

## Multi-levels Long-Narrow Lake Flood Routing Modeling

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**Abstract.** Nansi Lake, as a long-narrow lake, has the same features as those of rivers during flood routing. According to topographical and hydrological conditions of Nansi Lake, aided by DEM and remote sensing images of the study areas, combining field investigation and survey, several factors are generalized including boundaries of lake region, river centerlines, river trunk lines, flow pathway lines, no-effective flow regions and river cross section lines. The regions with fish ponds and densely covered by water plants are considered as no-effective flow regions. A coupled method to divide computed unit is adopted by topological generalization method under the multi-levels topological conditions. Flood routing models are built separately for the upper lake and the lower lake divided by the second-level dam constructed at the middle part of Nansi Lake, with individual topological relations, applying the method of comprehensive roughness. The models are tested and simulated by three actual floods in the past, the results manifest that it is feasible and effective to consider Nansi Lake as a river to build 1-D flood routing models.

**Keywords:** Flood Routing Modeling; Nansi Lake; Flood-Control Operation; One-Dimension Unstable Flow Model.

## 1. Introduction

Nansi Lake is located on the hidden fault zone at the junction of the accumulation plain of the west side of the Yimeng Mountains and the alluvial plain of the Yellow River in the central south of Shandong Province. In the 12th century, the Yellow River spread south, invaded the Sishui river, because of poor drainage and formed a lake, from north to south by Nanyang, Dushan, Zhaoyang and Weishan four lakes. The lake area is 1280 km² and the drainage area is 3181 km². Before treatment, the water system of Huxi Plain was disordered and the drainage was not smooth. The source of Hudong river is short and rapid, the flood is fierce, and the low-lying terrain along the lake, every flood season, the flood roll slope overflows, the lake river level rises sharply, the accumulation of waterlogging disaster. After the founding of the People's Republic of China, in order to eradicate all kinds of natural disasters, large-scale water conservancy construction began. After years of management and construction, Nansi Lake has changed from a lake with serious natural disasters into a lake with certain flood control and waterlogging capacity, water storage, fish and poultry farming, navigation and tourism functions. However, under the influence of water conservancy project construction and human activities in the lake, the underlying surface conditions of Nansi Lake have greatly changed, which in turn leads to the law of flood evolution in the lake. These changes make it difficult to reflect the actual situation of flood evolution in the lake by directly applying the flood evolution simulation scheme based on the traditional flood evolution model. It is not possible to provide technical support for flood control and water resource utilization in Nansi Lake. The results of flood evolution simulation or forecast play a huge role in flood control and mitigation and water resource utilization in Nansi Lake. When flood comes, decisions can be made on flood scheduling and personnel transfer according to the results of flood evolution simulation to reduce flood risk. In water resources planning and management, according to the simulation results of flood evolution, water resources can be rationally deployed, so as to obtain better comprehensive benefits in water resources allocation. The Nansi Lake area has the characteristics of complex river network. It is a "river network system" composed of "main stream", many "tributaries" and corresponding "flood storage areas". Under normal circumstances, the
solution of flood evolution in complex river network is more complicated, and many scholars have studied the flood evolution in complex river networks. Tan Weiyun, Hu Siyi et al. [1, 2] constructed a coupling model of one and two dimensions in the flood control system of Dongting Lake in the middle reaches of the Yangtze River, in which a one-dimensional model was adopted for the river network, a two-dimensional model was adopted for the lake, and the flood storage area was treated as the storage point of the reservoir. The model calibration and verification results showed that the established model was effective, indicating that this modeling method was reasonable and feasible. Wu Yamin et al. [3] generalized the natural river channel with multiple sandbanks into a small river network and constructed a one-dimensional hydrodynamic model for simulation, which achieved good simulation effect in the application of Dongjing River. Lu Kangming et al. [4] established a one-and two-dimensional coupling model in the Nanjing section of the