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**KU LEUVEN**



# 1D, 2D and hybrid surface flow models

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RAINGAIN INTERNATIONAL WORKSHOP  
ON URBAN PLUVIAL FLOOD MODELLING  
6 October 2014



# Contents

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1. Urban pluvial flooding
2. Modelling of urban pluvial flooding
3. Dual Drainage concept
4. 1D1D, 1D2D and Hybrid Models
5. 1D2D nested models
6. Conclusions



# Urban Pluvial Flooding

## Extreme rainfall events

Exceed the capacity of the drainage system!

Everything happens quickly – “flash floods”



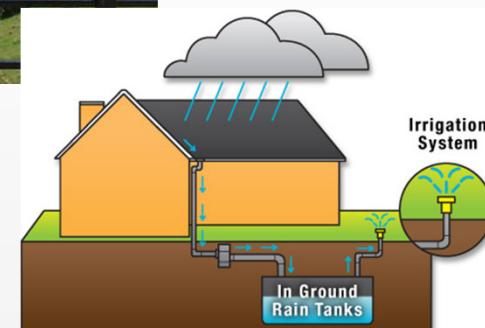
# Urban Pluvial Flooding

## Mitigation solutions?



Improved Forecasting and Event Management

Advanced (Water Sensitive) Urban Planning



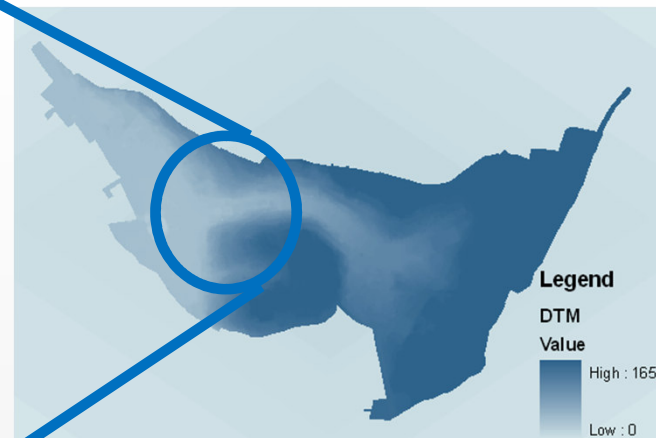
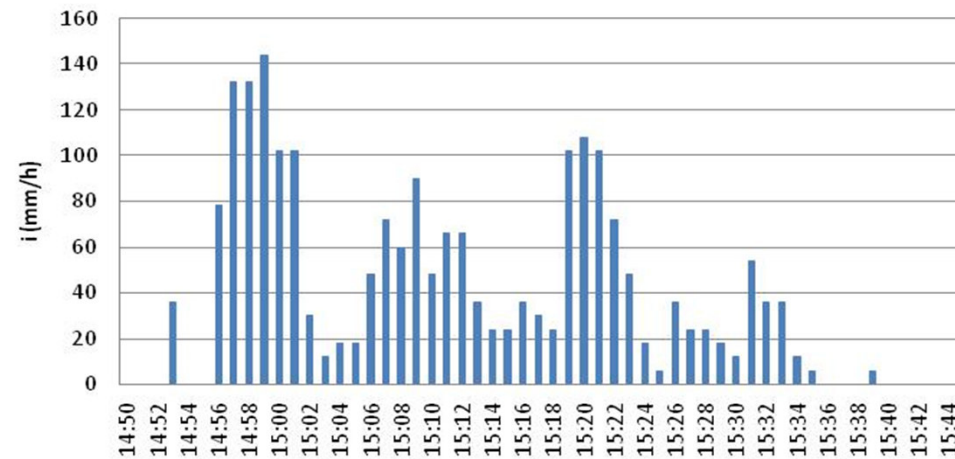
# Modelling of Urban Pluvial Flooding

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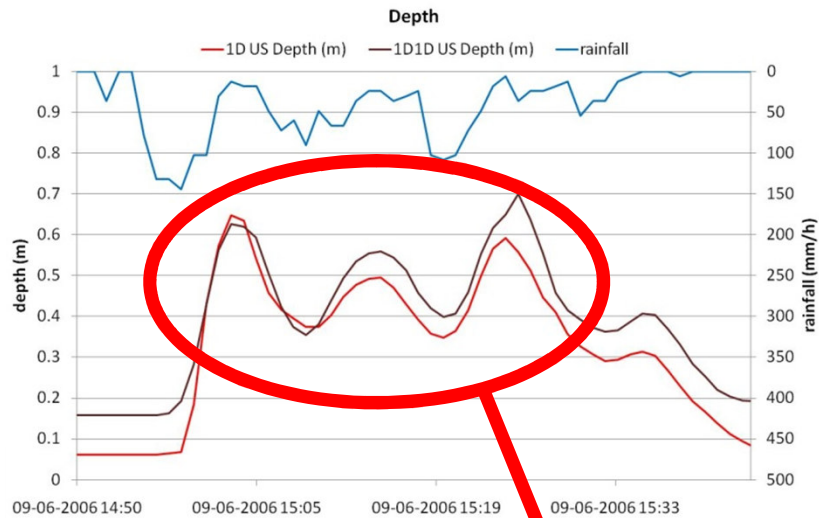
## Physically based modelling

- Realistic presentation of the terrain and physical features
- Use of mass and momentum conservation principles / equations
- Spatially and temporally distributed systems

