Simulation and Application Research on the River System Connectivity, Considering the Flood Control and Agricultural Water Objectives

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Abstract: With the rapid development in social economy, the waste water discharge amount in many cities of China is on the rise continuously. This has resulted in excess pollutants in rivers and lakes, deteriorating hydro-ecology environmental issues and so on. The problems have a serious impact on the social and economic development. Focusing on the demonstration site of Zhong Shun Da Wei, this paper started to approach how the connectivity of river-lake water system influenced the two objectives of the great water-retaining structure, which were flood control and agricultural water storage. It deeply probed into the basic theory and key scheduling technology of water system connection throughout the river networks in Zhong Shun Da Wei. The results are indicating as follows. 1). Under present condition, the demands on river system connection at the demonstration site of Zhong Shun Da Wei are mainly represented by two aspects, namely flood control and agricultural water divergence; 2). For Zhong Shun Da Wei, if it is primarily used to control floods, Scheme One is the optimal solution; 3). If it is mainly applied to agricultural water, Scheme Three is the optimal solution. The research findings can provide important technical support and theoretical basis for comprehensive dredging, renovation, hydro-ecological protection and other projects in Zhong Shun Da Wei.

1. Introduction
The river-lake water system is a significant carrier for water. As an integral part of the ecological environment, it also greatly supports our social and economic development. The birth of human civilization, the progress and development of human society are all inseparable with the river-lake water system. In China, we are faced with a severe situation of water resources. There are more people than available water; Besides, the water resources are unevenly distributed. This will be a long-standing basic national condition and water condition. In addition, the river-lake system is continually impacted by the social and economic activities, which causes a series of problems: weakening the connectivity of river-lake system; insufficient carrier capability of water resources and water environment, obstructing flood discharge, increasing water risk issues and so on. The water shortage and flood disaster are still major issues which influence the sustainable development of China's society and economy.

The connectivity of river-lake water system is an important way to reinforce the configuration ability...
of water resources [1]. In recent years, the scholars and experts at home and abroad have carried out extensive researches on the connectivity of river-lake water system. The study on water connectivity was earliest conducted by Vannote, et al [2] in 1980. He proposed "River Continuum" that regarded the rivers as a uniform continuum. And the continuity played a critical role in storing, transporting and transforming the materials and energy. Furthermore, it contributed to the integrity of river eco-environment structure and functions. The conception clarified the river continuity in ecological sense. In 2000, Tischendorf et al [3] defined the connectivity as the fluidity that corridor landscape promoted or hindered the organism among the resource patches from the aspect of landscape ecology. In 2005, the Yangze Water Resources Committee compiled the research report named as "Uphold the healthy Yangtze River, Promote the harmony of human and water" [4]. It has defined the water system connectivity as the connecting status of trunk river streams, lakes, wetlands and other water system. The definition reflected water flow continuity and the connectivity of water system. On this basis, in 2010 Zhang et al [5] further defined that water system connectivity consisted of two fundamental elements: 1). flowing water that can meet a certain demand; 2). connecting channels for water flow. In 2011, Wang et al [6] provided that the water system was an interconnected water network system which comprised various rivers, lakes and other water bodies. In the same year, Xu et al [7] defined that, any hydraulic relation among rivers and lakes built by natural force or engineering measures is collectively referred to river-lake water system interconnection; Dou et al [8] defined that, on the basis of natural water system, the river-lake water system connection could use natural and artificial forces to maintain, rebuild or structure the water flow connection channels which meet a certain functional target, thus maintaining the hydraulic relation and material circulation between different water bodies. In 2012, Xia et al [9] defined the water system connectivity as, on the basis of the river-lake water system which is formulated by natural and artificial forces, and the water flow connection channel is maintained, rebuilt or newly established to meet a certain functional objective, thus upholding relatively steady flowing water body and associated material circulation. In 2013, the Ministry of Water Resources released the "Guidance on Promoting the Interconnection of Rivers, Lakes and Reservoirs" [10] in accordance with the strategic target and constituent elements of water system connection. In the guidance, the river-lake water system connection was defined as the established hydraulic relation by leveraging corresponding engineering or non-engineering measures based on rivers, lakes and reservoirs. In 2014, Li [11] considered that the river-lake water system connection refered to a kind of hydraulic relation among the rivers, lakes and reservoirs. Based on the rivers, lakes, wetlands and reservoirs, the connection is established or transformed by means of scientific water diversion, guidance, communication, scheduling and else measures. In line with the characteristics of the water system in plain river networks, Zhou [12] developed analysis on the connectivity from the aspect of flood control in 2017. He defined river system connectivity as the connecting passageway of water flow that endowed the river network with storage and drainage functions. The river network was the physical foundation for connectivity; and the characteristic change of water levels was its expressive form.

