



ALMA MATER STUDIORUM
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Assessing fluvial flooding hazard with a DEM-based Hierarchical Filling-&-Spilling Algorithm: a case study in Northern Italy

**Simone Persiano⁽¹⁾, Francesca Carisi⁽¹⁾, Huimin Wang⁽¹⁾,
Valerio Luzzi⁽²⁾, Paolo Mazzoli⁽²⁾, Stefano Bagli⁽²⁾, Attilio Castellarin⁽¹⁾**

⁽¹⁾ DICAM - University of Bologna, Bologna, Italy

⁽²⁾ GECO sistema S.r.l., Cesena, Italy

Presenting Author: **Simone Persiano**
DICAM - University of Bologna, Bologna, Italy

Introduction

Need of **innovation** in urban flood-proofing tools and data.

- Hydrological and hydraulic **numerical models** provide accurate detailed inundation maps but are often very **resource intensive**.
- Development of simplified approaches based on LiDAR high-resolution DEMs raster-based analysis (e.g. **Hierarchical Filling-&-Spilling Algorithms**)

New simplified and computationally efficient **raster-based tools** exploiting open data and freely-accessible **Digital Elevation Models (DEMs)**.



SAFERPLACES <https://saferplaces.co/>
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Improved assessment of **pluvial**, **fluvial** and **coastal** flood hazards and risks in European cities as a means for building safer and more resilient communities.

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POLITÉCNICA



Meteorological Environmental
Earth Observation

Fast-processing pluvial flooding mapping: Safer_RAIN

Samela et al. (2020)

Source: *Samela et al. (2020)*

Hierarchical Filling-&-Spilling (HFS)

Main assumptions

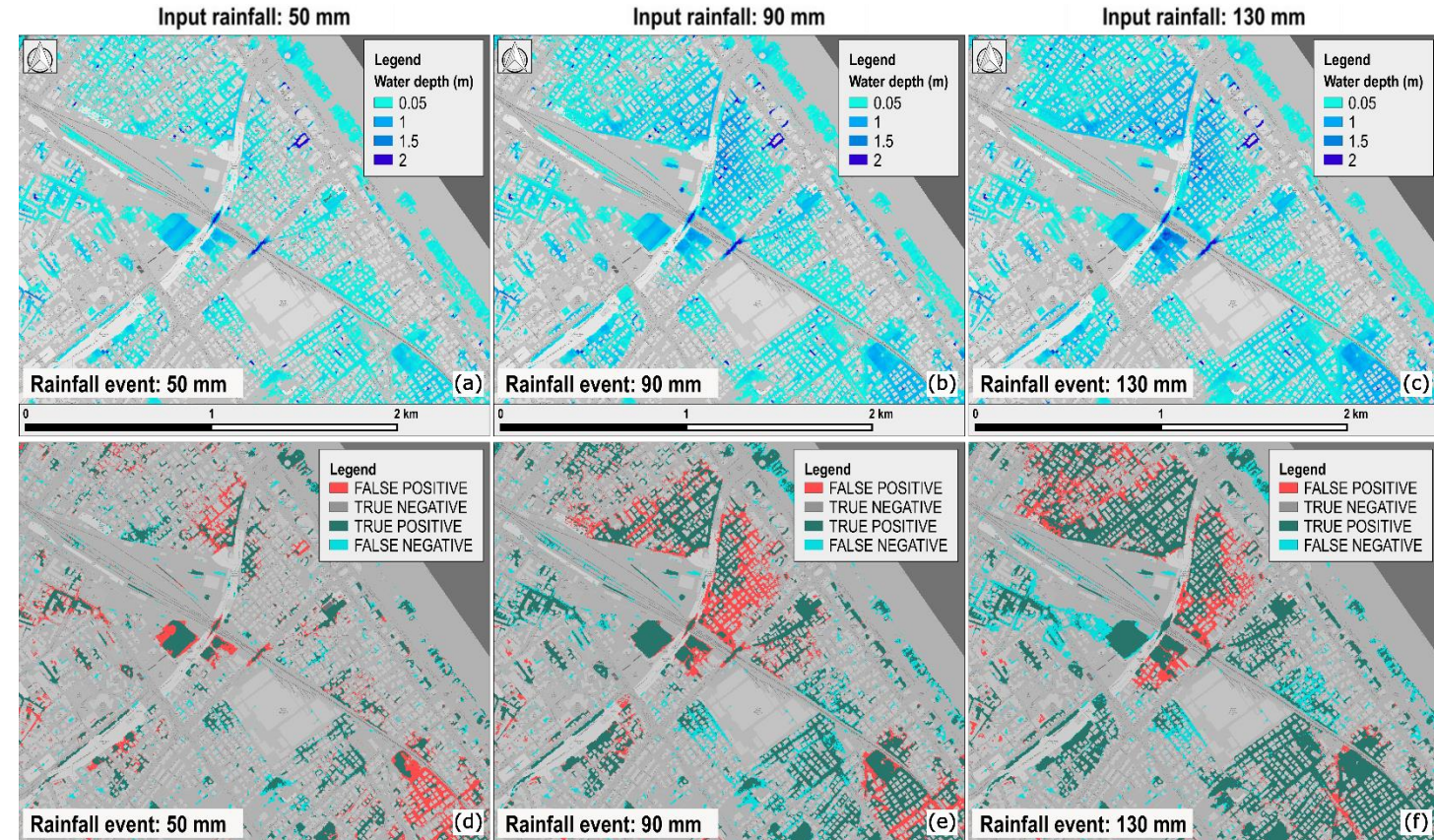
- (1) Dynamics is neglected: rainfall water volume flows downstream instantaneously
- (2) Water flows according to the D8 method

Safer_RAIN is composed of **two phases**:

1. **DEM preprocessing**: identification of the hierarchical structure of the depressions in the DEM (run once for the study area)
2. **Flooding**: identification of flooded areas and water depths, accounting for spatially-distributed rainfall inputs and infiltration processes (Green-Ampt module).

Samela et al. (2020)

- **Cons**: it does **not** incorporate the **dynamics** of overland flow and water-depth routing.
- **Pros**: effective tool for a **rapid and consistent** identification of **pluvial-hazard hotspots** under different rainfall and land-use scenarios.



[Click here for more details about the Safer_RAIN algorithm](#)

Research question and study area

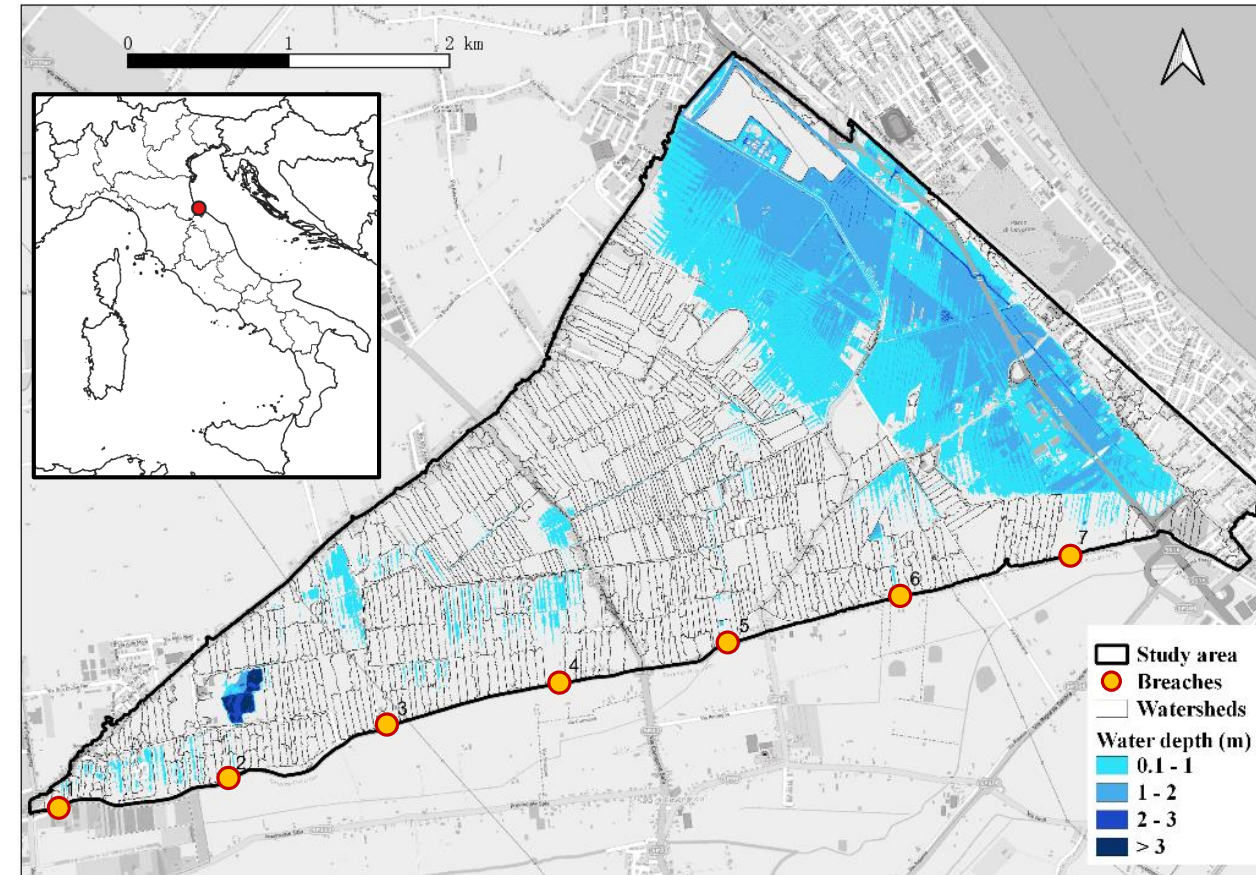
Research question: Although Safer_RAIN has been conceived for pluvial flooding hazard assessment, is it suitable for delineating **flooded areas** and computing **water depth in the aftermath of fluvial inundation** in predominantly flat floodplains?