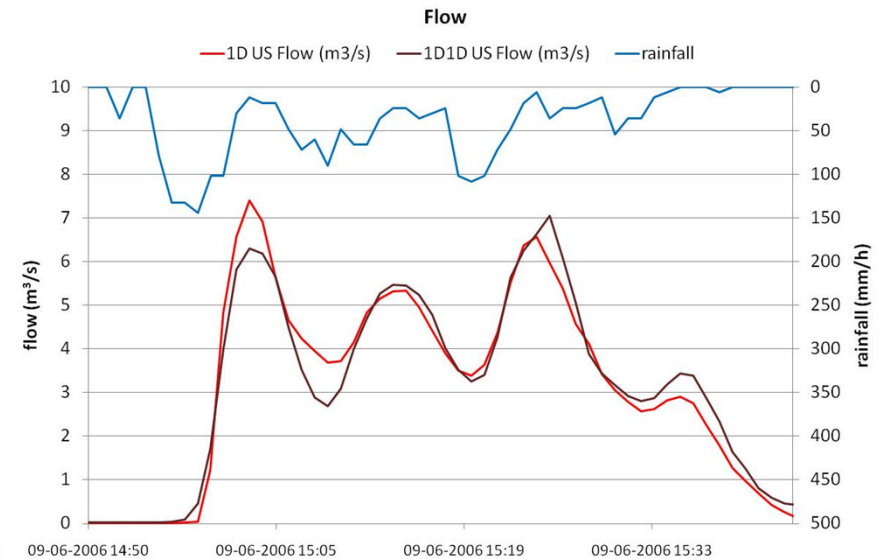
# Modelling of Urban Pluvial Flooding



# Modelling of Urban Pluvial Flooding



Depth level in a pipe upstream the flooded area

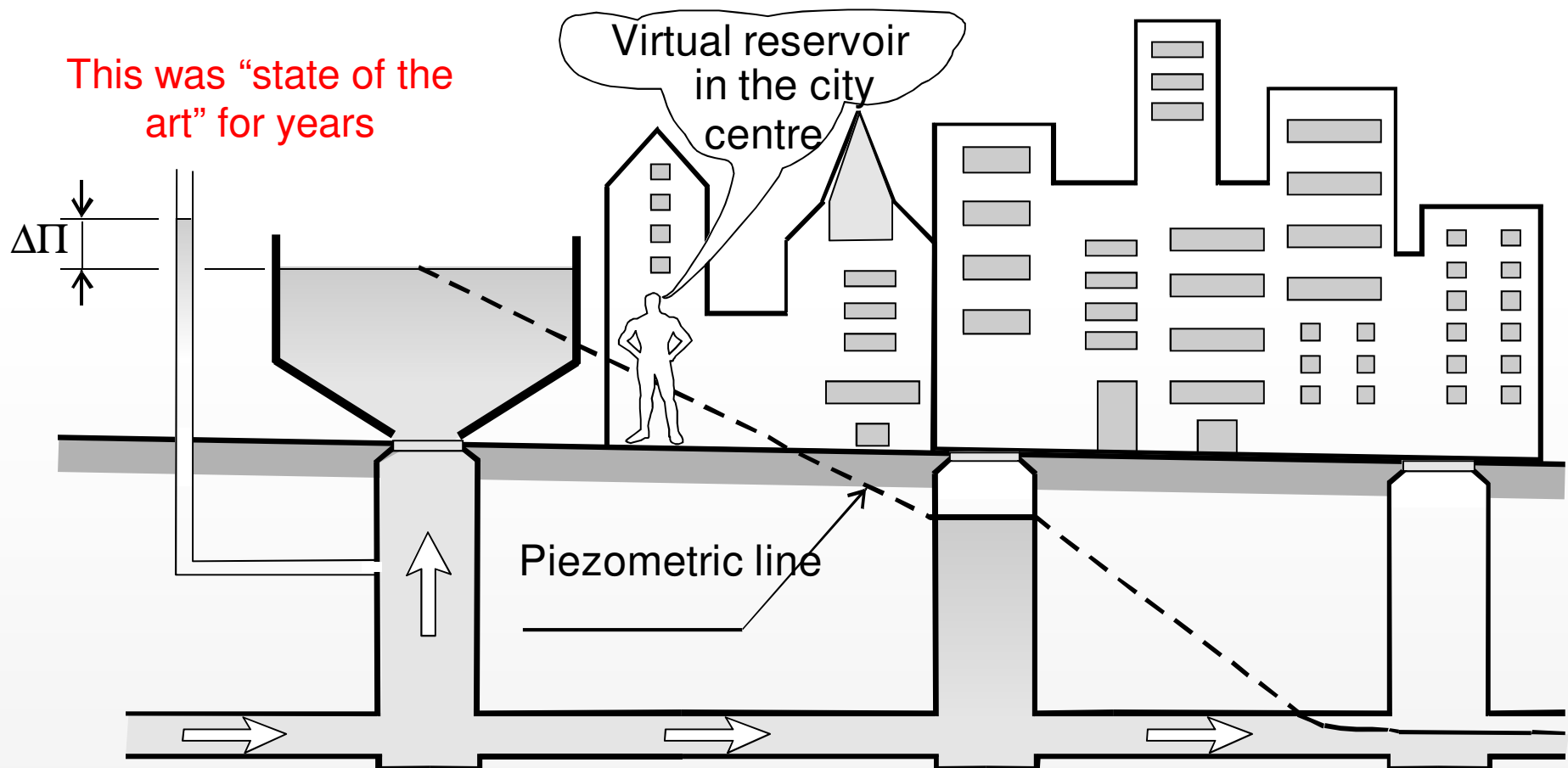


Flow in a pipe upstream the flooded area

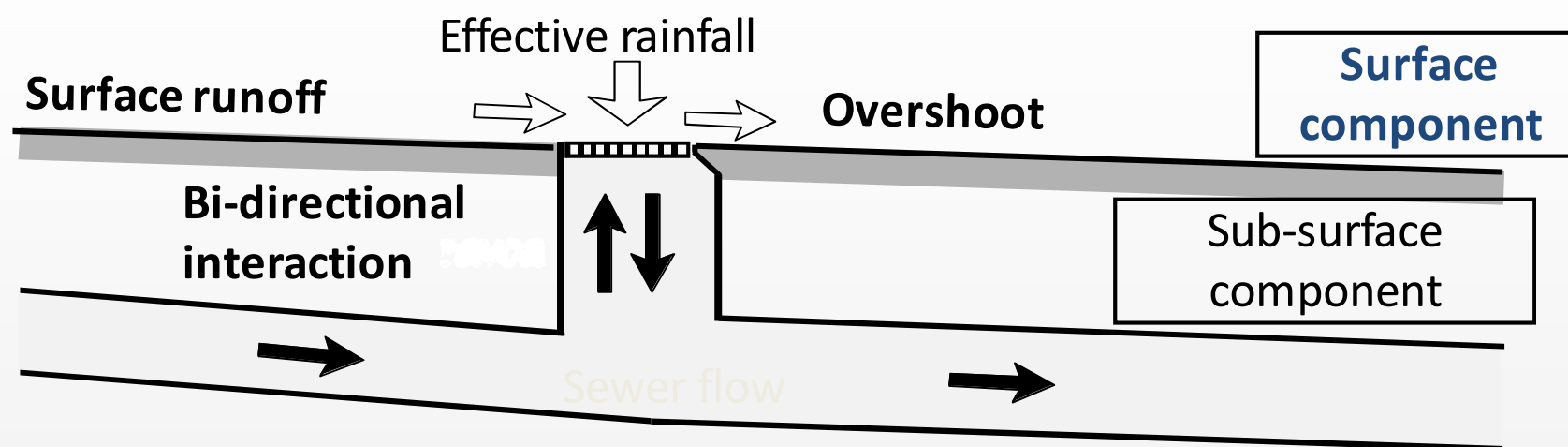
Not surcharged  
But we have pictures with flood!



# Modelling of Urban Pluvial Flooding



# Dual Drainage Concept

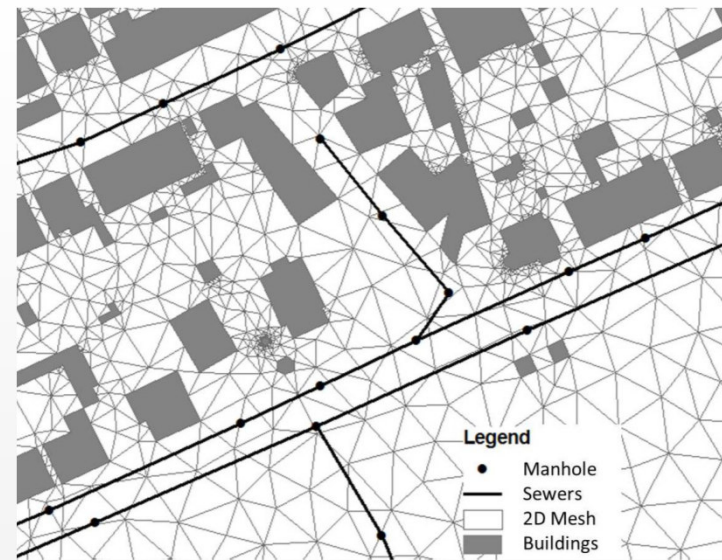
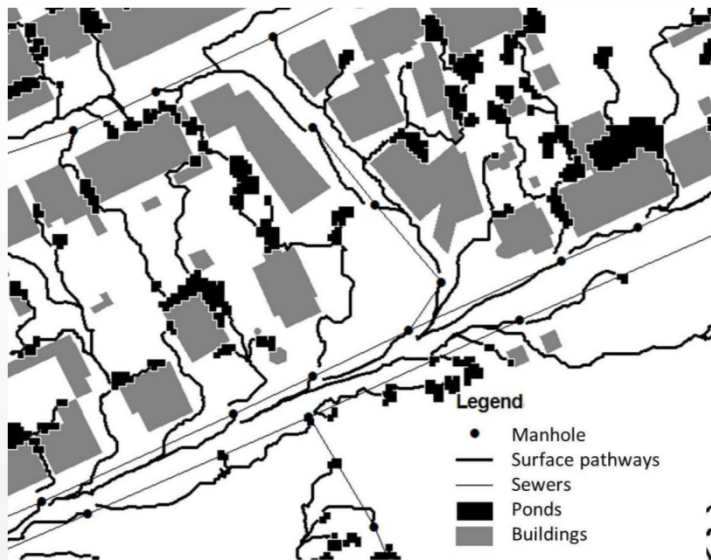


# Dual Drainage Concept

## Dual-drainage concept: **overland network** + **sewer network**

1D overland flow modelling

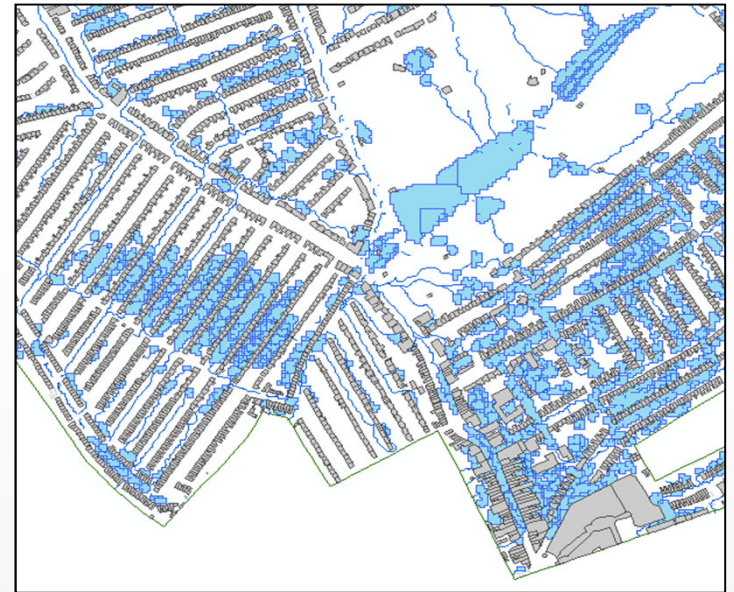
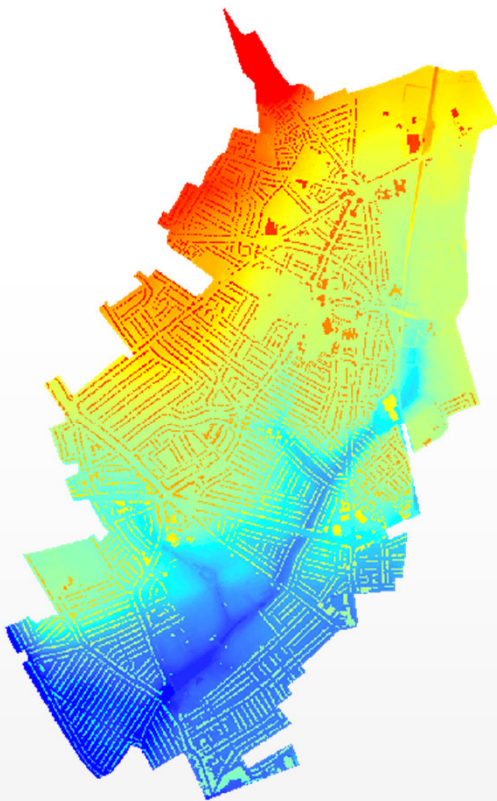
2D overland flow modelling



# Dual Drainage Concept

## 1D overland flow modelling

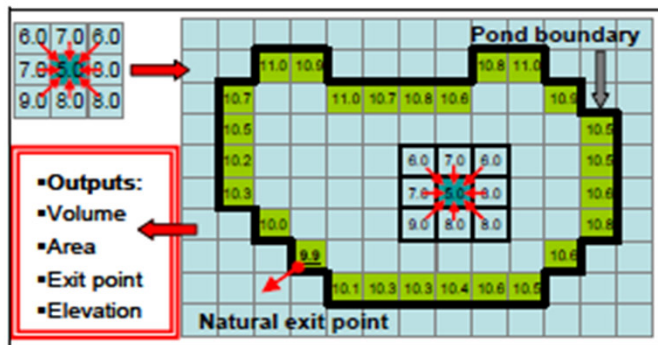
**Nodes** (ponds) and **links** (flow paths), generated based on DEM



