Limitations of the state of the art

Catchment scale SWE models make use of empirical loss formulation for the estimation of rainfall-runoff transformation.

SWE models make use of finite spatial discretizations unable to explicitly differentiate the inundations origins

Ph.D. research questions

Let's start from here…

Can we enhance the capabilities of the shallow water models for catchment hydrology?

Can we discretize whitin a shallow water model the fluvial and pluvial inundations?

SWE (i.e. Shallow Water Equations)

Runoff-On-Grid method

- Extend the Shallow water modelling for medium size humid and vegetated catchments (not only for flash floods or pluvial floods).
- Aims to bridge in an unified framework the distributed hydrological modelling and advanced hydrodynamic modelling
- Aims to implicitly integrate Ancedent soil moisture conditions, soil physics and subsurface hydrological processes in the governing hydrodynamic equations.

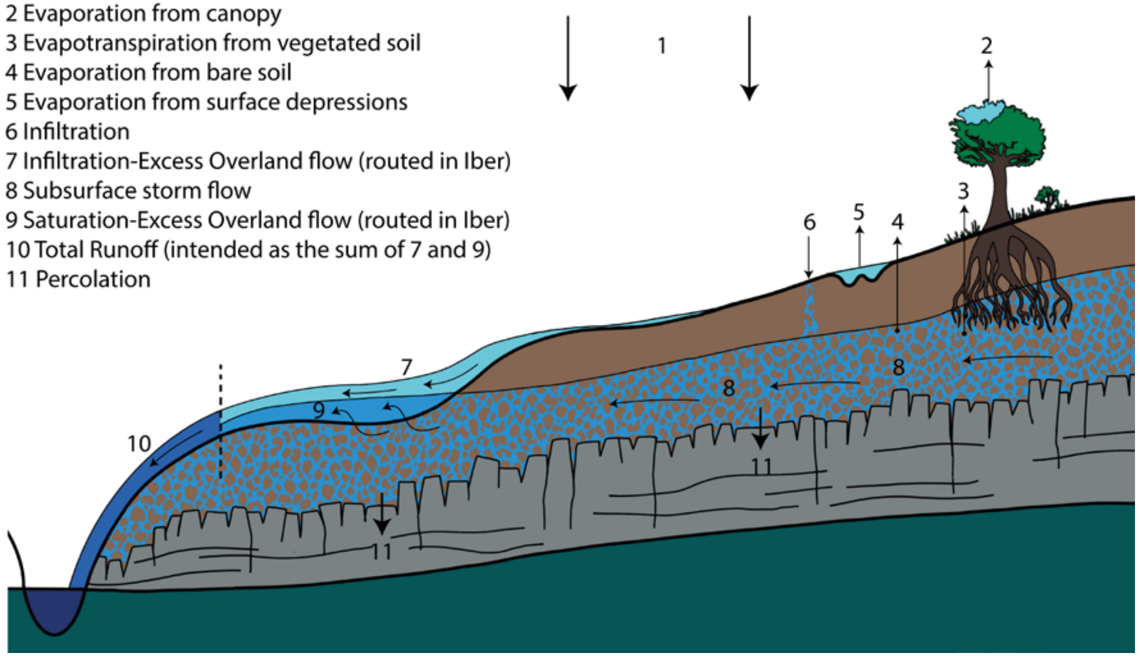
Based on the ***coupling*** of two reference models:

- *How much water (young or old) become runoff?*
answer the **DREAM model**

- *What is the impact of these volumes on the ground surface?*
answer the **Iber model**

Processes simulated by the DREAM-IBER model

1 Rainfall
2 Evaporation from canopy
3 Evapotranspiration from vegetated soil
4 Evaporation from bare soil
5 Evaporation from surface depressions
6 Infiltration
7 Infiltration-Excess Overland flow (routed in Iber)
8 Subsurface storm flow
9 Saturation-Excess Overland flow (routed in Iber)
10 Total Runoff (intended as the sum of 7 and 9)
11 Percolation



Governing equations and numerical coupling

$$S_{t+\Delta t} = \min(S_t + I_t - ET_{soil,t} - RG_t + RS_t \, , S_{max})$$

$$R_{tot,t+\Delta t} = max(0, P_{gross,t} - \Delta W_{int,t} - I_t - \Delta W_{dep,t} + SS_t)$$

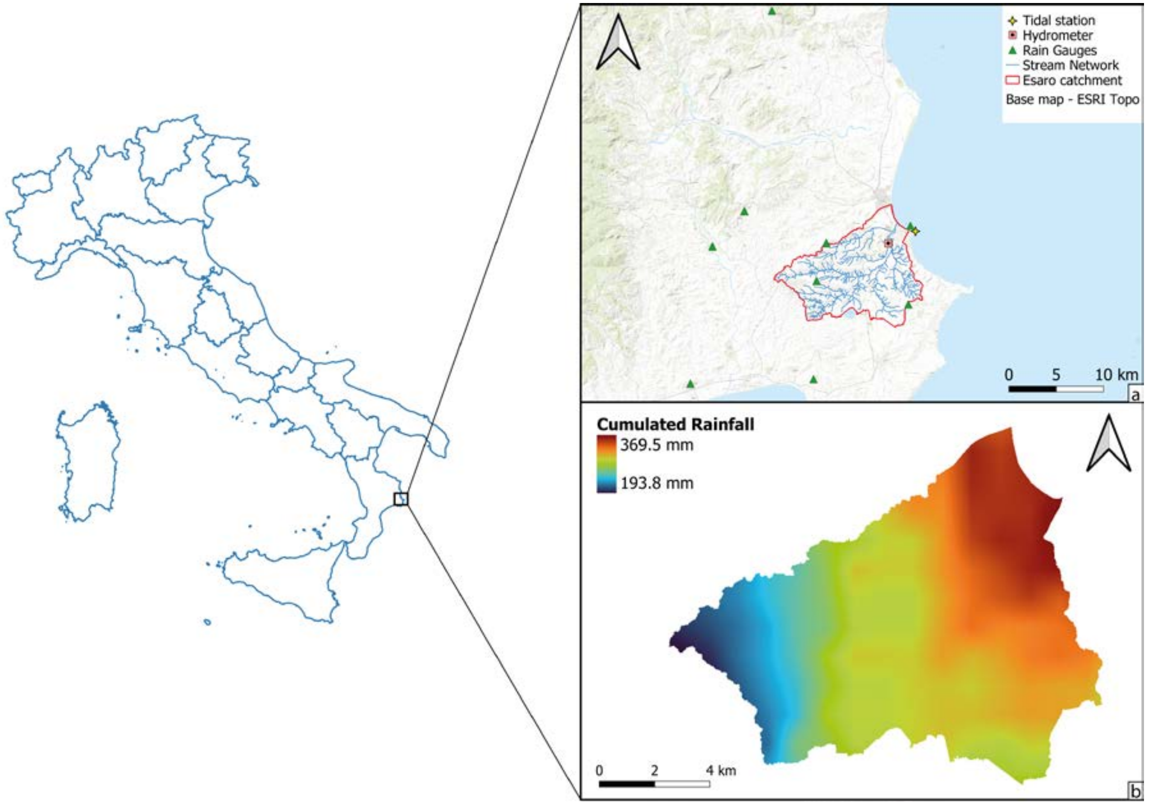
$$\frac{\partial h}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = R_{tot}$$

