Real-time Scheduling and Forecasting System for Urban Flood in Coastal Cities

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Content

PART I

Background:

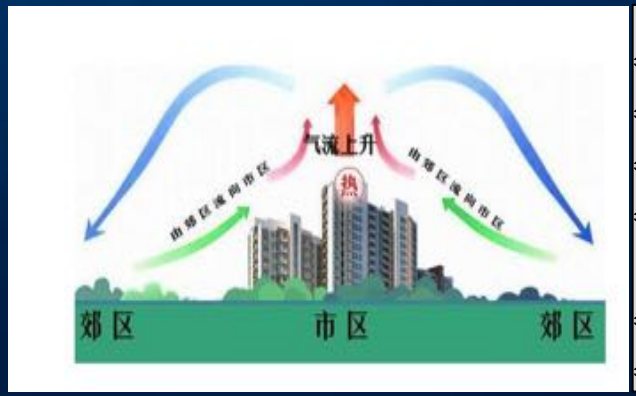
Urban Flooding/Waterlogging

Impact of Urbanization and Climate Change

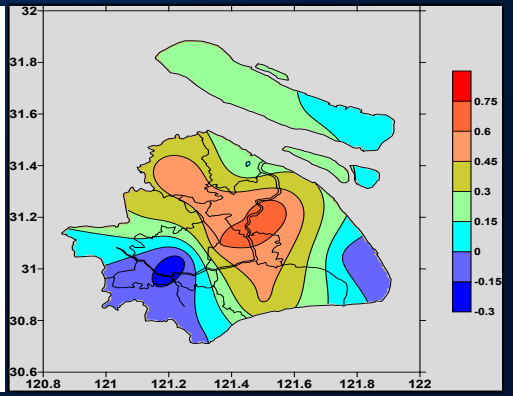
- IPCC AR5：全球变暖，极端降水和洪涝灾害更为频繁；气候变化引起的全球性风险大多集中在城市..... Climate change, more extreme precipitation and flood disasters; most of the global risks caused by climate change impact cities.
- 中国进入城市化快速发展阶段（从2000年30%发展到2018年59.6%），热岛效应及雨岛效应增强 China is undergoing rapid urbanization(urbanization rate: from 30% in 2000 to 59.6% in 2018) with increasing urban heat island effect and rain island effect.

中国城市化进程加速
Urbanization development in China

Picture Source：张建云等, 2019



城市热岛效应
Urban heat Island effect

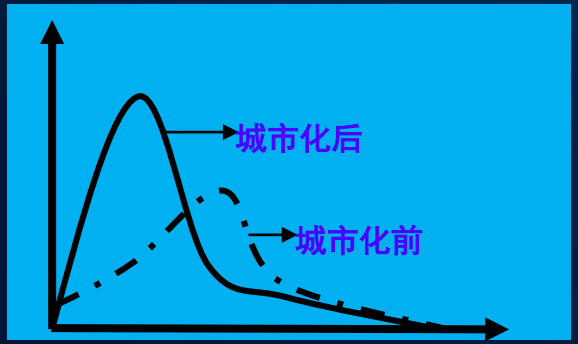


城市雨岛效应（沪，丁一汇）
Rain island effect

Impact of Urbanization and Climate Change

Urban development and construction have brought about a profound impact

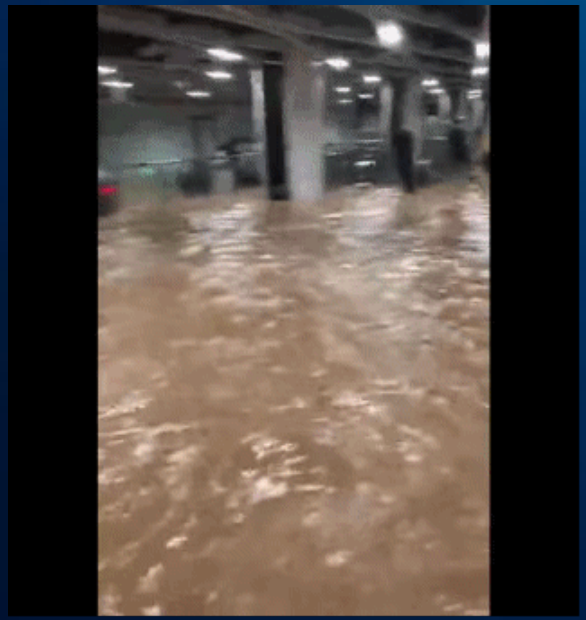
- ***Frequent flood disasters*** -- Natural drainage pattern changes, runoff yield increases, confluence speeds up, river and lake water systems are invaded, and stormwater storage capacity decreases
- ***Urban water shortage*** -- the demand for water is increasing, and the relationship between supply and demand of water resources is becoming increasingly tense
- ***Water environment and water ecological deterioration*** -- urban production and household sewage discharge continues to increase, and the load of non-point source pollution increases, exceeding the environmental carrying capacity of river and lake systems



Urban Flooding/Waterligging in China

Street becomes rivers, subway becomes underground rivers

—— Urban flooding/waterlogging in 2020



Subway in Guangzhou

Jingdezhen, Jiangxi

Bazhong, Sichuan

Effective Attempt

Sponge City

- ✓ Sponge city refers to a city that, like a sponge, has good elasticity in adapting to environmental changes and coping with natural disasters. When it rains, it *absorbs water*, *stores water*, *seepages water* and *purifies water*, and "releases" the stored water when needed and makes use of it.

- ✓ Sponge city construction should consider the *natural precipitation*, *surface water* and *groundwater system*. Coordinating *water supply*, *drainage* and other links of water recycling. Consider both complexity and longevity in the system.

