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# Flood Routing Numerical Model Linked-up by Rivers and Flood Detention Basins

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***Abstract:***

This paper presents a combined flood routing numerical model of one-dimension and two-dimension. The authors use the Finite Volume Method (FVM) in this model. The river-pattern grids and ground-pattern grids connect each other at multi-point and multi-passage in this model. Multi-point means many nodal points with relationship to each other, and multi-passage refers to the flow cross-sections at different dam break. Blocking buildings are modeled as broad crest weir flow. The model is well adapted to the complex conditions of rivers and five flood detention basins. The model is applied to Daqinghe detention Areas. The model simulates the flood routing process based on the “August 1996” flood data of Daqinghe detention areas, we verify the water level and discharge in rivers and flood reaching time in detention areas, and the verification results are satisfactory. Then we simulate the flood routing of 100 years return period, thus provides fundamental basis for flood control and disaster alleviation. The results of the study have been used to Daqinghe detention areas in Tianjin, and that gets good effect.

***Keywords:*** *flood detention basins; flood routing; numerical model; Finite Volume Method*

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## I. Introduction

Flooding is a serious natural disaster, with the features of breaking out suddenly, high frequency and wide distribution. In China, approximately 50% of the population and 70% of the property are threatened within the flood area, bringing about huge losses each year, with obviously rising tendency. To defend the flood strike, reduce the flood harm, research on the characteristics of flood motion is very necessary. Numerical simulation of flood routing is an important method among those representations of flood control. This paper set up a linked-up numerical model, which can timely and accurately predict and forecast flood routing of the simulated area.

As to the simulation of flood routing, many scholars have studied it. Cunge[1], Parthasarathi Choudhury[2] and Hone-Jay Chu[3]use the modified Muskingum method to simulate the flood routing, which improve the flood routing simulation in rivers, but it does not take into account the exchange volume in the motion equation between rivers and detention areas, it’s difficult to obtain sufficient accuracy. Recent years Finite Volume Method (FVM) has been widely used in flood routing simulation

[4-7]. One and two-dimensional joint flood routing numerical model can reflect the longitudinal discharge of flood diversion and the transverse exchange process inside and outside the channel. In 1995, Wang Chuanhai [8] established a flood model for the flood discharge and storage basin, Using the one-dimensional Saint Venant equations to simulate the flow movement in the river channel, and the two-dimensional shallow water equation to simulate the flow movement in the flood discharge area, thus solving the implicit coupling problem of one-dimensional and two-dimensional flow calculation. In 1996, Cheng Xiaotao [9] et al. used unstructured irregular grid instead of structured regular grid in the two-dimensional unsteady flow numerical model of Jingjiang Flood Diversion Area, which makes terrain generalization more flexible and accurate. The one-dimensional and two-dimensional numerical models of flood routing established by fan Ziwu and others [10] can simulate the longitudinal discharge of flood along the river channel and the transverse flow exchange process inside and outside the channel. However, the model takes the transverse water exchange inside and outside the channel as the source term of one-dimensional calculation distribution, and does not take into account the exchange volume in the motion equation, which will have a certain impact on the simulation accuracy. Huai et al. [11] made numerical simulation on flood downstream Weihe river and flooded area with an improved calculation method. D. Ga siorowski [12] et al, put forward the simplified flood routing model aiming at the mass and momentum balance errors in the non-linear diffusive wave model with the flow discharge as unknown. Renata [13] et al. set up a data based mechanistic approach to nonlinear flood routing and adaptive flood level forecasting. In 2011, Yang Fangli [14] et al. made some progress in the research of one-dimensional river network nested two-dimensional flood routing mathematical model, established one-dimensional river network nested plane two-dimensional flood routing mathematical model, realized one-dimensional and two-dimensional coupling, and exchanged dynamic information in real-time at the interface of one-dimensional and two-dimensional models. CHEN Yongcan [15] set up a 1D–2D coupled numerical model for shallow-water flows. Li Daming [16] et al. established a 2D flood routing numerical model with Finite Volume Method(FVM), using a correction method for a unit of water flow to improve the water balance computing model, which eliminated the negative depth and false flow phenomenon in Finite Volume Method. Other reserchers [17-18] try to solve the problems with different methods, but the results are not satisfactory in water balance computation.

