CHANNEL RESPONSE TO EXTREME FLOODS

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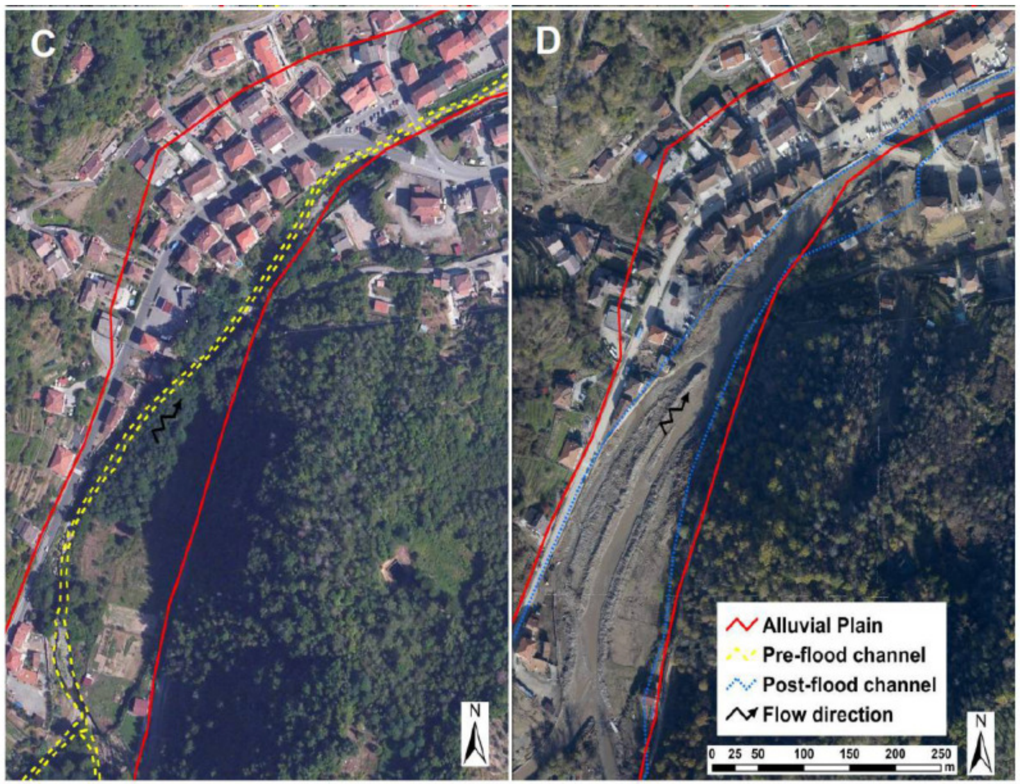
INTRODUCTION

- ✓ Floods are natural processes, taking place with different magnitude and frequency in all fluvial systems
- ✓ Floods are one of the major natural hazard that affect highly populated countries

Overall aim of this lecture:
Giving a new perspective («geomorphic perspective») about floods and related hazard



Which processes occur during floods?

Not only inundation!

Lateral mobility

Channel aggradation

Wood transport

Why the focus on extreme floods?

- ✓ Extreme floods may have strong impact on channel morphology and floodplain
- ✓ The risk associated to such floods can be very high
- ✓ In several areas extreme floods are likely to become more frequent (climate change)

