U C

Imperial College London

Urban Drainage Models: 1D, 1D/1D and 1D/2D

Nuno Eduardo Simões

PhD Student at Imperial College London (ICL)

Supervisor: Prof. Čedo Maksimović (ICL)

Co-supervisor: Prof. Alfeu Sá Marques (UC)

Junior Lecturer at University of Coimbra (UC)

Depart. of Civil and Environmental Engineering
Imperial College London

Prof. Č. Maksimović (ICL)
Lipen Wang (ICL)
Susana Ochoa (ICL)

Dr João Leitão (ICL)
Dr S. Boonya-aroonnet (ICL)

Prof.Alfeu Sá Marques (UC)
Rui Pina (UC)

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1. **Urban Floods**
2. Modelling
3. Dual drainage
4. Automatic Overland Flow Delineation
5. Application
6. Urban floods forecasting
7. Customisation of drainage networks
8. Monitoring system for calibration
9. Conclusions

Types of Urban flooding

Fluvial

Coastal

Ground water flooding

Pluvial Surface Flooding

Pluvial (Surface) Flooding

Extreme rainfall events!

Urban Flooding

- Poor drainage capacity of the sewer system
- Overland flow
- Poor drainage management
- Overloaded drainage system
- Everything happens quickly: **"flash floods"**

Forecasting

Management

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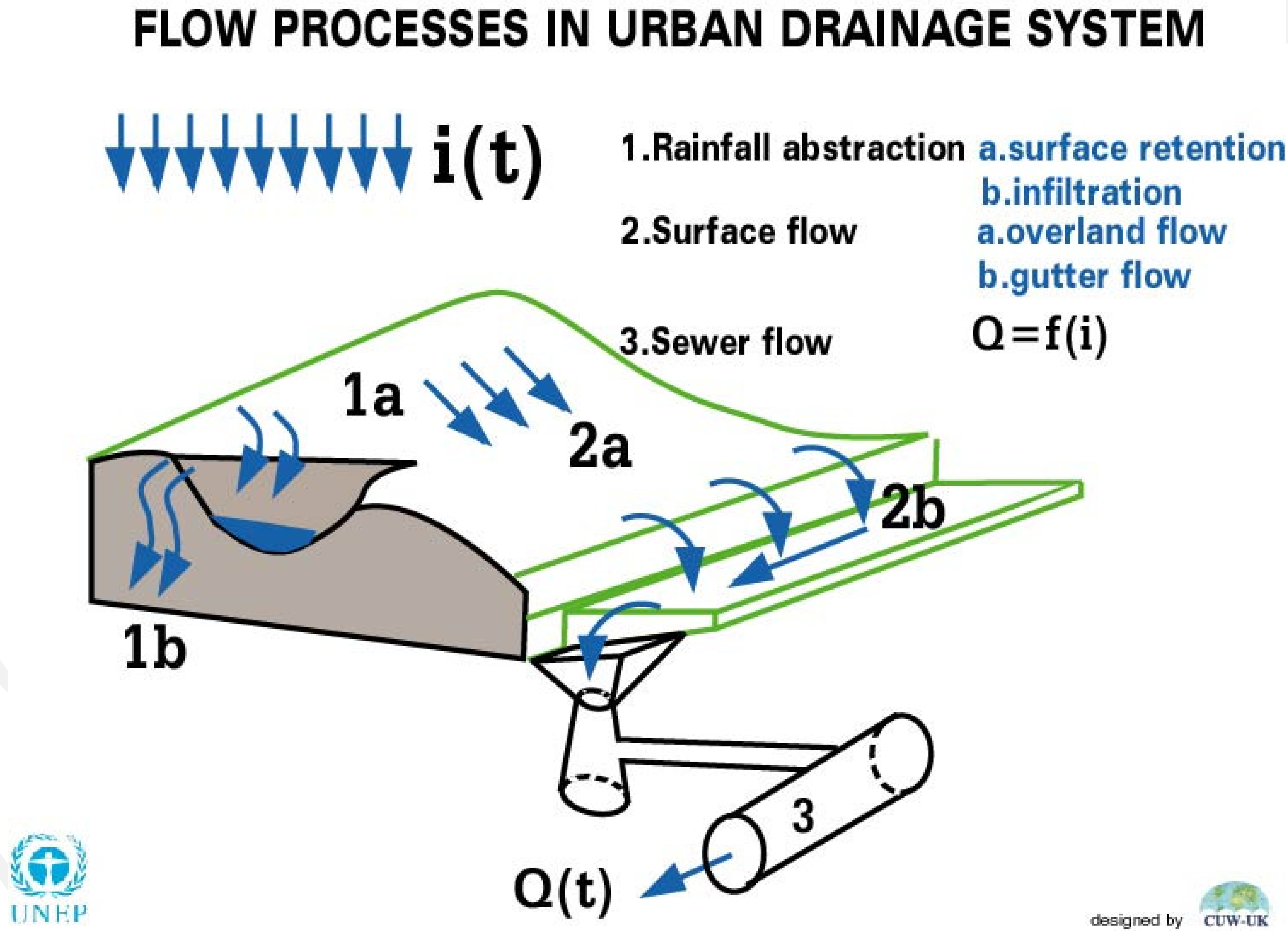
Urban Pluvial Flooding



Physically based modelling

- Realistic presentation of the terrain and of the physical features of the urban infrastructure
- Use of conservation principles / equations
- Spatially distributed systems and modelling principles

Saint-Venant Equations

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0$$

$$\underbrace{\frac{1}{A}\frac{\partial Q}{\partial t}}_{\text{local acceleration}} + \underbrace{\frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)}_{\text{convective acceleration}} + \underbrace{g\frac{\partial h}{\partial x}}_{\text{pressure}} = g(\underbrace{S_o}_{\text{bed slope}} - \underbrace{S_f}_{\text{friction slope}})$$

Diffusion wave equation

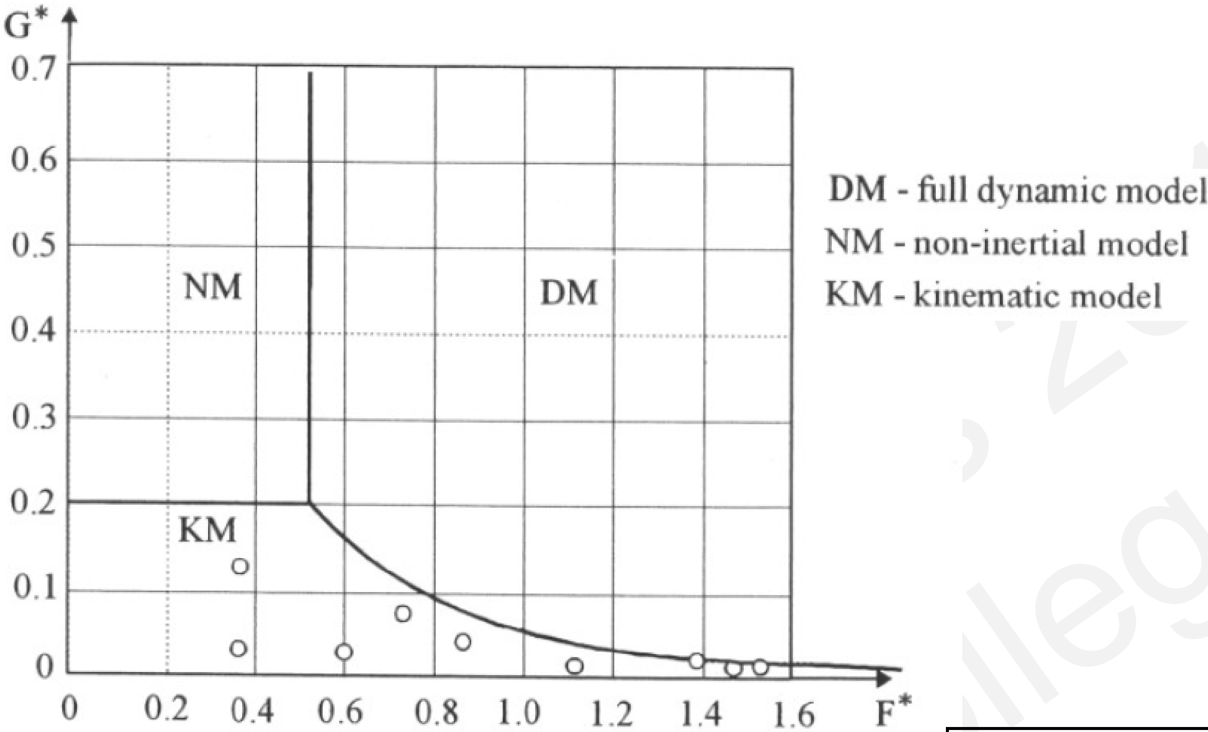
$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0$$

$$\frac{\partial h}{\partial x} = (S_o - S_f)$$

Kinematic Wave

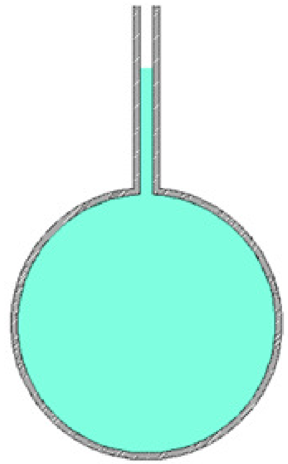
$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0$$

$$S_o - S_f = 0$$

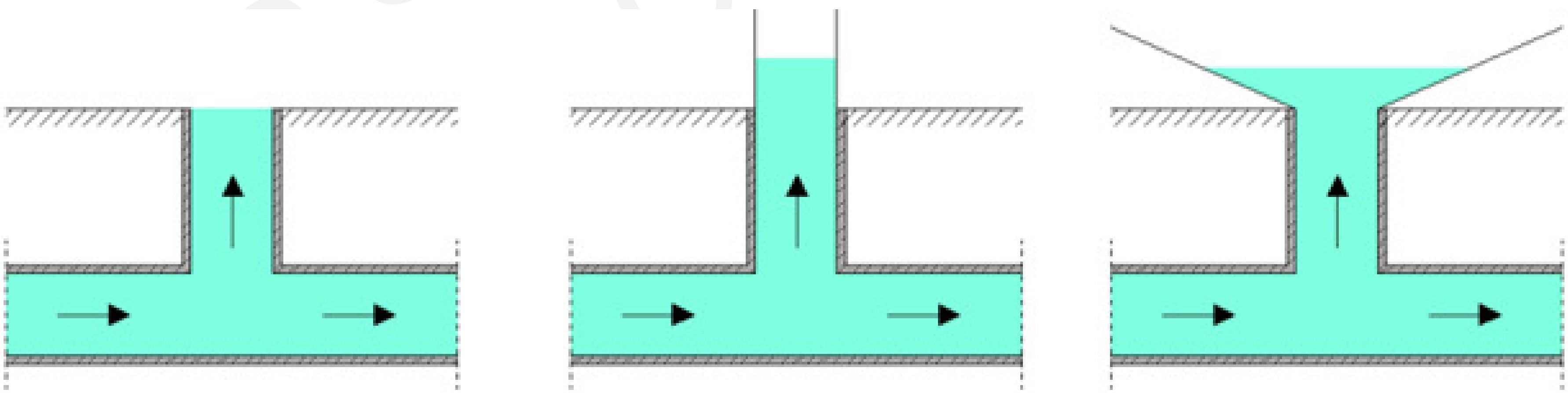


	Kinematic wave	Diffusive wave	Dynamic wave (Saint Venant equations)
Account for downstream backwater effects and flow reversal	No	Yes	Yes
Attenuation of flood waves	No	Yes	Yes
Account for flow acceleration	No	No	Yes

