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*Article*

# Urban Flood Analysis Model for Plain Tidal River Network Region

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**Abstract:** Considering characteristics of high river density, special underlying surface in plain river network region, and municipal drainage system function, river network drainage unit model is proposed, which is defined as a region surrounded by main river or embankment. Flood storage variety and control projects regulation of small rivers in each unit is simulated. With drainage catchment as an object, according to its drainage capacity, simplified municipal drainage model was developed. Coupling river network drainage unit model, simplified municipal drainage model and 2D flood routing model, urban flood analysis model for plain tidal river network region was developed, which could be applied to analyzing flood from upstream river, storm surge and local rainfall. Demonstration research was carried out in Puxi flood protected area in Shanghai.

**Keywords:** plain river network; urban flood; flood analysis; Shanghai; Puxi Flood Protected Area

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## 1. Introduction

In Chinese, coastal plain river network area is developed regions. Population and properties is concentrated, which often leads to severe loss when encountering flood hazard. Developing hydrodynamic model and simulating river network flood to offer technique support is an effective disaster relief measure. However, due to high river density, network-like rivers distribution, and natural disordered flow direction, developing and solving the model is always complicated. Because of the small slope of rivers, flood delivery mainly depends on joint operation of flood control projects, so they must be considered in the model. For coastal areas, river flow affected by natural tides or storm surges often presents tidal phenomenon, and the high water level blocked the upstream and local flood discharge. Tidal level must be taken into account in the flood control scheduling.

There's great difference on flood simulation between coastal plain river network area and others. Nowadays, amount of researches have been carried out on this field and could be divided to three types. The first one is developing 1D model, governor equations of river connections and solving them jointly[1-2], or developing 1D model for narrow channel, 2D model for wide ones and solving them in coupled ways[3-4]. These two methods have great advantages on simulating river flood, especially to the smaller rivers in river network. However, surface flood by river overflow or breach break could not be simulated. The second one is developing 2D models for surface flood routing. Finite difference and volume coupled methods was used for solving 2D models in flood detention and storage area[5]. 2D flood routing model with high resolution and quantity grid was established to simulate flood of left dike break of Yi River[6]. Adopting Godunov method to discrete equation, and approximate Riemann solution to compute interface flux, and second order precision HLLC algorithm to solve 2D equation, flood routing in flood plains was simulated[7]. However, to small rivers, this method is limited by grid size. Otherwise, huge numbers of grid must be adopted, which would lead to little time step and low efficiency. In order to solve the above problems, the third simulation one was induced, which is 1D and 2D coupled models. Based on a conservative upwind grid-centered finite volume and numerical flux coupled method, 1D and 2D models were established to carry out shallow water simulation[8]. Using lateral linkage to couple 1D and 2D hydrodynamic model, developing and solving Riemann problem, dyke break and overflow flood was simulated in flood protected zone[9]. Presenting coupled 1D and 2D hydrodynamic model with complex topography and irregular boundary, numerical flux was computed by HLLC algorithm, and MUSCL–Hancock predictor–corrector scheme was used to achieve high-accuracy and high-resolution results[10]. Several scholars of IWHR presented a method to couple 1D and 2D models, which was using 2D hydrodynamic model for surface flood, special passages model for flood on roads and in rivers. The model has been applied in many cities and flood protected area for its simple principle and stable calculation [11-13]. River and surface flood could be simulated respectively by 1D-2D coupled approach, which improved model applicability apparently. However, when simulating flood of river network region, most small rivers would not be included so as to simplify the model and acquire high computational efficiency. Due to the lack of these small rivers, attached flood control projects could not be simulated, which plays a key role on flood conveyance in river network region. Compared to actual flood drainage capacity, simulation result is always smaller, which did not reflect true underlying surface conditions. In this paper, conception of river network drainage unit (RNDU) model was proposed, coupled with 2D hydrodynamic models, and calculated sluices, pumps and other projects on smaller rivers respectively, which were neglected by methods of special passage or 2D grids. The model was used to simulate flood affected by tidal surge on plain river network urban region.