Above all, the river-lake water system connection is an imperative need for China’s social and economic development. It is also necessary to fulfill the national strategy deployed by the Party Central Committee. Nevertheless, present theoretical studies on river-lake water system connectivity are still in the exploratory stage. Neither the connotation of concept nor the technical method can even be counted as an integral system. The theory is far backward than the applied practice. Therefore, this research comprehensively considered wide-ranging elements such as flood protection, flood disaster, hydro-ecological protection in accordance with relevant theories on river system connection as well as actual engineering construction at home and abroad. Consequently, this paper deeply studied the connotation of conception, basic category and technical system of the water system in the river network area of the Pearl River Delta basin, thus exploring the key technology to realize connectivity. The research has promoted the water-supply pattern optimization along with the efficient utilization of water resources and benign circle of ecological environment in the Pearl Delta area. It aimed to promote the hydro-ecology environmental condition in river-lake water system as well as improve the bearing capacity under regional water environment.
2. Overview of the Research Area

2.1 Description of the region
Zhong Shun Da Wei is located downstream the river network of the Pearl River Delta and at the estuary of Xijiang River tributary. It is called “Zhong Shun Da Wei” because the great water-retaining structure extends across both Zhongshan city and Shunde city. As one of the five greatest united water-retaining structures in Guangdong province, the catchment area of Zhong Shun Da Wei is 779 km². It mainly comprises the Guzhen town, Xiaolan town, Dongsheng town, Henglan town, Shaxi town, Dachong town, Tanbei town, Banfu town, Gangkou town, Shalang, Zhangjiabian and Shiqi urban areas in Zhongshan, which is the political, cultural and economic center in Zhongshan city. Within the great water-retaining structure, the dominated agricultures are rice, sericulture, pond fish and sugarcane. There are more than twenty kinds of industries such as mechanical manufacturing, textile, chemicals and building materials.

In terms of topography, it is narrow in the north and wide in the south inside Zhong Shun Da Wei; Both the east and west sides are surrounded by water courses. The south of Zhong Shun Da Wei adjoins the Wugui Mountains. The Zhong Shun Da Wei has a kind of folded geological structure in the central Guangdong depression. The flood plain is situated within the north of the great water-retaining structure. It is mostly even with an altitude of 0.2 to 2.7 meters. And it is densely spread with river networks. The south of Zhong Shun Da Wei is mainly constituted by low mountains, hills and bench terraces. Wugui Mountain enjoys the highest peak of 531 m. The topography within this region is high in the northwest and low in the southeast. Now Zhong Shun Da Wei is traversed by the trunk stream (Qijiang river and Fuzhou River - Hengqin sea - Central drainage canal - Shijiao river segment) in the middle part. The overall length of two rivers is about 80 km. They rejoin in the Shiqi urban area of Zhongshan city. Together with the water way tributaries and plain drainage canals, there are totally 298 rivers. Except a few streams in Wugui mountain area which are one-way flow, a majority of the rest rivers are two-way flows due to the impact of tides. Many other water ways, drainage canals are cross-linked with the trunk river course to constitute a wide and structurally complex inland river network within the great water-retaining structure. The Guzhen water course, the West sea water course and Modaomen water course are in the east to Zhong Shun Da Wei. And in its north side is the East sea water course. The Xiaolan water course flows along the east of Zhong Shun Da Wei and the Hengmen water course into the sea. The trunk water way is basically distributed as a pattern of "three horizontals and three verticals" which flow into the Qijiang river.