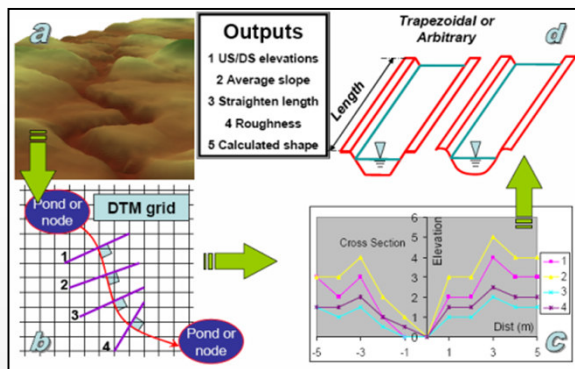
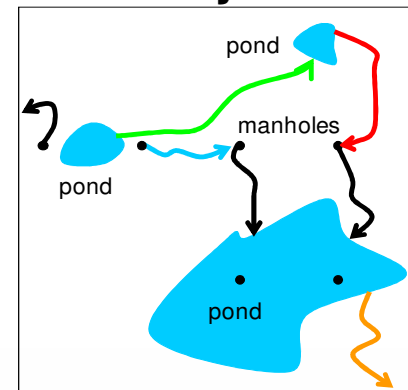
# Dual Drainage Concept

## Automatic Overland Flow Delineation (AOFD)

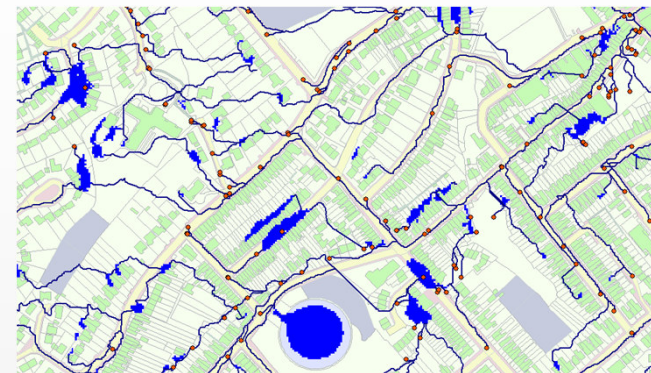
### 1. Pond delineation



### 2. Pathway delineation



### 3. pathways' geometry



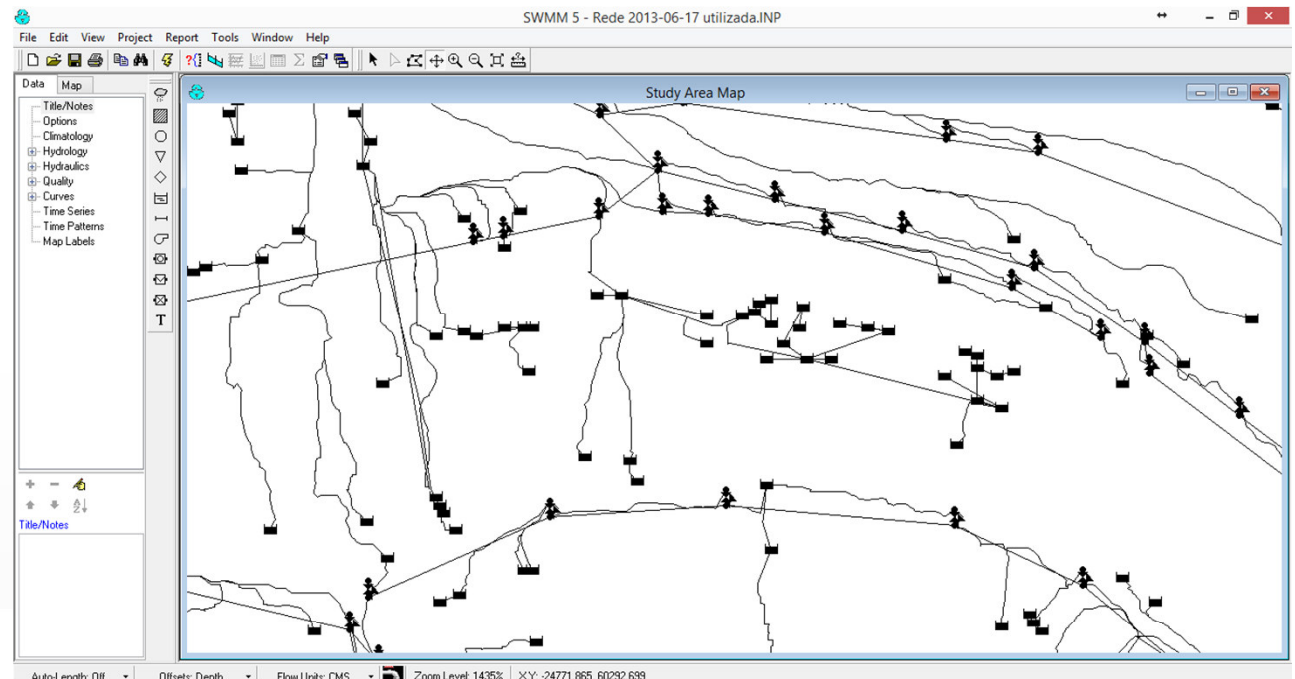
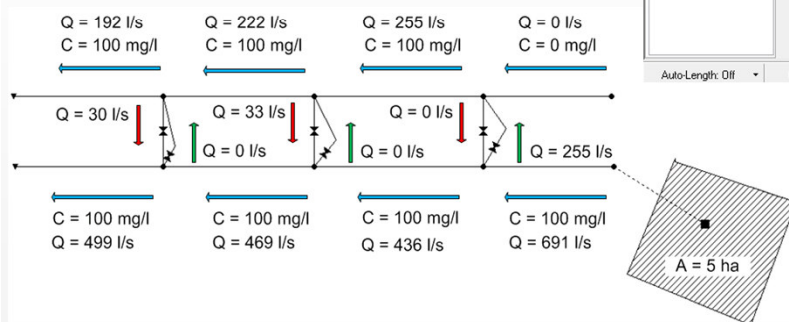
### 4. 1D overland network

# Dual Drainage Concept

## Automatic Overland Flow Delineation (AOFD)

### Coupled

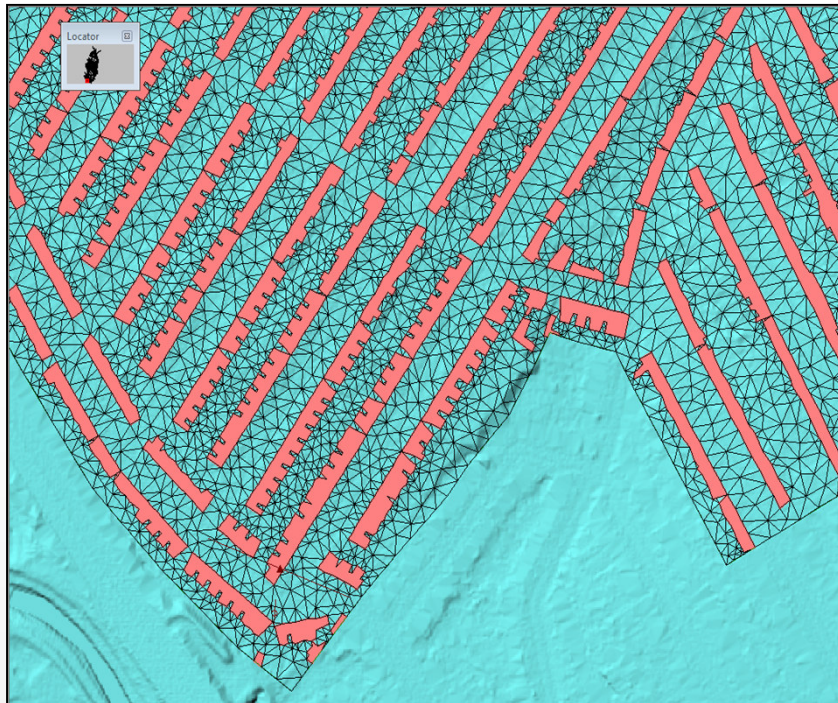
- SIPSON
- INFOWORKS
- SWMM



# Dual Drainage Concept

## 2D overland flow modelling

Surface divided into small elements (squares or irregular triangles)