## 2. Model principle

### *2.1 2D hydrodynamic flood routing model*

2D shallow equations were adopted to simulate surface and river flood using non-structure irregular grid. Except the normal mentioned 2D grid, smaller rivers defined according to grid size and roads were simulated by means of special river passages and special road passages respectively, which were sides of grids on geometry, but own cross section attributes. The equations could be expressed as follows:

$$\frac{\partial H}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=q \qquad (1)$$

$$\frac{\partial M}{\partial t}+\frac{\partial (uM)}{\partial x}+\frac{\partial (vM)}{\partial y}+gH\frac{\partial Z}{\partial x}+g\frac{n^2 u\sqrt{u^2+v^2}}{H^{1/3}}=0 \qquad (2)$$

$$\frac{\partial N}{\partial t}+\frac{\partial (uN)}{\partial x}+\frac{\partial (vN)}{\partial y}+gH\frac{\partial Z}{\partial y}+g\frac{n^2 v\sqrt{u^2+v^2}}{H^{1/3}}=0 \qquad (3)$$

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In which $H$ is water depth, $Z$ is water level, $M$ and $N$ is unit width discharge of $x$ and $y$ direction, $u$ and $v$ is velocity of $x$ and $y$ direction, $n$ is Manning's roughness coefficient, $g$ is gravity acceleration, $t$ is time, $q$ is source or sink representing effective rainfall and drain intensity.

### *2.2 RNDU model*

#### 2.2.1 Definition

RNDU is enclosed area surrounded by river, embankment or levee and other projects illustrated as Figure 1. In the model RNDU is conceptualized to be unit including boundary rivers, internal rivers, grid and projects such as pumps, sluices or others. Flood in RNDU is independent and includes two parts. The first one is flood in rivers inside RNDU, and the second one is surface water including rainfall and overflow or break flood from RNDU boundary rivers. In summary, flood of RNDU could be described as follows:

$$Q_{rp} = Q_r + Q_c = A_{rp}(Z_{rp})\frac{\partial Z_{rp}}{\partial t} \tag{4}$$

In which, $Q_{rp}$ is the whole flood of RNDU, $Q_r$ is flood in rivers inside RNDU, $Q_c$ is surface water inside RNDU, $A_{rp}(Z_{rp})$ is effective storage area inside RNDU, $Z_{rp}$ is storage water level of RNDU, and $t$ is time.