"Three horizontals": drainage channel in the north and south - distribution stream - shallow lake - Qijiang river; 160,000 m² drainage channel - distribution stream - shallow lake - Qijiang river; Jingong river - central drainage channel - Shijiao river - Qijiang river.

"Three verticals": Fuzhou river - Hengqin sea - central drainage channel - Shijiao river - Qijiang river; Chizhou river - west drainage channel - Qijiang river; west river sluice - Qijiang river - East river sluice.

The major streams in other towns are basically inter-connected with the trunk rivers.

2.2 Connectivity Requirements on River System
In light of the principal socioeconomic and ecological functions which Zhong Shun Da Wei undertakes, the existing issues of its river system are as follows:

(1). Deterioration of Surface Water Quality
As the urbanization of Zhong Shun Da Wei accelerates, water consumption grows rapidly. Meanwhile, a great amount of sub-standard domestic water and industrial water has been directly poured into the Qijiang River, the Fuzhou River, the Hengqin sea and other water bodies within the water-retaining structure. This speeds up the deterioration of water environment. At present, most river systems in Zhongshan city have been severely polluted. Although there are relatively rich surface water resources, the lack of high-quality water is still a threat.

With the rapid economic development in Zhongshan city, the population inside the region of Zhong Shun Da Wei is on the rise. Accordingly, the urban domestic waste water and industrial sewage are drained into the nearby water body. It gives sharp rise to the pollution load of water bodies, thus causing
progressively deterioration of water environment quality. Somewhere the river turns black and smelly. The water quality index already exceeds Class V. This severely harms people’s physical and mental health as well as their material and cultural lives, further undermining the city image that Zhongshan is an appropriate place for both living and starting new businesses.

(2). Deficient Regulation and Management on Sluices and Water Pump Stations

The water demand for living, irrigation, industry and other aspects increases with the development needs. To make the best of water resources, sluices and pumps have been used in large scale in Zhongshan city. In accordance with the statistics, at present there are twenty-eight sluices in outer river areas and twelve controlling water gates at the inner river ways. The built sluice gates artificially have altered the natural connection between the urban inland rivers and the outer rivers. They have obstructed the natural exchange between the main river courses outside the water-retaining structure and the river water bodies inside the structure, thus causing obstruction of the water network which ought to be connected in natural state. What is more, the controlling sluices were built inside the water-retaining structure to further block the connection of rivers in Zhong Shun Da Wei.

Moreover, there are a large number of towns inside the water-retaining structure (Xiaolan town, Dongsheng town, Guzhen town, Dachong town, Banfu town and Shaxi town, etc.), and the sluices and pump station in Zhong Shun Da Wei are respectively regulated by the administrative office of Zhong Shun Da Wei together with the towns and regions where the sluices and pump are located. They perform their own functions without interfering with each other. They regulate the governed sluices in accordance with their own water demand and water transfer requirement. This caused difficulty in uniform regulation on neither the river sluice pump inside and outside Zhong Shun Da Wei nor the inner river controlling sluice pump inside the water-retaining structure.

(3). Connection of River System Diversion

Zhong Shun Da Wei is located downstream the river network of the Pearl Delta and in the tributary estuary of the West River. It traverses the relatively developed Zhongshan City and Shunde City which possess large population. Thereupon, the task of flood control is rather heavy. At the meantime, the Zhong Shun Da Wei consists of several towns. Each town has its own supporting industry, most of which are planting and breeding industries. Thereupon, these areas need irrigation. At present, the water environment condition within the Zhong Shun Da Wei worsens every year. Given the relevant monitoring information, about 50% of the river ways in the water-retaining structure are Class V or even less than Class V. They fail to achieve corresponding requirements of the water function areas. Additionally, there are many sluices and dams inside Zhong Shun Da Wei. This results in obstructed water body of hydrodynamics in the river network, thus causing inferior connectivity and deteriorating water environment in the river network.