The paper applies FVM to establish the combination numerical model of rivers and detention areas of one-dimension and two-dimension. According to the complex terrain and water control works in flood detention areas, the corresponding river-pattern grids and ground-pattern grids either insert or link at multi-point and multi-passage, which makes them conditionally connected into reality to different flood conditions. If the water quantity is low, the flood can be restricted in rivers alone, while if it comes across larger flood in flood seasons, since the river is full of water, to ensure the safety of rivers and cities downstream, it needs diverse surplus flood to the detention areas and resort it, it can link up rivers with detention areas, meanwhile consider the use of railways, roads, rivers, dikes, sluices and all kinds of flood control measures. Conduct the calculation of flood diversion and flood detention, form numerical model of flood routing with the river-pattern grids and the ground-pattern grids connected at multi-passage.

## II. NUMERICAL MODEL OF FLOOD ROUTING OF RIVERS AND DETENTION AREAS.

### 2.1 Basic control equations

#### 2.1.1 Two-dimensional unsteady basic equations

Continuity equation:

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=q \tag{1}$$

Motion equation:

$$\frac{\partial M}{\partial t}+\frac{\partial (uM)}{\partial x}+\frac{\partial (vM)}{\partial y}+gh\frac{\partial z}{\partial x}+g\frac{n^2u\sqrt{u^2+v^2}}{h^{1/3}}=0 \tag{2}$$

$$\frac{\partial N}{\partial t}+\frac{\partial (uN)}{\partial x}+\frac{\partial (vN)}{\partial y}+gh\frac{\partial z}{\partial y}+g\frac{n^2v\sqrt{u^2+v^2}}{h^{1/3}}=0 \tag{3}$$

Where $h$ is the water depth, $z$ is the water level, $z=z_0+h$, $z_0$ is the bottom elevation, q is water source, $M,N$ are separately representatives of unit discharge in the x and y direction, and $M=hu, N=hv$, $u,v$ are separately representatives of mean velocity in the x and y direction, $n$ is the roughness, $g$ is the gravity acceleration.

#### 2.1.2 One- dimensional unsteady basic equations

Continuity equation:

$$\frac{\partial \mathrm{h}}{\partial \mathrm{t}}+\frac{\partial Q}{\partial \mathrm{x}}=\mathrm{q} \tag{4}$$

Motion equation:

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+gA\frac{\partial z}{\partial x}=gAS_f \tag{5}$$

Where $Q$ is the sectional discharge, A is the area of computed cross-section, $S_f$ is the frictional slope.

### 2.2 Discrete equations by the FVM

According to the grid laid out style of FVM, the unit grid is the control volume, to calculate water depth *h* at the mesh center and the charge *Q* at the passages around the mesh. On the basic of water balance theory, the integration of the normal flux on each side of the control volume along the circuit should be equal to the water demand of the control volume. Circum flux should be determined by the water level gradient of adjacent control volume center. The calculation of time has the staggered style of unit and passage.

### 2.2.1 Discrete of the continuity equations

(1) Ground-pattern and river-pattern unit

The ground-pattern unit indicates the unit that water can't pass through, it is the modeling of ground, roads, field and mountainous region. The river-pattern unit is the modeling of primary rivers. The ground-pattern unit has the process from possessing water to anhydrous condition, but the river-pattern unit always has water. The ground-pattern unit and river-pattern unit employs the same formula (6), but the ground-pattern unit should consider the infiltration charge. Included by $q_i$ in the formula(6).

