

Flood-prone areas delineation in coastal regions using the Geomorphic Flood Index

**Cinzia Albertini^{1,2}, Domenico Miglino², Vito Iacobellis³,
Francesco De Paola², and Salvatore Manfreda²**

¹ Dipartimento di Scienze Agro Ambientali e Territoriali, Università degli Studi di Bari, Bari, Italy

² Dipartimento di Ingegneria Civile, Edile e Ambientale, Università di Napoli Federico II, Napoli, Italy

³ Dipartimento di Ingegneria Civile, Ambientale, del Territorio, Edile e di Chimica, Politecnico di Bari, Bari, Italy

Email: cinzia.albertini@uniba.it

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INTRODUCTION

- Assessing flood risk in coastal zones is paramount due to the high population density and geomorphic features (smooth hills, flat-floor valleys) that characterize these areas.
- Coastal regions are characterized by a sequence of basins draining to the sea, frequently separated by small inter-basins whose flood hazard is controlled by the larger neighbouring ones. Therefore, inter-basin floodwater transfers can take place, exacerbating flood risk.

Need for properly delineating coastal areas exposed to flood inundation to reduce flood damages and prevent human and economic losses.

STATE OF THE ART

- Methodologies for flood hazard assessment and flood-prone areas delineation include hydrologic and hydraulic models and tools based on Digital Elevation Models (DEMs) and terrain morphology.
- Among recently developed DEM-based procedures, the Geomorphic Flood Index (GFI) method has been proved to be the most reliable in terms of flood hazard mapping and suitable for large-scale analyses in data-scarce regions [1-3].

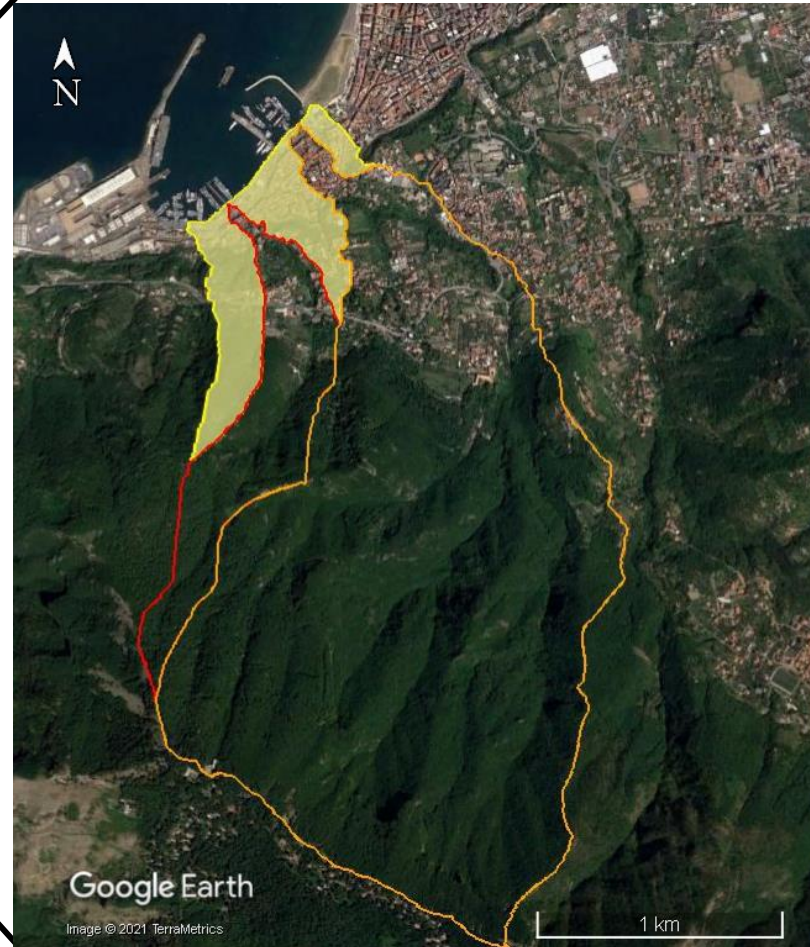
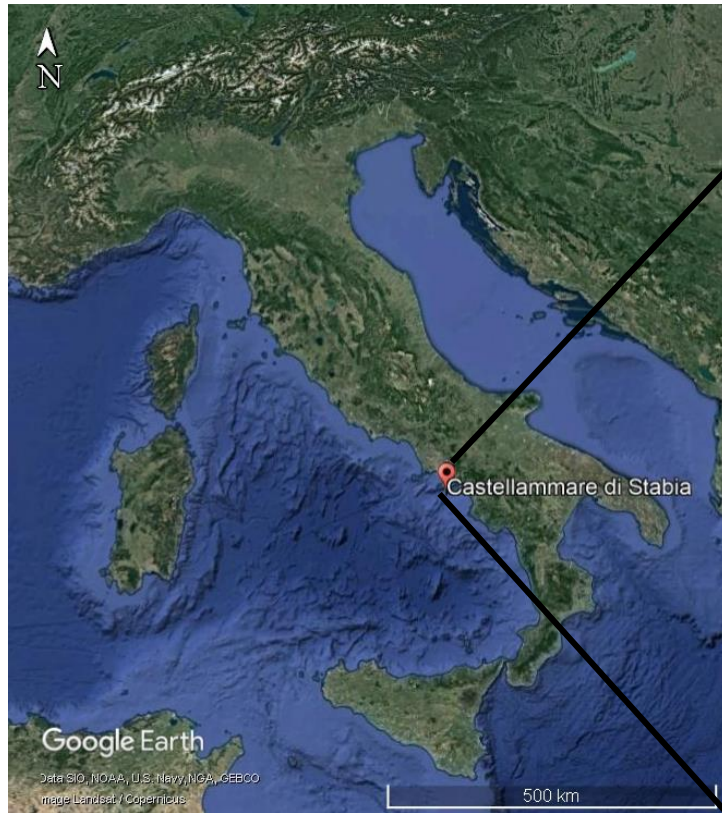
MOTIVATION

- The GFI strongly depends on the correct extraction of the river network and on the elevation difference to the nearest channel.
«The flat area issue» [4,5] refers to the difficulty in the identification of flow directions using DEMs, due to zero-slope areas, as it occurs in coastal zones.
- The GFI is usually computed at the basin scale and watershed boundaries represent a barrier for water transfers even if differences in elevation and slope between neighbouring basins allow it. Therefore, the GFI is not defined in the inter-basins, hereinafter called Undefined Inter-Basins (UIBs).