Therefore, the demands on river system connection in the Zhong Shun Da Wei region mainly consist of the following aspects: promoting water environment as the core and improving the quality of water body; raising the flood diversion and storage capacity on the basis of flood control safety; meeting the water consumption of irrigation by guaranteeing the supply of agricultural water.

3. One-Dimensional Model of the Water Quantity and Quality in the Tidal River Network

The one-dimensional model of the water quantity and quality in the tidal river network was built on the basis of the one-dimensional model of HydroMPM as well as the collected river course topography, sluice parameters, water level sequence and else available information. In accordance with the target demand of Zhong Shun Da Wei connection: flood protection and regulation for agricultural water, and water environmental improvement. The quantitative indexes of stream capacity and water body diversion were selected to reflect the target needs. By setting different connection schemes, calculating the quantitative indexes and simulating the situations as well as through comparative analysis on the indexes before connection and after connection, this research finally obtained the optimal connection scheme so as to meet multiple target needs of Zhong Shun Da Wei.
3.1 Basic Equation and Numerical Solution of Model

1. Governing Equation

Adopt Saint-Venant equations as the governing equations of the unsteady flow in river course. They consist of continuity equation and motion equation:

Continuity equation of water flow:
\[
\frac{\partial Z}{\partial t} + \frac{1}{B} \frac{\partial Q}{\partial x} = \frac{q}{B}
\]

Motion equation of water flow:
\[
\frac{\partial Q}{\partial t} + gA \frac{\partial Z}{\partial x} + \frac{\partial}{\partial x} (\beta uQ) + g \frac{|Q|Q}{c^2AR} = 0
\]

In the equations: \( x \) stands for the mileage (m); \( t \) stands for time (s); \( Z \) stands for water level (m); \( B \) stands for the surface width of water flow section (m). \( Q \) stands for discharge rate (m³/s); \( q \) refers to the discharge per lateral unit width (m²/s). The positive value indicates inflow and the negative value indicates outflow. \( A \) stands for the submerged cross-section area (m²); \( g \) stands for the acceleration of gravity (m/s²); and \( u \) stands for the mean cross-section flow rate; for \( \beta \), it stands for the correction factor; \( R \) stands for hydraulic radius and \( C \) stands for Chezy's coefficient. Here \( n \) stands for Manning roughness coefficient.

2. Junctions Connection Equation

The junctions of river network area refer to the inflow and outflow spots at relevant tributaries. The water flow conditions at these junctions are usually complicated. At present, it generally uses the approximate processing method to calculate the unsteady water flows in the river network. That is, the water flow at every tributary of junction is supposed to meet the connective conditions of water flow and water power at the same time:

Connective conditions of water flow:
\[
\sum_{i=1}^{m} Q_i = 0
\]

Connective conditions of water power:
\[
Z_1 = Z_2 = \ldots = Z_m
\]

In the equation, \( Q_i \) refers to the flow of No. \( i \) tributary at the junction. Positive value indicates inflow and negative value indicates outflow; \( Z_i \) indicates the mean cross-section water level of No. \( i \) tributary at the junction; \( m \) represents the number of tributary at the junction.

3. Basic Equation of Water Quality

The one-dimensional convective dispersion transportation equation was adopted in this calculation:
\[
\frac{\partial (AC)}{\partial t} + \frac{\partial (QC)}{\partial x} - \frac{\partial}{\partial x} \left( AE_x \frac{\partial C}{\partial x} \right) + S_c - S_g = 0
\]
\[
\sum_{j=1}^{N} \left( \frac{dC}{dt} \right)_{i,j} = \left( \Omega \right) \left( \frac{dz}{dt} \right)_{j}
\]

In the equation, \( E_x \) stands for vertical dispersion coefficient (m²/s); \( C \) stands for the density (mg/l) of materials that water flow carries; \( \Omega \) stands for the water surface area (m²) at the junctions and nodes of the river course; \( j \) stands for the serial number of node; \( i \) stands for the serial number of river course that is connected with node \( j \); \( S_c \) is referred to as the relevant attenuation term (s⁻¹) which is related to the transported materials(g/(s.m)).