Typical Sponge City Construction

Permeable Pavement

Rain Garden

Green Roof

Vegetative Swale

Bio-Retention Cell

Infiltration Trench

Effective Attempt

Real-time Scheduling and Forecasting

Data layer

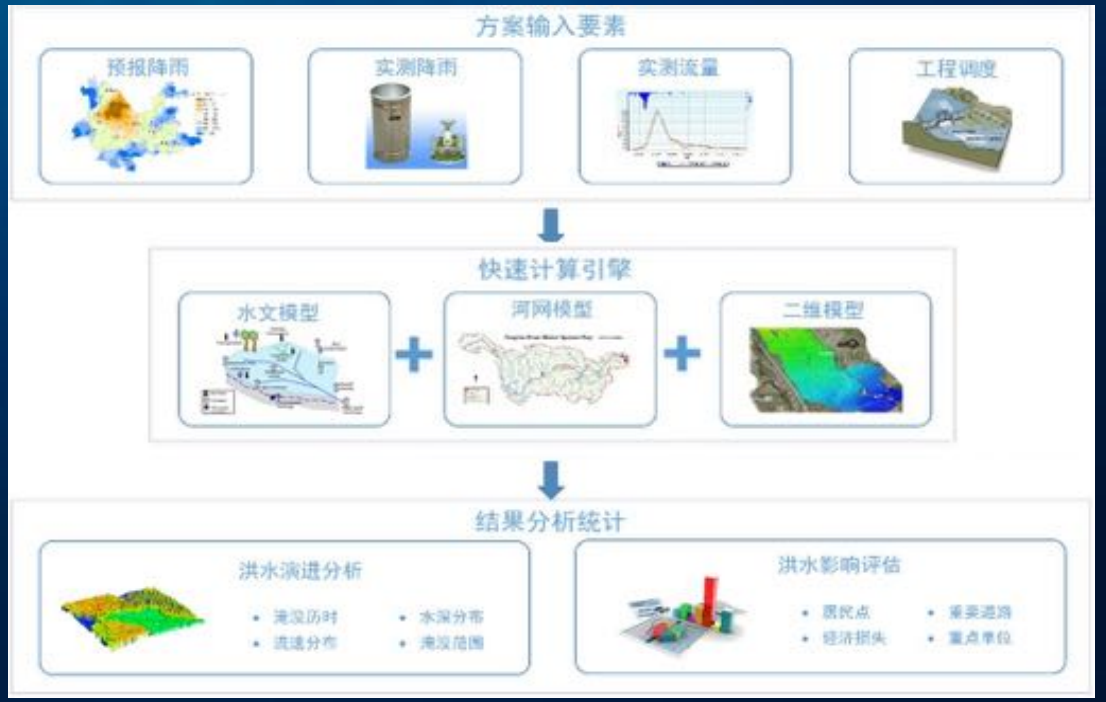
Data collection
Data storage
Data mining
…

Model layer

Hydrology Model
Hydrodynamic Mode
Statistical Model
Machine Learning Model
…

Application

Flood forecasting system
Real-time dynamic data
Flood evolution analysis
Flood impact assessment
…



Picture Source：王浩

✓System Integration: *Real-time Flood Simulation and Analysis System*

PART II

Integrated Model and Forecasting Systems

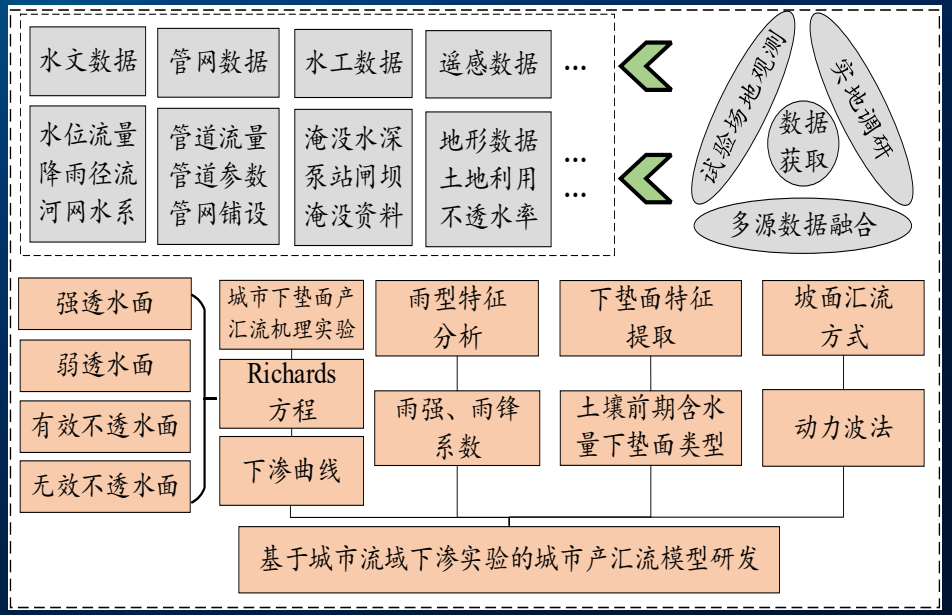
Hydrological Model

Computational Method:

- Runoff generation: Horton infiltration model
- Overland flow: Nonlinear reservoir model

Research Fields:

- The complex topography of the city, with Complex hydrological processes
- Parametric uncertainty in urban underlying surface
- Applicability of hydrological models



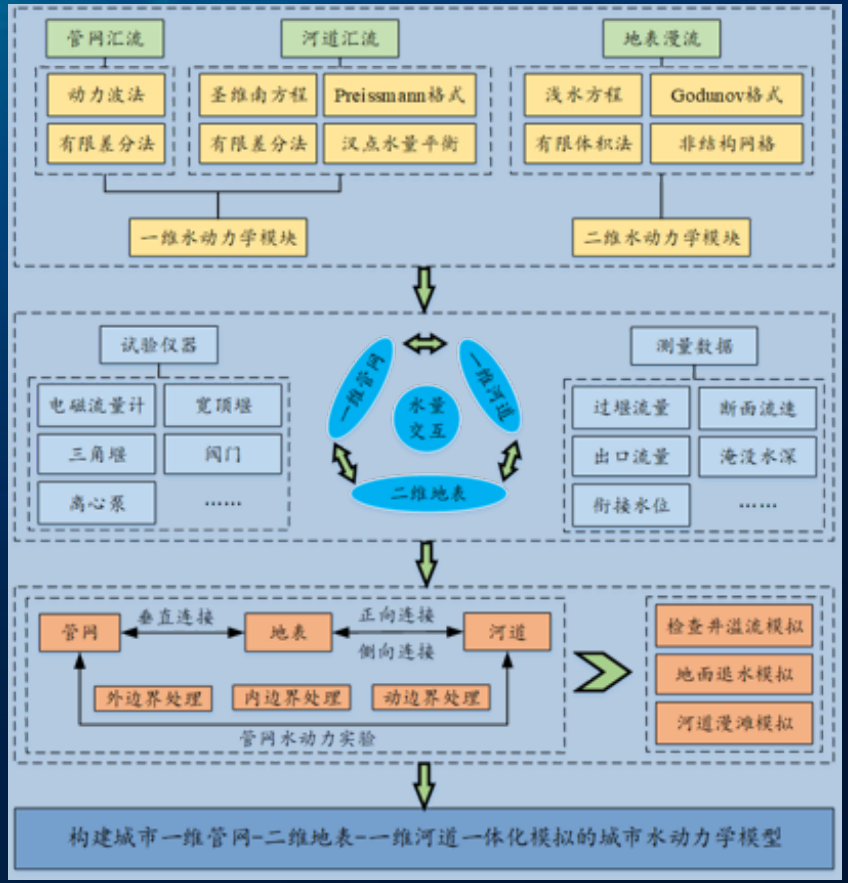
Hydrodynamic Model

Computational Method：

- 1D： Preissmann scheme, finite difference method
- 2D： Godunov scheme， finite volume method

Research Fields：

- Alternating pressure and non-pressure flow
- Coupling mechanism of pipelines, river and ground
- The complex topography of the city
- Balance the need to be accurate with the need to be fast
- GPU parallel computing