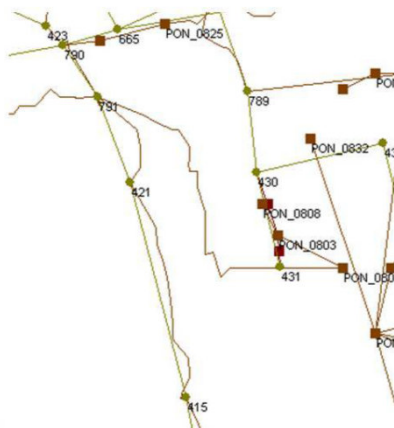
# Modelling of Urban Pluvial Flooding

## 1D-1D Models vs. 1D-2D Models

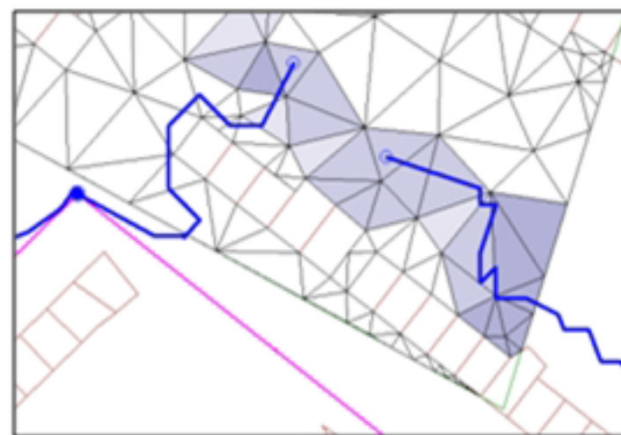
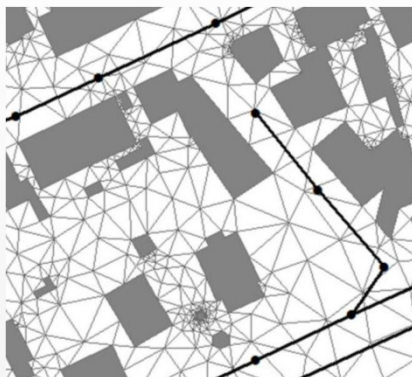
	1D-1D	1D-2D
Detail and Accuracy		✓
Computational time	✓	
Vizualization of results		✓

# Modelling of Urban Pluvial Flooding

**1D / 1D**

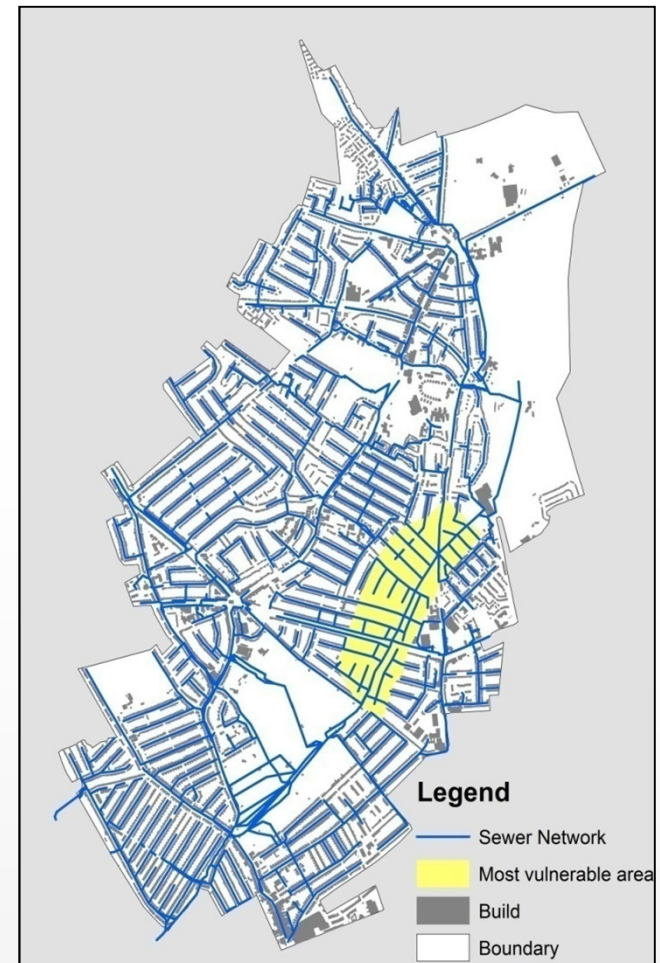
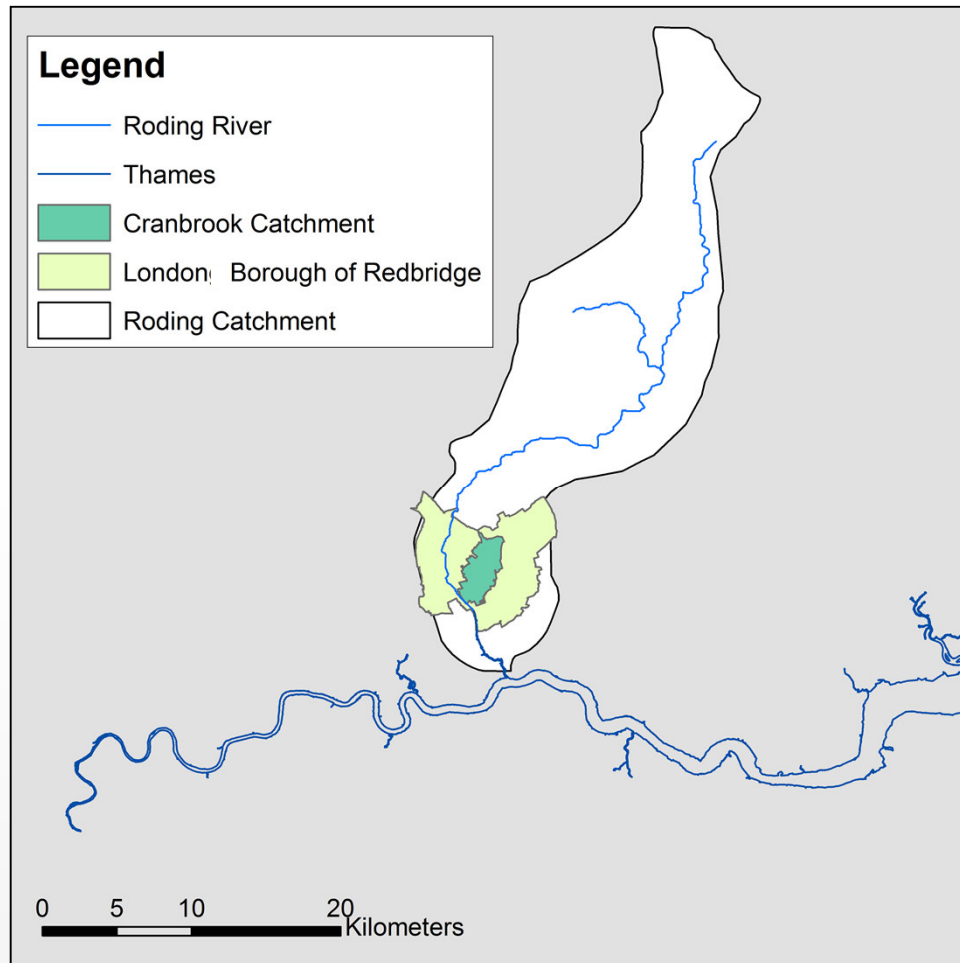