The one-dimensional mathematical model of river stream network adopted the “hierarchical joint solution method”. Its principle was establishing the discrete equation of river junction then solving it in
accordance with the recurrence relation of stream segment discrete equation. The basic principle of this algorithm is, firstly to use the Saint-Venant equations on every micro-segment between two adjacent cross-sections within the stream segment to get the discrete linear equations of the water level and flux at the cross section. Then the linear relations of water level and flux between two adjacent cross-sections within the stream segment are used together with the self-elimination of linear equations to formulate the stream segment equation. In this equation, the water level and flux are set as the state variables of the cross-section at the first and the end of river segment. Next, the compatible equation and boundary equation at river junctions are used to eliminate a state variable at the beginning and end of the stream segment. After that, the convergence equations based upon the junction water level (or flux) is completed. Finally, use Thomas algorithm to solve the simplified equations.

3.2 Generalization of Calculation Area
This modeling area embraced the main river way of Fuzhou river, the West discharge canal, as well as the river ways that are connected with Qijiang river of Zhong Shun Da Wei. This paper generalized the calculation area in wake of the current river way conditions in Zhong Shun Da Wei. There were totally 1511 cross sections, 140 river sections, 251 junctions, 28 boundary sluices and 12 controlling sluices in the overall river network model.

Figure 1. Simplified map of the river network in Zhong Shun Da Wei

3.3 Initial Conditions and Boundary Conditions
(1). Initial Conditions
Before calculating and simulating the model, it is necessary to set the initial values for the model documents. For the hydrodynamic simulation model, it is supposed to set the hierarchical solution, the initial water depth, water level, water flow, warm start or not, as well as calculating the time step and the starting time, simulating the overall duration and the model’s output time step, the general minimum submerging area of the cross section, etc. The initial conditions of the model in this paper include the hierarchical solution, the initial water level at the cross-section, as well as calculating the time step, calculating the starting time, simulating the overall duration, the model’s output time step, real-time monitored sampling time step and the initial pollutant density. The simulated hierarchical solution method in this paper applied four-level unified solution and compressed matrix without a warm start.
The simulating duration was between 8:00 Jan. 1, 2014 and 7:00 Jan. 27, 2014. The initial water level was set as per the mean water level of all boundary sluices at zero hour. The initial flow was 1m³/s; and the initial pollutant density was 40mg/L. The calculating time step was set as 300s. For convenient statistics, this paper set the starting time as 0hr, and the overall simulating duration as 623 hours. The model’s output time step was 3600s, and real-time monitor sampling time step was 3600s, too.

(2). Boundary Conditions
The boundary conditions of this model mainly consist of the boundary type, the boundary water level (m), the flow flux (m³/s) along the boundary of river network and the time sequence process; it also comprises the boundary time sequence for the material composition of C1 pollutant, as well as the scheduling rule and status of sluice. The boundary conditions in this model used the tidal water-level boundaries of the outer river which were provided by the administrative office of Zhong Shun Da Wei. The scheduling rules of the boundary sluices and controlling sluices were set as per the designed operating modes; and the sluice status was set according to the actual status of the sluices. In accordance with the setting scheme of the pollutant density hereafter, the boundary density of this pollutant was set as 0mg/L.

3.4 Model Control Parameters
(1). Hydrodynamic parameters
The hydrodynamic parameters include the Gama value of difference coefficient, the acceleration value of gravity, and the Manning coefficient

(2). Water Quality Parameters
The water quality parameters mainly consist of pollutant degradation coefficient, namely omig. Given that the pollution in Zhong Shun da Wei was caused by oxygen-consuming organic pollutants, COD was used as the simulation factor. Regardless of degradation, this simulation only considers the convection diffusion.