lower Yangtze River, with Datong Hydrographic station as the upper boundary inflow condition and Yongning Chang section and Yanzi Ji section of Baguazhou branch as the lower boundary. The coupling model of one-and two-dimensional hydraulics was used to simulate and calculate, and good simulation results were obtained. Xie Zuotao et al. [5] used a one-and two-dimensional nested model to simulate river and lake flood evolution in the Jingjiang-Dongting Lake complex river network model, which could comprehensively consider the complex situations of river and lake river separation, river network interlacing, river cut-off in dry season and overflow in flood season, and achieved good results in practical application. He Zilin et al. [6] analyzed the flood-dike area in Dongting Lake area and simplified the flood-dike area in Dongting Lake area into a one-dimensional low-water level river channel for flood diversion evolution simulation based on the characteristics of its small area and large number. The model had a good fit in flood diversion calculation. Zhang Xingnan et al. [7] took the Huaihe River Basin as an example and based on the built digital basin platform, studied the HEC-RAS model based on the numerical solution of one-dimensional partial differential equations of non-constant flow, proposed a complete boundary condition treatment and flood process simulation scheme, and developed a flood evolution simulation system for river reach in plain area. The results of calibration and verification of the model through the measured flood show that the numerical solution of the unsteady flow model is stable and the simulated flood process is consistent with the measured series. Li Daming et al. [8] adopted the finite volume method to establish a 1-2D connection mathematical model of flood evolution adapted to the complex conditions of river course and flood detention area, and applied it to the Daqing River flood detention area to verify the model of river level, discharge and arrival time of flood detention area, and the verification results were basically consistent. According to the research results, there are two main treatment methods for flood evolution of complex river network: one is to determine the general trend of flood movement of non-uniform river channels in the whole river network and the effect of flood diversion in flood storage and detention area, which is used for comprehensive flood management, mainly using one-dimensional Saint-Venant equation to solve; The other is to simulate the flow of water in the river network, to deal with the flood movement under the complex terrain conditions such as water overland, culvert, dry river bed, etc., to obtain more detailed hydraulic calculation results, and to use one or two-dimensional hydrodynamic models for simulation. Nansi Lake is a narrow and long lake, and the flood evolution process has the characteristics of flood evolution in the river course. Therefore, this paper will generalize the elements of the lake according to the actual topography and hydrological conditions of the lake, and divide the lake into upper and lower lakes. One-dimensional flood evolution models of the upper and lower lakes will be established respectively by using the combined roughness method under high and low water conditions, and the historical floods will be simulated and verified, in order to understand the characteristics of the flood evolution in the lake. It provides flood warning and water resource planning for Nansi Lake. The Nansi Lake is situated on the concealed fault zone at the intersection of the accumulation plain on the west side of Yimeng Mountains and the alluvial plain of Yellow River in central south Shandong Province. In the 12th century, due to poor drainage, a lake was formed as a result of Yellow River spreading south and invading Sishui river, leading to the
formation of four lakes-Nanyang,Dushan,Zhaoyang and Weishan. The area of the lake is 1280 km2 with a drainage area of 3181 km2. Before treatment,Huxi Plain's water system was disordered with inadequate drainage. After years of management and construction following China's founding,Nansi Lake transformed from a disaster-prone lake into one capable of flood control,water storage,fish farming,navigation and tourism functions.Nansi Lake has undergone significant changes due to human activities and water conservancy projects which have impacted its flood evolution process.Therefore traditional flood evolution models may not accurately reflect its current situation or provide technical support for flood control and water resource utilization.In order to address this issue it is important to establish one-dimensional flood evolution models for both upper and lower lakes using combined roughness methods under high and low water conditions.This will allow for simulation and verification of historical floods in order to understand their characteristics within Nansi Lake.

