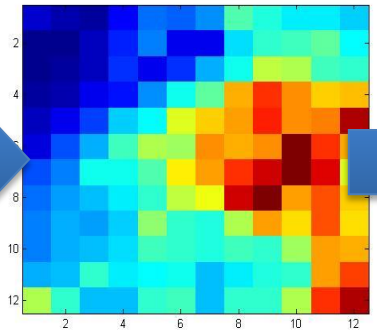
High-resolution urban drainage (flooding) simulation

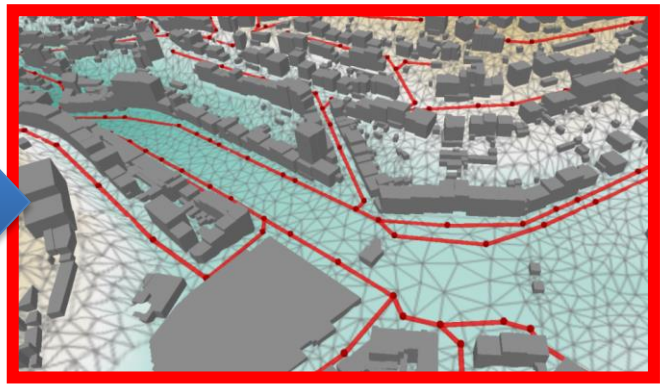
by

Susana Ochoa-Rodriguez, Imperial College London

Radar technologies



Radar QPEs



High res urban drainage modelling using improved QPEs

- Implementation of models at pilot locations and evaluation of model structures
- Testing of models with improved rainfall inputs and evaluation of the impact of rainfall input resolution on modelling outputs
- Investigation of alternatives for local surface water flood forecasting systems

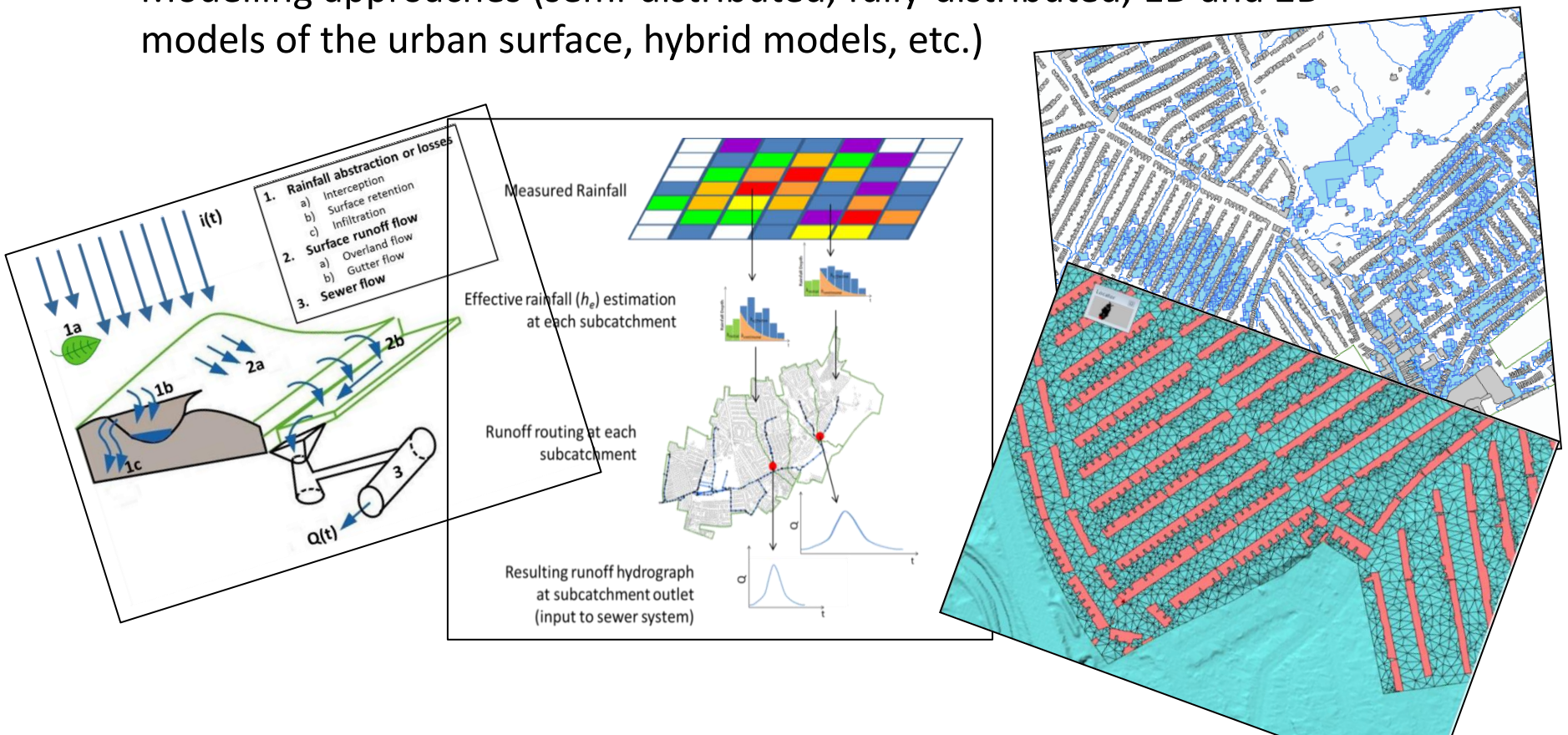
Investing in Opportunities
This project has received European Regional Development Funding through INTERREG IV B.
INTERREG IVB

Implementation of models at pilot locations and evaluation of model structures

PILOT LOCATIONS

Model building and analysis tools and recommended practices

- Review document on urban pluvial flood models: current theory and practice
  - Model inputs and components
  - Modelling approaches (semi-distributed, fully-distributed, 1D and 2D models of the urban surface, hybrid models, etc.)



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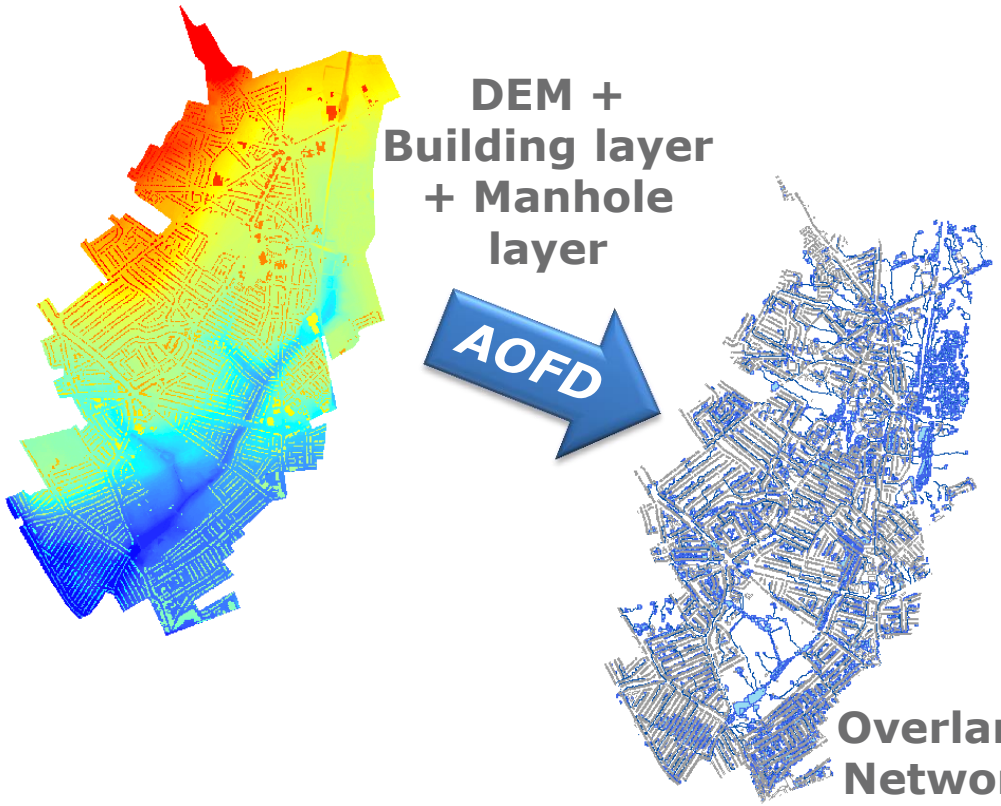

