Study on General Impact of Territorial Water Diversion on Improvement of Water Environment in Wuchengxiyu Zone in Taihu Lake Basin

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Abstract

A hydraulics and water quality numerical model of Taihu Lake Basin was set up and water quality parameters were determined according to examination. The model was validated by the prototype water diversion experiments conducted in Zhangjiagang city and Chuangshu city and in particular general impact of territorial water diversion projects on the water environment improvement in Wuchengxiyu Zone in Taihu Lake Basin was analyzed.

Keywords: Taihu Lake Basin; Hydraulics and water quality numerical models; Prototype water diversion experiment; Improve water environment.

Introduction

Wuchengxiyu Zone in Taihu Lake Basin is a typical plain drainage zone[1], where population is densely distributed, economy is booming, number of pollution sources is rising, water system is complicated and water environment problem is getting increasingly severe. According to the data released in the Water Resources Statement of Taihu Lake Basin and Southeast Rivers (2002), 88.9% of the river length evaluated is rated water quality Class IV or even worse and 53% is worse than Class V. To achieve rapid improvement in water quality, upgrade the capacity of water resources and boost the capacity of water assimilation and self-purification, the current water diversion is an effective approach for improvement in water environment [2-4].

This article adopts the prototype water diversion experiments that were respectively conducted in Zhangjiagang in August 2003 to validate the water environment model in the entire region. Furthermore, based on drainage water quantity and quality model[3-7], detailed calculations are made to evaluate general impact of water diversion in multiple methods and planned medium- and long-term water diversion on the improvement in water resources in Wuchengxiyu Zone.
1 General Impact of Water Diversion in Multiple Schemes on Water Environment in Wuchengxiyu Zone

In recent 10 years, with rapid development of industry and agriculture, pollutants drained into the rivers and lakes in Wuchengxiyu Zone of Taihu Lake Basin, its water environment is increasingly deteriorating. To effectively contain the deterioration of water resources in the zone, more forceful actions shall be taken to restrain pollutant emissions. With no immediate effect of current pollutant control efforts readily evident, it is considered to be a practical and effective countermeasure to improve water environment by water diversion. The water is diverted from two sources: one is Yangtze River and the other is Taihu Lake. It works to effectively improve water environment of Taihu Lake as well as Wuchengxiyu Zone to implement water diversion from Taihu Lake through planned Dushan Hydro-Junction Project and medium and long-term water diversion from Yangtze River. This section conducts analytical demonstration of comprehensive impact of regional water diversion on the water environment in Wuchengxiyu Zone of Taihu Lake Basin.

1.1 Water Diversion Scheme

For water diversion scheme, please refer to Table 1.

Table 1 Water Diversion Schemes

| Scheme                  | Water Diversion Method and Quantity                                                                 | Hydrological Year | Dispatching of Gates on River                      |
|-------------------------|-------------------------------------------------------------------------------------------------------|-------------------|----------------------------------------------------|
| Planned near-term       | To divert water at 50 m3/s from Taihu Lake at horizontal junction of Liangxi River and the Canal      | Dry year          | Normal dispatching                                 |
| Scheme 1                |                                                                                                       |                   |                                                    |
| Planned Near-term       | To divert water at 50 m3/s from Taihu Lake at vertical junction of Liangxi River and the Canal         | Dry year          | Normal dispatching                                 |
| Scheme 2                |                                                                                                       |                   |                                                    |
| Planned Near-term       | To divert water at 50 m3/s from Taihu Lake at vertical junction of Liangxi River and the Canal        | Dry year          | Full water diversion of Xicheng Canal, Baiqu Port and Xinxia Port |
| Scheme 3                |                                                                                                       |                   |                                                    |
| Planned Medium-term     | Make access in the channel from Xingou River to Zhihu Port and build gates on both sides of Xingou River and Zhihu Port and to divert water at 100m3/s from the Yangtze River. | Dry year          | Normal dispatching                                 |
| Scheme                  |                                                                                                       |                   |                                                    |
| Planned Long-term       | To divert water at 100m3/s to Xingou River from the Yangtze River and water drains to Xicheng Canal and water is diverted to Baiqu Port at 60m3/s, and water drains at Zhangjiagang and is diverted to Wangyu River at 180m3/s | Dry year          | Normal dispatching                                 |
| Scheme                  |                                                                                                       |                   |                                                    |

1.2 Analysis of Impact of Calculations of Schemes on Water Environment in Wuchengxiyu Zone

For the analytical result of impact of calculations of all schemes on water environment in Wuchengxiyu Zone, please refer to Table 2.

