

Comparison of different infiltration methods for flood numerical analysis: modelling the 19 June 1996 extreme event of Cardoso (Alpi Apuane, Italy)

Michele Amaddii^{1,2}, Enrico D'Addario¹, Leonardo Disperati¹, Pier Lorenzo Fantozzi¹

¹ Department of Earth, Environmental and Physical Sciences, University of Siena, Via Laterina 8, 53100 Siena, Italy;

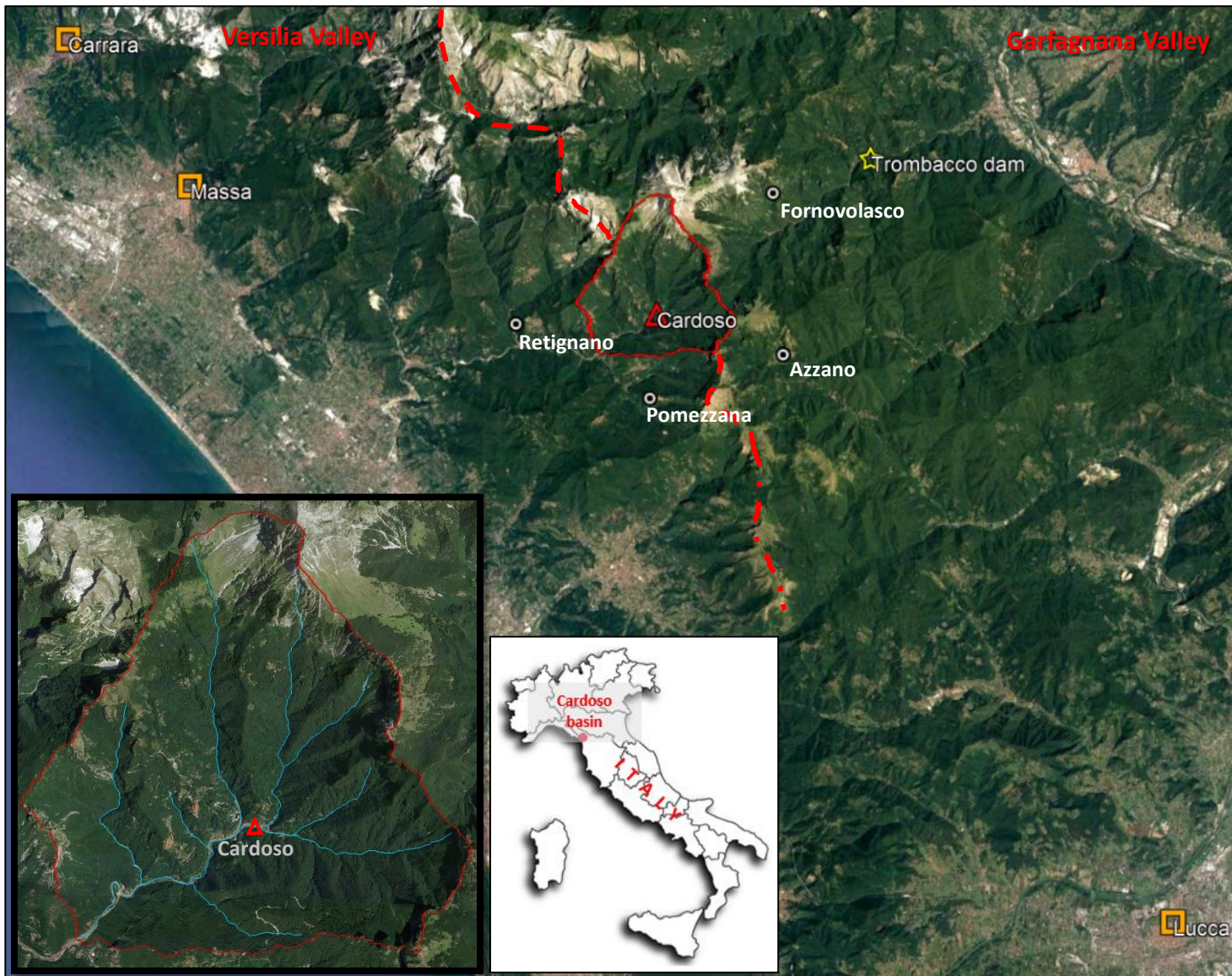
² Department of Earth Sciences, University of Firenze, Via G. La Pira 4, 50121 Firenze, Italy;

*Corresponding author: michele.amaddii@unifi.it

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STUDY AREA



Region: North-western Tuscany, Alpi Apuane, Italy

Cardoso basin area: 13 km², included in the Versilia Valley

Elevation: 163-1859 m a.s.l.

Mean Annual precipitation: 2000 mm/y
In the last 250 years 7 flood/debris flow events were verified in the Versilia Valley: 1774, 1829, 1846, 1885, 1902, 1992, 1996

The rainfall events can be very intense in the Alpi Apuane Chain, generating flash floods, debris flows and landslides and causing deaths and damages



OBJECTIVES

Improving the knowledge of infiltration/runoff processes on an area where the hydrogeological risk is very high, starting from the numerical analysis of the 19 June 1996 Cardoso event (the most severe debris flow event in Tuscany)

CASE STUDY: The Cardoso 19 June 1996 Extreme Event

The 19 June 1996 Extreme Event of Cardoso:

Total rainfall event: 475 mm/12 h

Peak rainfall event: 160 mm/h

Landslides: 170 hillslopes debris flows and 335 channelized debris flows

750.000 m³ of mobilized material

13 deaths



METHODS – Hydrological Modelling BY FLO-2D

Testing different infiltration methods for flood numerical analysis and reconstruction of peak discharge: Curve Number and Green-Ampt, implemented in the FLO-2D model.

For the numerical model the FLO-2D software (O'Brien et al., 1993) was used, testing and comparing two different infiltration methods: the Green Ampt physically based model (Green and Ampt, 1911) and the SCS Curve Number empirical method (SCS, 1956).

I) Green-Ampt

- Soil layer: Hydraulic saturated conductivity & Soil Depth (field survey) + Rock Outcrop & Effective Impervious Area (based on aerial photo-interpretation and Land Cover)
- Land use layer: Saturation + Vegetation Cover + Initial Abstraction + Impervious Area (based on FLO-2D manual and Land Cover)