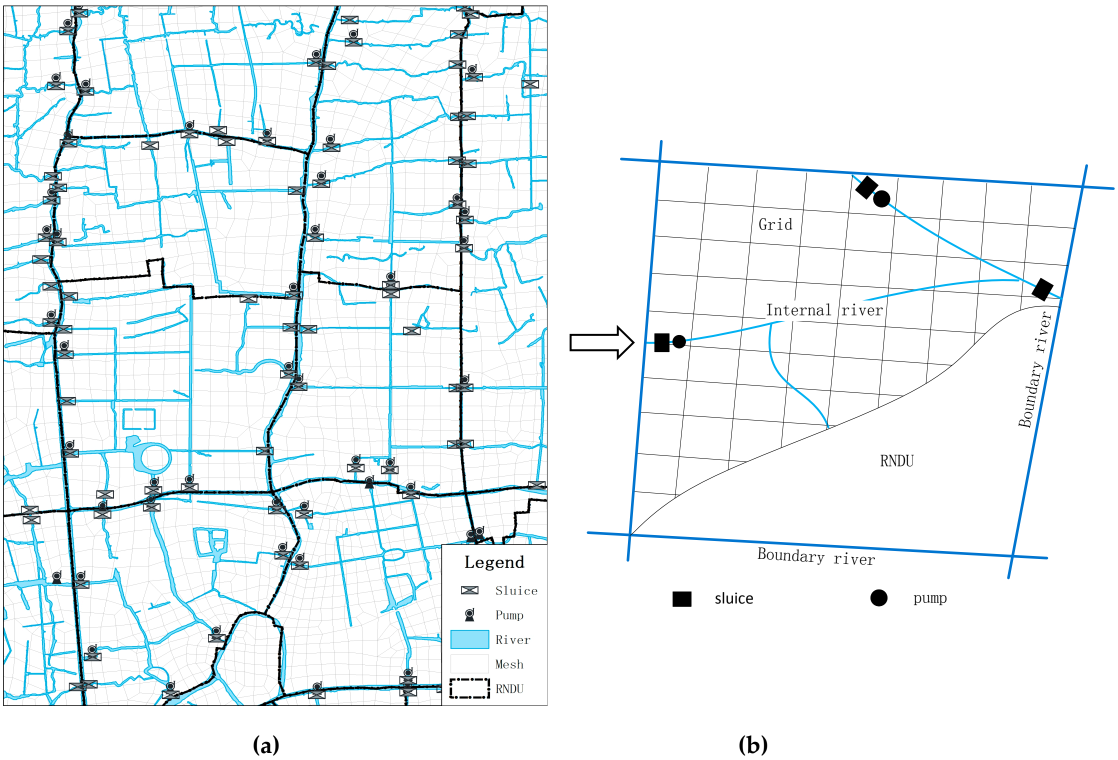


**Figure 1.** Sketch map of RNDU. (a) Actual river, dyke and projects distribution; (b) RNDU conception sketch.

Boundary rivers are passages discharging flood outside the RNDU. Internal rivers, which generally are low level tributaries of boundary rivers, discharge internal flood of RNDU to boundary rivers. In plain tidal river network region, slope between different cross sections in the same river or different rivers is always small. In addition, there is almost no change on water level between RNDU internal rivers for its small area. Because of the little slope and water level change, flood discharge is affected by tide and usually depends on flood control projects schedule. When high tide level occurs, sluices on boundary rivers would be shut down to prevent back flow, and flood discharge only depends on pumps. When low tide level occurs, sluices on boundary rivers would be opened, and flood discharge is controlled by sluice drain capacity. Compared to pump drain, flood discharge through sluices plays more crucial role.

In order to avoid calculating difficulty on solving complicated river network model, different methods are adopted to calculate RNDU boundary rivers and internal rivers. For boundary rivers, 1D river network model is developed, which can simulate flood routing and river storage. For internal rivers, conception of virtual storage volume(VSV) is introduced to represent river storage function, which is realized by setting virtual storage area and water depth on overlapped grid by internal rivers. The two parameters of VSV on each grid are decided by river distribution and actual storage of each river section locating on the grid. According to the new proposed conception of VSV, formula (4) could be represented as:

$$Q_{rp} = \sum_{i=1}^{n} A_{r_i}(Z)\frac{\partial Z_{r_i}}{\partial t} + \sum_{i=1}^{n} A_{c_i}(Z)\frac{\partial Z_{c_i}}{\partial t} \qquad (5)$$

In which $i$ is grid number in single RNDU, $A_r$ is virtual storage area, $A_c$ is area, $Z_r$ is virtual storage water height, and $Z_c$ is submerged water height of grid $i$.

2.2.2 Flood and water-logging discharge simulation

For each RNDU, flood and water-logging discharge is realized by exchange flood between internal rivers and boundary rivers. However, because of RNDU characteristics mentioned as above in plain tidal river network region, flood discharge course generally should be under control and assist of projects such as pump and sluice. In order to reflect RNDU discharge, projects simulation should be included. Just like rivers, projects are classified to two types according to their position in RNDU. For the projects on the boundary rivers of a RNDU, traditional formula are used to calculate flood discharge, that is pump drain formula and weir flow formula respectively by specific regulation rules. For projects on internal rivers of RNDU, the relation between projects and rivers could not be established in the model due to lack of rivers. This leads to that projects have to be calculated by a RNDU entirety and not be simulated individually.

Pumps or sluices are generally located at the same place for implement combine regulation. So exchange of flood between internal rivers and boundary rivers of RNDU could be controlled jointly. When high tide occurs, pumps would work and the corresponding sluices would be closed, and the total discharged flood mainly be determined by pump drainage capacity. When low tide occurs, sluices would be opened and the corresponding pumps would be halted, and the total discharged flood mainly be determined by sluice drainage capacity. Based on above pattern, total drainage capacity of pumps is calculated according to formula (6), and the correspond capacity of sluices is calculated according to formula (7):

$$\sum q_p = \sum k q_{p\max} \tag{6}$$

$$\sum q_g = \sum m\sigma A\sqrt{2gh} \tag{7}$$

In formula (6) $q_p$ is pump actual drainage capacity, $q_{pmax}$ is max drainage capacity, $k$ is pump drainage coefficient, which is determined by pump regulation rules. In formula (7) $q_g$ is sluice actual drainage capacity, $m$ is flow coefficient, $\sigma$ is submerged coefficient, and $h$ is water level difference between boundary rivers and virtual storage volume. Because water head between plain river network and each single RNDU area is small, each internal river is assumed to have identical water level. According to this assumption, water level of VSV is set to be average value of grids VSV in RNDU when calculating $h$.

*2.3 municipal drainage simulating*

Flood in river could not be discharged in time is the main reason that plain tidal river network region is liable to be flooded. Municipal drainage system drain should be included when simulating urban area flood. Generally, municipal drainage system is designed to drain by partition, so facilities such as drainage pumps, conduits and manholes et al, are designed according to the partition drainage criteria. Currently, there are three type of relatively mature methods of simulating municipal drainage including equivalent volume method[14][15], and equivalent drainage network method[12-13], as well as developing hydraulic models of actual conduit network, such as what SWMM model did. River network flood routing and storage or discharge is crucial for plain river network region flood simulation. Because river network flood model scale is often larger than rainstorm waterlogging model on urban center region, equivalent volume model is more applicable.

$$q_{cd_i} = q_{dd} * A_{c_i} / A_{dd} \tag{8}$$

In which, $q_{cd_i}$ is grid drainage capacity, $q_{dd}$ is drainage capacity of partition where grid $i$ is located, $A_{dd}$ is partition area.

