Numerical Simulation of Urban Ponding and Its Application in Beijing

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- **Background: Urban Ponding in Beijing**
- **Introduction of BUW model**
- **Simulation in Different Scenario**
- **. . .**
- **Risk Warning and its Application**
- **Next Work and How to Cooperation**

Beijing is a ponding-prone and fragile city

10 JUL 2004

17 JUN 2014

23 JUN 2011

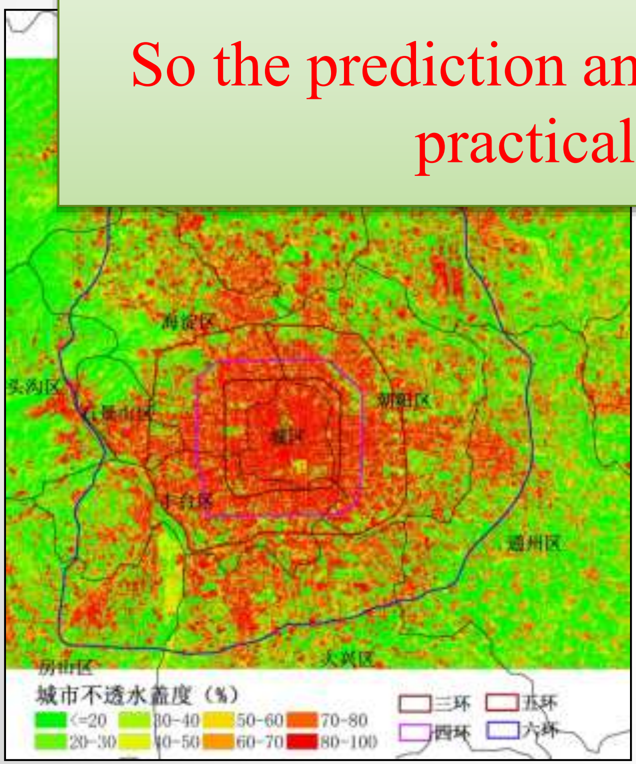
21 JUL 2012

Beijing is a ponding-prone and fragile city

1. Underground Space Development: The hollow overpass, Subway……

All the above can not be improved in the short term.

So the prediction and risk warning of urban ponding may be a practical breach for disaster prevention.



2. Too Much Impervious Underlying Surface

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Based on the complex terrain and large city characteristics, the geographic information of Beijing was cut into 6458 grids and 14607 channels (Resolution: 1km×1km). Focused on the urban hydrodynamic and hydrographic process, the Beijing Urban Waterlogging (BUW) numerical model was built to **simulate the ponding depth.**

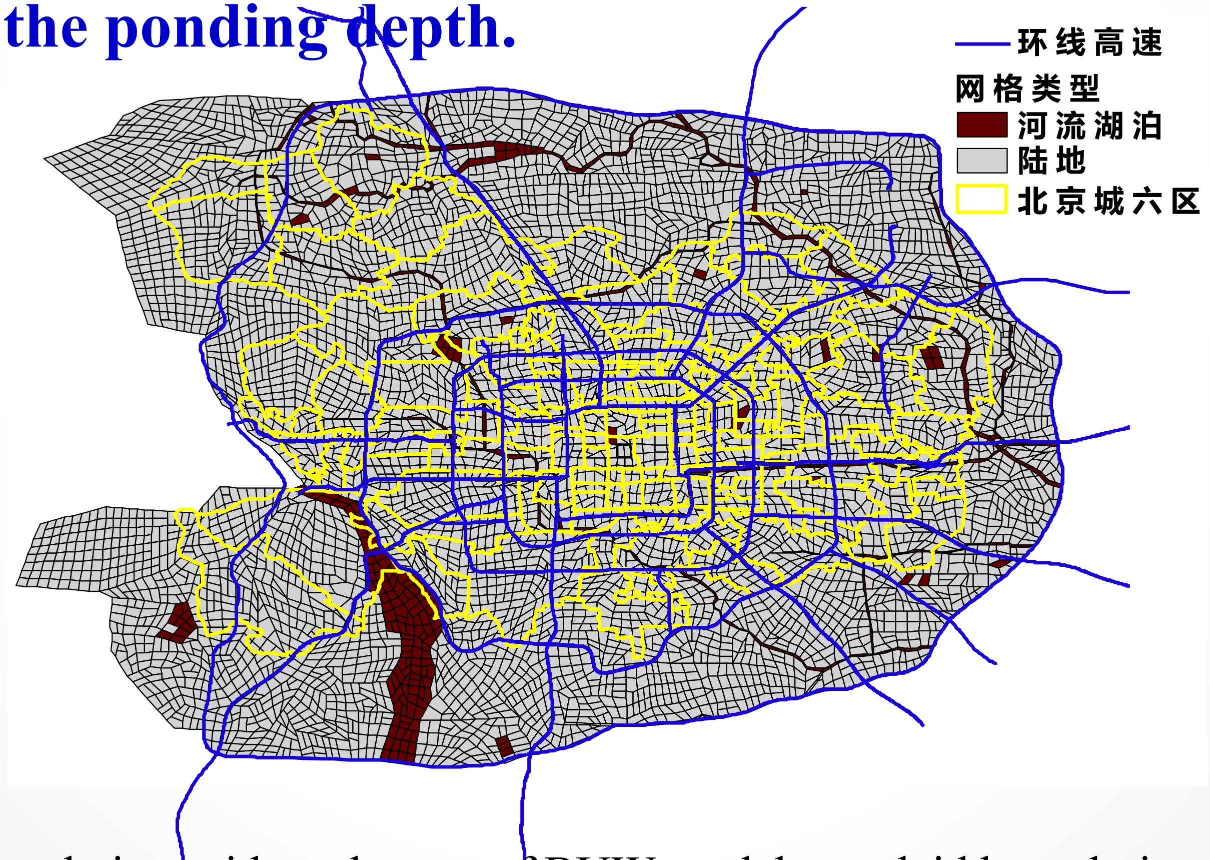


Fig.1 Simulation grids and range of BUW model, overlaid boundaries and roads

Hydrological Processes on the Surface

2.2.1 地表水文过程基本原理

BUW 模型应用有限体积法的思想，为反映城市复杂的地形、地貌特征，采用无结构不规则网格设计计算区域，以城市地表和明渠河道水流运动为主要模拟对象。地表水文过程的基本控制方程以平面二维非恒定流方程[6]为骨架。

二维非恒定流基本方程如下：

连续方程：

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

动量方程：

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

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

式中，H 为水深；Z 为水位，q 为源汇项，也就是径流量；M，N 分别为 x，y 方向上的单宽流量，且 $M=Hu$，$N=Hv$；u，v 分别为流速在 x，y 方向上的分量；n 为糙率；g 为重力加速度。

- Driven by the rainfall data
- Elevation is the most important factor
- Flow on the surface and in the river is the main object simulated.