Equation(1) is integrated along the circuit and then dispersed as following:

$$H_i^{T+2dt} = H_i^T + \frac{2dt}{A_i}\sum_{k=1}^{K} Q_{ik} L_{ik} + 2dtq_i^{T+dt} \tag{6}$$

Where $H_i$ is the water depth of the No. $i$ mesh, $A_i$ is the unit area, $L_{ik}$ is the length of the No $i$ passage, $Q_{ik}$ is the unit discharge of the No $k$ passage of the No $i$ mesh, $q_i$ is the pumping and drainage water of the No $i$ mesh, $T$ is the starting time, $dt$ is the time step.

(2) Special passage-pattern unit

Special passage- pattern unit refers to the narrow river passage, in the model it is handled as linear unit.

$$H_{di}^{T+2dt} = H_{di}^T + \frac{2dt}{A_{di}}(\sum_{k=1}^{K} Q_{ik}^{T+dt} b_{ik} + \sum_{j=1}^{2N} Q_{ij}^{T+dt} L_{ij}/2) + 2dtq_{di}^{T+dt} \tag{7}$$

In the above, $H_d$ , $A_d$ are separately the mean water depth and area of the special unit, $\sum Q_k$ and $\sum Q_j$ are separately the discharge along the linear unit and the sum of discharge exchanged between lateral passages and other meshes , $q_d$ is the source of the special unit, $b$ is the width of the passage, $L$ is the length of the passage.

### 2.2.2 Discrete of the motionequations

The calculation of the rim flux of the control volume depends on different terrain of the rivers and detention basin such as railways, roads, bridges, submerged breakwater, dikes, sluices etc. Different passage should use different theoretical model to generalize. Such as ground passage, river passage, continuous dike and all kinds of sluices. The passage is mainly generalized as following circumstances:

(1) Ground-pattern passage of shallow water, the both sides of the passage are ground and the water depth is less than 0.5m, and there is no dike and such water-blocking buildings. Considering that the topographic relief of the detention basin is not very large, the flood routing on the ground is primarily affected by gravity and resistance, neglect the items of accelerated velocity, derive the discrete motion equation of ground passage by difference method.

$$Q_j^{T+dt}=sign(Z_{j1}^T-Z_{j2}^T)H_j^{5/3}(\frac{|Z_{j1}^T-Z_{j2}^T|}{dL_j})^{1/2}\frac{1}{n} \tag{8}$$

In the above, $sign$ is sign function, it means the plus-minus of $Q_j^{T+dt}$ and $(Z_{j1}^T-Z_{j2}^T)$ is the same, $dL_j$ is the sum distance of adjacent unit center to passage center.

(2) Ground –pattern passage of deep water or wide river-pattern passage, both sides of the unit are ground and the water depth is greater than 0.5m, or the both meshes besides the passage are river-pattern, the passage is cross- section. Motion equation is discrete in normal direction of the passage.

$$Q_j^{T+dt}=Q_j^{T-dt}-2dtQ_j^{T-dt}\frac{V_{j2}^T-V_{j1}^T}{dL_j}-2dtgH_j\frac{Z_{j2}^T-Z_{j1}^T}{dL_j}-2dtg\frac{n^2Q_j^{T-dt}|Q_j^{T-dt}|}{H_j^{7/3}} \tag{9}$$

In the above, $Z_{j1}^T$, $Z_{j2}^T$ are the water depth of the unit besides the passage, $V_{j1}^T$, $V_{j2}^T$ are the projective velocity of unit center besides the passage in the normal direction of the passage, $H_j$ is the mean water depth of the passage.

(3) Narrow river-pattern passage, for the river with smaller width in detention basin, unable to neglect, to calculate easily, it is simulated as linear unit with depth, length and width, reflect the phenomena that the water flow down the river and water exchange between the river and ground of both sides. If there is any water-blocking building on both sides, it can be supposed as embankment. Discrete motion equation as following:

$$Q_j^{T+dt}=Q_j^{T-dt}-2dt\frac{(Q_{j2}^{T-dt})^2-(Q_{j1}^{T-dt})^2}{dx_jA_j}-2dtgA_j\frac{Z_{j2}^T-Z_{j1}^T}{dx_j}-2dtgA_jS_j \tag{10}$$