*2.4 Numerical discretization and solution*

Non-structural irregular grid is adopted to discretize the whole region. Water level is calculated at grid shape center, and flux is calculated at grid side called passage in this paper. Formula (1) is discretized as follows for each grid:

$$H_i^{T+2DT} = H_i^T + \frac{2DT}{A_i}\sum_{j=1}^{n} Q_{i_j}^{T+DT} L_{i_j} + 2DTq_i^{T+DT} \tag{9}$$

In which $A_i$ *is grid area, T is current time, DT is half time step,* $Q_{i_j}$ is discharge per unit width of $j$ passage on grid $i$, n is passage number of grid $i$, $L_{i_j}$ is length of passage $j$ on grid $i$, $q_i$ is

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source and sink.

The source and sink formula is:

$$q_i^{T+DT} = q_{rf_i}^{T+DT} - q_{cd_i}^{T+DT} - q_{r_i}^{T+DT} \quad (10)$$

In which, $q_{rf}$ is rainfall intensity, $q_{ri}$ is drainage capacity to VSV of grid *i*.

When discretizing momentum formula (2) and (3), passages are classified to general passages and water blocking passages according to different simulation demand of urban surface, rivers and linear projects.

General passages refer to passages in river or on surface, which momentum formula is discretized as follows:

$$Q_j^{T+DT} = Q_j^{T-DT} - 2DTgH_j^T \frac{Z_{j2}^T - Z_{j1}^T}{DL_j} - 2DTg \frac{n^2 Q_j^{T+DT} |Q_j^{T-DT}|}{(H_j^T)^{\frac{7}{3}}} \quad (11)$$

In which, $Z_{j1}$、$Z_{j2}$ is grid water level besides passage *j* respectively, $H_j$ is average water depth of passage *j*, $DL_j$ is space step.

Water blocking passages refer to road, railway, levee et al. Weir formula is adopted to calculate flow through this kind of passages. Special passages are classified to river passages and road passages, whose flux along direction and exchange with grid(s) on both sides should be calculated. Continuous equation is discretized as follows:

$$H_{dk}^{T+2DT} = H_{dk}^T + \frac{2DT}{A_{dk}} \left(\sum_j^n Q_{k_j}^{T+DT} b_{k_j} + \sum_j^{2n} Q_{k_j}^{T+DT} L_{k_j} / 2\right) + 2DTq_{dk}^{T+DT} \quad (12)$$

In which, $H_{dk}$, $A_{dk}$ is average water depth and surface area of special passage *dk*, $\sum_j^n Q_{k_j}^{T+DT} b_{k_j}$ is special passages flow sum along direction connected to special node *k*, $\sum_j^{2n} Q_{k_j}^{T+DT} L_{k_j} / 2$ is flow sum between special passages connected to special node *k* and lateral grids, $q_{dk}^{T+DT}$ is source and sink, $b_{k_j}$ is special passage width, $L_{k_j}$ is special passage length.

Source and sink term of special river passage includes rainfall and flow from municipal drainage system or RNDU flood drained by pumps and sluices.

$$q_{dk}^{T+DT} = q_{rf_{dk}}^{T+DT} + q_{dd_{dk}}^{T+DT} + q_{p_{dk}}^{T+DT} + q_{g_{dk}}^{T+DT} \quad (13)$$

In which, $q_{rf_{dk}}^{T+DT}$ is rainfall intensity, $q_{dd_{dk}}^{T+DT}$ is drainage capacity which municipal drainage system drain to special node k, $q_{p_{dk}}^{T+DT}$ is drainage capacity which pumps of RNDU drain to special node k.

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For internal rivers of RNDU, only flood storage variation needs to be calculated, that is VSV variation of each grid in RNDU. In order to calculate grid VSV variation, an assumption is made that is if grid VSV does not reach the highest storage water level, flood to grid is supposed to drain to VSV first. Formula to calculate grid VSV water level and drainage capacity to VSV is (14) and (15) respectively:

$$Z_{r_i}^{T+2DT} = Z_{r_i}^{T} + \min((Z_{r_i\max} - Z_{r_i}^{T})/2DT, (q_{rf_i} + H_i^T/2DT - q_{gc_i}^{T+DT} - q_{pc_i}^{T+DT}))\,2\mathrm{DT} \quad (14)$$

$$q_{r_i} = (Z_{r_i}^{T+2DT} - Z_{r_i}^{T})/2DT \quad (15)$$

In which, $Z_{r_i}$ is grid VSV, $Z_{r_i\max}$ is max water level, $q_{gc_i}$ is sluices drainage capacity of RNDU to grid *i*, $q_{pc_i}$ is pumps drainage capacity of RNDU to grid *i*.