Application of Safer_RAIN for fluvial flooding

A given **flood volume** is assigned to the pixels coinciding with the **fluvial flooding point-sources** (e.g. simulated levee breach or overtopping) as the input to Safer_RAIN, which is then used for flooding the downstream floodplain portion.

Study area:

Pisciatello river (Northern Italy) floodplain ~1300 hectares



Analyses: Different flood scenarios (levee breaching) are simulated with 1 and 7 breaches:

- Safer_RAIN applied to LiDAR DEM at 1m resolution
- Fully-2D hydrodynamic model **HEC-RAS** applied to DEM at 1m and 5m resolutions



Comparison in terms of:

- Flooded areas
- Water depth distribution

Application: HEC-RAS

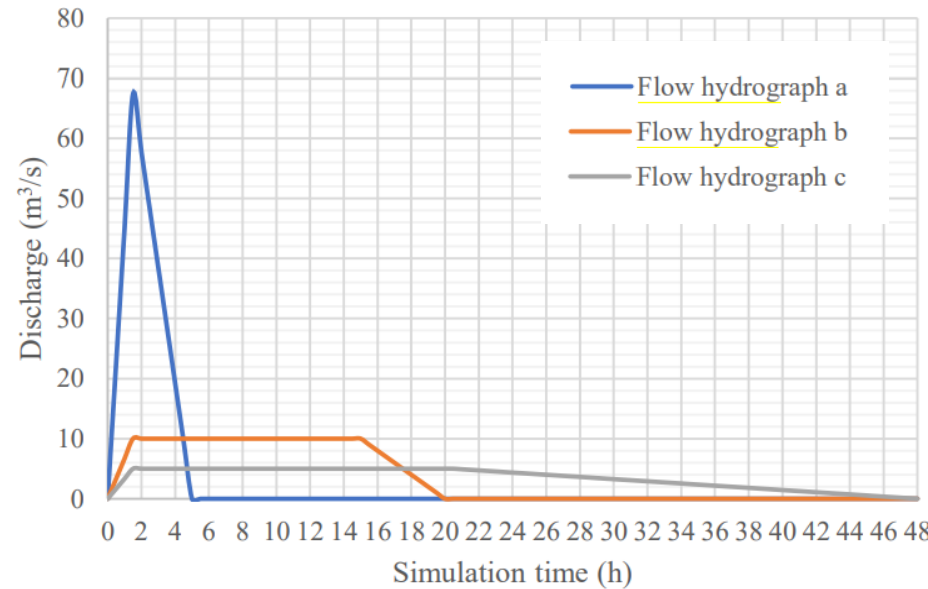
Input data

- DEM
- Land cover data
- Computational grid
- Boundary Condition Lines (BCL)
- Computational options: Diffusion Wave Equations

Sensitivity analysis

- 1m vs 5m grid resolution
- with vs without extruded buildings
- inflow dynamics (hydrographs)

Inflow hydrograph



Boundary Condition Lines (BCL2, BCL3)
outlets for the flow



Application: HEC-RAS

Note: total flood volume in each simulation is **606600 m³**

Input data

- DEM
- Land cover data
- Computational grid
- Boundary Condition Lines (BCL)
- Computational options: Diffusion Wave Equations

Output

- Water depth
- Surface water elevation
- Velocity
- Inundation boundary
- Flood animation

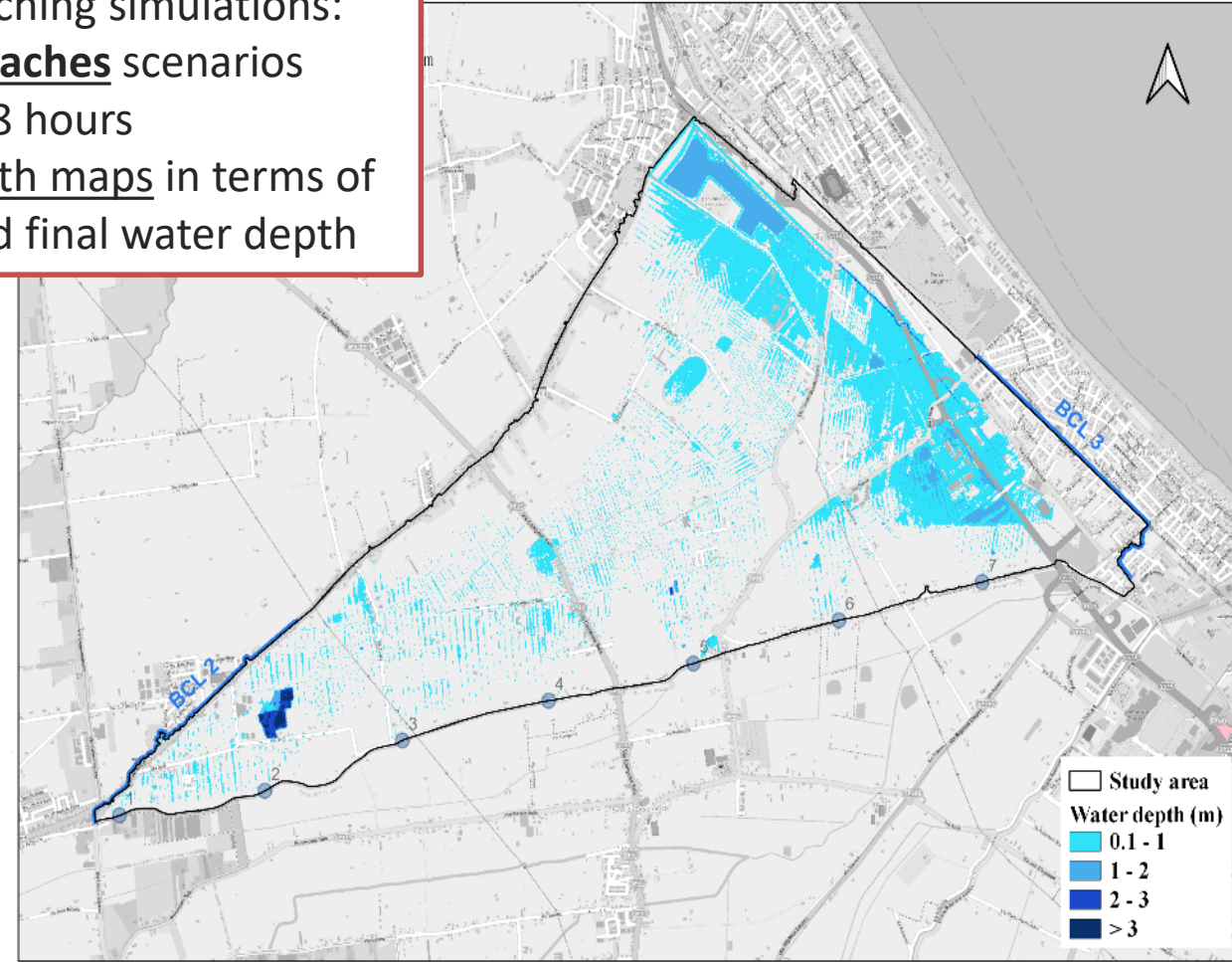
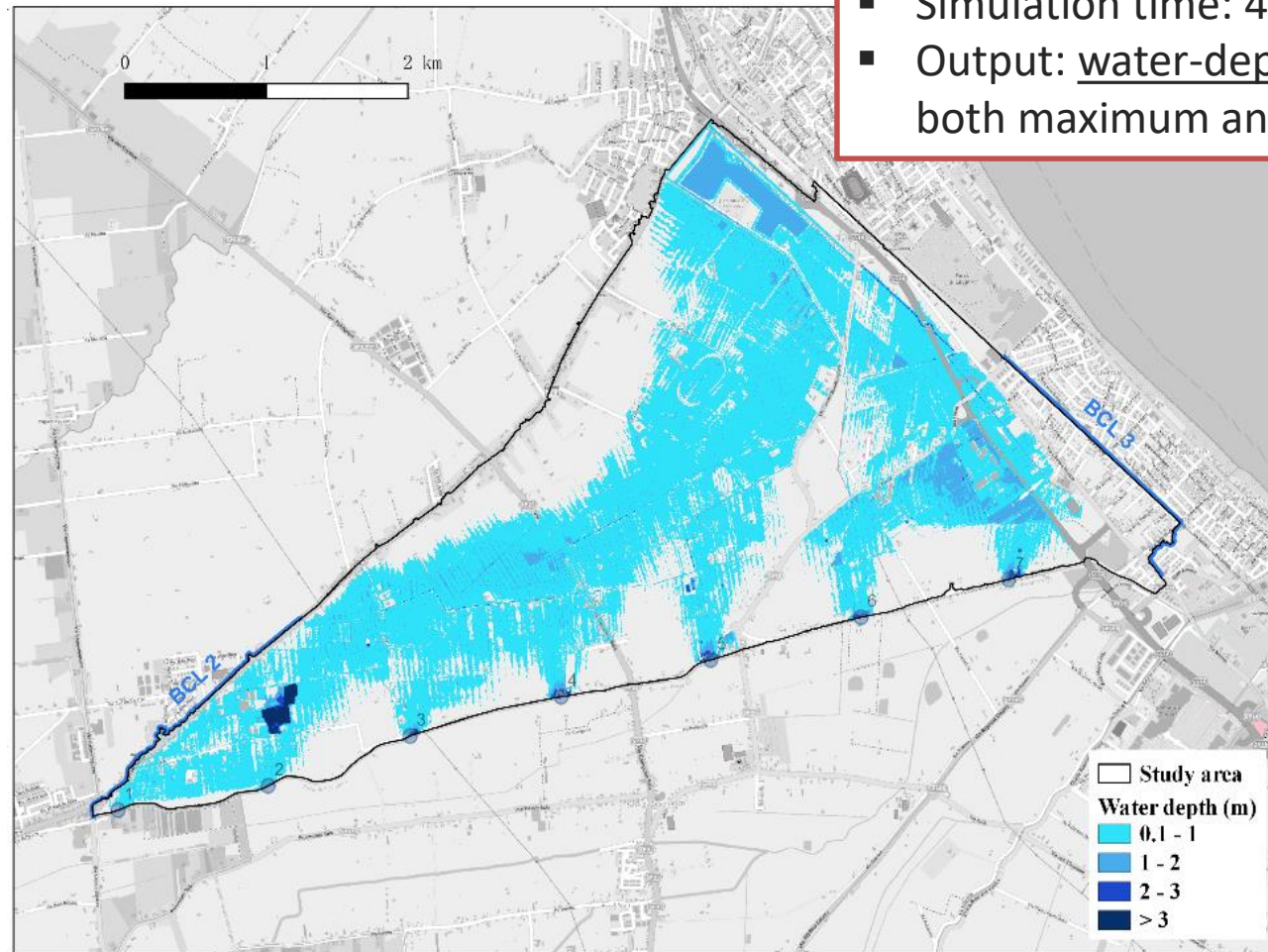
Simulation	Study area dimension (ha)	LiDAR DEM with extruded buildings	Resolution of computational grid (m)	Upstream boundary condition (Hydrograph) Max discharge (m ³ /s)	Downstream boundary condition (Normal depth friction slope) BCL 2 BCL 3		Computation interval (s)
HR_ZA1	50	Yes	1	67.4	0.003	0.0035	1
HR_ZA5	50	Yes	5	67.4	0.003	0.0035	1
HR_ZB1	50	No	1	67.4	0.003	0.0035	1
HR_67.4	1352	Yes	5	67.4	0.003	0.0005	15
HR_10	1352	Yes	5	10	0.003	0.0005	15
HR_5	1352	Yes	5	5	0.003	0.0005	15
HR_breach 1-7	1352	Yes	5	67.4	0.003	0.0005	15