The calculation of discharge between Special-pattern passage and meshes of both sides employs the formula of broad crest weir flow.

$$Q_j^{T+dt}=\sigma_s m\sqrt{2g}H_j^{\frac{3}{2}} \tag{11}$$

Where $m$ is discharge coefficient, $\sigma_s$ is submerged coefficient

(4) Gate-pattern passage, the open up and shut of the gate of river courses depend on the flood control. The open up and shut of tidal gate should be adjusted by the difference between the water level of rivers and sea level. The flow rate of the gate is determined by the water level up and below the gate.

## III. THE APPLICATION OF THE MODEL IN DAQINGHE DETENTION AREAS

### 3.1 Brief introduction of the calculated field of Daqinghe detention areas

Daqinghe detention areas in the south of Tianjin City in China, it is the key area of flood control of Haihe River basin, the flood volume proportion in previous floods occupied about 30% to 50%; it is the biggest threaten of water courses to Tianjin City. The total drainage area is 45131 km$^2$, the mountainous area is 18800 km$^2$, the hilly area is 2655 km$^2$, the plain area is 2367 km2. There are five detention basins of the Daqinghe detention areas, refering to Dongdian, Wenanwa, Jiakouwa, Tuanbowa and Beidagang.

### 3.2 Subdivision of Meshes

The maximum characteristics of the meshes subdivision is the separate subdivision from the rivers to detention areas, then the river-pattern meshes and ground-pattern meshes are connected at special point by certain relationship.

The river-pattern mesh of one-dimension and two-dimension is the generalization of the river courses according to the river width. Wider rivers are generalized as two-dimensional river-pattern unit; narrower rivers are generalized as one-dimensional linear river-pattern unit, using square grid to divide the detention basin with considering the terrain and blocking building, the authors programmed for it and get the ground-pattern mesh, ultimately put the rivers and detention areas together in the same coordinate, and form the numerical model grids. The river-pattern grids and ground-pattern grids of detention basin both inset and link up, they are conditionally connected at multi-point and multi-passage. Connected mesh of river-pattern and ground-pattern is shown in fig.1.

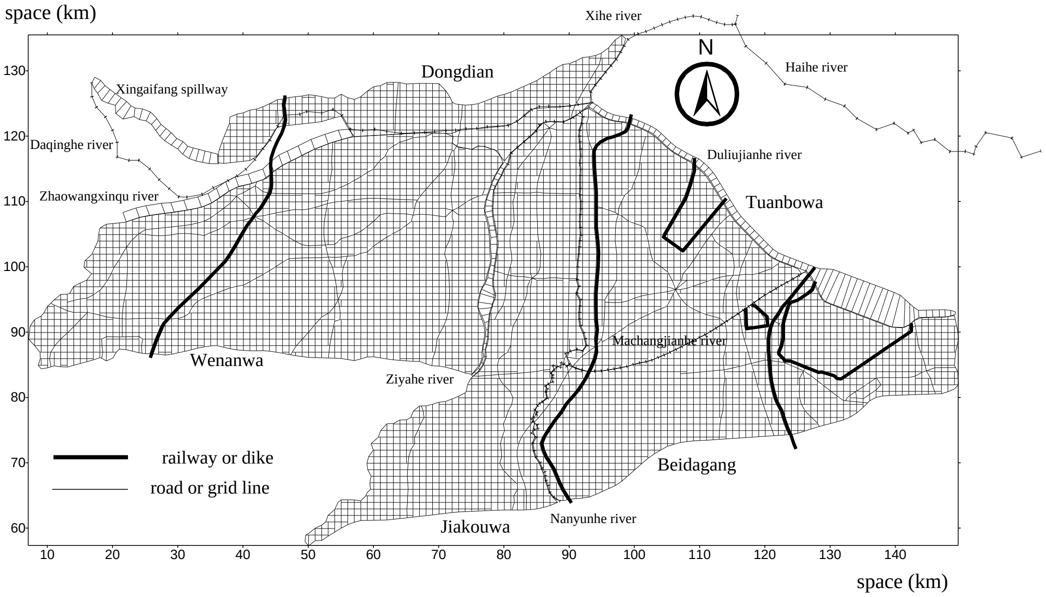


Fig.1 Sketch of conjunction grid of river-pattern and ground-pattern of Daqinghe detention areas