OBJECTIVES

- To propose a modified version of the GFI method based on an iteration procedure, in order to map flood-prone areas in the UIBs considering floodwater transfers between neighbouring basins.
- To analyse the reliability of a threshold-based binary classification to map flooded areas.
- To assess the sensitivity of the method to flood events with different return period.

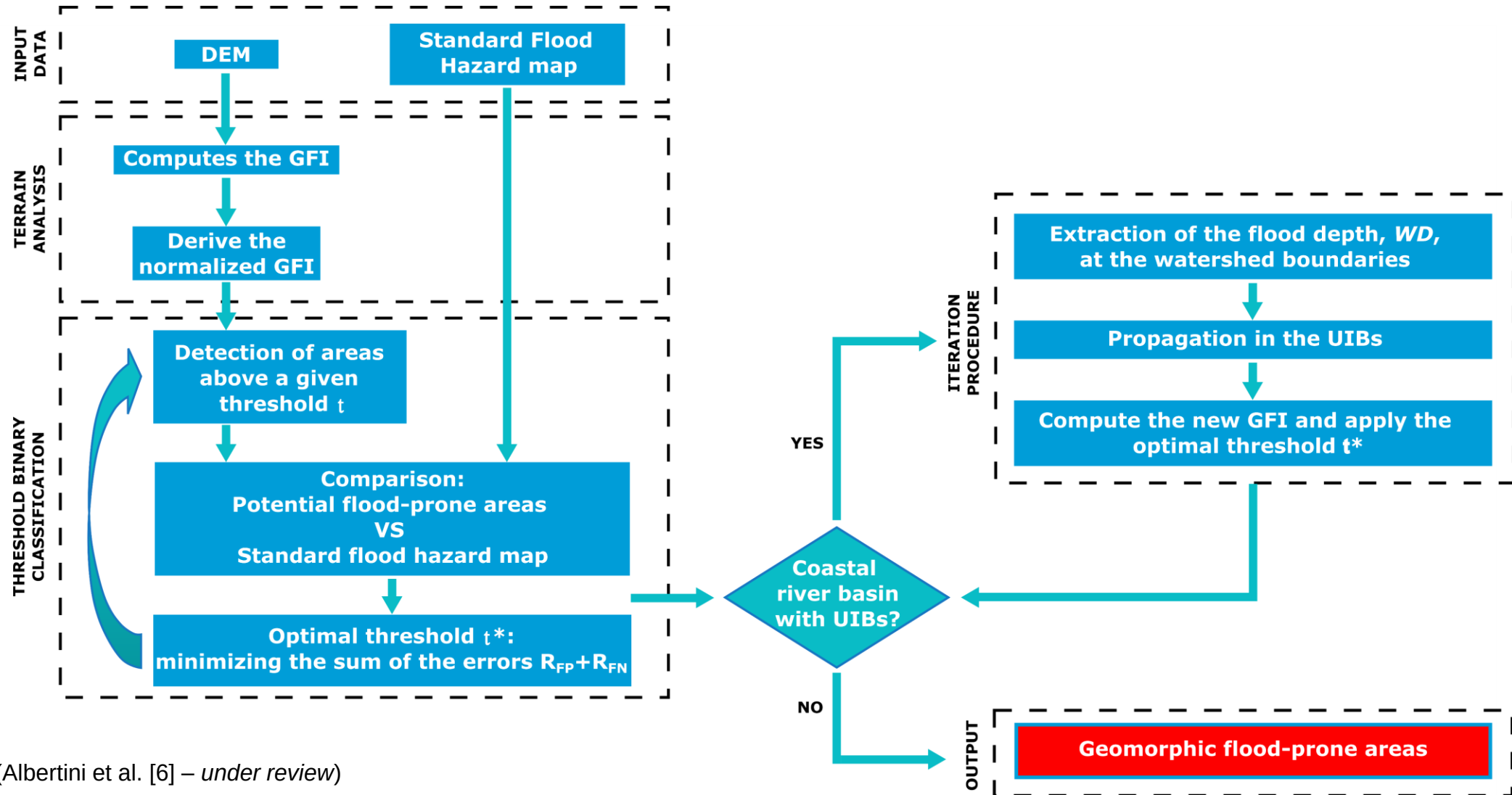
LOCATION OF THE CASE STUDIES: Castellammare di Stabia, Naples, Italy

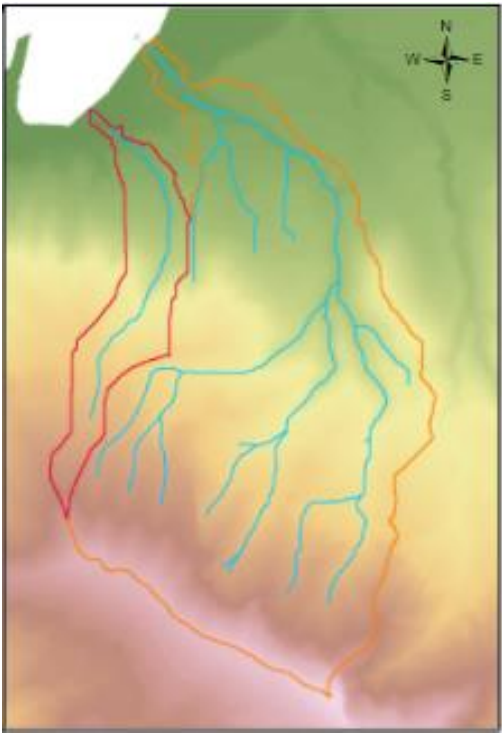


-  **San Pietro Creek basin**
Training area
-  **Cognuolo Creek basin**
Validation area
-  **UIBs**

(Map source: Google, SIO, NCAA, U.S. Navy, NGA, GEBCO, Landsat)

METHODOLOGICAL WORKFLOW





0 0.1 0.2 0.4 0.6 0.8 Km

DEM (m a. s. l.)