2. Construction of the one-dimensional flood evolution model of Nansi Lake

2.1 Principle of the one-dimensional hydrodynamic model

The basic equation used in the 1 D hydrodynamic model is the SVIS system[9,10]. The system was proposed by French scientist Saint Veren in 1871. The system of equations represents the function of the change of non-constant flow section hydraulic elements in the open channel with time and space,and the equation without considering the side flow is expressed as follows:

\[
\begin{aligned}
& \frac{\partial Z}{\partial t} + \frac{\partial Q}{\partial x} = 0 \\
& \frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{Q^2}{A} \right) + gA \frac{\partial Z}{\partial x} = -g \frac{Q |Q|}{c^2 AR}
\end{aligned}
\]

(1)

Where: Q is the flow rate (m3/s), A is the section area (m2), and B is the width of the river water surface(m), h for water depth (m), S0 the lower bottom of the river, \( \alpha \) the drag ratio reduction, \( u \) the average flow rate of the section (m/s), \( \alpha \) for the momentum correction coefficient, gFor gravity acceleration (m/s2).

The nondimensional equation is a nonlinear hyperbolic partial differential equation, whose analytical solution is unable to be directly obtained by giving appropriate solution conditions,namely boundary conditions and initial conditions.

2.2 Construction of the one-dimensional flood evolution model of Nansi Lake

Due to the long and narrow shape, the upstream catchment area of the lake is complex, and most of the lake is occupied by fish ponds and aquatic plants, so the nansi Lake shows different flood evolution characteristics at high and low water level respectively(Figure 1). Based on this characteristic of the South Four Lake, the one-dimensional flood evolution model is established based on the one-dimensional hydrodynamic model.Based on this characteristic of the South Four Lake, the one-dimensional flood evolution model is established based on the one-dimensional hydrodynamic model.Based on this characteristic of the South Four Lake, the one-dimensional flood evolution model is established based on the one-dimensional hydrodynamic model.
2.2.1 Generalization of lake area elements

On the basis of field investigation, according to the needs of modeling and the actual situation of Nansihu Lake area, combined with the basic terrain data conditions, this paper generalizes the terrain of Nansihu Lake area. The basic data used are mainly the remote sensing image data, DEM data and the large cross-section data measured in the lake area. The main research contents include:

(1) Determination of the boundary of the lake District

The calculation of regional boundary is the premise of flood simulation. The determination of lake boundary in this paper includes the determination of upper boundary, lower boundary, east boundary and west boundary.

Liangji Canal is located in the upper reaches of all the rivers entering the lake, so the control station Houying station of Liangji Canal is selected as the upper boundary of Nansi Lake. The Hanzhuang Gate of the lower lake is the main outlet of the water volume of the whole Nansi Lake, so the Hanzhuang Gate is chosen as the lower boundary of the Nansi Lake. At the same time, Nansi Lake is divided into upper lake and lower lake by the secondary dam, and the secondary dam has measured water level and discharge data. Therefore, the Nansi Lake is divided into two independent parts, the upper lake and the lower lake, when the flood evolution simulation is carried out. The upper boundary of the corresponding upper lake is the Houying station, and the lower boundary is the secondary dam. The upper boundary of the lower lake is the secondary dam, and the lower boundary is the Hanzhuang Gate.

The east and west sides of Nansi Lake have obvious different geographical characteristics. The boundary between the east and west sides of the lake is determined based on the measured cross section data. Firstly, a region is set up in the western and eastern regions of the lake respectively, and the highest elevation points in the corresponding regions are extracted. There are levees along the lake in the west area, and the maximum elevation points in the range are basically consistent with the levees, but there are deviations in the points where the river enters the lake in some sections. Therefore, the boundary of the western part of the lake takes the levee line as the basic boundary, and the elevation points are appropriately modified. However, there is no complete dike in the eastern part of the lake, and the distribution of the maximum elevation points in the eastern part of the lake is scattered. In order to determine the calculation range of the model, based on the extracted maximum elevation points, combined with remote sensing images, the elevation points that do not conform to the actual terrain conditions were manually adjusted to make them conform to the actual terrain conditions, and finally the boundary of Hudong District was obtained.