Hydrological Processes Underground

2.2.2 地下水文过程基本原理

排水管网及配套的泵、闸、管网出口等组成了自成体系的城市地下水文系统，对城市内涝有很大的影响。在降雨过程中，地面积水在管道内汇集后沿各自管道系统汇合至出口处，再经过出口处的闸门、泵站或淹没出流管道排到河道中，形成“雨水—地面积水—管道汇水—管道排水—河道汇水”的模拟过程。为节约计算资源，模型将管道的属性概化为：（1）经过网格中心，（2）经过网格周边通道的中点与相临网格相连（图 2）。获取全部城市排水管网有极大的难度，考虑到排水管网主要分布在道路下面，部分管网按道路长度概化长度，按道路等级概化管径。排水管网

形式，模型中必须考虑在同一

一维明渠流动：

连续方程： $\frac{\partial y}{\partial t} + U$

动量方程： $g\frac{\partial}{\partial}$

一维有压流动：

连续方程： $\frac{\partial H}{\partial t}$ (5)

$\frac{\partial H}{} \quad \frac{\partial U}{} \quad U\frac{\partial U}{}$

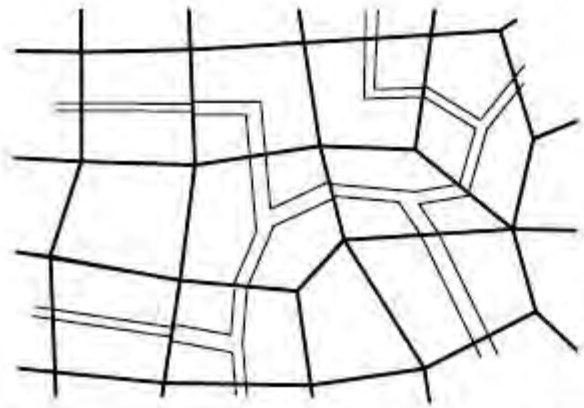


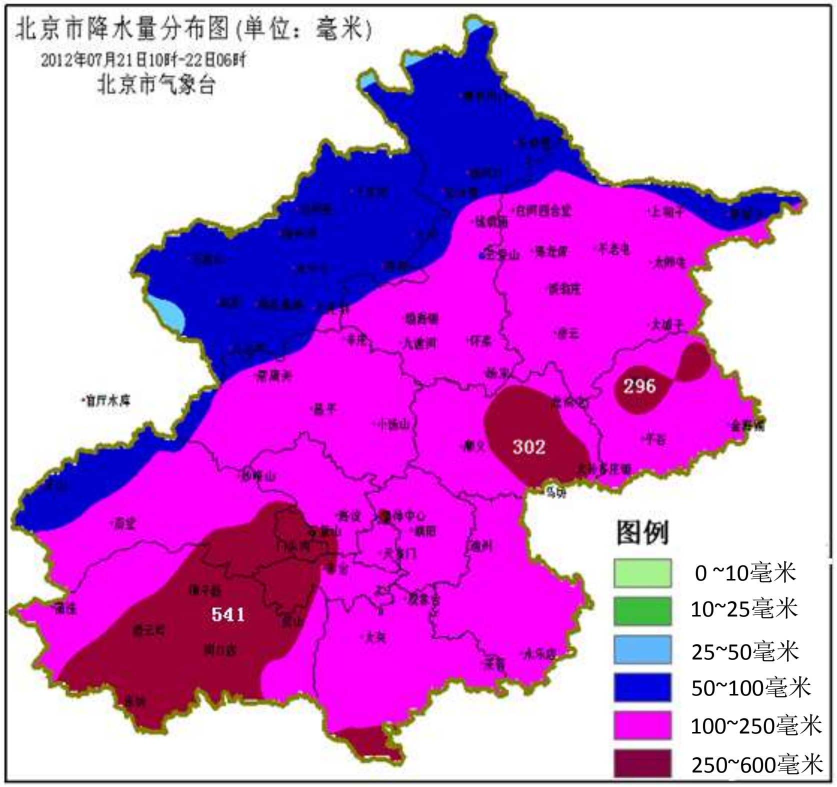
图 2 排水管网概化示意图（双管线为管网，单实线为网格通道）

Fig.2 generalization of drain network (double line denotes pipe and single line denotes grid boundary)

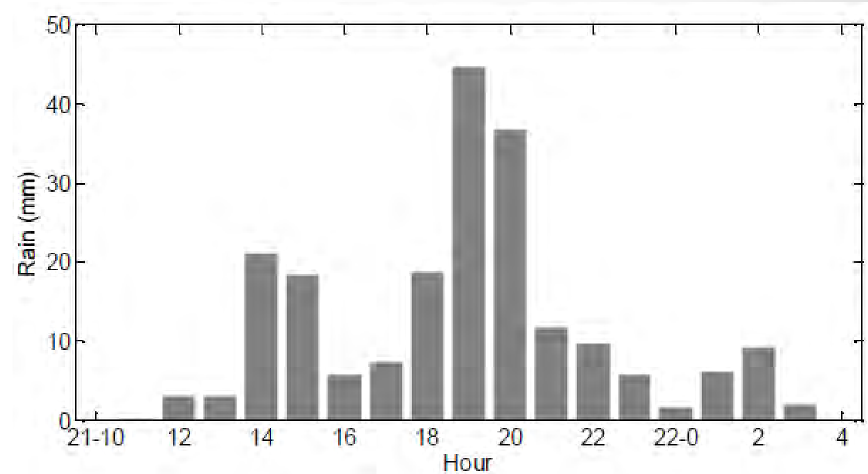
- **Physical Process:** **Rainfall-Ponding-Pipe Catchment-Pipe Drainage-River Catchment**
- **The drainage network is not real and estimated from roads.**

断面的过水面积，U 为断面的单宽流量，S_f 为摩阻坡降。

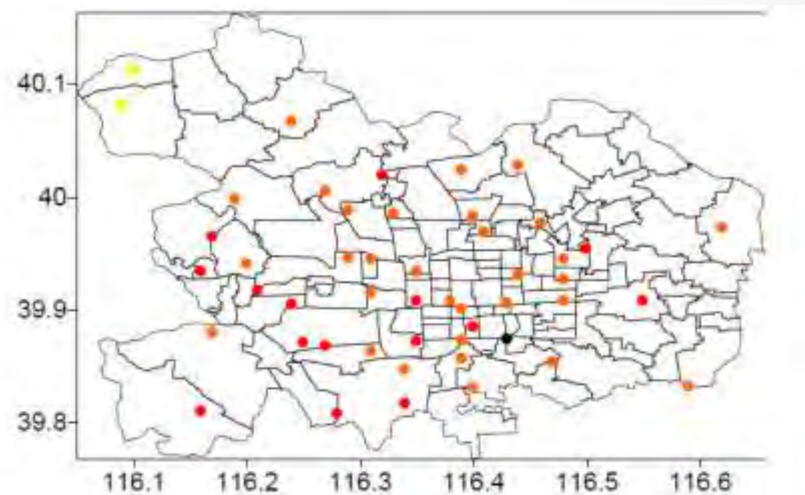
CASE: Torrential Rainstorm on 21 JUL 2012