Value

High : 1276
Low : 0

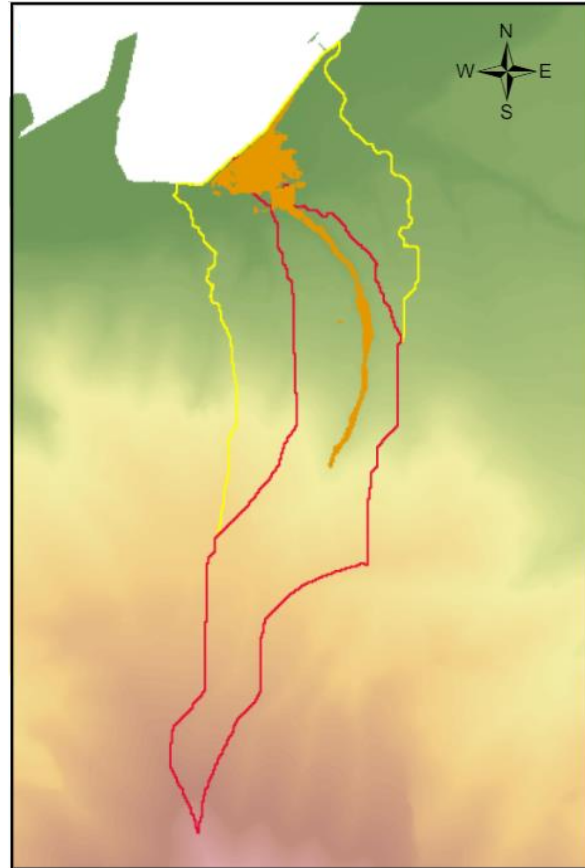
Cognuolo Creek basin



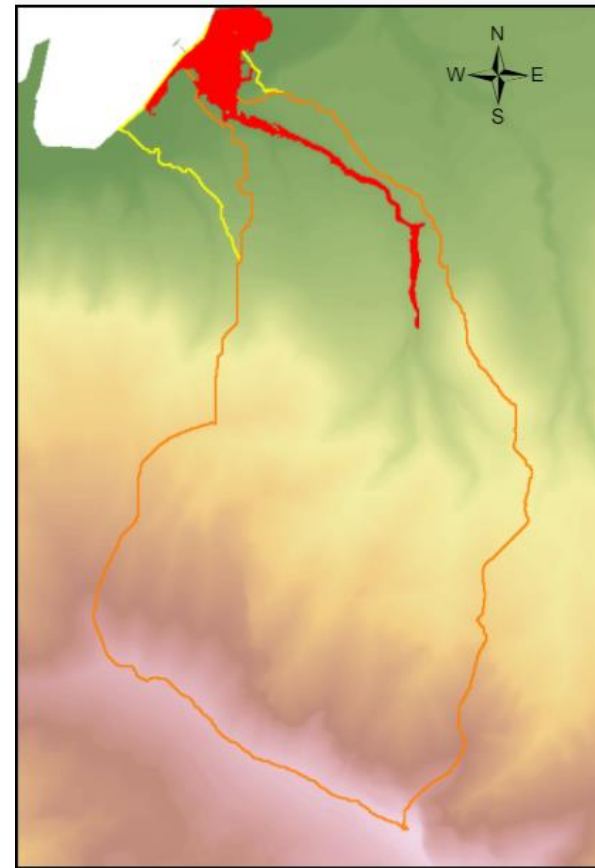
Hydraulic flood hazard map



(T=300 yr)



0 0.1 0.2 0.4 0.6 0.8 Km



0 0.1 0.2 0.4 0.6 0.8 Km

San Pietro Creek basin
Hydraulic flood hazard map
(T=300 yr)

INPUT DATA

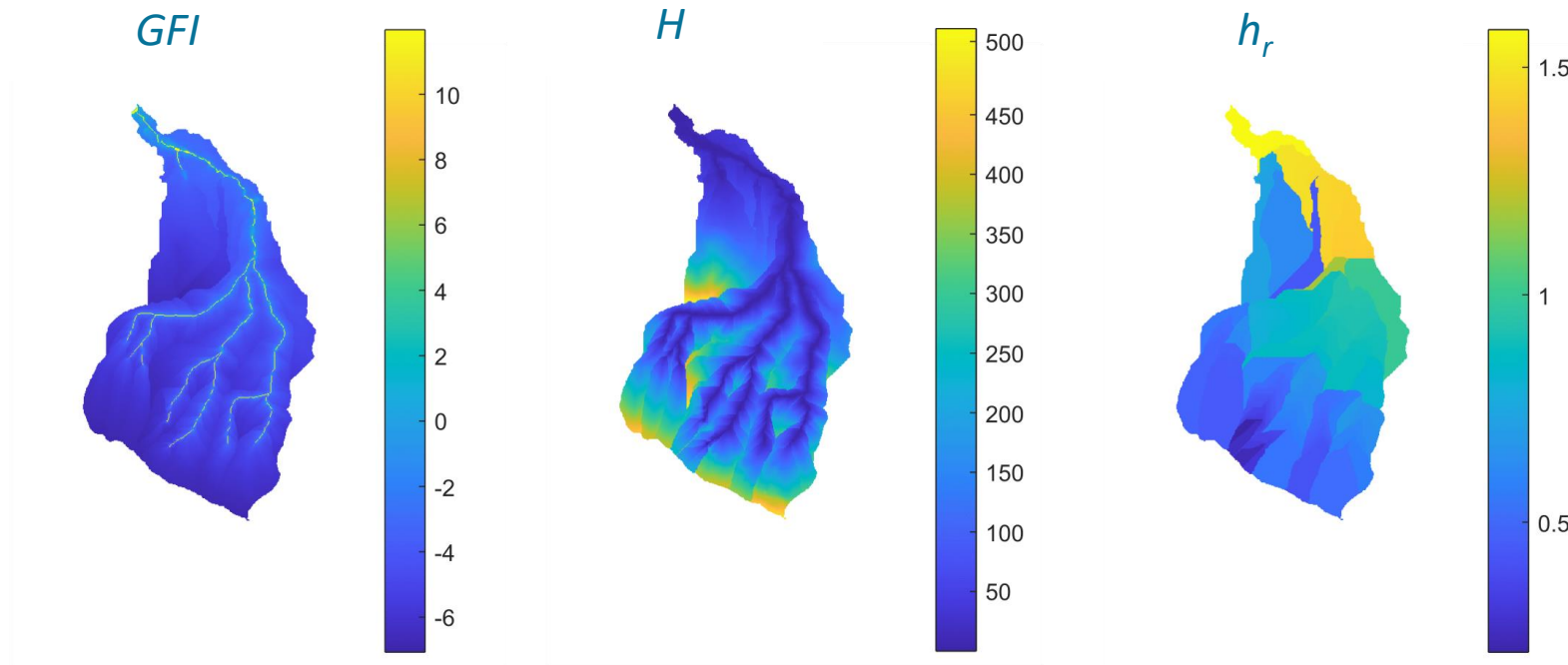
1) DEM

2) Standard flood hazard maps for the training and validation case studies, obtained from 2-D hydraulic simulations.

