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Pluvial flooding and efficiency of urban drainage

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Problem overview

Flooding events in urban areas occur quite frequently as a consequence of rain events of lower intensity than the design one, even in case of correct network dimensioning.
Inlets are in those cases the critical nodes, and efficient drainage is only ensured when care is taken on their appropriate design and positioning within the drainage area.
The lack of maintenance and overloads in the hydraulic system conducing street waters into the pipe network are often responsible for drainage failures.

Evaluation of flood risk in urban areas is made even more difficult if one considers that pluvial flooding are normally more frequent than floods occurring from natural water bodies and they may involve even small portions of the urban zones.

The methodology

Adopting a hydrodynamic model describing the propagation of flood waves (based on the DSV equations in 2 dimensional form) allowing for the topographic complexity of the area (buildings, manholes, etc.) and for the characteristics of prevailing imperviousness typical of urban areas.

Assesment of FLOOD RISK

Evaluation of the water depth distribution and the current velocities of flood event

Knowledge of the building/ social characteristics of urban areas from digital map data

Production of risk maps based on properly defined risk indexes.

further for PLUVIAL FLOODING

Knowledge of the inlets effectiveness and maintenance

+

Knowledge of intense short-duration rainfall (sub-hourly pulses)

Flood propagation model (I)

FLURB-2D (URBan FLood Propagation 2-D) :

Inertial model based on the Saint Venant equations originally developed for simulating the overland flow propagation on alluvial plains with uneven topography (Aronica et.al, 2008, Aronica and Lanza, 2005).

$$\frac{\partial H}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = 0$$

$$\frac{\partial (uh)}{\partial t} + gh\frac{\partial H}{\partial x} + ghJ_x = 0$$

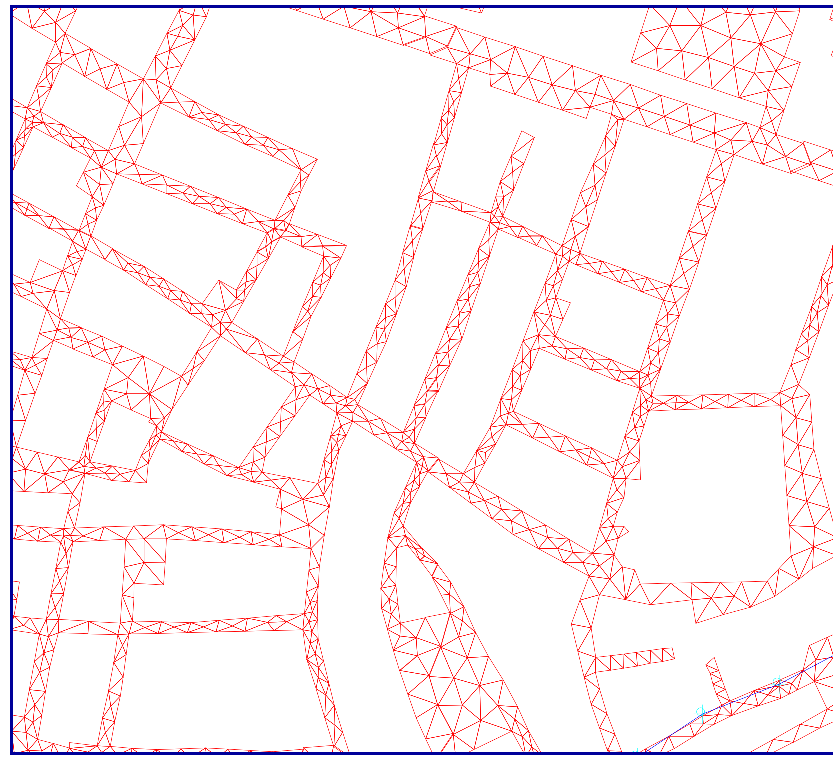
$$\frac{\partial (vh)}{\partial t} + gh\frac{\partial H}{\partial y} + ghJ_y = 0$$

where:
H is the free surface elevation
u and v are the *x* and *y* components of flow velocity
h is the water depth

These equations were solved by using a finite element technique with triangular elements. The free surface elevation is assumed to be continuous and linear inside each element, where the unit discharges in the x and y directions are assumed to constant.