Precipitation, maximum=541mm



Rainfall intensity in urban area from 10AM to 10PM

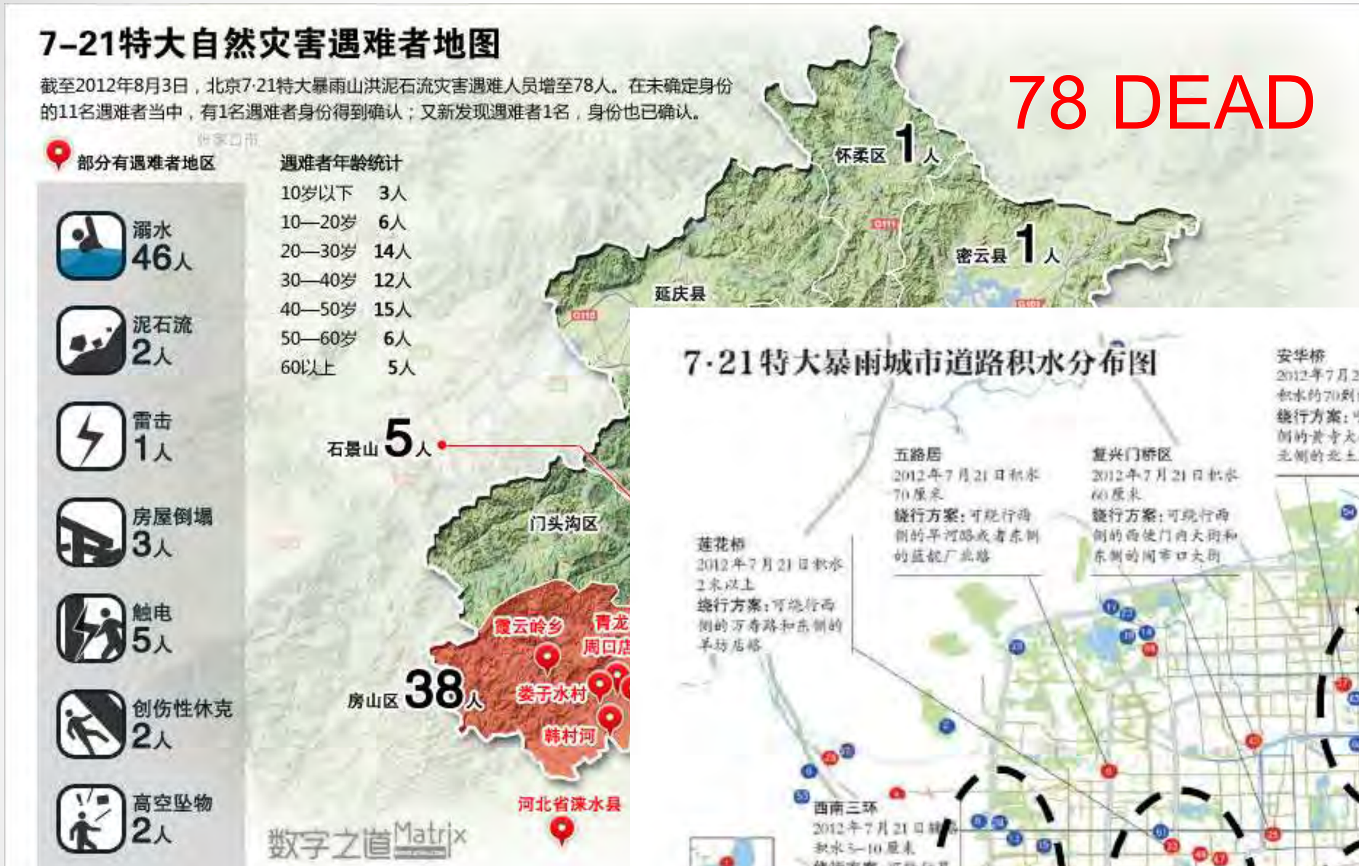


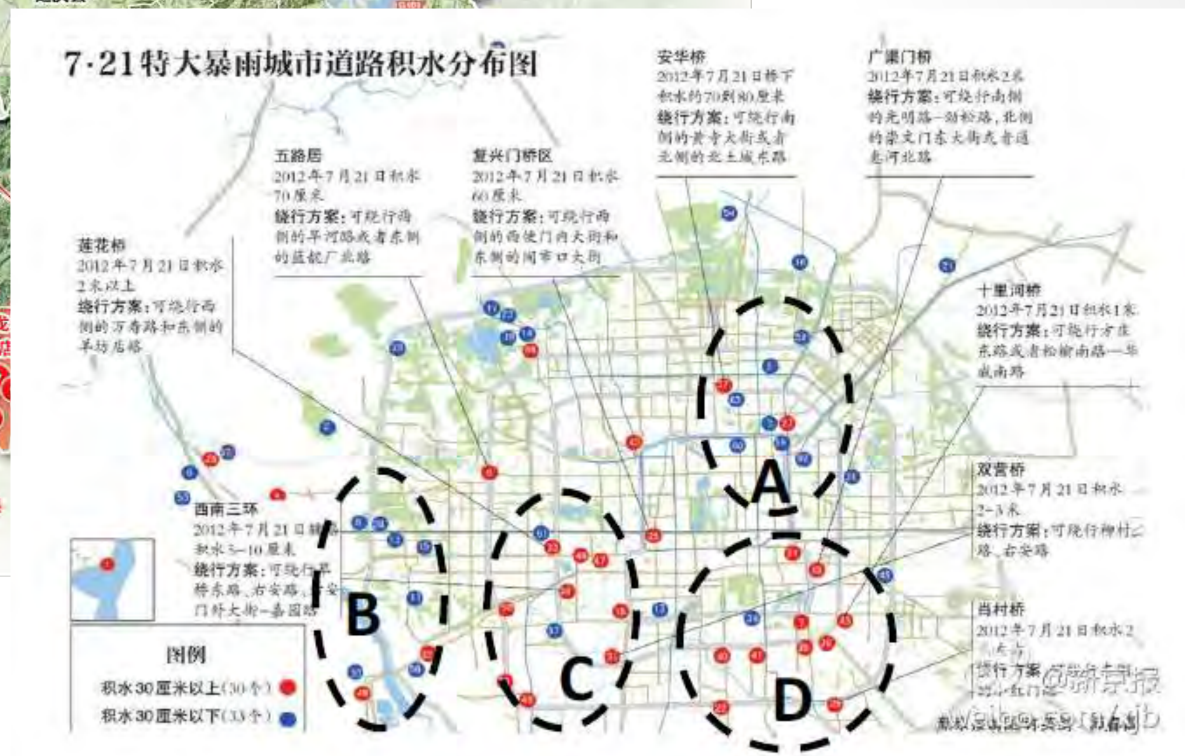
- The warning grade which the maximum rainfall intensity achieved, (blue>20, yellow>30, orange>40, red>60, black means no warning, unit: mm/h)