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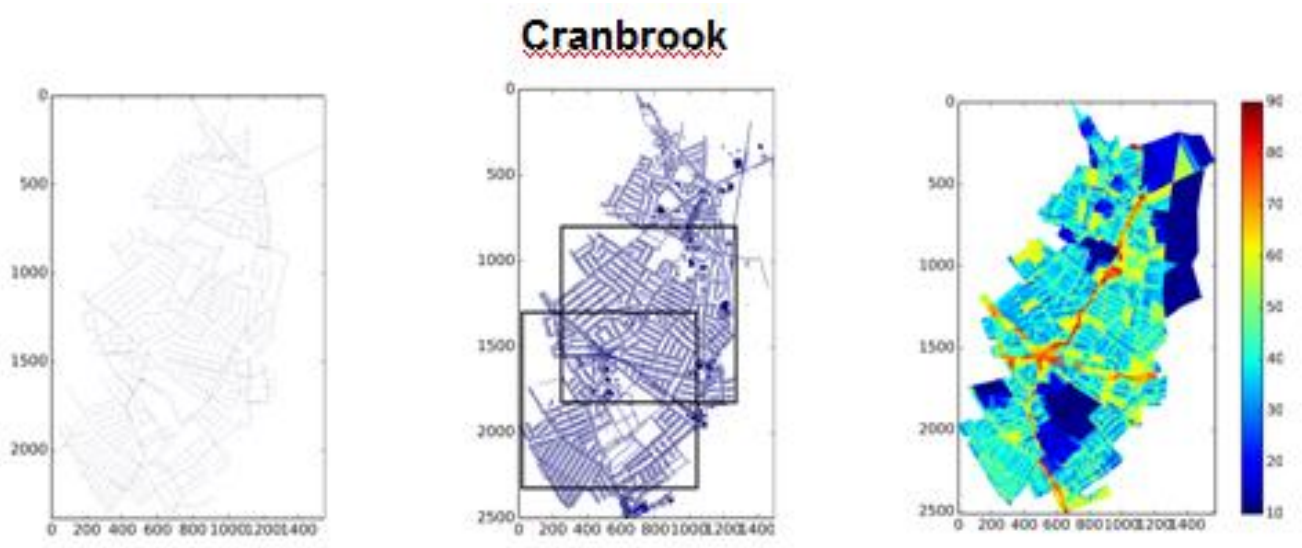

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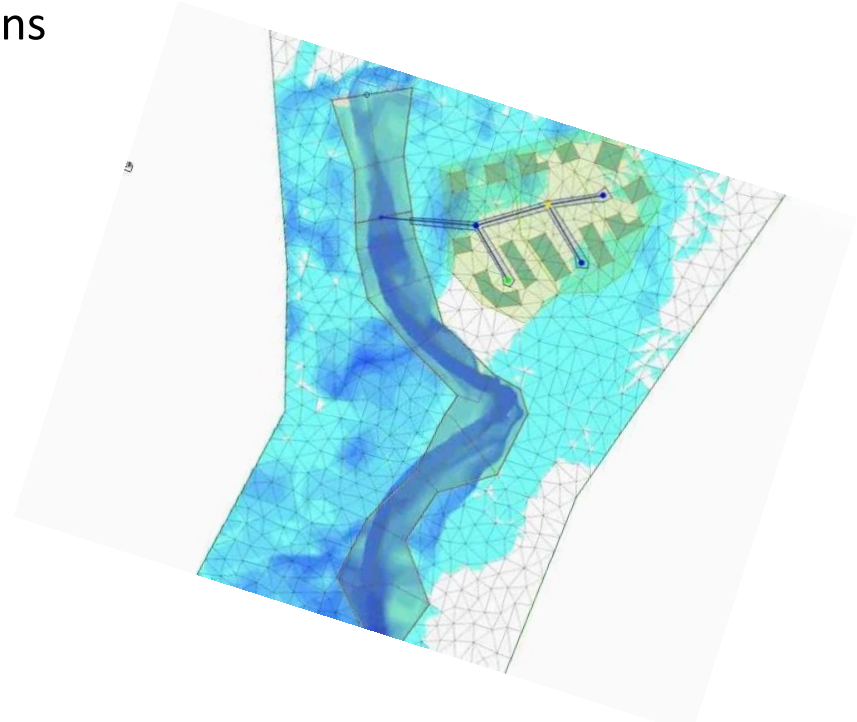
- Recommendations for dealing with open channels and other small surface features in urban pluvial flood simulations



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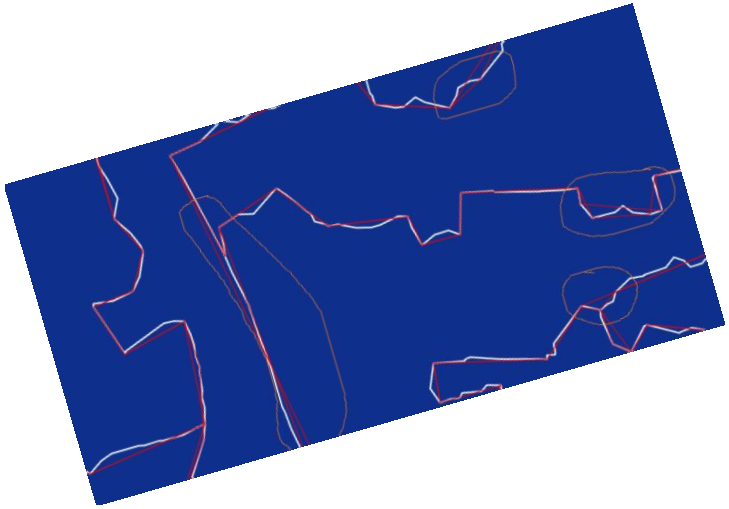
- General recommendations for dealing with buildings in 2-dimensional (2D) urban flood simulations



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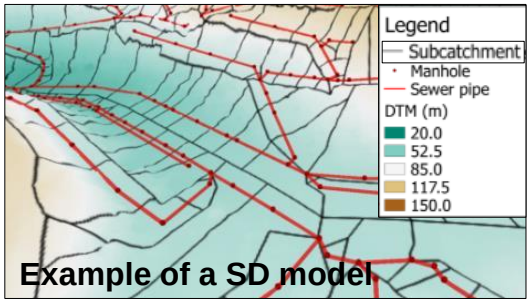
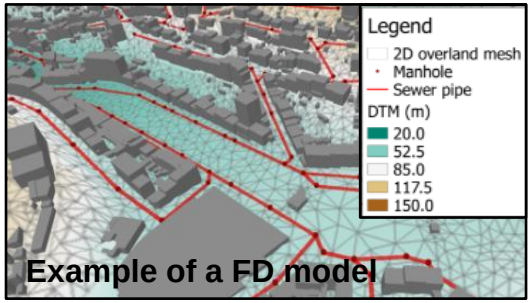
Comparison of semi- vs. fully-distributed models

SEMI-DIST. (SD)
Rainfall applied through sub-catchments



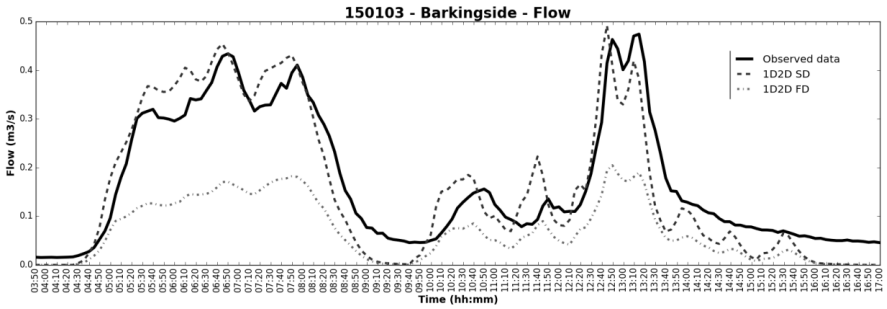


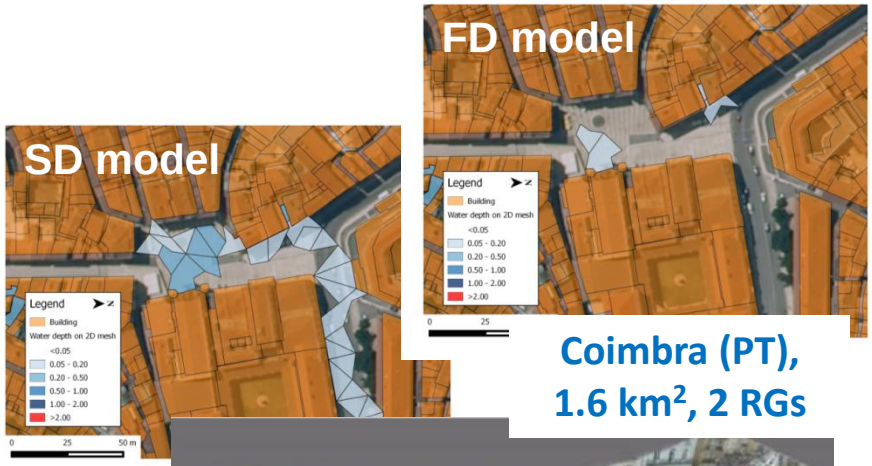
FULLY-DIST. (FD)
Rainfall applied directly on 2D surface model