II, III) Curve Number

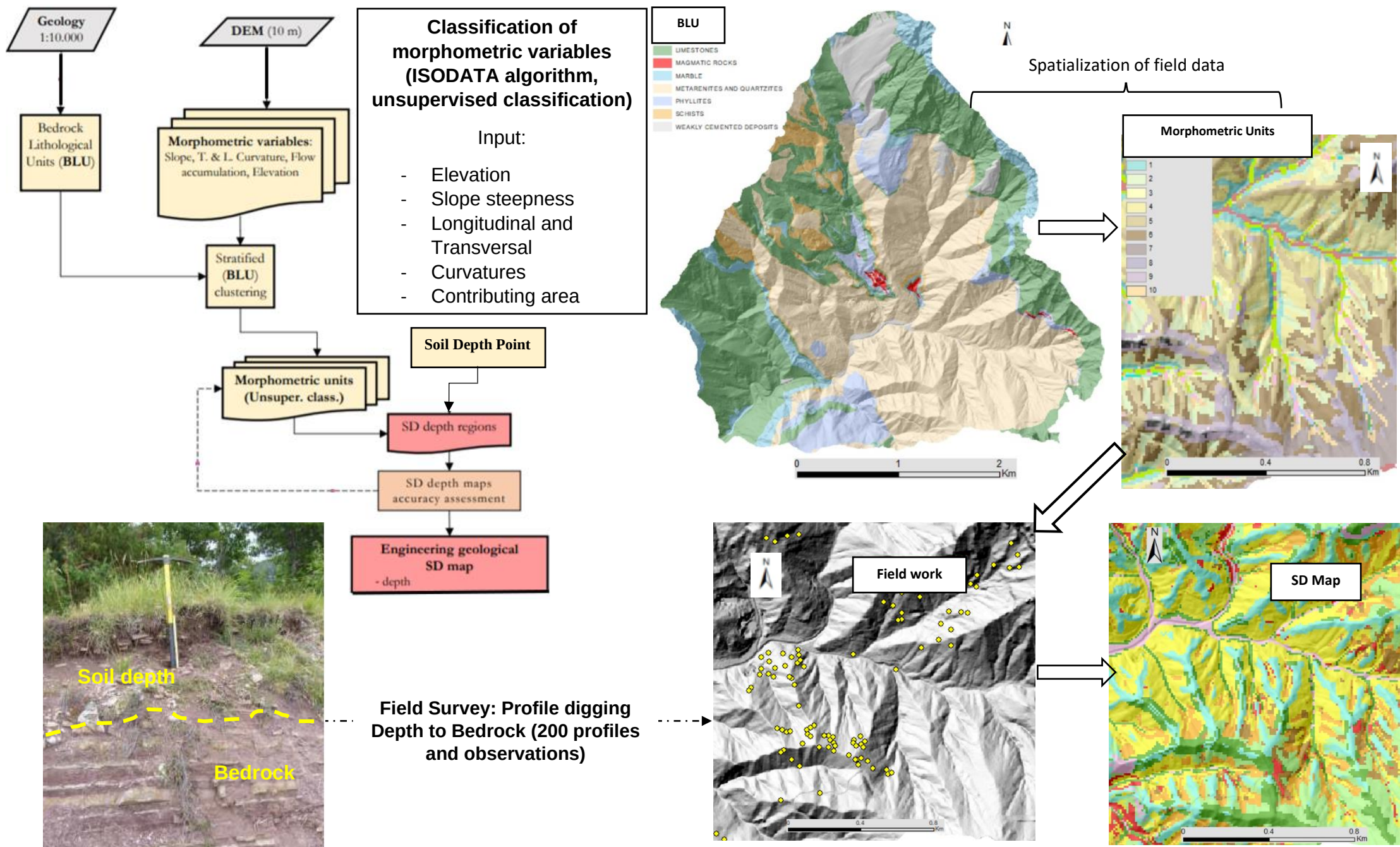
Different methods for HSG assignment

- II) USDA-NRSC (Hydrology National Engineering Handbook, version 2009) based on Hydraulic saturated conductivity and Soil Depth
- III) Classic subjective method: A, B, C, D (?)

Common data input for method I) and II): Soil Depth (**SD**) and Hydraulic Saturated Conductivity (**Ksat**)

Others input data of FLO-2D: LiDAR (5x5m), N Manning (based on Land Cover), surface detention

METHODS – Soil Depth Assessment

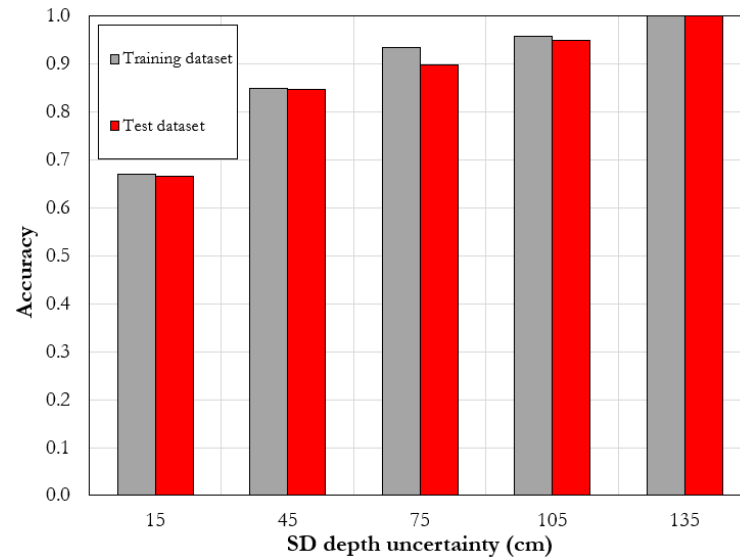


METHODS - Soil Depth Assessment

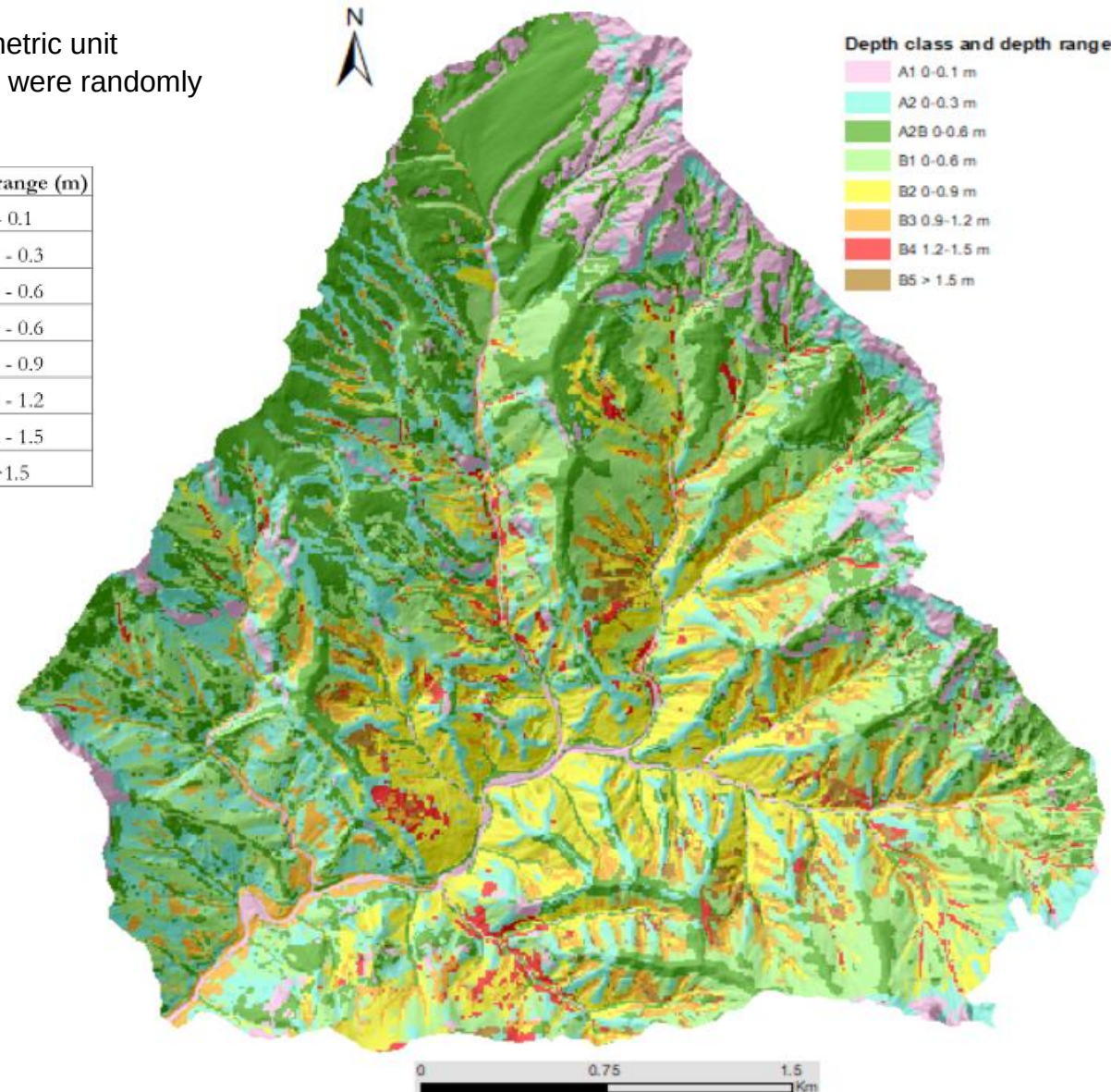
- The depth measurements are classified following the depth nomenclature classes
- For each morphometric unit the frequency of depth measurement classes are evaluated
- The most frequent depth class is assigned to each morphometric unit
- For uncertainty and accuracy assessment, site observations were randomly split in training dataset (70%) and test dataset (30%)