RNDU is relatively independent and separated from other units by levee on boundary rivers. So projects in RNDU are only allowed to drain flood of the unit it belongs. Based on this assumption, formula (6) and (7) could be replaced by (16) and (17):

$$\sum q_p = \min\left(\sum_{i=1}^{n_1} A_{r_i}(Z_{r_i}^{T+DT} - Z_{r_i\min})/2DT, \sum_{j=1}^{m_1} k_j q_{p_j}\right) \quad (16)$$

$$\sum q_g = \sum_{i=1}^{m_2} m_i \sigma_i A_i \sqrt{2g(Z_{rp} - Z_i)} \quad (17)$$

In which, $n_1$ is grid number, $m_1$ is pump number and $m_2$ is sluice number respectively in RNDU. $Z_{rp}$ is average water level of the whole grid VSV in RNDU. $Z_i$ is special river node water level that the sluices of RNDU drain.

Flood of RNDU grids is only discharged by projects. The drainage capacity is calculated by the ratio of grid VSV to the whole grid VSV in RNDU. The formula is:

$$q_{pc_i} = \frac{A_{r_i}(Z_{r_i}^{T+DT} - Z_{r_i\min})}{\sum_{i=1}^{n_1} A_{r_i}(Z_{r_i}^{T+DT} - Z_{r_i\min})} * \sum q_p \quad (18)$$

$$q_{gc_i} = \frac{A_{r_i}(Z_{r_i}^{T+DT} - Z_{r_i\min})}{\sum_{i=1}^{n_1} A_{r_i}(Z_{r_i}^{T+DT} - Z_{ri\min})} * \sum q_g \quad (19)$$

In which, $Z_{r_i\min}$ is min water level of grid VSV.

Boundary rivers of RNDU are calculated as special rivers in hydrodynamic model. Flood drained to special river node *k* is calculated by the ratio of pump or sluice drain capacity to the whole pumps or sluices ones in RNDU. The formula is:

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$$q_{p_{dk}} = \frac{k_{dk} q_{p_{dk}}}{\sum_{j=1}^{m_1} k_j q_{p_j}} * \sum q_p \quad (20)$$

$$q_{g_{dk}} = \frac{q_{g_{dk}\max}}{\sum_{j=1}^{m_1} q_{g_j \max}} * \sum q_g \quad (21)$$

In which, $q_{g\max}$ is max drainage capacity of sluice.

## 3 Application of the model

### *3.1 Case domain*

Puxi flood protected area of Shanghai was taken as a study case, which is on left bank of Hangpu River, on the south of Lanlu-Mao-Xie River and upstream of Huangpu River, on the west of Jiangsu province, and on the north of Yangtze River, involves 13 counties. The total domain area is 2136 km$^2$ (Figure 2).

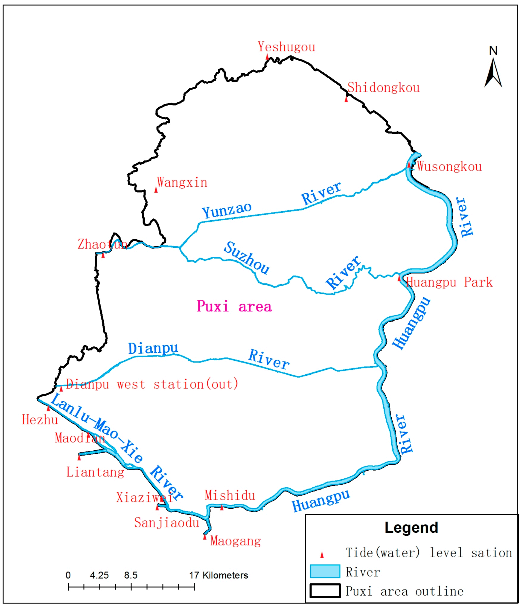


**Figure 2.** Puxi flood control protected area location

### *3.2 Mode setup*

#### 3.2.1 Grid generation

Non-regular grid was generated using mask area range as outer control boundary, dikes including flood wall, seawall, and levee as inner control boundary. The total grids number was 134723. For simulating river flood routing, wide rivers were discretized to be 2D grids, and the narrow ones were treated as special river passages, which are charged by districts,

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counties or towns. The total special river passages number was 10053. Grade 1-3 roads were treated as special road passages. The total special road passages number was 29687.

3.2.2 RNDU

There are 308 RNDUs composed by Puxi area boundary, Huangpu River, special river passages, and levee (Figure 3). 233 of them were simulated in model, which included flood control projects such as pumps and sluices. Before the simulation, topology of RNDU to grids, pumps and sluices was built in the model.