Application: HEC-RAS

Flood simulation scenarios

- Trigger: levee breaching simulations: 1 breach and **7 breaches** scenarios
- Simulation time: 48 hours
- Output: water-depth maps in terms of both maximum and final water depth

Maximum water depth



Final water depth

Application: HEC-RAS

Simulation scenario	Study area dimension (ha)	Computational grid resolution (m)	Runtime	Error	Percent error	Outflow Volume (10 ³ m ³)	Ending volume (10 ³ m ³)
HR_ZA1	50	1	37:45:44	0.3447	0.05682	585.5	21.42
HR_ZA5	50	5	00:25:37	0.1604	0.02644	589.2	17.59
HR_ZB1	50	1	39:38:38	0.2785	0.04591	585.1	21.82
HR_10	1352	5	7:40:40	0.1737	0.02880	0	603.2
HR_5	1352	5	7:11:31	0.2405	0.03988	0	603.2
HR_breach 1	1352	5	12:19:13	0.1244	0.02050	3.630	603.1
HR_breach 2	1352	5	13:11:16	0.1455	0.02398	0	606.7
HR_breach 3	1352	5	13:05:23	0.1326	0.02186	0	606.7
HR_breach 4	1352	5	12:31:00	0.1621	0.02673	0	606.8
HR_breach 5	1352	5	6:24:37	0.1023	0.01686	0	606.7
HR_breach 6	1352	5	4:16:51	0.07421	0.01223	0	606.7
HR_breach 7	1352	5	4:01:02	0.05888	0.009706	0	606.7

Application: Safer_RAIN

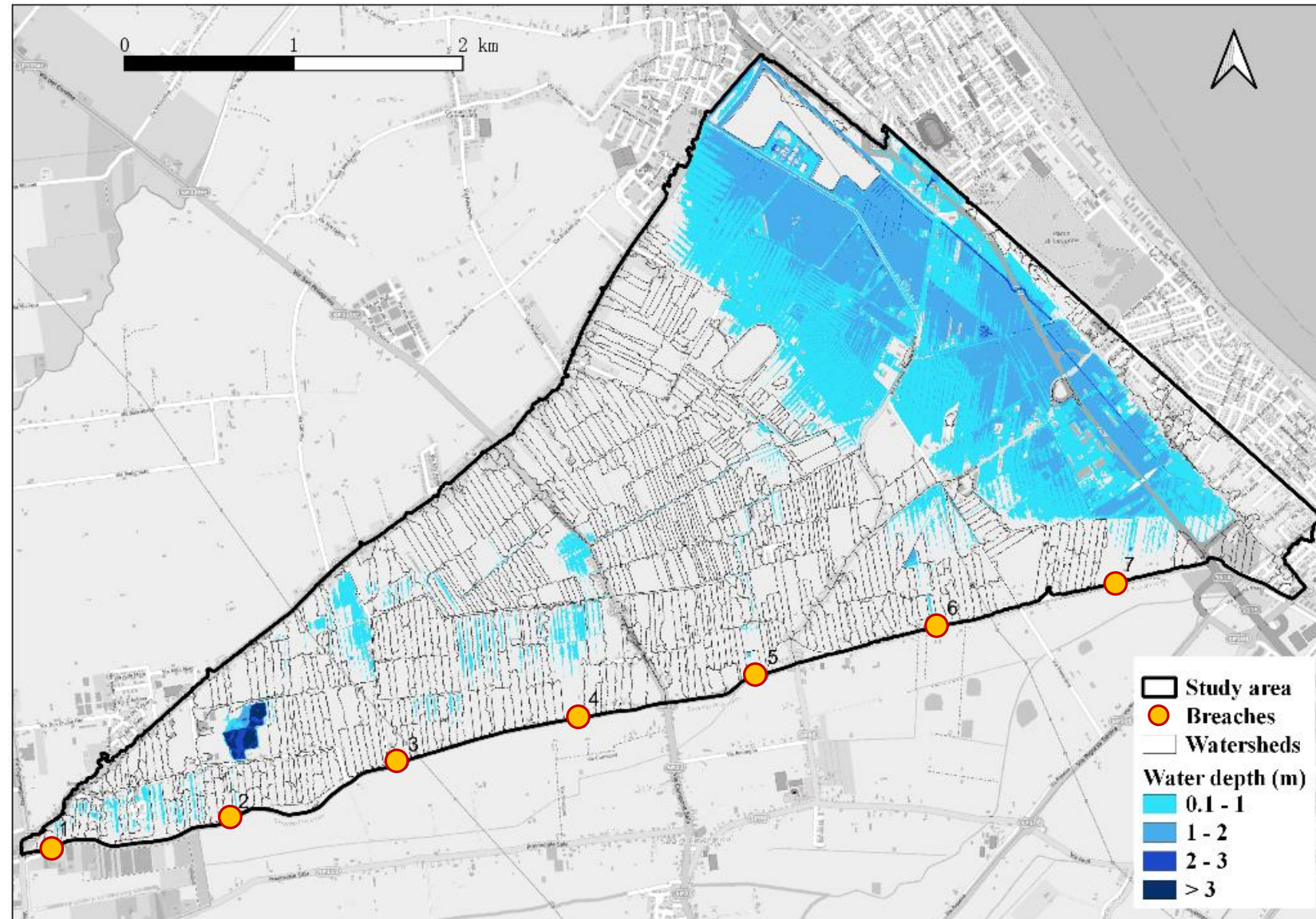
Fluvial flooding simulation with Safer_RAIN

Input data

- 1m LiDAR DEMs
Study area: 1352 hectares
- Flood volume for each breach (point-source): 606600 m³

Settings

- Threshold area: 300 m²
(minimum area of a blue-spot)
- Slicing: 0.05 m
(height of the level-set needed for identifying the vertical hierarchical structure of depressions)



Comparison: HEC-RAS vs Safer_RAIN

Flood Area Index (FAI)