**1D / 2D**



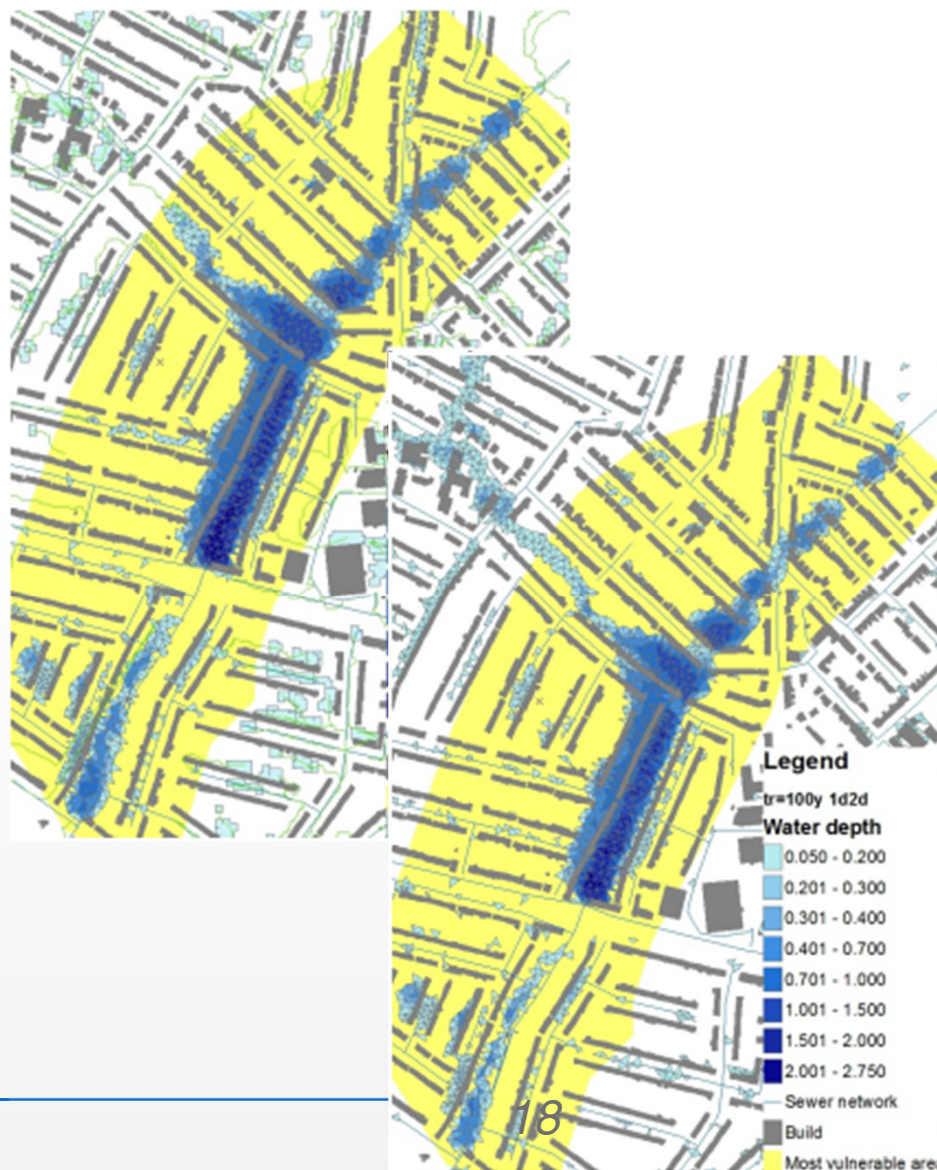
**Hybrid**  
**1D/1D + 1D/2D**

# Case Studies

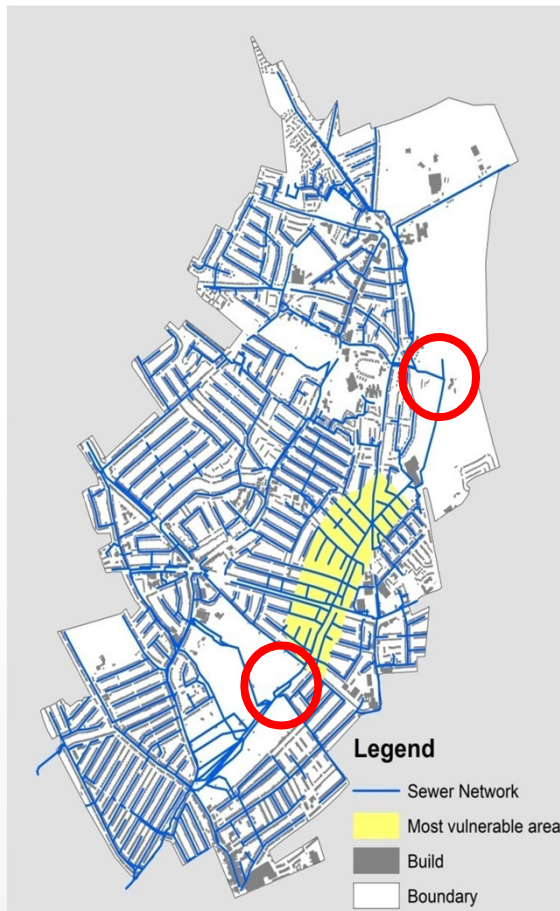


# Hybrid Model Results

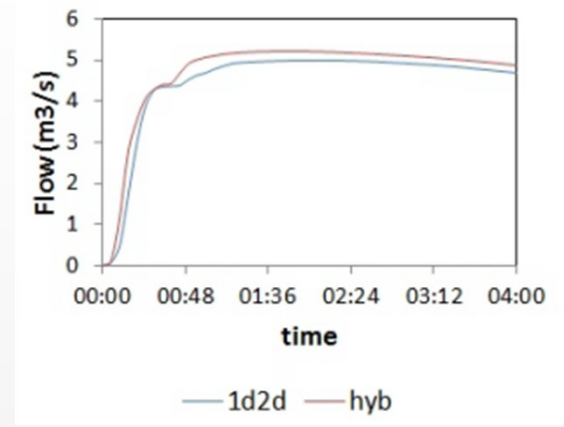
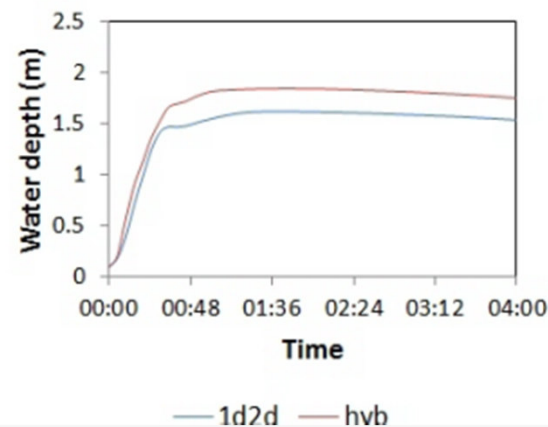
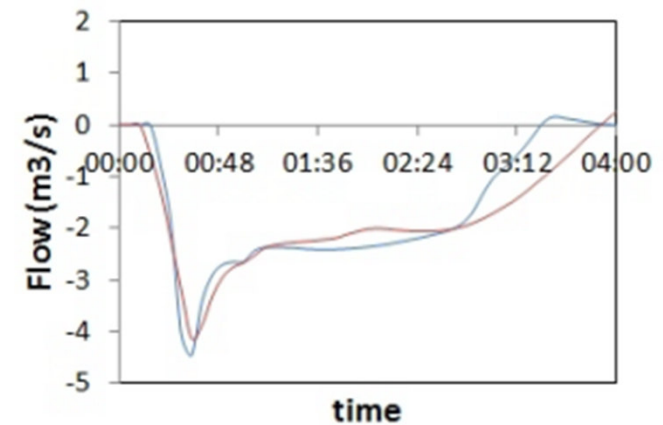
event	model	[mm:ss]	vs 1D1D
300	1D1D	03:46	
min	Hybrid	03:41	-2%
30 yr	1D2D	42:53	1038%
300	1D1D	03:20	
min	Hybrid	04:25	33%
100 yr	1D2D	53:55	1517%
300	1D1D	02:56	
min	Hybrid	04:39	58%
200yr	1D2D	56:04	1811%



# Hybrid Model Results

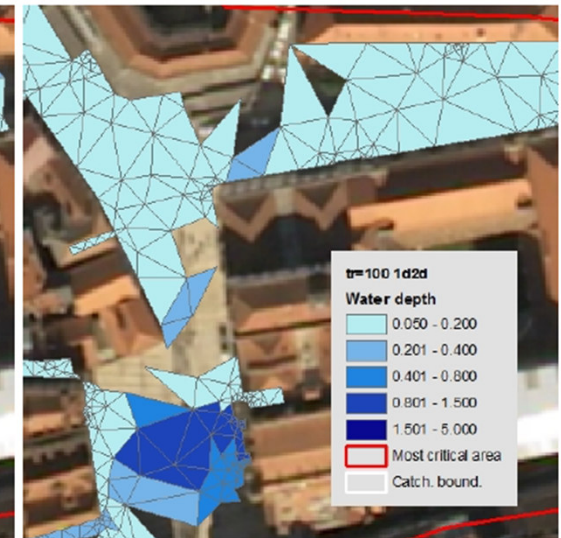
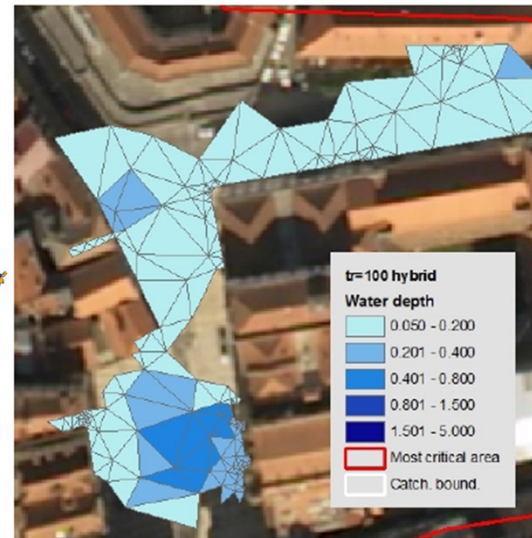
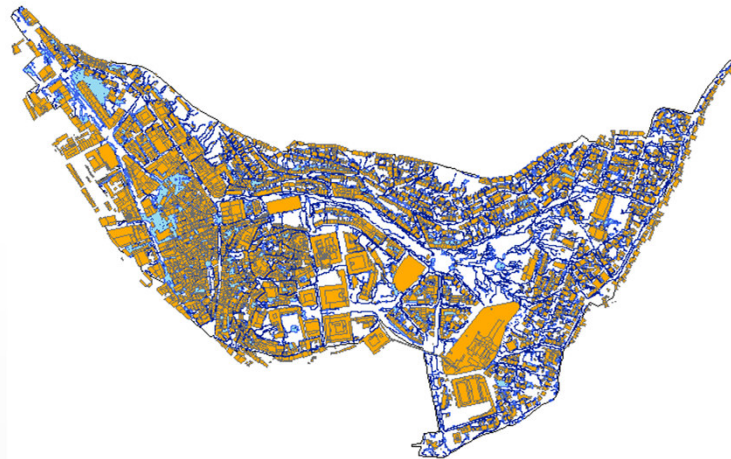


Inflow from  
the over. net to pipe  
system



Water level in Manhole and flow in pipe

# Hybrid Model Results



event	duration	model	simulation time [hh:mm:ss]	difference to 1D1D
100 yr return period	250 min	1D1D	00:02:41	
		Hybrid	00:03:35	+34%
		1D2D	00:05:13	+94%
500 yr return period	250 min	1D1D	00:02:26	
		Hybrid	00:04:02	+66%
		1D2D	00:08:17	+240%

## Conclusions

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- Where the drainage system has adequate capacity it can be modelled as 1D only, but the dual drainage concept must be taken into account for pluvial flood modelling
- all models which have an overland flow component require an accurate Digital Terrain Model (DTM) as a prerequisite for the quality and reliability;
- 1D-1D modelling is more time consuming to set up than 1D-2D but it is considerably faster computationally to run;

## Conclusions

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- The new Hybrid models can be as good as 1D2D models in critical areas but much faster.
- 1D-2D modelling is considerably more computationally demanding, but should be used where overland flow pathways can be multi-directional;
- results from 1D-2D modelling can be more easily presented to non technical audiences;

## Development of a *nested* 1D/2D urban surface model

Why?