- Same datasets used for model building
- Same rainfall input & runoff volume model
- Main difference: spatial discretisation & routing

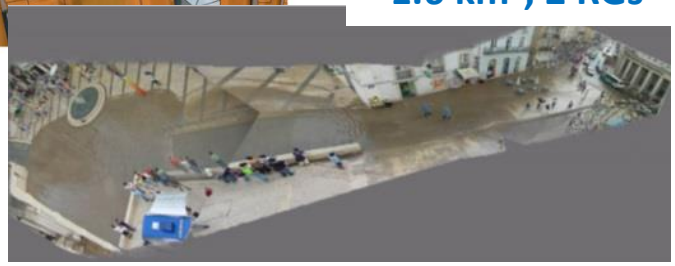
Results

Cranbrook (UK), 8.6 km^2, 4 RGs





Coimbra (PT), 1.6 km^2, 2 RGs



- FD models require higher detail of the sewer network than normally available, else: inaccurate results.
- If high-resolution data are not available: SD models could be a better choice

Investing in Opportunities
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INTERREG IVB

Impact of spatial and temporal resolution of rainfall inputs on operational urban hydrological modelling outputs

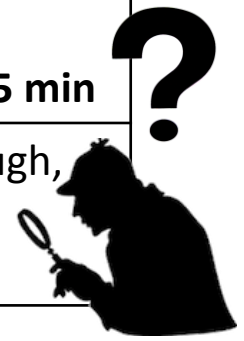
… Some questions yet to be answered

- Is the resolution of commonly available radar rainfall estimates (1 km / 5-10 min) enough?

- Can current urban drainage models take full advantage of higher resolution rainfall estimates?

Multiple studies on this topic

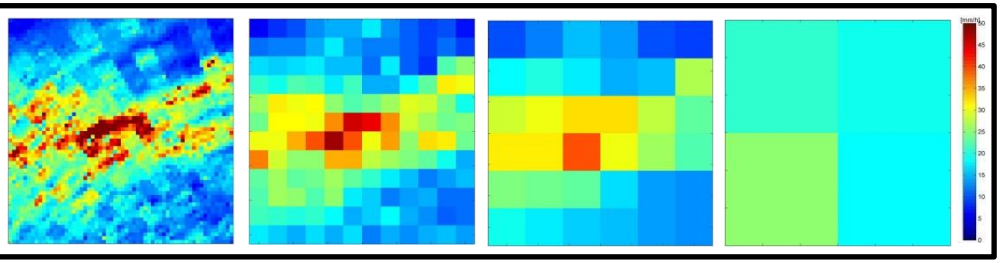
Author	Type of study	Required resolution
Schilling (1991)	Theoretical	**1 km / 1-5 min**
Fabry et al. (1994)	Rainfall analysis at small areas - no hydraulic modelling involved	**100 – 500 m / 1 – 5 min**
Einfalt et al. (2004; 2005)	Theoretical	**100 – 500 m / 1 – 5 min**
Berne et al. (2004)	Rainfall analysis and recorded flows – no hydro modelling	Depends on area For A = 5 km^2: **3 km / 5 min**
Gires et al. (2012; 2013); Wang et al. (2012)	Stochastic rainfall downscaling + hydraulic modelling (1 catchment)	**1 km / 5 min** not enough, especially at small drainage areas

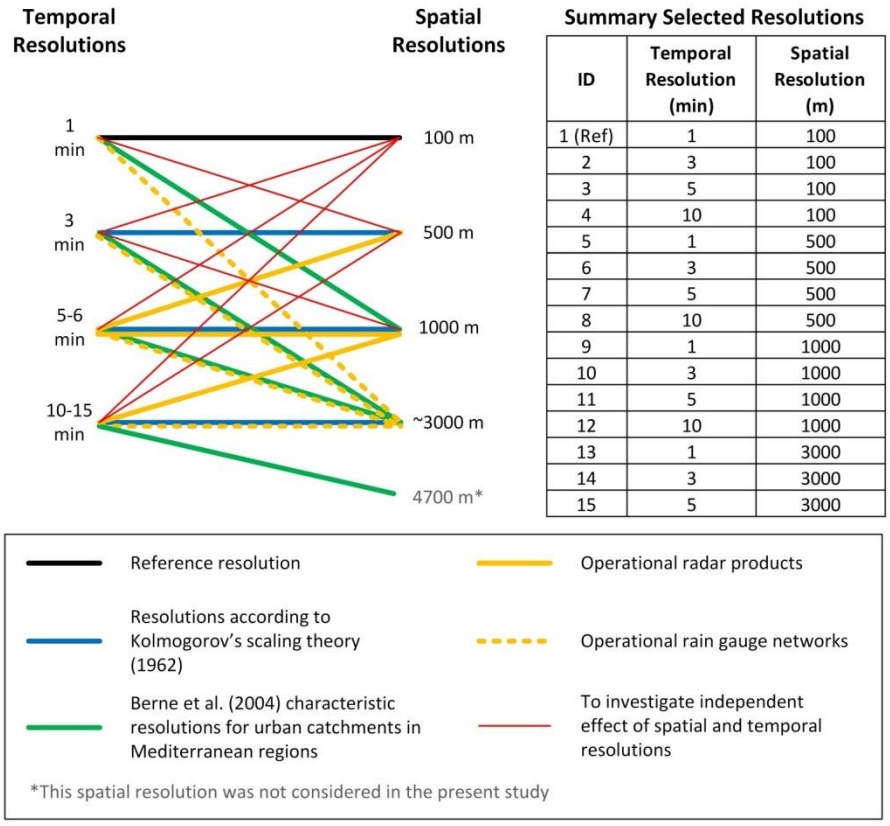


MULTI-CATCHMENT, MULTI-STORM INVESTIGATION OF THE IMPACT OF SPATIAL AND TEMPORAL RESOLUTION OF RAINFALL INPUTS ON OPERATIONAL URBAN HYDRODYNAMIC MODELLING OUTPUTS

Rainfall data:

- 9 storms recorded by X-band radar
- 16 spatial-temporal resolutions:
  100 m – 3 km & **1 min – 10 min**





Summary Selected Resolutions

ID	Temporal Resolution (min)	Spatial Resolution (m)
1 (Ref)	1	100
2	3	100
3	5	100
4	10	100
5	1	500
6	3	500
7	5	500
8	10	500
9	1	1000
10	3	1000
11	5	1000
12	10	1000
13	1	3000
14	3	3000
15	5	3000

- **Coarser spatial resolutions** generated through **aggregation** (i.e. averaging)
- **Coarser temporal resolutions** generated through:

i. **Sampling**

ii. **Aggregation**

MULTI-CATCHMENT, MULTI-STORM INVESTIGATION OF THE IMPACT OF SPATIAL AND TEMPORAL RESOLUTION OF RAINFALL INPUTS ON OPERATIONAL URBAN HYDRODYNAMIC MODELLING OUTPUTS