Flood propagation model (II)

The finite element approach avoids a simplified description of the hydraulic behaviour of flooded areas due to the fact that triangular elements are able to reproduce the detailed complex topography of the built-up areas, i.e. blocks, streets, etc. exactly as they appear within the floodable area. Particularly, blocks and other obstacles are treated as internal islands or internal boundaries within the triangular mesh covering the entire flow domain

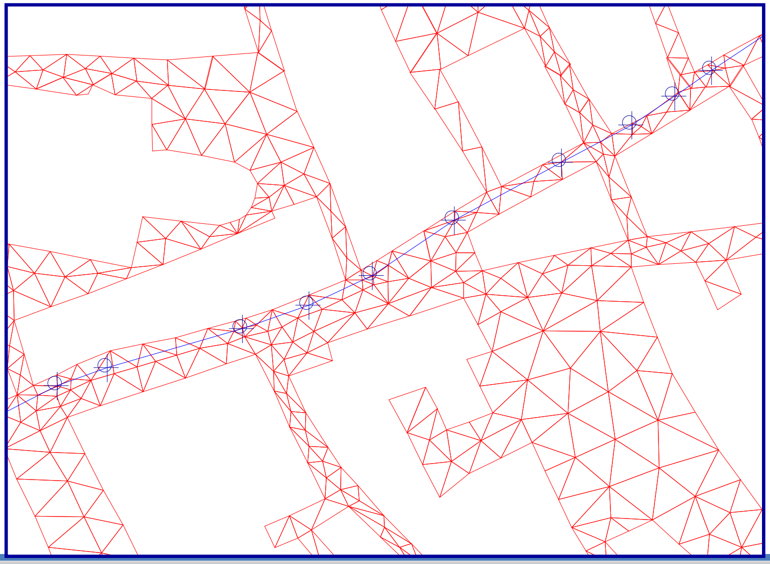


Flood propagation model (III)

In this new version of the model here presented, inlets are considered by specifying a stage discharge relationship in the following form:

$$q = c_o \cdot a \cdot h^b$$

where
***a* and *b* are two coefficients depending on the type (grate, curb, etc.) and geometric characteristics of the inlet (such as number and position of the bars in the grate, gutter slope, etc.),**
***h* is the flow depth**
c_o is the efficiency coefficient.

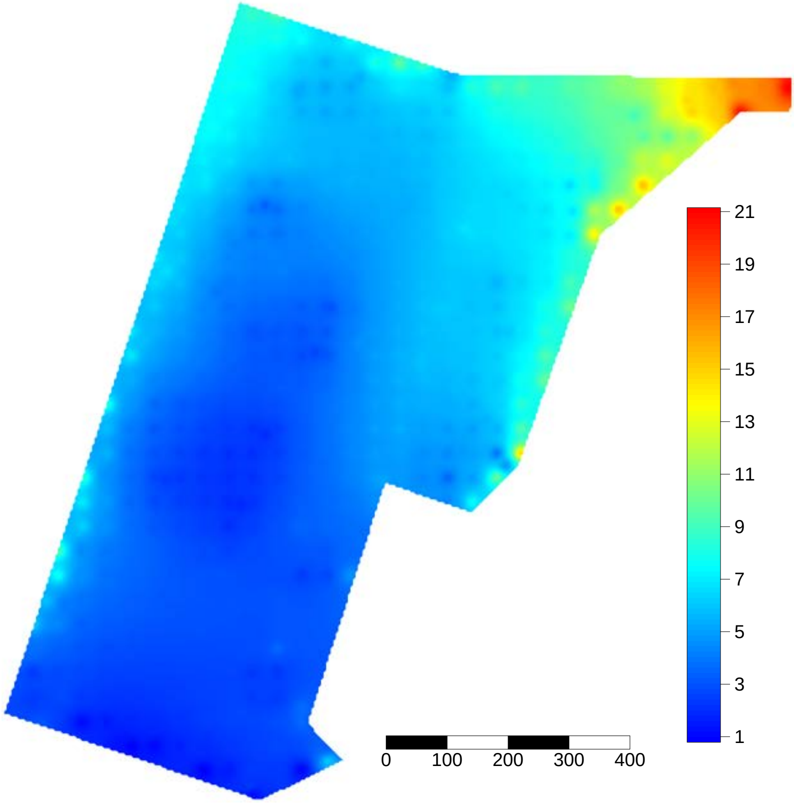


In particular, c_o represents the inlet clogging condition thus varying between 0 and 1 (0 = total clogging, 1 = no clogging).