CASE: Torrential Rainstorm on 21 JUL 2012

CASE: Torrential Rainstorm on 21 JUL 2012

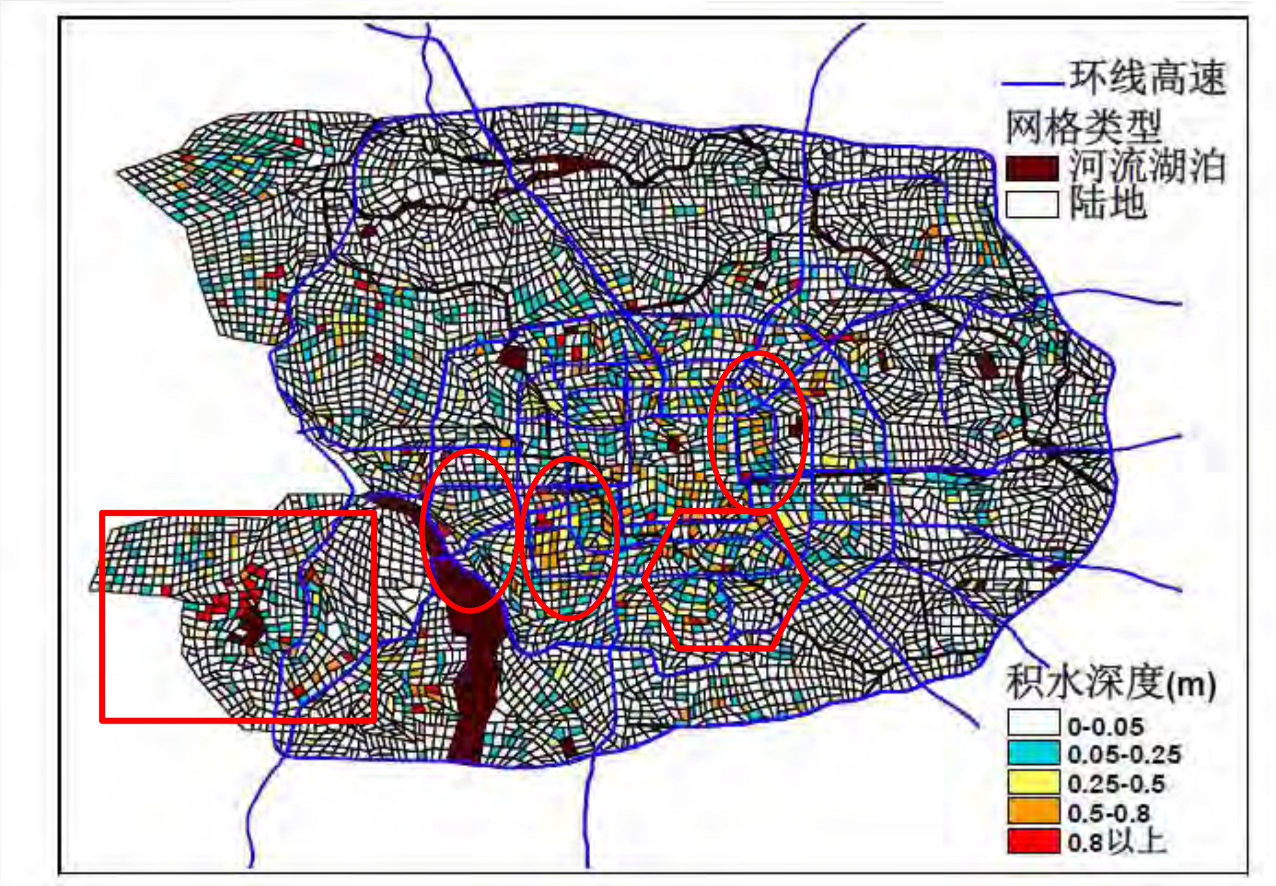
78 DEAD





Distribution of urban road ponding

CASE: Torrential Rainstorm on 21 JUL 2012



1. Simulated spatial distribution well.
2. The depth in ABC areas is close.
3. The hard-hit Fangshan can be reflected.

But, the depth of area D is obviously lower.

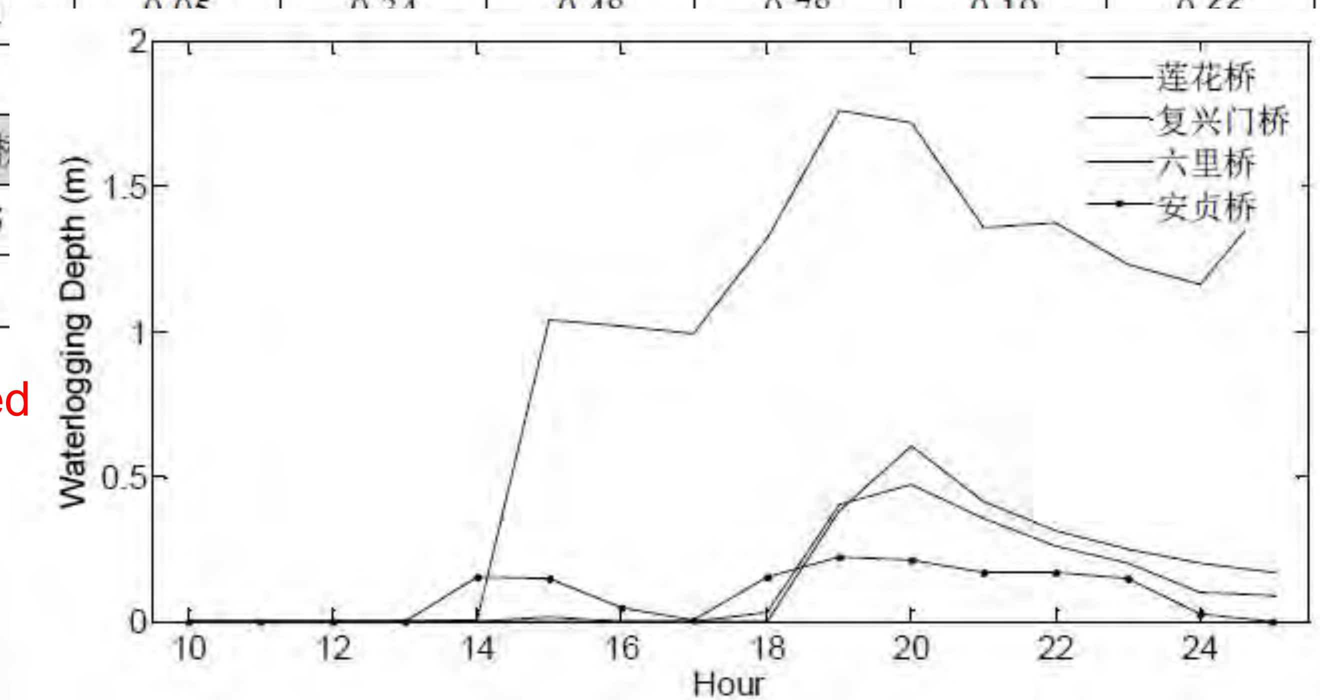
Maximum ponding depth simulated by BUW

CASE: Torrential Rainstorm on 21 JUL 2012

Comparison between simulation and observation of "7.21" depth in concave bridge

Bridge	莲花桥	五路桥	复兴门桥	安华桥	广渠门桥	十里河桥	双营桥
Simulation	1.77	0.65	0.61	0.62	0.67	0.69	0.64
Observation	>2	0.7	0.6	0.7-0.8	2	2	2-3
Bridge	金安桥	西苑桥	丽泽桥	六里桥	正阳桥	安定门桥	东便门桥
Simulation	0.41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Observation	0.3						
Bridge	安贞桥						
Simulation	0.25						
Observation	0.3						

The depth simulated is almost slightly lower, but usable.



Simulation curves of hourly ponding depth in bridge zone

OTHER CASES: Four Combinations

Long-Time Small-Intensity Type: 11 AUG 2013

Short-Time Big-Intensity Type: 23 JUN 2011

Short-Time Small-Intensity Type: 17 JUN 2013

Long-Time Big-Intensity Type: 21 JUL 2012

The spatial distribution, ponding time, duration, process, specially the maximum depth can be simulated well by BUW model for the four different combinations.