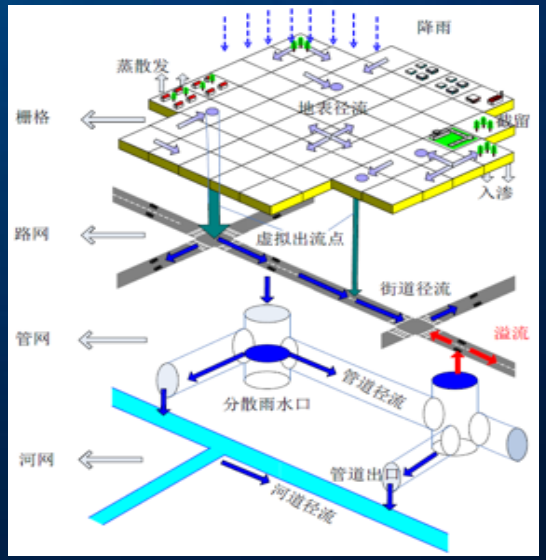


Multiprocess in Urban Water Exchange

Ground(2D)

Pipeline(1D) ⟷ River(1D)

Picture Source：Pan et al. , 2012



Surface Runoff

Overland Flow

Pipeline Flow

Stream Flow

Multiprocess in Urban Water Exchange

Flow routing model in subareas

$$\begin{cases} Q = \dfrac{A^{5/3} S^{1/2}}{nP^{2/3}} & \text{Manning formula} \\ \dfrac{\partial V}{\partial t} = A\dfrac{\partial d}{\partial t} = A \cdot i_{(t)} - Q_{(t)} & \text{Water balance equation} \end{cases}$$

Newton-Raphson Method

$$\frac{\partial d}{\partial t} = i_{(t)} - \frac{W}{A \cdot n}\left(d - d_s\right)^{5/3} S^{1/2}$$

$$\frac{d_1 - d_2}{\Delta t} = i - \frac{WS^{1/2}}{A \cdot n}\left(d_1 + \frac{1}{2}\left(d_2 - d_1\right) - d_s\right)^{5/3}$$

Flow routing model in drainage pipelines based on dynamic wave method

$$\begin{cases} \dfrac{\partial A}{\partial t} + \dfrac{\partial Q}{\partial x} = 0 & \text{Continuity Equation} \\ \dfrac{\partial Q}{\partial t} + \dfrac{\partial}{\partial x}\left(\dfrac{Q^2}{A}\right) + gA\dfrac{\partial H}{\partial x} + g\dfrac{n^2 Q|Q|}{AR^{4/3}} = 0 & \text{Momentum Equation} \end{cases} \Rightarrow \begin{cases} \dfrac{\partial Q}{\partial t} - 2Av\dfrac{\partial A}{\partial t} - v^2\dfrac{\partial A}{\partial x} + gA\dfrac{\partial H}{\partial x} + gAS_f = 0 \\ \dfrac{\partial H}{\partial t} = \dfrac{\sum Q_i}{\omega} \end{cases}$$

Overland flow on urban ground based on shallow water equation

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} + \frac{\partial \mathbf{G}}{\partial y} = \mathbf{S} \qquad \mathbf{U} = \begin{bmatrix} h \\ hu \\ hv \end{bmatrix}, \mathbf{F} = \begin{bmatrix} hu \\ hu^2 + gh^2/2 \\ huv \end{bmatrix}, \mathbf{G} = \begin{bmatrix} hv \\ huv \\ hv^2 + gh^2/2 \end{bmatrix}, \mathbf{S} = \begin{bmatrix} 0 \\ gh\left(S_{fx} + S_{0x}\right) \\ gh\left(S_{fy} + S_{0y}\right) \end{bmatrix}$$

$$S_{fx} = -\frac{n^2 u\sqrt{u^2+v^2}}{h^{4/3}}, S_{fy} = -\frac{n^2 v\sqrt{u^2+v^2}}{h^{4/3}}, S_{0x} = -\frac{\partial z_b}{\partial x}, S_{0y} = -\frac{\partial z_b}{\partial y}$$

Deal with the local terrain

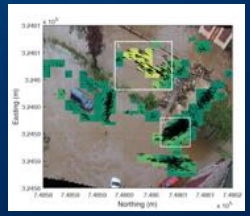
固壁边界法（Building hole，BH）； 设定高程法（Building block，BB）；人工加糙法（Building resistance，BR）；容积率浅水方程法（Building porosity，BP）