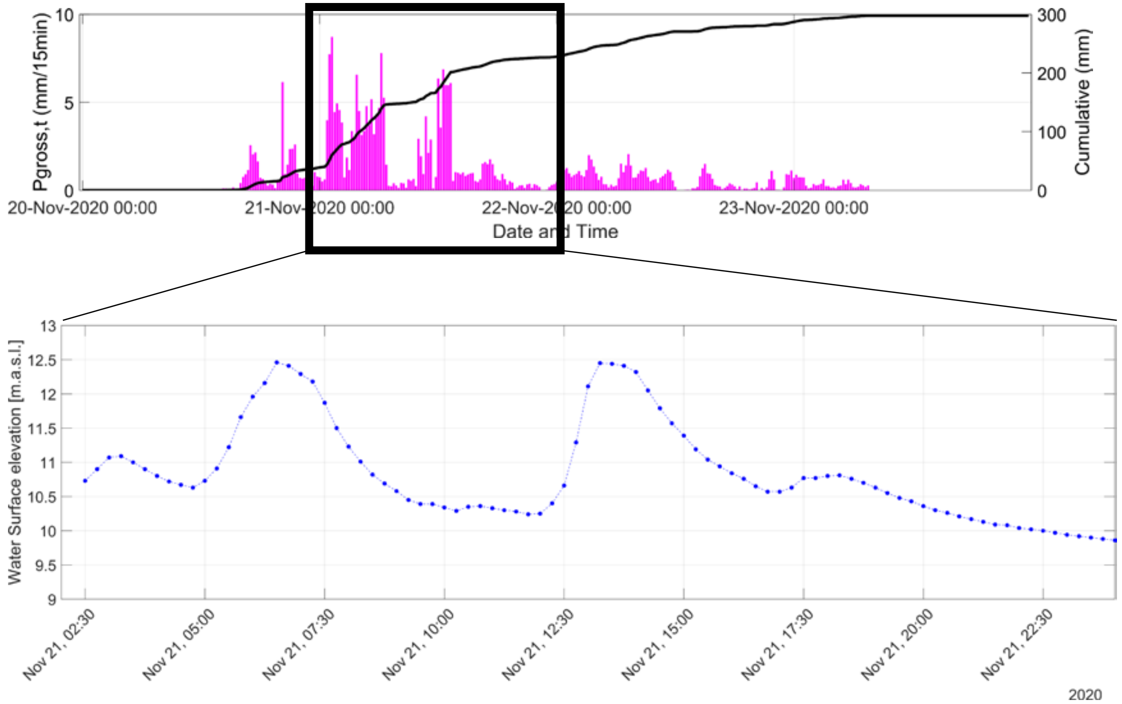
very different from the net rainfall

$$\frac{\partial q_x}{\partial t} + \frac{\partial}{\partial x}\left(\frac{q_x^2}{h} + \frac{gh^2}{2}\right) + \frac{\partial}{\partial y}\left(\frac{q_x q_y}{h}\right) = -gh\frac{\partial z_b}{\partial x} - g\frac{n^2}{h^{7/3}}|\mathbf{q}|q_x$$

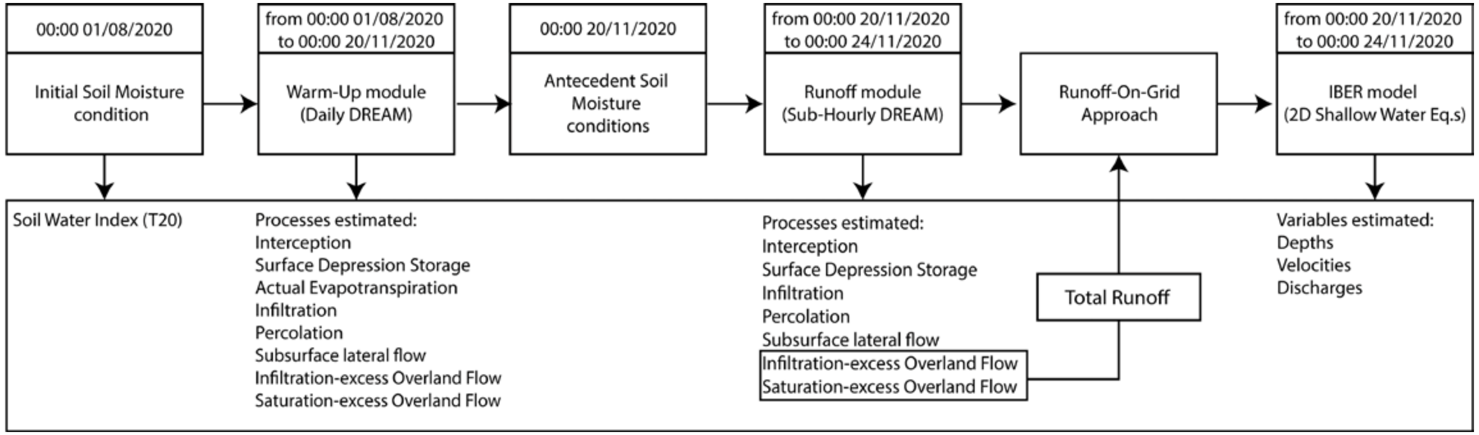
$$\frac{\partial q_y}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q_y^2}{h} + \frac{gh^2}{2}\right) + \frac{\partial}{\partial x}\left(\frac{q_x q_y}{h}\right) = -gh\frac{\partial z_b}{\partial y} - g\frac{n^2}{h^{7/3}}|\mathbf{q}|q_y$$