First order group	Depth class	Description	Depth range (m)
A ("thin" SD)	A1	Continuous or prevailing outcropping bedrock	0 - 0.1
	A2	Continuous or prevailing SD cover	0.1 - 0.3
	A2B	As A2 with local not-mappable areas with depth >0.3 m	0.1 - 0.6
B ("thick" SD)	B1	Bedrock generally not outcropping, continuous SD cover	0.3 - 0.6
	B2	Bedrock generally not outcropping, continuous SD cover	0.6 - 0.9
	B3	Bedrock generally not outcropping, continuous SD cover	0.9 - 1.2
	B4	Bedrock generally not outcropping, continuous SD cover	1.2 - 1.5
	B5	Bedrock generally not outcropping, continuous SD cover	>1.5

Success and prediction rates of SD map (e.g. Metarenites-Quartzites BLU)



Soil Depth Map



METHODS - Hydraulic Saturated Conductivity Assessment

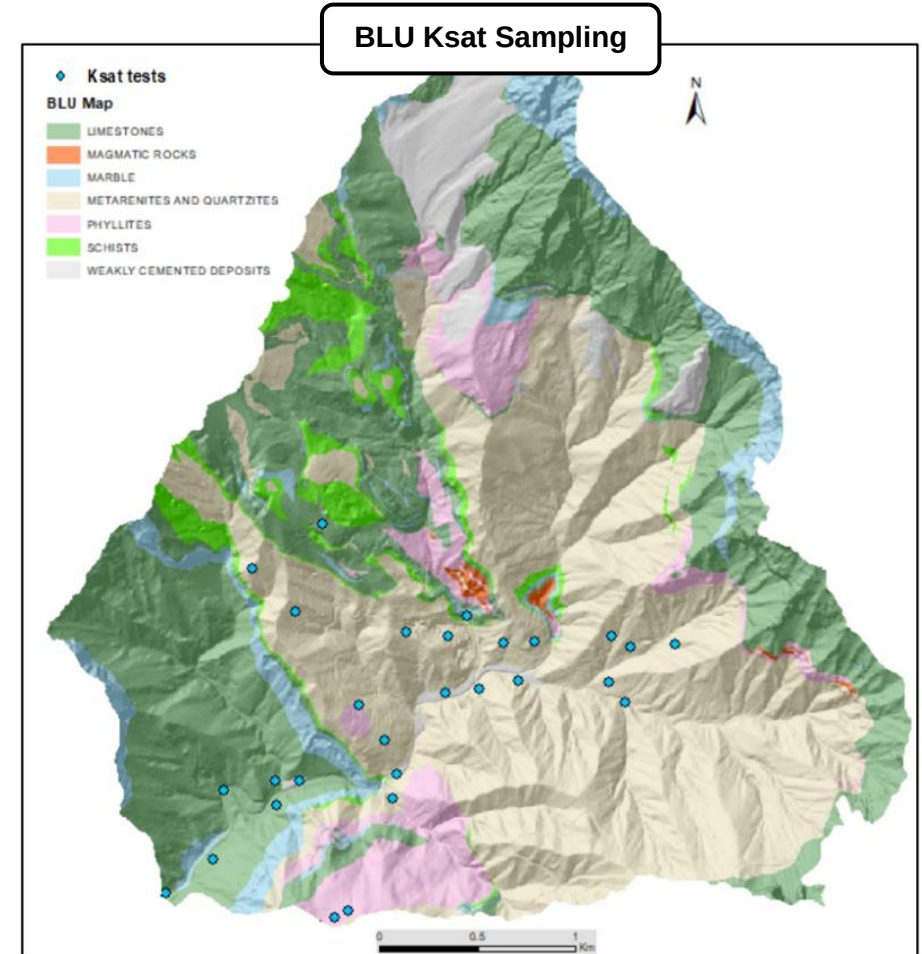
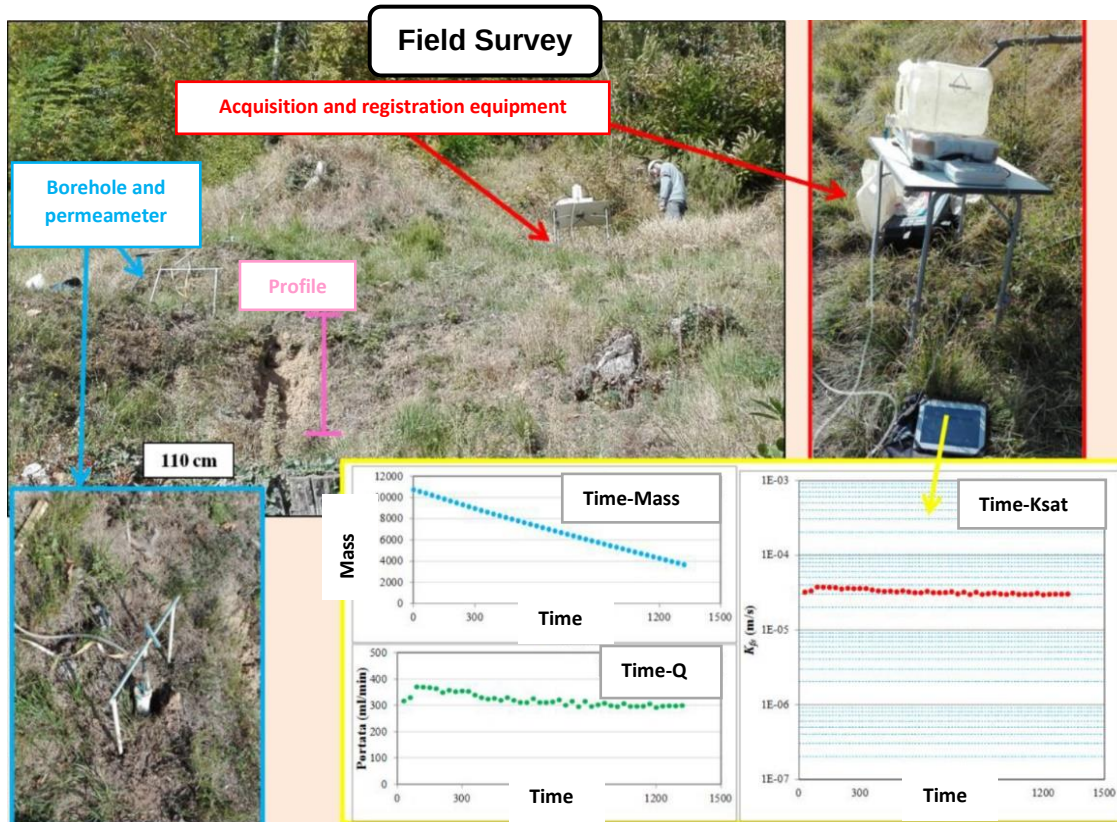
Ksat tests