THE GEOMORPHIC FLOOD INDEX

$$GFI = \ln \left(\frac{h_r}{H} \right) \quad (1)$$

- h_r is the water level in the nearest element of the river network identified following the hydrological paths;
- H is the elevation difference between the two points.



THRESHOLD BINARY CLASSIFICATION

- 1) Normalization of GFI values between -1 and +1.
- 2) Binary map of potential flood prone areas applying a threshold value, τ , as described in [2].
- 3) Calibration of the optimal τ that minimises the sum of the false positive rate (R_{FP}) and the false negative rate (R_{FN}) by comparing the GFI-derived binary map with the standard flood hazard map:

$$\tau_{\text{OPTIM}} = R_{FP} + R_{FN} \quad (2)$$

Performances were evaluated drawing the Receiver Operating Characteristics (ROC) curves and measuring the Area Under the Curve (AUC) [7]. The true positive rate (R_{TP}) and true negative rate (R_{TN}) were also chosen as validation statistics.

THE ITERATION PROCEDURE

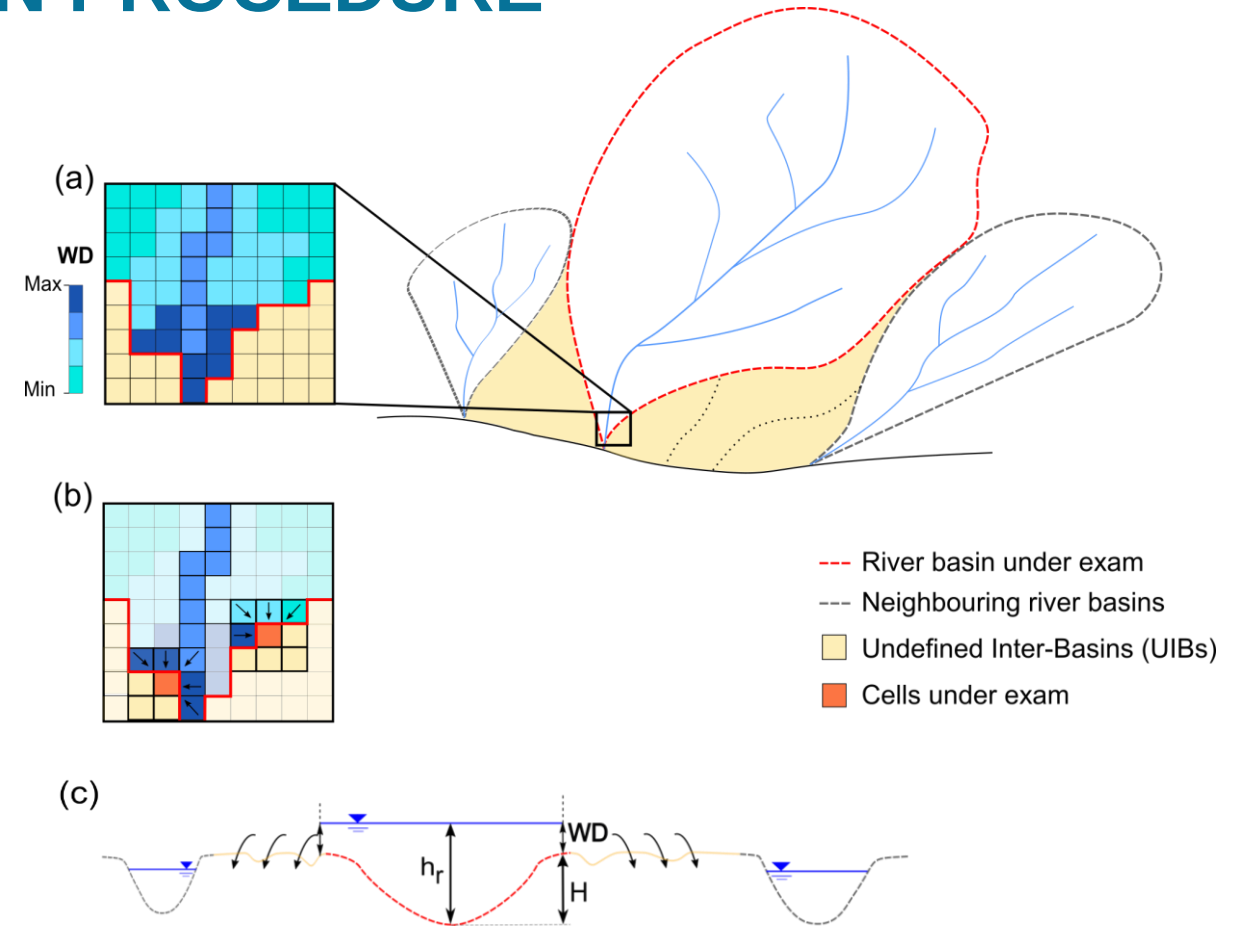
- 1) Extraction of the flood depth, WD , at the watershed boundaries according to [8]:

$$WD = h_r - H \quad (3)$$

- 2) Calculation of a new contributing area:

$$A_r = (WD \cdot e^\tau)^{\frac{1}{n}} \quad (4)$$

- 3) Propagation of A_r according to flow directions.
- 4) Iteration until UIBs areas reduce.