(2) Extraction of river center line

In the one-dimensional flood evolution model, the Central Line of the river involves the calculation of the division of the reach and the calculation of the storage capacity of the reach. The
actual river network is represented by the Central Line of the river, and each calculated reach in the river network has a corresponding Central Line of the river. In addition, the Central Line of the river is also used to calculate the starting distance of the section from the downstream. Because of the complexity of the terrain conditions in Nansi Lake, it is necessary to conduct special research on the determination of the channel center. Based on the terrain conditions of Nansi Lake, this paper uses DEM and remote sensing information to construct a flood evolution simulation coupling river network represented by the river center line in the lake. It consists of two parts: the main channel in the lake and the interval inflow.

① The main channel in the lake

In order to improve navigation capacity, the channel of Nansi Lake has been regulated. Compared with the bottom of the lake on both sides, the excavated main channel has a lower bottom elevation and is the main flood passage in the lake. Based on DEM data and remote sensing image, the main channel is determined and the river center line is established.

![Fig. 2 Schematic diagram of the main channel](image)

② Local inflow

According to the framework of the slope flood prediction scheme of Nansi Lake basin, there are 11 rivers entering the lake with measured flow data in the lake area, among which Houying station is the upper boundary of the superior lake, and the remaining 10 are used as interval inflow.

For the interval inflow with measured data, the river center line is established on the remote sensing image for the corresponding inflow river according to the forecast scheme, and the river center line of the interval inflow is coupled with the river center line of the main channel to form the flood evolution river network in the lake area. For the interval without hydrological station control, the process of flow in and out of lake runoff is calculated according to the forecast scheme, and it is assumed to flow evenly into the corresponding nodes in the above coupled river network in the region.
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(3) Determination of the main channel line

The channel of Nansi Lake constitutes the main criterion of the flood evolution in the lake area. While the runoff evolution basically exists in the main lake during low water, and the flow rate of high water in the main lake is far greater than that of other areas on both sides, so the determination of the main channel line is very important. The main channel line is the edge of the main channel, which is used to separate the main channel from the whole lake bed. In this paper, the contour lines of the river center line generated by DEM and then the remote channel information are used to extract the main channel line; for the incoming channel, the buffer function in the geographic information system is used to generate a fixed width buffer zone to summarize the main channel line.
(4) Determination of the water flow path lines

Flow path line is used to represent the water flow in the direction of movement, respectively in the left river floodplain, the main channel and the right river floodplain, the main channel of the same as the river center line, while the floodplain flow path line reference remote sensing map and contour information, roughly determined in the water in the center of the floodplain movement. In this paper, the center line of the main channel is generalized, while for each interval, there is no generalized flow path line because of its few sections. In one-dimensional hydraulic calculation, it is necessary to determine the distance between adjacent sections, and this distance $\Delta t$ has different positions on the section, which can be determined by the length of the flow path line between adjacent sections.
Fig. 6 Schematic diagram of water flow path lines

(5) Determination of invalid water flow area

There are plenty of fish ponds and aquatic plants in the lake area. When the water is low, the beach is above the water surface, or the water body is basically static. High water has the capacity to store water, but the flood capacity is very weak. These areas are represented in the model by invalid flow areas. Therefore, only the water balance and not the momentum balance are considered in the calculation of the invalid flow region. In this paper, the spatial distribution of fish ponds and aquatic plants was extracted from remote sensing images. Then, based on DEM, the spatial overlay analysis method is used to determine the elevation of the invalid flow area. Spatial distribution of invalid flow area?

(6) Determination of river section

In one-dimensional flood evolution simulation, the channel cross section is the dividing line of the calculation unit. A cross-section line is used to represent the position, orientation, scope and topography of a cross-section. In this paper, 126 measured cross-section data of Nansi Lake are used to divide the calculated cross-section of the main lake. For the controlled intersectional inflow, there is a lack of measured section data, but the intersectional inflow is mostly short. Generally, there are 5 sections, one section is located at the control station, one section is located at the entrance to the lake, and the remaining sections can be evenly distributed on the inflow channel of the interval. After entering the lake district, it is connected with the corresponding main lake section. For the interval inflow without hydrologic station control, the slope simulation calculation process is directly added to the corresponding main flow section.