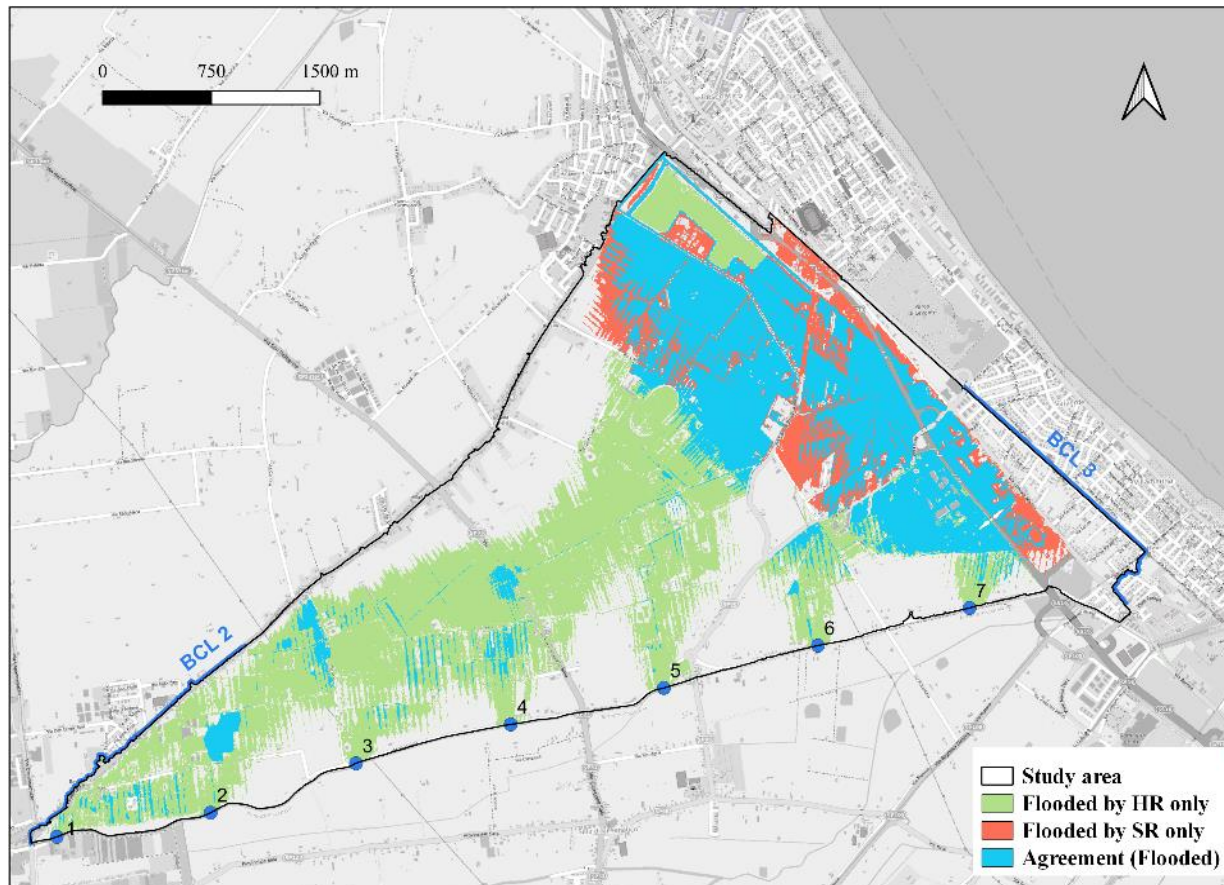
$$FAI = \frac{A}{A + B + C}$$

A: areas that are **flooded in both simulations**

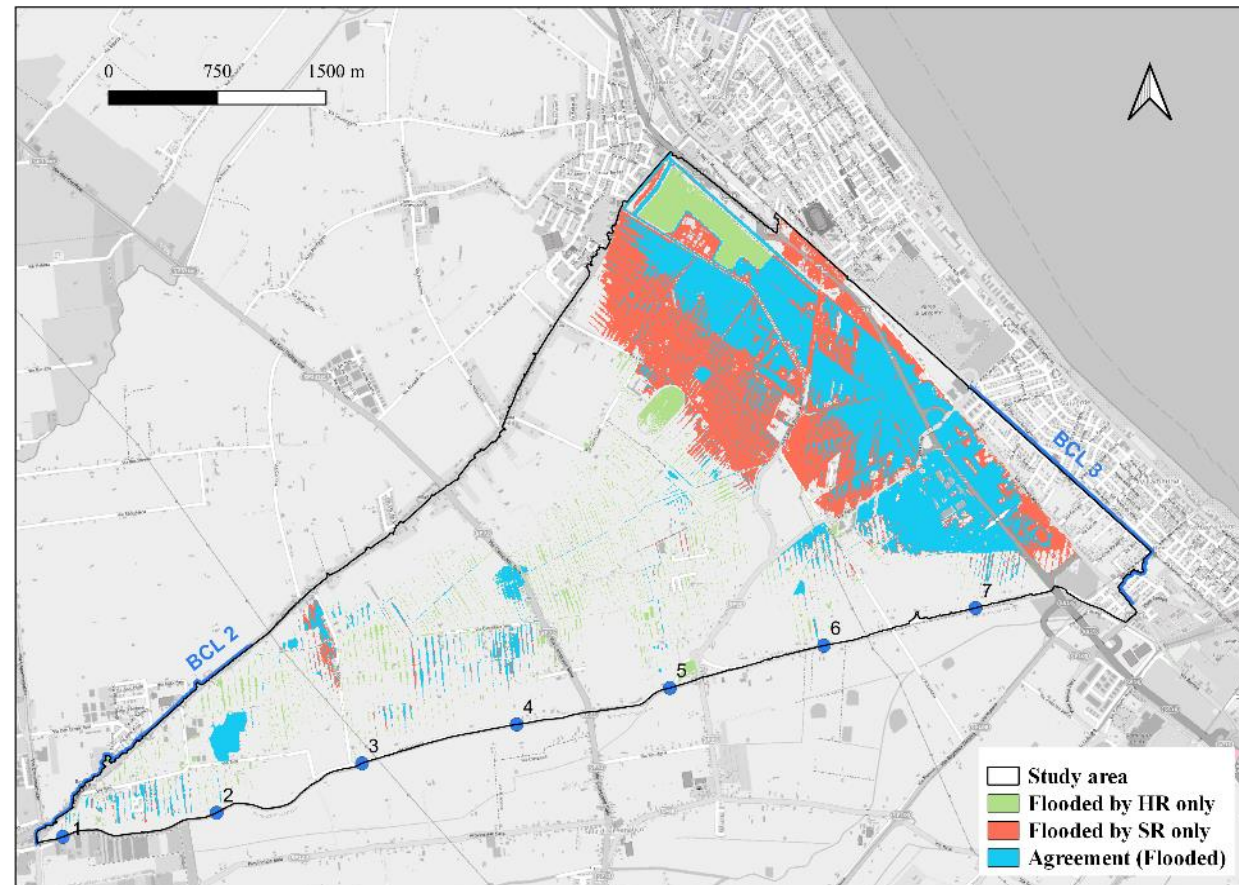
B: areas that are **flooded in HEC-RAS only**

C: areas that are **flooded in Safer_RAIN only**

Comparison in terms of maximum water depth



Comparison in terms of final water depth



Comparison: HEC-RAS vs Safer_RAIN

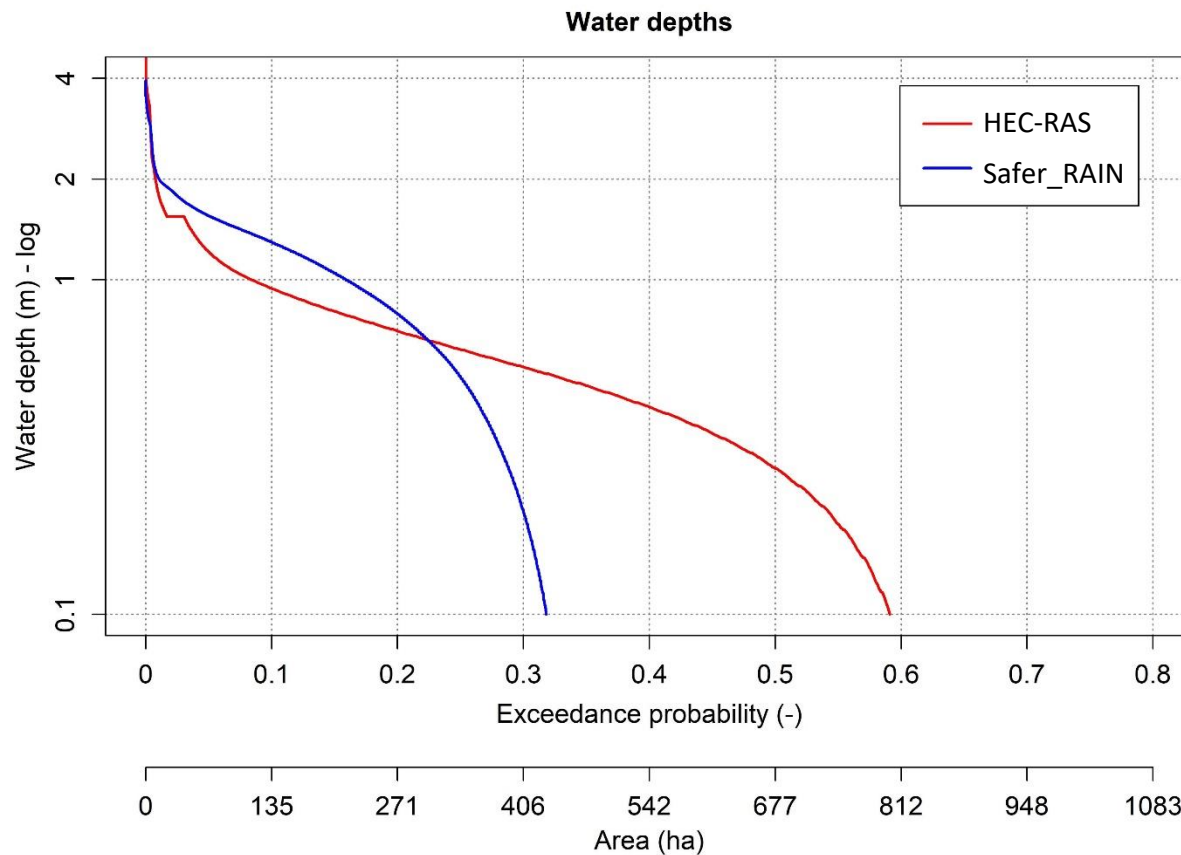
Flood Area Index (FAI)