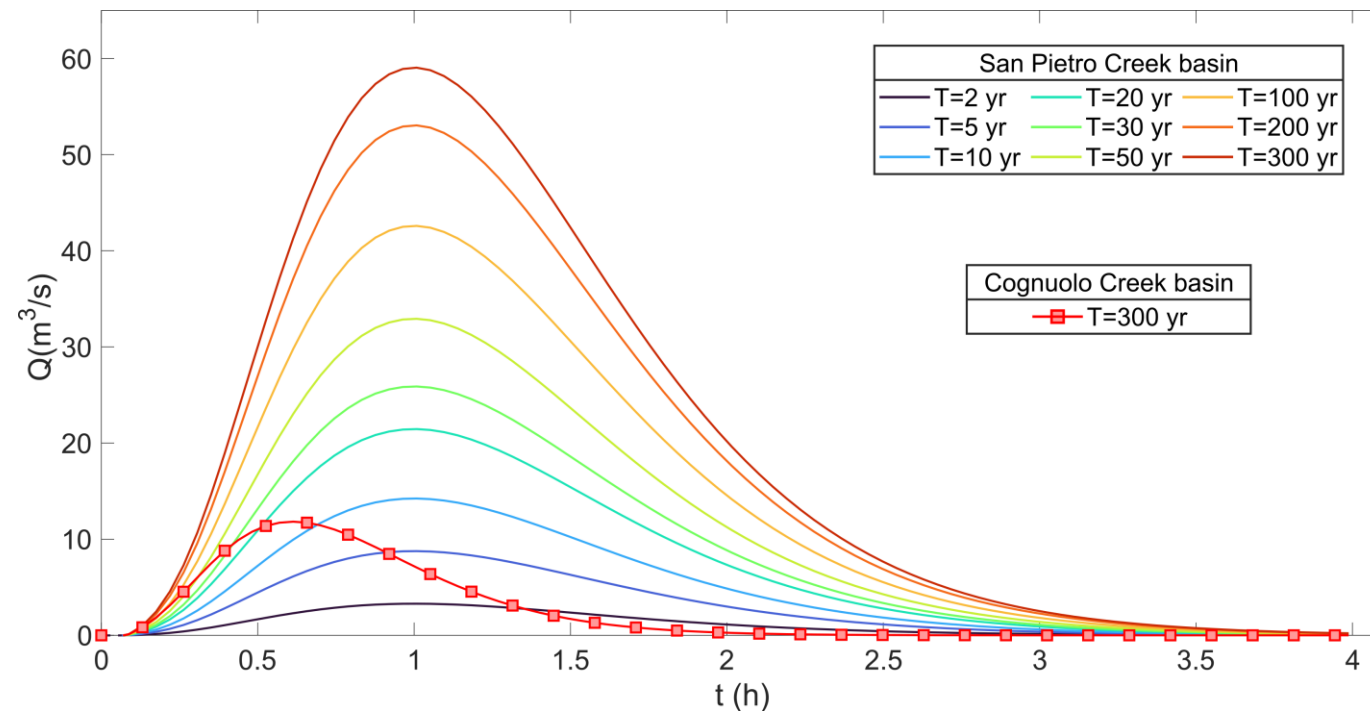
(Albertini et al. [6] – *under review*)

After the new contributing area is assigned, the final GFI is computed and the threshold binary classification is applied.