3.5 Model Calibration and Verification
This model calibrated and verified the hydrodynamic parameters. The calibration was undertaken from 16:00 May 2, 2014 to 04:00 May 4, 2014. It used the synchronous observed information at the middle section of Qijiang River to calibrate the model parameters.

In this model, the boundary conditions of water level at every sluice utilized the measured tidal level processes within the same time slot. The sluice scheduling rule followed the actual on-off settings of the outer river sluice within the same time slot. The calibration results were shown in Figure 2a. Otherwise, the model was verified as per the observed information of synchronous water levels at the central part of Qijiang River during 19:00 May 5, 2014 and 7:00 May 7, 2014. The verification results were shown in Figure 2b. It can be seen that the calculated values fit well with the measured values. The final hydrodynamic parameters in this model was 0.85 gama value, 0.02 overall Manning value and 0.01~0.35 partial Maning value.
4. Pattern Analysis on the Target Connection under Different Scheduling Targets

The scheduling of Zhong Shun Da Wei aimed to protect the flood, store agricultural water and promote the water quality. Different connection schemes were set up to simulate the one-dimensional water quantity and quality models in the river network of Zhong Shun Da Wei. By comparison and analysis on the regulating targets under different schemes, it finally obtained the optimal connection scheme. Prior to simulation on different scheduling targets, it is supposed to use specific quantitative indexes to reflect the advantages and disadvantages of various scheduling objectives.

In this paper, the stream capacity in river network was used to reflect the flood protection objective; the agricultural water objective was reflected by the diversion in river network. That is:

- Flood protection objective: minimum stream capacity in river network \( \min \left( \sum_{t=1}^{T} V_t \right) \)
- Agricultural water objective: maximum diversion in river network \( \max \left( \sum_{t=1}^{T} W_t \right) \)

4.1 Setting of Connection Schemes

(1). Before Connection

Through the on-site investigation and access to relevant information, Zhong Shun Da Wei river network connects a number of towns and regions. In addition, the boundary sluices and controlling sluices within the jurisdiction are not under unified regulation in daily management. To guarantee full advantages of their own water resources and meanwhile avoid waste of water resources, the administrations shut down all their governed controlling sluice gates. That explains the long-term shutdown at the hydraulic connecting channels of the major river courses in the water-retaining structure and the river channels in the towns. In the meantime, the sluices to the outer rivers are opened or shut down in accordance with the tidal level. The key principle is, in divergence process, when the water arrives at the control level, the sluices will be shut down; when the tide ebbs, the sluices will be opened. Therefore, the operation scheme for this sluice was regarded as the present scheme before connection. It can be summarized as follows. The controlling sluice gates in towns are all shut down (No. 1 to No. 12 controlling sluices are all closed); the other sluices to the outer rivers will be shut down immediately when the incoming water arrives at the control level; when the water ebbs, the sluices will be opened.

(2). After Connection

Under current conditions, the scheduling targets for Zhong Shun Da Wei connection respectively focused on flood protection, agricultural water and water quality. The corresponding model parameters are as follows: minimum stream capacity of river network, maximum diversion of river network, shortest decreasing period for pollutant density.

Based upon the general objective of connection, the following connection schemes were formulated. Below were the details:

- Scheme One - All controlling sluice gates are open, and the other water gates remained unchanged.
- Scheme Two - All controlling sluice gates are open, the East River sluice is used for directional drainage (drainage only, no diversion: until the outer boundary water level decreases by the control level, the sluices will be shut down). The other sluices to the outer river are used for directional diversion (diversion only, no drainage: until the outer boundary water level rises to the control level, the sluices will be shut down).
- Scheme Three - Every controlling sluice is used for directional diversion or drainage. The East River sluice is used for directional drainage and other sluices of the outer river are used for directional diversion. When the water rises up to the control level, the sluice will be shut down.
- Scheme Four - Every controlling sluice is used for directional diversion or drainage. The East River sluice and the Pujin sluice are used for directional drainage. Other sluices of the outer river are used for directional diversion. When the water rises up to the control level, the sluice will be shut down.