Comparison	FAI	FAI
	Max water depth	End water depth
HR_ZA1 vs HR_ZA5 (HR, 1m vs 5m grid resolution)	0.970	0.803
HR_ZA1 vs HR_ZB1 (HR, with vs without extruded buildings)	0.946	0.980
HR_67.4 vs HR_10 (HR, inflow a vs inflow b)	0.540	0.873
HR_67.4 vs HR_5 (HR, inflow a vs inflow c)	0.431	0.698
SR_1 vs HR_1 (SR vs HR, simulated with 1 breach)	0.147	0.318
SR_7 vs HR_7 (SR vs HR, simulated with 7 breaches)	0.367	0.480

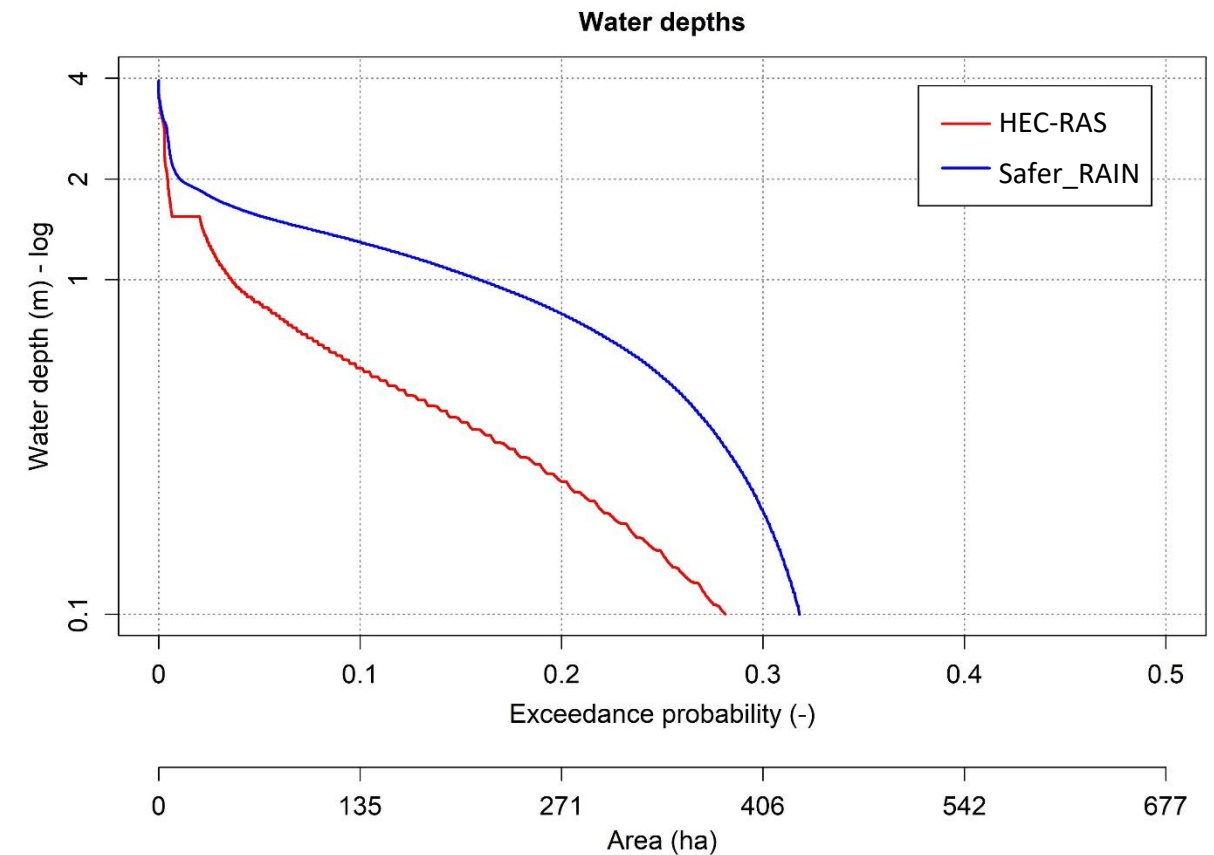
Comparison: HEC-RAS vs Safer_RAIN

Water-depth distribution 7 breaches scenario

Maximum water depth



Final water depth

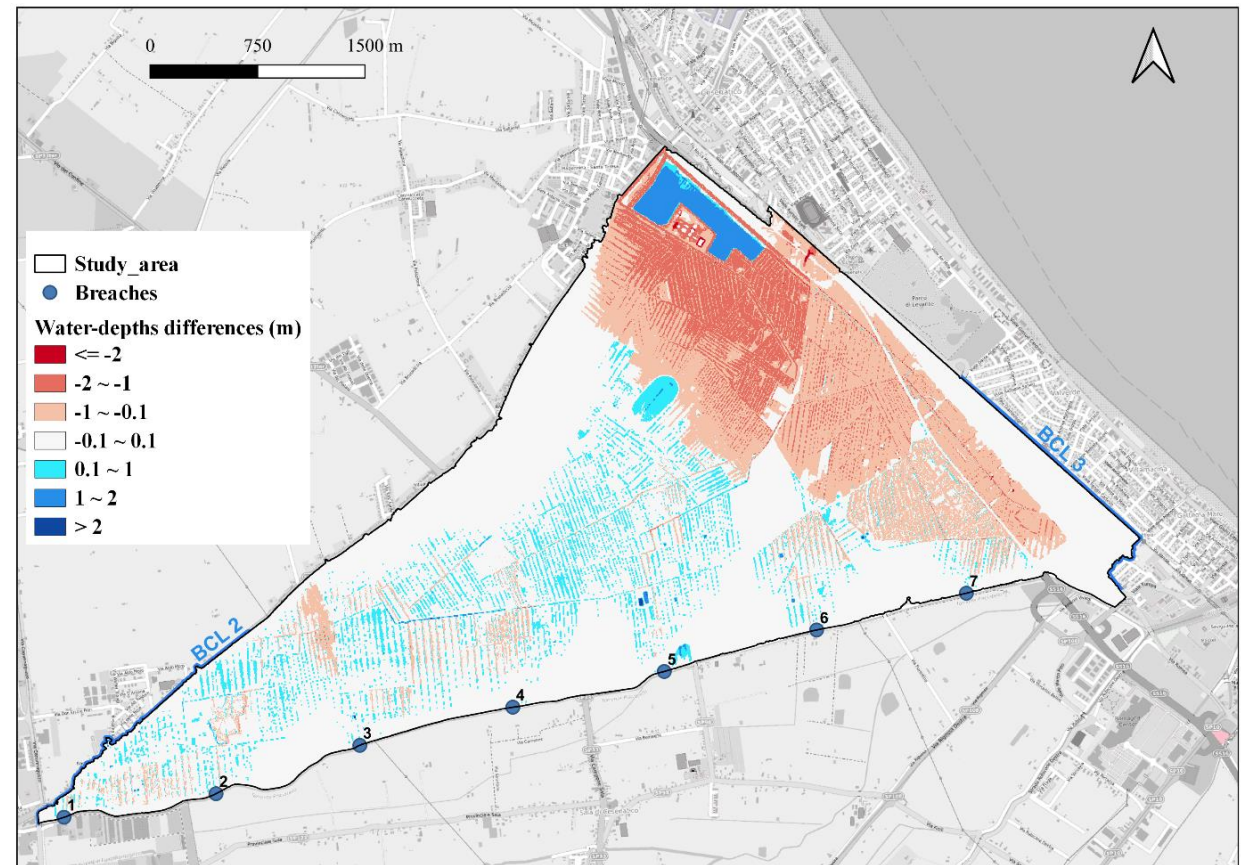
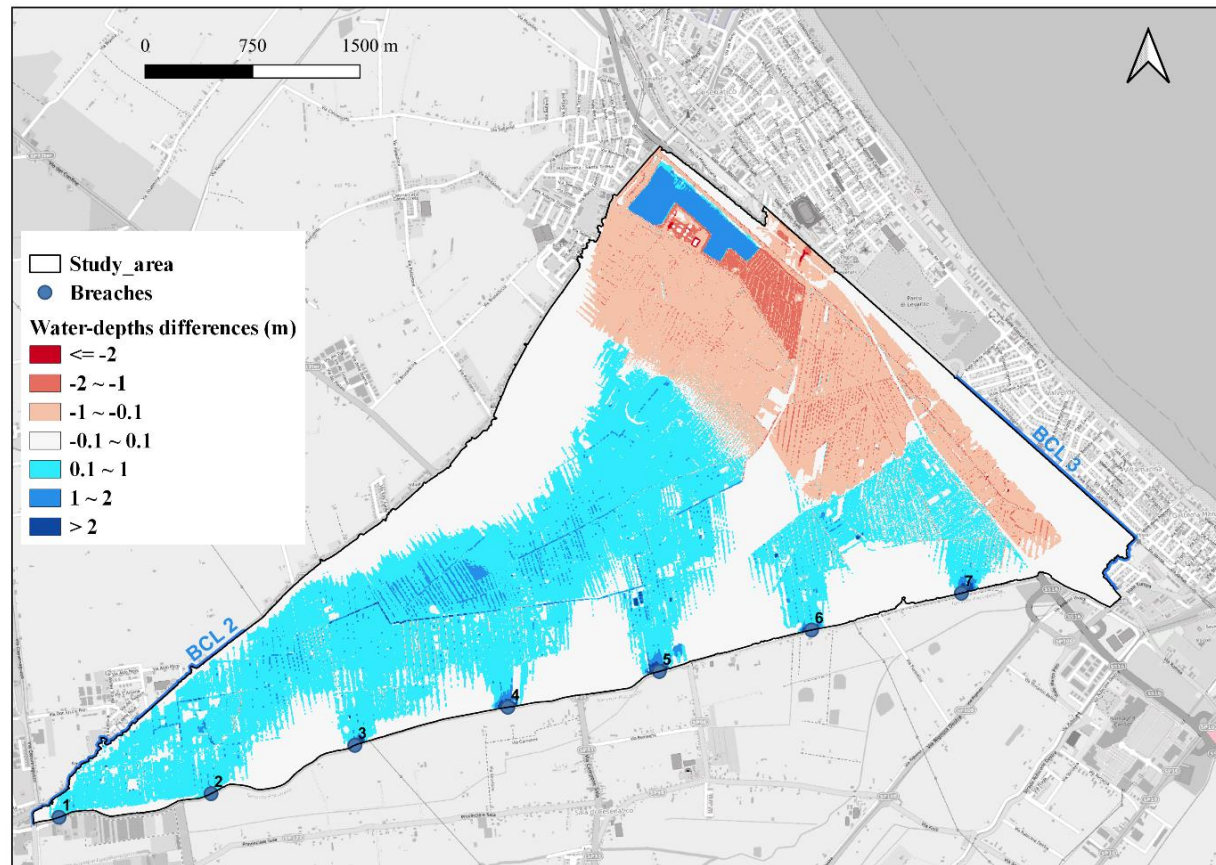