Study case: Flood of the Esaro River (Calabria, Italy) November 2020

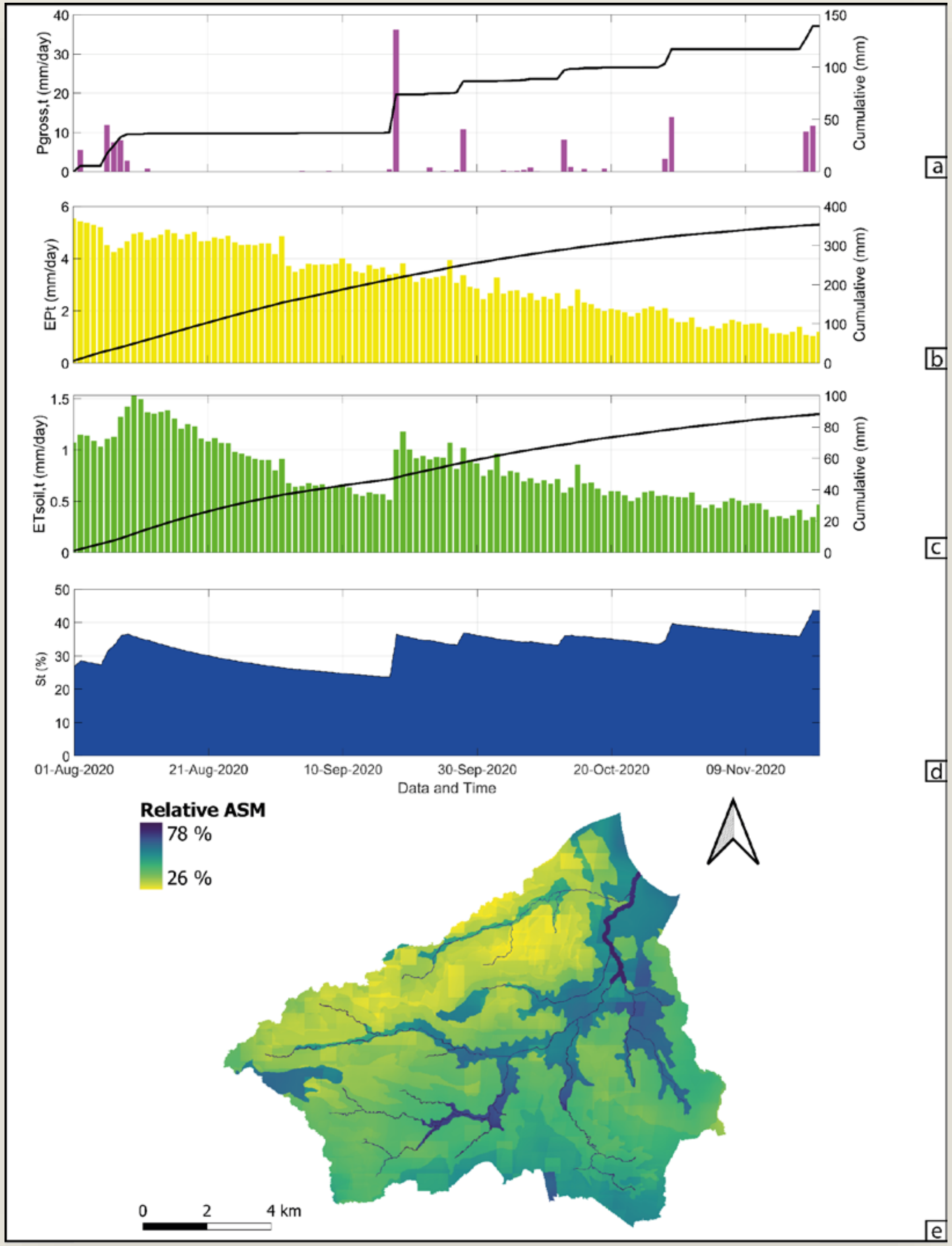




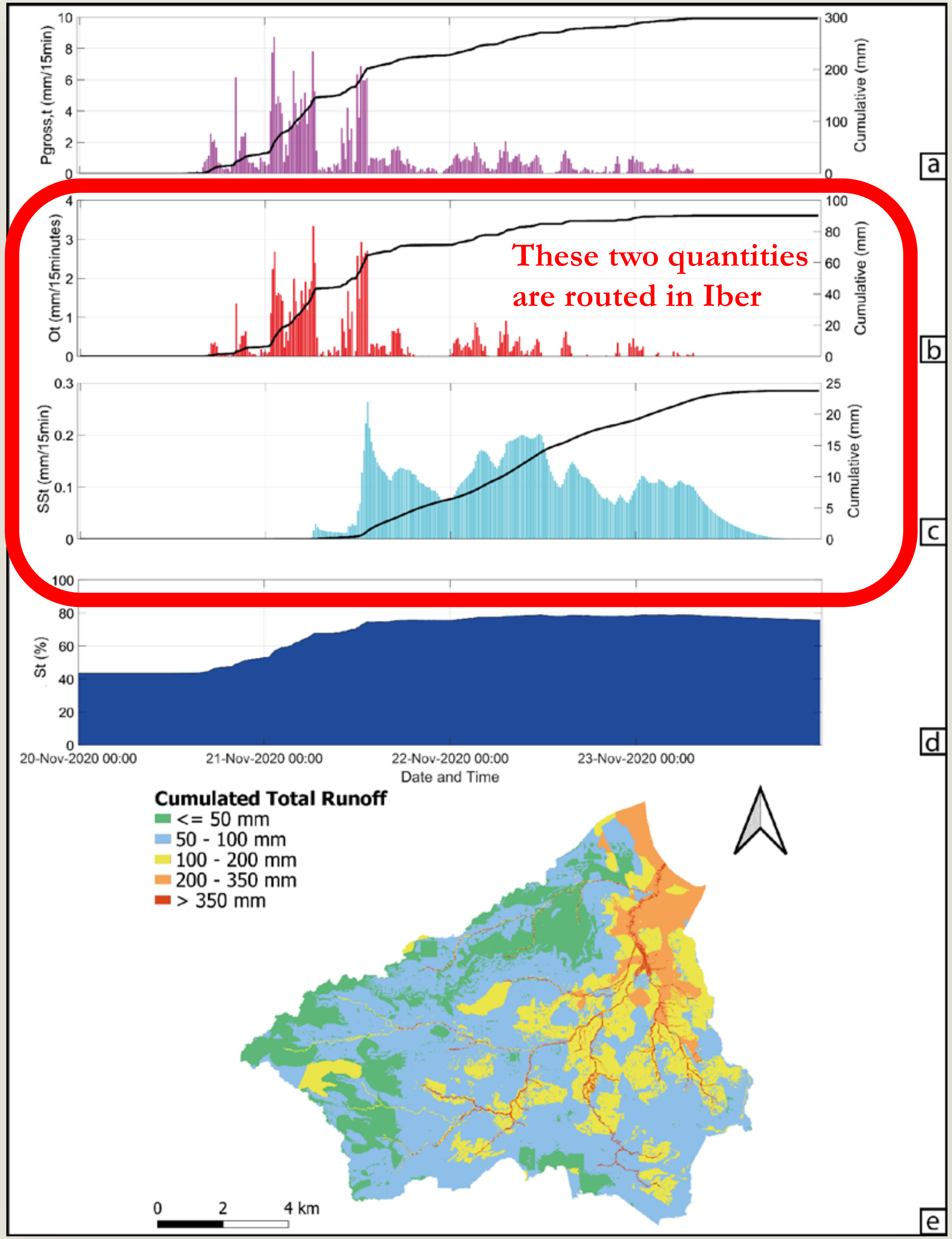
Workflow adopted for the reconstruction



Results



Warm-up DREAM results

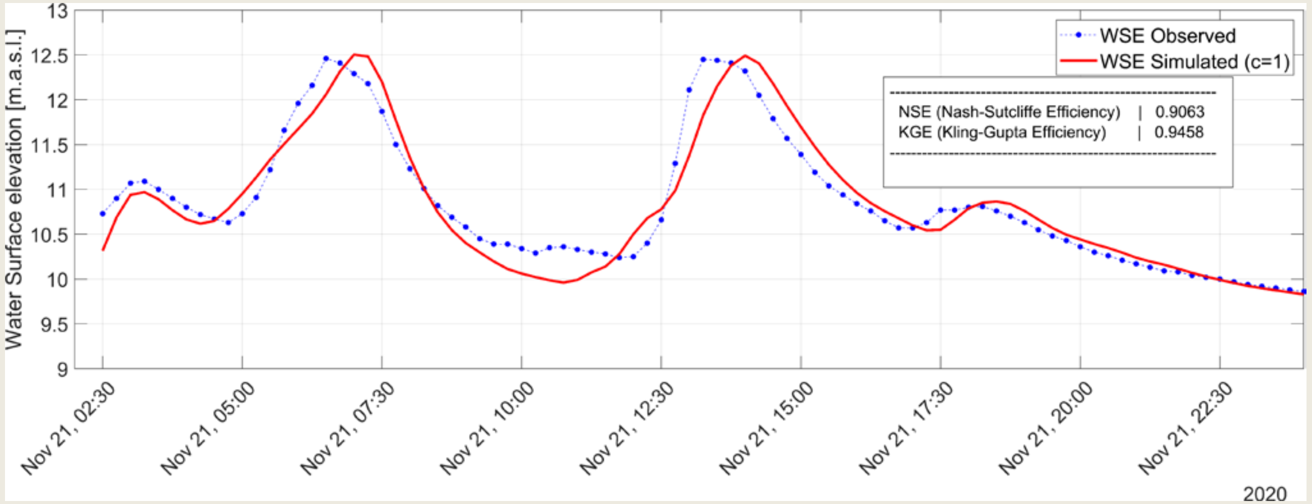


Runoff DREAM results

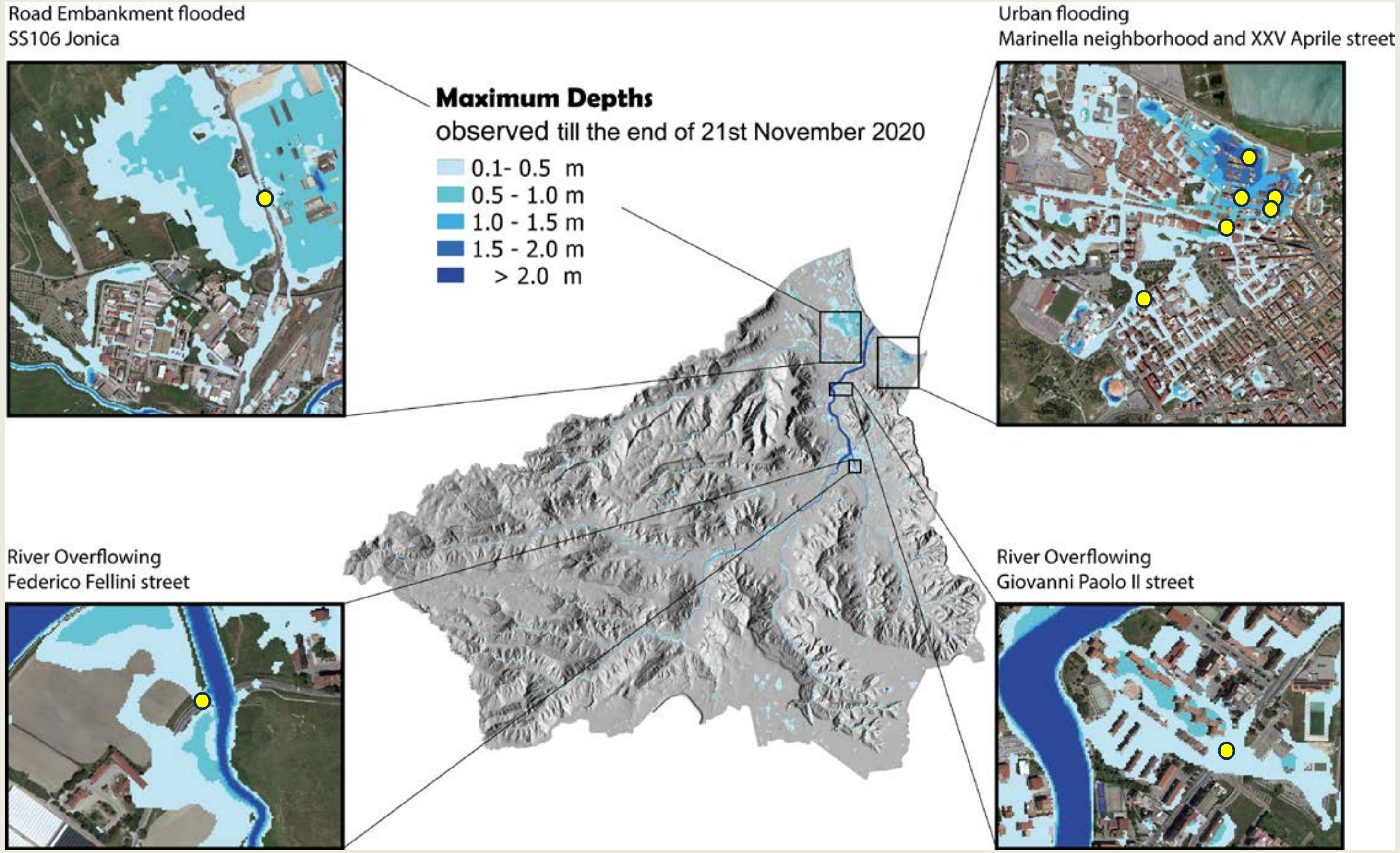
Calibration and Qualitative validation

3D comparison (simulated depths vs reality)

Calibrated WSE at Bridge San Francesco Hydrometer



Iber results



Conclusions (1)

- The Runoff-On-Grid is very useful for embedding simplistically hydrological 'knowledge' in shallow water models *(i.e., Antecedent soil moisture conditions, soil physics, and subsurface hydrological processes)*
- The Runoff-on-Grid approach enhances the capabilities of both DREAM and IBER models
- The Runoff-on-Grid approach can be useful for extending surface hydrodynamic modelling in umid and vegetated catchment
- The Esaro flooding (November 2020) was induced from a combined contribution of surface and subsurface hydrological processes

State of the manuscript: Perrini P., Cea L., et al., (submitted)

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Ph.D. research questions

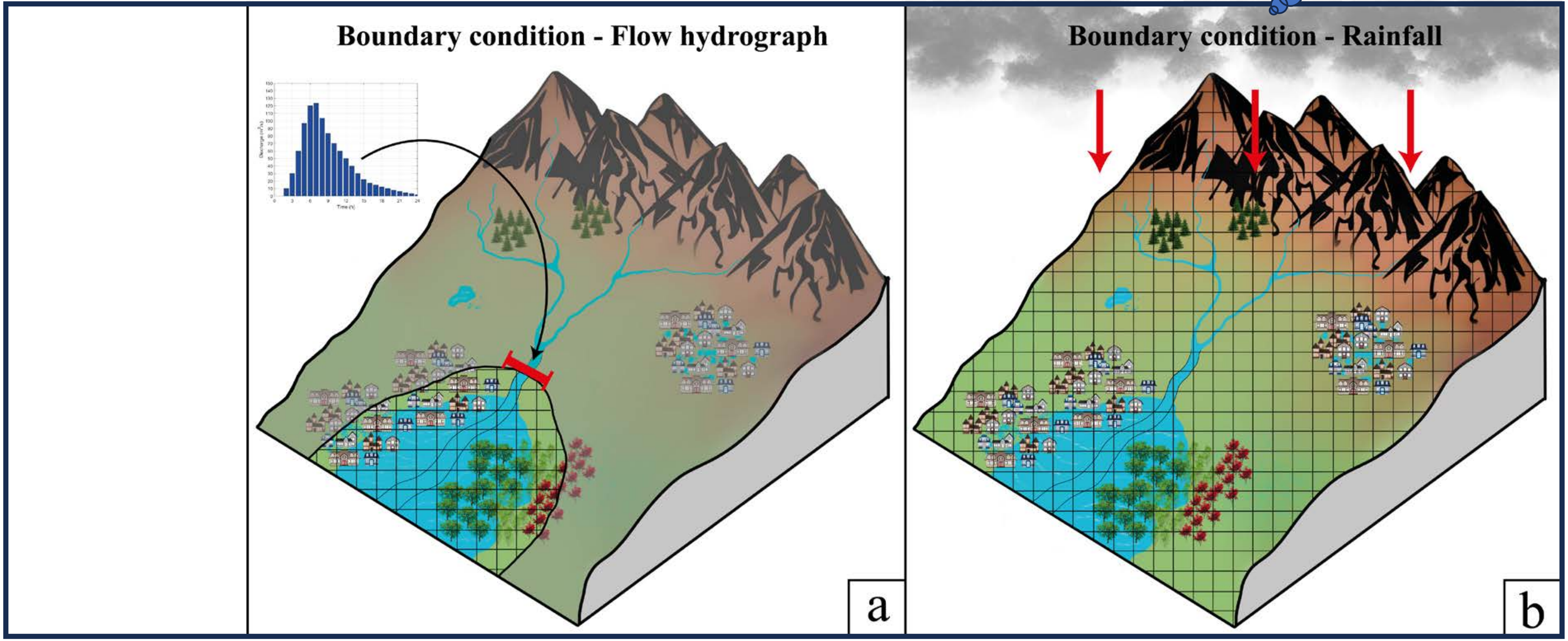