The in situ hydraulic conductivity measurement was carried out by the Aardwark constant head borehole permeameter.

Ksat kit:

- Aardvark Permeameter
- Digital Scale which can be connected to a personal computer and record the measurements automatically and accurately, using the specific software
- 30 m tubing
- water jugs and a setup table

It is possible to view the real-time graph of soil-water flux rate during the measurement period.

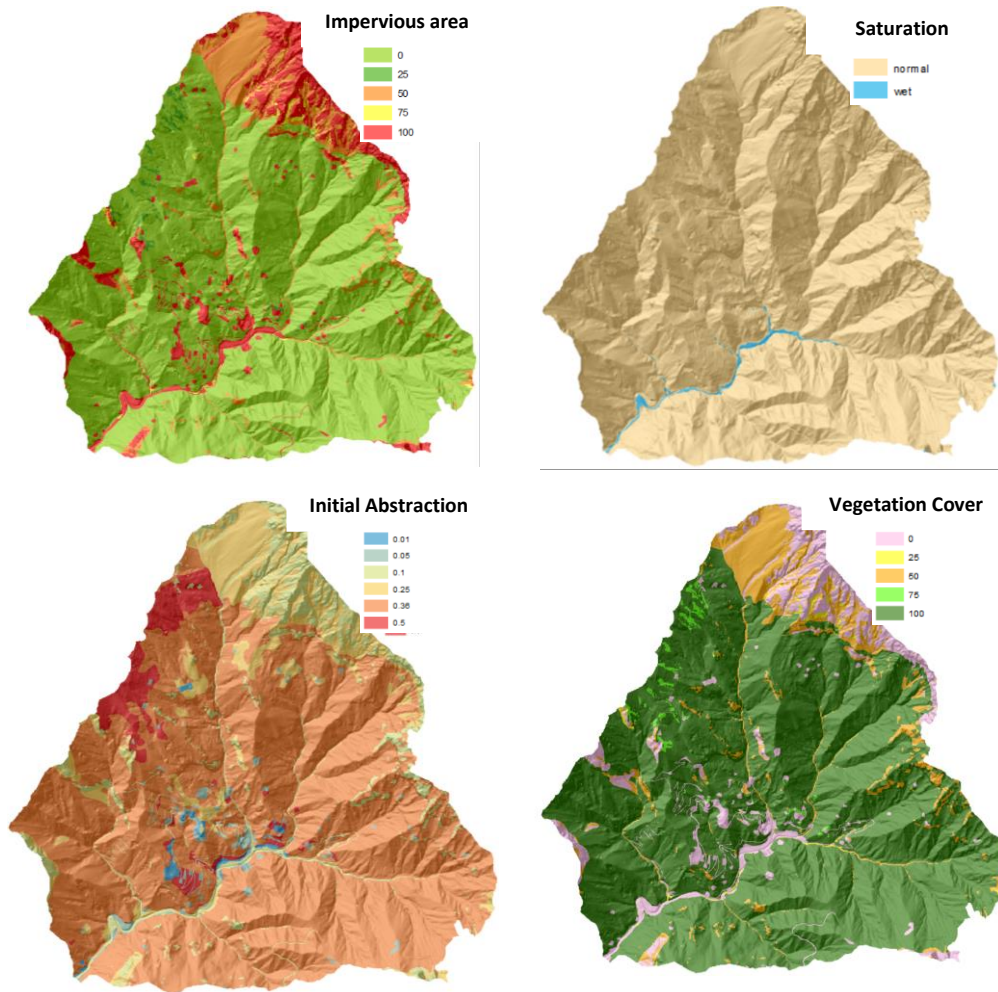


Bedrock Lithology	Ksat (m/s)
LIMESTONES	3.9E-05
MARBLE	2.3E-05
METARENITES AND QUARTZITES	3.2E-05
PHYLLITES	3.8E-05
SCHISTS*	2.5E-05

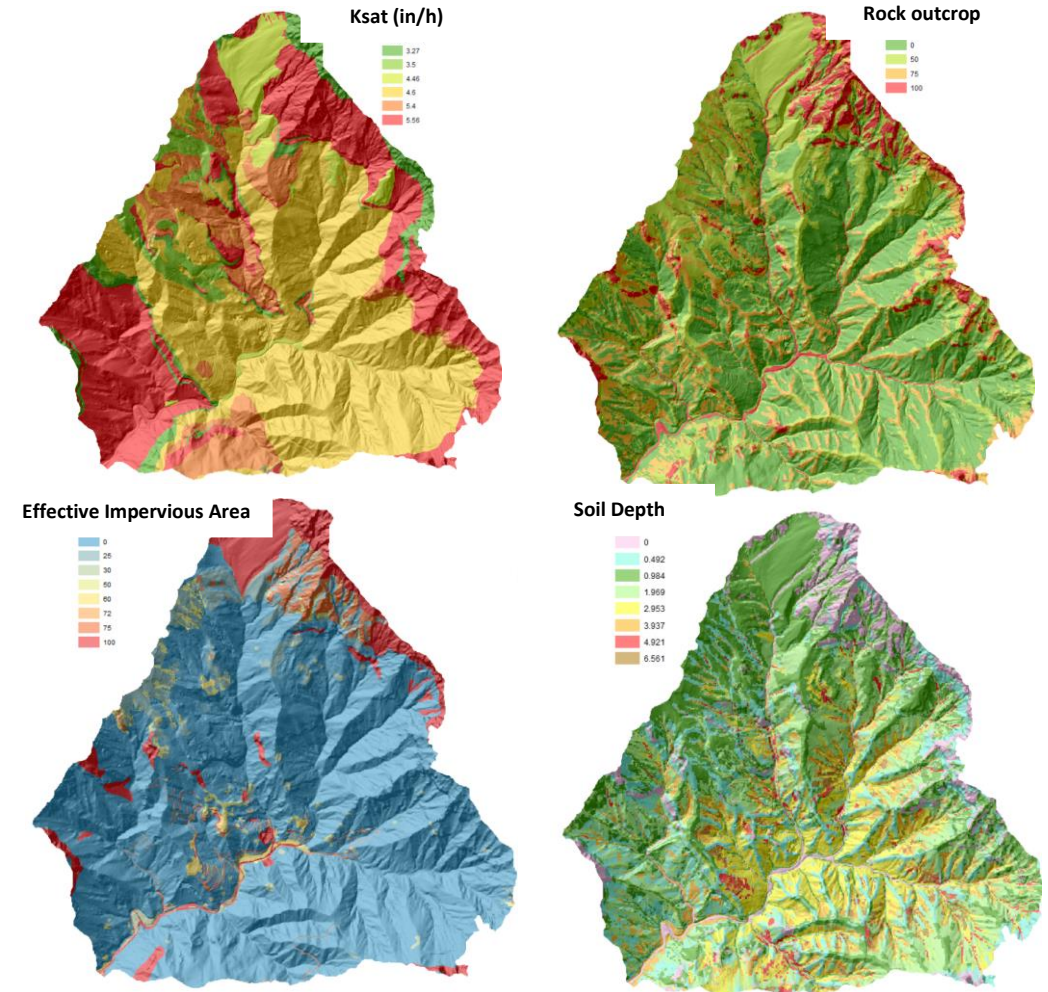
*Test sites located near Cardoso basin from other rock outcrops of Versilia Valley. Assumption: at the rainfall scale (considering the high rainfall rate) bedrock is impermeable