Comparison: HEC-RAS vs Safer_RAIN

Water-depth differences
(HEC-RAS – Safer_RAIN)
7 breaches scenario

Maximum water depth

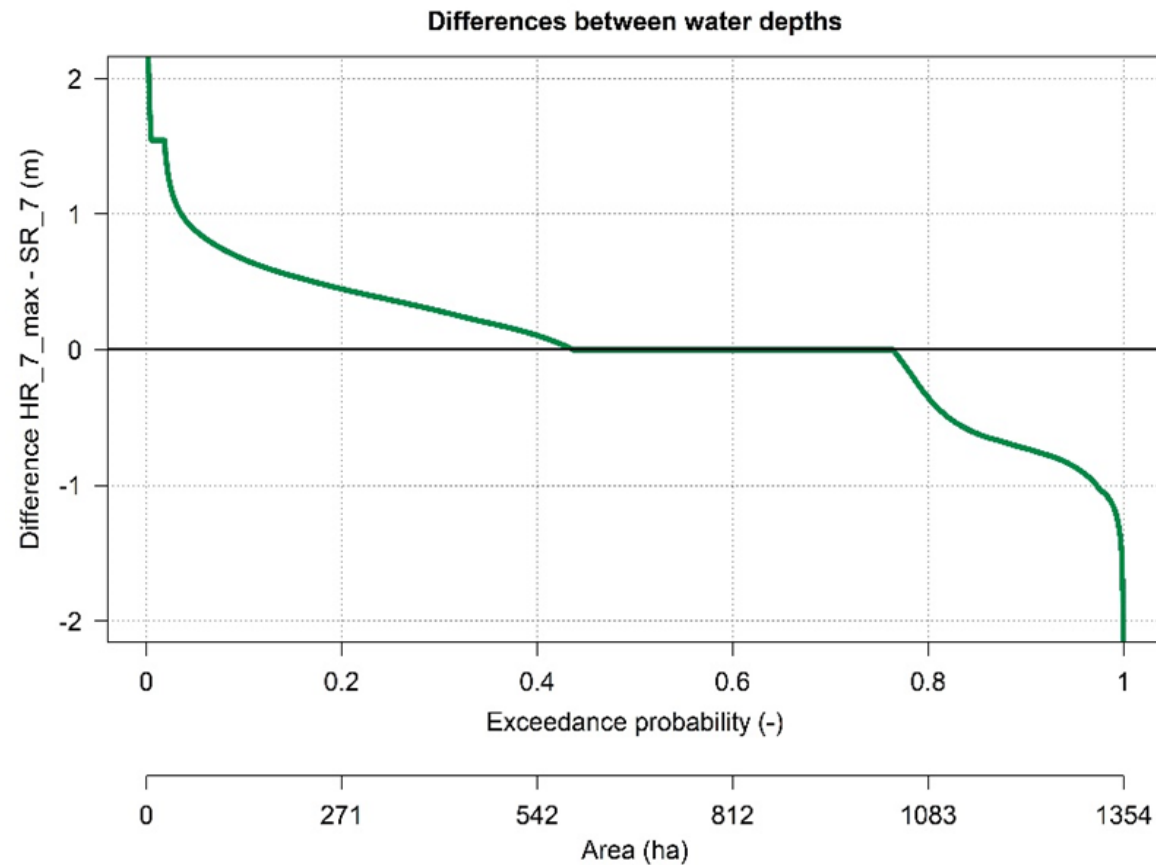
Final water depth



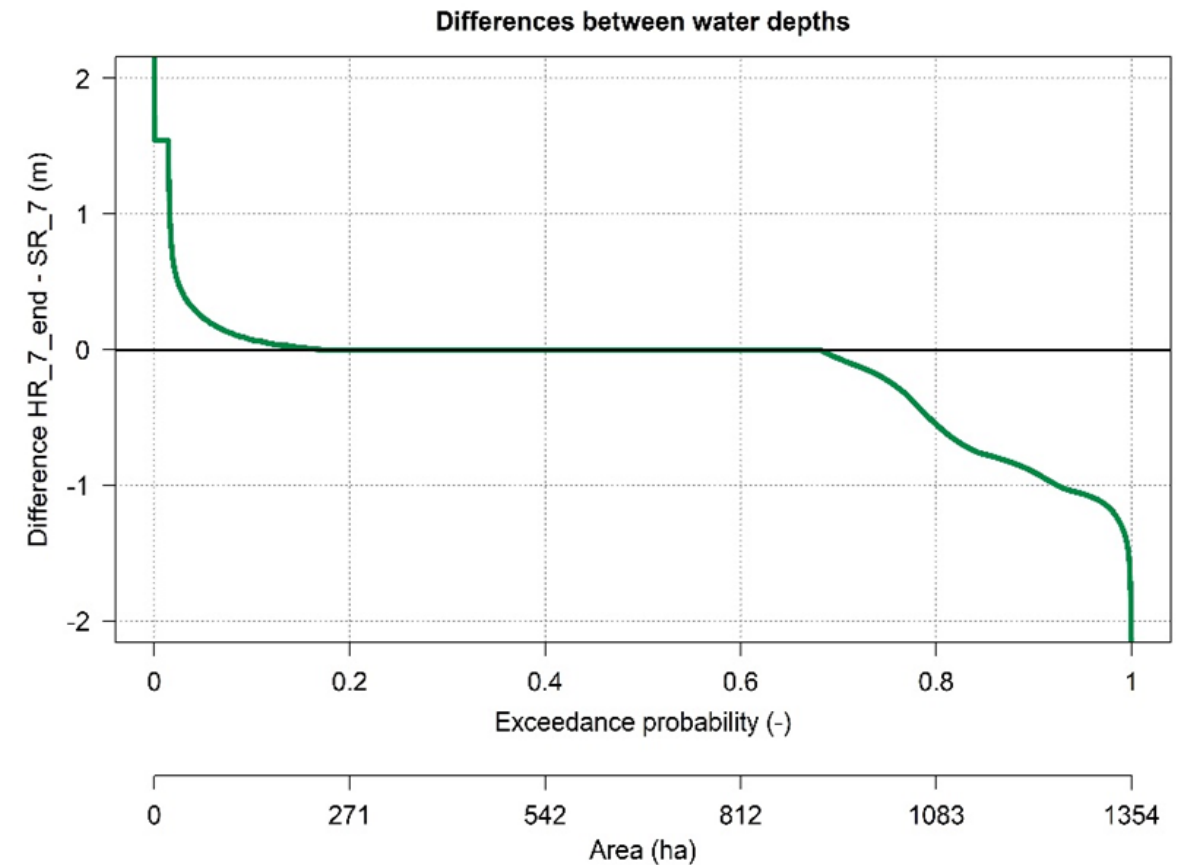
Comparison: HEC-RAS vs Safer_RAIN

Water-depth differences
(HEC-RAS – Safer_RAIN)
7 breaches scenario

Maximum water depth



Final water depth



Conclusions

	Safer_RAIN	HEC-RAS
Findings	▪ Less resource-intensive ▪ Fast-processing (in seconds) ▪ Viable for simulating fluvial flooding over large area at high resolution (1 m)	▪ Massive computational settings ▪ High computational costs (in hours) ▪ Not viable for large area at high resolution (5 m) ▪ DEM with extruded buildings generates more realistic result
Future work	▪ Perform fluvial flooding simulations with Safer_RAIN for other case studies and scenarios ▪ Consider more than a single drainage direction ▪ Reproduce real fluvial flooding event	▪ Implement simulation without outlet boundary condition lines, so that no water flow can leave the domain