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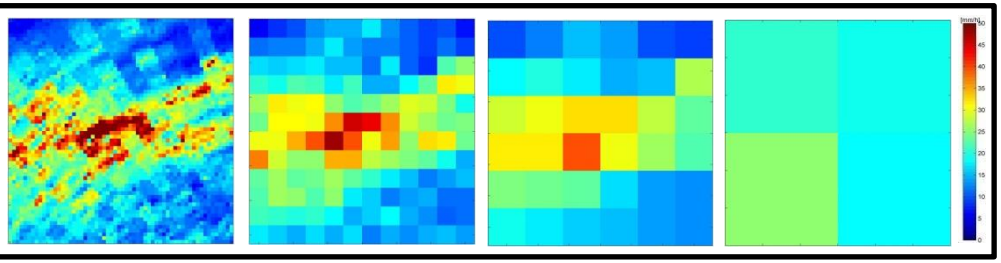
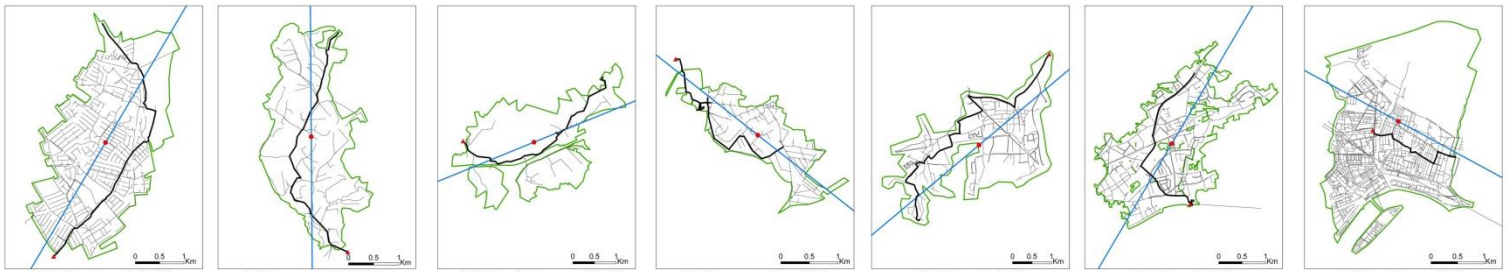


Semi-distributed operational urban drainage models of 7 RainGain pilot sites

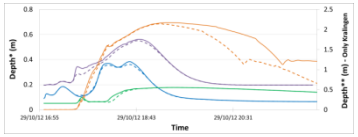


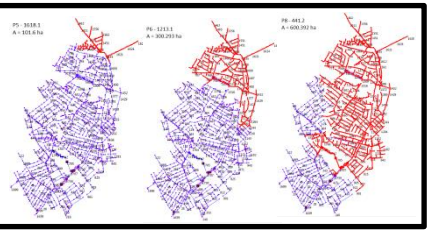
Areas:
3 – 8 km^2

In 4 NWE countries

Analysis and inter-comparison of results considering:

- Storm *spatial* - *temporal* characteristics
- Catchment characteristics

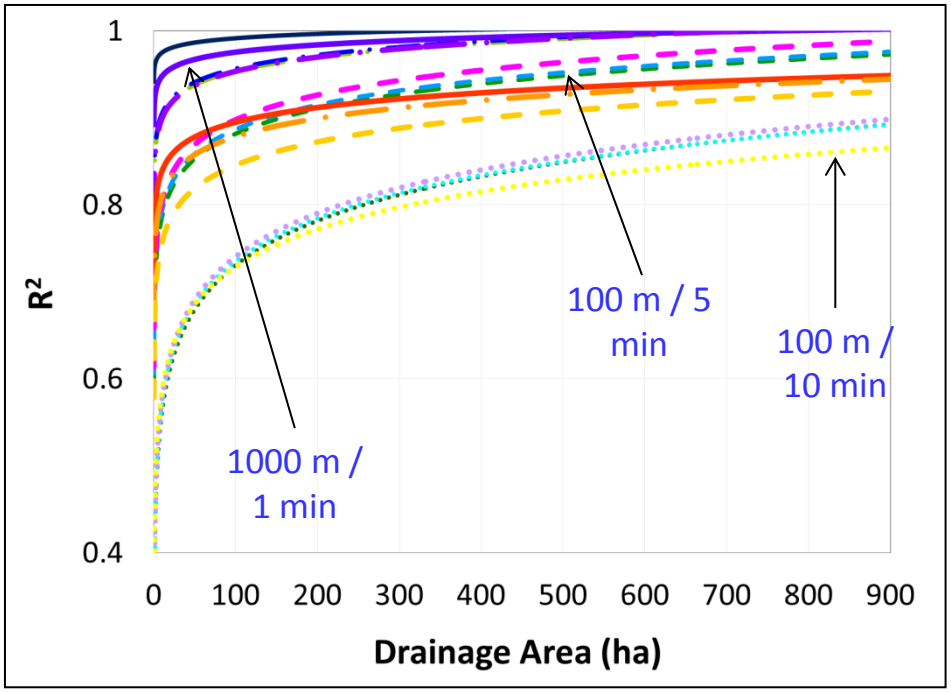


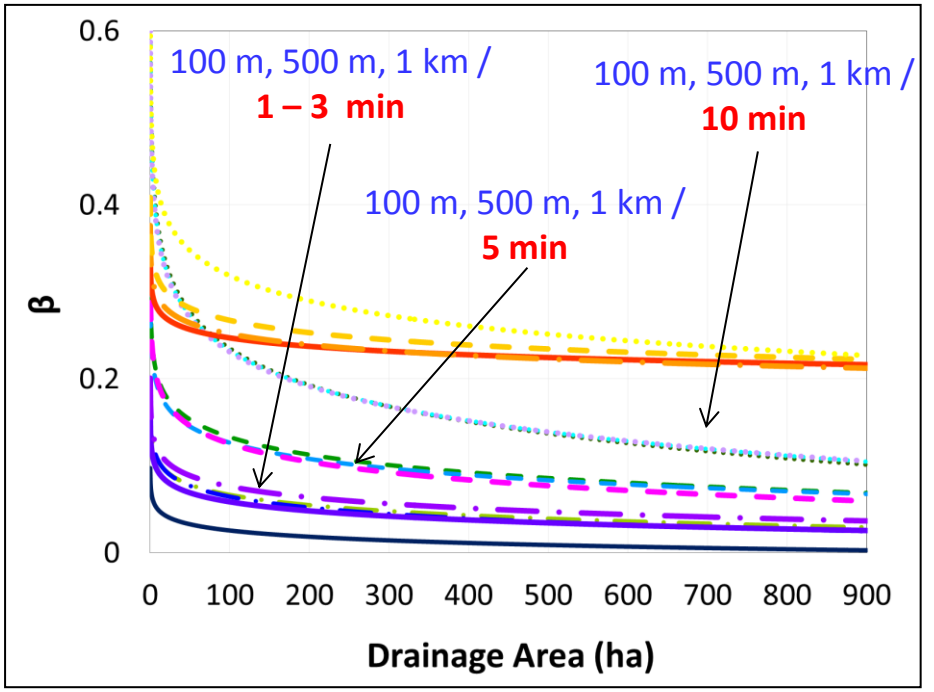


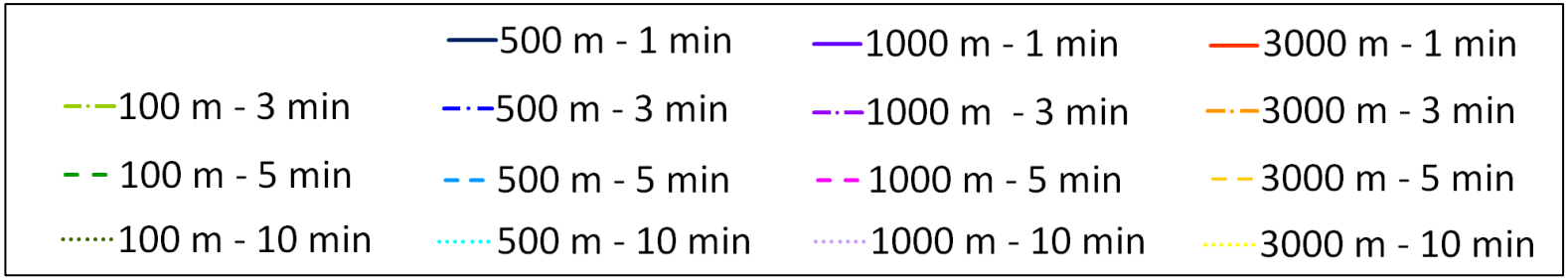
A methodology for characterising and standardising rainfall inputs and results was devised, thus allowing inter-comparison