METHODS – I) GA Input Data For FLO-2D Hydrological Modelling

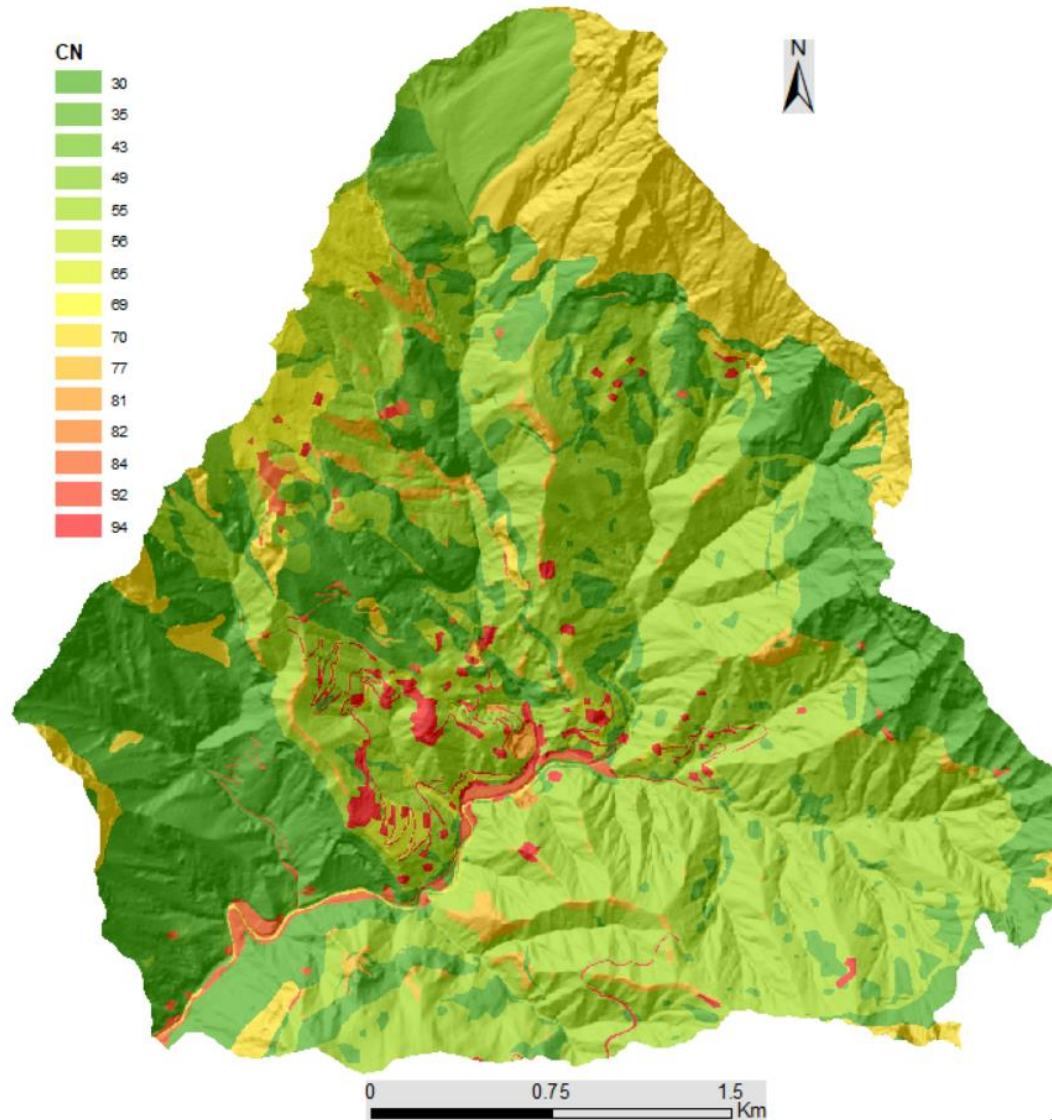
I) GA Landuse layer



I) GA Soil layer



METHODS – II) CN Input Data For FLO-2D Hydrological Modelling



Depth to water impermeable layer ^{1/}	Depth to high water table ^{2/}	K_{sat} of least transmissive layer in depth range	K_{sat} depth range	HSG ^{3/}
<50 cm [<20 in]	—	—	—	D
50 to 100 cm [20 to 40 in]	<60 cm [<24 in]	>40.0 $\mu\text{m/s}$ (>5.67 in/h)	0 to 60 cm [0 to 24 in]	A/D
		>10.0 to $\leq$ 40.0 $\mu\text{m/s}$ (>1.42 to $\leq$ 5.67 in/h)	0 to 60 cm [0 to 24 in]	B/D
		>1.0 to $\leq$ 10.0 $\mu\text{m/s}$ (>0.14 to $\leq$ 1.42 in/h)	0 to 60 cm [0 to 24 in]	C/D
		$\leq$ 1.0 $\mu\text{m/s}$ ($\leq$ 0.14 in/h)	0 to 60 cm [0 to 24 in]	D
	$\geq$ 60 cm [$\geq$ 24 in]	>40.0 $\mu\text{m/s}$ (>5.67 in/h)	0 to 50 cm [0 to 20 in]	A
		>10.0 to $\leq$ 40.0 $\mu\text{m/s}$ (>1.42 to $\leq$ 5.67 in/h)	0 to 50 cm [0 to 20 in]	B
		>1.0 to $\leq$ 10.0 $\mu\text{m/s}$ (>0.14 to $\leq$ 1.42 in/h)	0 to 50 cm [0 to 20 in]	C
		$\leq$ 1.0 $\mu\text{m/s}$ ($\leq$ 0.14 in/h)	0 to 50 cm [0 to 20 in]	D
>100 cm [>40 in]	<60 cm [<24 in]	>10.0 $\mu\text{m/s}$ (>1.42 in/h)	0 to 100 cm [0 to 40 in]	A/D
		>4.0 to $\leq$ 10.0 $\mu\text{m/s}$ (>0.57 to $\leq$ 1.42 in/h)	0 to 100 cm [0 to 40 in]	B/D
		>0.40 to $\leq$ 4.0 $\mu\text{m/s}$ (>0.06 to $\leq$ 0.57 in/h)	0 to 100 cm [0 to 40 in]	C/D
		$\leq$ 0.40 $\mu\text{m/s}$ ($\leq$ 0.06 in/h)	0 to 100 cm [0 to 40 in]	D