Let's continue …

Can we enhance the capabilities of the shallow water models for catchment hydrology?

Can we discretize whitin a shallow water model the fluvial and pluvial inundations?

Floods typologies and sources of hazard

The SWE models don't see any of these differences



Figures drawn by Maddalena Perrini

… we need and external source of information to aide the SWE !!

Can a tracer aide pluvial and fluvial hazard mapping?

Methodology:

- Where do the fluvial hazard maps begin?
- Advection process of a conservative tracer
- Tracer-aided SWE model

$$\frac{\partial h}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = \mathrm{R} - \mathrm{I}$$

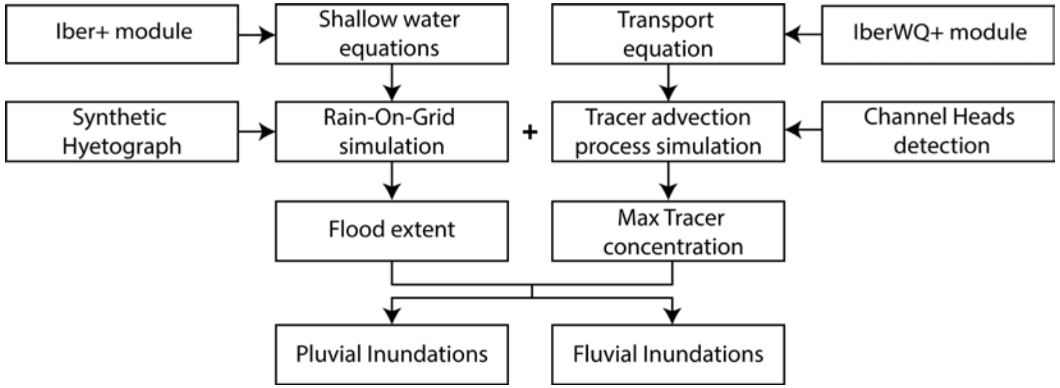
$$\frac{\partial q_x}{\partial t} + \frac{\partial}{\partial x}\left(\frac{q_x^2}{h} + \frac{gh^2}{2}\right) + \frac{\partial}{\partial y}\left(\frac{q_x q_y}{h}\right) = -gh\frac{\partial z_b}{\partial x} - g\frac{n^2}{h^{7/3}}|\boldsymbol{q}|q_x$$

$$\frac{\partial q_y}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q_y^2}{h} + \frac{gh^2}{2}\right) + \frac{\partial}{\partial x}\left(\frac{q_x q_y}{h}\right) = -gh\frac{\partial z_b}{\partial y} - g\frac{n^2}{h^{7/3}}|\boldsymbol{q}|q_y$$