Ochoa-Rodriguez et al. (2015), JoH

Drainage Area vs. Stats - Log Functions per rainfall input

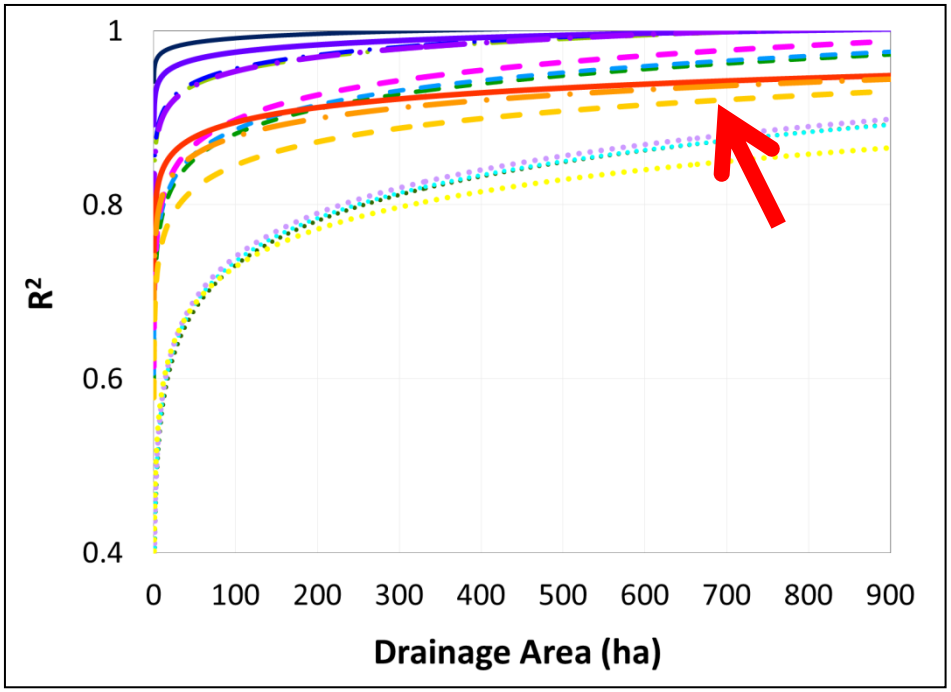


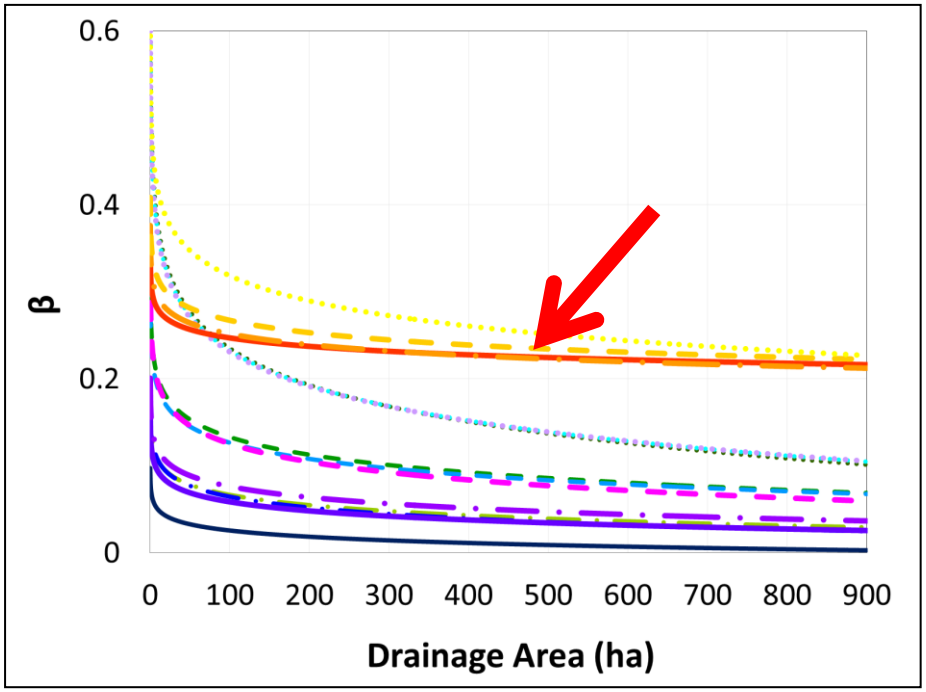




- In general, coarsening of temporal resolution **(by sampling)** has stronger influence than coarsening of spatial resolution

Log Functions per rainfall input - Drainage Area vs. Stats





500 m - 1 min
1000 m - 1 min
3000 m - 1 min
100 m - 3 min
500 m - 3 min
1000 m - 3 min
3000 m - 3 min
100 m - 5 min
500 m - 5 min
1000 m - 5 min
3000 m - 5 min
100 m - 10 min
500 m - 10 min
1000 m - 10 min
3000 m - 10 min

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- Spatial resolution: big (and dominant) drop in performance only at 3 km resolution

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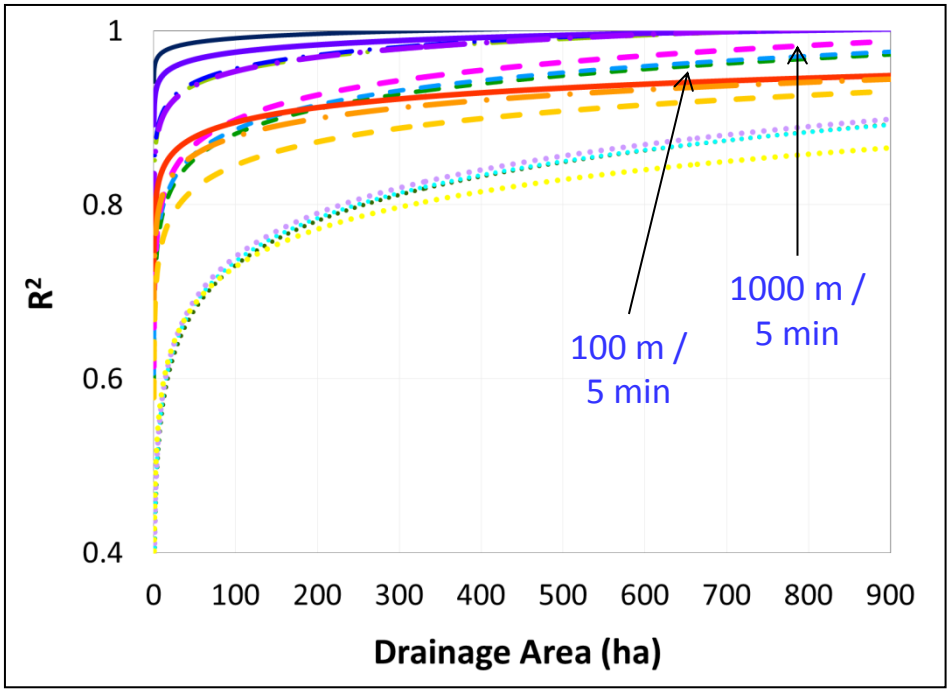

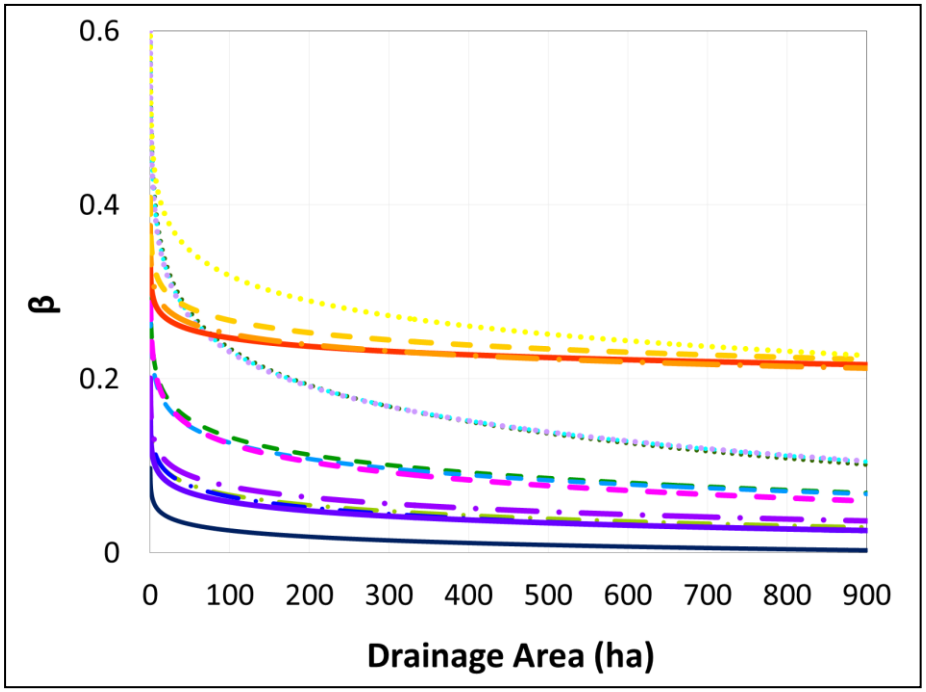

500 m - 1 min
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100 m - 5 min
500 m - 5 min
1000 m - 5 min
3000 m - 5 min
100 m - 10 min
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3000 m - 10 min