The study site

Foce Area of Genoa

Digital Elevation Model (4 m res)

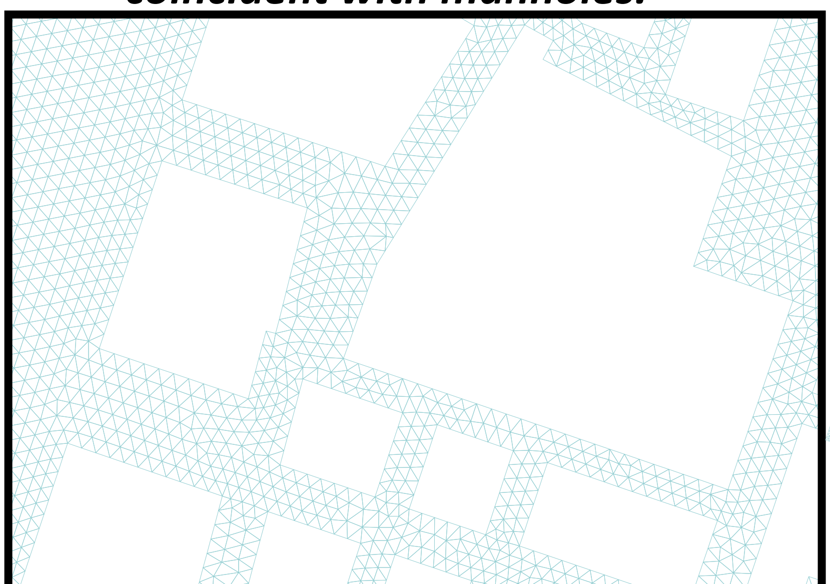


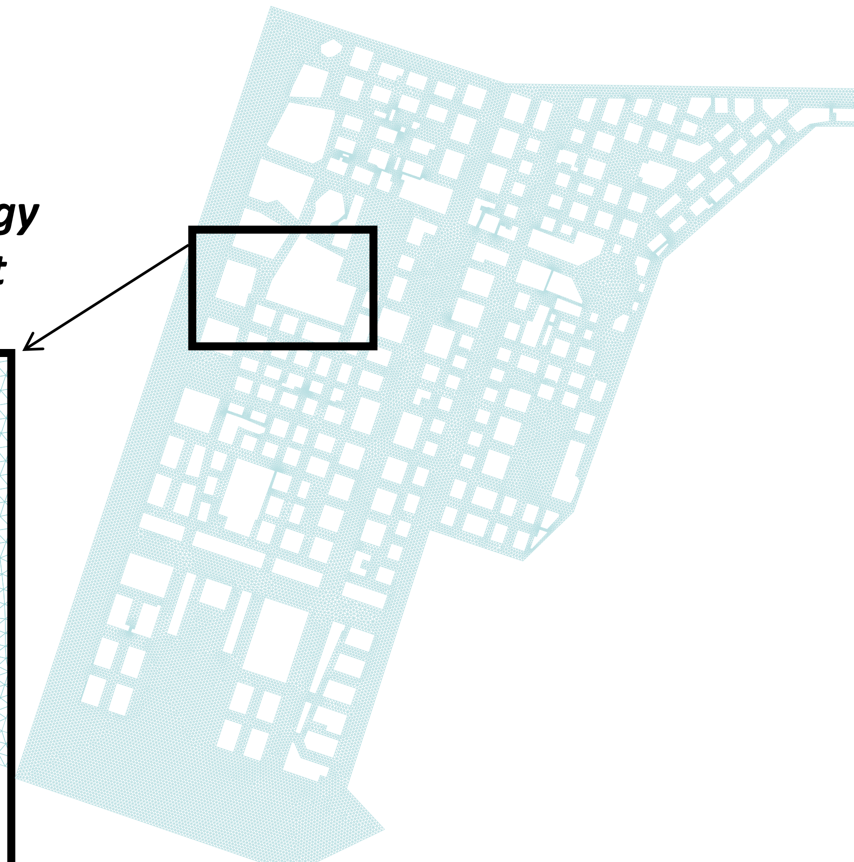
Mesh of the study site

Total domain area = 0.53 km^2

- **31936 nodes**
- **56602 triangular elements**

The mesh is defined based on the morphology and in order to make internal nodes almost coincident with manholes.