Because the section is the basis of one-dimensional hydrodynamic model calculation, the above generalizations for the Nansi Lake area are finally reflected in the section, including the location of the main trough and the section spacing. The coupling between the section and the generalized elements is realized through the superposition analysis of the elements and the section lines. For example, the overposition analysis of the section lines and the river center line can obtain the river name, river name and starting distance of the section lines. The location of the main channel on the cross section can be obtained by superposition analysis between the section line and the main channel line. The distance between adjacent sections in the floodplain and the main trough can be obtained by superposition analysis between the section lines and the flow path lines, and the
distribution of the invalid flow areas can be obtained by superposition analysis between the section lines and the invalid flow areas. After the above spatial topological analysis, the coupling division of computing units under the condition of multivariate terrain is completed.

![Fig. 7 Schematic diagram of the lake surface section line](image)

2.2.2 One-dimensional flood evolution model of the superior lake

The superior lake flows from the Liangzi Canal to the secondary dam, during which there are 9 sections with control stations and 8 sections without control stations. According to the generalization of the basic geography of the South Si Lake area, the topological relationship of the superior lake is shown in Figure 8.

![Fig. 8 Topological relationship of the superior lake of Nansi Lake](image)

According to the topological relationship of the superior lake, the boundary conditions of the model are the flow or water level process of all control stations in Figure 1, and the types of boundary conditions are selected considering the data, in which the water level is the average water level of the three sluice gates. Table 1 shows the section number of each control station and the type of boundary conditions.

There are three stations in Nanyang, Makou, and the secondary dam gate in the superior lake area. The water level of the three stations at the initial time is the initial condition of the corresponding section, among which the water level of the secondary dam sluice is the average water level of the corresponding time of the secondary dam sluice, and the other sections are interpolated by using the initial value of the above section.
### Table 1. The boundary conditions of the superior lake

<table>
<thead>
<tr>
<th>Boundary site</th>
<th>Section number</th>
<th>Boundary condition type</th>
</tr>
</thead>
<tbody>
<tr>
<td>After the camp</td>
<td>Each section of the</td>
<td>rate of flow</td>
</tr>
<tr>
<td>Huang Zhuang academy of classical learning</td>
<td>The first section</td>
<td></td>
</tr>
<tr>
<td>Ma Lou</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tengxian County</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liangshan gate</td>
<td>Uncontrolled interval inflow of 1-8</td>
<td></td>
</tr>
<tr>
<td>Sun Zhuang</td>
<td>Secondary dam gate</td>
<td>NSH068</td>
</tr>
<tr>
<td>Fish city</td>
<td></td>
<td>1-3 Average water level on the gate</td>
</tr>
<tr>
<td>FengWangZhuang</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2.3 One-dimensional flood evolution model of the lower lake

The lower lake flows from the second dam to Hanzhuang sluice, during which there are 2 stations with control stations and 4 stations without control. According to the generalization of the basic geography of the Nansi lakes, the topological relationship of the lower lakes is shown in Figure 2.

![Fig. 9 Topological relationship of lower lakes of Nansi Lake](image)

The same as the superior lake, the boundary conditions are selected by considering the data. The flow process of the secondary dam is the flow sum of the three sluices in the corresponding time. Table 2 shows the section number where each control station is located and the type of boundary conditions.

The water level stations in the lower lake of Nansi Lake include secondary dam sluice, Weishan Island and Hanzhuang sluice. The water level at the initial time of the calculation is taken as the initial condition of the model. The water level of the secondary dam sluice is the average water level of the three sluices, and the other sections are interpolated by using the initial value of the above sections.