Surcharge



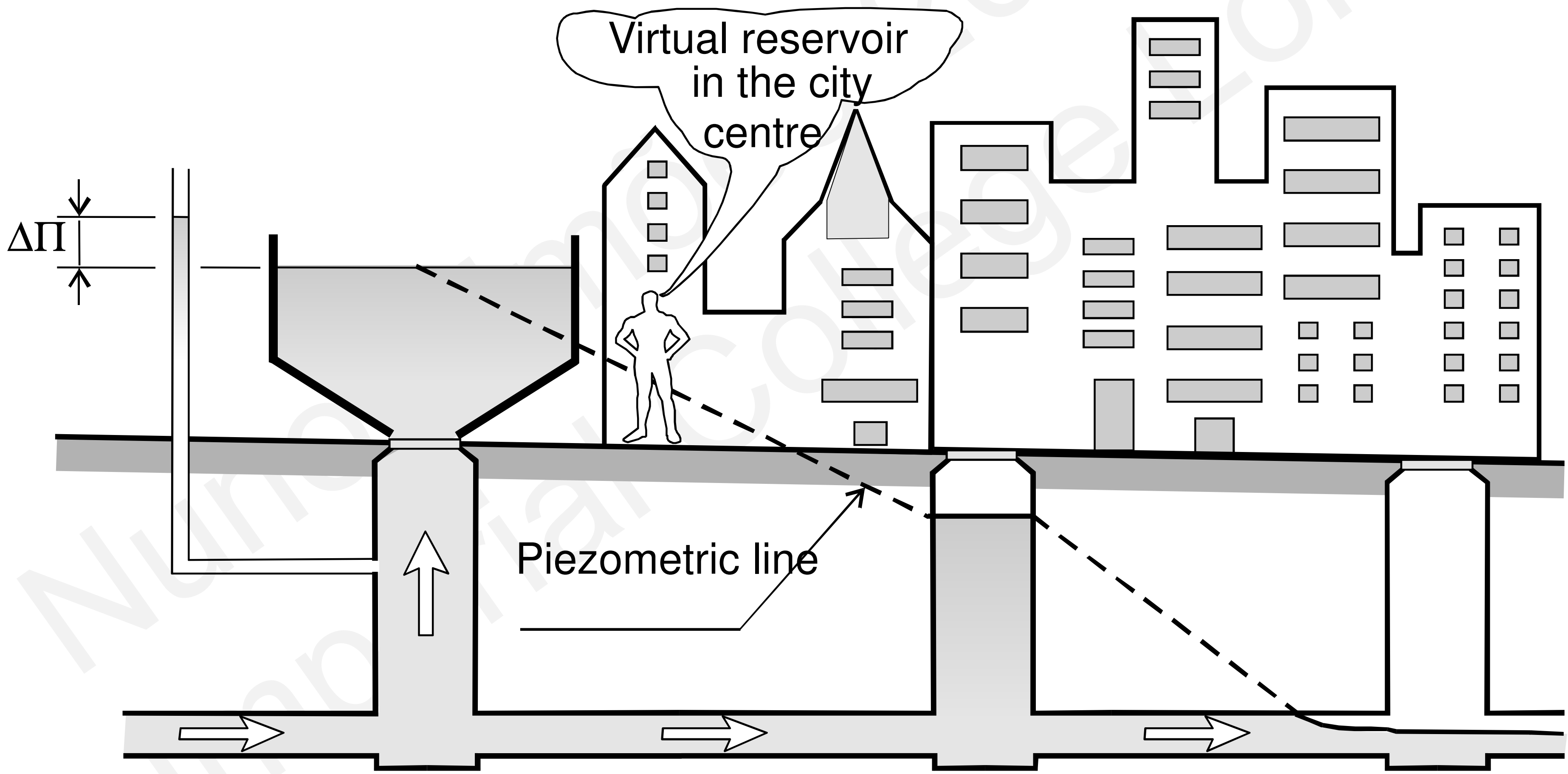
Preissman Slot



Interaction with surface

Virtual reality in modelling

This was “state of the art” for years



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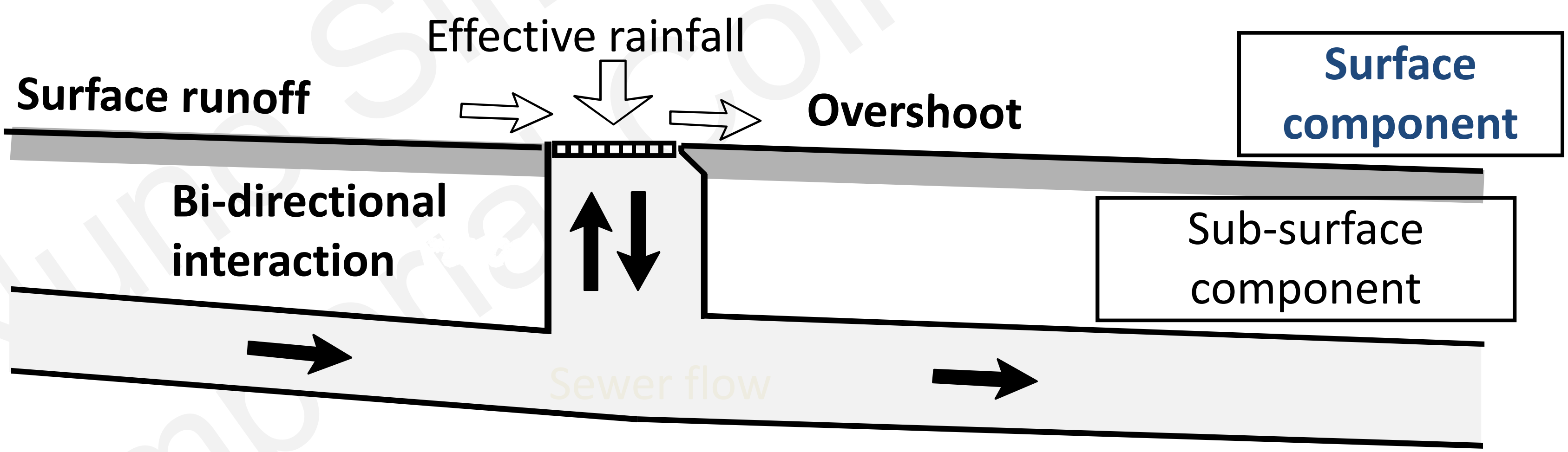
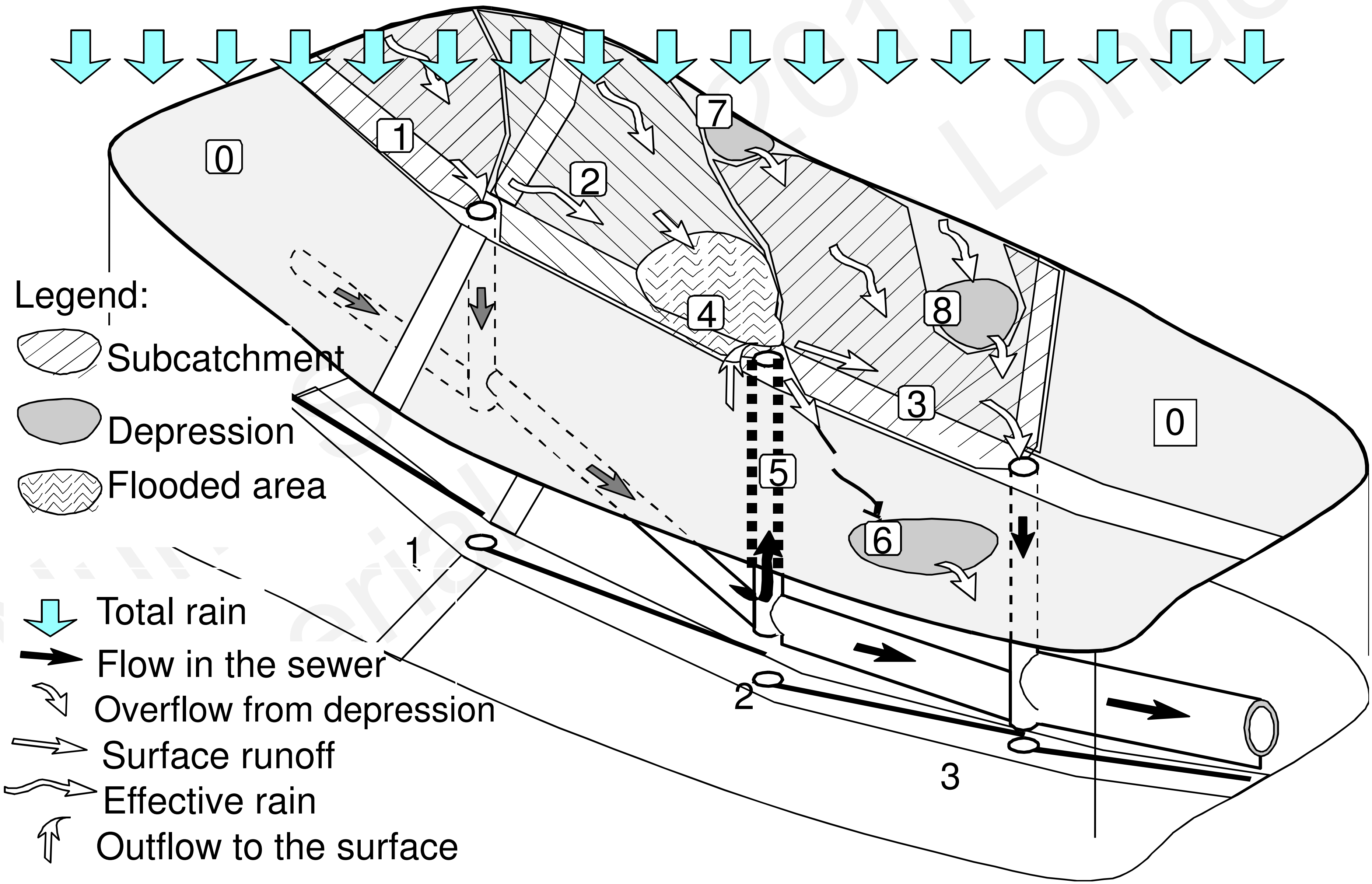
Pluvial Flooding – Dual Drainage Concept