Application of Remote Sensing

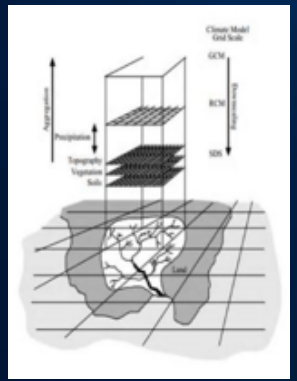
Multi-source Data Fusion

Satellite Remote Sensing +

Gauge Observation +

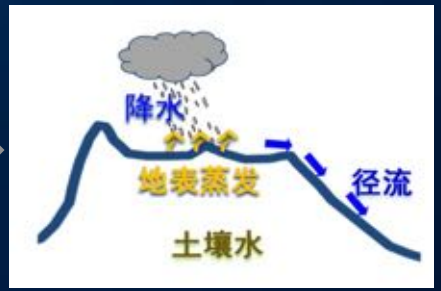


Data Mining



Spatial scale conversion

High resolution remote sensing data

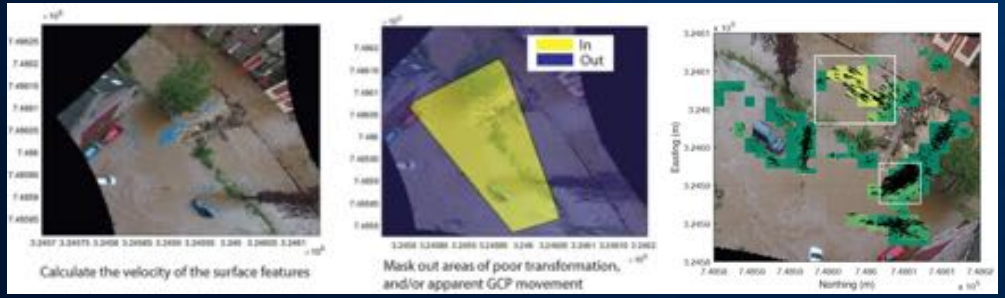


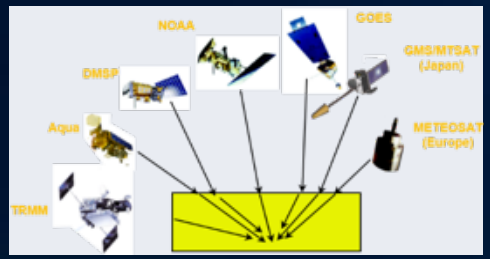
Urban water cycle

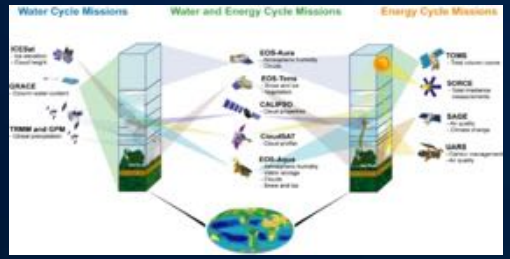
Application of Remote Sensing

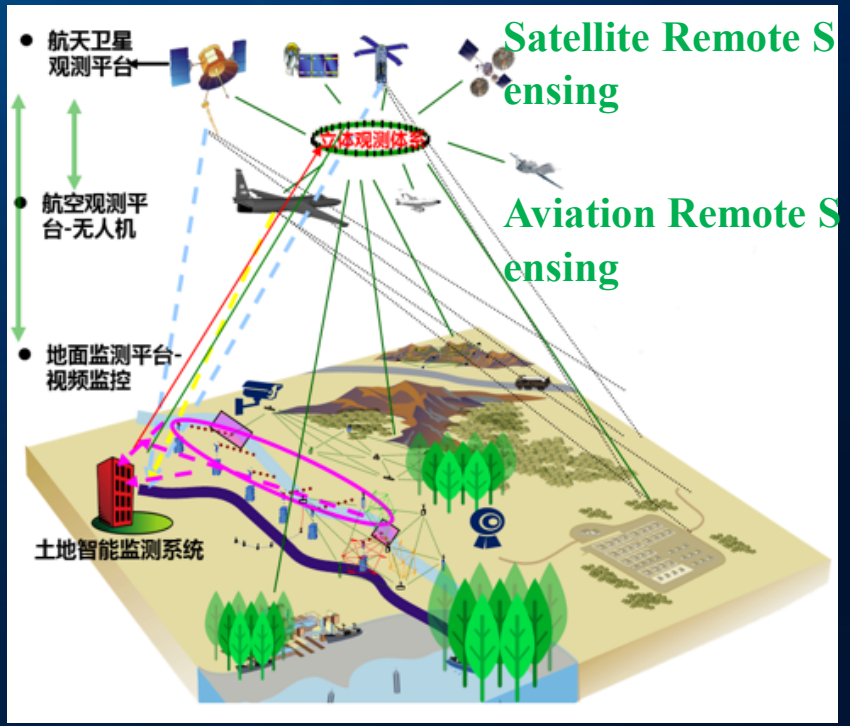
- Remote sensing monitoring
- Flood feature extraction
- Remote sensing imagery interpretation

  - Flood area extraction





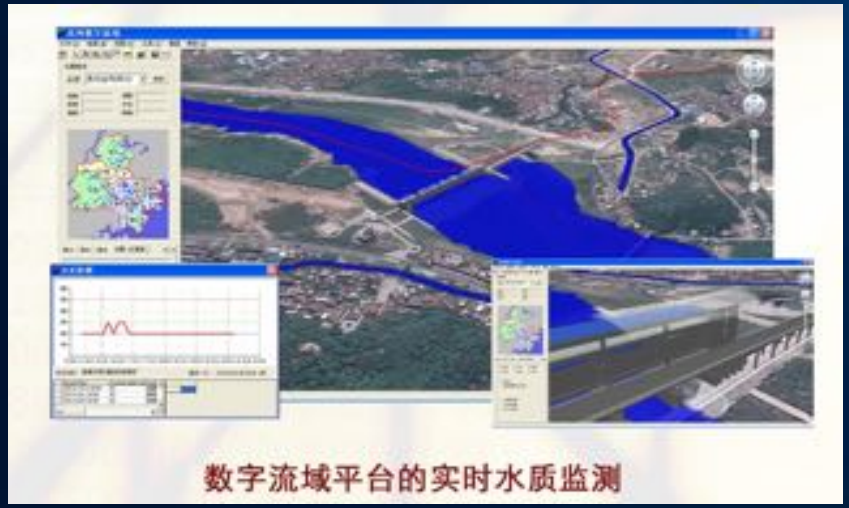




Picture Source: http://www.otitan-hf.com/solution.php?tid=266

Integrated Model and Forecasting Systems

- **Integrated hydrological models, hydrodynamic models, and machine learning models**
- **Real-time forecasting by using models**



Scheduling Layer	**Scheduling pattern** ● Scheduling with experience ● Scheduling with pre-arranged planning ● Scheduling with smart algorithm
Forecasting Layer	**Key data to forecast** ● Water level in key river section ● Water quality ● City roads ● Inundation in the area ● Pipeline state
Model Layer	**Coupled models** ● Runoff generation ● Flow concentration ● Overland flow **Other models** ● Data based model ● Numerical weather model
Data Layer	**Monitoring && Collection** ● GIS data ● RS data ● Urban stations data ● History inundation **Preprocessing** ● Data mining ● Data fusion ● Data assimilation ● Scale transformation

Related Technology

Deep Learning

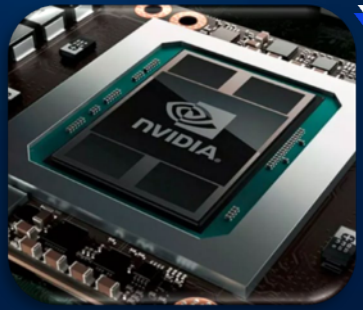
Deep neural networks were used to fit the relationship among the complex process of flood.

Flood Monitoring

Abundant data sources are an important support for improving future flood prediction.

Data Mining

Based on the abundant multi-source data, the key data in the flood can be obtained for model construction, calibration and verification.



Parallel Computing

Compared with the CPU, the GPU calculation efficiency is significantly higher, which is conducive to the real-time calculation of flood.