Transport equation

$$\frac{\partial hC_i}{\partial t} + \frac{\partial q_x C_i}{\partial x} + \frac{\partial q_y C_i}{\partial y} = Q_{tracer}$$

- Workflow in Iber software:



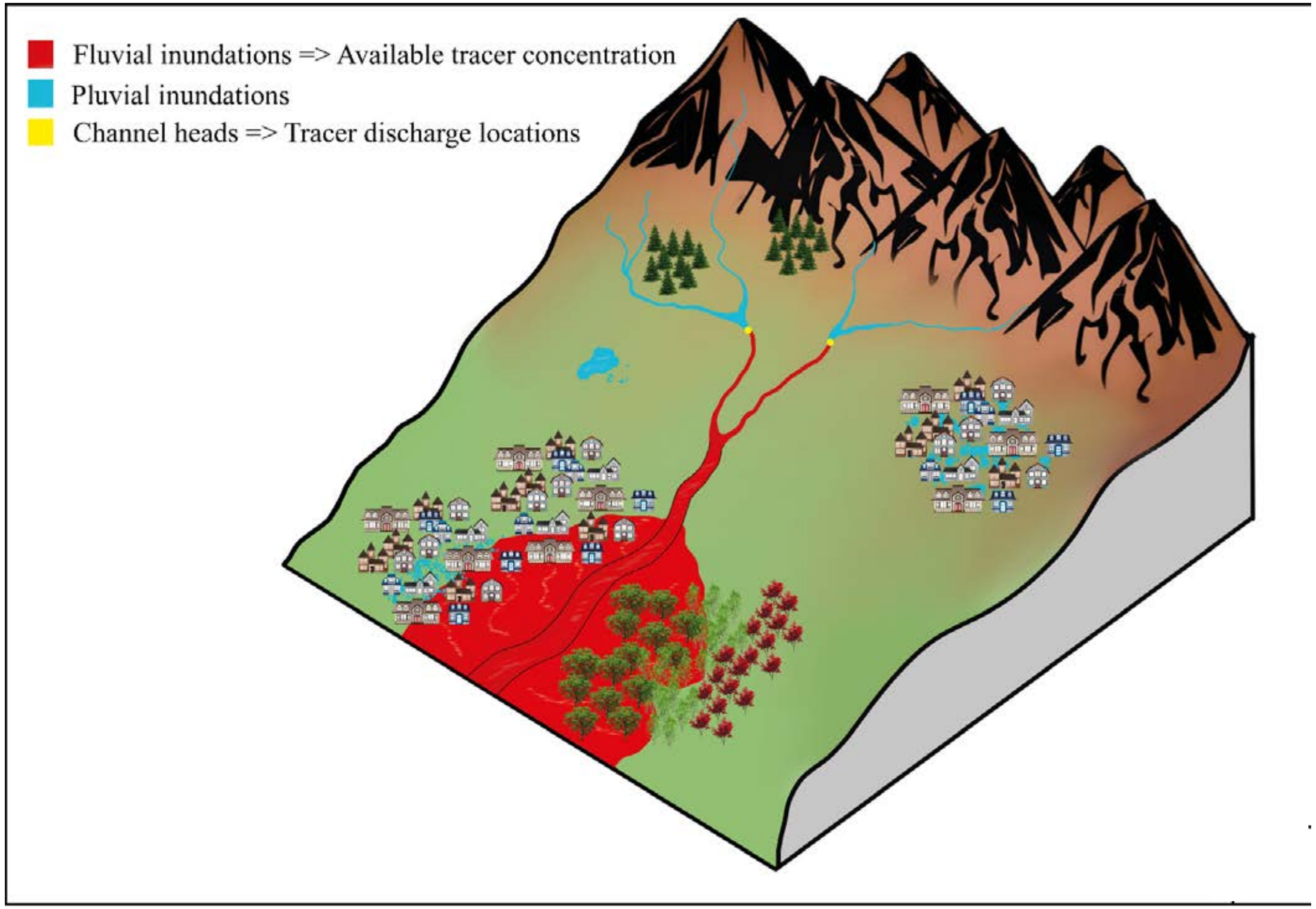
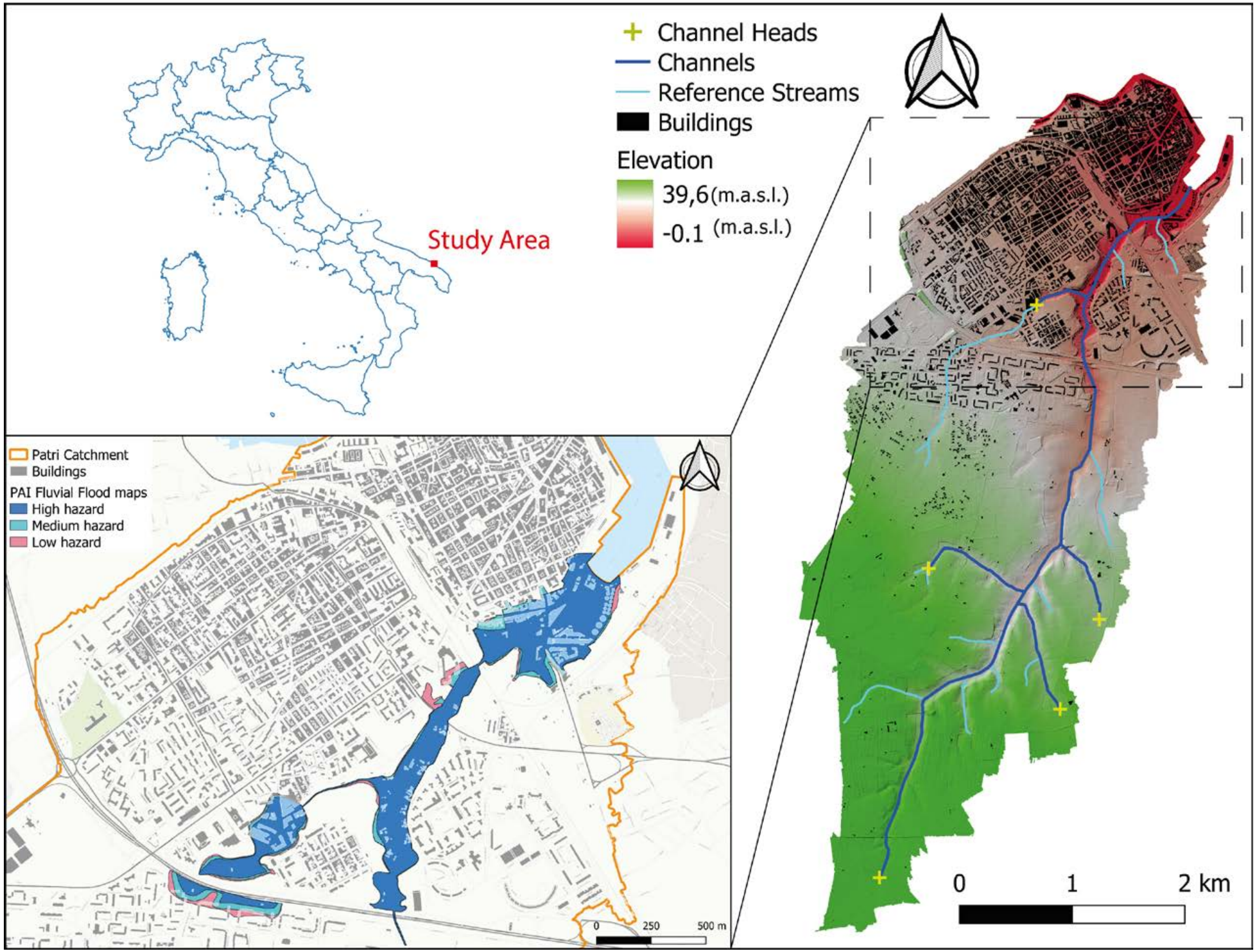


Figure drawn by Maddalena Perrini



Study Case:

Patri Catchment (Puglia, Italy)

- Small and ungauged catchment (16 km2)
- Prone to pluvial and fluvial flooding
- Channel head detection:
  - LiDAR based DTM (0.5 m)
  - HR AGEA ortophoto
- Official Flood hazard maps
  (National and European directives)