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**THANK YOU
FOR YOUR ATTENTION**

Simone Persiano – simone.persiano@unibo.it

Attilio Castellarin – attilio.castellarin@unibo.it

DICAM – University of Bologna

www.unibo.it

Safer_RAIN

Samela et al. (2020)

Hierarchical Filling-&-Spilling (HFS) developed within the **SaferPLACES project** for assessing pluvial flooding hazard (flooded areas and water depths) accounting for spatially-distributed rainfall inputs and infiltration processes.

Main assumptions

1. Dynamics is neglected: rainfall water volume flows downstream instantaneously
2. Water flows according to the D8 method

INPUTS

High-resolution DEM



Rainfall depth



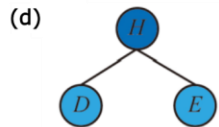
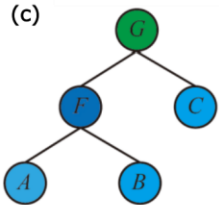
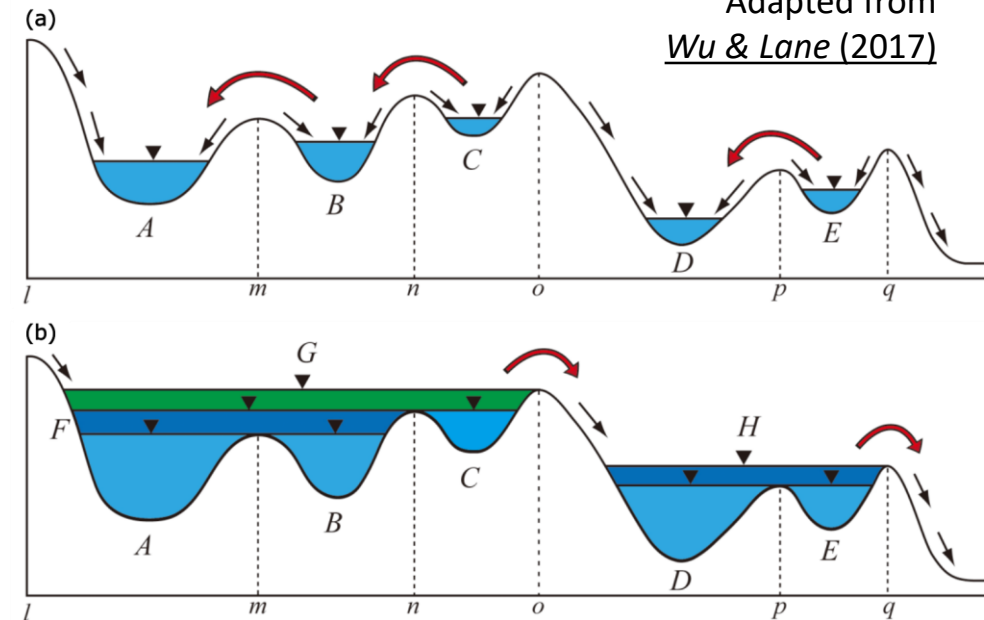
1. DEM PRE-PROCESSING

- 1) Definition of **horizontal hydrological hierarchy**: identification of blue-spots (first-level depressions, **G** and **H**) through **DEM pit-filling**, and corresponding pour-point and contributing watersheds;
- 2) Definition of **vertical hierarchical structure within each blue-spot**, the higher-level depressions (**A**, **B**, **C**, **D**, **E**, and **F**), their hierarchical relationship and water-level / volume relationship through **Top-down level-set method**, Wu et al., 2018)

2. FLOODING PHASE

- 3) Identification of **flooded areas for a given rainfall volume**, partial filling is addressed through a **Bottom-up level-set method**

Adapted from
Wu & Lane (2017)



Continue exploring...

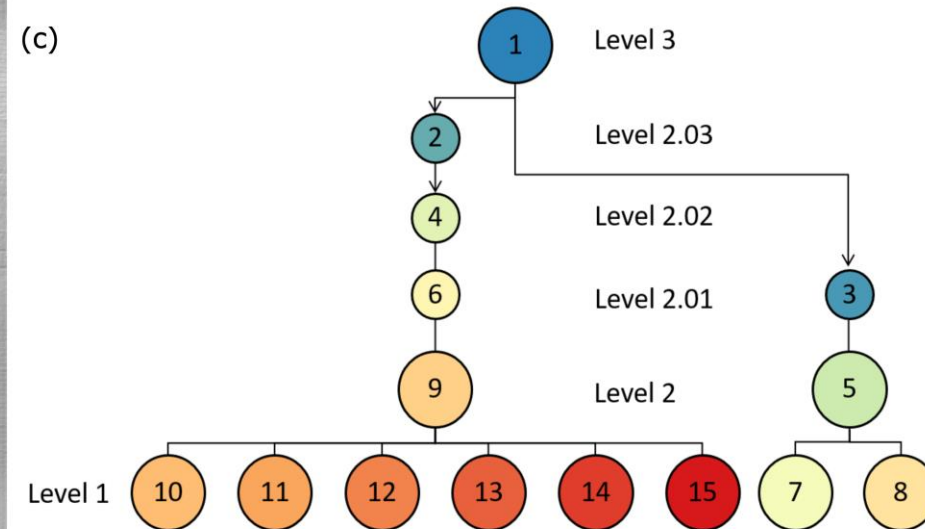
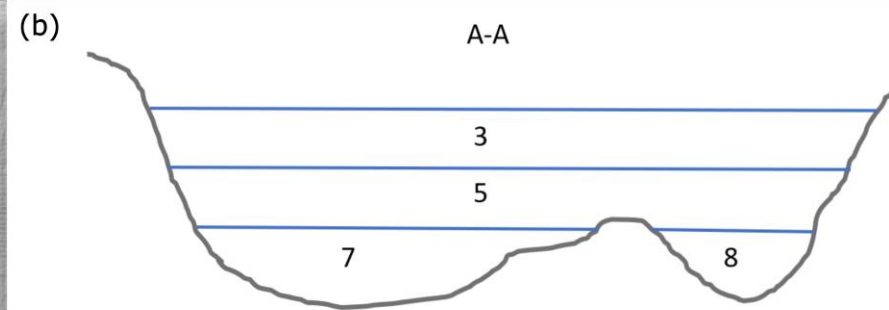
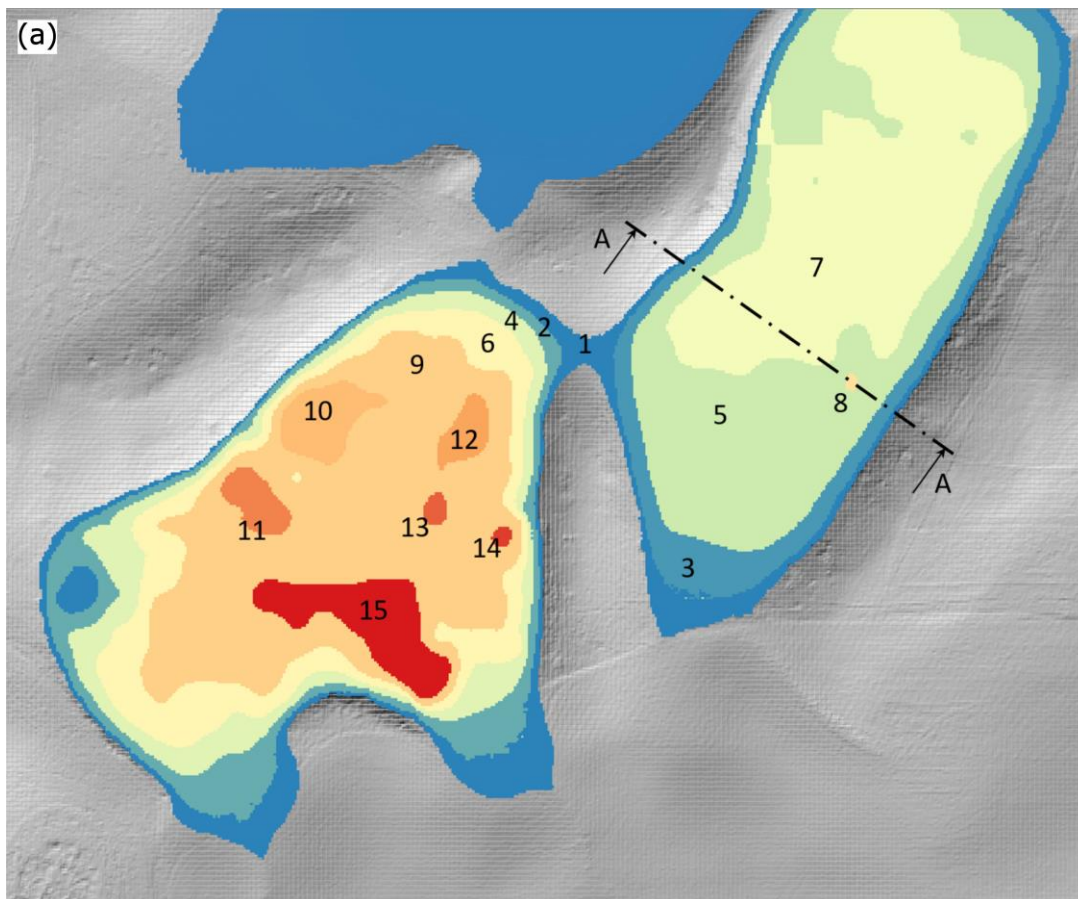
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Safer_RAIN