PART III

A Case Study in Fuzhou City

Urban Flood Management with Rainfall Forecasting

Real-Time Simulation and Analysis System

- **Monitoring and Warning:**

  To find the flood threat

- **Prediction and Forecasting:**

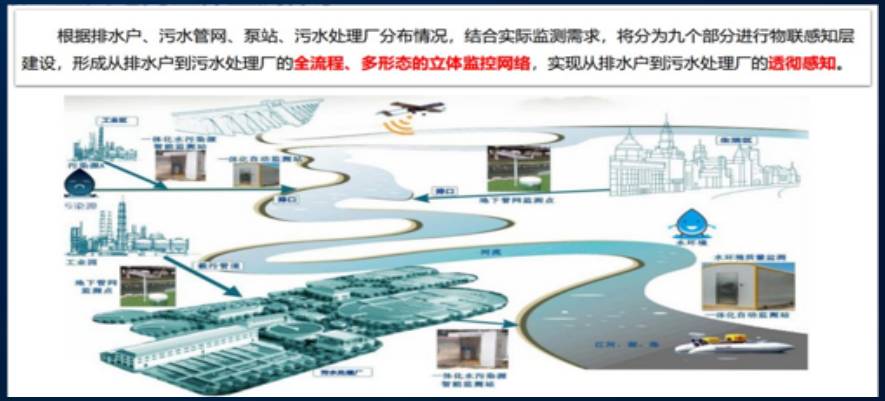
  To analyze the flood threat

- **Scheduling and Decision:**

  To analyze the flood threat

- **Command and Control :**

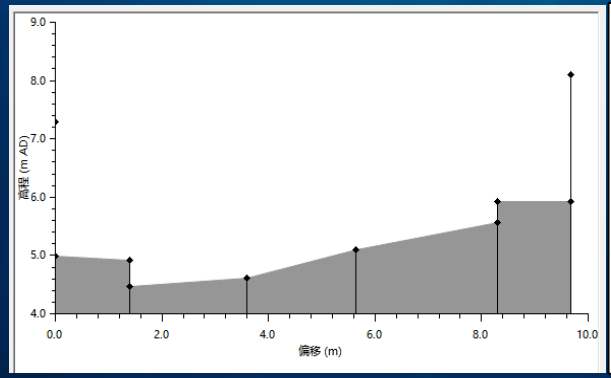
  To solve the flood threat

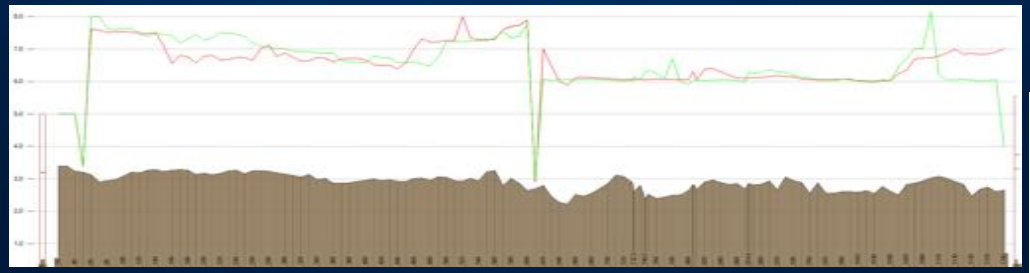


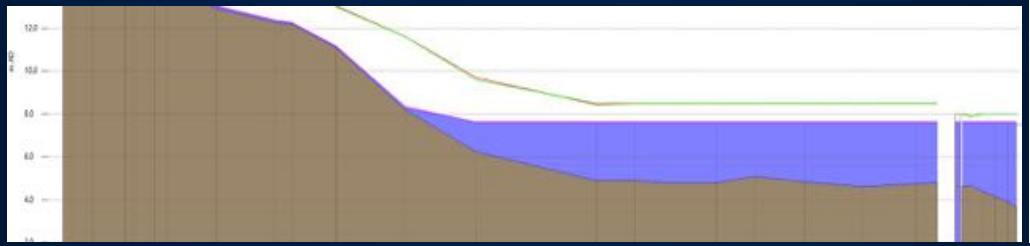
Step 1: Data Pre-processing Model Development