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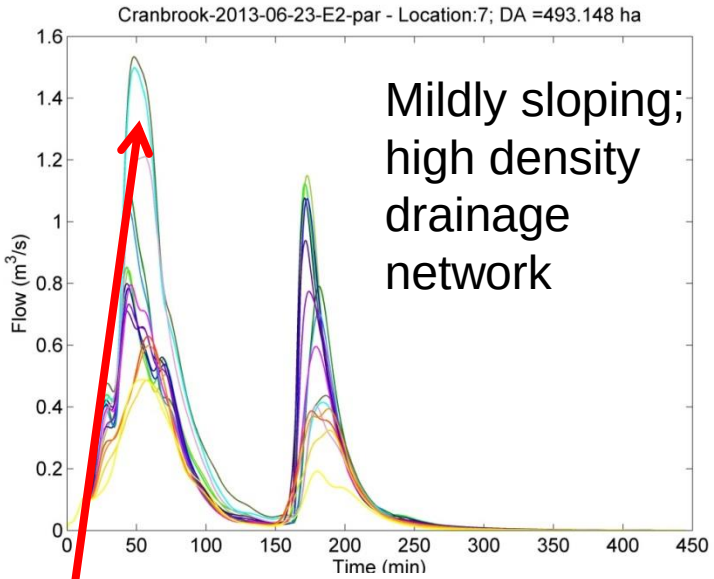
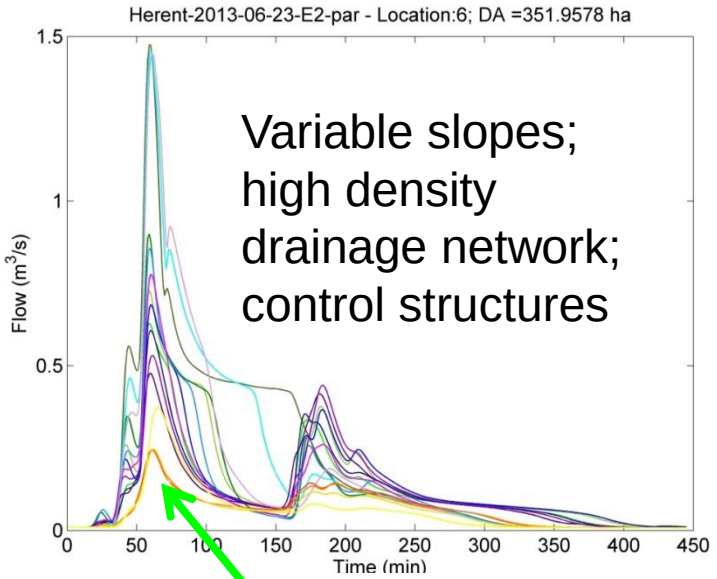
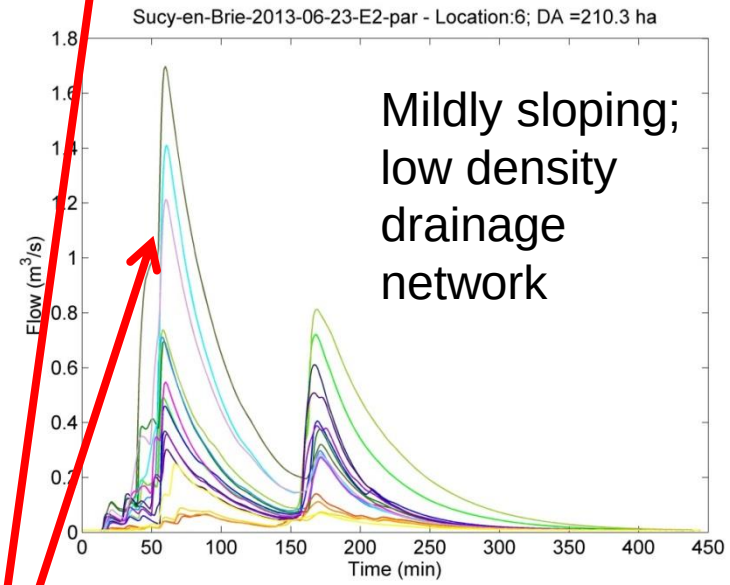
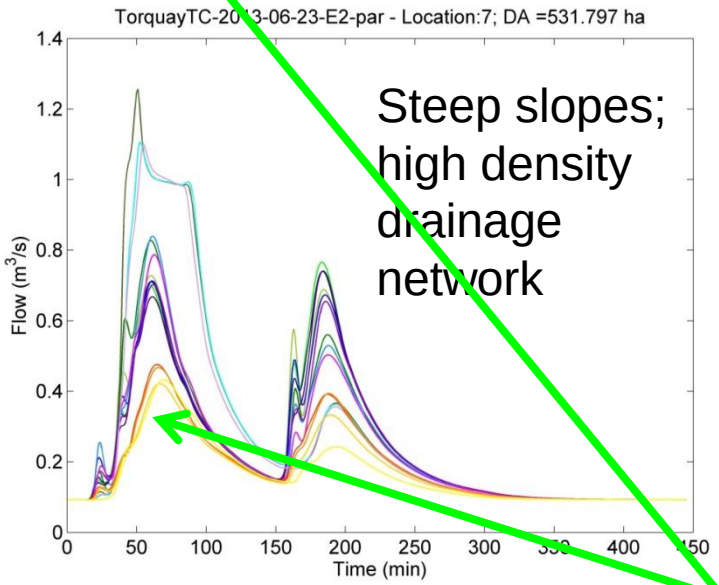
- Spatial resolution: big (and dominant) drop in performance only at 3 km resolution
- Interaction between temporal and spatial resolutions





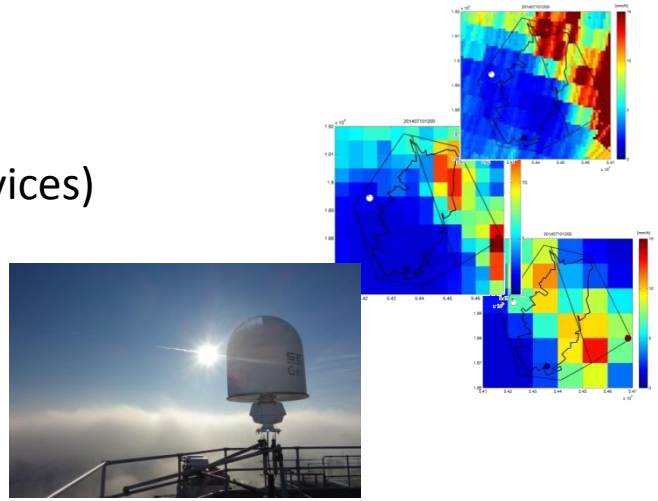




Ref
100m-3min
100m-5min
100m-10min
500m-1min
500m-3min
500m-5min
500m-10min
1km-1min
1km-3min
1km-5min
1km-10min
3km-1min
3km-3min
3km-5min
3km-10min

Implications of this study

(currently available resolution: 1 km / 5-10 min)



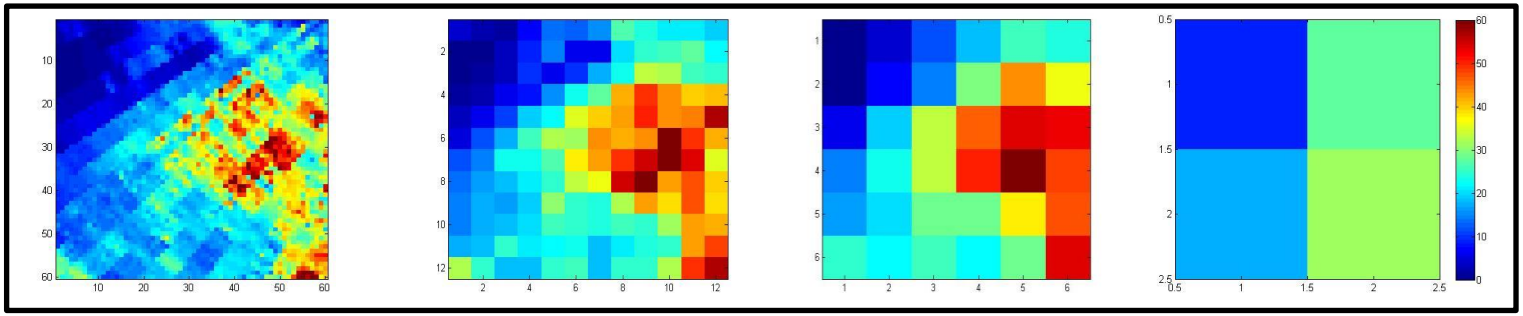
- Required temporal resolutions: < 5 min
  - Not commonly available (from national weather services)
  - Alternatives for obtaining it:
    - Temporal interpolation of radar images

    (*Wang et al., 2015, JoH*)
    - Stochastic temporal downscaling – practical use?
    - Use of X-band radars (*Ochoa-Rodriguez et al. (2014), WRaH*)
- Spatial resolution ~ 1 km (commonly available) seems sufficient for urban hydrological applications, except for very small drainage areas (~<1ha)
- Spatial resolution ≥ 3 km is insufficient (rain gauges?)!
- Impact of rainfall input resolution depends mainly upon drainage area and storm characteristics; proposed method to characterise spatial – temporal features of storms works well!