Dual drainage concept, pond delineation and link with network

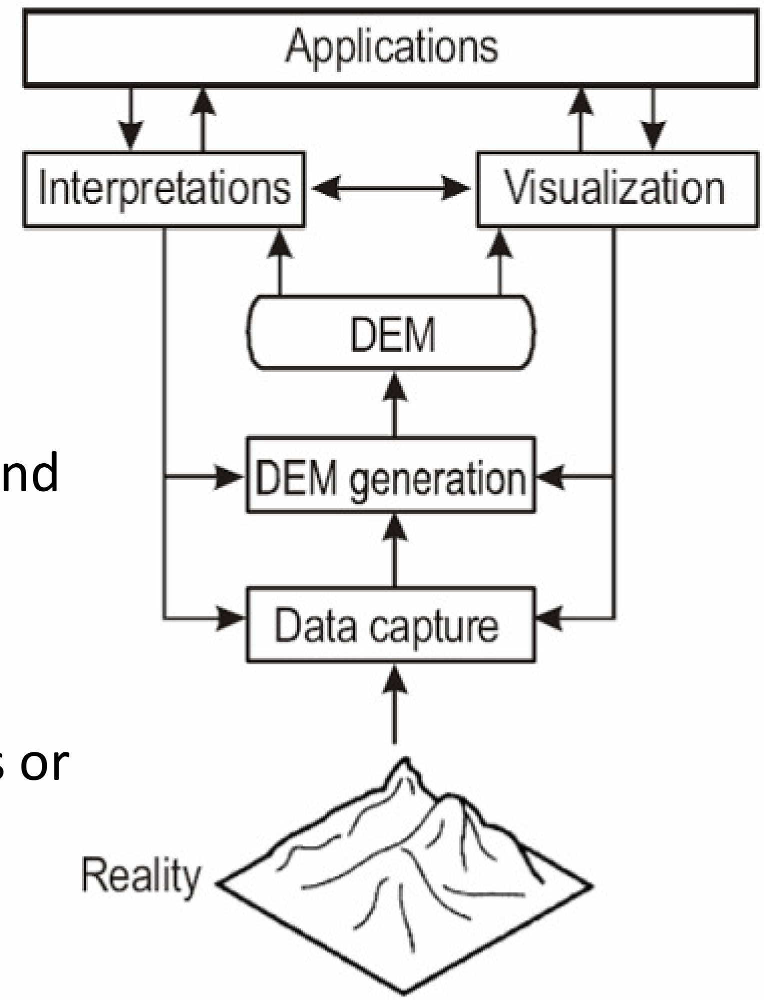


DEMs and Urban Flood Modelling

- **Dual-drainage concept (1D/1D and 1D/2D)**
- Sewer system (manholes and pipes).
- Overland system (depressions and
- flow paths).

- **1D overland flow modelling**
- Overland system consists of nodes (ponds) and links (flow paths), generated using DEM.

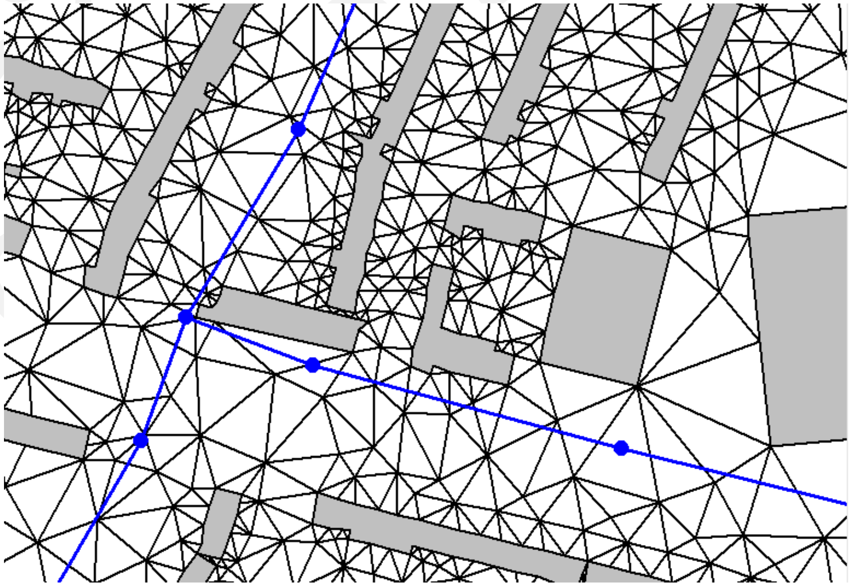
- **2D overland flow modelling**
- Surface divided into small elements (squares or irregular triangles)



Urban Flood Modelling

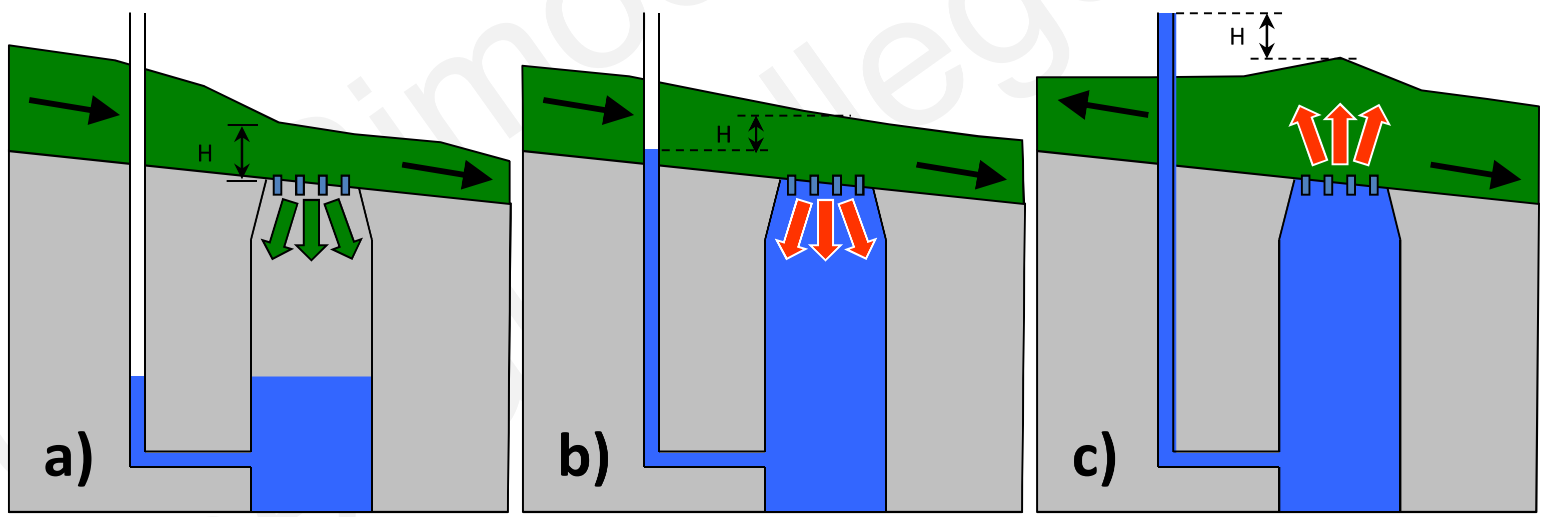
1D/1D

1D/2D



Flow directions can alternate during an extreme rainfall event

- Surface runoff enters drainage system.
- Surcharges from manhole.



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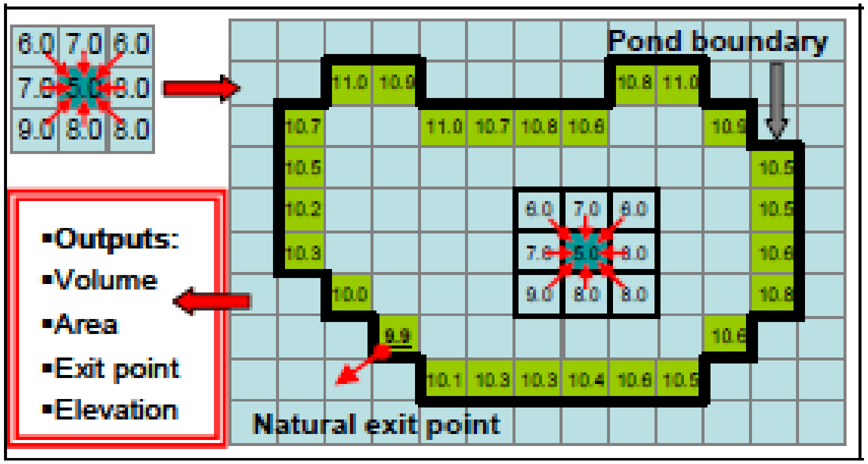
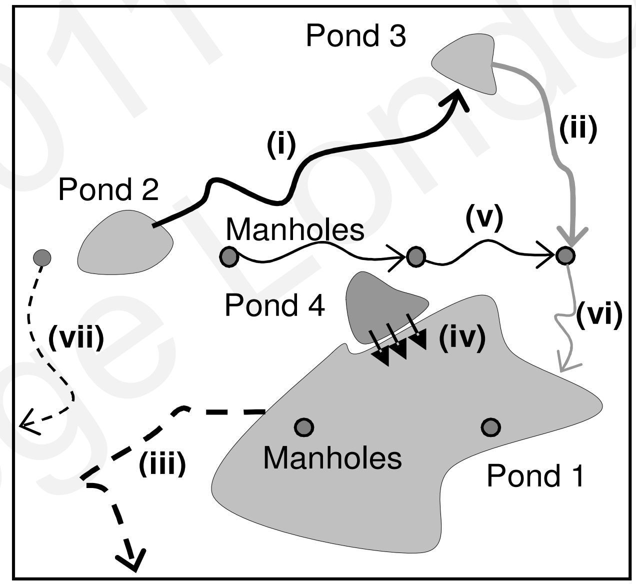
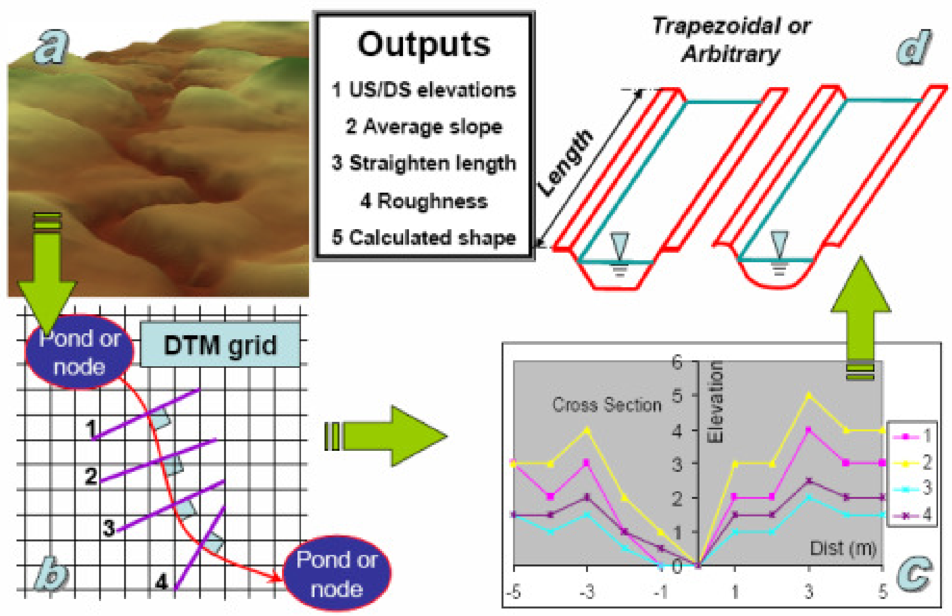
AOFD - Automatic Overland Flow Delineation