## IV. VERIFICATION OF THE MODEL

### 4.1 Verification of the flood routing of one-dimensional river network

The Verification of the flood routing of one-dimensional river network uses the data of Daqinghe River. It controls discharge upstream and controls water level downstream. It calculates and verifies three places, they are Taitou, Duliujianhe Flood Intake Gate, Xihe Gate. Fig.2 to fig.4 are the discharge comparison drawings with measured value to calculated value.

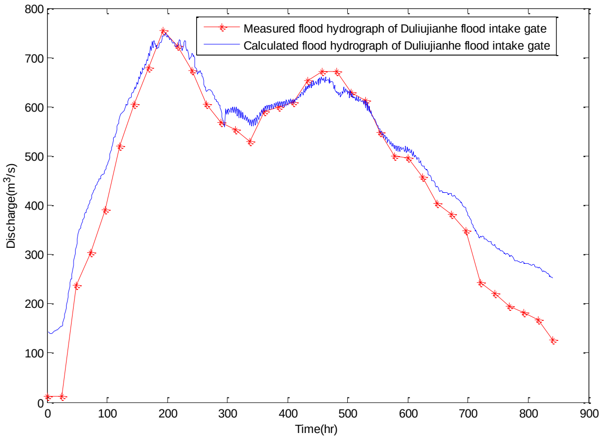


Fig.2 the comparison of measured and calculated discharge of Duliujianhe flood intake gate

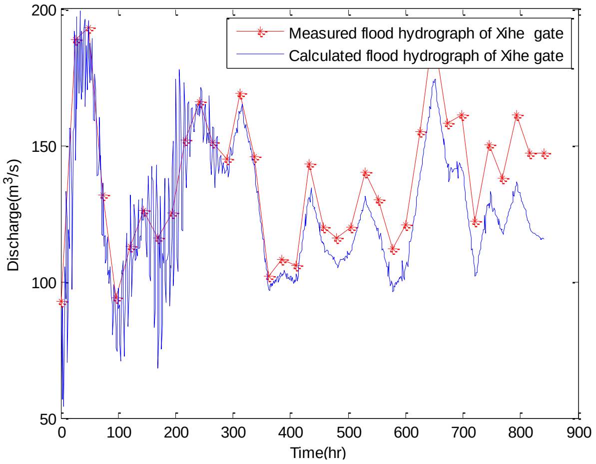


Fig.3 the comparison of measured and calculated discharge of Xihe gate

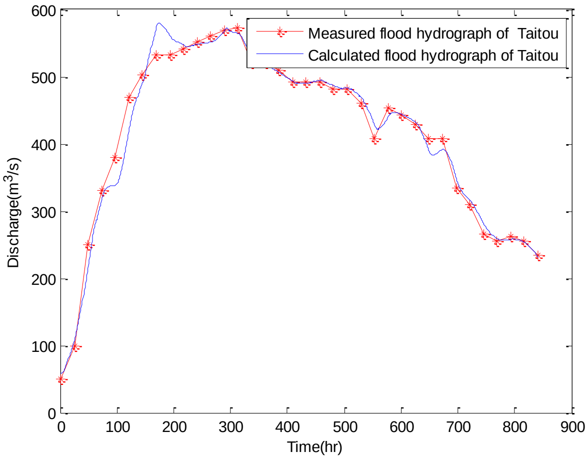
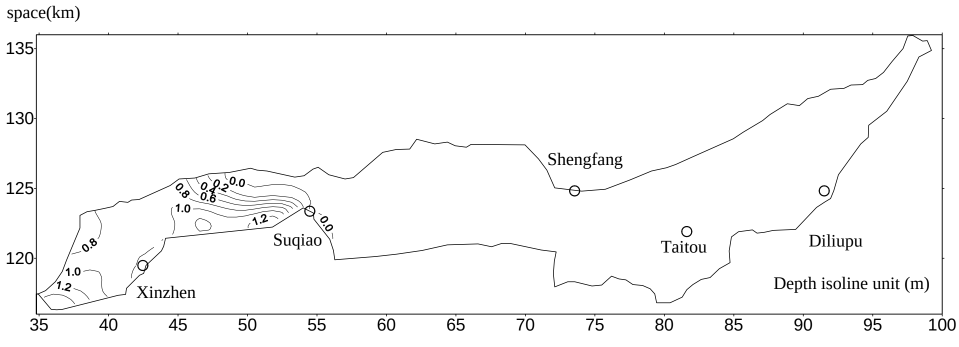