Impact of rainfall input resolution on semi-distributed and fully-distributed urban drainage models

Case studies:

Coimbra, PT (1.6 km²) & Sucy-en-Brie, FR (2.7 km²)



Subcatchments:

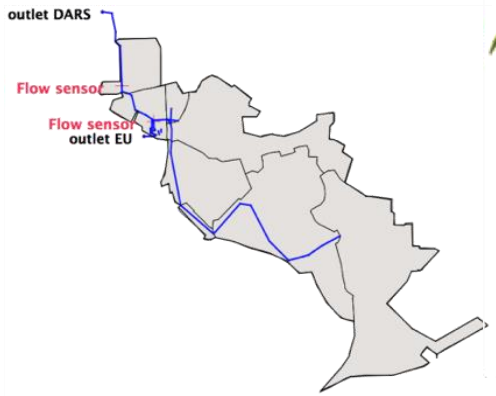
- **Coimbra:**

Mean: 0.18 ha
Median: 0.16 ha

- **Sucy-en-Brie:**

Mean: 39.9 ha
Median: 13.0 ha

Semi-Dist.



Fully-Dist.

2D model resolution:

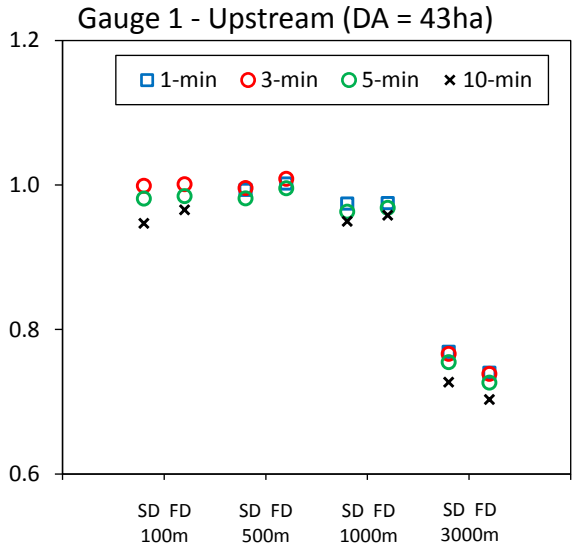
- **Coimbra:**

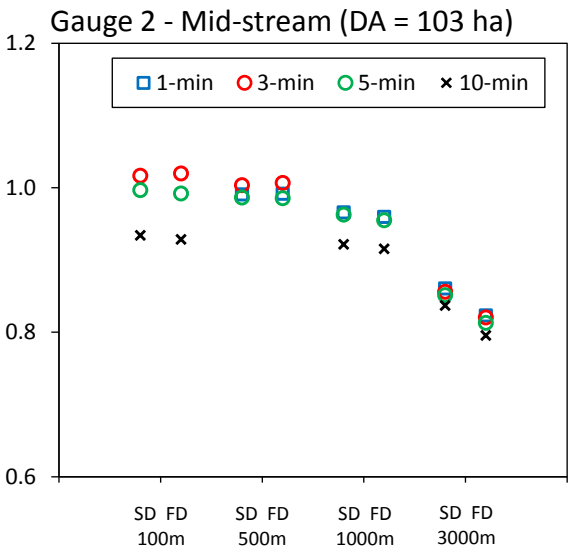
Triangular mesh:
25 m² - 678 m²
mean of 89 m2

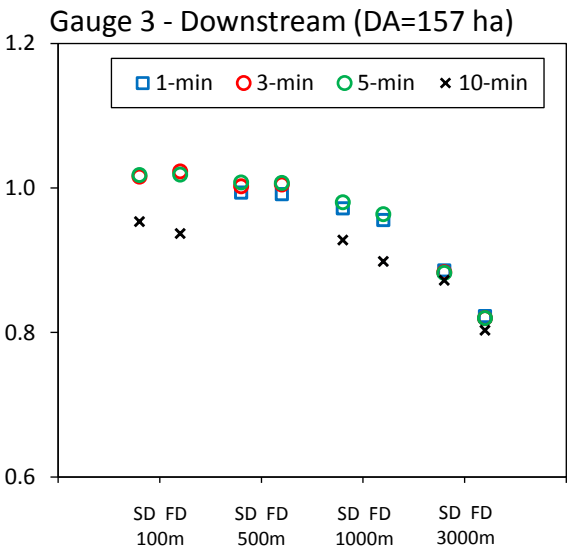
- **Sucy-en-Brie:**

Rectangular grid:
10 m x 10 m

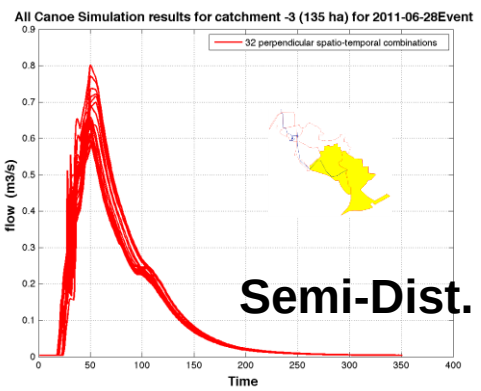
Regression Coefficient Beta (100 m / 1 min as reference)

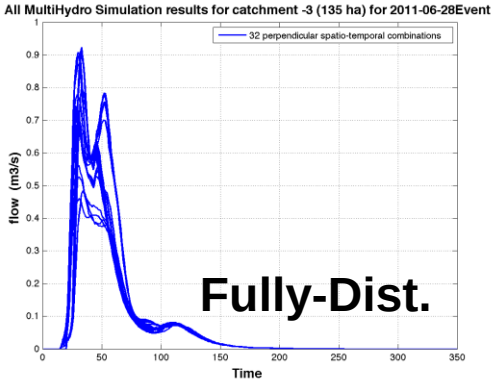


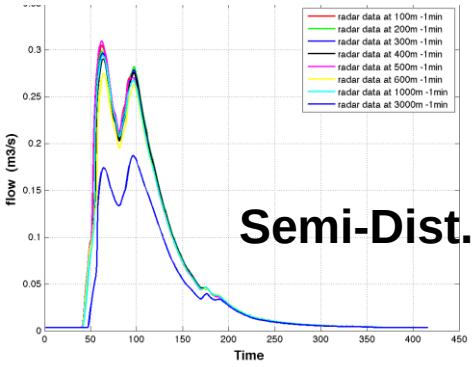


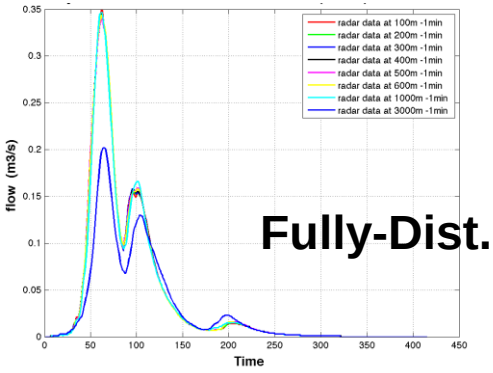


- Fully-distributed models generally more sensitive
- For both models: biggest drop at 3 km spatial resolution and 10 min temporal resolution
- In FD models: using coarser data means you're wasting high res rainfall (RG for detailed models?) -> FD requires high res rainfall data









SUMMARY & LESSONS LEARNT

- **One size does not fit all!** Type of model depends on:
  - Purpose (CSO reduction? Flood visualisation?)
  - Available computer power
  - Data availability: surface data, sewer data & rainfall data

THESE MUST ALWAYS BE IN AGREEMENT

- Fully-distributed models are generally desirable, particularly when ponding is a relevant flooding mechanism. In fact, current tendency is clearly towards fully distributed models, but:
  - Runtimes are still problematic – option: use of nested / hybrid models
  - Fully distributed models require far more detailed data which is not always available and which is harder to process. Tools to deal with some of these challenges have been developed.
- Strong interaction between temporal and spatial resolution of rainfall inputs
- While temporal resolution has shown to have a stronger effect on hydro results, measuring rainfall at higher temporal resolution can lead to improved accuracy.

