Sewer Overflow Flood Risk Analysis MOdel Dafni Enabled

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City Catchment Analysis Tool - CityCat

CityCAT is a software tool for modelling, analysis and visualisation of surface water flooding.

It enables assessment of combined pluvial and fluvial flood risk and effects of different flood alleviation measures.

What's new?

- Easy to use
- Uses readily available data (OS Mastermap or OpenStreetMap and LiDAR)
- Includes buildings and green space and other urban features
- Coupled sewer drainage network and surface flow

City Catchment Analysis Tool

CityCat components:

- Mastermap parser (outlines of buildings, roads, infrastructure, etc.)
- Numerical grid generator
- Flow model: shallow water equations and numerical solutions
- Infiltration model: Green-Ampt method and Richards' equation for variably saturated flow in one-dimension.
- Roof storage: blue roofs and green roofs
- Sewer network: equations for mixed flow in pipes and integration with the overland flow model

City Catchment Analysis Tool

MasterMap data are used to delineate the urban features such as: buildings, roads and permeable surfaces

The computational grid is generated automatically using the DTM.

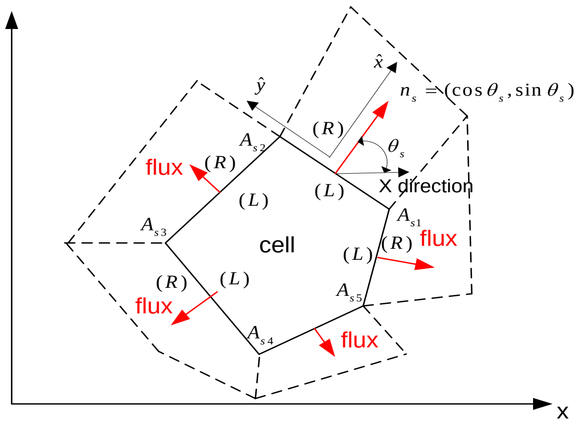
MasterMap data are used to exclude the buildings' footprint from the grid.

This improves the ability of the model to capture realistically the flow paths in urban areas and reduces the simulation time due to the reduction in the number of computational cells. The removed cells form the "buildings" layer are used in the roof drainage algorithms.

Free surface flow equations

Shallow Water Equations

$$\partial_t \mathbf{Q} + \partial_x \mathbf{F}(\mathbf{Q}) + \partial_y \mathbf{G}(\mathbf{Q}) = \mathbf{S}(\mathbf{Q})$$



The vectors are given as follows:

$$\mathbf{Q} \equiv [q_1, q_2, q_3]^T = \left[h, hv_x, hv_y\right]^T; \mathbf{F}(\mathbf{Q}) \equiv [f_1, f_2, f_3]^T = \left[hv_x, hv_x^2 + gh^2/2, hv_x v_y\right]^T$$

$$\mathbf{G}(\mathbf{Q}) \equiv [g_1, g_2, g_3]^T = \left[hv_y, hv_x v_y, hv_y^2 + gh^2/2\right]^T; \mathbf{S}(\mathbf{Q}) = \boldsymbol{S_o} - \boldsymbol{S_f}$$

Where v_x and v_y represent the depth-averaged velocity components in the x and y directions respectively; h is the water depth; g is the gravity acceleration;

$\boldsymbol{S_o} = \left[0, gh\partial_x z_b, gh\partial_y z_b\right]^T$ is the bed slope source term and z_b denotes the bed elevation; $\boldsymbol{S_f} = \left[0, ghSf_x, ghSf_y\right]^T$ is the friction term

Infiltration model

Green-Ampt method

The Green-Ampt method is used to estimate infiltration in pervious areas as a function of the soil hydraulic conductivity, the porosity and the suction head

The time dependent solution is obtained using an iterative method.

Richards' equation

the Richards' equation for variably saturated flow in 1D can also be used to estimate infiltration:

$$\partial_t \theta = \partial_z [K \, \partial_z h] + \partial_z K$$

where h is the pressure head, $\theta(h)$ is the volumetric moisture content, t is time, z is the spatial coordinate, $K(h)$ is unsaturated hydraulic conductivity

Blue-green features

Roof storage model

Two types of roof storage are applied to the buildings layer of the grid. These are:

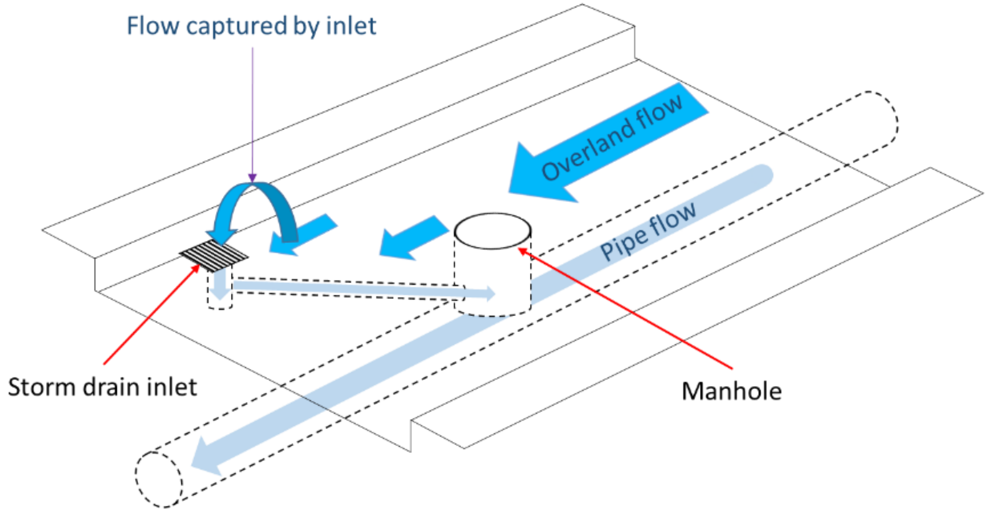
- "blue roof" which is based on the available volume of storage
- "green roof" which uses the Green-Ampt algorithm or the Richards' equation.

CityCat – Drainage network

subsurface drainage network model

Subsurface drainage model can handle realistic conditions, i.e. both free-surface and pressurised flows as well as two-way flows (in and out of sub-surface).

Model realistic scenarios such as pluvial flooding due to blocked sewers and flooding from sewers due to insufficient capacity.



Bertsch (2019)

Drainage network models

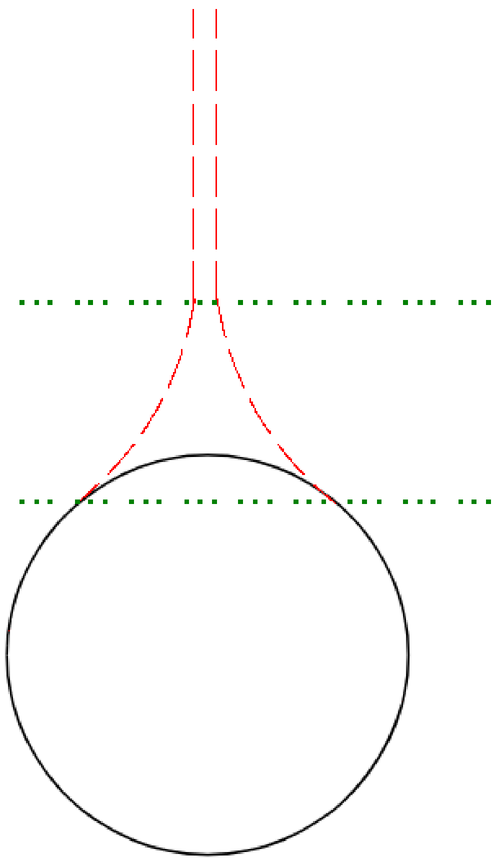
Subsurface drainage network models

There are a few models currently available for drainage networks.

All are based on the St. Venant equations which describe free surface flow.

The Preissmann slot is used to model pressurised flow. The method was introduced in 1964 by Cunge and Wegner.

The equations are solved using finite differences and the primitive variables are used (water depth and discharge)



Drainage network models

Subsurface drainage network models

Advantages:

- Very easy to implement. One set of equations is used for both free surface and pressurised flows
- Very fast. The numerical solution is very simple.

Disadvantages:

- The wave celerity which is the velocity with which a variation in the flow travels along the pipe can be very wrong.
- Problems with conservation of mass.