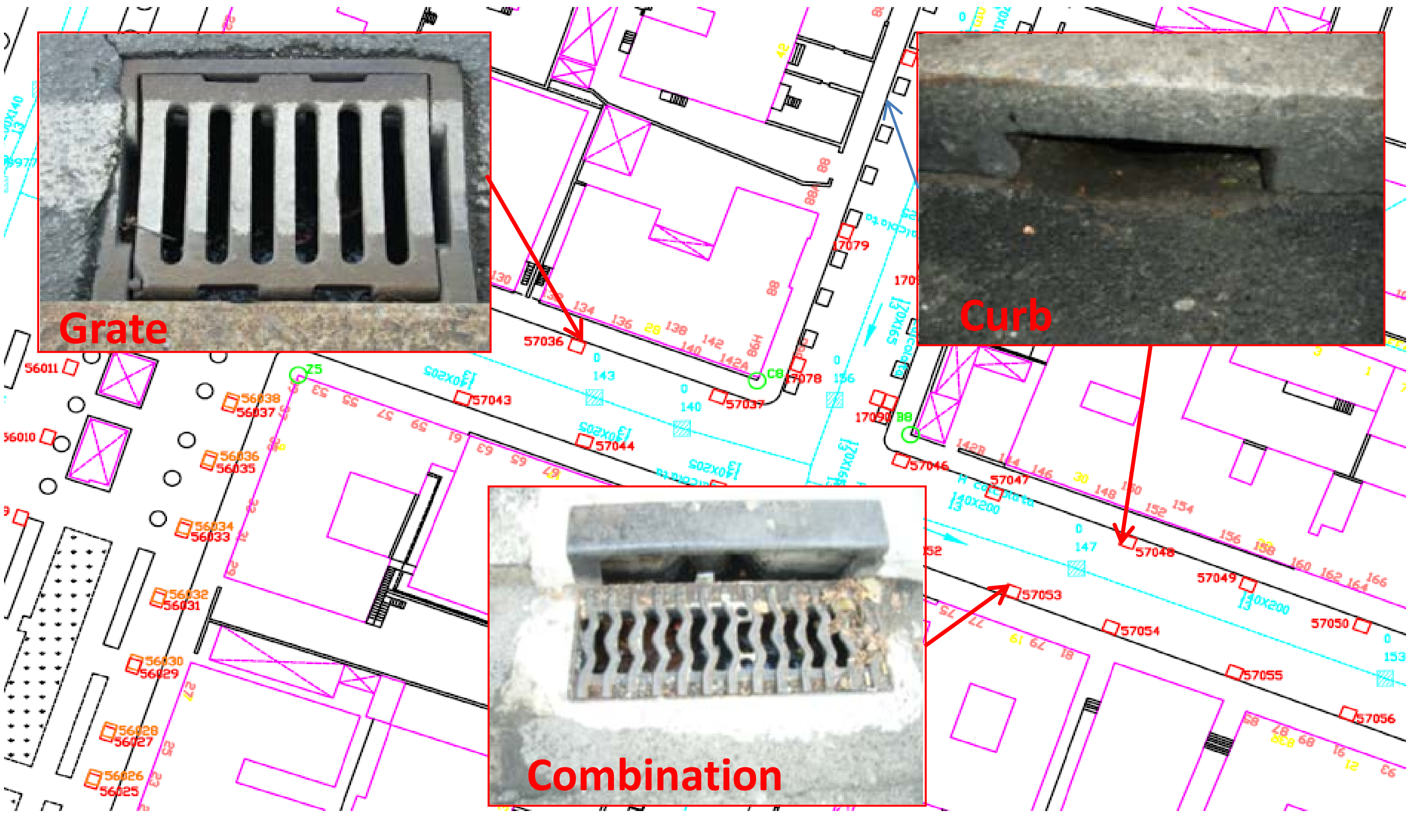




Manning coeff. = 0.02 s/m$^{1/3}$

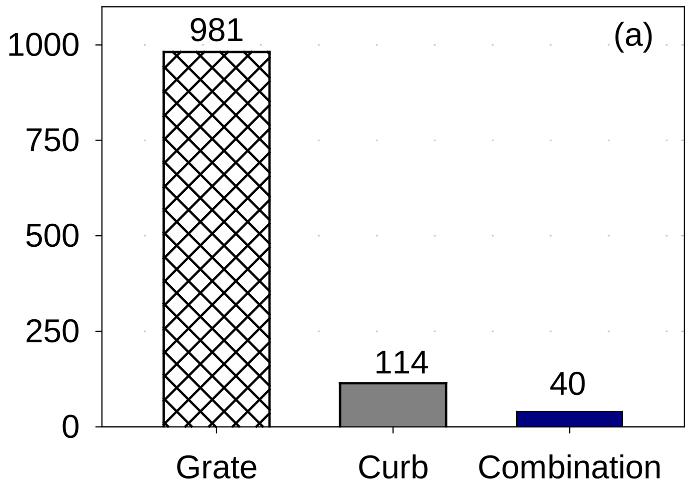
Surveying inlets

A survey is carried out and the type (grate, curb, etc) and geometric characteristics of each inlet (dimension, number of bars, etc.) are observed in the study area.