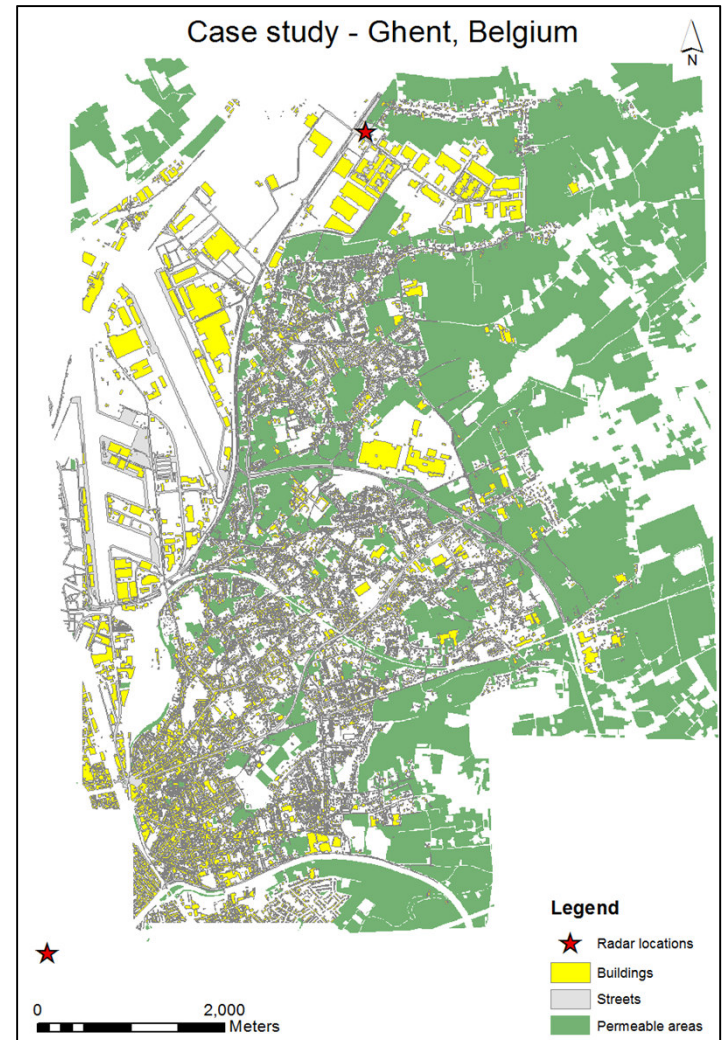
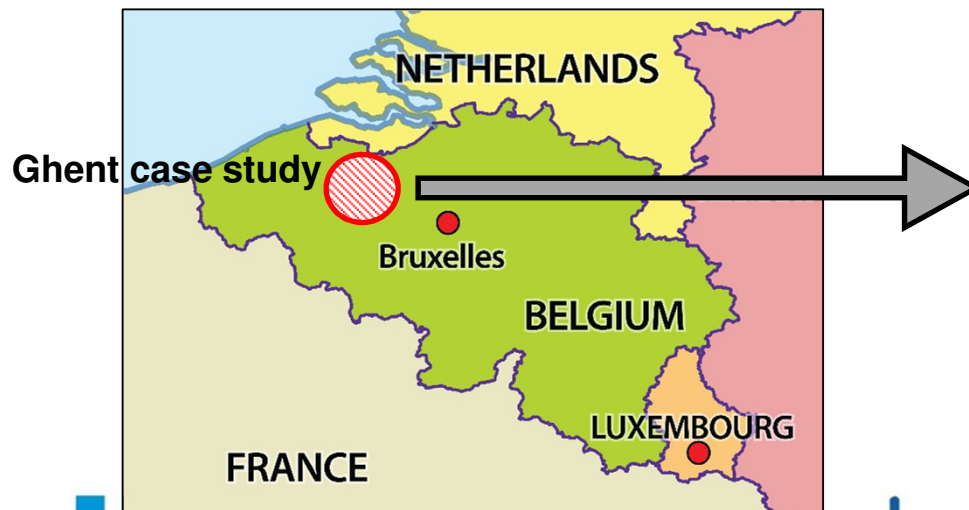


- Reduce social-economic-environmental damage
- 1D-1D models may be limited for complex urban terrains
- 1D/2D aim to address these *limitations* with the use of:
  - Unstructured TIN mesh
  - Full integration with sewer system (1D) model
  - Increased detail and model accuracy
- Need for flood forecasting/nowcasting applications
  - Identify and minimize flood risk
  - Support *local authorities* in developing methodologies/software tools for flood *forecasting and management* systems
- Likely impact of climate change in future scenarios



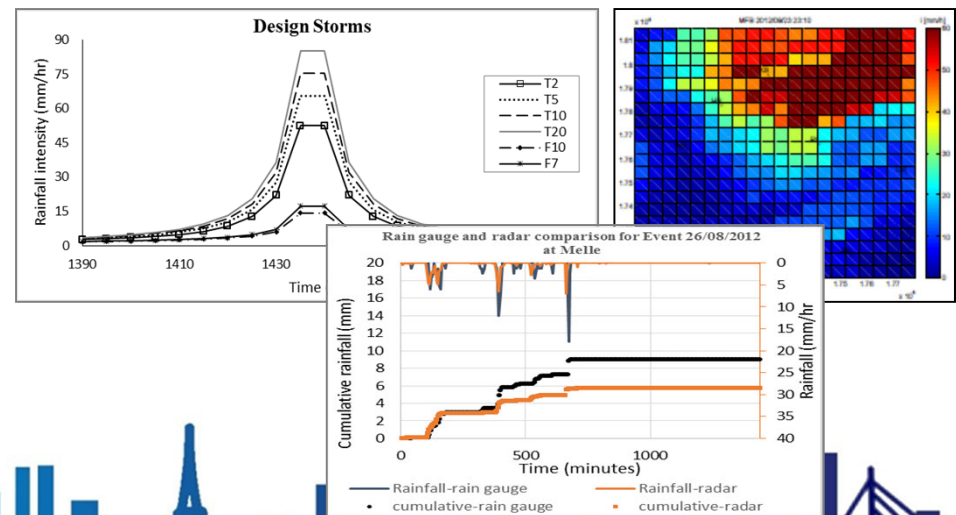
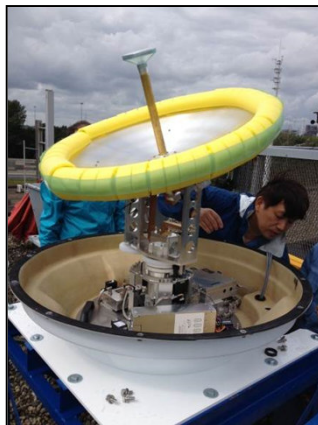
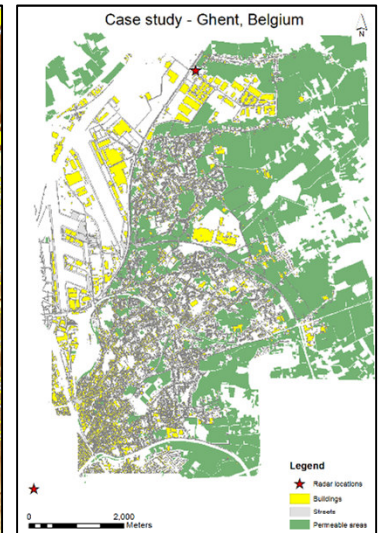
### Ghent, Belgium

- Located approx. 51.05° N and 3.73° E
- Total area of **subcatchments** 2747.421 ha
- Sewer model consists **6025 sewer** pipes
- Slope range: 0-0.94 m/m ( average: 0.0035m/m)
- Dominant soils: **sandy and loamy sand**



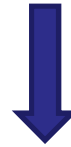
### Input data sources

- Semi distributed model of Ghent
- High resolution DTM map (0.5m x 0.5m)
- Rainfall data sources
  - Rain gauge network
  - C-band radar data (KMI\*)
  - X-band radar data (Furuno)
- GIS data: Green zones, buildings, streets.



\* KMI, Royal Meteorological Institute of Belgium

## Nested 1D/2D urban surface model build up



Varying mesh resolutions depending on purpose



WHICH

Identification of mesh zones based on:

1. High flood risk areas
2. Streets polygons
3. Low flood risk areas

HOW



## Nested 1D/2D urban surface model build up

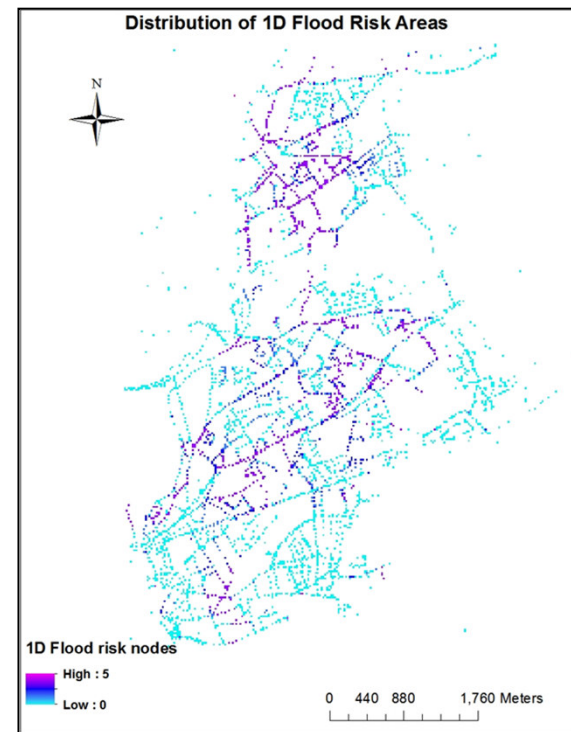
### 1. High flood risk areas (fixed mesh resolution)

Identification of flood risk zones based on sewer modelling and 1D/1D modelling.