HYDRAULIC MODELS

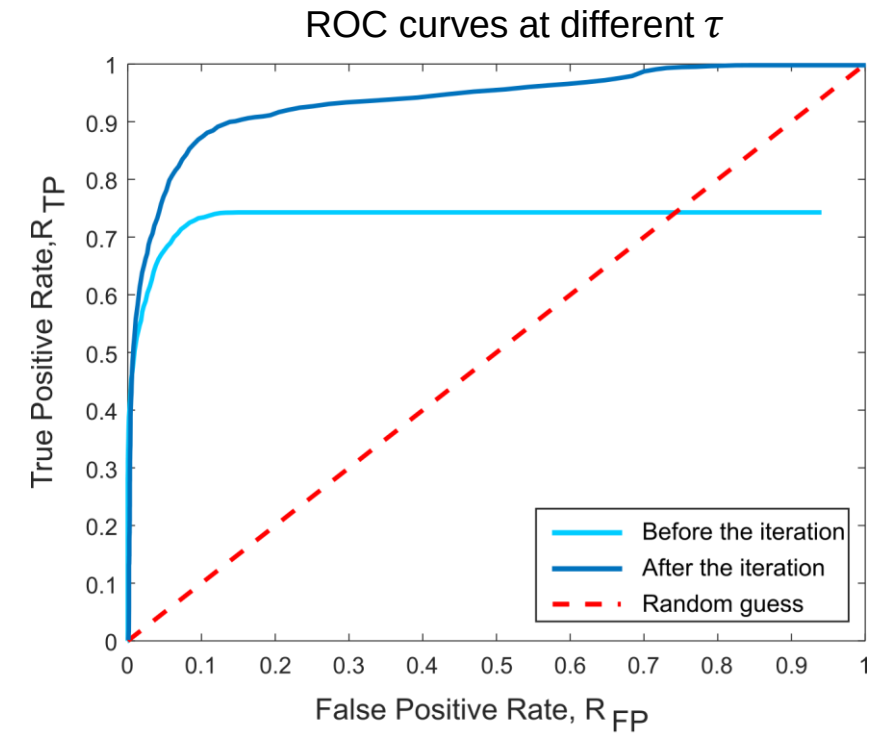
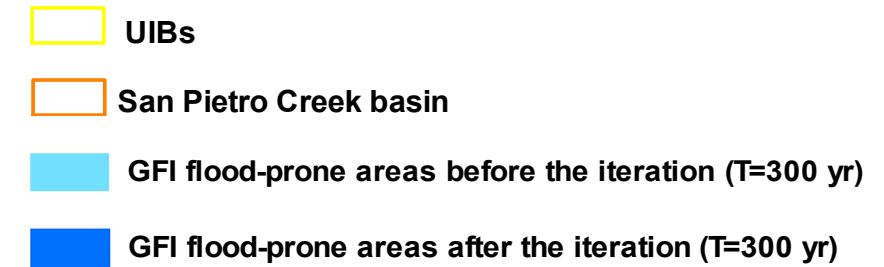
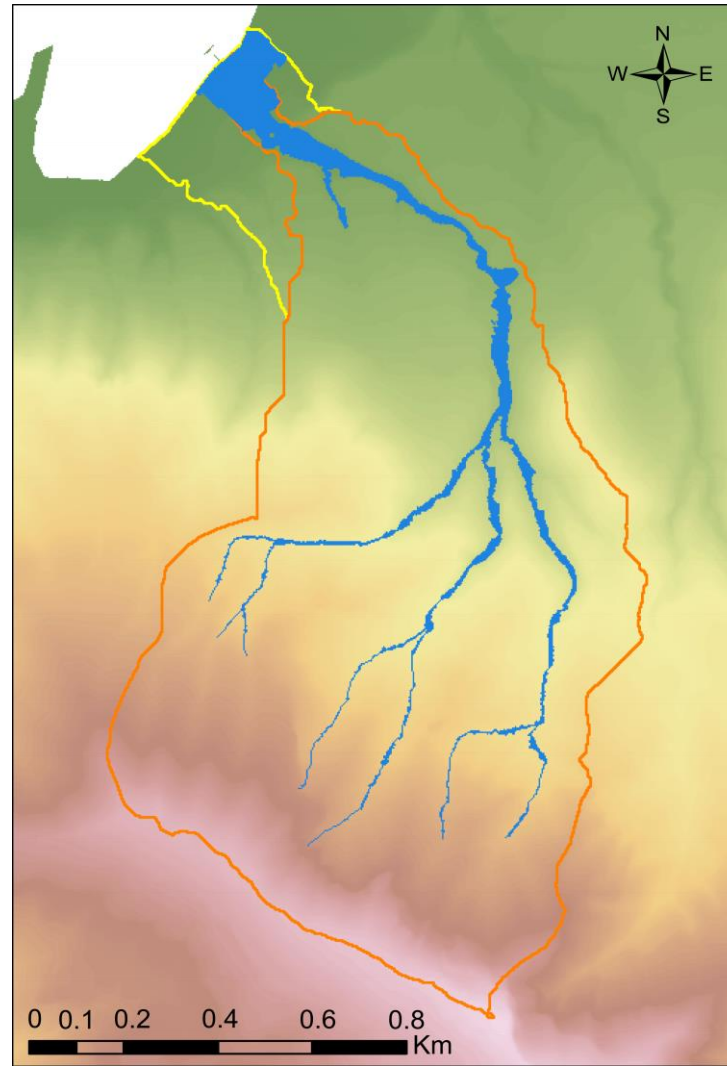
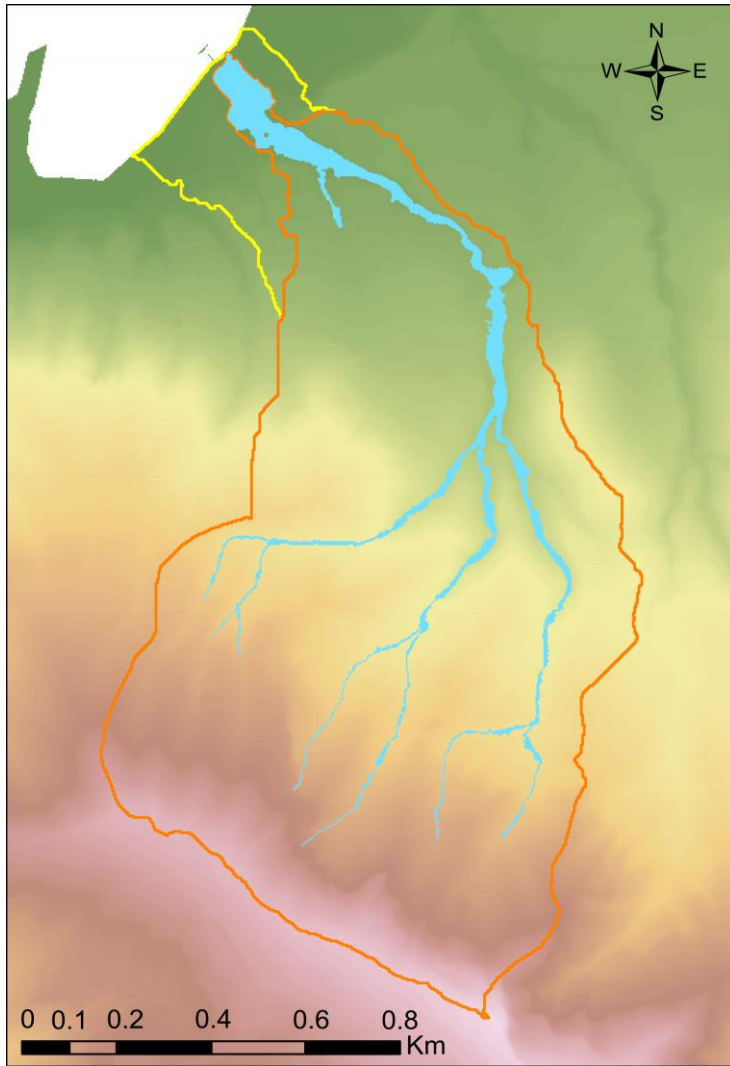
2-D hydraulic simulations were carried out to derive the standard flood hazard maps for the San Pietro and Cogneolo Creek basins.

Hydraulic maps for flood events with different return periods were also derived to carry out the sensitivity analysis of the method to the return period in the San Pietro Creek basin.

