HYDRAULIC MODELLING OF NENJIANG RIVER FLOODPLAIN IN NORTHEAST CHINA

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ABSTRACT

In 1998, the worst flood recorded for over 200 years hit the Songhua River Basin and Nenjiang River Basin from June to August, covering the area of 137,000 km2. The magnitude and severity of the flood had threatened large cities surrounding these two rivers and gravely affected other urban and rural areas.

In this study, two-dimensional hydraulic models of Nenjiang River were established to model the design 100- and 200-year floods. One global model for the whole river and five other locals for the vulnerable sections were established. The global model was developed for the purpose of calibrating and validating the parameters and the five other local models were focused on the river sections in high potential risk of breaches or collapse.

In these local models, two scenarios of design 100- and 200-year floods were simulated. The flood information such as water level, discharge, current max velocities and average velocities were calculated, which could be used to help finding the vulnerable and risky portions of the embankments, and inundated depths in the floodplain were also calculated.

Keywords: Hydraulic models, Embankments, Flood information

INTRODUCTION

According to the available statistics, the dikes of the main rivers in Songliao Basin have a length of 3,270 km. The design flood control standards of some existing dikes are lower than the standards established by related authorities. Among these, such as Shuangyang River and Wuyuer River basins, the design flood control standard is only of 5 to 10 years.

The flood control capacity of some existing dikes does not meet the standard of design flood fighting capacity. The height of a large number of dikes are lower than the high warning water level, and worse still, some of the dikes are built with loose earth or sands. As they had been built a long time ago, the quality has become worse, and further aggravating the vulnerabilities or risk of breaches.

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Flood control structures and dikes are vulnerable and easily damaged by big-scale flood. Mostly the dikes in Nenjiang River Basin are composed of earth soil and sand soil; some were even built directly on sand bases. At present, the total length of sand-fill or earth-fill dikes is about 498 km, about 15% of the total length of the dikes in the Basin. Among those dikes, there is only a small fraction of the number that was protected by revetments. There is high potential risk of breach when floods occur. Therefore, the study is to find a feasible way to simulate the embankment and river issues under the impact of a flood with 2D hydraulic models.

STUDY AREA

The study area is focused on the section of Nenjiang River from the station of Ayanqian station (Ni'erji reservoir Dam) to Dalai gauging station, the length of which is approximately 600 km, including the main channel and flood plain and embankments on both sides. Figure 1.1 shows the map of the study area.

In 1998, the total rainfall was 1140 mm, which were nearly 1.9 times larger than the average (1999 to 2008) precipitation during the normal rainy season. The average rainfall of 1998 in Nenjiang River was 643 mm, 70% more than the depth in normal rainy season.The average depth of rainfall was 492.3 mm from June to August, which was 1.4 times than the historic average depth of rainfall (357.4 mm).

Figure 1 Map of study area

OBJECTIVES

The general objectives of this study are to enhance the flood prevention capacity and to reduce flood disaster of Nenjiang River Basin by building a basin wide 2D hydraulic model and other five local hydraulic models for small scale dikes. The detailed development tasks of the system are as follows:

- Collect and process the topographic data of the basin, historic and real-time hydrologic data of gauging stations of Nenjiang River
- Build the global 2D hydrodynamic model from Ni'erji to Dalai
- Calibrate and validate the coefficients by using historic flood data
- Establish local models for different sections selected from the main dikes

- Calculate different scenarios of floods and analyze the simulation

This study aims to develop hydraulic 2D models to predict flood events in both spatial and temporal aspects. The study focus is to obtain flood information on:

- Flood flow rates and water level
- Flood inundating areas
- Distribution of flow field information
- Floods risks and damage

HYDRAULIC MODELLING

In this study, a commercial software package of MIKE21 has adopted to build the global and the other five local models. It is based on the numerical solution of the two-dimensional shallow water equations - the depth-integrated incompressible Reynolds Averaged Navier-Stokes Equations.
The spatial discretization of the equations is performed using a cell-centered finite volume method (FVM). The spatial domain is discretized by subdivision of the continuum into non-overlapping elements. In the horizontal plane an unstructured grid is used comprising of triangular elements. An approximate Riemann solver is used for computation of the convective fluxes, which makes it possible to handle discontinuous solutions. For the time integration an explicit scheme is used.