### 2. Street polygons (fixed mesh resolution)

First 2D modelling results highlighted the importance of **streets** during flood events



## Nested 1D/2D urban surface model build up

### 3. Low flood risk areas

Sensitivity analysis to come up with optimal mesh resolution at low flood risk areas

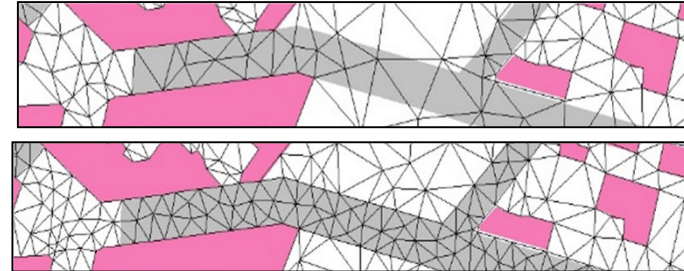
How ?

Eight mesh resolutions combined with three different scenarios:

Fixed mesh resolutions:

- High flood risk mesh resolution 12.5-50 m<sup>2</sup>
- Street mesh resolution 3.75-15 m<sup>2</sup>

- Min and Max. triangle size (m<sup>2</sup>) of 125-500; 100-400; 75-300; 50-200; 37.5-150; 25-100; 18.75-75; 12.5-50
- Low flood risk area only (scenario 1); Low flood risk and streets (scenario 2); Low flood risk, streets and infiltration areas (scenario 3)



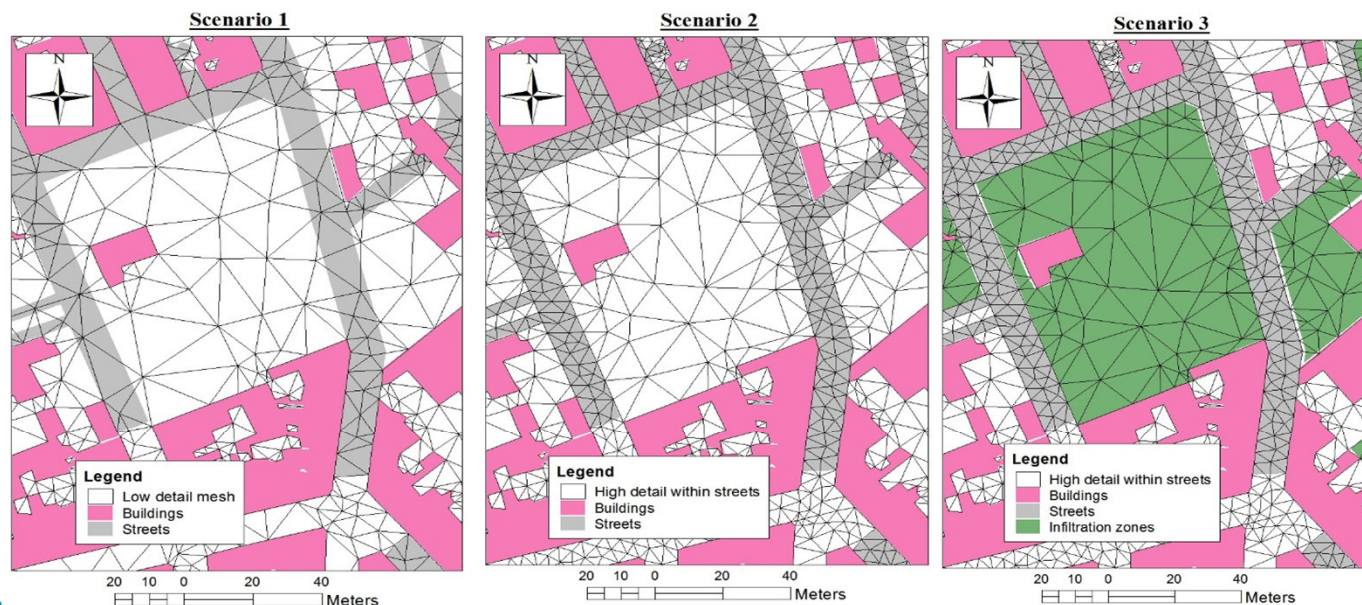
## Nested 1D/2D urban surface model build up

For all 3 scenarios:

- Terrain sensitive meshing
- Min-Max ratio 1:4
- Worst case T20 composite storm
- Buildings as voids

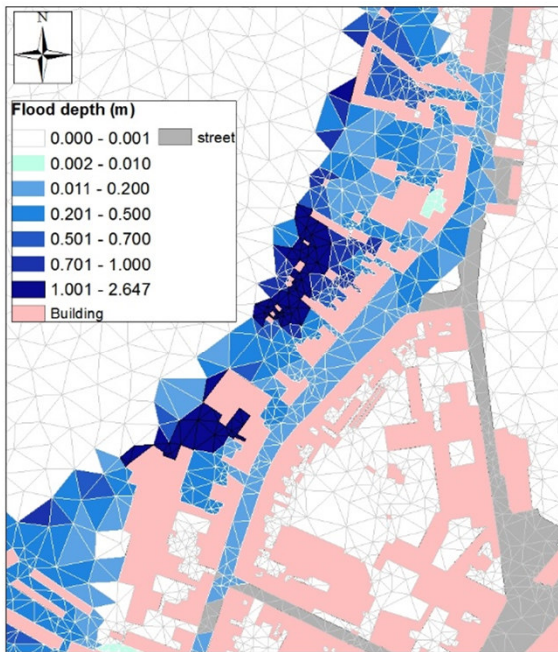
Scenario 3:

- Horton Infiltration
  - $f_0$  of 200mm/hr
  - $f_c$  of 12.7mm/hr
  - decay constant of 2/hr

