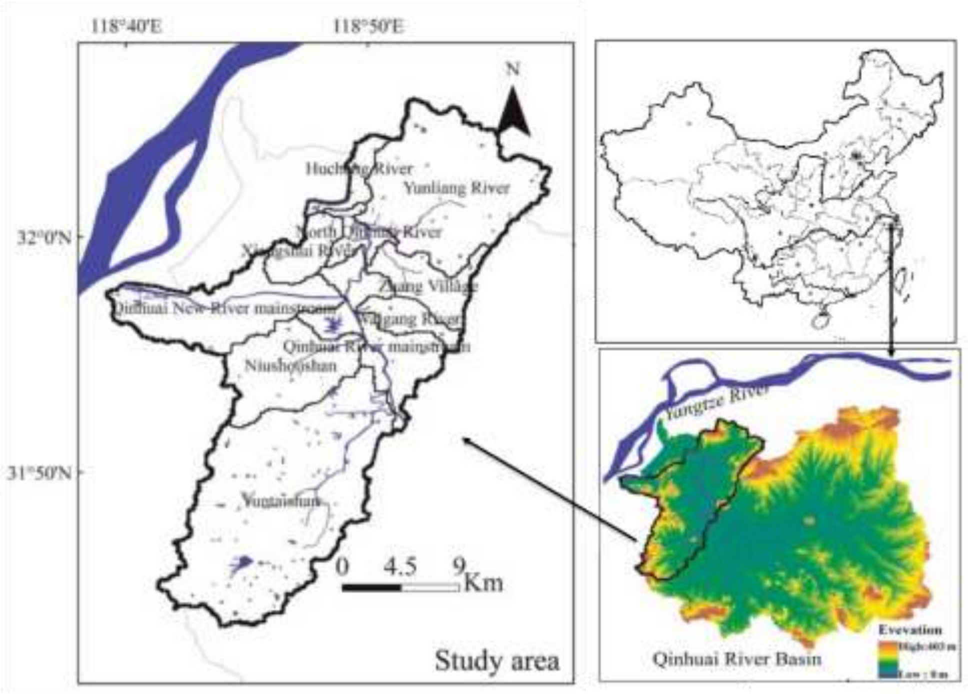

**Figure 1:**The location of Qinhuai River basin

### 2.2. Data acquiration and processing

TM images from 1979 and 2006 were collected and interpreted in this paper to monitor the land use cover change. The information source of drainage pattern is based on 1:50000 paper topographic map in 1979 and digital topographic map in 2006. The land use maps, river networks map were also used in the image processing. River systems, forest type, as well as their distribution were extracted from thematic maps and TM images. The hydrological data were mainly from the hydrology department of Nanjing government and the lower government. The porosity of the soil and paddy field water condition were from empirical value and modified by the experiments in nearby areas.

### 2.3. Conceptual model

The water of the catchment are normally stored inside rivers, channels, lakes, reserviors, natural wet land, paddy field, forests, and so on. We divided all these water bank into 4 water storage modules. The defination and formulas of each storage module are given in Table 1.

**Table 1:** The conceptual model of catchment storage capacity

| Modules | Formulas | Notes |
|---|---|---|
| **River network model** | River network storage capacity refers to the total water volume the river network can accommodate under the alert water level.<br>$C_r = \sum_{i=1}^{n} A_i * L_i$<br>$A = \frac{W + [W - 2m(H-E)]}{2} * (H-E) * L$ | $C_r$ is the river channel storage capacity;<br>$A_i$ is the average cross-sectional area of the river section i;<br>$L_i$ is the length of the river section i;<br>H is the alert water level;<br>W is the bankfull river width;<br>m is the slope coefficient;<br>E is the river bottom elevation. |

| | | |
|---|---|---|
| **Lake model** | The lake model involves the water storage estimation of permanent water surface body, including lakes and reservoirs.<br>$C_l=\sum_{i=1}^{n}S_i\times(H_i-E_i)$ | $C_l$ is the lake storage capacity;<br>$S_i$ is the area of the lake/reservior i;<br>$H_i$ is the alert water surface level of lake/reservior i;<br>$E_i$ is the bottom elevation of lake or reservior i; |
| **Wetland model** | The wetland water storage capacity estimation model in this study is based on bucket hypothesis and water balance theory (Krasnostein and Oldham, 2004; Ludden *et al*., 1983).<br>$C_w=\sum_{i=1}^{m}(S_i*D_i*\varphi)\ +S_p*d_p$ | $C_w$ is the wetland storage capacity;<br>$S_i$ is the area of the natural wetland i;<br>$D_i$ is the bucket depth of the wetland i;<br>$\varphi$ isthe porosity;<br>$S_p$ is the total area of paddy field;<br>$d_p$ is the maxium water depth in paddy field during the natural growth process of the rice.<br>$P_i$ is the maximum water holding capacity of soil type i. |
| **Forest model** | The forest floor sever as water source in dry season and reservoir during flood season. The water storage capacity estimation model is as follows,<br>$C_e=\sum_{i=1,j=1}^{m,n}\left[\rho_i*S_{ij}*\left(D_i*P_i+D_j*P_j\right)\right]$ | $C_e$ is the ecological land use storage capacity;<br>$\rho_i$ is the density of the forest;<br>$S_{ij}$ is the area of the forest with the tree type i, soil type j;<br>$D_i$ is the thickness of forest floor with the tree type i;<br>$P_i$ is the maximum water holding capacity of forest floor with the tree type i;<br>$D_j$ is the thickness of soil with the soil type j;<br>$P_i$ is the maximum water holding capacity of soil type i. |
| **Storage** | $C=C_r+C_l+C_w+C_e$ | |