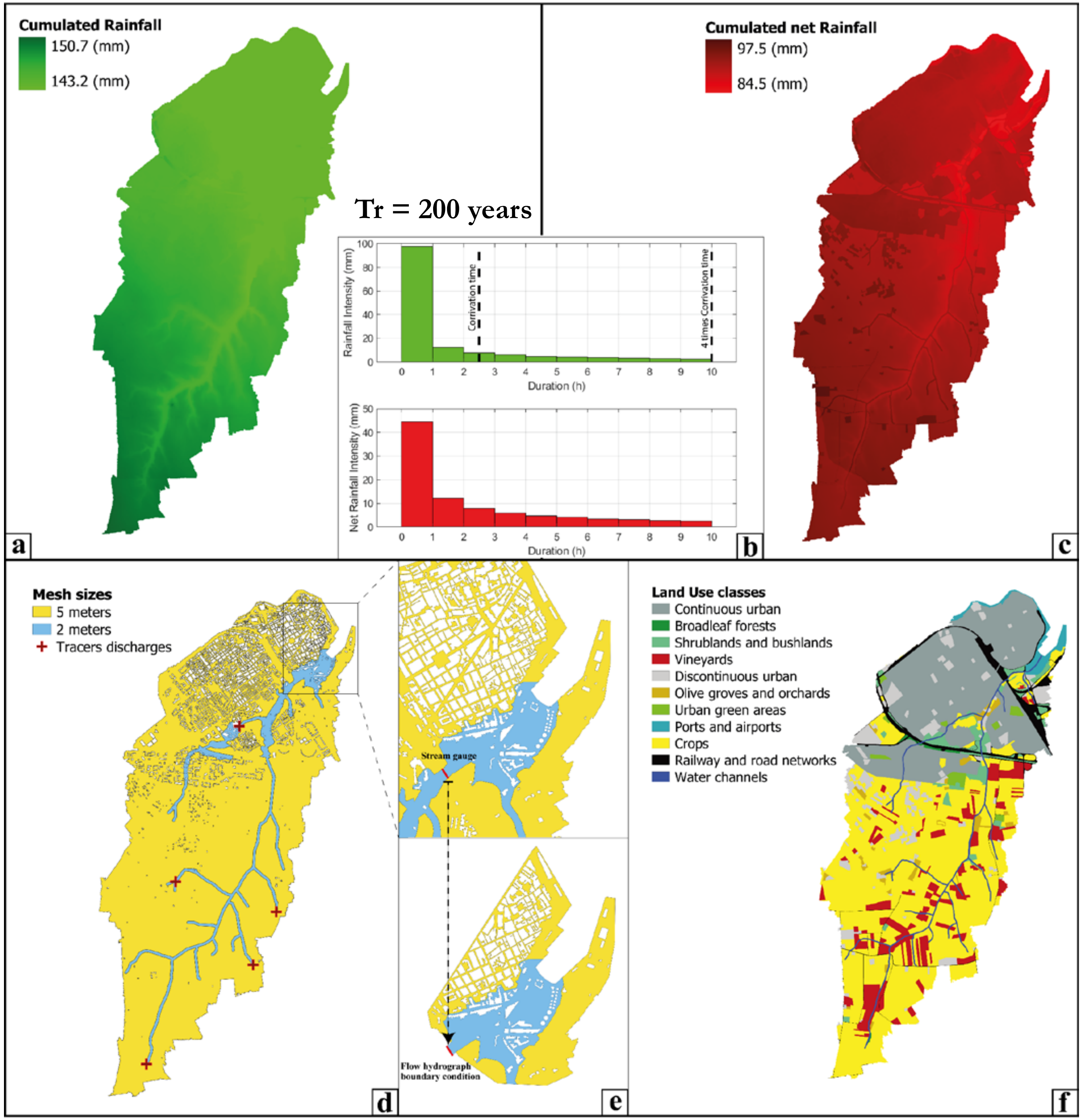
Synthetic storm event

- VAPI Puglia Depth-Duration-Frequency curves
- Chicago hyetograph following Ferro, (2013)
- Infiltration method following DeSmedt, (2000)

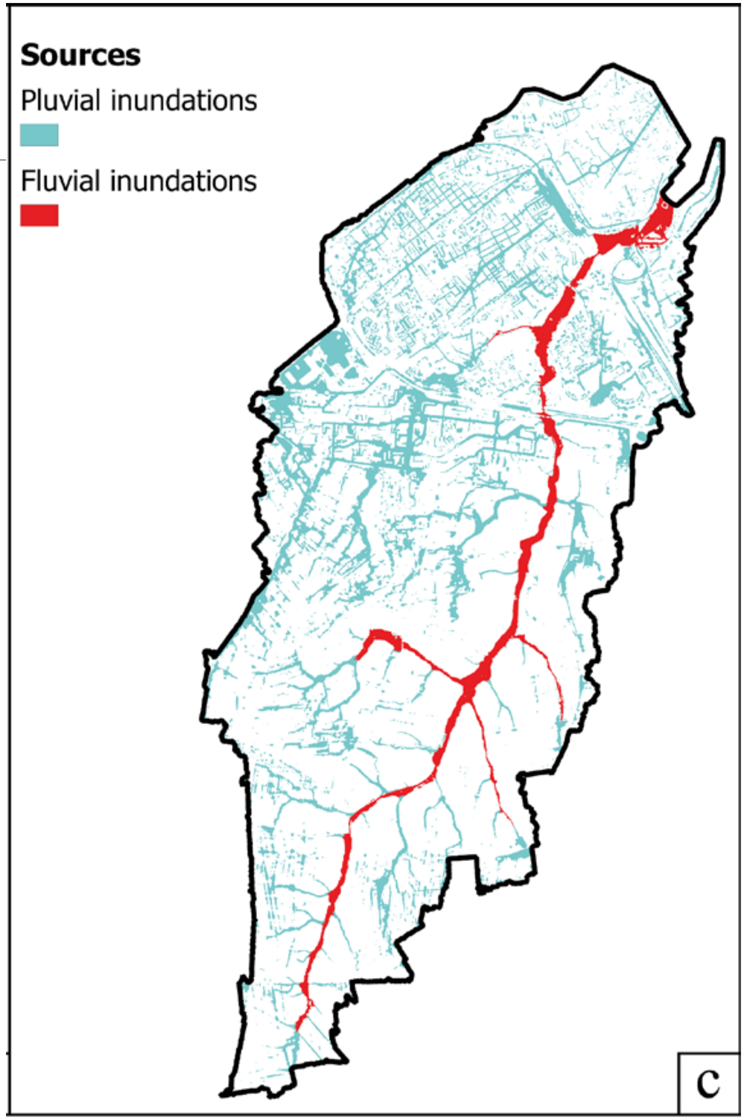
Models set-up

Two geometries:

- Catchment scale tracer aided model (<u>*CSTA model*</u>)
    - Tracers discharges
- Upstream boundary condition model (<u>*BC model*</u>)