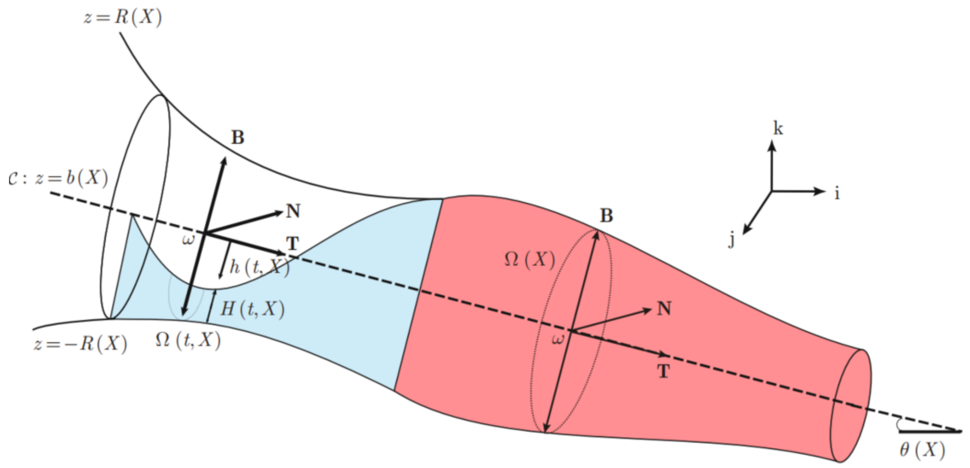
Drainage network models

CityCat subsurface drainage model:

The model is based on the St Venant equations and a conservative form of the Allievi equations based on the compressible Euler equations

Advantages:
- Free surface, pressurised and mixed flows can be modelled accurately
- There is no restriction in pressurised wave speed
- Realistic situations can be modelled such as flooding from sewers due to insufficient capacity.
- Can be used for pumping stations

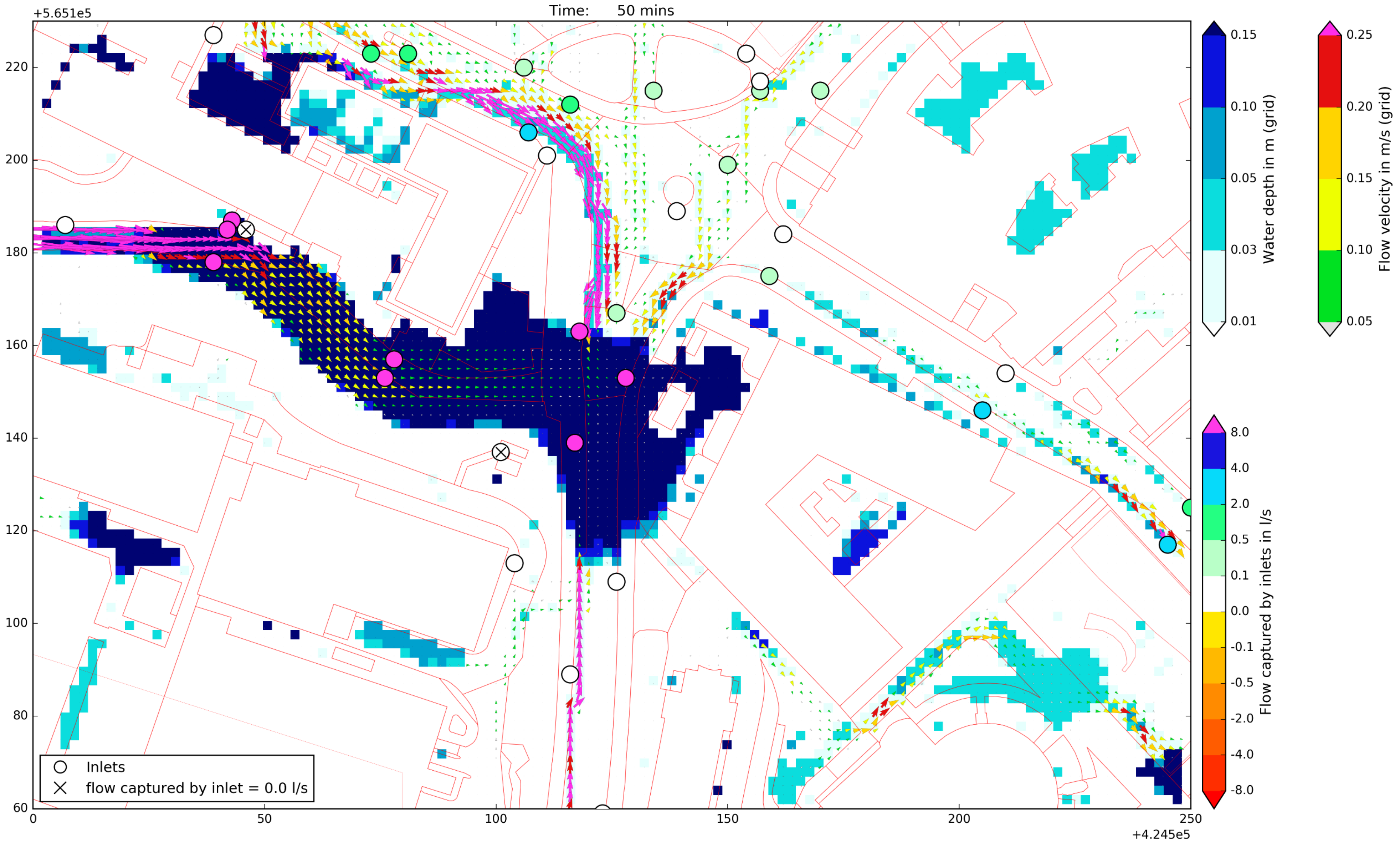
Disadvantages:
- Complex and difficult to implement
- Robust solvers required for the non-linear systems of equations.
- Slow compared to the Preissmann slot method.



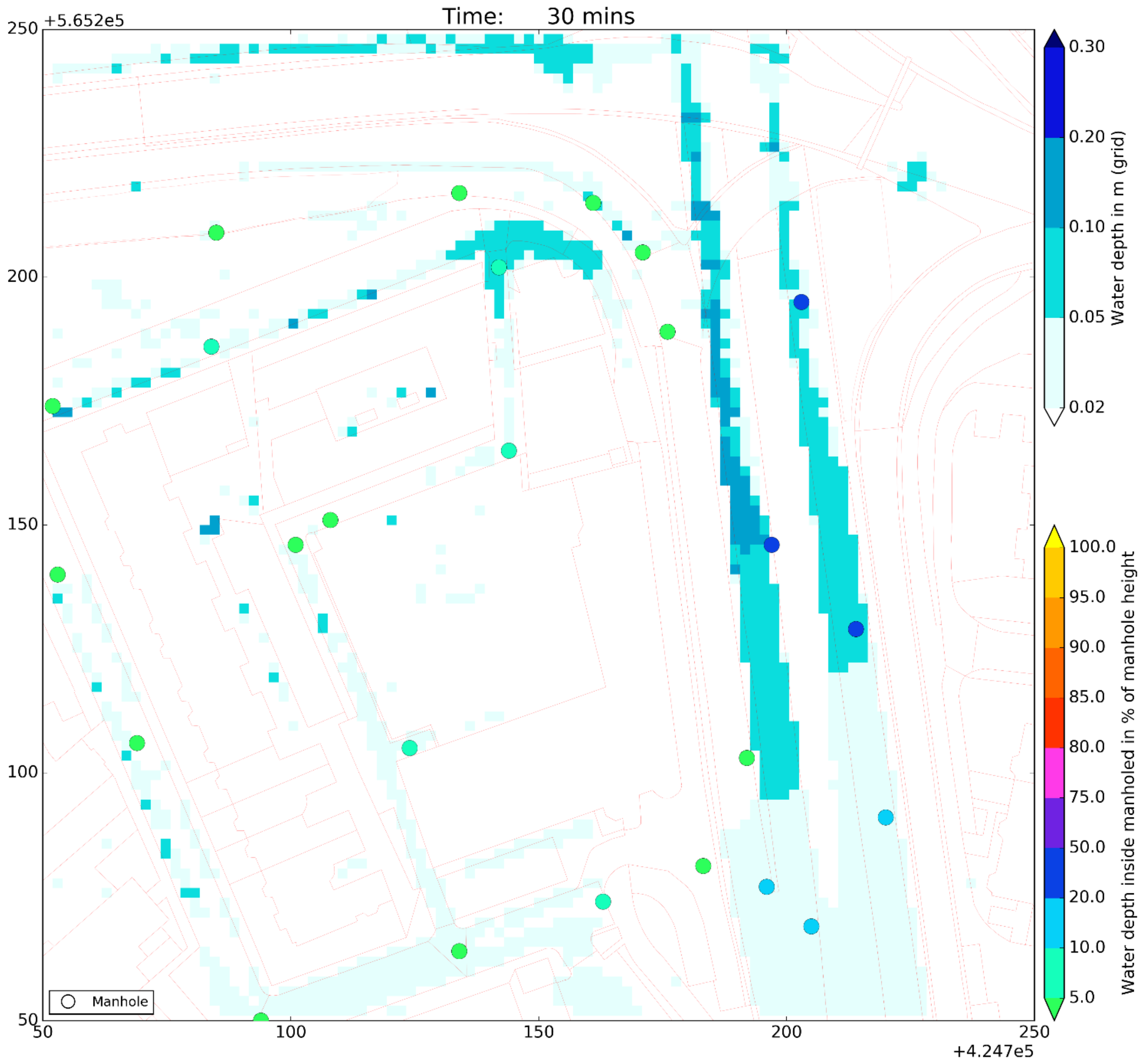
Bourdarias, et al. (2012)