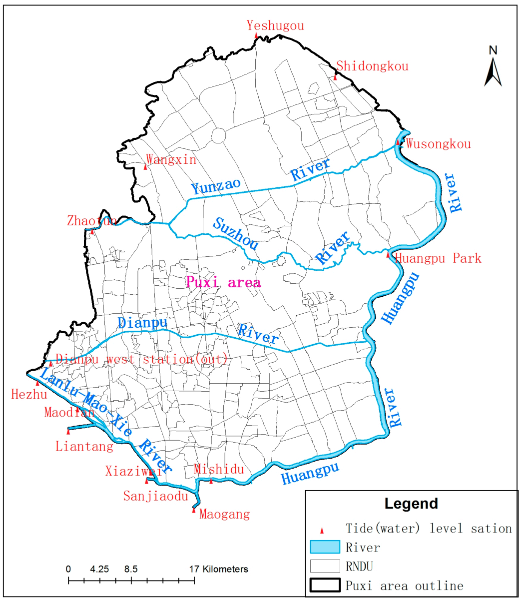


**Figure 3.** RNDU of Puxi flood control protected area

3.2.3 Municipal drainage catchment

There are 157 municipal drainage catchments in Puxi area as Figure 4 shows. Each of them was set to be an integral drain calculation object. Through setting drainage parameters and establishing topology to contained grids, municipal drainage system was conceptualized and simulated in model.

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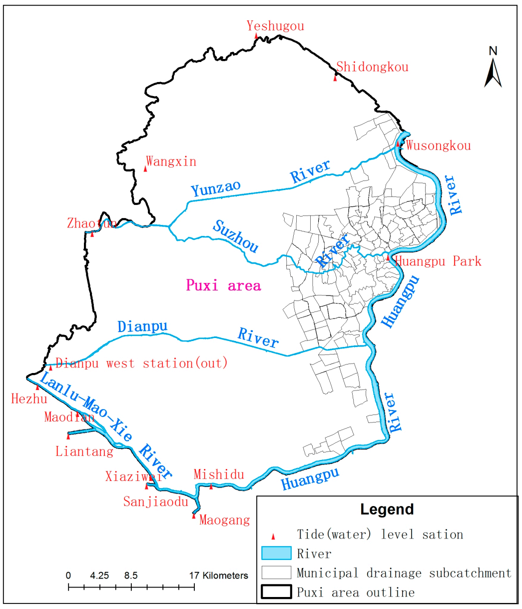



**Figure 4.** Municipal drainage catchment of Puxi flood control protected area

3.2.4 Rainfall and tide (water) level calculation condition

"Feite" typhoon Rain-flood in 2013 was used to verify the model. Three days of the maximum rainfall intensity from 6th-9th on October was selected as calculation condition, which was input to models by 90 rainfall stations in and nearby Puxi area.

Tide (water) level condition was input to models by seven stations as Fig.2 shows. The upstream boundary of Huangpu River and its tributary was set at Hezhu, Liantang and Sanjiaodu station. The downstream boundary of Huangpu River was set at Wusong station. The west-north boundary of rivers drained to ocean was set at Shidongkou station. The west boundary of Dianpu River was set at outside of Dianpu west sluice station. The upstream boundary of Suzhou River was set at Zhaotun station. The other west rivers were supposed to be no flow change with outside. The rainfall process was input by the stations in Puxi area.

*3.3 Results*

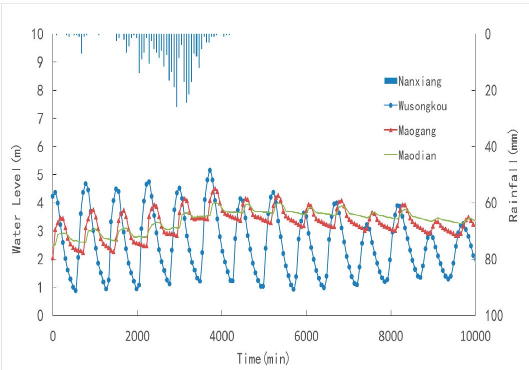
For urban on plain river network region, inundation and damage caused by overflow or levee break flood is often more severe than by rainstorm waterlogging, so river network flood simulation effect is crucial for flood analysis. The following is river network simulation precision analysis of Puxi area through comparing simulated results to observed or summary reports.