	60 to 100 cm [24 to 40 in]	>40.0 $\mu\text{m/s}$ (>5.67 in/h)	0 to 50 cm [0 to 20 in]	A
		>10.0 to $\leq$ 40.0 $\mu\text{m/s}$ (>1.42 to $\leq$ 5.67 in/h)	0 to 50 cm [0 to 20 in]	B
		>1.0 to $\leq$ 10.0 $\mu\text{m/s}$ (>0.14 to $\leq$ 1.42 in/h)	0 to 50 cm [0 to 20 in]	C
		$\leq$ 1.0 $\mu\text{m/s}$ ($\leq$ 0.14 in/h)	0 to 50 cm [0 to 20 in]	D
>100 cm [>40 in]		>10.0 $\mu\text{m/s}$ (>1.42 in/h)	0 to 100 cm [0 to 40 in]	A
		>4.0 to $\leq$ 10.0 $\mu\text{m/s}$ (>0.57 to $\leq$ 1.42 in/h)	0 to 100 cm [0 to 40 in]	B
		>0.40 to $\leq$ 4.0 $\mu\text{m/s}$ (>0.06 to $\leq$ 0.57 in/h)	0 to 100 cm [0 to 40 in]	C
		$\leq$ 0.40 $\mu\text{m/s}$ ($\leq$ 0.06 in/h)	0 to 100 cm [0 to 40 in]	D

No antecedent rain

>100 cm
[>40 in]

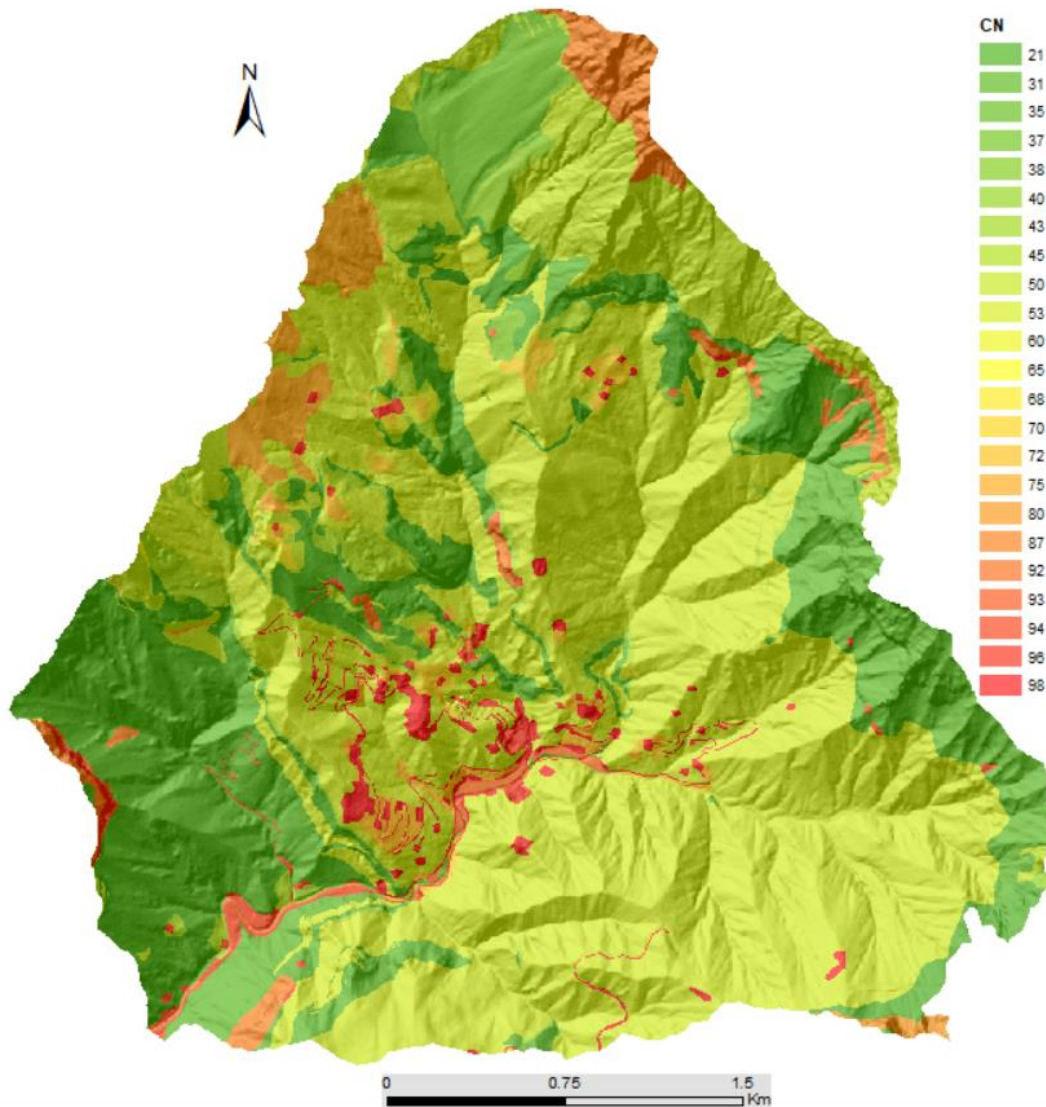
Assumption: at the rainfall scale (considering the high rainfall rate) bedrock is impermeable)

- 1/ An impermeable layer has a K_{sat} less than 0.01 $\mu\text{m/s}$ [0.0014 in/h] or a component restriction of fragipan; duripan; petrocalcic; orstein; petrogypsic; cemented horizon; densic material; placic; bedrock, paralitric; bedrock, lithic; bedrock, densic; or permafrost.
- 2/ High water table during any month during the year.
- 3/ Dual HSG classes are applied only for wet soils (water table less than 60 cm [24 in]). If these soils can be drained, a less restrictive HSG can be assigned, depending on the K_{sat} .