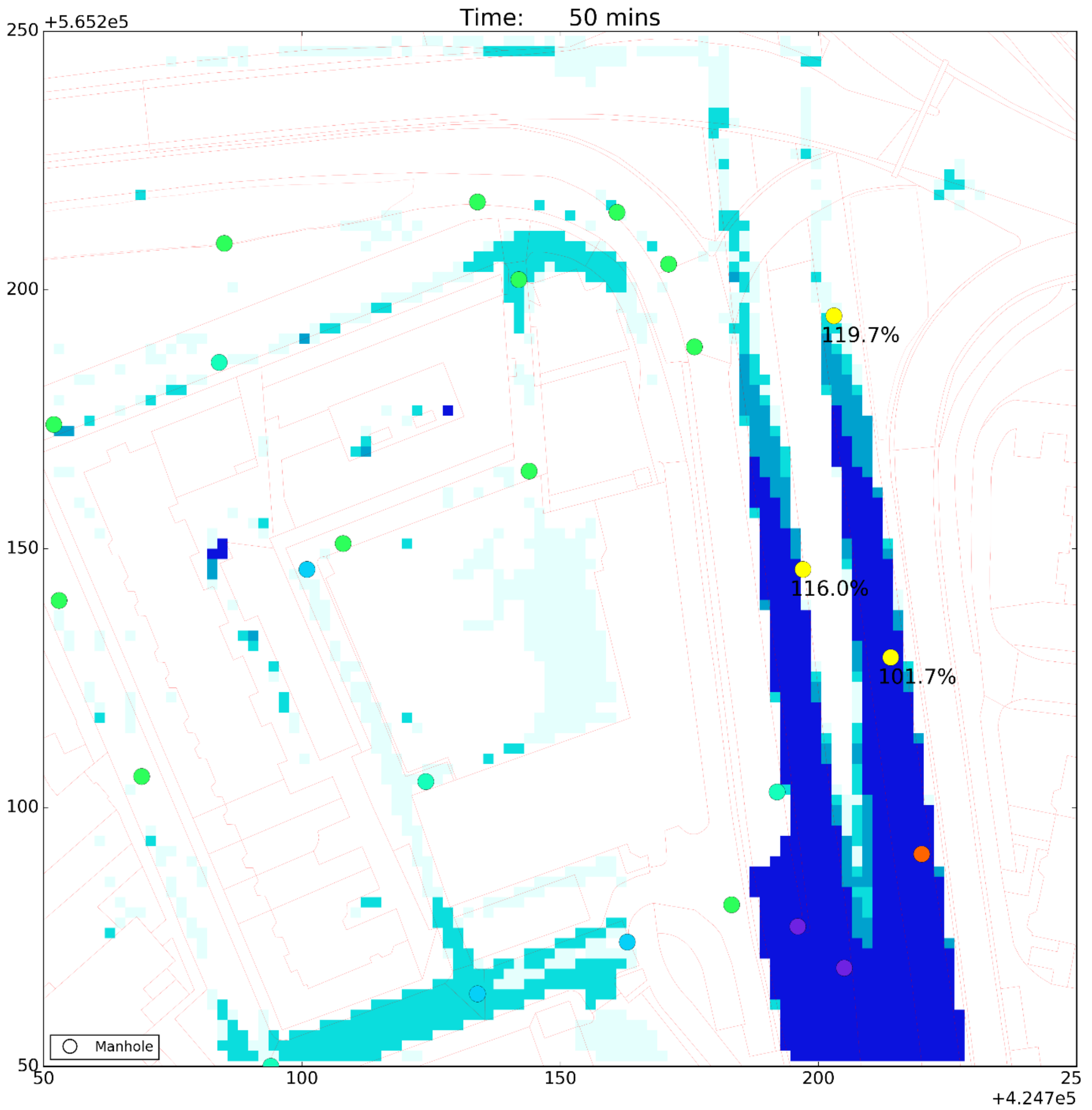
CityCat - Applications

Storm drain inlets



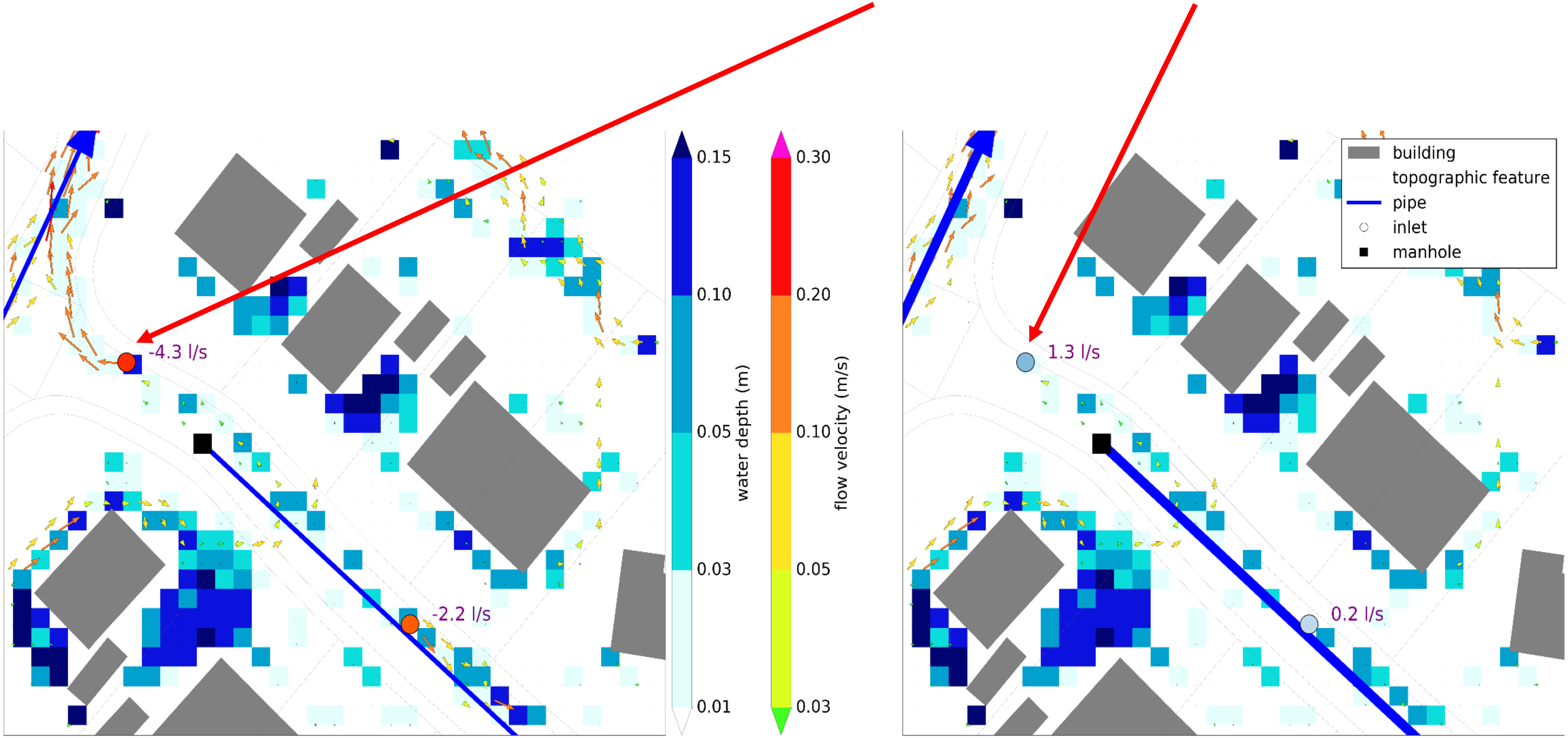
Manholes – pressurised (right)