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Urban ponding simulation in different return-periods

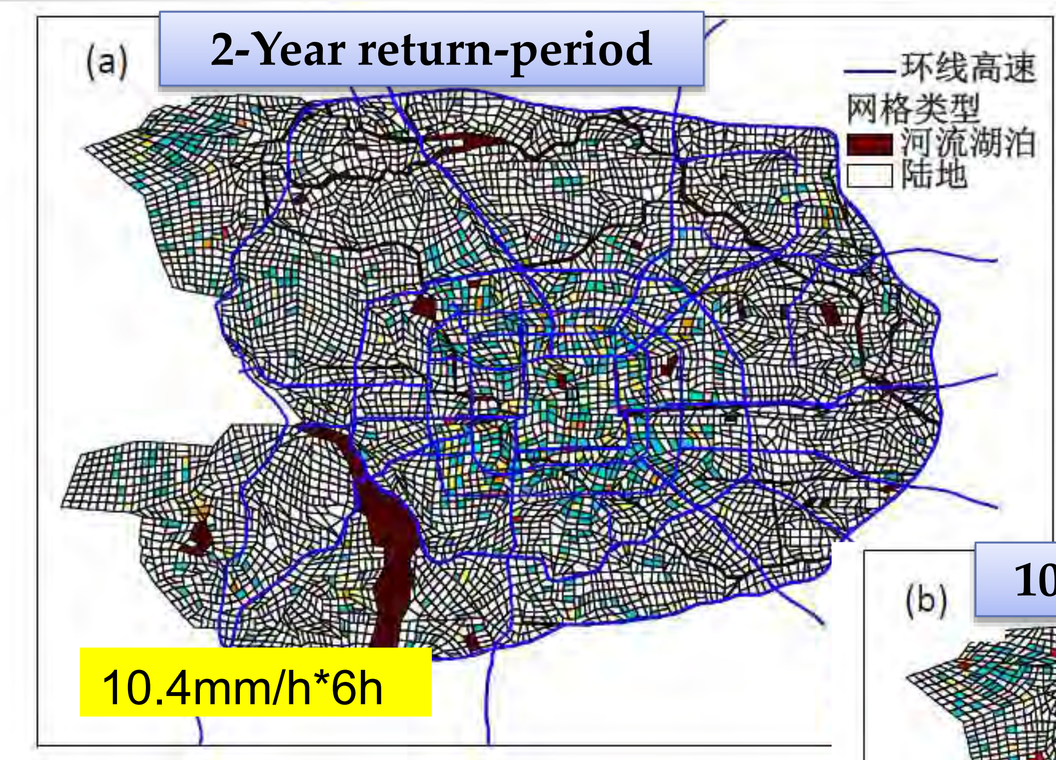
The rainfall data-by-minute are used by Generalized Pareto Distribution (GPD) method to determined the 360-minute rainfall in different return-periods.

2-Year return-period	62.4mm

Represent the standard of drainage networks used in Beijing now.

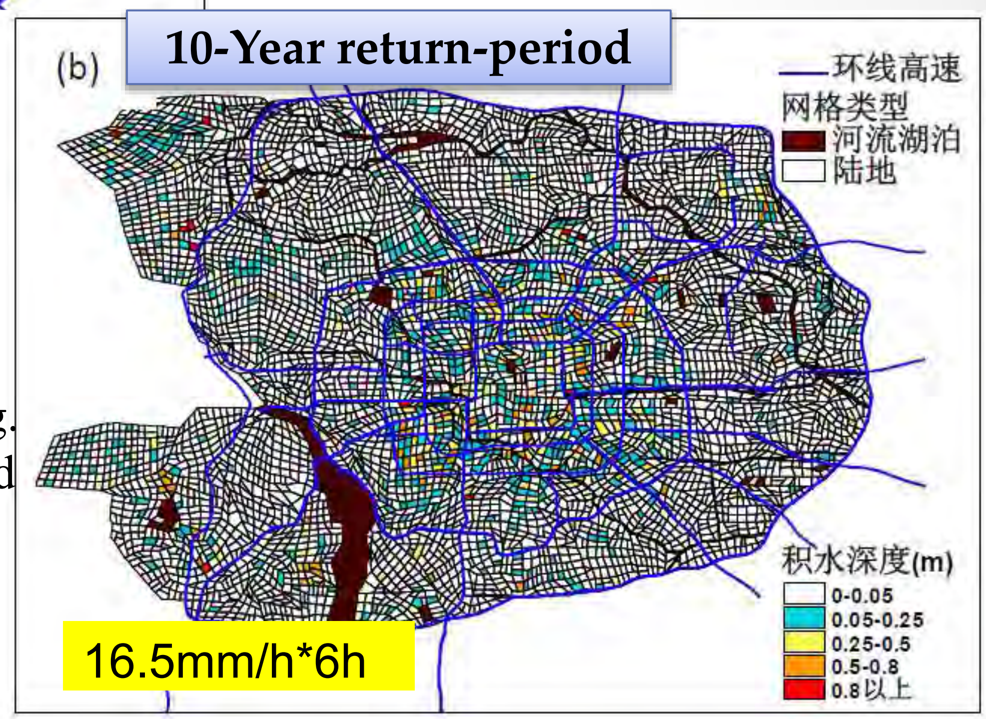
10-Year return-period	98.8mm
50-Year return-period	157.1mm
100-Year return-period	208.2mm

Sequence: 34.7, 34.7, 34.7, 34.7, 34.7, 34.7, 0, 0, 0, 0, 0

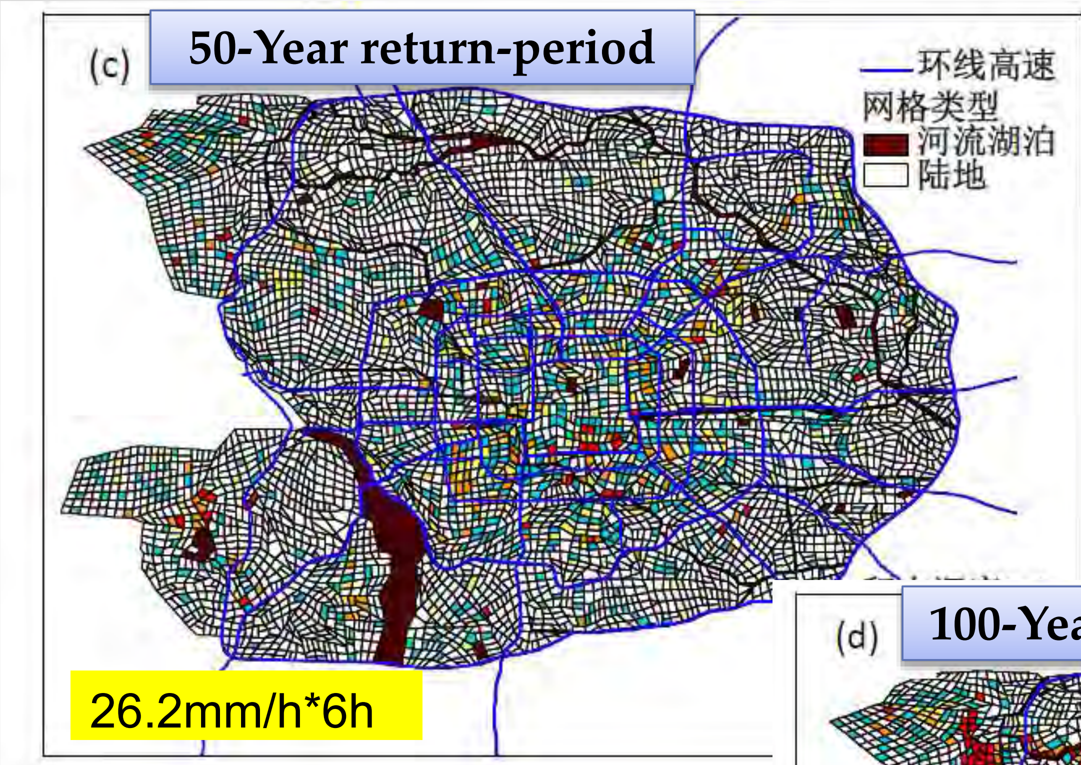


- There would be some isolated ponding points inside 4-Ring.
- And the ponding point occurred more in the south than in the north, mostly bellow 25cm.