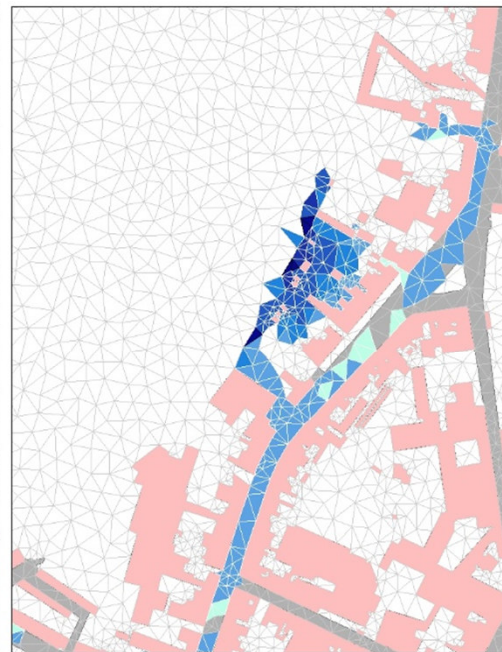


## *Nested* 1D/2D urban surface model results

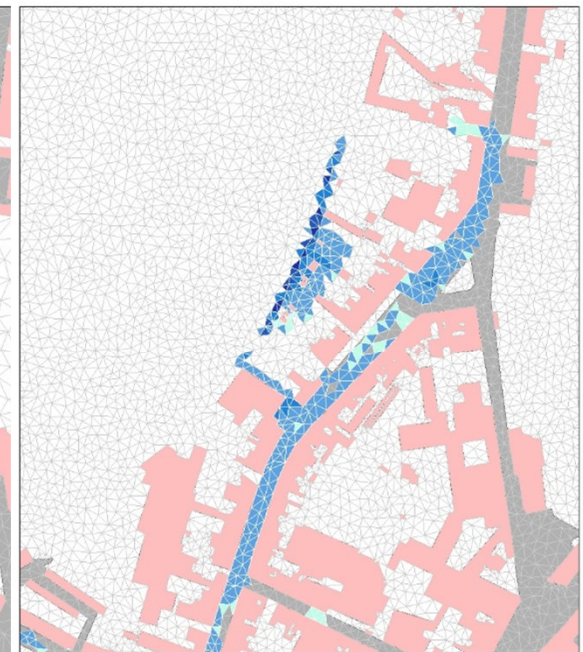
a) 125-500 m<sup>2</sup>



b) 75-300 m<sup>2</sup>



c) 18.75-75 m<sup>2</sup>



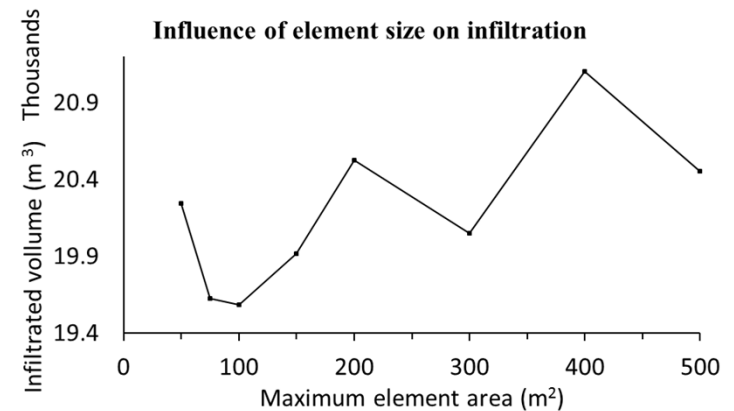
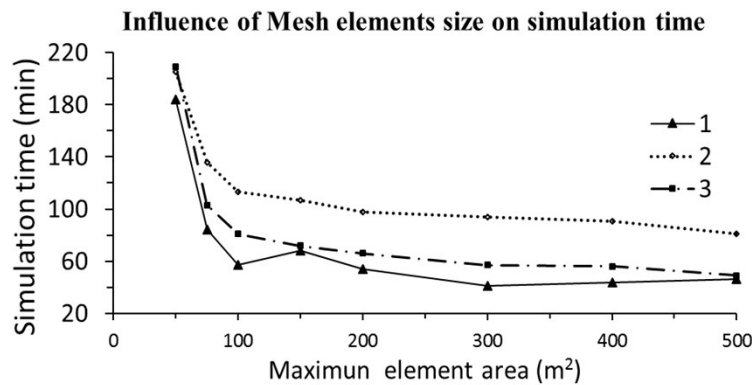
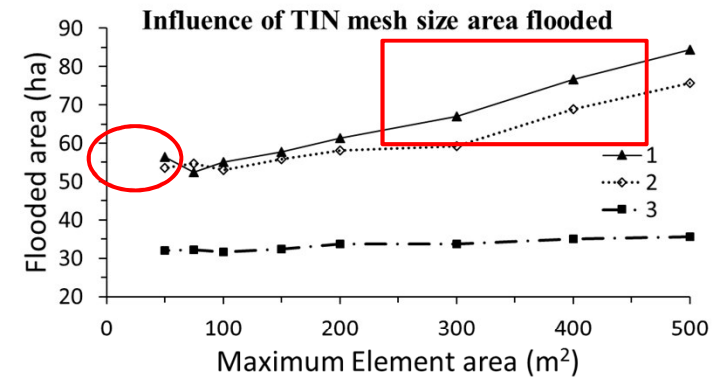
0 40 80 160  
Meters

Flooded depth (m) for three different mesh solutions



## Nested 1D/2D urban surface model results

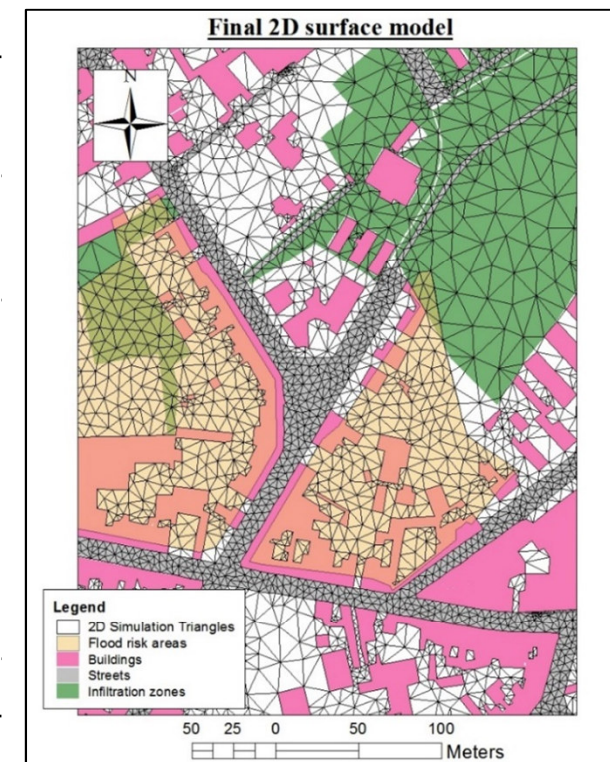
- Largest flood area at scenario 1
- Less than 200 m<sup>2</sup> scenario 1 and 2 very similar
- Gentle slope start at 300 m<sup>2</sup>  
(less influenced by resolution)
- High simulation time for resolutions lower than 100 m<sup>2</sup>
- Mesh resolution dependence onto infiltrated volume
- Optimum 2D resolution: 75-300 m<sup>2</sup>



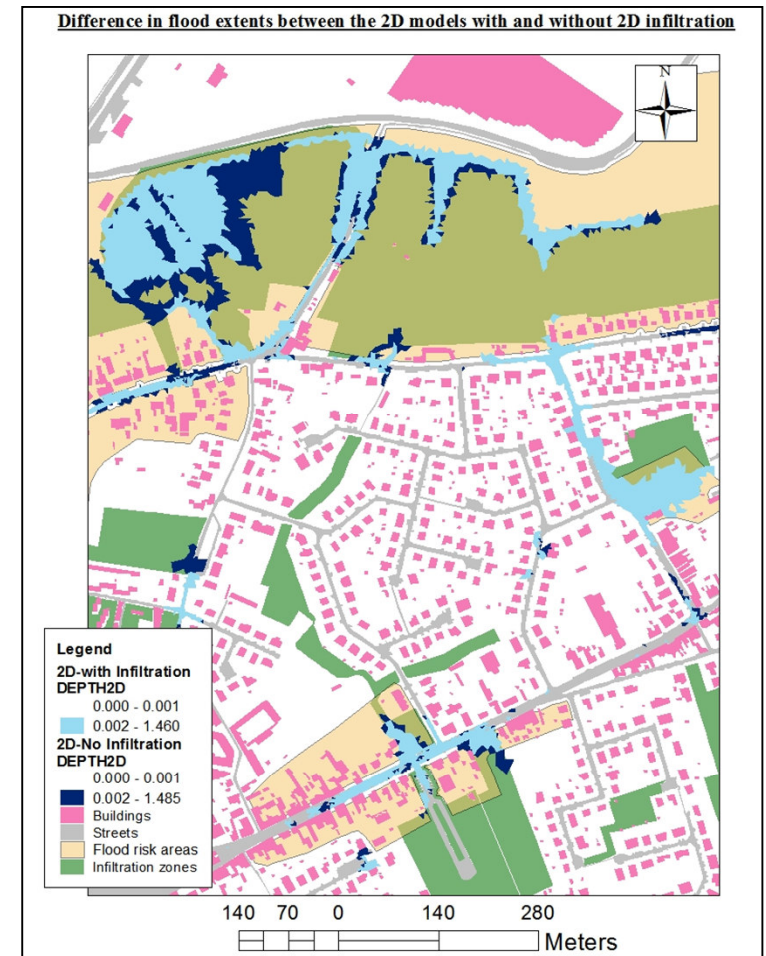
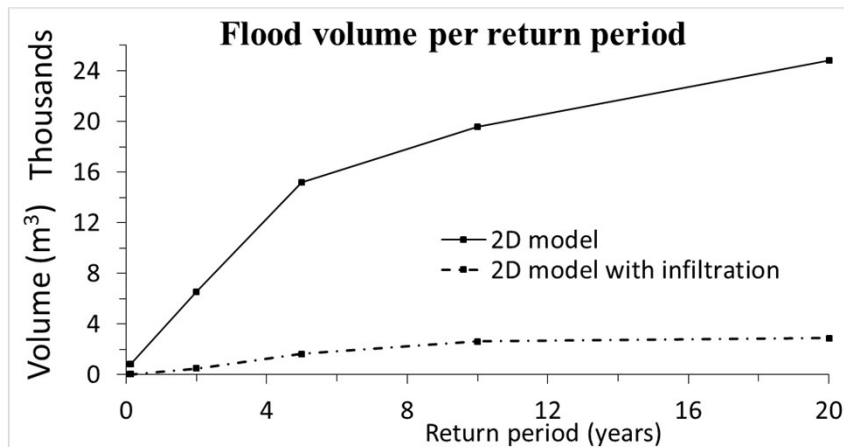
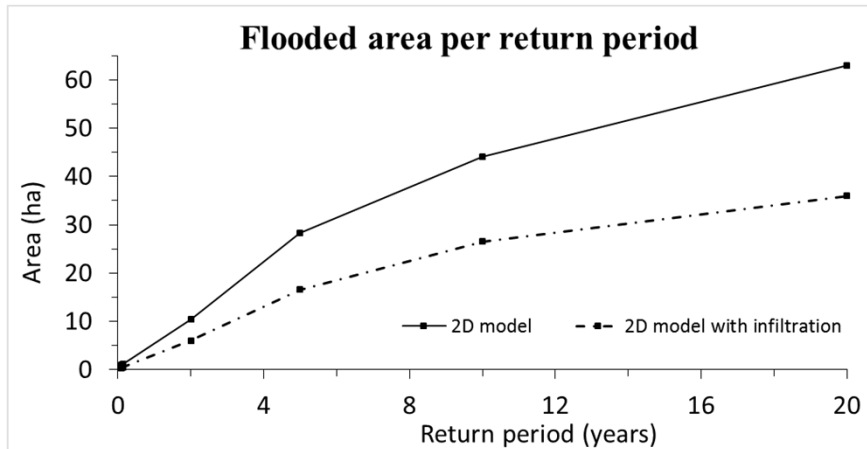
## Nested 1D/2D urban surface model results

Flood results comparison between the final nested 2D model with and without infiltration

Return period [years]	Flood volume in 2D surface [m3]		Simulation time [min]		Infiltrated volume	
	2D	2D Infiltration	2D	2D Infiltration	2D Infiltration [m3]	%
0.1	814.115	45.388	35	32	326.096	87.78
0.14	854.250	40.978	36	34	370.677	90.05
2	6533.527	481.405	54	44	3278.932	87.20
5	15163.390	1634.49	78	55	8667.624	84.13
10	19550.370	2622.504	97	59	14104.481	84.32
20	24827.930	2881.52	107	65	20025.415	87.42
Average						86.82



## Nested 1D/2D urban surface model results



## ***Conclusions:***

- 1D/2D models can represent the urban flood dynamics
  - Simulations are high computational and time demanding
- Nested 2D models can be suitable approaches to overcome computational and simulation time problems
  - Need to define optimal resolution at each mesh zone



## *Conclusions:*

- Surface characterization becomes an important task
  - Specially for fully distributed modelling
- Resolution of DTM data determines the quality of results
  - High resolution DTMs are more time consuming



# Thank you!