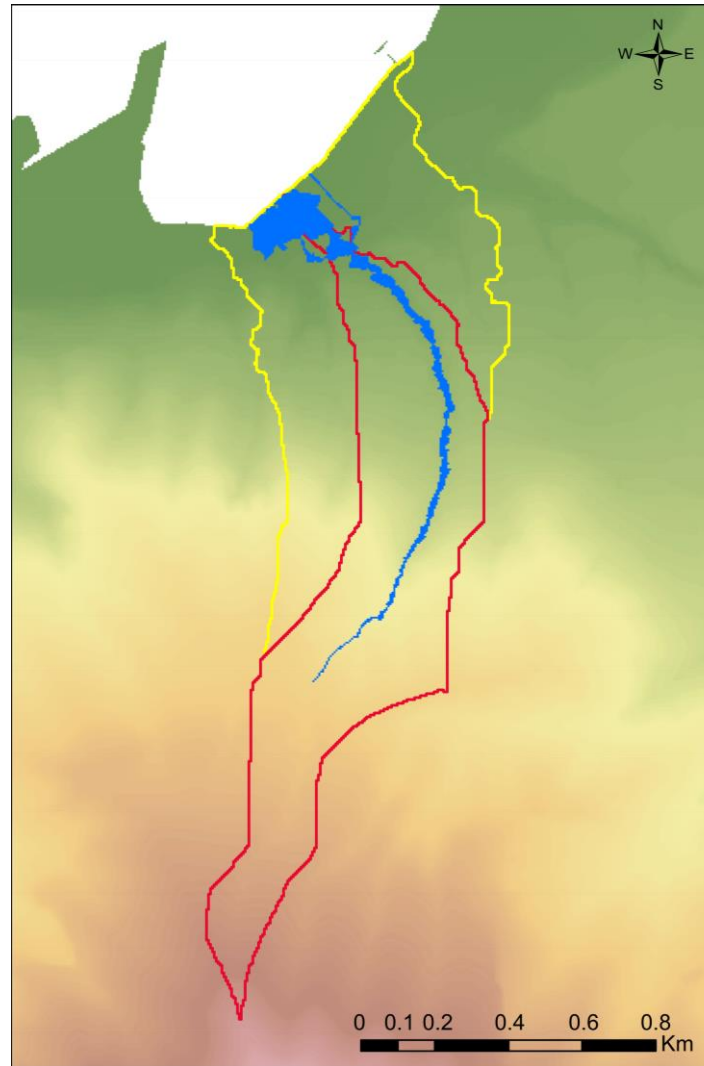
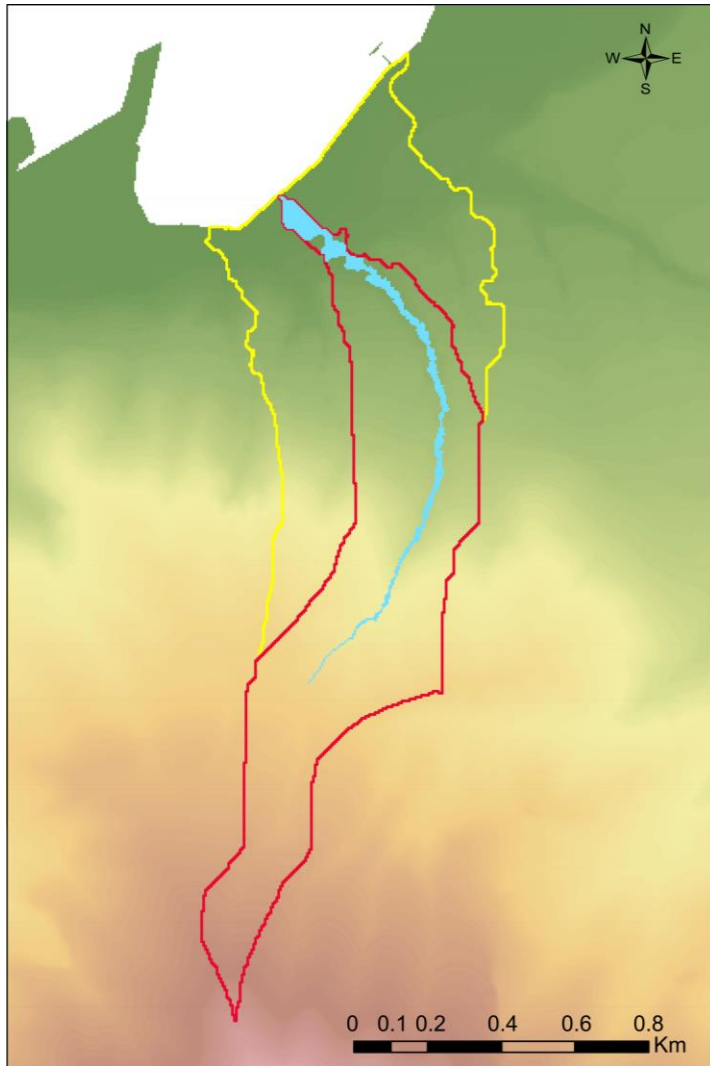


Input hydrographs

RESULTS: Training area



RESULTS: Validation area



- UIBs
- Cognuolo Creek basin
- GFI flood-prone areas before the iteration (T=300 yr)
- GFI flood-prone areas after the iteration (T=300 yr)

In this case, no calibration was performed to obtain the optimal threshold, τ , instead the same parameter calibrated for the San Pietro Creek basin was applied to discriminate between flooded and non-flooded areas.

PERFORMANCE METRICS

Table 1. Performances of the threshold binary classification implemented in the San Pietro Creek basin case study.

	τ	R_{FP}	R_{TP}	$R_{FP} + R_{FN}$	AUC
Before the iteration	-0.470	0.072	0.714	0.359	0.741
After the iteration	-0.470	0.095	0.868	0.227	0.936