Fig.4 the comparison of measured and calculated discharge of Taitou

4.2The verification Flood routing model of two-dimensional detention areas

The verification Flood routing model of two-dimensional detention basin is the numerical simulation of inflow discharge of Dongdian detention basin and the reaching time of it.

The water depth layout shown in fig. 5(a) to 5(c) is that of the incoming flood of Dongdian detention basin shown in August 1996.



0 Depth isoline arrives at Suqiao 18:29 on August 8th 1996

Fig. 5(a) The water water depth of Dongdian detention basin on August 8th 1996

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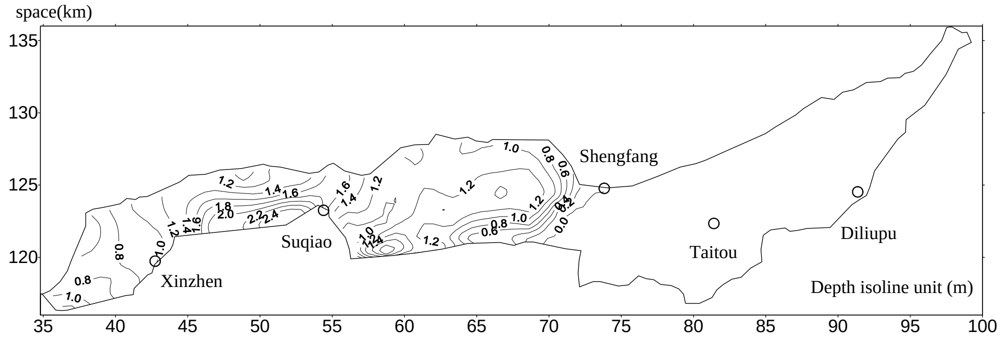
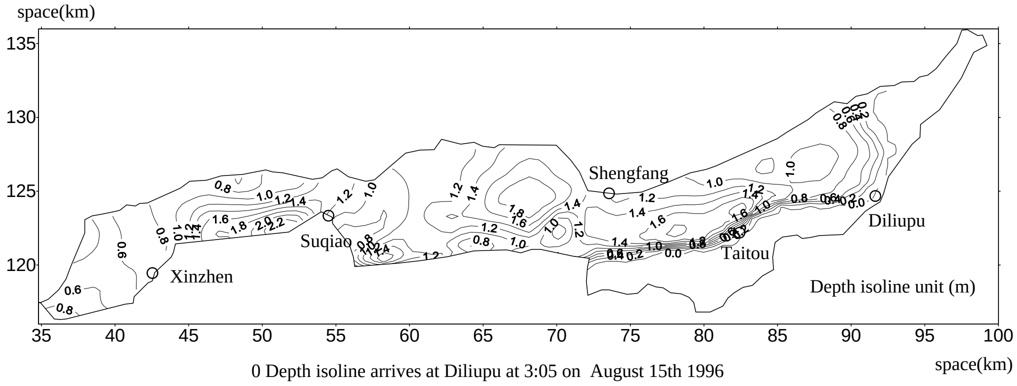


0 Depth isoline arrives at Shengfang at 17:27 on August 12th 1996

Fig. 5(b) The water depth of Dongdian detention basin on August12th 1996



0 Depth isoline arrives at Diliupu at 3:05 on August 15th 1996

Fig. 5(c) The water depth of Dongdian detention basin on August 15th 1996

4.3 flood routing simulation of 100-year return period

Fig.6 shows the inflow flood conditions of 100-year return period, inflow water is from Xingaifang, Zaolinzhuang and Xiaoguan.