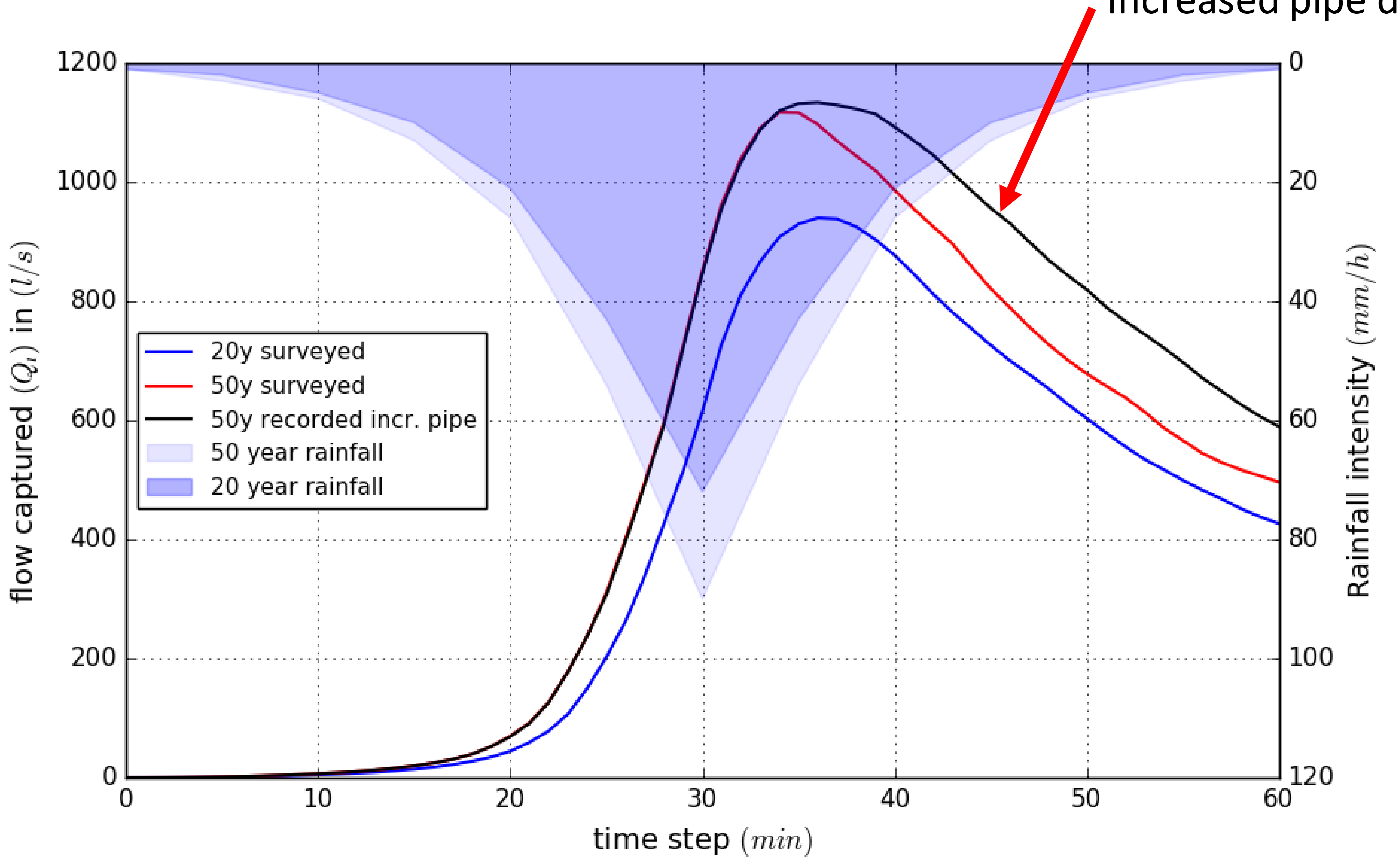
Scenarios – Pipe sizes

Implications on inlet condition: surcharging vs draining



Implications on captured flow volumes

Increased pipe diameters



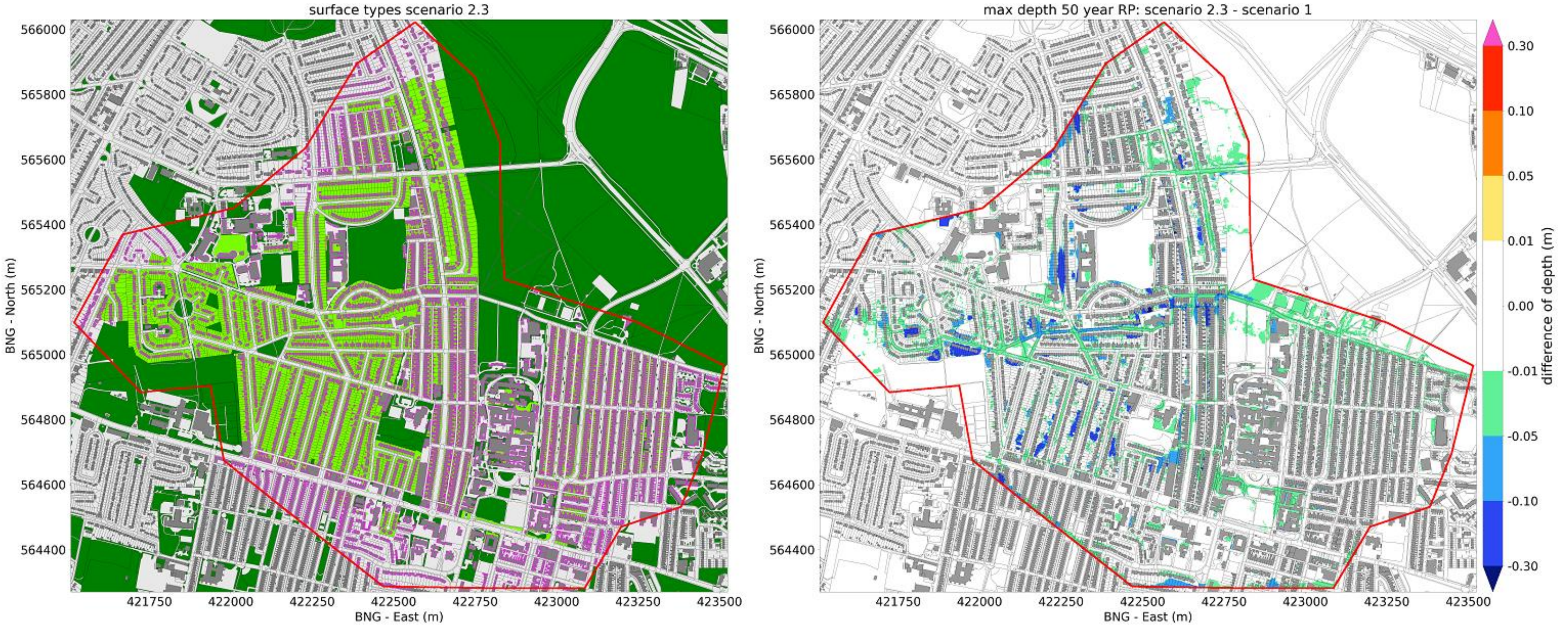
Modelling Blue-Green Infrastructure

Permeable Surfaces