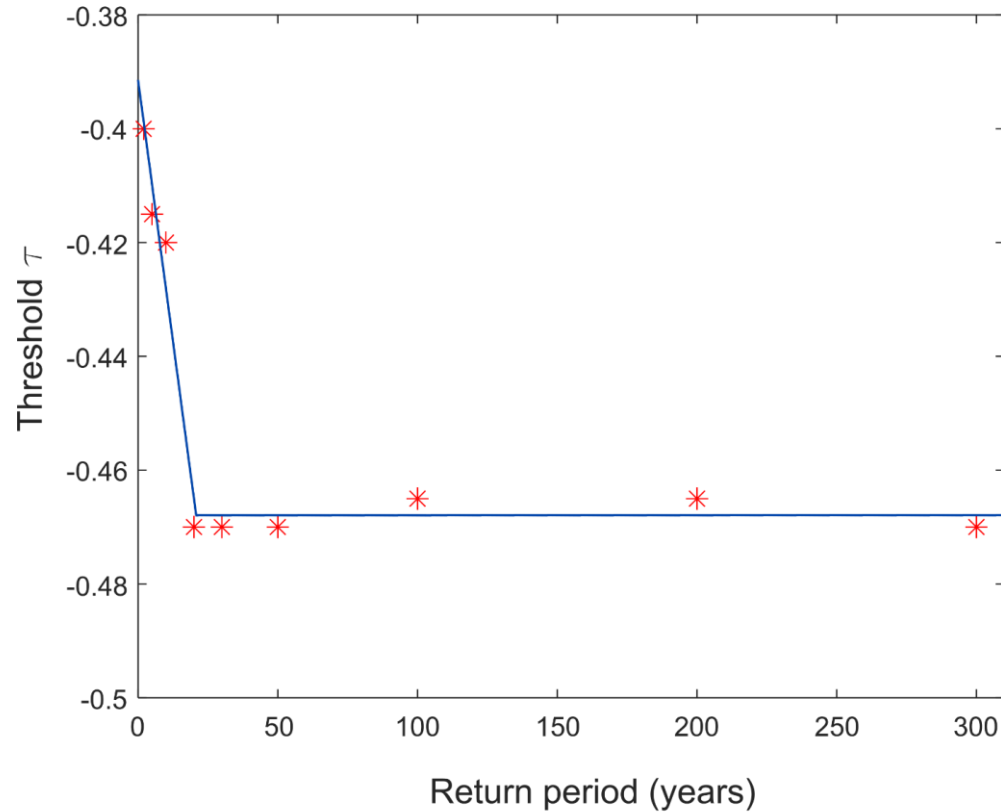
Table 2. Performance obtained in the validation process over the Cognuolo Creek basin.

	τ	R_{FP}	R_{TP}	R_{FN}	R_{TN}
Before the iteration	-0.470	0.005	0.556	0.444	0.995
After the iteration	-0.470	0.019	0.786	0.214	0.981

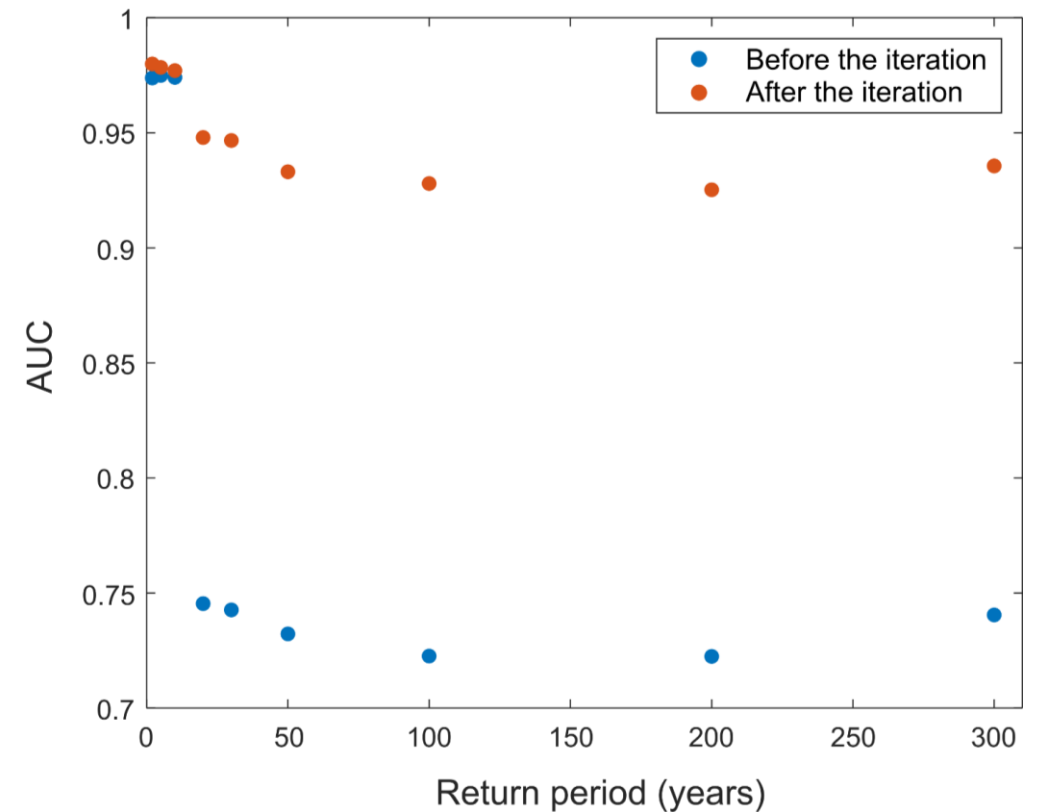
RESULTS: Sensitivity to the return period

$T = 2, 5, 10, 20, 30, 50, 100, 200, 300$ years

Distribution of the optimal threshold τ



Variation of the Area Under the Curve



CONCLUSIONS: Flood-prone areas mapping in the UIBs

The iteration procedure coupled with the GFI method showed that:

- By modifying the map of contributing areas, **it is possible to extend flood mapping in the UIBs through the GFI method with good performances** (AUC value equal to 93% against a value of 74% obtained with the traditional GFI method).
- The threshold binary classification performed before and after the iteration procedure led to the same optimal calibrated threshold, proving that **τ is a consistent and reliable parameter in predicting flood-susceptible areas**. The fact that it seems not to be influenced by the introduced iteration procedure suggests that it can be directly applied to the modified GFI without searching for a new optimal value.

CONCLUSIONS – Sensitivity analysis

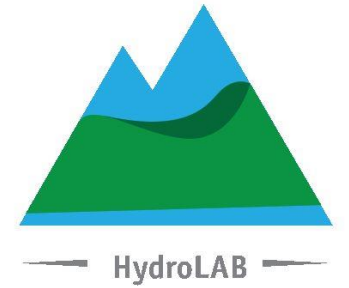
The sensitivity analysis against the return period showed that:

- The relationship between the threshold, τ , and the return period of floods is linear up to the return period of 20 years, underlining that **flood extent changes significantly in the range of lower return period**. After this level, the threshold seems to be independent of the return period of the flood event and relatively minor changes in the extent of flooded areas are observed.
- The proposed methodology helps in detecting flood-prone areas in flat-floor valleys, especially to predict flood extent of extreme events. In fact, the results proved that **a methodology able to capture water transfers between sub-basins for flood events with return period higher than 10 years is necessary**.

Acknowledgements

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<https://www.salvatoremanfreda.it/index.php/matcass/>



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