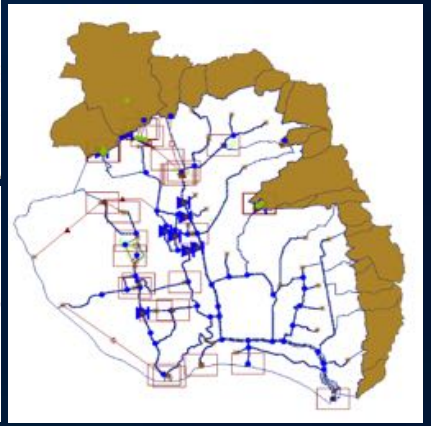
Model Development

- ✓ Land use data
- ✓ Pipelines
- ✓ Manholes
- ✓ Dam, Storage, Pumps…





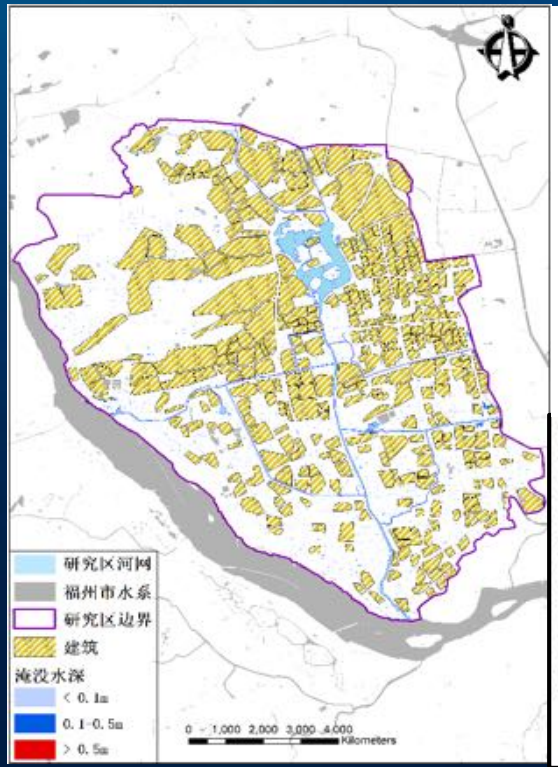


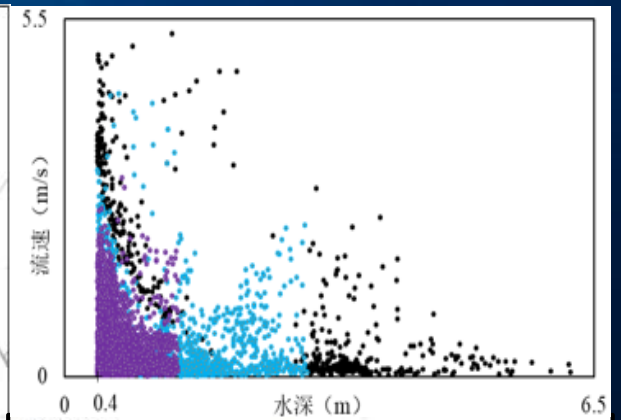


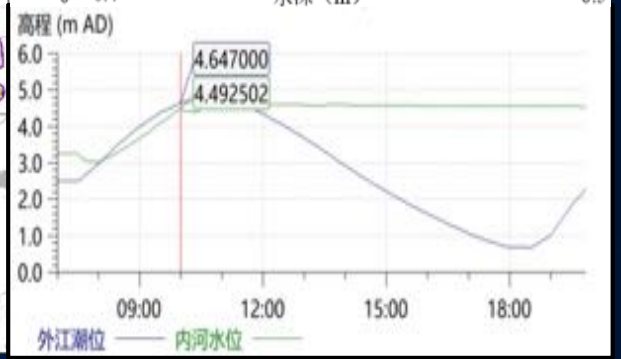
Step 2: Urban Flood Simulation

Urban Flood Simulation

- ✓ Model Calibration
- ✓ Grid Generation
- ✓ High resolution terrain data



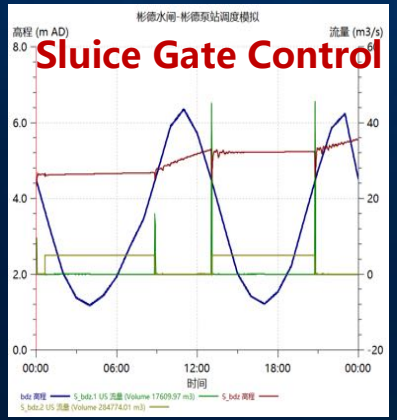


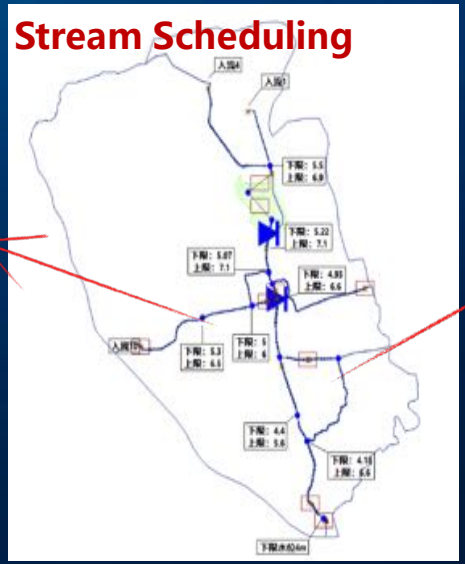


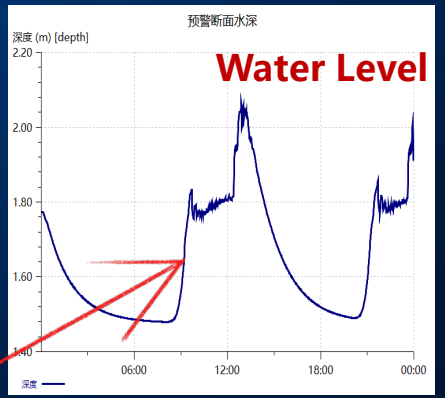
Step 3: Hydraulic Structure Scheduling

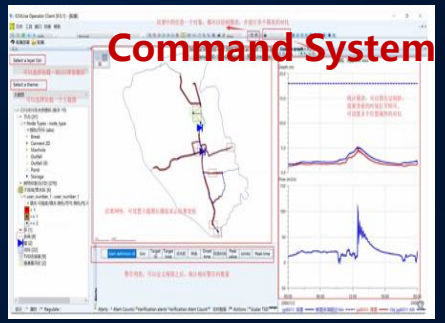
Reservoir Flood Control

- ✓ River-Lake-Reservoir Control
- ✓ Gate-Pump-Weir Control
- ✓ Smart Control
- ✓ r`





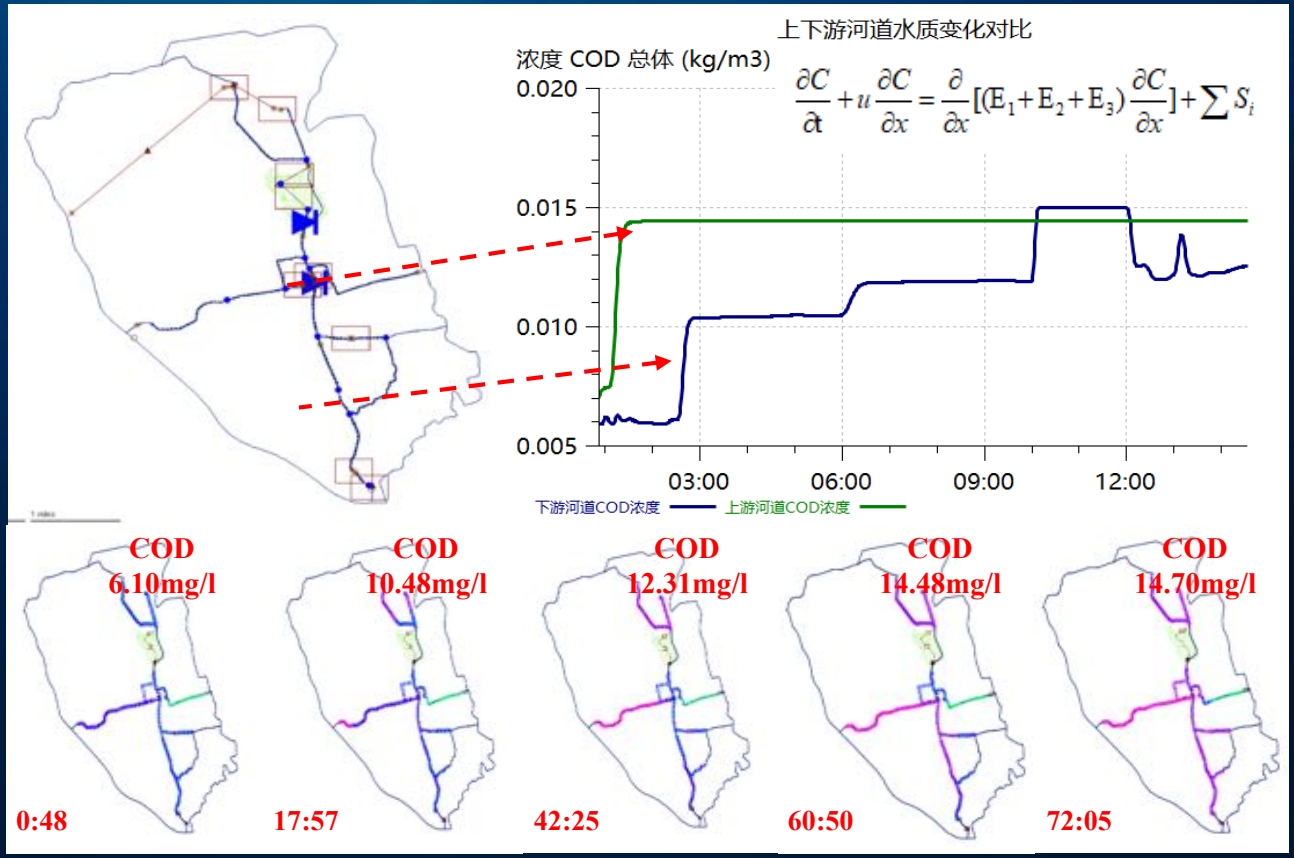




Step 4: Water Quality Simulation

Water Quality Simulation

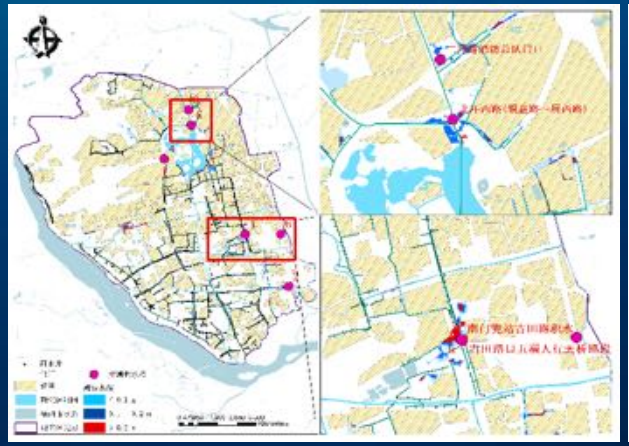
- ✓ COD, BOD, DO, TP…
- ✓ Temporal Evolution
- ✓ Spatial Evolution
- ✓ r`