### Table 2. Lower lake boundary conditions

<table>
<thead>
<tr>
<th>Boundary site</th>
<th>Section number</th>
<th>Boundary condition type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary dam</td>
<td>NSH068</td>
<td>rate of flow</td>
</tr>
<tr>
<td>Chai Hu shop</td>
<td>Each section of the</td>
<td>Boundary condition type</td>
</tr>
<tr>
<td>Pei city</td>
<td></td>
<td>stage</td>
</tr>
<tr>
<td>Uncontrolled interval inflow of 1-4</td>
<td></td>
<td>rate of flow</td>
</tr>
<tr>
<td>Han Zhuangzha</td>
<td>NSH108</td>
<td>stage</td>
</tr>
</tbody>
</table>
2.2.4 Model parameters and coefficients

(1) Time step

In the one-dimensional flood evolution model, the selection of time step has no significant impact on the stability of the calculation, so the time step of the original data and the calculation efficiency are mainly considered to determine the time step. 10s is determined as the calculation time step of the model through the comparative analysis of the simulation results of different time periods and the calculation efficiency.

(2) Roughness ratio

In one-dimensional flood evolution model, the roughness value \( n \) is an important parameter that needs to be calibrated. Roughness is a numerical coefficient that relates section characteristics (hydraulic radius, section area, etc.), flow and slope coefficient. The roughness of natural river channels is related to many factors, such as the size of river bed sand and stone particle size, the formation or disappearance of sand slope, the curvature of river channel, the irregularity of section shape, the pool in the deep trough, the vegetation on the sand, the erosion and deposition of the channel, and the artificial structures for regulating the river channel. These complex factors vary not only along the length of the channel, but also with the change of the water level in the same reach. Roughness of natural river is a comprehensive coefficient to measure the influence of irregularity and roughness of river bed and side wall shape on flow resistance, which can be expressed as a function of water level, distance and time:

\[
 n = n(z, x, t) \quad \ldots \ldots \quad (2)
\]

Where \( n \) is the roughness, \( z \) is the water level, \( x \) is the distance, and \( t \) is the time.

The roughness directly affects the accuracy of flood evolution. From the previous analysis, we can see that there are many factors affecting the roughness. In fact, the function analytical formula of formula (2) is not obtained, that is to say, the roughness value cannot be calculated through the function relationship. In the existing research and actual engineering, the roughness value is generally obtained by rate determination, that is, the roughness value is set in advance for simulation calculation, and the roughness of the section of the control station is determined through the simulation of the measured hydrological data control station and the measured flow rate or water level process, and then the roughness of these sections is transferred to other sections. The objective function of roughness rate can generally be taken as the absolute value and minimum error of simulated and measured flow rate or water level process, namely:

\[
 \min E_T = \left| \sum_{j=1}^{N} e_j \right| \quad \ldots \ldots \quad (3)
\]

Among: \( E_T \) is the absolute sum of simulated and measured flow rate or water level process error; \( J \) the number of flood periods for the scheduled rate; \( e_j \) for the simulated and measured flow rate or water level error value in the \( j \) th period. Since each section can only have one roughness value when calculating the one-dimensional flood evolution model, and each section of Nansi Lake consists of two parts: main trough and beach, it is necessary to convert the roughness value of the main trough and beach into a comprehensive roughness value input model for calculation. In this paper, formula (4) is used to determine the comprehensive roughness:

\[
 n = \left[ \sum_{i=1}^{N} \left( p_i n_i^{1.5} \right) \right]^{2/3} \quad \ldots \ldots \quad (4)
\]

In formula (4): \( n \) for the comprehensive rough rate; \( p_i, n_i \) they are the wet week and roughness \( i \) of the first section respectively, \( P \) for the wet week of the entire section.
There are few hydrological and water level stations in Nanshi Lake. In this paper takes Nanshi Lake as a whole to determine the roughness of the section of the control station based on the simulation and measured process lines of the control station. The initial value of roughness of Nansi Lake is set to 0.07 and beach is set to 0.11.

3. Simulation results and analysis of the one-dimensional flood evolution model of Nansi Lake

3.1 times of flood selection

Considering the synchrony of flood time in each sub-basin and lake area, and the magnitude of flood, this paper selected 3 representative floods for validation and analysis, and the start and end times of floods are shown in Table 3.