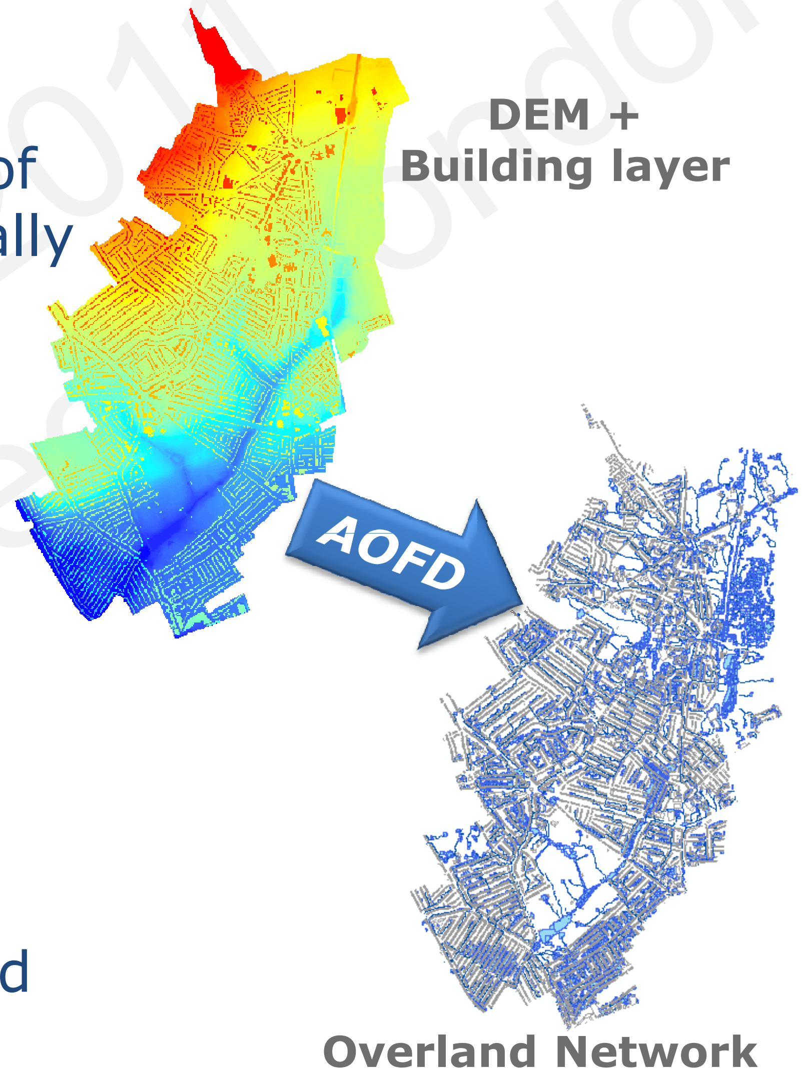






AOFD METHODOLOGY

- Tool for analysis and generation of overland network and automatically quantifying hydraulic parameters for simulation model of pluvial urban flooding
- Based on Digital Elevation Model information
- **Nodes**: ponds and associated storage capacity
- **Links**: pathways + computed geometry
- Interactions between the overland flow and sewer systems



Overland Network of Cranbrook Catchment

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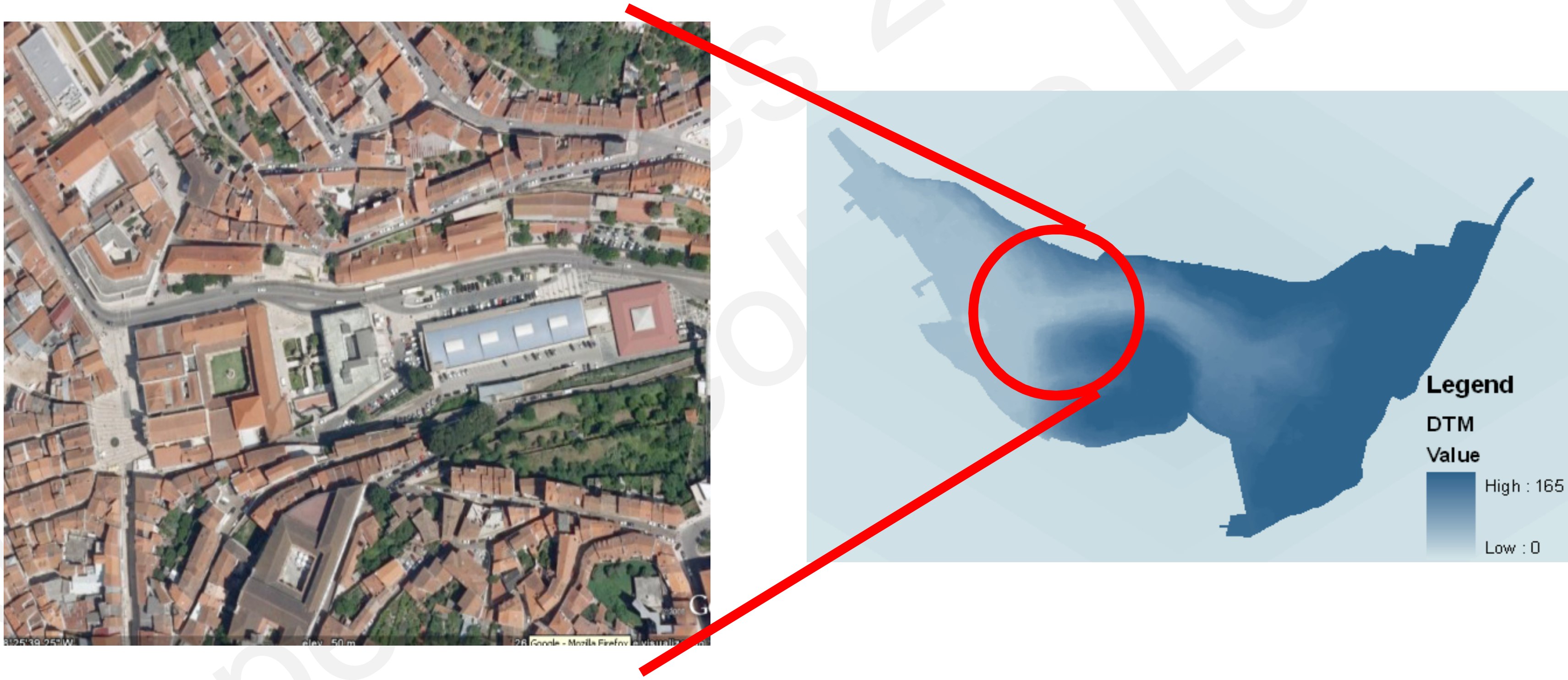
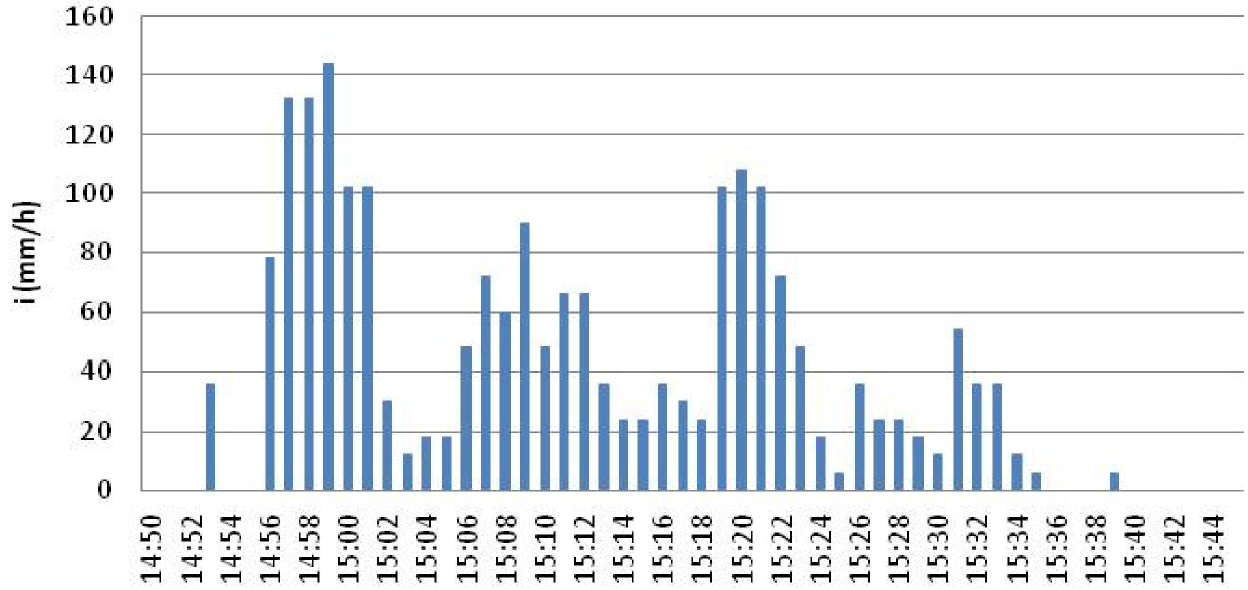
Application – Coimbra, Portugal