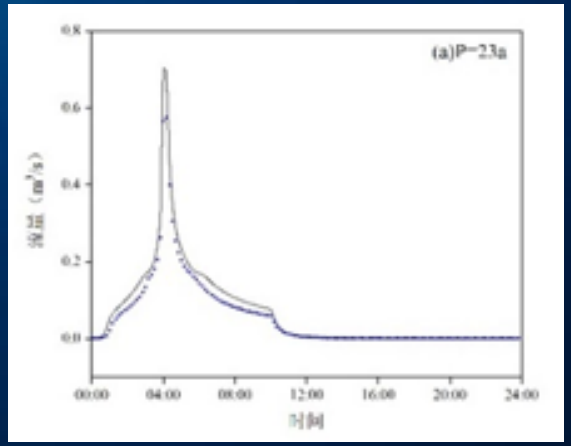


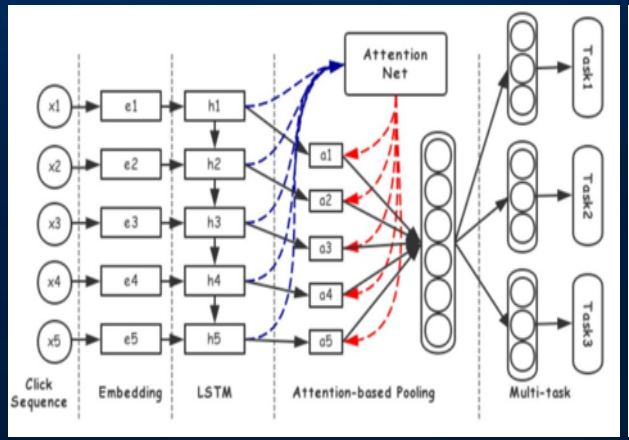
Step 5: Urban Flood Forecasting

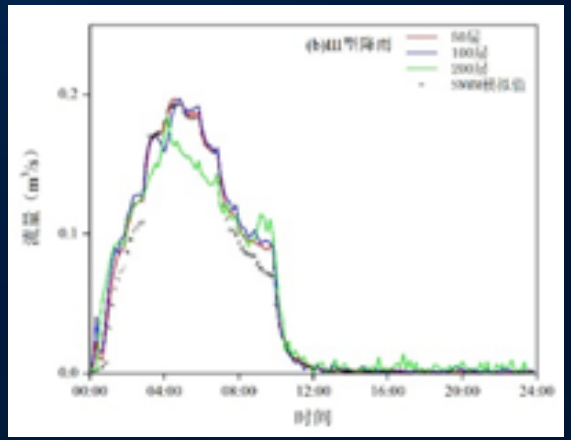
Flood Forecasting

- ✓ **Physically-based Model Forced Method**
- ✓ **Data Forced Method**



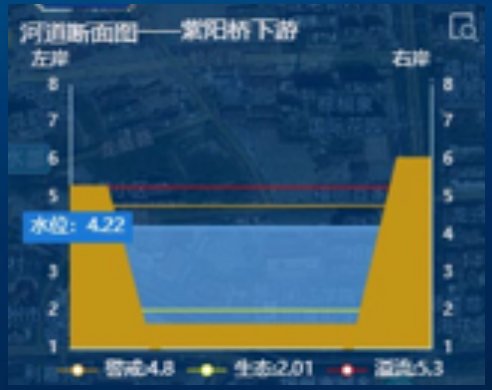


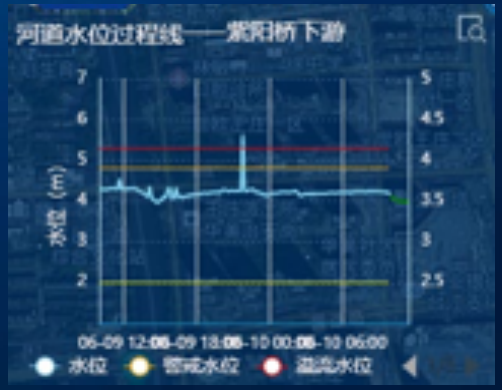


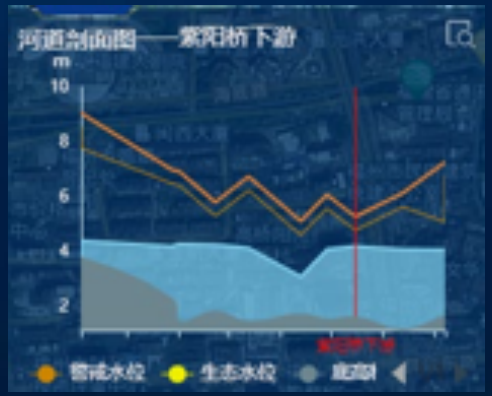


Real-Time Monitoring and Simulation System

Function 1: Query and Monitoring of Rainfall, Typhoon, Inundation, Water Level.