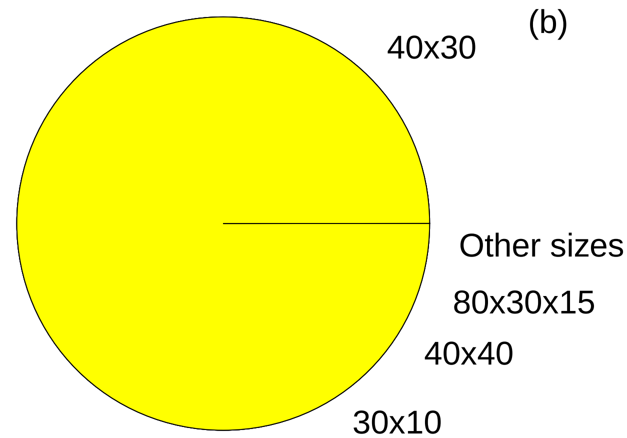


Modelling inlets (I)

Typology



Size



Parameter of the stage discharge relationship

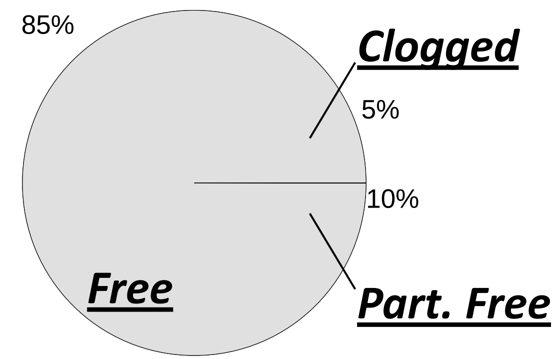
Inlet typology	Size (cm)	*h*<0.12 m *a*	*h*<0.12 m *b*	*h*>0.12 m *a*	*h*>0.12 m *b*
Grate	40x30	1.26	1.5	0.21	0.5
Curb	30x10	0.2019	1.5	0.2019	1.5
Combination	80x10x15	2.464	1.5	0.7	0.69

The parameters are reported for the more typical inlets (in terms of size and typology).

Modelling inlets (II)

In order to point out the impact of the inlets effectiveness during the survey the operational condition of each inlet has been recorded.

→ Actual operational conditions of the manholes (survey of October 2008)