- Deeper and joint ponding inside 4^{th} Ring.
- New ponding area between 4^{th} and 5^{th} Ring.
- Diminishing scale from east to the west and from south to the north

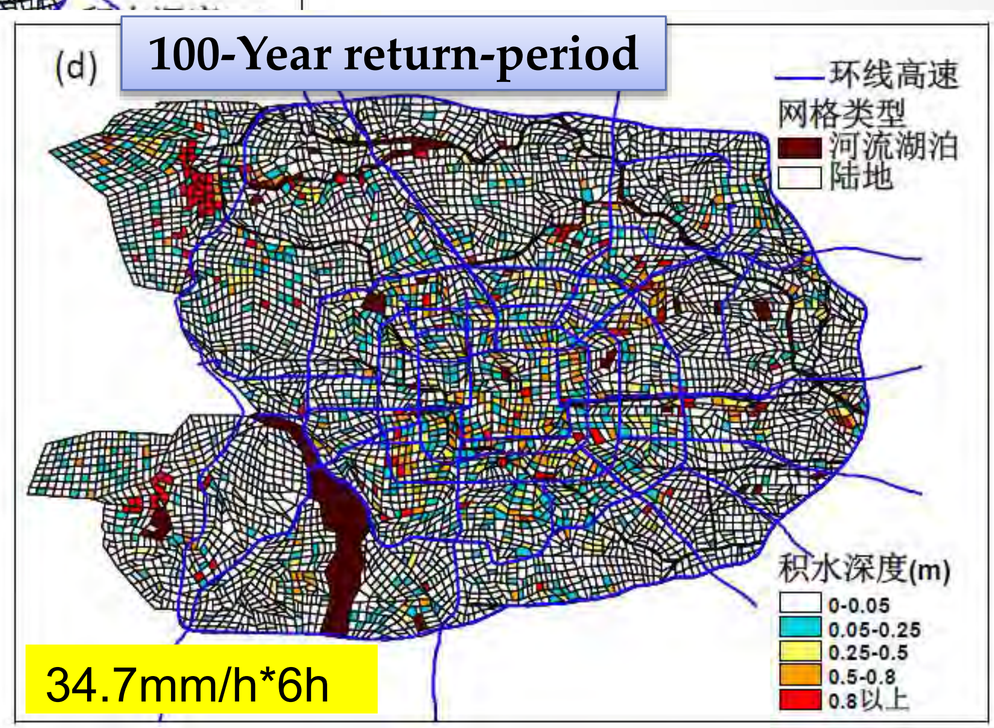


Maximum ponding depth simulated under 2-yr (a), 10-yr (b) return-period scene



- More serious ponding points inside 5-Ring (25-80cm).
- Deeper than 50cm gushed water around QINGLENG lake.

- Server ponding in the whole 5-Ring, most exceeding 50cm in the south.
- Ponding deeper than 80cm maybe caused by flash flood and concave bridge.



Maximum ponding depth simulated under 50-yr (c) and 100-yr (d) return-period

Faced the rainfall of "7.21" in different drainability

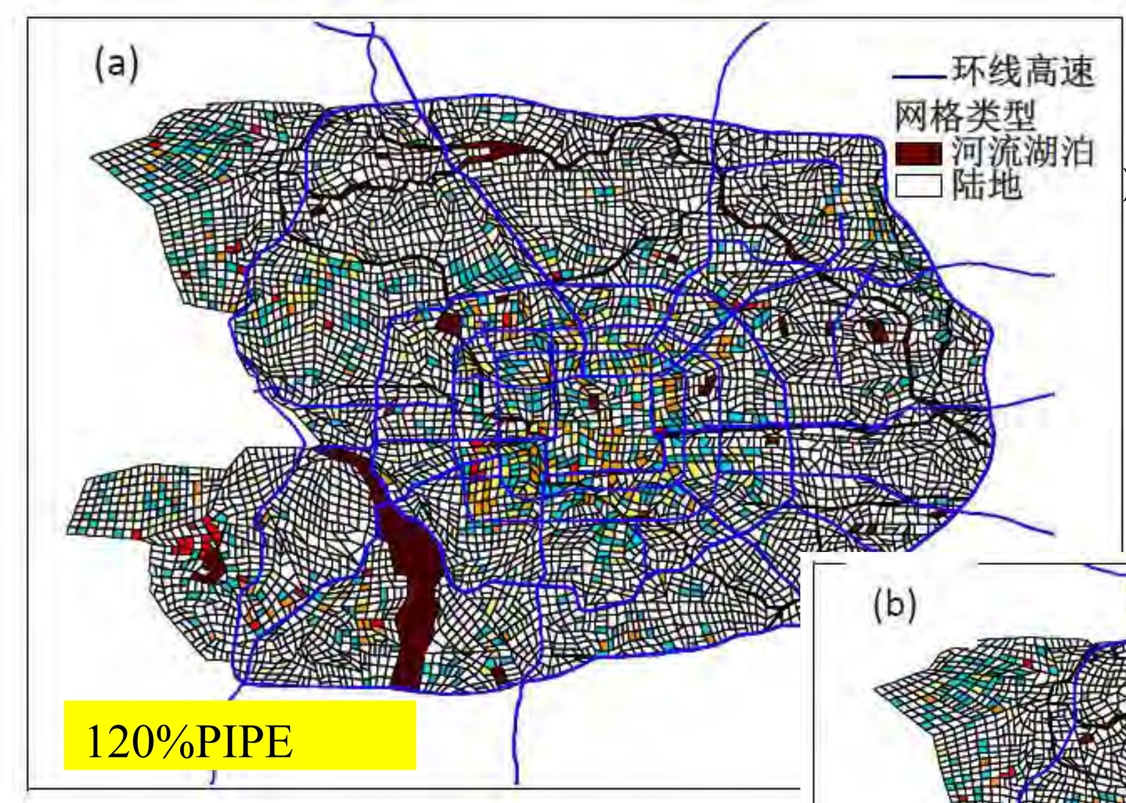
20% broadening of pipe diameter (120%PIPE)

60% broadening of pipe diameter (160%PIPE)

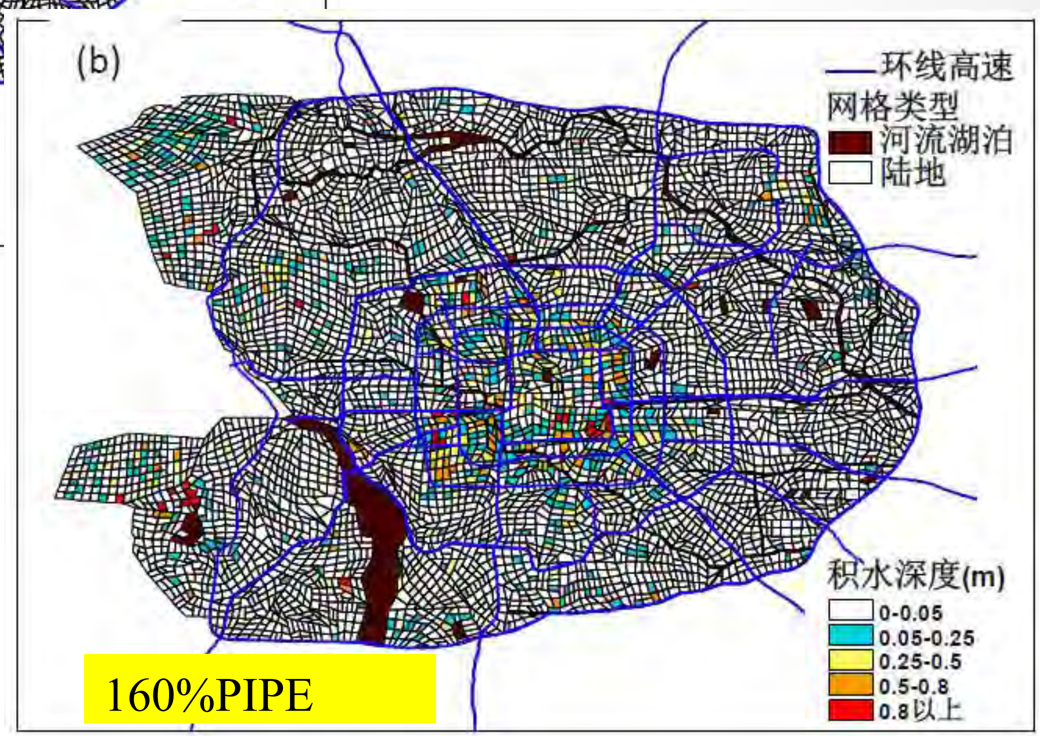
100% broadening of pipe diameter (200%PIPE)