Global model

In the generation of the meshes, the tools of ArcGIS and MIKE Zero are used. The basic topographic mesh is generated from the interpolation of original elevation points. Channel network and dikes were created from an existing river map. The main channels (center lines) were digitized and all necessary information was encoded including river elevation and special nodes representing locations of upper and lower boundaries or control points as source and sinks.In this model, it is assumed that in the simulation there occurs no overflow and breaches of the embankments and the embankments themselves are the solitary external boundaries. So the embankments themselves are considered as closed boundaries, meanwhile, the input and output controlling cross section in upper and lower boundaries are set as open boundaries, where the water level and discharge are given as input boundary conditions.
The input of the open upper boundary of Nenjiang River is the discharge series of Ayanqian, and the lower boundary is water level series of Dalai.
The time step also concerns the stability and accuracy of the model (DHI, 2008). Time step of the new version MIKE21 software is not constant but dynamic, which is determined by stability code under the condition of *CFL<1*.

$$CFL = \left(\sqrt{gh} + |u|\right)\frac{\Delta t}{\Delta x} + \left(\sqrt{gh} + |u|\right)\frac{\Delta t}{\Delta y}$$

Where h is the total water depth, u and v are the velocity components in the x- and y-direction, g is the gravitational acceleration, Δx and Δy are characteristic length scale in the x- and y-direction for an element, Δt is the time step interval.
In this study, the Flood and Dry parameters are set: h_{dry}=0.005 m； h_{flood}=0.05 m； h_{wet}=0.1 m.

Manning roughness coefficient is the most important parameter in the model; its value varies with the composition of riverbed and flood plain.

Calibration and validation

The 1989-year flood was used to calibrate and 1988-year flood was used to validate.

To see how well the simulated value fit the observed data, a coefficient of determination of R-Squared (R^2) was used in this study.

$$R^2 = \frac{[\sum_{i=1}^{n}(P_i - \bar{P})(O_i - \bar{O})]^2}{\sum_{i=1}^{n}(P_i - \bar{P})^2 \cdot \sum_{i=1}^{n}(O_i - \bar{O})^2}$$

Where R^2 is the square of the correlation coefficient between observed and forecasted values, $\bar{P} = \frac{1}{n}\sum_{i=1}^{n} P_i$ is the average of simulated value, $\bar{O} = \frac{1}{n}\sum_{i=1}^{n} O_i$ is the average of observed value, P is simulated value, O is observed value.

The figure 2 below shows the comparison of simulated and observed water levels in the process of calibration by using the 1989-year flood.