Intervention

Impact

Permeable Surfaces & Water Butts



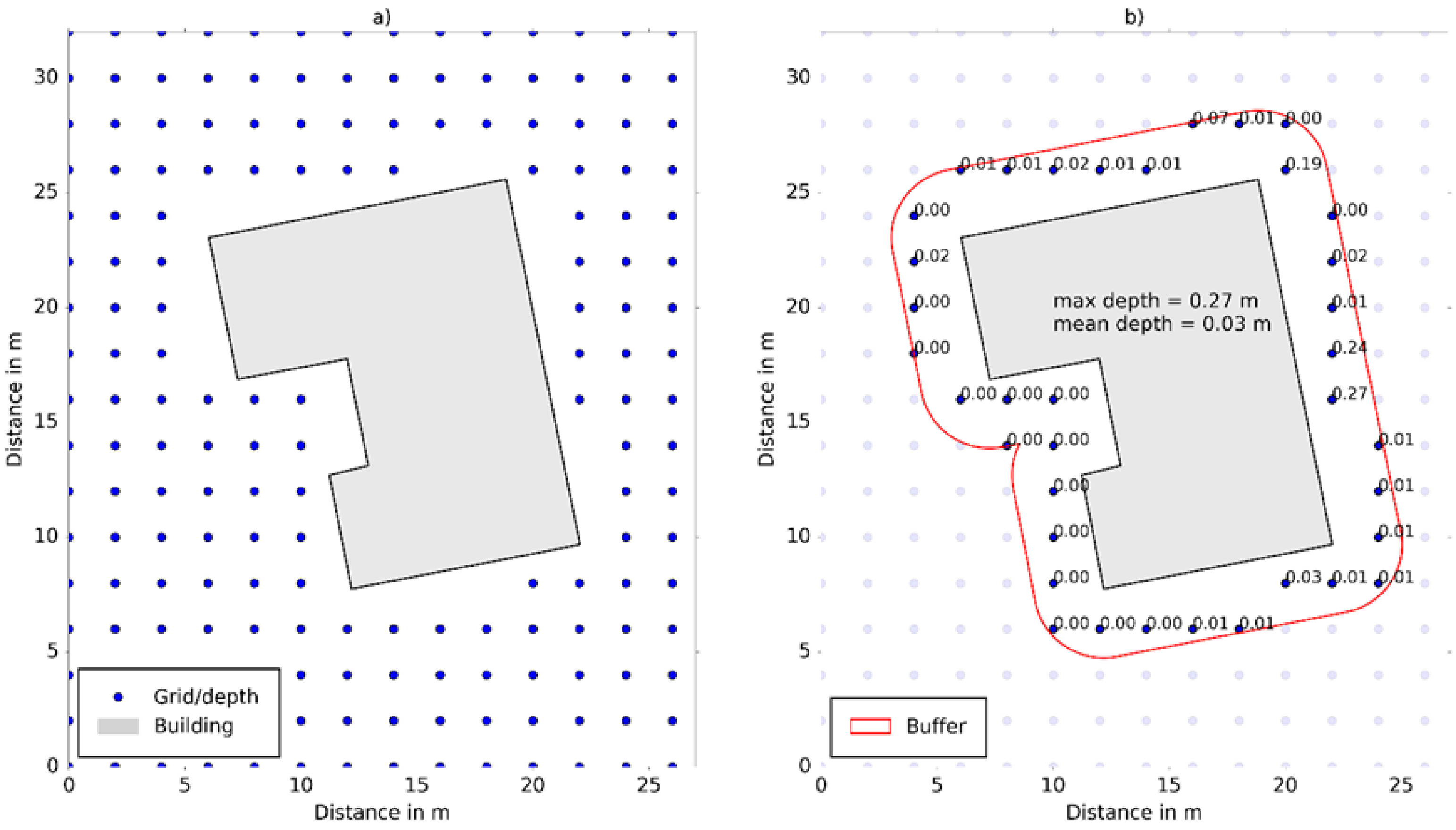
Intervention

Impact

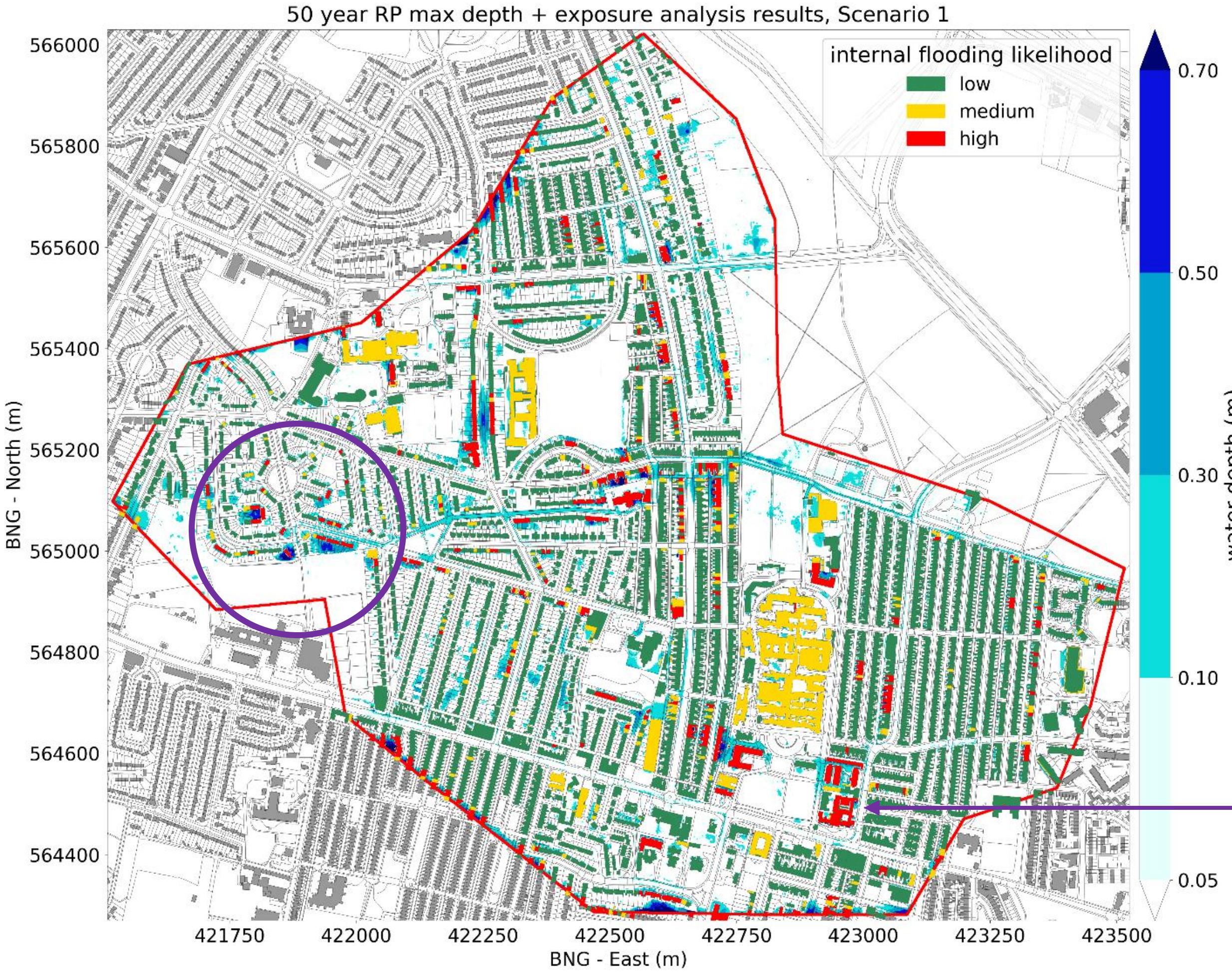
Exposure Analysis

- High resolution hydrodynamic modelling results
- Exact building geometries
- Buffer analysis
- Classification scheme