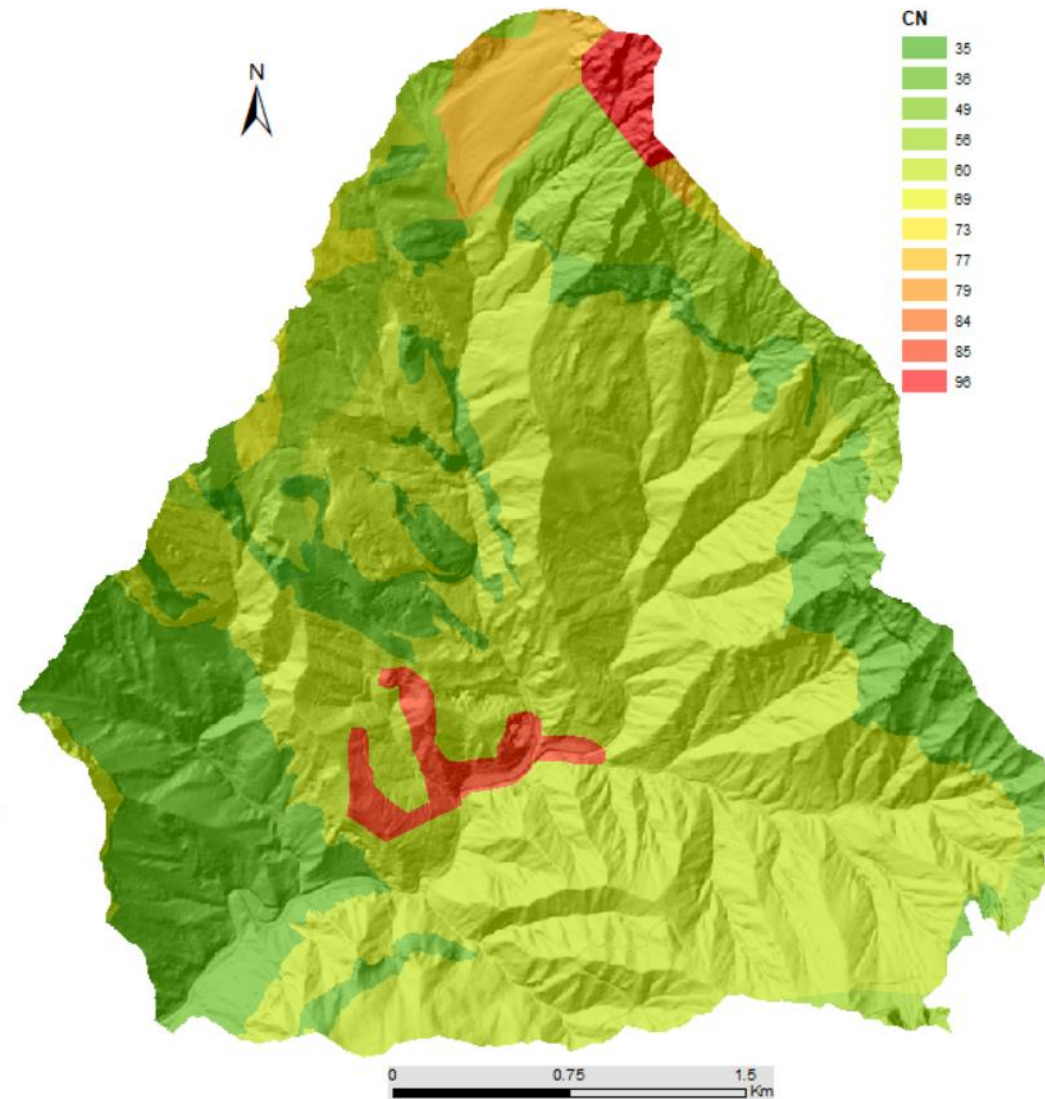
METHODS – IIIa,b) CN Input Data For FLO-2D Hydrological Modelling

III) CN “classic method”: subjective assignment of HSG: A, B, C, D (?)

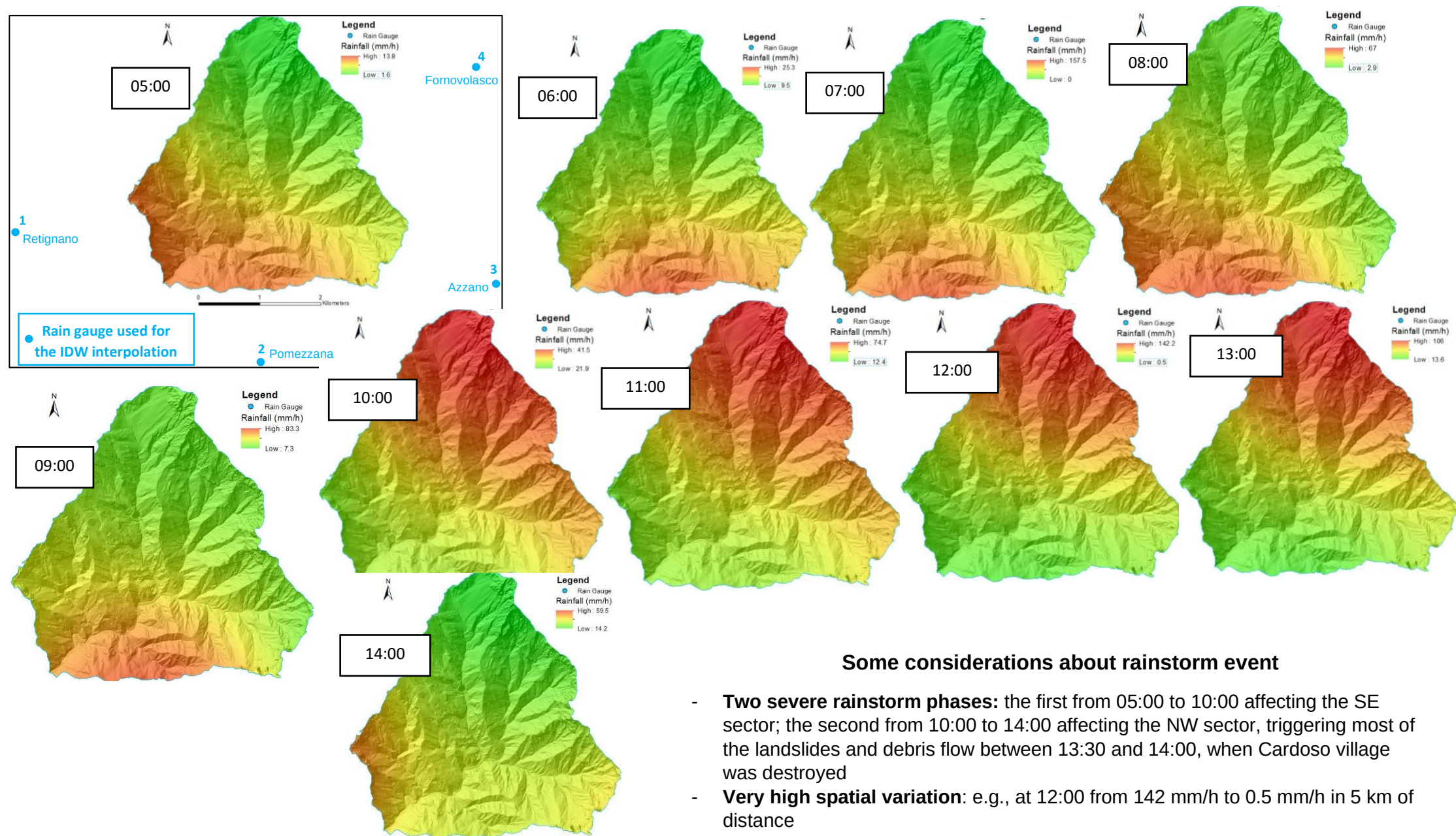
IIIa) CN obtained by HSG assignment of Cazorzi and Bincoletto (2005)