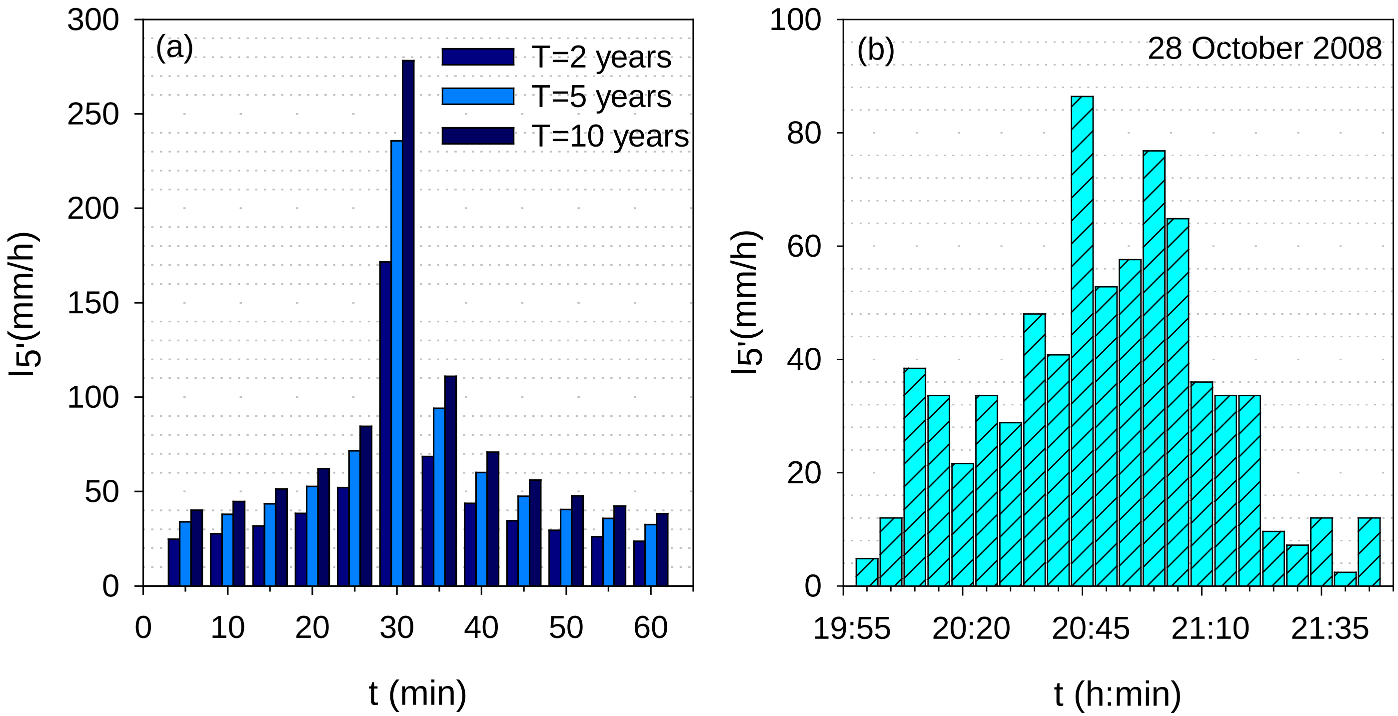
Impact of the inlets effectiveness

The impact is examined by simulating three different scenarios:

1. ***Operating*** **scenario: fully operational inlets;**
2. ***Observed*** **scenario: actual operational condition of the inlets ;**
3. ***Blocked*** **scenario: no connection between the catchment surface and the drainage network.**

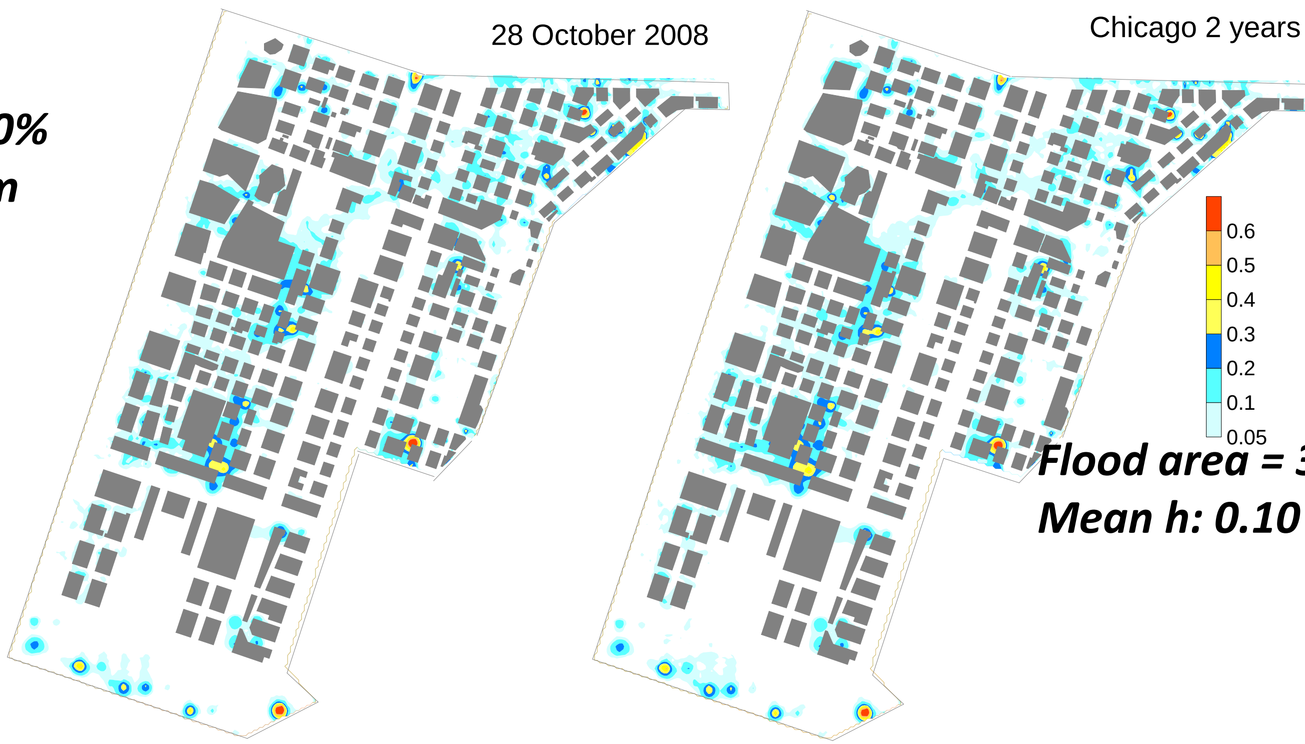
The hydrological analysis

The analysis is carried out by using as input a real event and synthetic hyetographs derived from the analysis of rain data collected at the raingauge station of Villa Cambiaso (Genoa).