4.2 Analysis on Flood Control Objective

(1). Current Situation

Count the stream capacity of the river network at different times (shown in Figure 3). The stream capacity in the river network fluctuates over time. At the 423rd moment, the stream possesses a
maximum capacity of 48,921,900m³; at the 481st moment, the stream possesses a minimum capacity of 42,643,640m³.

Figure 3. River network stream capacity at various times of current conditions

(2). Scheme One to Scheme Four

As to Scheme One, count the stream capacity of river network at various times (shown in Figure 4a). It could be seen that the stream capacity of the river network fluctuates over time. At the 423th moment, the capacity was a maximum of 58,877,100m³; at the 481th moment, the stream capacity was a minimum of 31,055,500m³. The mean stream capacity was 42,524,100m³.

As to Scheme Two, count the stream capacity of river network at various times (shown in Figure 4b). It showed that the stream capacity of the river network fluctuates over time. At the 15th moment, the capacity was a maximum of 58,174,300m³; at the 1st moment, the capacity was a minimum of 39,640,000m³. The mean stream capacity was 46,107,800m³.

As to Scheme Three, count the stream capacity of river network at various times (shown in Figure 4c). It showed that the stream capacity of the river network fluctuates over time. At the 15th moment, the capacity was a maximum of 58,082,600m³; at the 1st moment, the capacity was a minimum of 39,640,000m³. The mean stream capacity was 46,097,100m³.

As to Scheme Four, count the stream capacity of river network at various times (shown in Figure 4d). It could be seen that the stream capacity of the river network fluctuates over time. At the 15th moment, the capacity was a maximum of 57,448,000m³; at the 1st moment, the stream capacity was a minimum of 39,640,200m³. The mean stream capacity was 45,758,700m³.

Figure 4a. Scheme One. Stream capacity of river network at various times

Figure 4b. Scheme Two. Stream capacity of river network at various times
4.3 Objective Analysis on Agricultural Water

(1). Current Conditions

Count the water diversion and drainage amount at twenty-eight boundary sluice gates, see Figure 5. It can be seen from Figure 5 that, in current scheme, seventeen sluices had net inflow within the simulation period. Among them, the overall diversion amount at Pujin sluice gate was a maximum of 26,669,300 m$^3$, followed by 22,796,200 m$^3$ at Xihe sluice gate. A minimum diversion was 32,700 m$^3$ at Shajiaokou sluice gate. Within the simulation period, the general diversion of whole river network was 105,746,500 m$^3$.

(2). After connection

Scheme One to Scheme Four

As to Scheme One. Count the water diversion and drainage amount at twenty-eight boundary sluice gates, see Figure 6a. It can be seen from Figure 6a that, in Scheme One, fourteen sluices had net inflow within the simulation period. Among them, the overall diversion amount at Pujin sluice gate was a maximum of 26,684,800 m$^3$, followed by 24,734,400 m$^3$ at Xihe sluice gate. A minimum diversion was 216,300 m$^3$ at Baihaowei sluice gate. Within the simulation period, the general diversion of whole river network was 112,607,500 m$^3$.

The statistics of water diversion and drainage for 28 boundary gates in Option Two are shown in Figure 6b. It can be seen from Figure 6b: Under Option Two, since each boundary gate in this option is set to regulate and control the Donghe Sluice for directional drainage, the rest of the Outer River Sluices are oriented for water diversion. Therefore, there are 27 sluices with net water diversion during the simulation time. Among them, the maximum water diversion volume of the Xihe sluice is 181,250,200 m$^3$. 
m$^3$, the minimum water diversion volume of the Xinjiao sluice is 188,800 m$^3$, and the total water diversion volume of the entire water network during the simulation time is 402970700 m$^3$.