Rain Gain

Investing in Opportunities

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Alternatives for local surface water flood forecasting systems

- Evaluation of approaches / system structure
- Technologies for system implementation

Feasibility analysis of different local surface water flood forecasting systems

By UK National Observers
(local authorities, practitioners, met services and academics)

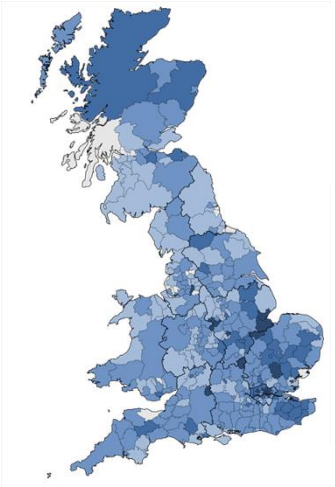
Two questions were discussed:

1. Single national services vs. two tier (national-local) service?

2. What type of system?

General approach?

Single national service OR Two-tier national/local service



- Rainfall (weather forecast) from national service (FFC)
- Local system, especially for hotspots, operated by LAs in collaboration with EA

What kind of local system?

In general, flood forecasting systems can be of 3 types (Hénonin et al. 2010):

a) **Empirical scenario-based system:** warning thresholds based on knowledge of the area (e.g. Extreme Rainfall Alert service)

b) **Pre-simulated scenario-based system:** results catalogue built from previous hydraulic simulations (e.g. data-driven models)

c) **Real-time simulations-based system:** real-time hydraulic modelling

- The main input for all 3 systems is rainfall forecast
- All 3 systems could benefit from complementary hydro telemetry data

What kind of local system?

Type of system	Accuracy/Quality	Cost/ease of implementation	Cost/ease of operation
(a) Empirical scenario-based			
(b) Pre-simulated scenario-based			
(c) Real-time simulations-based system			

- **Technically:** all systems are feasible
- **Monetary and human resources availability:** only (a) and (b) for the time being
- **Type (b):** good balance
- Gradual capacity building

Main constraints:

- Insufficient accuracy of rainfall estimates and forecasts
- Lack of capacity at local authorities
- Low-levels of public flood risk awareness
- Limited budget

TECHNOLOGIES FOR SYSTEM IMPLEMENTATION (For automatic, RT linkage of rainfall inputs to storm water/flood models)

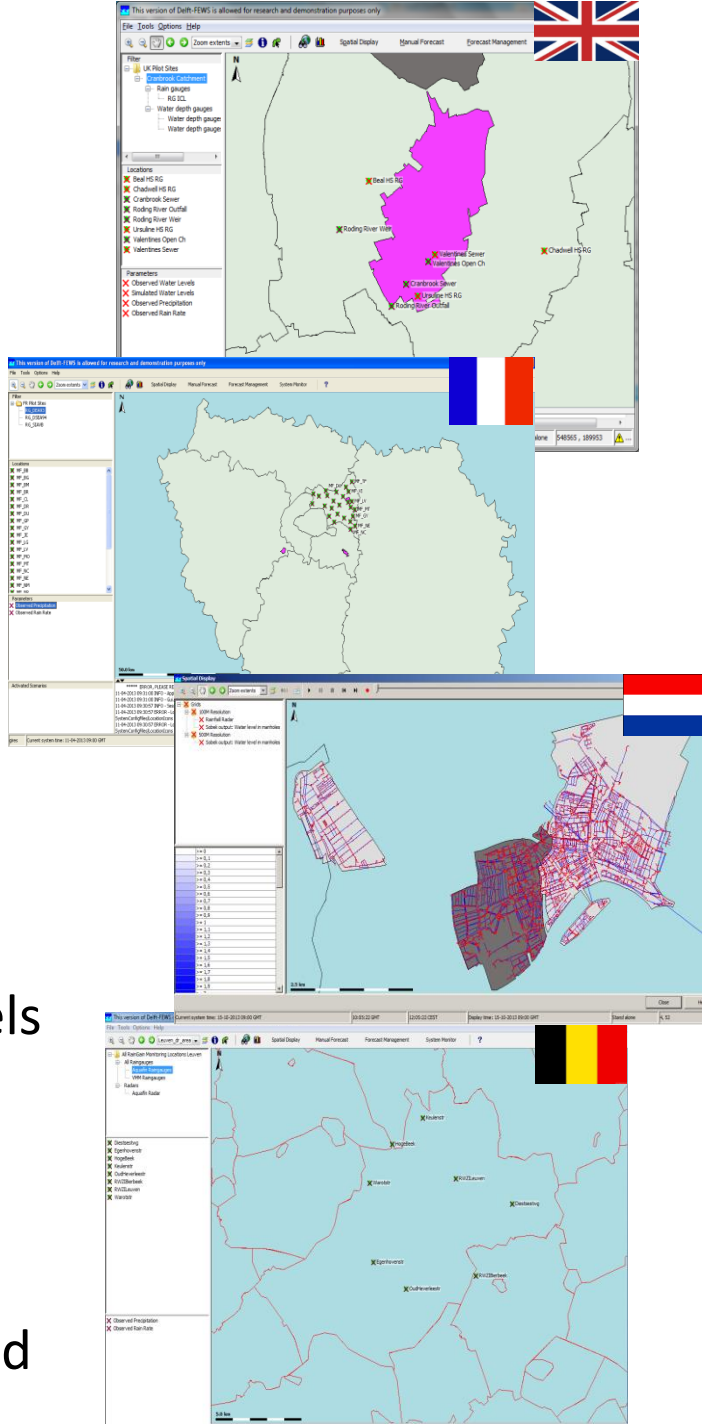
- Initially: analysis of existing shells/platforms that allow automatic linkage of rainfall inputs & hydro models:

  In-house linkage of input data and models; UrbanFlood Common Information Space (CIS); Innovyze Floodworks & **ICM Live**; **Delft-FEWS**

- Test of Delft-FEWS, FloodWorks and InfoWorks ICM platforms at different pilot sites
- Learned about their advantages and disadvantages, bottlenecks for implementation of these systems, amongst others

Testing of Delft-FEWS platform

- **Delft-FEWS:**
  - Open shell (allows linking components)
  - Freely available
  - Widely used for operational flood forecasting (yet seldom used for urban drainage systems)
- **Pilot platform with basic functionalities was implemented:**
  - To import rainfall inputs
  - Link rainfall inputs to urban drainage models in SWMM
  - Visualise runoff estimates (and compare against records)
- Documentation and training material developed



Testing of FloodWorks and InfoWorks CS systems: Leuven Pilot Area

Initial idea :
InfoWorks CS 2D → FloodWorks

- Licence restrictions for large urban systems
- Software suite not commercially supported anymore after 2015

Final setup
InfoWorks ICM → ICM Live

- One integrated software suite
- No database limitations
- Much more new developments to be expected

Current status of Leuven RT system

- Realtime rainfall data collection and processing
  - RMI radar (C-band, 5')
  - Leuven LAWR radar (X-band, 5 x 1')
  - Leuven raingauges (n x 1')
- Automatic simulation launch (1D model)
  - Every 10 minutes
  - 5 h hindcast (+ 1 h forecast)
- Automatic alert generation
  - E-mail

Future extensions of Leuven RT system

- Implement rainfall forecast modules and forecast simulation
  - C-band available shortly
  - X-band : needs more research
- Replace 1D by 2D model
  - Await new DEM for more stable 2D model
  - Find optimum between accuracy and speed
  - Which parameters to use for alert generation ?

	+	-
Delft-FEWS	• Free • Multiple built-in tools • Widely used for national flood forecasting systems	• Implementation not so user-friendly • So far, it is not possible to link InfoWorks models to this platform
FloodWorks	• User-friendly interface • Tailored to work with InfoWorks CS, which is widely used operationally	• Limited data handling – e.g. limitation in the number of rainfall grids that one can use (hence limiting the use of high res rainfall estimates) • Commercial software (licence costs & limited possibilities for customisation/improvement)
InfoWorks ICM Live	• User-friendly interface • Tailored to work with InfoWorks ICM, which is widely used in the UK	• Relatively new software - still suffers from a number of problems • IW ICM 2D simulation times are currently still too high to allow frequent updating of the simulations. • Commercial software

THANK YOU

(Questions during Q&A Session!)