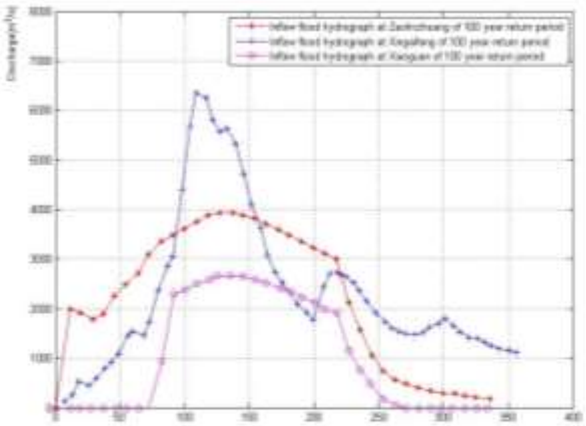
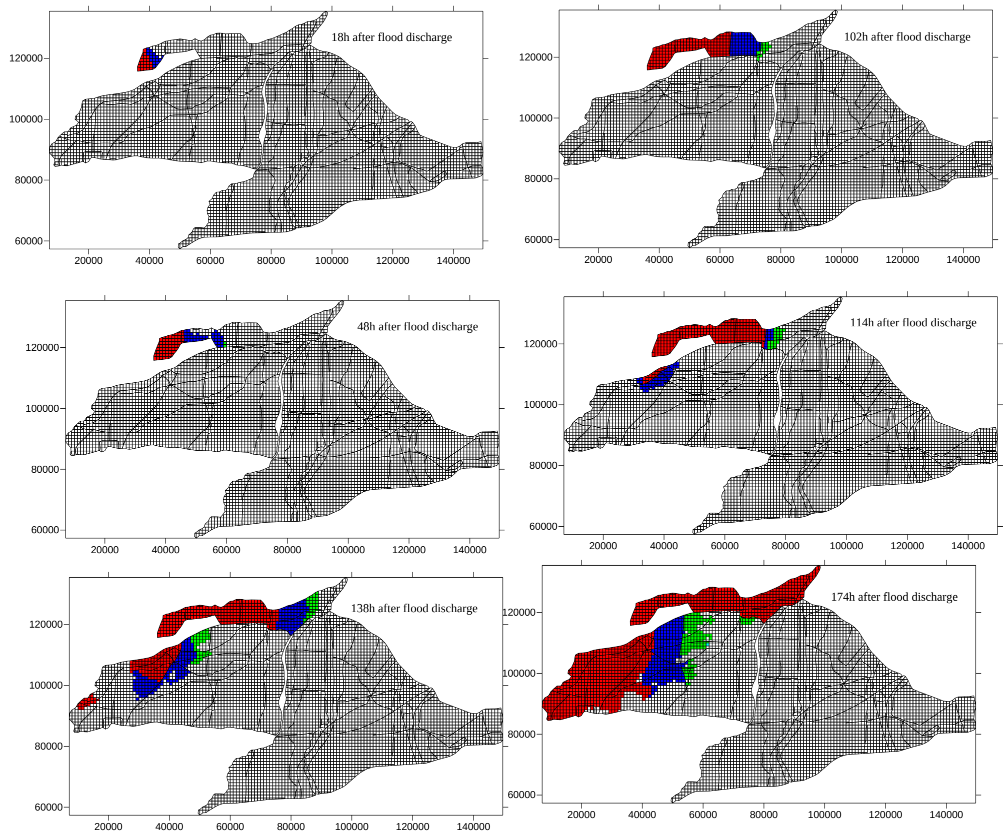


Fig.6 the inflow flood of three control sites of 100 year return period

The data volume of the model is enormous, the author selects part data to produce several figures to show the flood routing situations, shown in fig. 7.