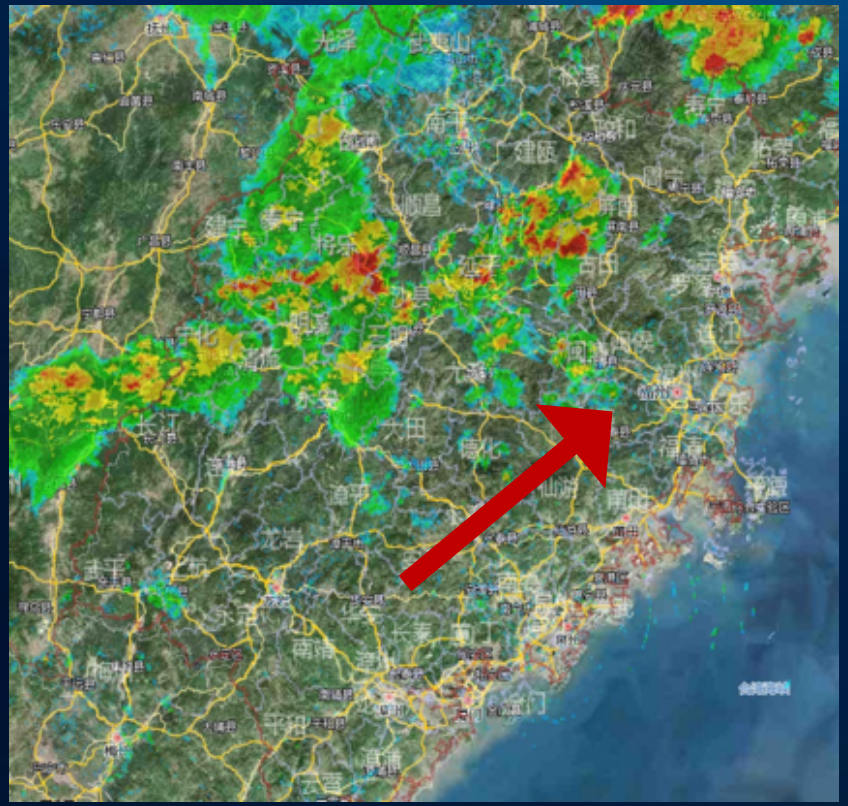


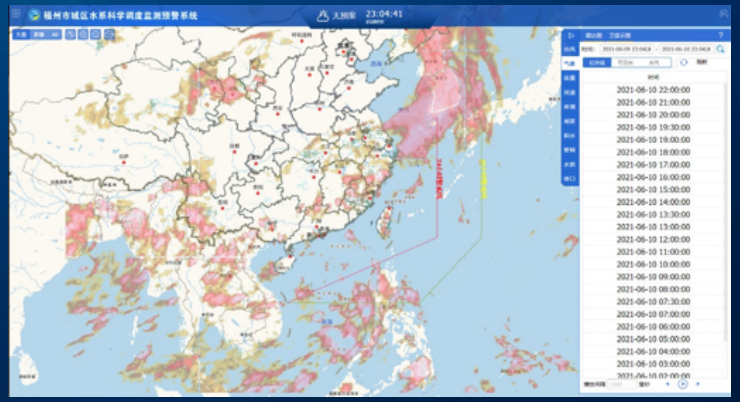


序号	时间	水位(m)	水深(m)
1	2021-06-10 10:00	4.170	2.560
2	2021-06-10 09:50	4.220	2.610
3	2021-06-10 09:40	4.210	2.600
4	2021-06-10 09:30	4.220	2.610
5	2021-06-10 09:20	4.230	2.620
6	2021-06-10 09:10	4.230	2.620
7	2021-06-10 09:00	4.230	2.620
8	2021-06-10 08:50	4.240	2.630
9	2021-06-10 08:40	4.230	2.620
10	2021-06-10 08:30	4.240	2.630
11	2021-06-10 08:20	4.240	2.630
12	2021-06-10 08:10	4.240	2.630
13	2021-06-10 08:00	4.220	2.610
14	2021-06-10 07:50	4.230	2.620
15	2021-06-10 07:40	4.230	2.620

Real-Time Monitoring and Simulation System

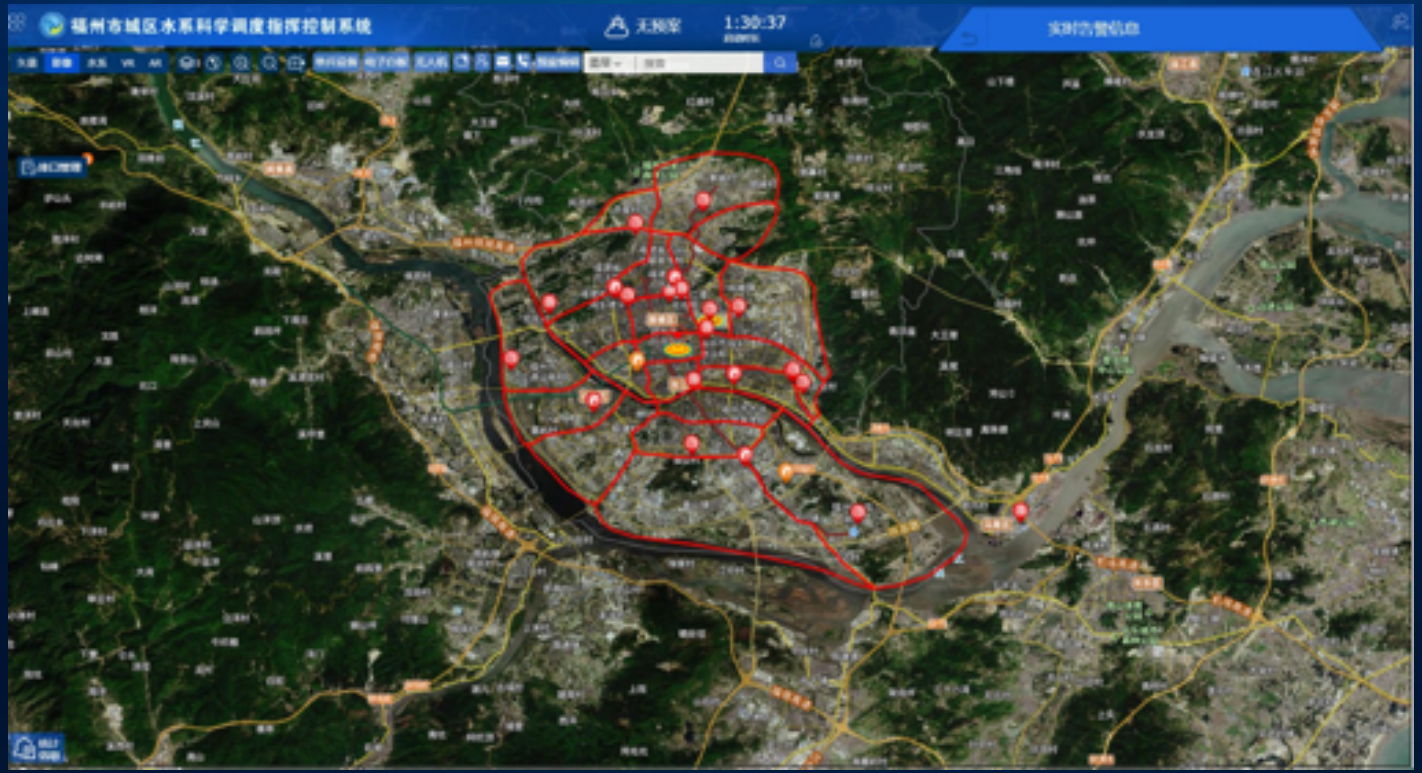
Function 2: Generation and Optimization of Scheduling Schemes





Real-Time Monitoring and Simulation System

Function 3: Real-time Urban Flood Simulation and Results Analysis



Real-Time Monitoring and Simulation System

Function 4: Real-time Urban Scheduling System

PART V

Conclusion

Ⅰ 水文水动力学模型是实时预报的关键

Hydrodynamic model is the key to the real-time forecasting

研发集成的，精确的，效率高的水文水动力模型，是洪涝实时预报系统的核心和关键。

*The development of an **integrated, accurate and efficient hydrodynamic model** is the core and key of the real-time flood forecasting system.*

Ⅱ 多学科交叉助力解决洪涝难题

Multidisciplinary collaboration helps to solve the problem of urban flooding/waterlogging

结合水文、水动力、遥感、人工智能等多领域、多学科，优势互补，建立完善的数据-模型-预测-指挥一体化智慧管理系统。

*Combined with hydrology, hydrodynamics, remote sensing, artificial intelligence and other fields, multi-disciplines, complementary the respective advantages, to establish a **data-model-forecasting-command** integrated intelligent management system.*

Thank You for Your Attention !

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