IIIb) CN of Tuscany region dataset



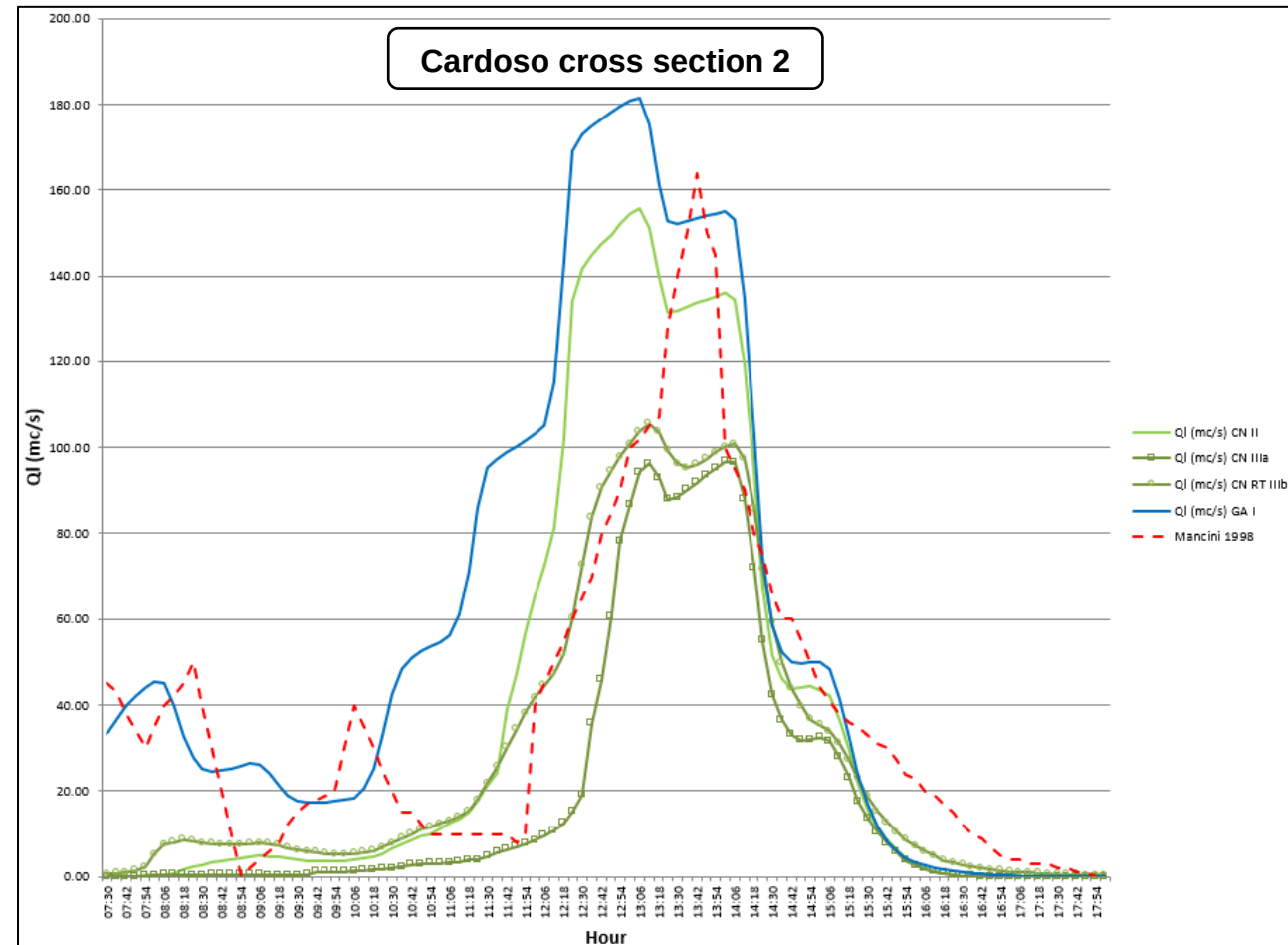
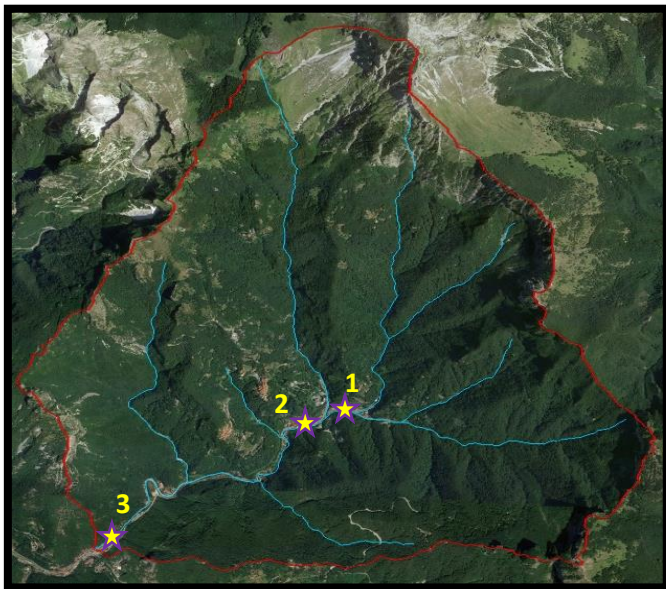
METHODS – Rainfall IDW Spatial Interpolation



PRELIMINARY RESULTS - Comparison between modelled discharge and discharge from literature

No discharge gauges were present in 1996 during the event, therefore the results of this study were compared with literature data (Mancini, 1998) for three cross sections along the Cardoso Valley

- Peak discharge modelled and calibrated by Mancini (1998): $164\text{m}^3/\text{s}$ at 13:30
- Two different peaks were obtained implementing method I) and II): the first of $181\text{-}155\text{ m}^3/\text{s}$ (I-II, respectively) at 13:05 and the second of $155\text{-}135\text{m}^3/\text{s}$ (I-II, respectively) between 13:30/14:00, when the Cardoso village was destroyed
- Peak discharges obtained by method IIIa&b, both underestimate the peak discharge modelled by Mancini (1998): about $95\text{-}100\text{ m}^3/\text{s}$, in addition the peak arrival time does not correspond to the evidences.



Cross section	Discharge m^3/s				
	Mancini peak (1998)	GA I Peak	CN II Peak	CN IIIa	CN IIIb
Cardoso - cross section 1	76	91	63	46	46
Cardoso - cross section 2	164	155	135	105	95
Pontestazzemese - cross section 3	201	222	165	113	122

CONCLUSIONS

- The spatial distribution of Soil Depth and Ksat allows a comprehensive representation of the hydrological-morphological framework of the Cardoso catchment; furthermore, soil depth data can be used for modelling the potential solid volume involved from a landslides or debris flows;
- A correct determination of the liquid discharge also allows to obtain more realistic debris-graphs, for debris flows modeling;
- Both Green-Ampt (I) and Curve Number (II) methods show similar results and are consistent with the historical literature data and information, considering three relevant transects close to the village;
- The results obtained by applying the method (III) are strongly conditioned by the subjective assignment of the HSG and they can be different in terms of peak discharge, flood wave arrival time and maximum water level.

NEXT STEPS

- Extend the study area to include the hydrometer of the Ruosina village, situated 5 km downstream Cardoso, in order to calibrate and validate the results of other recent intense rainstorm event and modeling future scenarios;
- Implementation of different hydrological models that allow to also consider the permeability of the fractured bedrock.