<table>
<thead>
<tr>
<th>Hong number</th>
<th>start time</th>
<th>terminal time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004100714</td>
<td>2004-10-7 14:00</td>
<td>2004-10-19 20:00</td>
</tr>
<tr>
<td>2006070308</td>
<td>2006-07-03 08:00</td>
<td>2006-07-11 08:00</td>
</tr>
<tr>
<td>2008081714</td>
<td>2008-08-17 14:00</td>
<td>2008-08-28 02:00</td>
</tr>
</tbody>
</table>

3.2 Analysis of the results

In this paper, the measured water level process of Nanyang station, Makou station and Weishan station in the lake is used to verify and analyze the model simulation results, in which Nanyang station and Makou station are located in the higher lake and Weishan station is located in the lower lake. The error table of the three flood simulations is shown in Table 4, and Figure 3 to Figure 5 show the simulation results of the 2006070308 floods of the Nanyang, Makou and Weishan stations of the three hydrological control stations respectively.

<table>
<thead>
<tr>
<th></th>
<th>2004100714</th>
<th>2006070308</th>
<th>2008081714</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>maxim um change (mm)</td>
<td>Flood peak error(mm)</td>
<td>The deterministic coefficie nt</td>
</tr>
<tr>
<td>Nanyang station</td>
<td>80</td>
<td>10</td>
<td>0.56</td>
</tr>
<tr>
<td>Makou station</td>
<td>20</td>
<td>0</td>
<td>0.93</td>
</tr>
<tr>
<td>Weishan station</td>
<td>40</td>
<td>20</td>
<td>0.83</td>
</tr>
</tbody>
</table>
The simulation results of three major floods show that the one-dimensional flood evolution model of Nansi Lake established in this paper can simulate the flood process well, and has a good simulation accuracy for the flood peak water level. However, there are also errors in the model, which are manifested in good simulation and small error in flood rising stage and large simulation error in flood falling stage. The main reasons for the errors are as follows:

(1) Model error

The premise of the one-dimensional flood evolution model established in this paper is that the flow in the lake conforms to the one-dimensional flow law, that is, the flow direction is perpendicular to the cross section, and the flow or water level on the same cross section is the same. But in fact, the cross section of Nansi Lake is wide, the flow condition is complicated, and the transverse slope phenomenon is common. For the secondary dam as the boundary, the water level process of the three sluices is generally different, and the model using the average water level process of the three sluices as the boundary condition will bring errors.

(2) Interval inflow simulation error
The model treats the intersectional inflow as a tributary directly into the Nansihu Lake. However, due to the complexity of the lakeside topography, the intersectional inflow water cannot completely and immediately enter the lake and spread downstream, and part of the water will be stored in the invalid flow area. The model does not deduct this part of water for the time being and does not consider its movement process, resulting in large errors in the simulation of the falling flood section. For example, in the flood of 2006070308, the flow process of Nanyang Station and Makou Station had interval inflow at the flood peak, which led to the error between the simulated and measured water level.

(3) Measurement error

Due to the limitation of station network, instruments and existing observation technology, there are errors in the observation of hydrological elements such as flow and water level, which lead to errors between simulated and measured water levels.

(4) Station representative error

According to the above analysis, there is transverse slope in the lake, and the water level process measured by the control stations in the lake, Nanyang Station, Makou Station and Weishan Station, is only the water level process at the point where the measuring station is located. Taking the water level process at this point as the water level process of the whole section will also lead to the error between the simulated and measured water level.

4. Conclusion

Nansihu Lake is a narrow and long lake with the characteristics of a river. Based on the coupled generalization of the terrain of Nansihu Lake, one-dimensional flood evolution models of the upper and lower lakes of Nansihu Lake were established based on a one-dimensional hydrodynamic model and the boundary of the secondary dam. The model took the whole lake as a river network for simulation calculation. The area densely covered with fish ponds and aquatic plants was treated as an invalid water flow area. The results of three flood simulations show that the model established in this paper can meet the requirements of flood simulation research in Nansi Lake to a certain extent. In the future, it is possible to strengthen the spatio-temporal monitoring of water level and flow pattern in the Nansihu Lake area, and use two-dimensional or three-dimensional hydrodynamic model to study the flood research process in the Nansihu Lake area.

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