Samela et al. (2020)

(1) DEM PRE-PROCESSING

Identification of depressions (blue-spots) and their vertical and horizontal structure



INPUT:

- **DEM (LiDAR)**
- **Height** of the level-set needed in the top-down preprocessing phase
- **Threshold** for blue-spots (minimum volume, or area, or maximum depth)

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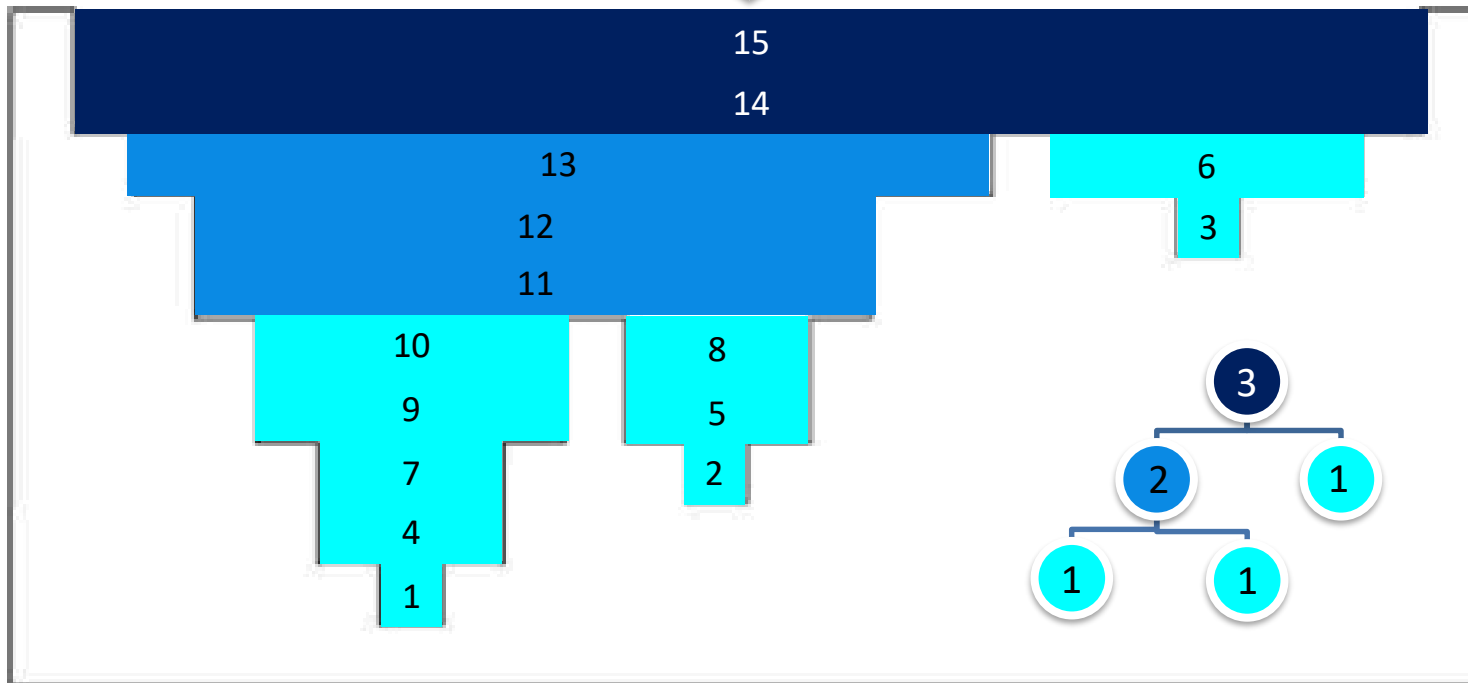
Safer_RAIN

Samela et al. (2020)

(2) FLOODING

INPUT:
Rainfall depth
(or volume)

Rainfall
volume



BOTTOM-UP LEVEL-SET METHOD

Bottom-up level-set method is used for quantifying **partial filling** in nested higher-level depressions:

1. it starts from an **empty condition** (the blue-spot A is empty)
2. according to their vertical hierarchy, **nested depressions are gradually filled** through a bottom-up level-set method
3. gradual filling is performed step-by-step, **rotating depressions** with same hierarchical order

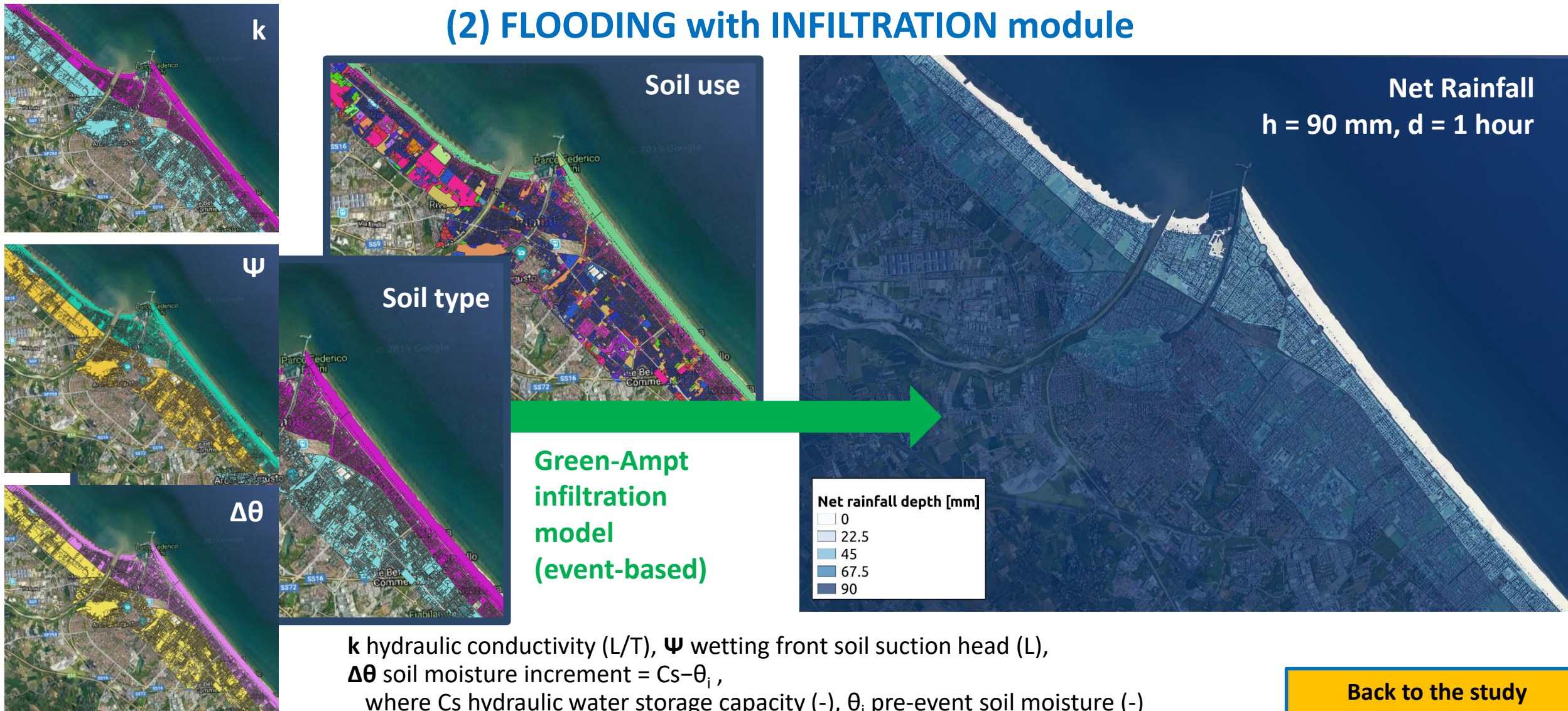
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(2) FLOODING with INFILTRATION module



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