140% broadening of pipe diameter (240%PIPE)

To assess the role of drainage network and supply for modified plan

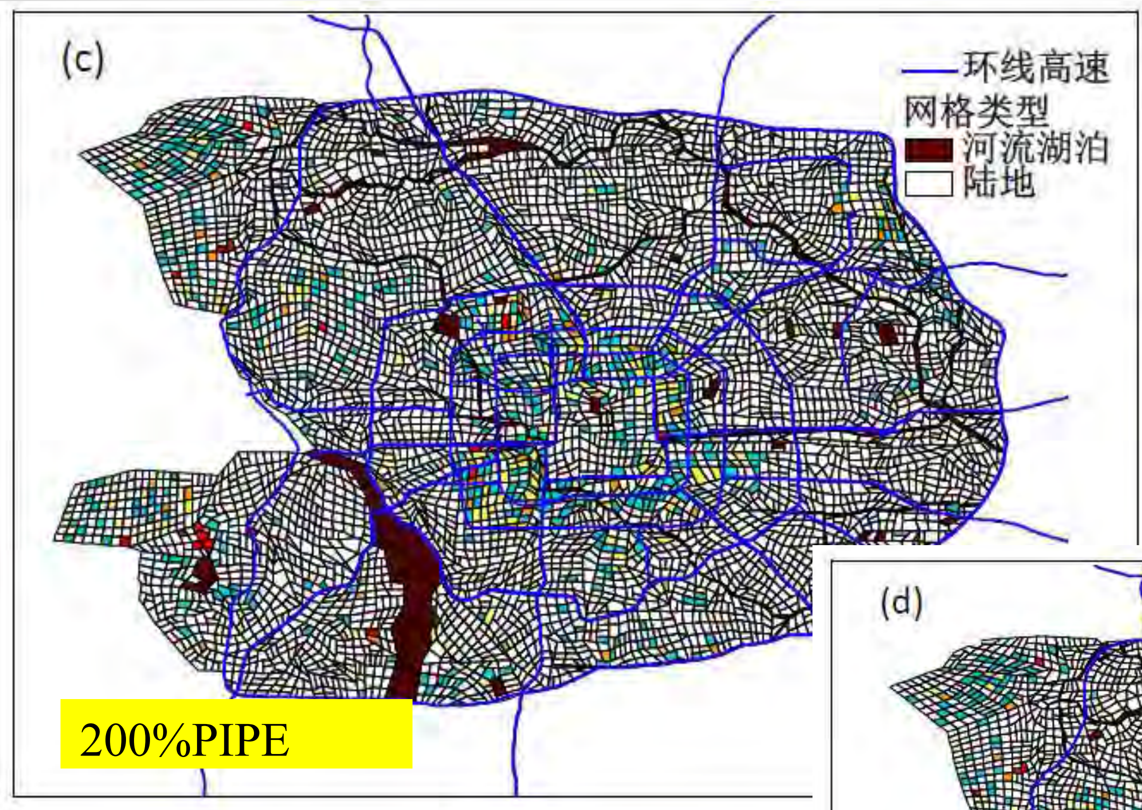


- Urban drainage would not be improved obviously with 20% broadening of pipe diameter.



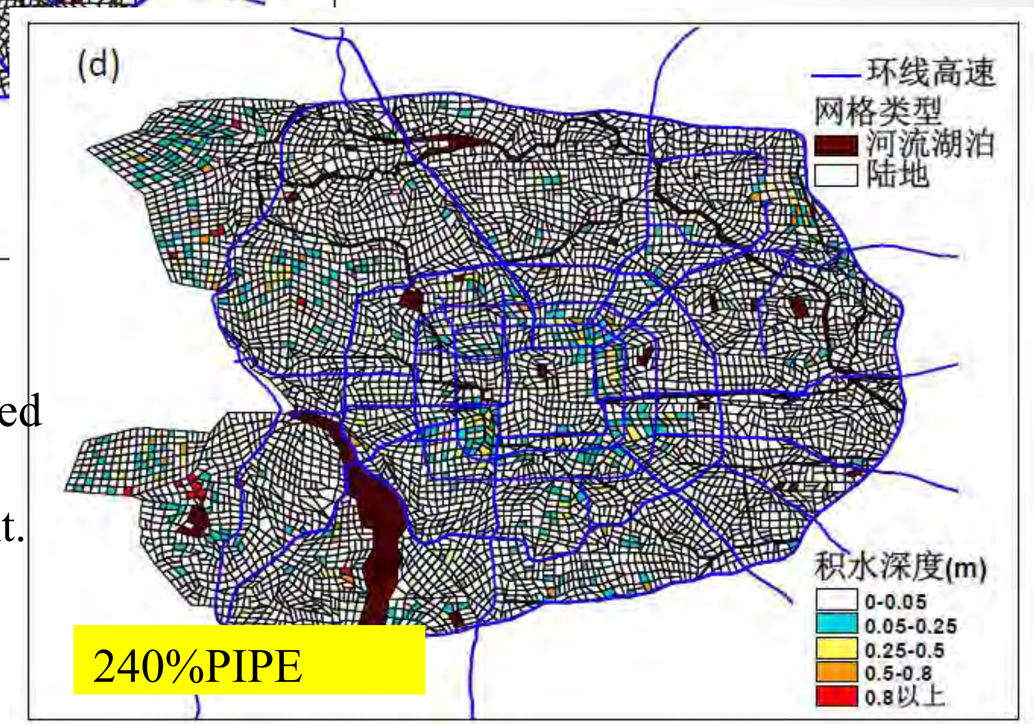
- The ponding weakened distinctly between 4-Ring and 5-Ring and slightly inside 4-Ring in 60%+PD experiment.

Max ponding depth in “7.21” rainstorm with 1.2 (a), 1.6 (b) times pipe diameter



- There would be only shallow ponding between 2-Ring and 4-Ring in 100%+PD experiment.

- When the pipe diameter were broadened continuously, there would no ponding inside 6-Ring in 140%+PD experiment.