Simulation results: Impact of precipitation (I)

Flood area = 30%
Mean h: 0.10 m

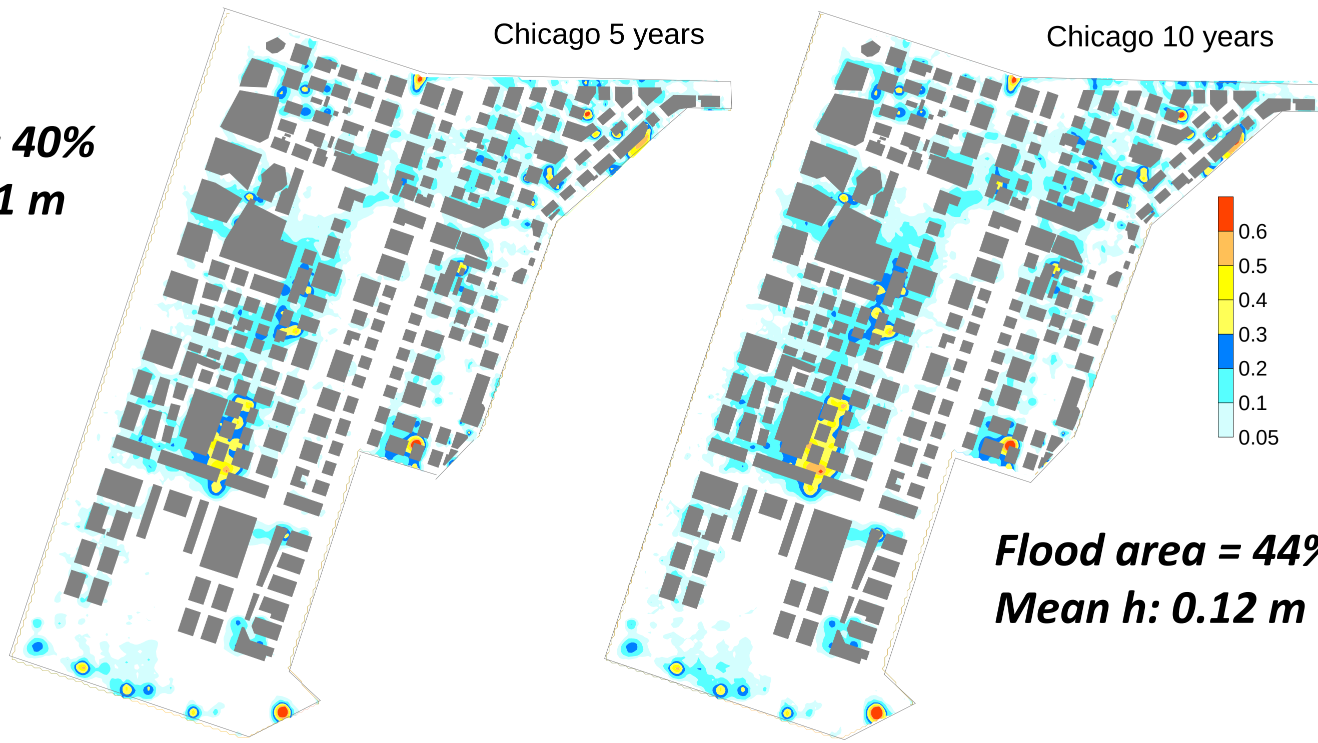


Flood area = 32%
Mean h: 0.10 m

Comparison of the maps of maximum water depth for the 28th October 2008 and the event with T=2 years confirms similar flooded areas for event characterized by similar intensities. The flooding maps are related to the operating inlets scenario.