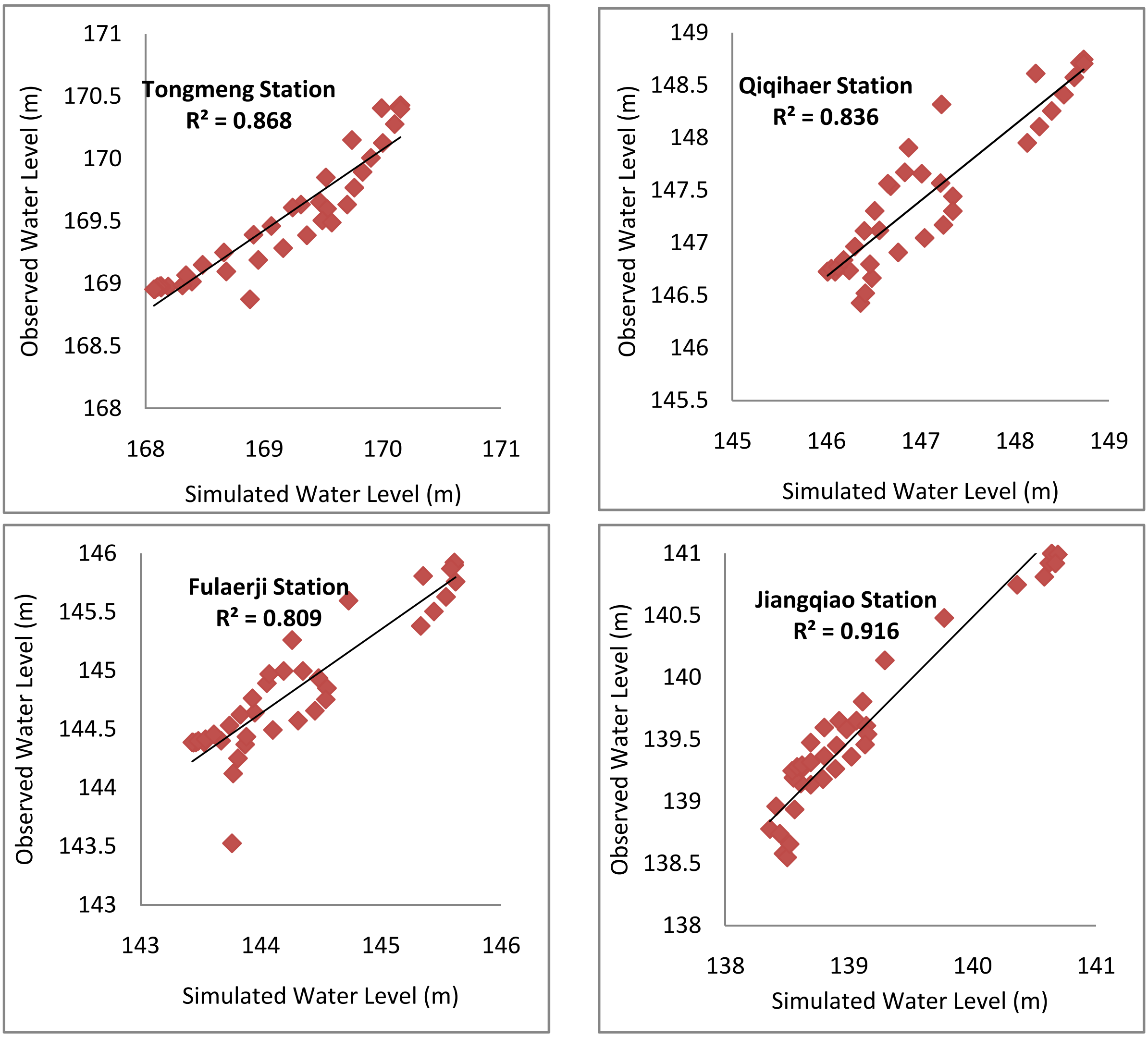

Figure 2 Comparison of simulated and observed water level of control stations by using R^2

The figure 3 below shows the comparison of simulated and observed water level in the process of validation by using the 1988-year flood.