## 3. Results and analysis

### 3.1. The variation of catchment storage capacity

Based on the conceptual modules proposed above, the storage capacity of each module and the total catchment are calculated, and the results are shown in table 2. The total catchment storage capacity decreased by 13.45% from 1980s to 2010s, due to the land use cover change and river network structure change. River network storage is the most stable module, which decreased by 16.25%. The most sensitive module is lake/reservoir storage, which increased 70.75% in study period. The storage capacity of wetland and forest declined severely, due to the wetland area and forest area decrease.

**Table 2:** River network structure change from 1980s to 2010s

| Period | $C_r$ | $C_l$ | $C_w$ | $C_e$ | C |
|---|---|---|---|---|---|
| **1980s/$10^6m^3$** | 129.05 | 28.55 | 28.36 | 21.43 | 207.39 |
| **2010s/$10^6m^3$** | 108.08 | 48.75 | 15.44 | 7.22 | 179.49 |
| **Change/$10^6m^3$** | -20.97 | 20.20 | -12.92 | -14.21 | -27.90 |
| **Relative change/%** | -16.25 | 70.75 | -45.56 | -66.31 | -13.45 |

### 3.2 The contribution of the storage modules

The contribution of each storage module to the total catchment storage capacity is shown in Fig. 2. The main storage module is river network module, which accounts for 62.23% and 60.22% in total catchment storage capacity in 1980s and 2010s, respectively. In 1980s, the lake/reservoir storage, wetland storage and forest storage were similar. With the process of urbanization, the lake/reservoir become much superior than the other two modules in 2010s, while the forest storage contributed only 4% to the total catchment storage capacity.

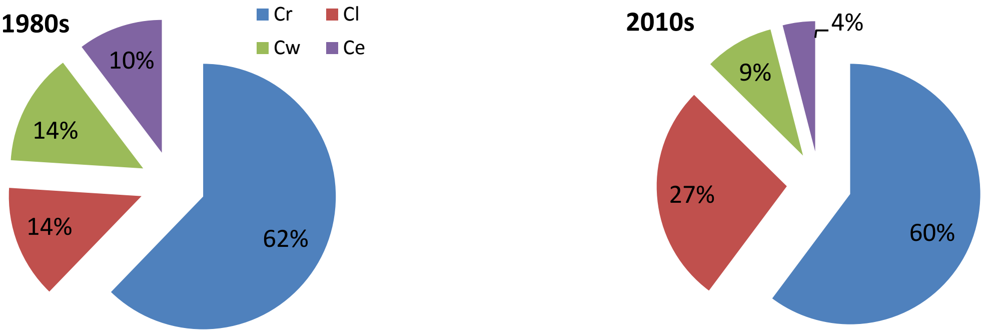

**Figure 2:** The contribution of each storage module to the total catchment storage capacity

## 4. Discussion

### 4.1. Recovery and optimization of the storage capacity

Further analysis about the river network change revealed a different trend of variation for rivers of different level. Higher level rivers like main Qinhuai river and its main branch were normally widened and controlled by the new built modern hydraulic engineering facilities. The river length and complexity decline were mainly caused by the disappear of low level rivers located in the villages and towns. The storage capacity decline of wetland and forest is another source of the catchment storage deterioration. The forest and wetland storage reduced by 44.56% and 66.31% respectively. According to the transfer matrix of land use cover change, the forest and wetland were mostly occupied by urban construction. In summary, to protect and restore the low level rivers, wetland and forest would efficiently help optimize the storage capacity.

### 4.2. The limitations and uncertainties

The primary aim of this study was to estimate the total water storage in catchment scale, and its variation due to the underlying surface and river network structure. The conceptual models may involves the uncertainty in following respects, (1) the geometry of the river cross sections and lakes. TM image have been proven to be reliable source for the surface area of different land type, but the elevation under the water surface from the DEM is still under developing. (2) the interpretation of the TM image. Due to the resolution of the data source, especially the TM images in earlier period with relative low resolution (60m), might result in inaccuracy in transitional zone of the land use types. (3) the hydrological process of surface water, ground water, evaporation and precipitation. We focused on the surface water and soil water of the ecological land use in this study, and assumed a kind of static status of the water body.

## 5. Conclusion and outlook

This study is estimated the catchment storage capacity with a conceptual model based TM images, thematic maps, digital elevation model, and hydrological data from gauge stations. Analysis of the variation of total storage and module storage revealed that,

1) the conceptual model estimated that the current storage capacity of Qinhuai river catchment is 179.49*106 m3, decreased by 13.45% during the study period owing to the urbanization;
2) the river network contributed most to the total catchment storage, while the lake/reservoir storage is the most sensitive module to the urbanization;
3) to recover and optimize the catchment storage capacity, the low-level rivers, forest and wetlands should be protected and restored.

Due to the limitation of the data source, the results might has some uncertainties. More data with higher time and space resolution, and more data from field measurement or experiment would improve the results. The spatial and temporal distribution of the storage capacity and its variations would be an interesting topic in the future. To further investigate and develop the conceptual model, we plan to involve the connectivity of the water bodies into it.

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