As to Scheme Three, count the drainage and diversion at the twenty-eight boundary sluice gates (see Figure 6c). It can be seen that Scheme Three and Scheme Two were identical. There were twenty-seven sluices for net diversion during the simulation. Among them, the overall divergence at the West River sluices was a maximum of 182,148,700 m$^3$. The Xinjiao sluice possessed a minimum diversion of 162,900 m$^3$. Throughout the simulation, the overall diversion of the whole water network was 403,198,200 m$^3$.

As to Scheme Four, count the drainage and diversion at the twenty-eight boundary sluice gates (see Figure 6d). It can be seen that in Scheme Four, the Pujin sluice and the East River sluice were set as directional drainage. The other sluices were set as directional diversion. Therefore, there were twenty-six sluices for net diversion within the simulation period. Among them, the overall divergence at the West River sluice was a maximum of 193,775,000 m$^3$. The overall diversion at Xinjiao sluice was a minimum of 174,000 m$^3$. Throughout the simulation, the overall diversion of the whole water network was 371,300,400 m$^3$.

4.4 Optimal Selection of Interconnection Schemes

In terms of the stream capacity, the mean stream capacity under current scheme prior to connection was 42,643,600 m$^3$. After connection, the mean stream capacity in Scheme One was 42,524,100 m$^3$. In Scheme Two, the mean stream capacity was 46,107,802 m$^3$; that was 46,097,100 m$^3$ in Scheme Three and 45,758,700 m$^3$ in Scheme Four. As a result, Scheme One simulated the least stream capacity as 42,524,100 m$^3$, which was the nearest to the capacity 42,643,600 m$^3$ in current scheme. Thereupon, Scheme One is the optimal.

In terms of water diversion, the water diversion under current scheme prior to connection was
105,746,500 m³. After interconnection, the water diversion in Scheme One was 112,607,500. In Scheme Two, the water diversion was 402,970,700; that was 403,198,200 in Scheme Three and 371,300,400 in Scheme Four. As a result, Scheme Three simulated a maximum water diversion as 402,970,700, which was 3.81 times as much as 105,746,500 m³ in current scheme. Therefore, Scheme Three is the most favorable solution.

5. Conclusion

This paper studied the demonstration site of Zhong Shun Da Wei. Based upon the developed one-dimensional model of HydroMPM, it built the one-dimensional model to research the water flux and water quality of the tidal river network. According to the connection objectives of Zhong Shun Da Wei, which are flood control and storage for agricultural water, the stream capacity of the river network and the water diversion were used as the quantitative indexes in reflecting the two corresponding target needs. This paper devised various connection schemes and simulated the quantitative indexes under different conditions. Furthermore, by comparing the indexes before and after connection, it eventually obtained the optimal interconnection scheme which met the multi-target demands on Zhong Shun Da Wei. The major conclusions are as follows:

(1). In comprehensive consideration of the water resources configuration, flood protection and alleviation, as well as the water environmental improvement and other objective demands, this paper developed a model of water consumption and water quality for river network. This model is useful to simulate the hydro-dynamic characteristics and water quality for single river channel, complex plain river network and tidal network. In the meantime, it can also simulate the sluice scheduling of both unsteady flow and constant flow.

(2). Under present conditions, the demand on the river system connection at the demonstrate site of Zhong Shun Da Wei mainly consists of two aspects, namely flood control and agricultural water storage.

(3). On the basis of the developed HydroMPM model, this paper has built the one-dimensional model of water consumption and water quality for Zhong Shun Da Wei. It selected the quantitative indexes of stream capacity and water diversion amount to reflect two interconnection needs. In addition, the model simulated various interconnecting schemes. For the Great Water-Retaining Structure, if it is primarily used to protect floods, secondly used to storage agricultural water, the first solution is optimal; otherwise, the third solution is the optimal scheme.

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