9 June 2006

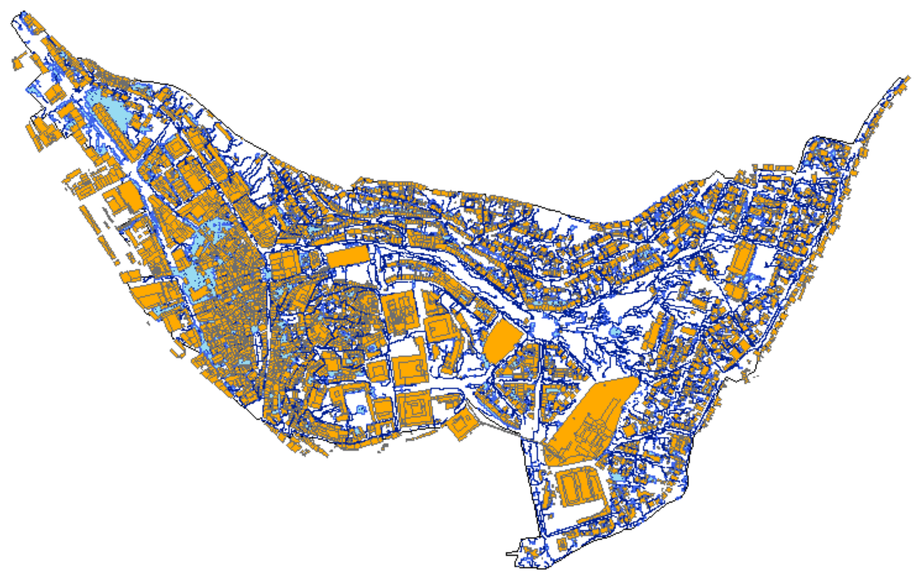


	Duration				
	5 (min)	10 (min)	15 (min)	30 (min)	45 (min)
Intensity (mm/h)	122.4	76.8	72.4	61.6	47.6
Return Period	10	8	20	>50	50

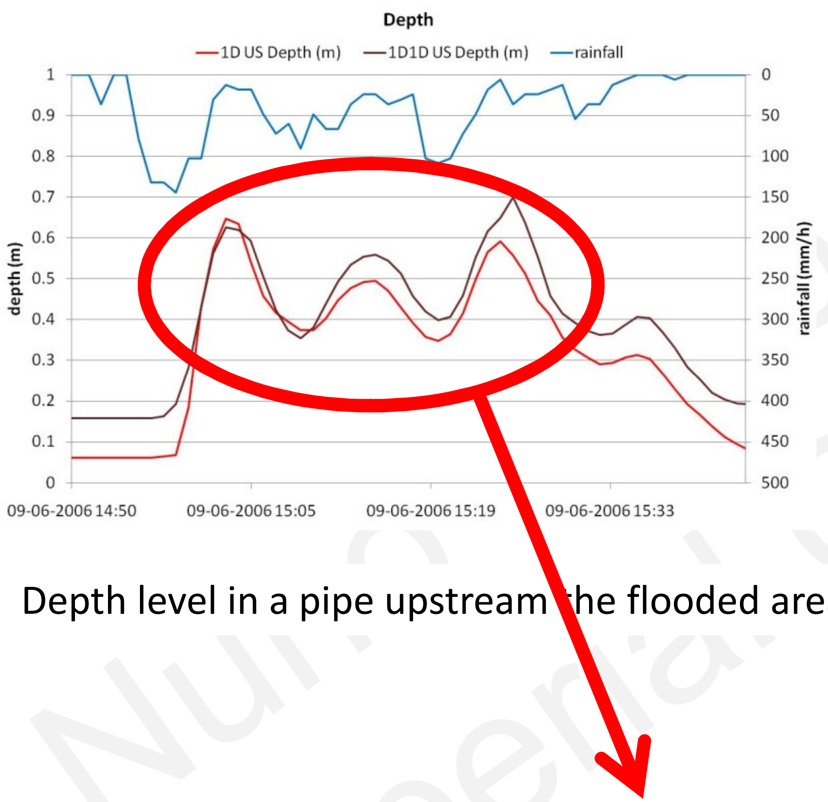
Results

Sewer System

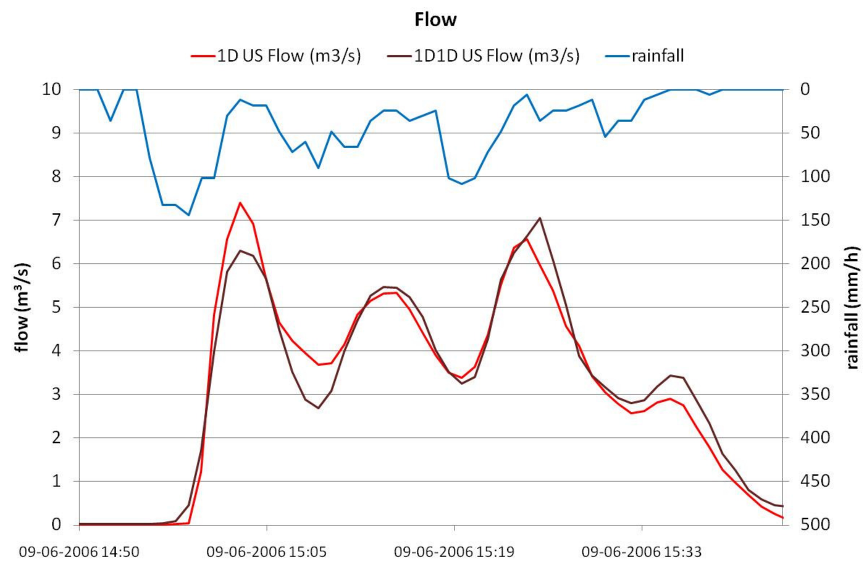
1D Overland network



Results



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!

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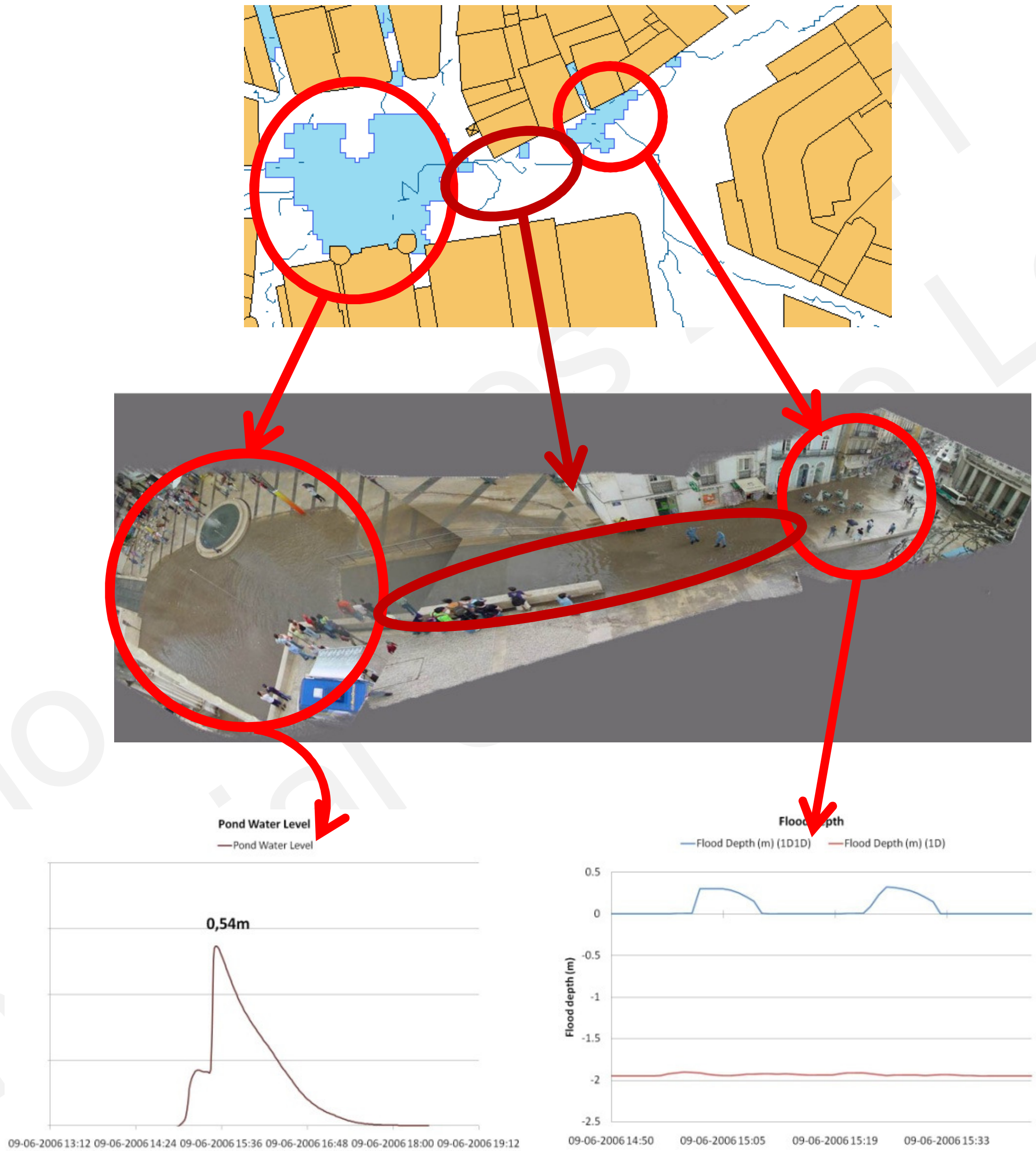

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Urban flood forecasting

- Time available is one of the critical aspects of flood forecast modelling
- **AIM:** predict in 15 minutes the flood magnitude and extension that might occur for the following 3 hours.
  - Short term rainfall forecast
  - Runoff surface flood

Are the advanced models (1D/1D and 1D/2D) adequate to predict urban flooding, i.e. fast enough to satisfy real time prediction?

Fast Flood forecast with high accuracy and reliability can be achieved by:

– Computational techniques (better hardware)
– Customisation of the catchment's area and network characteristics (our focus)