Table 2 Result of Calculations of all Schemes
Table 2 indicates that water diverted from Meiliang Lake to Wuxi city through Dushan Hydro-Junction contributed to improvement of the city’s water environment to some extent with average ammonia nitrogen concentration lowered by a range of 1.4-2.5mg/L and COD$_{Mn}$ by a range of 3.3-4.6mg/L. For peripheral rivers in Wuxi city, water environment improves to some extent at sections where channels of Bodu Port, Jiuli River, the Grand Canal depart from the urban area of Wuxi, with average concentration of ammonia nitrogen lowered by a range of 1.5-2.3mg/L and COD$_{Mn}$ by a range of 2.1-4.9mg/L. It also contributes to the improvement of water environment at sections where the Grand Canal runs across Wuxi and Suzhou, with average concentration of ammonia nitrogen lowered by a range of 2.0-2.2mg/L and COD$_{Mn}$ by a range of 3.9-4.2mg/L. However, it results in some negative impact on the water environment of Changzhou section on the upper reach, if no water is diverted into the gates on the river, ammonia and nitrogen concentration increases by approx. 0.9mg/L and average concentration of COD$_{Mn}$ increases by a range of 0.4-0.8mg/L. Taking into account water diversion of gates on the river, in general it does not cause any water quality deteriorating of Changzhou section on the upper reach of the Canal. Both medium-term and long-term schemes that divert water downward from the Yangtze result in some improvement in water environment in Wuchengxiyu Zone. Though the improvement is not so evident as that resulted from water diversion from Taihu Lake, it imposes smaller impact on the water quality of Changzhou section on the upper reach.

2 Model Validations through Prototype Water Diversion Experiments

2.1 Water diversion scheme

Model validation is conducted in parallel in order to study the effect of water diversion on the improvement of water environment in Zhangjiagang area. From August 12 to 13 2003, an experiment of water diversion to the area between Dongxu and Ergan River in Zhangjiagang is carried out. Water is diverted to Dongxu Port and Yigan River for more than 4 hours with the gate on the west bank of Shizi Port closed, the gate on east bank of Ergan River closed, sleeve gates on inland rivers at Yangshe, Zhoujiaqiao, Houcheng and Fuqian opened and Donglai west sleeve gate closed. In 18 hours since the start of water diversion, the gates on Ergan River opens to discharge water with other gates along the river closed, and sleeve gates on inland rivers are operated in the same way as water diversion and the pump station at Gudu port always remains closed.

2.2 Water quantity validation

For validation of key section flow surveyed, please refer to Fig. 1.
2.3 Water quality validation

For validation of water quality surveyed at key section, please refer to Fig. 2.

Interfacing Section Between Yigan River and Nanheng Sleeve Gate  
Section at Vocational School Bridge on Dongheng River

2.4 Result Analysis

Calculation values of water quantity and quality models at all sections well match their survey values with a relative tolerance just ranging from 10% to 20%, and this water diversion experiment have had evident effect on improvement of drainage’s water resources in Zhangjiagang. While the water diversion is launched with gates opened, permanganate index and ammonia and nitrogen concentration at all sections see apparent drop. Though momentary increase in concentration is found in the return water at some survey points, this experiment is of vital importance to the improvement of water environment of the entire Zhangjiagang drainage.

3 Study on Regional Drainage Water Quantity and Quality Modeling and Rating

3.1 Water Quantity Model

- Basic equation
  
  River control equation: Basic equation that describes one-dimension inconstant flow of open channel is the one-dimension Saint-Venant equation system.

\[
\frac{\partial Q}{\partial x} + B_w \frac{\partial Z}{\partial t} = q \tag{1}
\]

\[
\frac{\partial Q}{\partial t} + 2u \frac{\partial Q}{\partial x} + (gA - Bu^2) \frac{\partial Z}{\partial x} - u^2 \frac{\partial A}{\partial x} + g \frac{n^3 |Q|}{R^{4/3}} = 0 \tag{2}
\]

in which:

- \( t \) is coordinates of time, \( x \) is coordinates of space, \( Q \) represents water flow quantity, \( Z \) represents water level, \( U \) represents average section flow rate, \( n \) represents roughness, \( A \) represents overflow section area, \( B \) represents main flow section width, \( B_w \) represents water surface width (comprising main flow width \( B \) and additional width that only have effect on water accumulation and adjustment), \( R \) represents hydraulic power radius, and \( q \) represents side inflow quantity.
Node equation: water flow movement on all nodes shall comply with mass and energy conservation laws as well as meet the two conditions indicated below

\[ \sum_{j=1}^{m} Q_j = (\Omega_{i+1}^j - \Omega_i^j) / \Delta t \]
\[ Z_i = Z_j, \quad i=1, 2, \ldots, m \quad j=1, 2, \ldots, m \]

In which:
- \( K \) represents node number, \( m \) represents the number of rivers that enters (exit) the \( K \)th node,
- \( \Omega_i \) represents accumulative water quantity of node,
- \( Q_i \) represents the water flow quantity of the \( i \)th river that enters the node.

○ Model solving
  Values of four-point implicit difference scheme are adopted to solve the aforementioned differential equation system.

○ Determination of roughness coefficient
  Model rating is carried out in accordance with available data of 1995 and 1996, which results in the roughness of rivers in Taihu Lake Basin ranging from 0.015 to 0.022.

3.2 Water Quality Model

■ Basic equation

\[ \frac{\partial (AC)}{\partial t} + \frac{\partial (AUC)}{\partial x} = \frac{\partial}{\partial x} \left( AE \frac{\partial c}{\partial x} \right) - KAC + S \]

In which:
- \( C \) represents average section concentration of pollutant,
- \( U \) represents average section flow rate,
- \( A \) represents average section area,
- \( E \) represents longitudinal dispersion coefficient,
- \( S \) represents the quantity of discharged pollutant [8-9],
- \( K \) represents degradation coefficient of pollutant,
- \( x \) is coordinates of space, and \( t \) is coordinates of time.

Node equation:

\[ \sum_{j=1}^{m} (Q_i C)_j = (C \Omega_i) (\frac{dZ}{dt}) \]

○ Model solving
  Values of upwind implicit difference scheme are adopted to solve the aforementioned differential equation system.

○ Water quality parameters
  COD\(_{Mn}\) and NH\(_3\)-N degradation coefficients of major rivers in Taihu Lake Basin are obtained through calculations that combine field survey and lab simulation tests as shown in Table 3 in details. Among them, the degradation coefficient of COD ranges 0.1-0.3/day and that of ammonia and nitrogen ranges 0.1-0.22/day.

### Table 3  Pollutant Degradation Coefficient Reference Value (20°C)  Unit:1/d

| River                        | COD\(_{Mn}\) | Ammonia & Nitrogen |
|------------------------------|--------------|--------------------|
| Beijing-Hangzhou Canal       | 0.23         | 0.22               |
| Ancient Canal                | 0.12         | 0.10               |
| Tuhe River                   | 0.24         | 0.08               |
| Wangyu River                 | 0.1-0.30     | 0.15               |
| Taipu River                  | 0.1-0.28     | 0.13               |
| Loujiang River               | 0.1-0.30     | 0.07               |

Based on the available water quality survey data of Taihu Lake Basin in 1995, water quality rating is carried out through numerous water quality model simulation tests and final parameters results are determined as shown in Table 4.

### Table 4   Water Quality Parameters in Taihu Lake Basin (d-1)

|               | KC  |
|---------------|-----|
| River         | 0.1-0.2 |
| Lake          | 0.004 |
4 Conclusions

The validation of water quantity and quality models of the drainage in the entire region by typical prototype territorial water diversion experiments in Zhangjiagang demonstrates that such models give good description of the process of water quantity and quality change of river network in the plain area. Furthermore, such models are adopted to analyze the comprehensive impact of water diversion on the water environment in Wuchengxiyu Zone, which concludes that either diversion water to Wuxi city from Meiliang Lake through Dushan Hydro-Junction Works or from the Yangtze in medium and long term results in water quality improvement in Wuchengxiyu Zone. Only if the gates on the rivers are in normal dispatching condition with water diverted from Taihu Lake, nominal impact on Changzhou section on the upper reach is registered. If all the gates on the rivers function to divert water, obvious water quality improvement in urban and surrounding areas of Wuxi is demonstrated. Therefore, it is recommended that all the gates on the rivers shall function to divert water during water diversion through Dushan hydro-Junction Works to mitigate negative impact on water quality of Changzhou section on the upper reach and to contribute to water quality improvement of river channels in urban and surrounding areas of Wuxi.

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