Simulation results: Impact of precipitation (II)

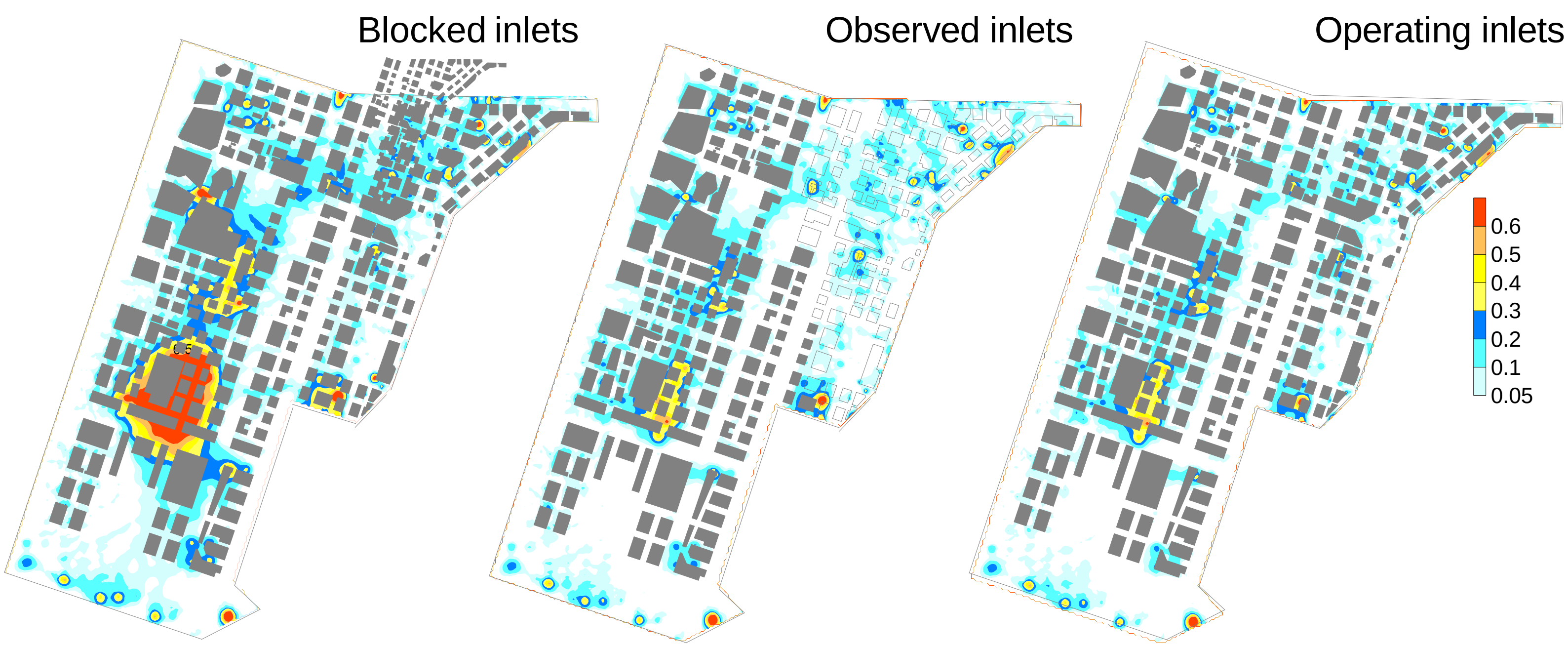
Flood area = 40%
Mean h: 0.11 m



Flood area = 44%
Mean h: 0.12 m

Comparison of the maps of maximum water depth for the Chicago event with T = 5 and 10 years confirms, as expected that the flood areas increase with the return period of precipitation. The flood areas are quite distributed, however the topography concentrates the volume of excess water in a depressed region.

Simulation results: Impact of operational conditions



Comparison of the maps of maximum water depth for different operational conditions of the inlets: blocked, observed efficiency and operating inlets.

#The flooding maps are related to the Chicago event with T =10 years.

The differences between the flood volume in the operating and observed scenarios is limited and this difference decreases if considering less intense precipitation events.

Conclusions

The drainage efficiency of the Foce urban sub-catchment is analysed by modelling synthetic hyetographs (T equal to 2, 5 and 10 years) and a real event (28th October 2008) together with three inlet efficiency scenarios characterised by the observed, fully operating and fully blocked inlet conditions.

Simulation results allow highlighting:

- **local flooded areas due to drainage failures are observed for all precipitation events;**
- **the calculated mean water depth slightly increases with the return period of precipitation;**
- **the difference between the volumes in the operating and observed scenarios is limited, confirming that the latter scenario corresponds to satisfactory maintenance conditions of the drainage system (85% of fully operating).**

Future perspectives

- **Simulation of the effect of inlets operational conditions with varying the inlet position in the drainage network;**
- **Impact of DEM data used in the analysis;**
- **Calibration/Validation of the model with observed measure of water depth.**

….. Thank you for the attention!