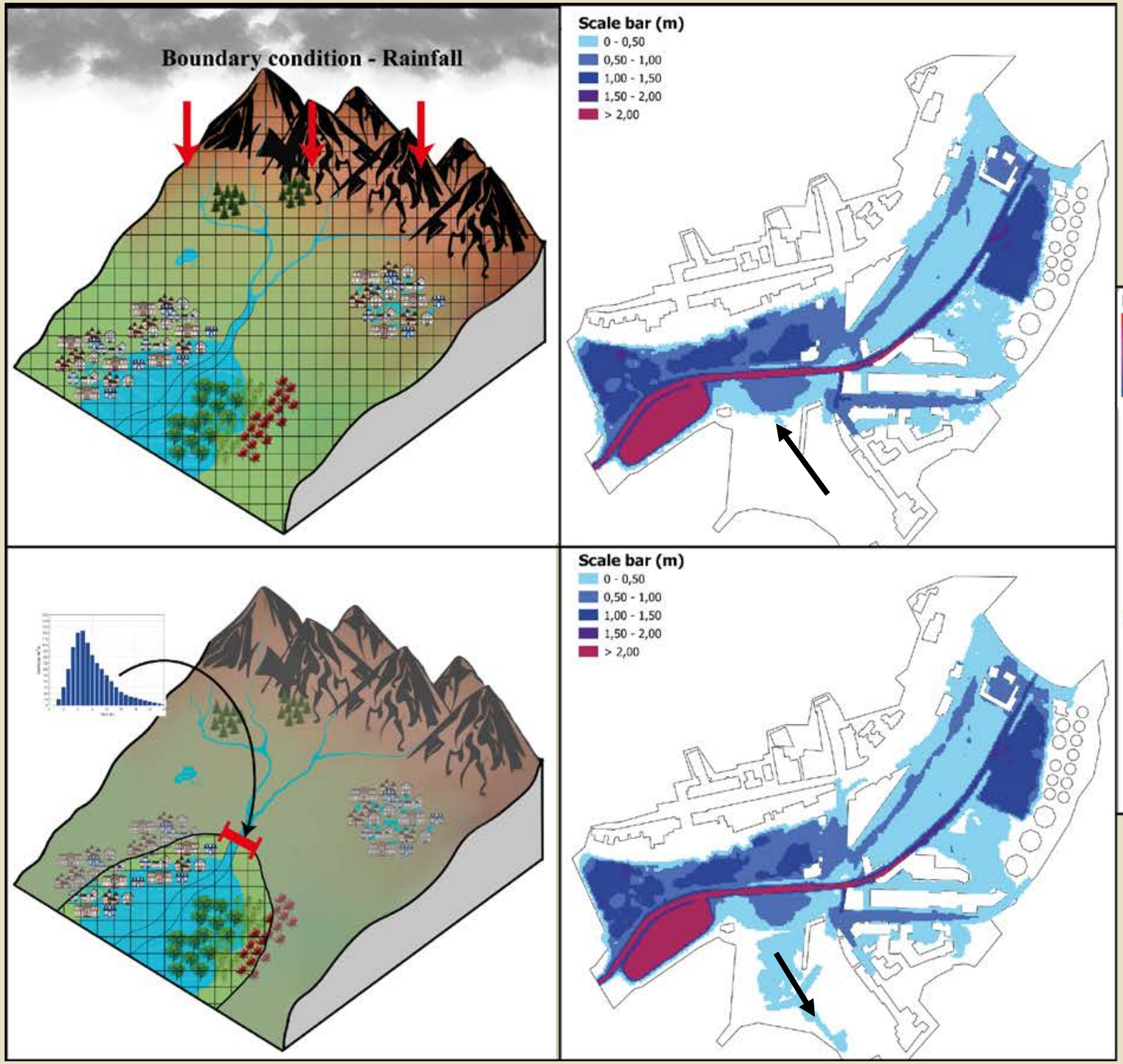
Results

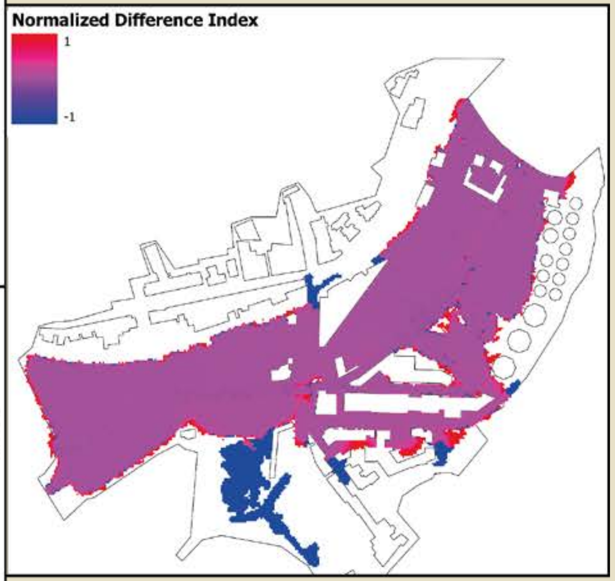


Catchment-scale approach vs Boundary condition approach

CSTA model

BC model





Pluvial and fluvial hazard mapping

<u>Hydrodynamic variables:</u>
Maximum depths
Maximum velocities

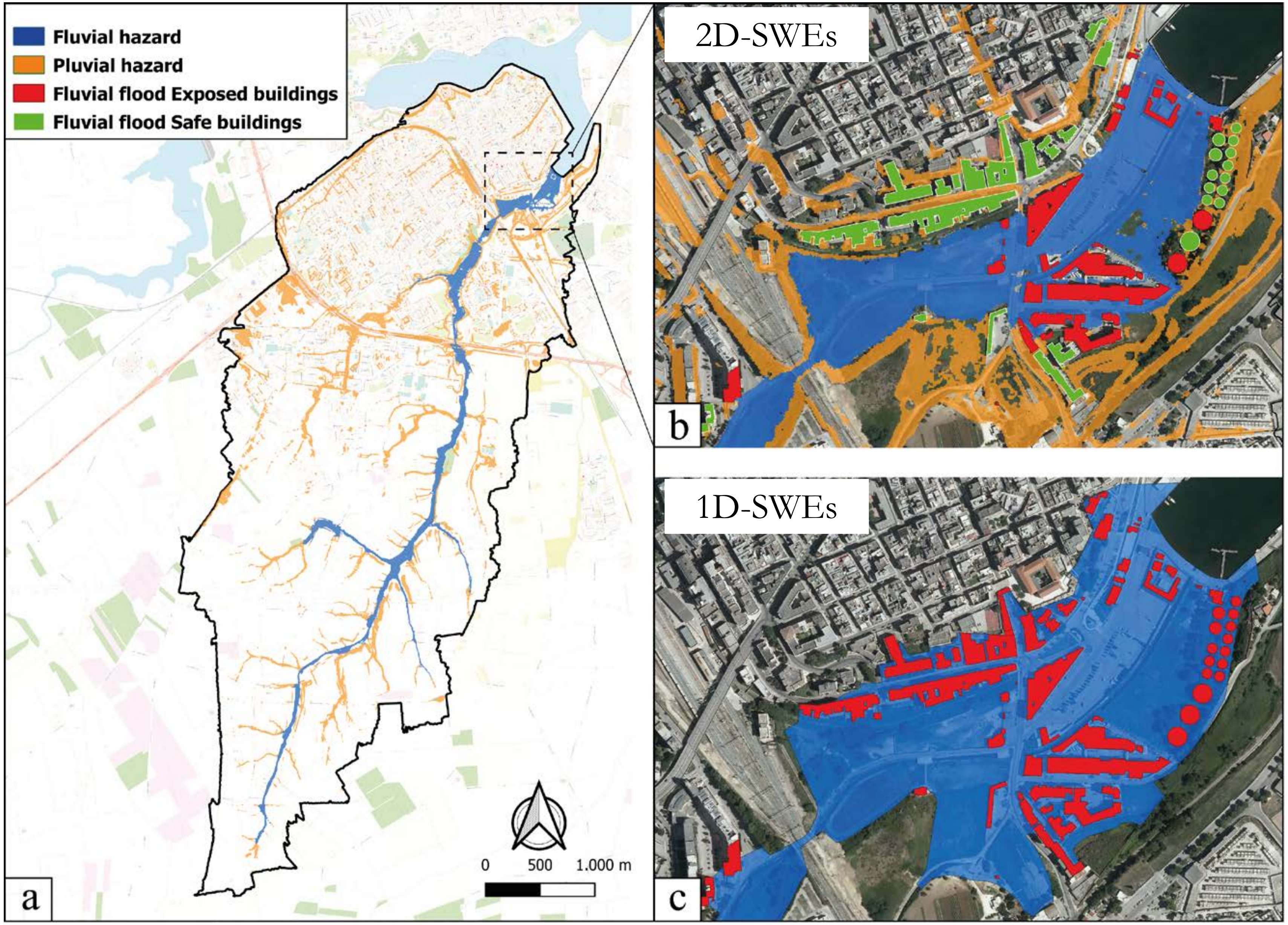
↓

<u>Flood Hazard index</u>
(local authorities)
&
<u>Pluvial-Fluvial discretization</u>