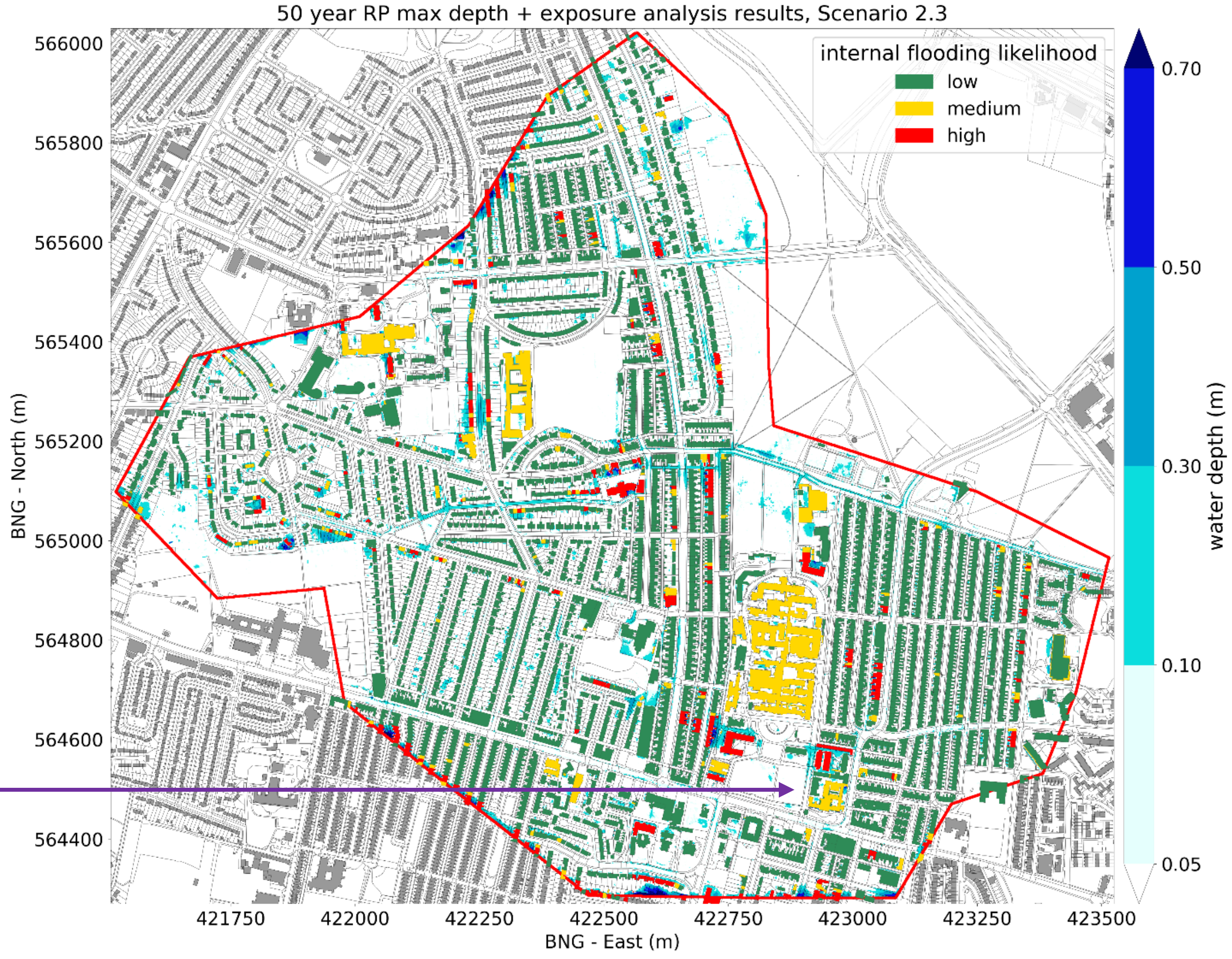
class	*mean (m)*	*max (m)*	*internally flooded*
low	0.0 - 0.09	< 0.3	no
medium	0.0 - 0.09 0.1 - 0.29	> 0.3 < 0.3	no
high	>= 0.1	>= 0.3	yes