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Simplification of Networks

Pruning technique

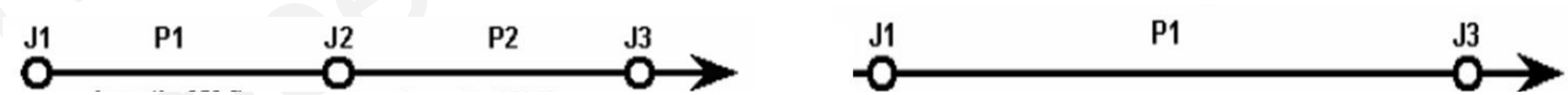
- Exclusion of peripheral model links and their associated upstream nodes

  e.g.: L<10m; Width<300mm

Merging technique

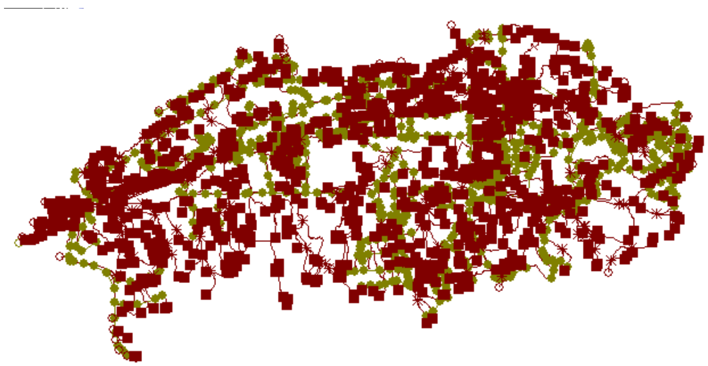
- Grouping of similar consecutive model links based on their attributes (similar hydraulic capacity)

  e.g.: difference in dimension of consecutive links <100mm

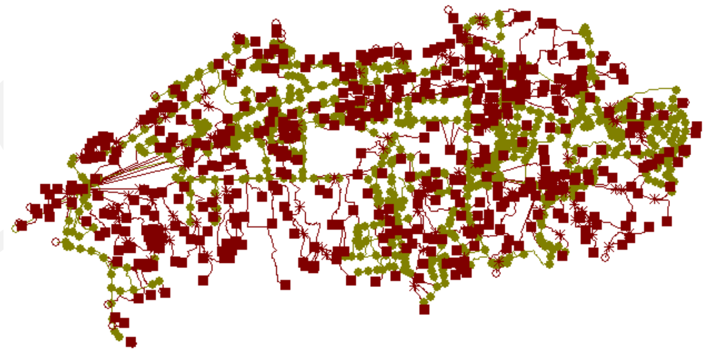


Both techniques required catchments allocation and storage compensation

First Strategy

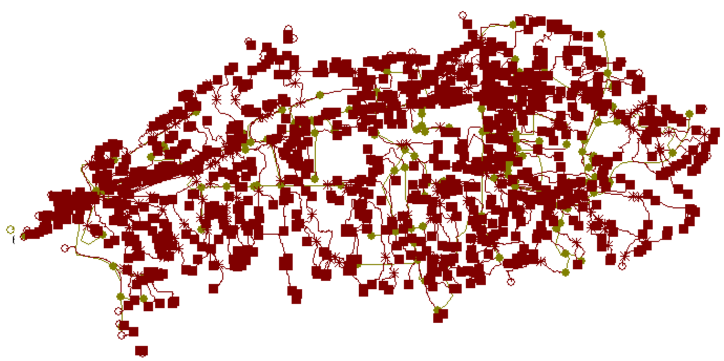


Complete 1D/1D model (1D/1D)



1D/1D model pruned and merged together ((1D/1D)pm)

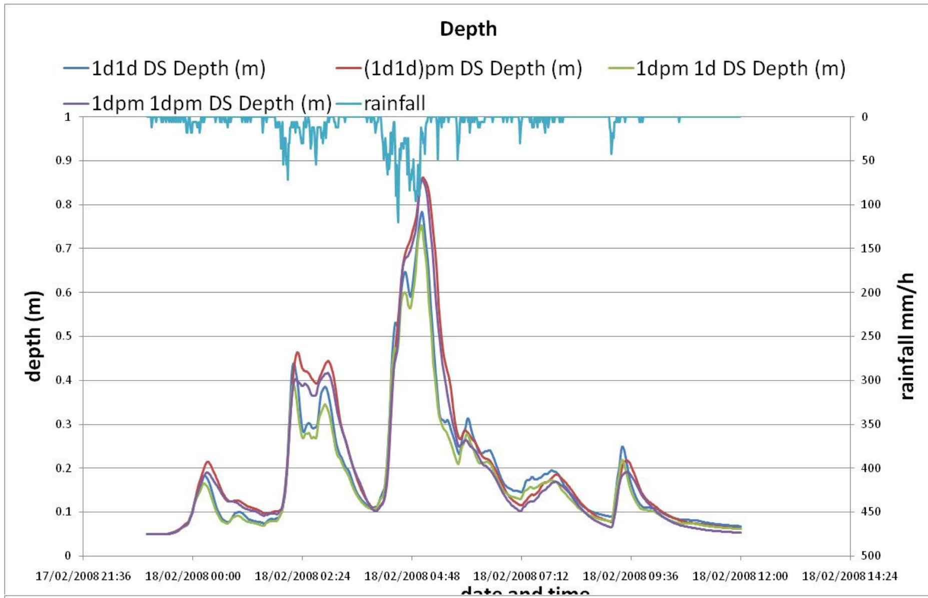
Second Strategy

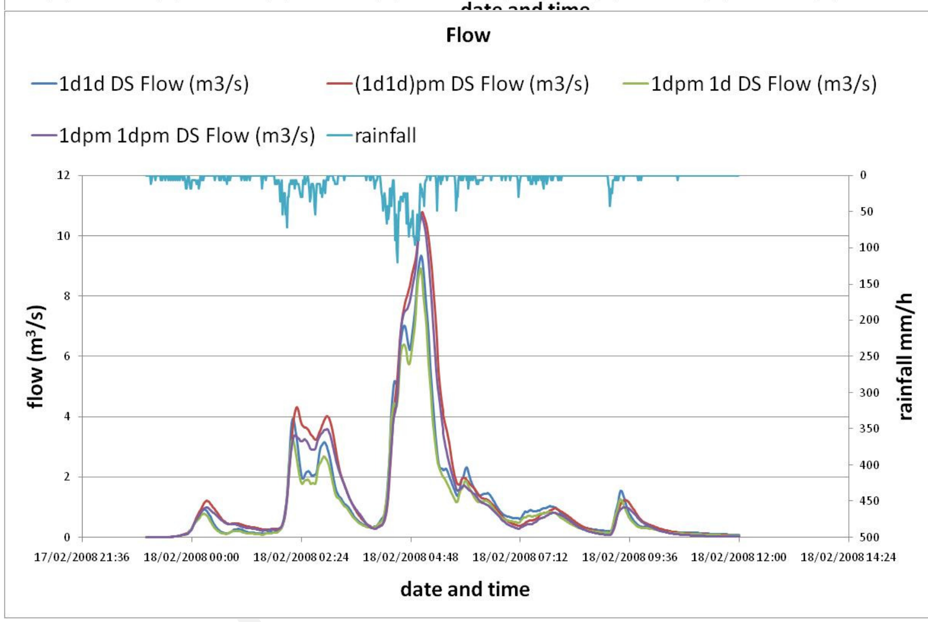


Sewer system pruned and merged and complete overland model (1Dpm/1D)

Sewer system pruned and merged and overland model pruned and merged separately (1Dpm/1Dpm)

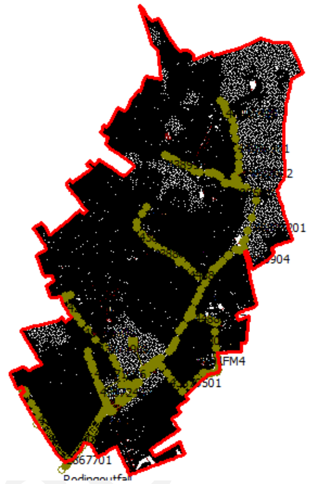
Simulation time

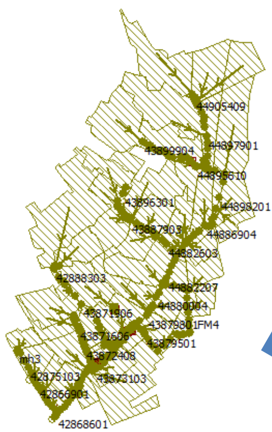




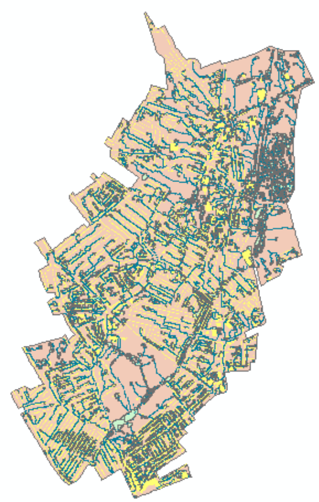
Type of network	Simulation time for rainfall A 780 min	Reduction of the simulation time
1D1D	193 s	-
(1D1D) pm	122 s	71s (-37%)
1Dpm1D	89 s	104s (-54%)
1Dpm1Dpm	44 s	149s (-72%)