Max ponding depth in "7.21" rainstorm with 2.0 (c), 2.4 (d) times pipe diameter

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- **Risk Warning and its Application**
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Risk Warning Grades:

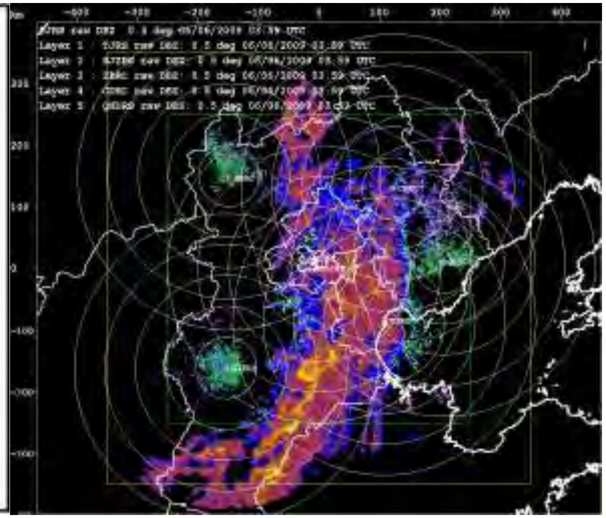
1. According to fording depth of motor vehicles

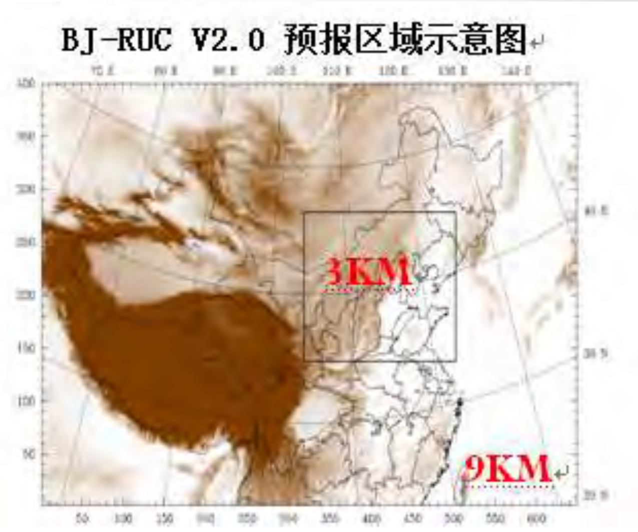
Type	Fording Depth（mm）
Heavy Truck	1000-1200
Truck	450-800
Large Bus	500-800
Medium Bus	280-750
SUV	390-850
Car	270-600

2. Dividing Ponding Depth into 4 grades

Grades	Range (mm)	Affected Reference
Blue	100≤PD＜250	Pedestrian
Yellow	250≤PD＜500	Car, SUV and Medium Bus
Orange	500≤PD＜800	Large Bus and Truck
Red	PD ≥800	Heavy Truck

The rainfall configuration for BUW's input





5-hr observation

6-hr QPF-Blending Rain

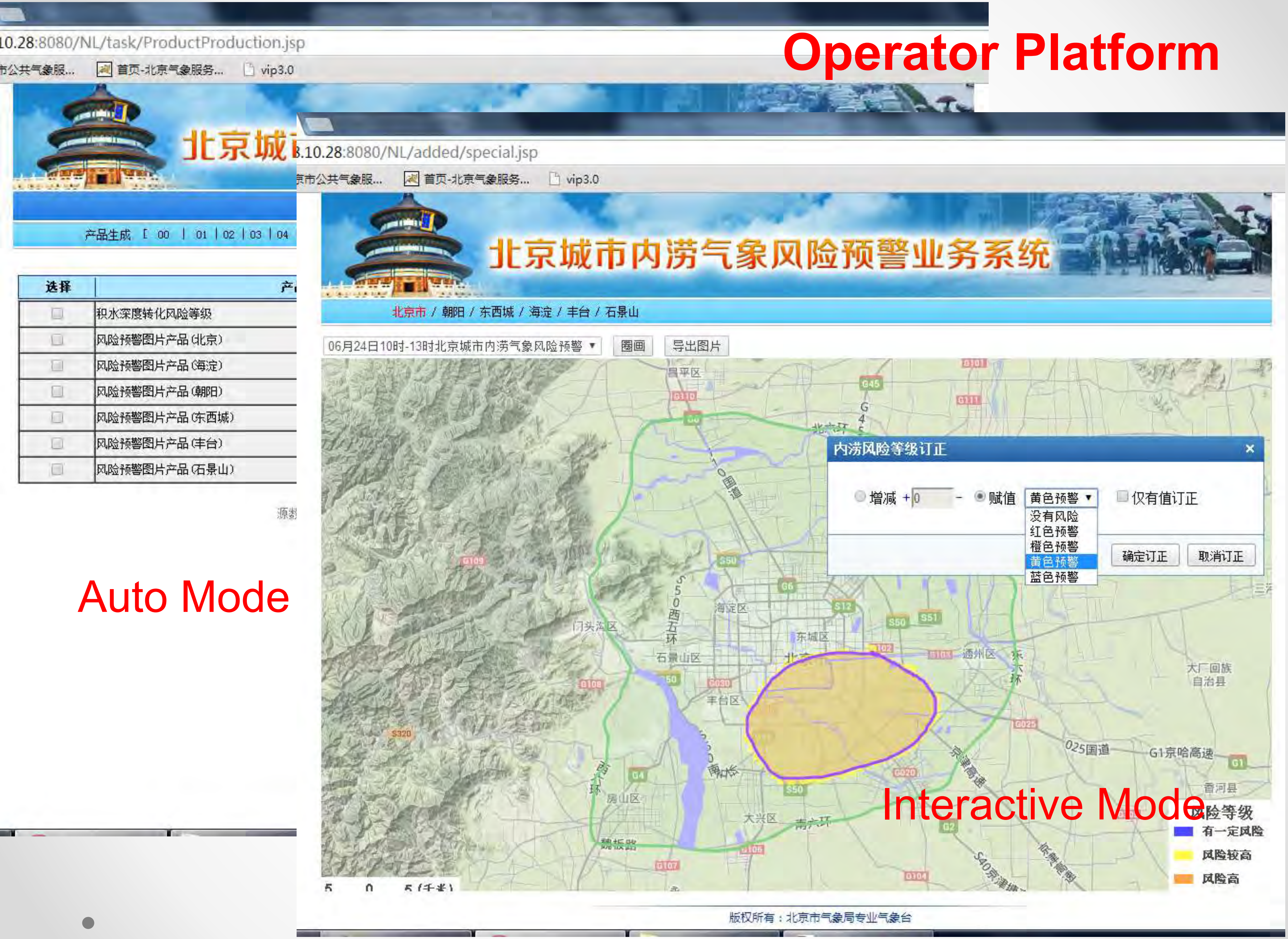
6-hr BJ-RUC Rain

12-hr forecast

In actual service, three rainfall sequences are connected to drive the BUW model.

- The first 5-hr rainfall observation is used for spining-up and initializing ponding depth and pipe flow.
- The second 6-hr blending QPF and last 6-hr BJ-RUC rainfall forecast is used for simulating and forecasting the next 12-hr urban waterlogging risk.

Operator Platform



Service Platform

Furthermore, a decision-making service system based on GIS was built to improve service effect. The ponding observation data and urban waterlogging risk warning update timely in this platform.

2006年
模型初建

2011年
排水集团

2012年
服务系统

2013年
模型重构

2014年
风险预警

2015年
区县预警

2016年
桥+地铁……

其他：

- 北京道路交通气象灾害监测预警服务系统
- 北京城市内涝气象灾害监测预警服务系统
- 北京城市极端天气事件灾害风险管理系统
- “北京气象”应急决策（智能手机APP）
- 物联网交通保畅
- 城市气象灾害保障服务系统
- 城市安全运行气象保障服务系统
- 北京市排水集团专业服务网站
- 北京道路天气通
- ……

Probably 10 service platform used our product, mostly for decision-making

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- Update the GIS data and drainage networks.
- Improve the description of concave bridge and foreign water.
- Develop the Road Ponding Model.
- Use the MPI parallel computing to raise efficiency.
- Add mountain boundary to suit the terrain in Beijing.
- Learn international achievement and improve BUW

Thank you