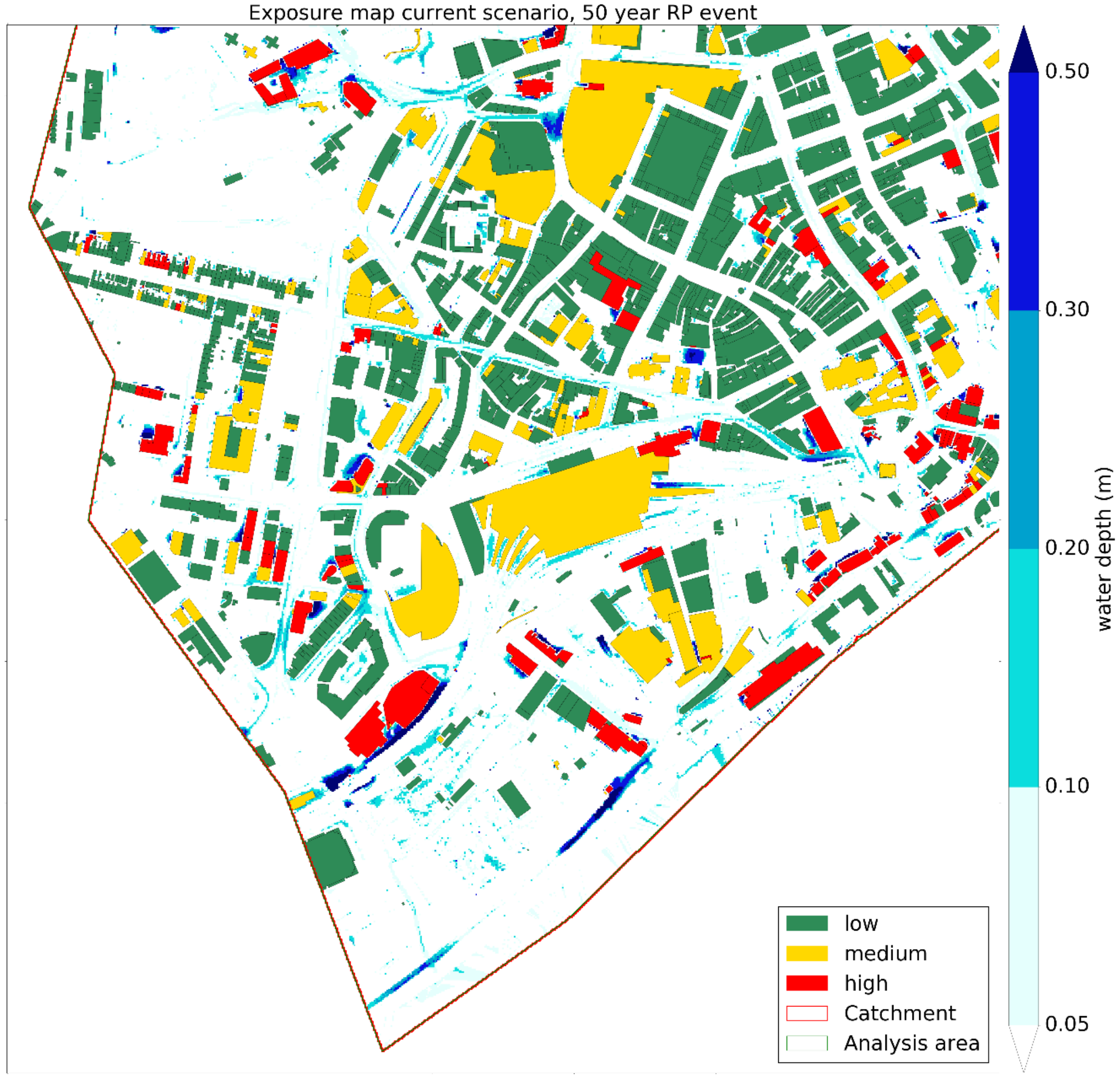
Current situation



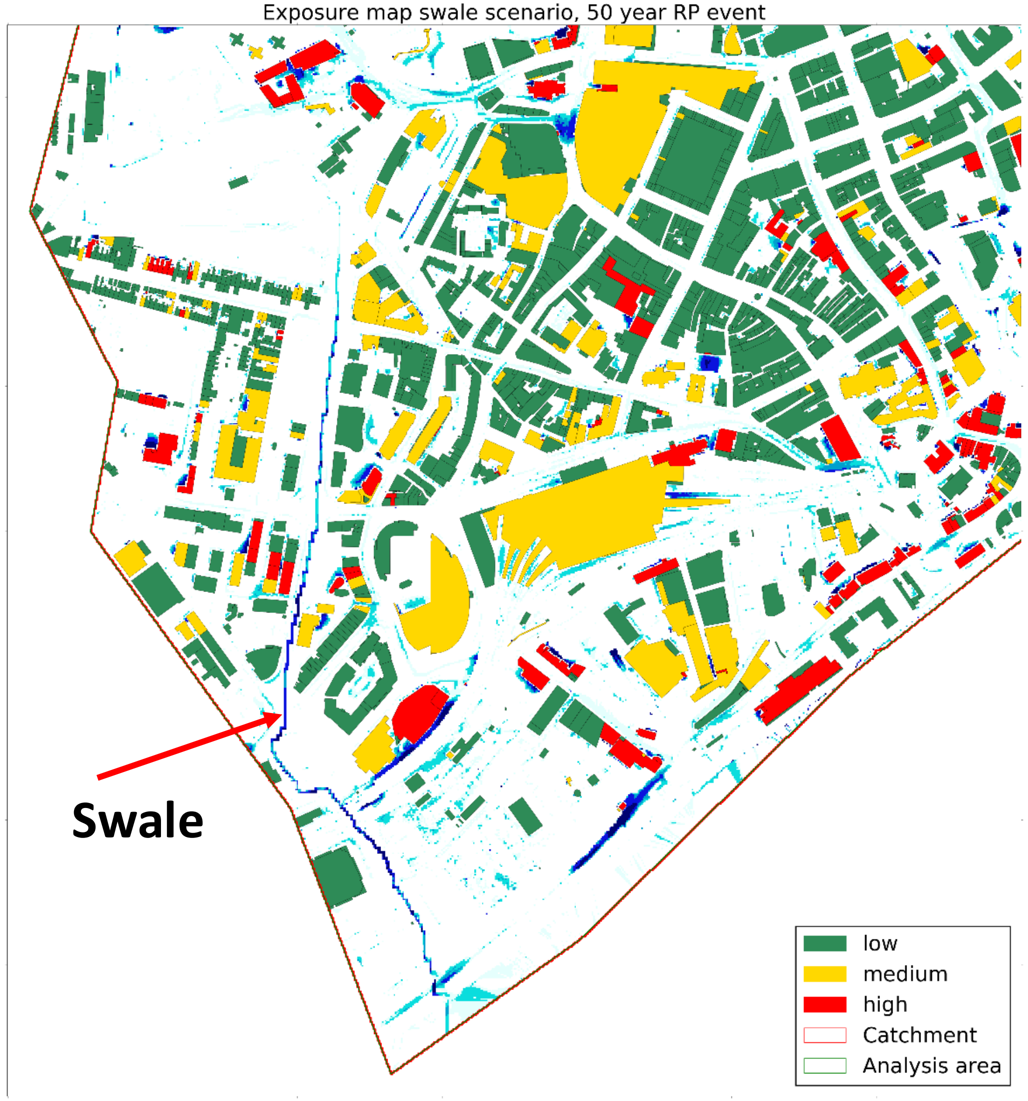
Permeable Surfaces & Water Butts



Swale



Exposure map current scenario, 50 year RP event
low
medium
high
Catchment
Analysis area
0.50
0.30
0.20
0.10
0.05
water depth (m)



Exposure map swale scenario, 50 year RP event
Swale
low
medium
high
Catchment
Analysis area

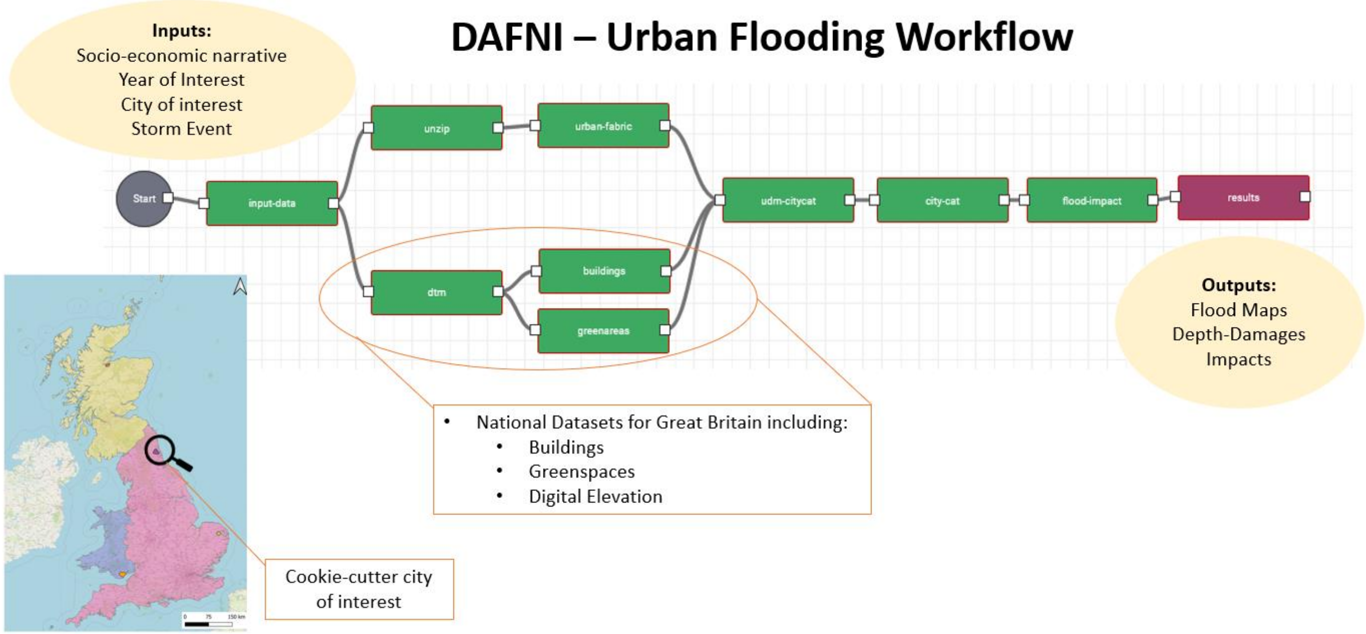
CityCat on DAFNI

CityCat on DAFNI

CityCat was containerised and deployed on DAFNI (OpenCLIM project)

The existing “Urban flooding workflow” allows users to run models to assess flood risk

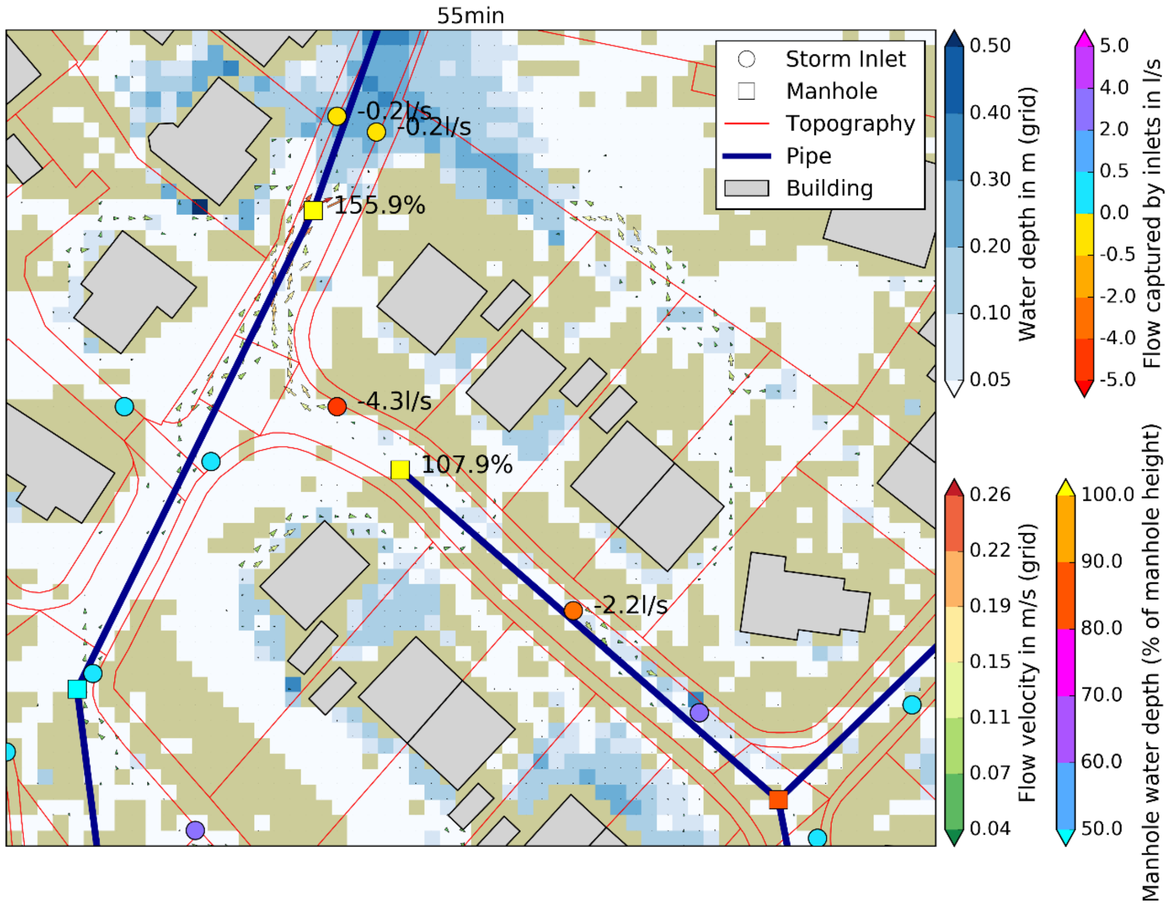
Models can be setup for any city in the UK for a range of storm events, climate uplifts and socio-economic narratives (UK-SSPs)



Aim of the project

Develop and demonstrate a platform on DAFNI for understanding and simulating urban drainage for any UK city.