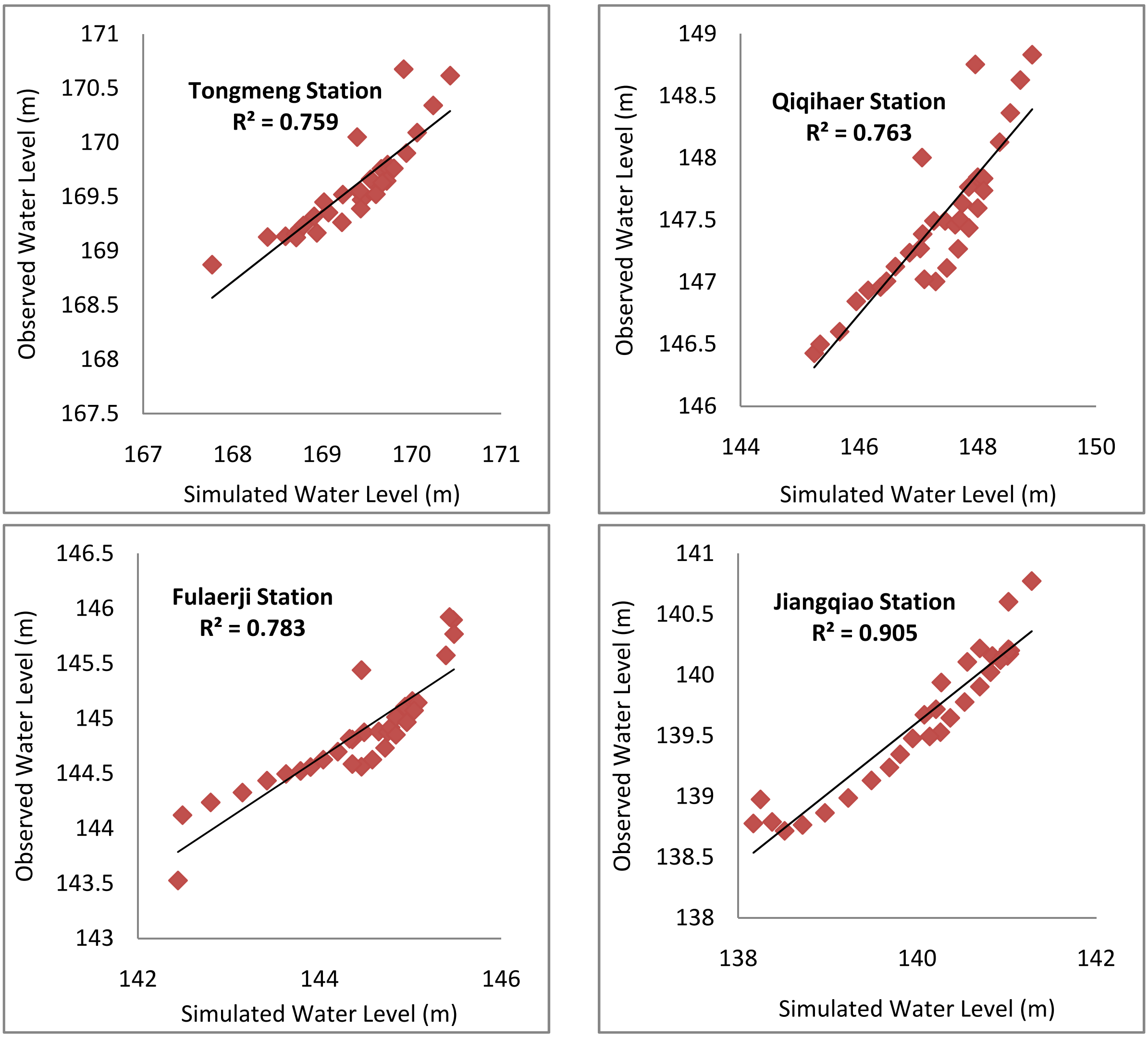

Figure 3 Comparison of simulated and observed water level of control stations by using R^2

Local Models

In the local models, smaller triangular element length was adopted, and basic principles are shown below:

- Parameters adopted in the local models are the same as those used in the original model;

Table 1 Basic information and structures of Local models

Name of Model	Total number of elements	Min. Length of elements length (m)	Max. Length of elements length (m)
Tuanjie_dike	26090	40	200
Nefu_dike	43470	16	500
Qifu_dike	24254	20	2258
Tuoli_dike	21897	60	710
Zhaoyuan_dike	30400	35	450

- Triangle elements length in flood plain should be smaller than 200 m (in the global model 800 m was used);
- Triangle elements length in main channel should be small than 50 m (in the global model 200 m was used);
- Total amount of elements be less than 50,000

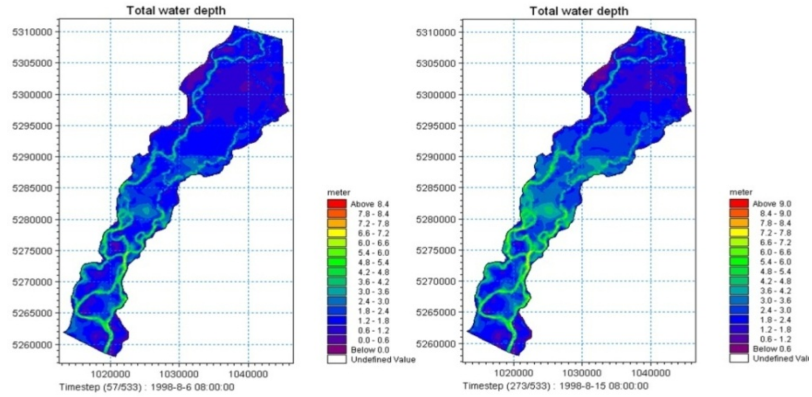

Figure 4 Comparison of the total water depth of inundated area in Qifu using design 100 year flood

CONCLUSION

A widely-accepted modelling tool, MIKE21 was applied to build the 2D model in the study, which provided a feasible module for simulating such a long river in Northeast China, which was less costly A 2D global model covering whole study area and five local models signifying the identified high risk embankment areas were developed, and based on the simulated distribution of velocity and the depth of inundated area, vulnerable sections could be generally identified. In addition, under the high pressure of high water level, the embankments would result in pipe flow phenomena, breach, slope slide and collapse. It is suggested to carry out the slope protection works and to strengthen the dike bases. If possible, it’s better to heighten the dikes or even to re-construct the existing ones.

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