（1）Huangpu River

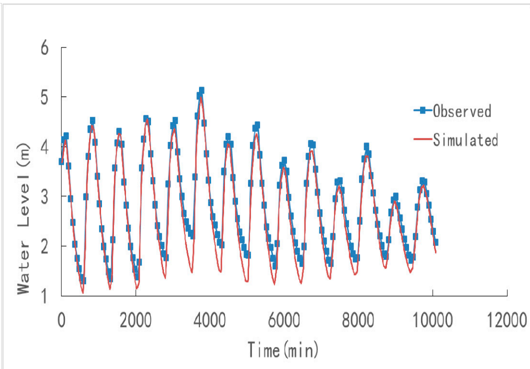
Because Huangpu River undertakes flood discharge of Puxi area, Huangpu River flood simulation precision could reflect the overall effect of river network flood in Puxi area. Comparison of observed and simulated water level at typical stations including Huangpu park, Mishidu and Xiaziwei station on Huangpu River was presented in Table 1 and Figure 5. Table 1 shows errors of peak water level between observed and calculated value was less than 0.1m and errors of appearance time of peak water level was less than 30 minutes at Huangpu park station and even smaller at Mishidu and Xiaziwei sation. Fig.4 shows calculated water level curve was coincided well with calculated one including level value and appearance time. But calculated values of low water level were smaller than actual ones. One of the main reason was that part of the pumps and sluices were neglected, and the second one was only Puxi area on left side of Huangpu River was simulated while Pudong area on right side was neglected , which all led to less water drained to Huangpu River.

**Table 1.** Measured and simulated highest water level comparison of typical stations during "Feite" typhoon in 2013

| Station Name | Peak tide(water) level（m） | | | Appearance time(min) | | |
|---|---|---|---|---|---|---|
| | observed value | calculated value | error | observed value | calculated value | error |
| Huangpu park | 5.12 | 5.04 | 0.08 | 2013/10/8 14:35 | 2013/10/8 15:00 | 25 |
| Mishidu | 4.60 | 4.58 | 0.02 | 2013/10/8 16:00 | 2013/10/8 16:10 | 10 |
| Xiaziwei | 4.35 | 4.35 | 0.00 | 2013/10/8 16:00 | 2013/10/8 16:05 | 5 |



(a)



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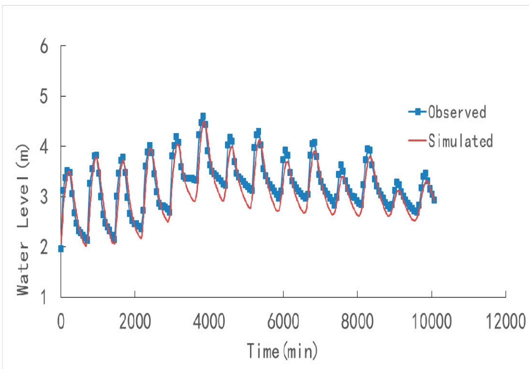
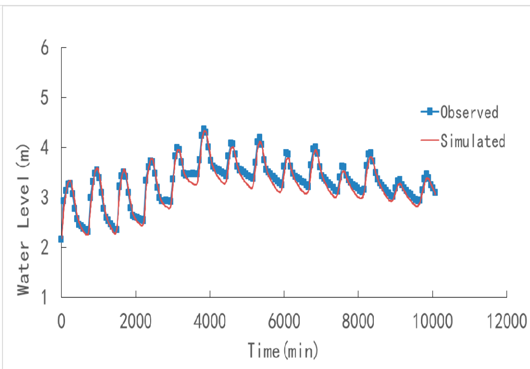


(c)



(d)

**Figure 5.** Water level and rainfall course at typical stations during "Feite" typhoon. (a) Observed water level at Maodian, Wusongkou and Maogang station, rainfall at Nanxiang station; (b) Observed and simulated water level at Huangpu park station; (c) Observed and simulated water level Mishidu station; (d) Observed and simulated water level at Xiaziwei sataion.

（2）Other rivers

For RNDU boundary rivers, flood simulation effect was analyzed by comparing simulation result and summary statistics. According to government summary reports of Shanghai and its districts or counties, overflow and levee collapse happened on rivers of Puxi area, including leek and overflow on Suzhou River, overflow on Zheze River and West Daying River of Qingpu district. Compared to simulated results, there was overflow on Suzhou River, West Daying River, Zheze River, Huanggu River and Shang'ao River, which was coincide with actual river flood.