↓

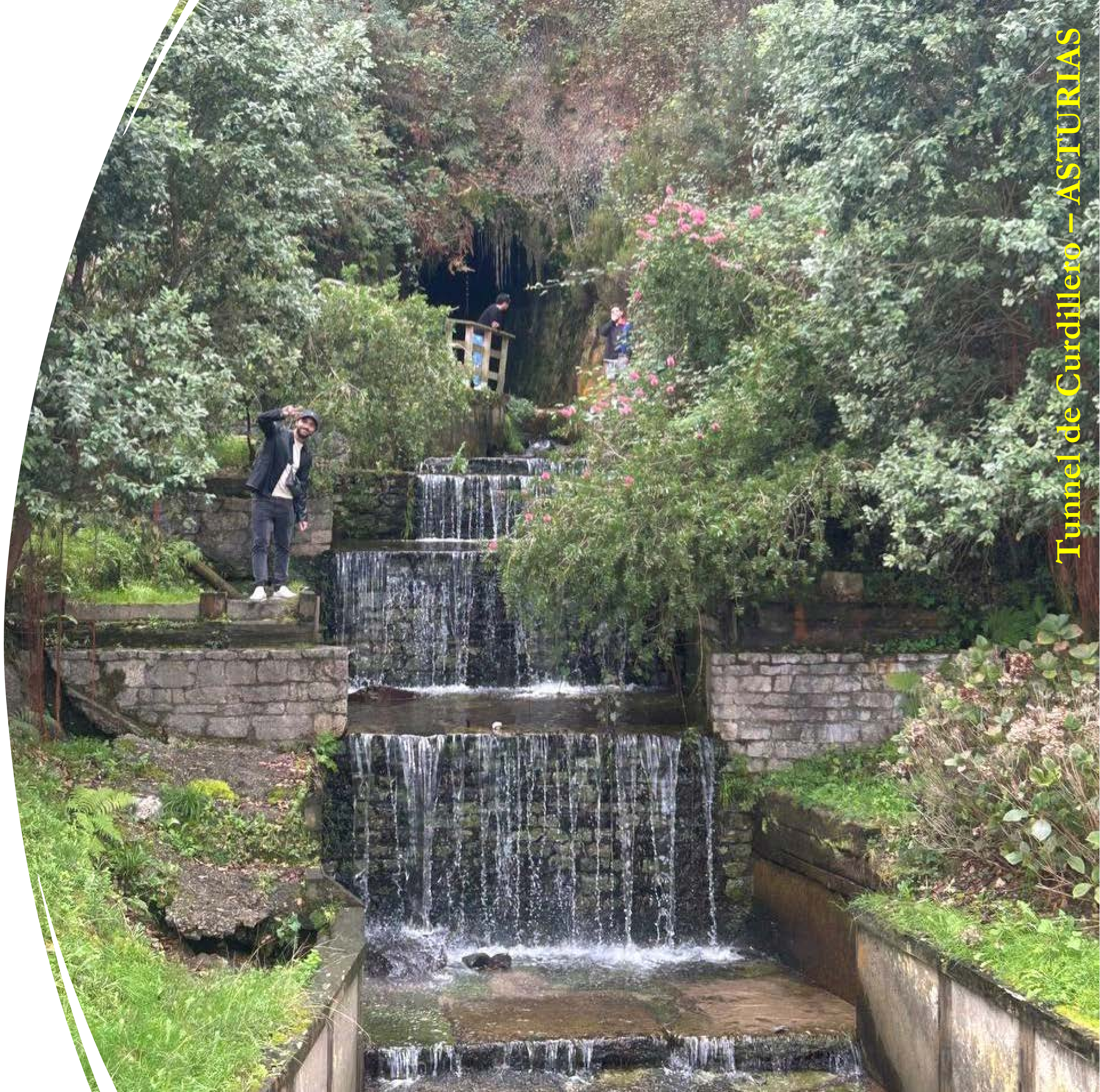
Pluvial hazard
&
Fluvial hazard

Figure **b** & **c**: comparison between Official and tracer-aided fluvial flood hazard maps



Conclusions (2)

- Trancers can improve the description of the inundation sources whitin a modelling framework
- The proposed method is able to discretize, at the catchment scale, fluvial and pluvial inundations
- The approaches used in hydrodynamic modelling can have a strong impact in the flood mapping
- Pluvial and fluvial inundations can have a comparable '*degree of hazard*', paradoxally the pluvial one is not regulated
- The method can be extended also for discretizing compound '*fluvial-pluvial-coastal*' inundations



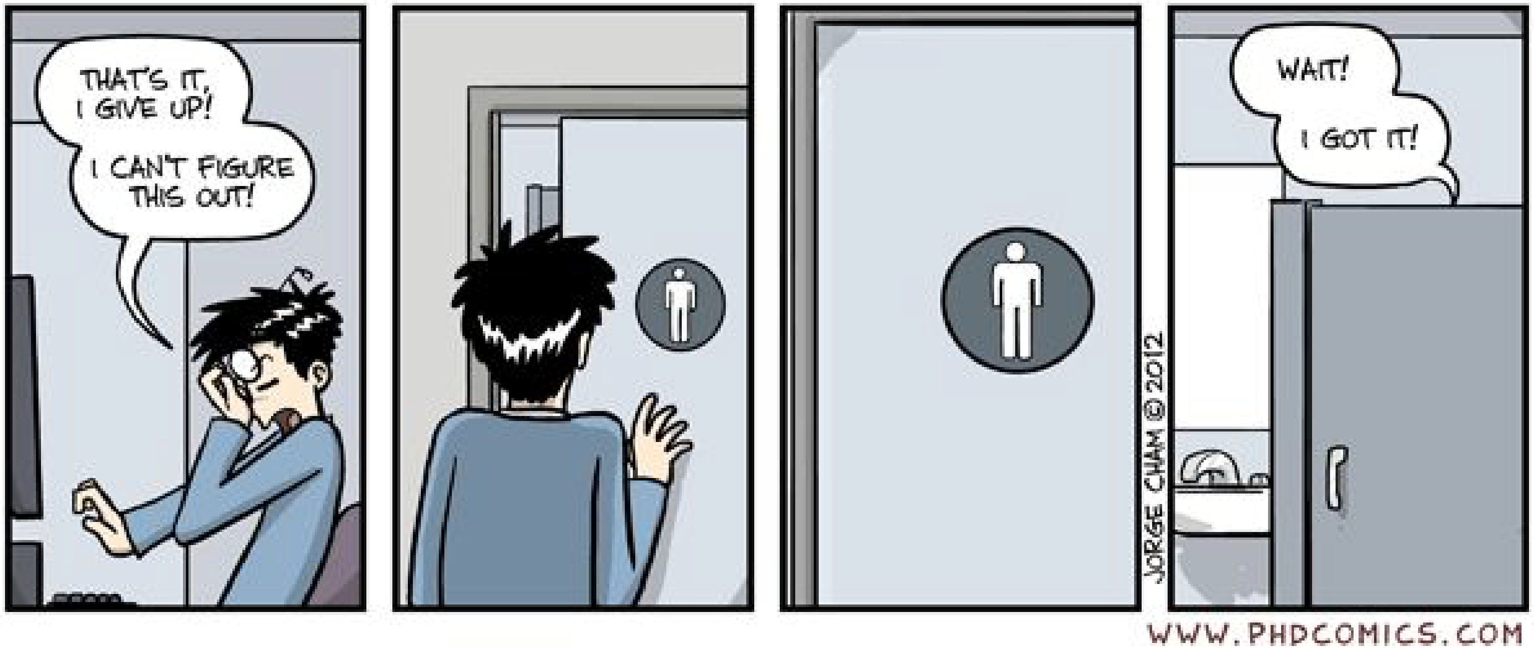
State of the manuscript: Perrini P., …, Cea L. (in preparation)

Q&A

1. Can we enhance the capabilities of the shallow water models for catchment hydrology? → A Runoff-On-Grid approach to embed hydrological processes in SWE models

2. Can we discretize whitin a shallow water model the fluvial and pluvial inundations? → A tracer-aided method to discretize pluvial and fluvial inundations in SWE models

… are there any questions ?



But science and technology are not enough. In developing and testing hypotheses in hydrology there is need for intuition, skill, imagination and creativity; qualities generally attributed to the field of arts. Hydrological modelling requires art, as will be elaborated further down.

Savenije, H. H. (2009). HESS Opinions" The art of hydrology“ Hydrology and Earth System Sciences, 13(2), 157-161.

An advice to a young PhD student:

CQ + PQ > IQ

McDonnell, J. J. (2019). Navigating an Academic Career: A Brief Guide for PhD Students, Postdocs, and New Faculty (Vol. 74). John Wiley & Sons. (original citation by Thomas Friedman)