1D / 2D
simulation

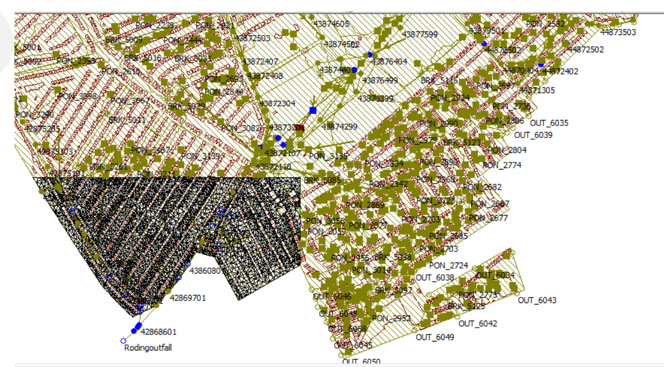




1D Sewer
Simulation

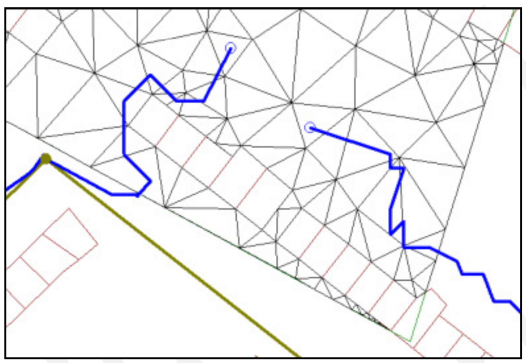


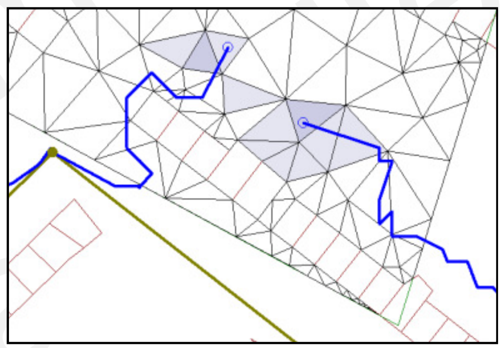
1D / 1D
simulation

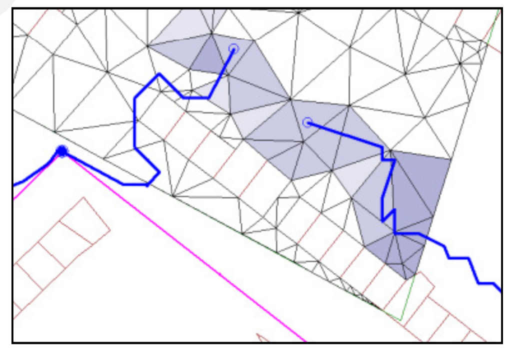


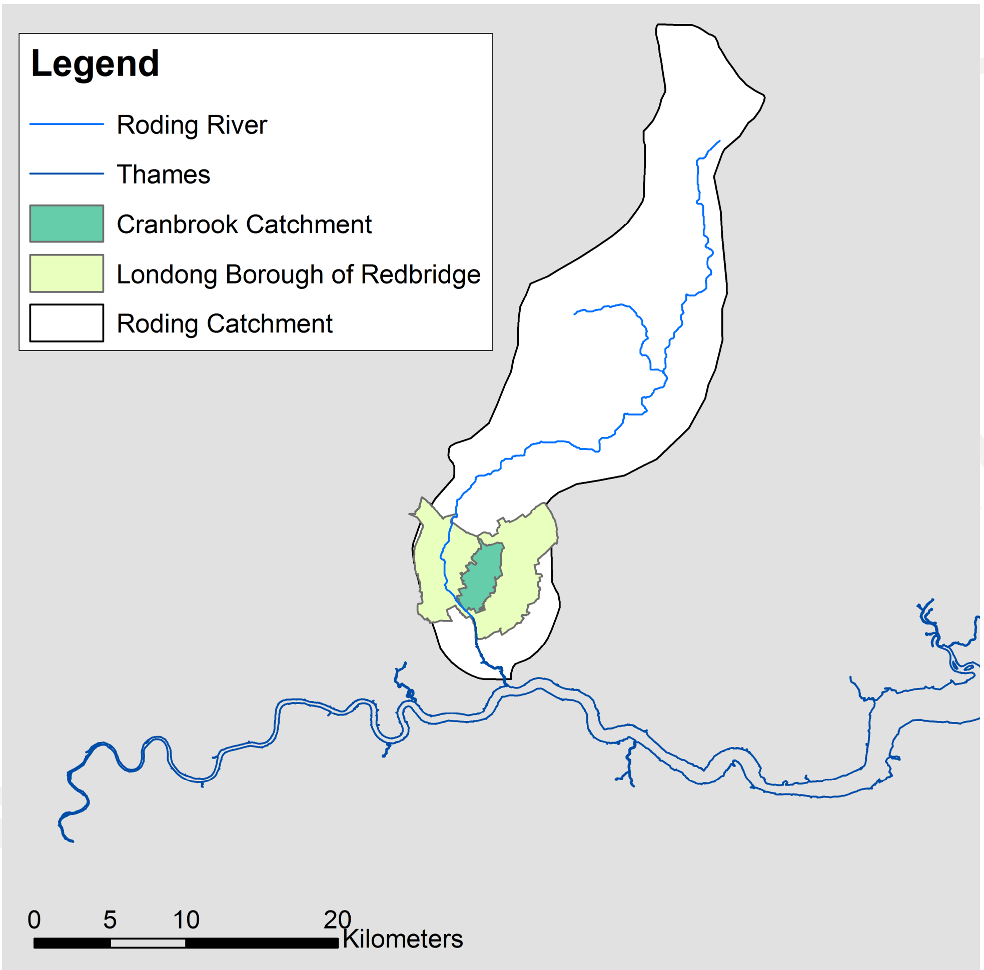
Hybrid
1D/1D + 1D/2D
simulation

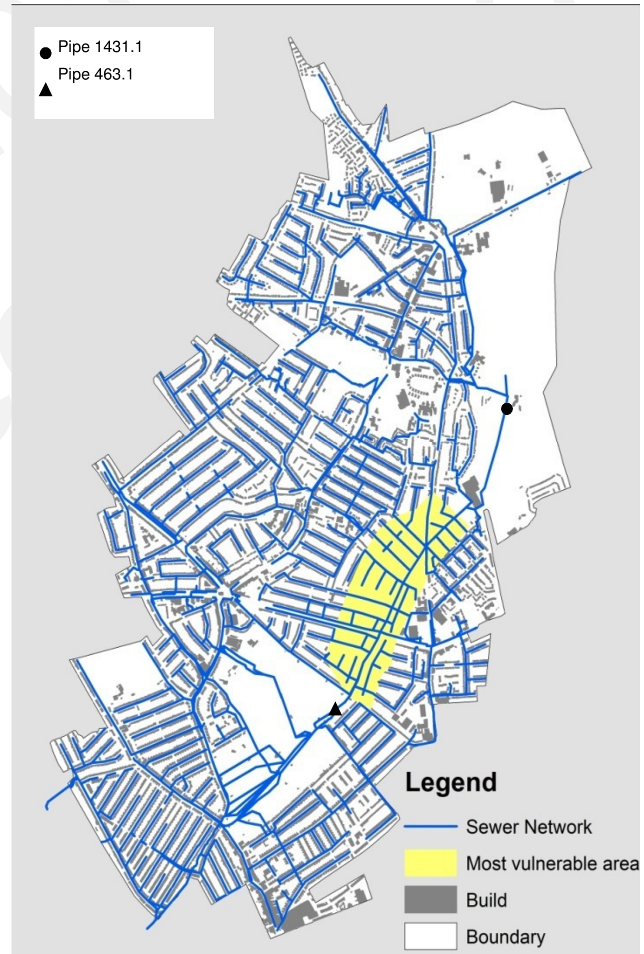
Interaction between 1D Overland Network and 2D Overland Network



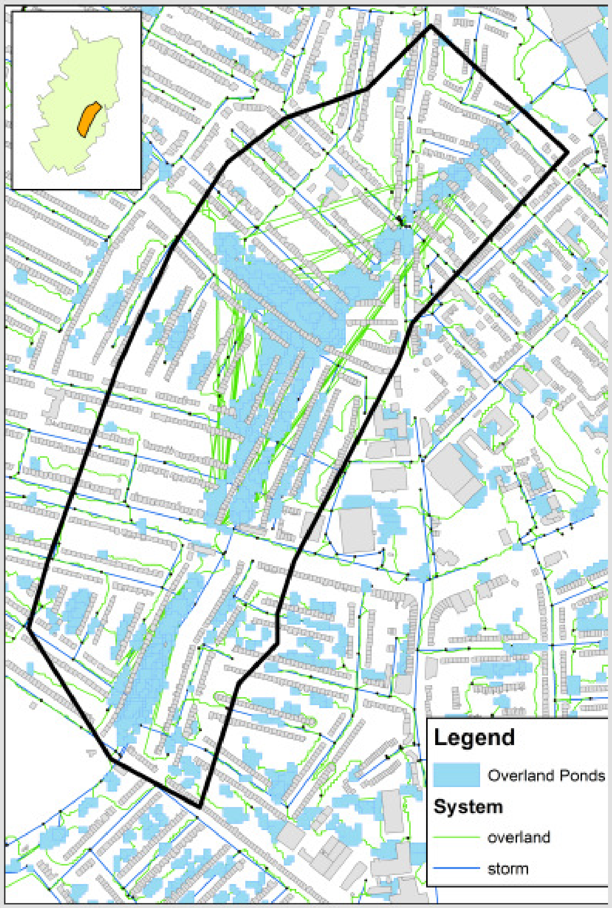




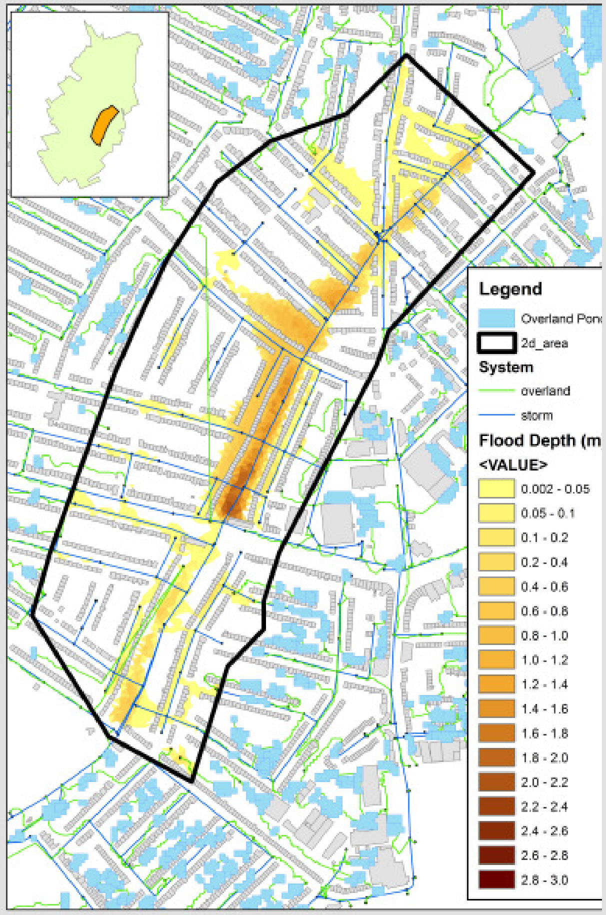

Legend
Roding River
Thames
Cranbrook Catchment
Londong Borough of Redbridge
Roding Catchment
0
5
10
20
Kilometers