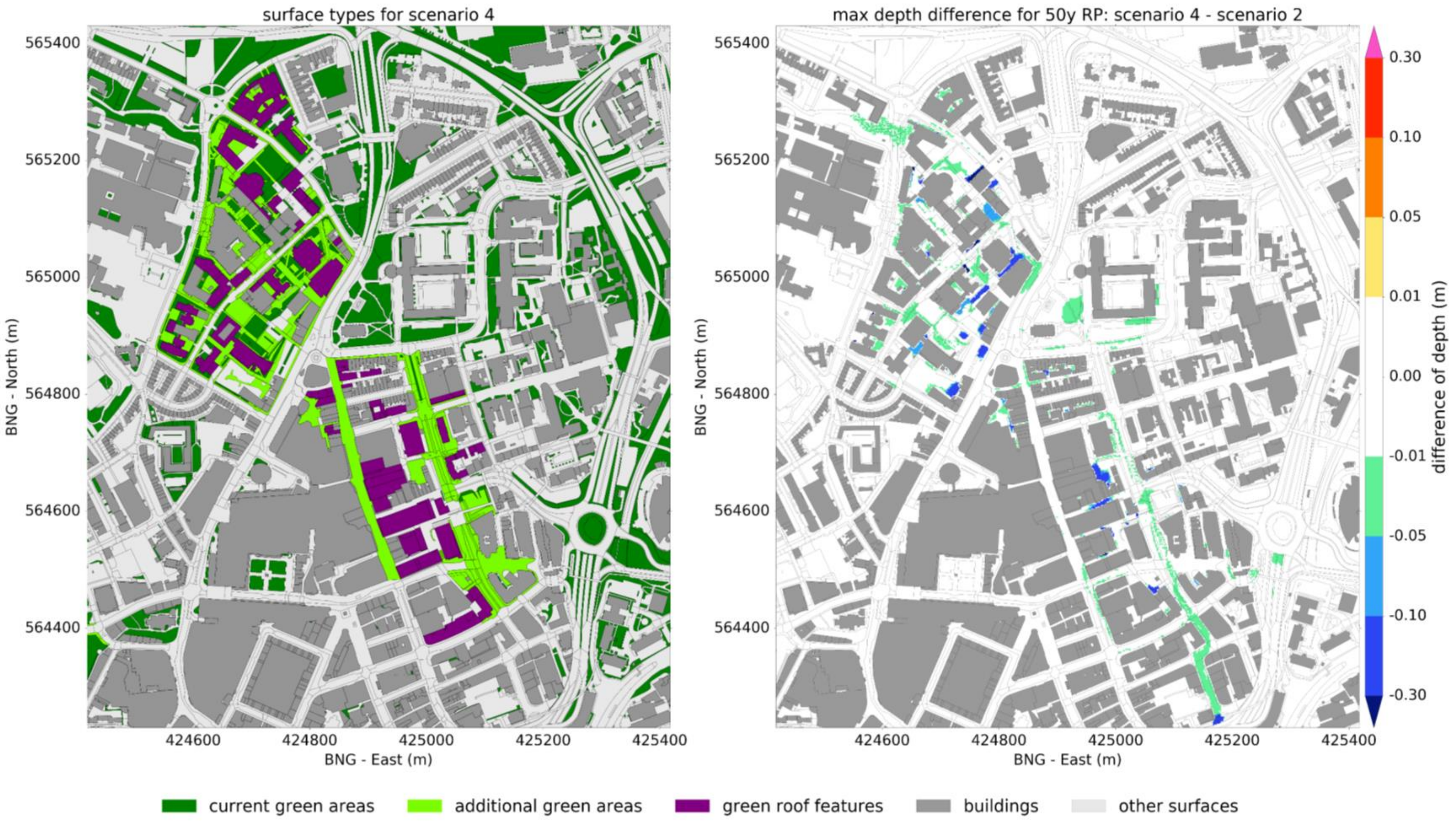
Functionality to design and test a range of strategies to mitigate Storm Overflows spills (or combined sewer overflows)



CityCat on DAFNI

How?

- Extend functionality to allow users to assess the effectiveness of blue-green mitigation features



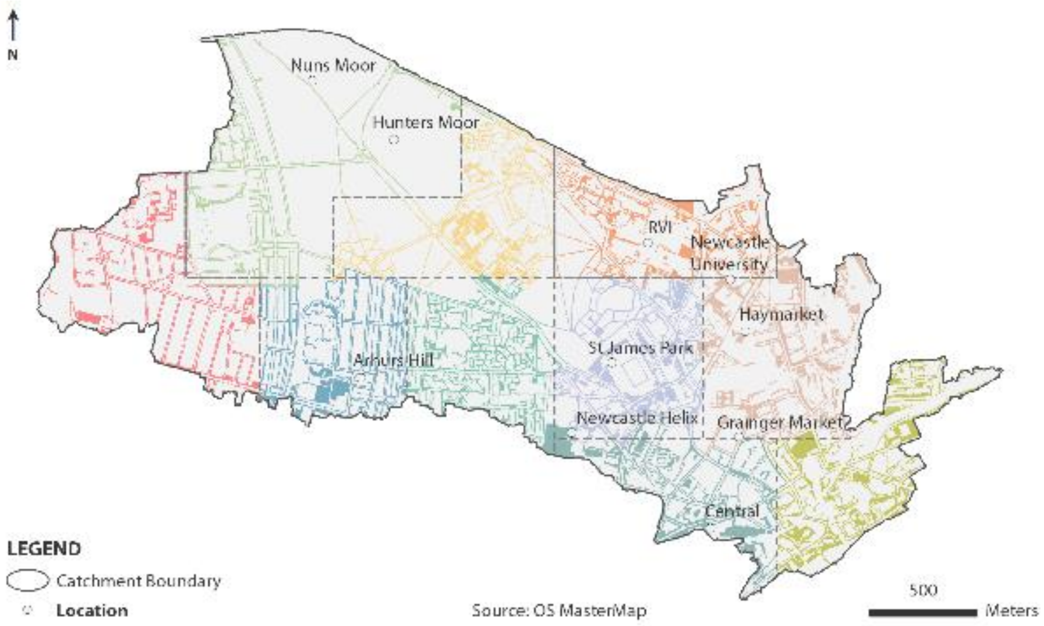
Intervention

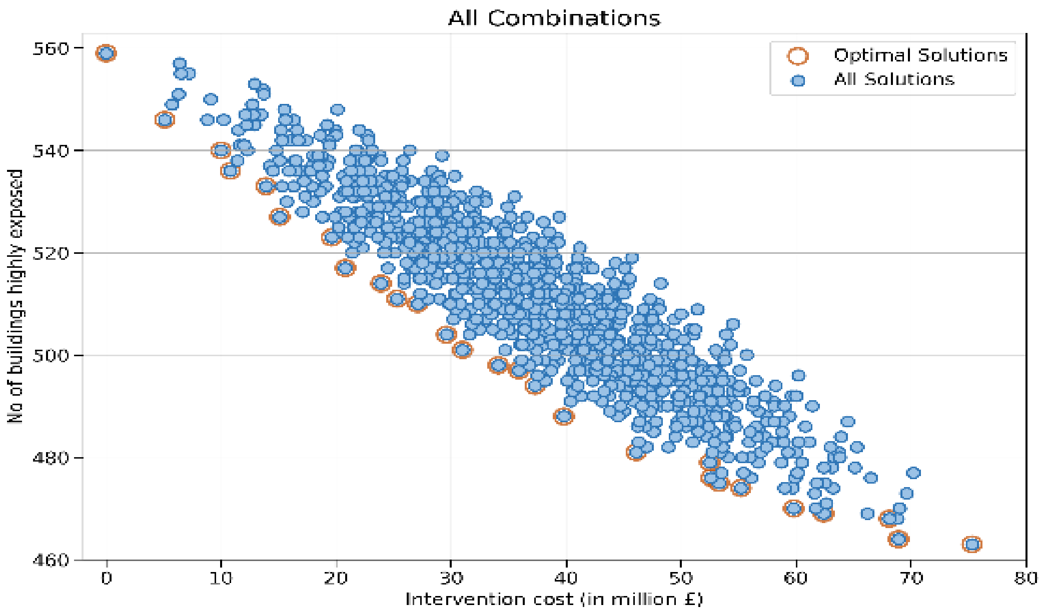
Impact

CityCat on DAFNI

How?

- Optimise BGI design using a Genetic Algorithm tool to optimise the location of BGI to allow users to assess flood and storm overflow risk





Aim of the project

How?

- Develop a tool to better visualise and use the (surface and pipe) drainage network for model set up and analysis of results

- develop a methodology to flexibly explore a wide range of rainfall events and design constraints.

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