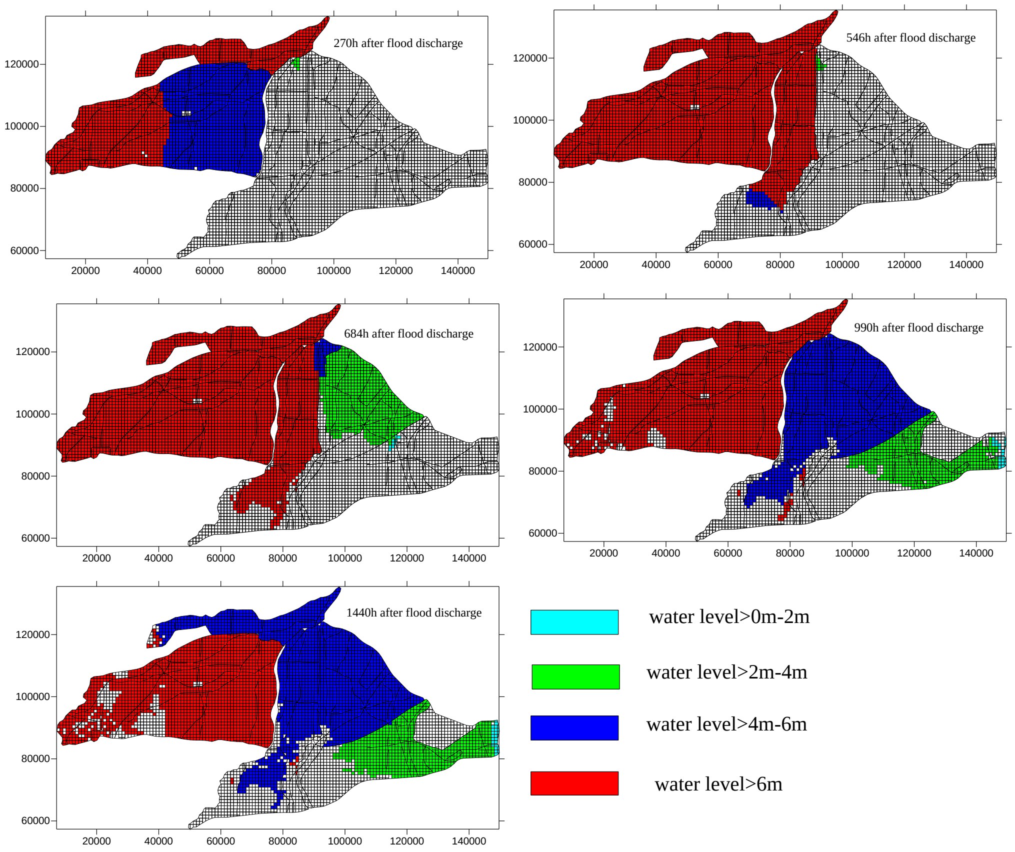


Figure 7 flood submerging graph of Daqinghe detention areas

## V. CONCLUSION

In the numerical model the authors take into account the insert and link up of shallow rivers, wide rivers and five detention areas in different conditions, and build one-dimensional and two-dimensional river-pattern grids and two-dimensional ground-pattern grids. The model has the features of both insert and link up at multi-point and multi-passage. By means of the calculations of the model, it derives the important regimen information such as the right time when flood reaches the detention basin, submerged scope, during time and water depth etc. The model simulates the flood routing of complex watershed well. It supplies scientific support to determine the timing of the five detention areas and corresponding diversion flow. In the meantime, it provides certain basis for the flood disaster and risk evaluation of Tianjin. It supports the exploitation of simulation Interfaces. The study has theoretical meaning and practical significance.

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