Pipe 1431.1
Pipe 463.1
Legend
Sewer Network
Most vulnerable area
Build
Boundary

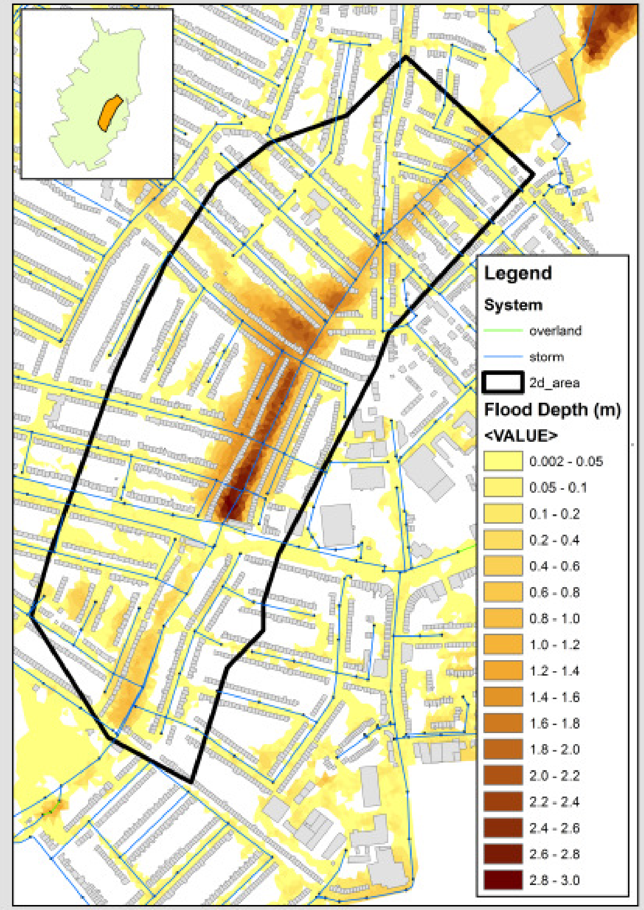
1D1D

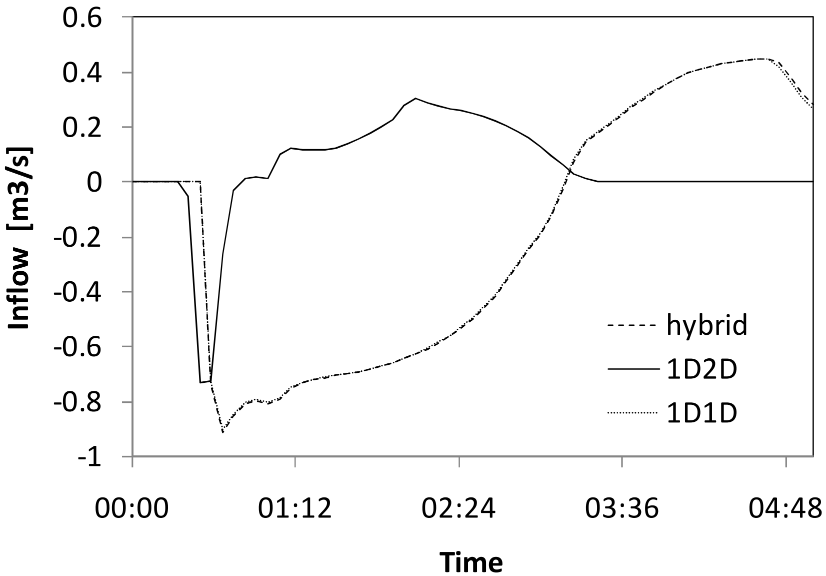


Hybrid

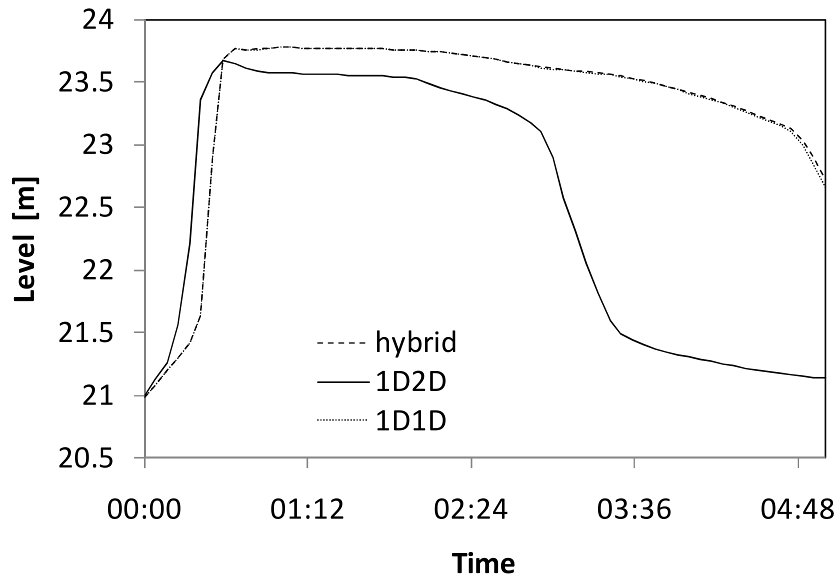


1D2D

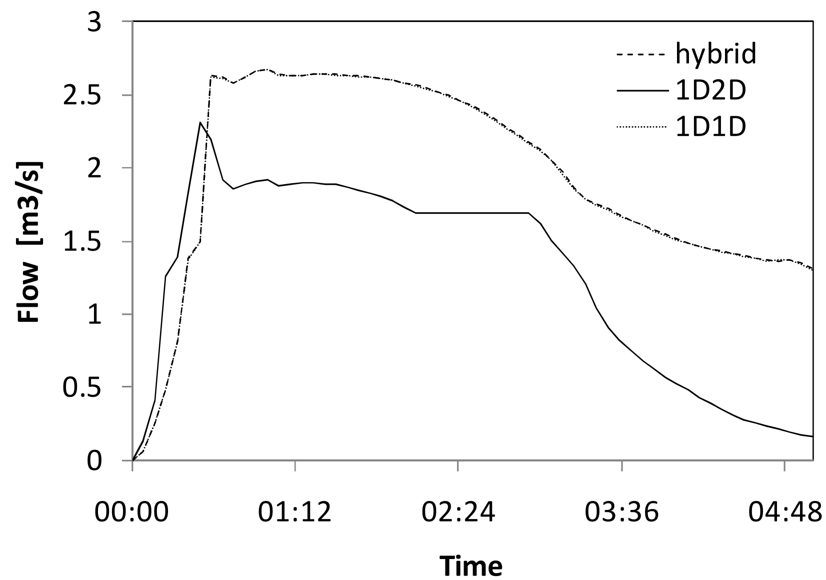




Inflow from the overland network and sewer system



Water level in downstream node



Flow in the pipe

Simulation Time

event	model	[hh:mm:ss]	vs 1D1D	vs hybrid
300 min 30 yr	1D1D	00:01:46		
	Hybrid	00:04:31	156%	
	1D2D	00:45:23	2469%	905%
300 min 100 yr	1D1D	00:02:11		
	Hybrid	00:05:20	144%	
	1D2D	01:11:10	3160%	1234%
300 min 200yr	1D1D	00:04:40		
	Hybrid	00:05:49	25%	
	1D2D	01:16:05	1530%	1208%

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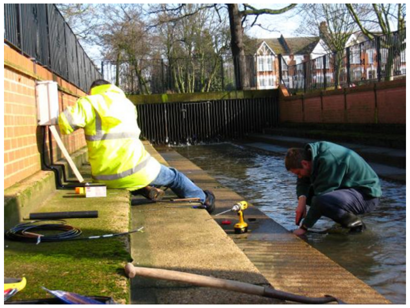
Monitoring System - Cranbrook

- 3 tipping bucket rain gauges, with 1-2 min data “sampling”.
- 1 pressure sensor for Roding River level monitoring. Real time frequency: 5/10 min.
- 2 sensors for water depth measurement in sewers. Real time frequency: 5/10 min.
- 1 sensor for water depth measurement in open channels (downstream boundary condition).



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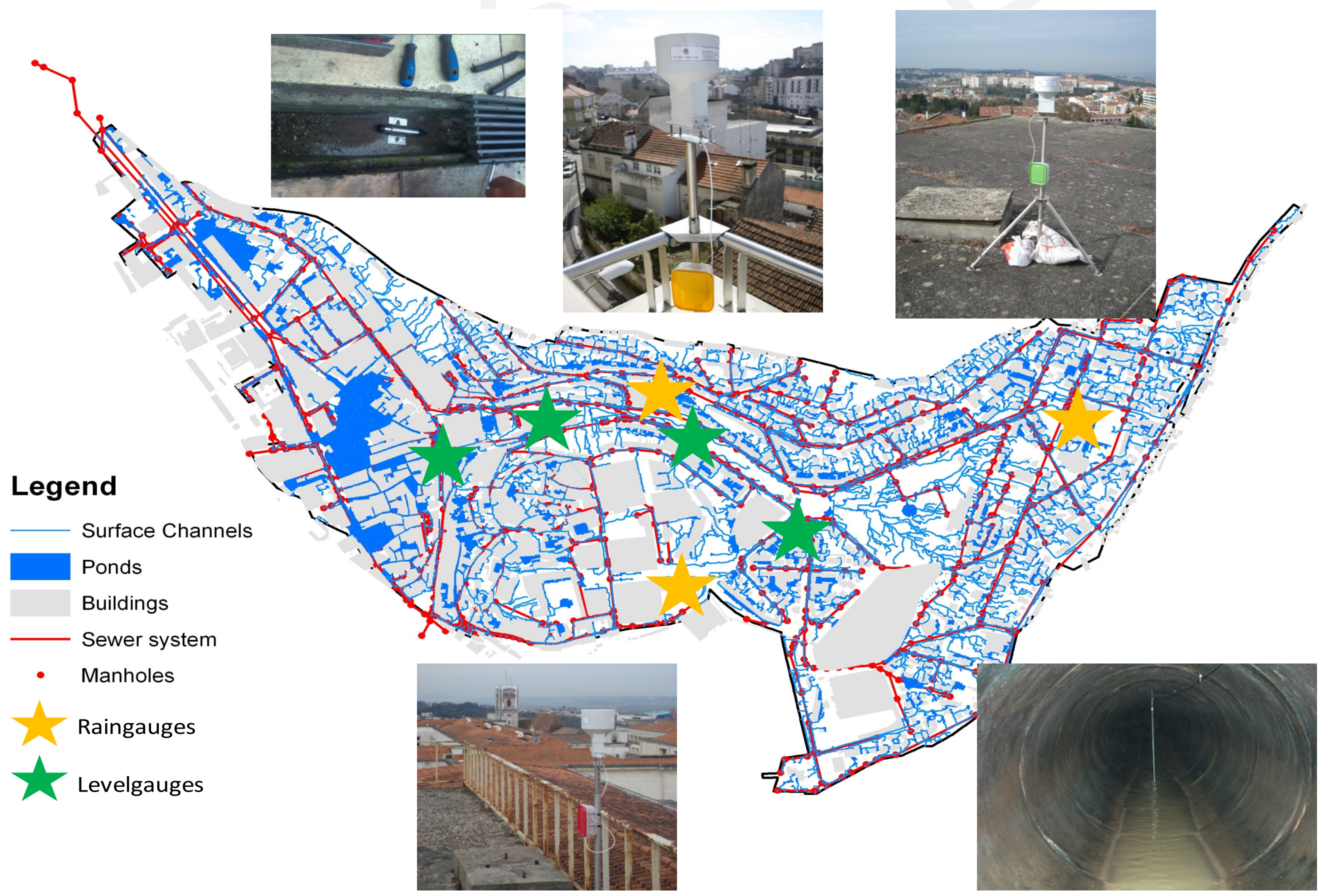
Monitoring System - Coimbra

- 3 tipping bucket rain gauges
- 3 sensors for water depth measurement in sewers.
- 1 sensor for water depth measurement in the surface.



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Conclusions

- Where the drainage system has adequate capacity it can be modelled as 1D only;
- 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

- 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;
- With the new strategy to simplify the hydraulic network it is possible to reduce the simulation time with very similar hydraulic results;
- The new Hybrid models can be as good as 1D2D models but much faster.

Further reading

Maksimović, Č., Prodanović, D., Boonya-aroonnet, S., Leitão, J. P., Djordjević, S., and Allitt, R. (2009). Overland flow and pathway analysis for modelling of urban pluvial flooding. Journal of Hydraulic Research, 47(4):512-523

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Leitão, J. P., Simões, N. E., Maksimović, Č., Ferreira, F., Prodanović, D., Matos, J. S., and Sá Marques, A. (2010). "Real-time forecasting urban drainage models: full or simplified networks?" Water Science & Technology—WST Vol 62 No 9 pp 2106–2114.

Simões, N., Leitão, J. P., Pina, R., Ochoa, S., Sá Marques, A., Maksimović, Č. (2011) Urban drainage models for flood forecasting: 1D/1D, 1D/2D and hybrid models. 12th International Conference on Urban Drainage, Porto Alegre, Brazil. (submitted)