## 4 Conclusions

Hydrodynamic model was developed simulating 2D flood routing and RNDU draining considering characteristics of high density rivers, little slope, complex flood control projects regulation in plain tidal river network region. The model could be used to simulate and analyze flood caused by upstream flood, rain storm, tide surge et al and their interaction. Taking Puxi area as verification example, the model was proved to be useful. The simulation results could be used to draw flood risk map for insurance, flood control planning or other relevant business. The model has following characteristics:

(1) With 2D plane unsteady flow equations used for surface flood and broad rivers, 1D of special passages used for roads and narrow rivers, RNDU conception and its included flood control projects discharge calculation method was proposed, which equipped the model to simulate small river discharge in plane river network region and avoid developing complexity and low efficiency 1D-2D coupled models for all rivers and urban roads.

(2) For pumps and sluices, based on their position and functional classification in RNDU, projects operation effect was simulated in different methods. For projects on special rivers, traditional formula was adopted, which was pump discharge formula for pumps and weir formula for sluices. But for projects on small rivers, pumps and sluices discharge was simulated by another different method, which was using RNDU drainage calculation formula. The special calculation method solved the problems that projects could not be simulated because of small rivers missing in hydrodynamic model.

(3) Influence of high and low tide was considered for pumps and sluices regulation in RNDU. At high tide, sluices were closed and flood was discharged by pumps. At low tide, sluices were opened and flood would flow freely. This way of flood discharge in the model was consistent with projects regulation.

(4) Urban municipal drainage was simulated by equivalent volume technique according to each drainage system capacity. This method coordinates big scale simulation for river network and small scale simulation for municipal drainage.

## References

1. Guiquan Xu; Qingjiang Chen; Changtai Chen; Guochuan Ding. Influence of flood diversion of Wusong River on flood control and waterlogging prevention in Shanghai and its countermeasures. Urban Roads Bridges & Flood Control,2007,5:193-195.
2. Zuxin Xu; Shiqiang Lu. Hydrodynamic model for tidal river network. Journal of Hydrodynamics, 2003(2):176-181.
3. Zuxin Xu; Hailong Yin. Development of coupled one-dimensional and two-dimensional hydrodynamic model for tidal rivers. Journal of Hydrodynamics, 2004, 19 (6):744-752.

4. Chuanhai Wang; Xiaohua Xiang. Generic 2-D river network numerical model. Advances in Water Sciences, 2007, 18 (4):516-522.
5. Xiaotao Cheng; Lei Yang; Xijun Chen. Numerical model of flood propagation in detention basin. Journal of Natural Disasters, 1995, 5(1):34-40.
6. Jianming Ma; Xu Xu; Nianqiang Zhang; Zongren Tang. Flood risk mapping for left dyke breaking of Yi River. The 3rd youth science and technology conference symposium of Chinese hydraulic engineering society, 2007.
7. Bin Tang; Xiaohui Lei; Feng Zhang. Numerical simulation of flood routing in damming flood detention basin. SOUTH-TO-NORTH WATER TRANSFERS AND WATER SCIENCE & TECHNOLOGY, 2012, 10(4):61-65.
8. M.Morales-Hernández; P.García-Navarro; J.Burguete, et al. A conservative strategy to couple 1D and 2D models for shallow water flow simulation.Computers & Fluids. 2013, 81:26–44.
9. Wenlong Chen; Lixiang Song; Linghang Xing; Wenming Zhang; Jianzhong Zhou. A 1D-2D coupled mathematical model for numerical simulating of flood routine in flood protected zone. Advances in Water Science. 2014, 25(6): 848-855.
10. Qiang Liu; Yi Qin; Yang Zhang. A coupled 1D–2D hydrodynamic model for flood simulation in flood detention basin. Natural Hazards.2015, 5(2):1303-1325.
11. Jinwei Chou; Na Li; Xiaotao Cheng, et al. The simulation system for heavy rainfall in Tianjin city. Journal of Hydraulic Engineering, 2011, 11:34-42.
12. Jing Wang; Na Li; Xiaotao Cheng. Improvement and application of numerical model for the simulation of flooding in urban area. Journal of Hydraulic Engineering, 2010, 41(12):1393-1400.
13. Xiaotao Cheng. Urban Flood Prediction and Its Risk Analysis in The Coatal Areas of China. Beijing: China Water & Power Press, 2009.
14. Nianqiang Zhang; Jiangming Ma; Jikang Lu; Jiangang Liu; Jinhong Wan. Multi-models coupling based study on urban flood risk analysis technology. Water Resources and Hydropower Engineering, 2013, 44(7):125-129.
15. Jianming Ma; Jikang Lu; Nianqianq Zhang; Xiang Lan. Design and development of 2-D hydraulic modelling system for flood risk analysis and mapping. Journal of China Institute of Water Resources and Hydropower Research, 2009, 7(1):21-27.
16. Shanghai water authority, <Detailed Implementing Rules of Water Resource Scheduling For water control regions of Shanghai> (Shanghai water authority [2012]627th), July, 12, 2012.