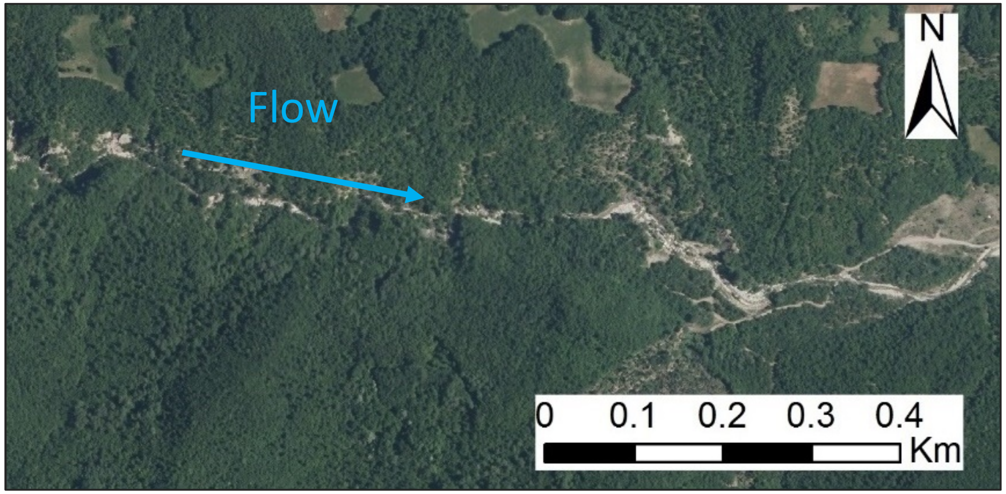
Outline of the lecture

1. Analysis of geomorphic response to extreme floods
2. Understanding processes: linking geomorphic response to driving factors
3. Case study: the Magra River flood event

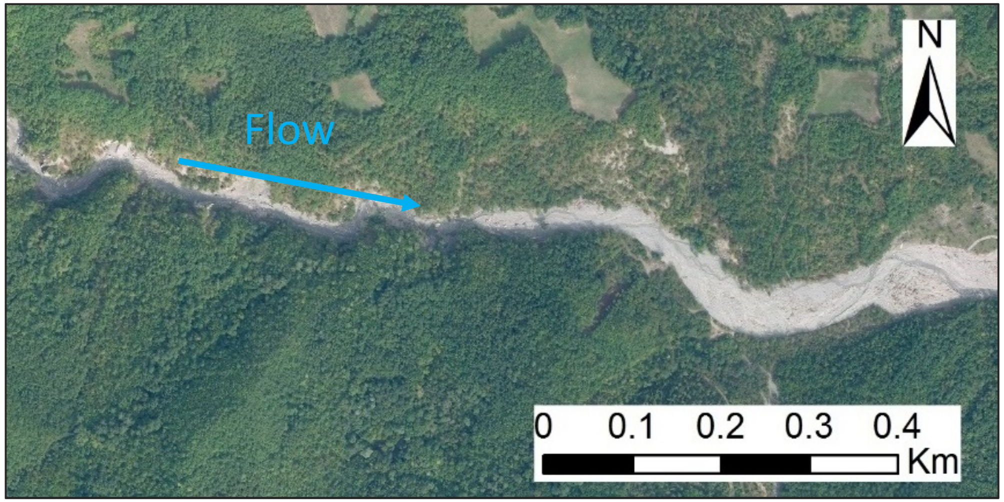
Hazard assessment: do we have effective tools to predict geomorphic response to extreme floods? Which processes can be expected in a specific river reach?

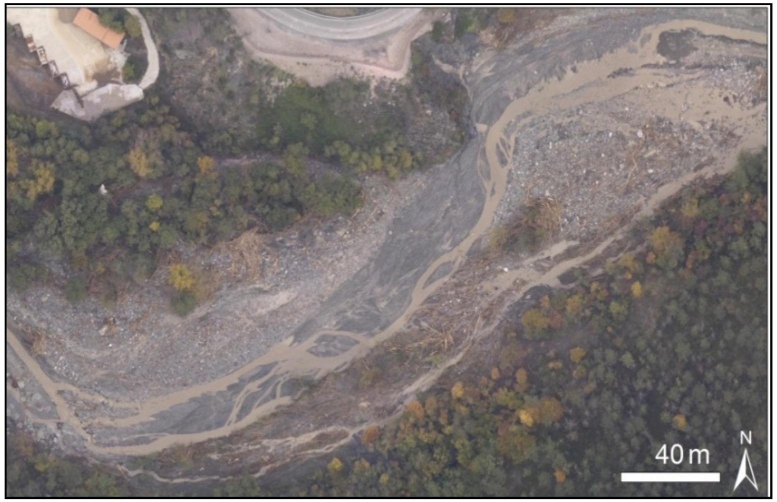
Channel Changes

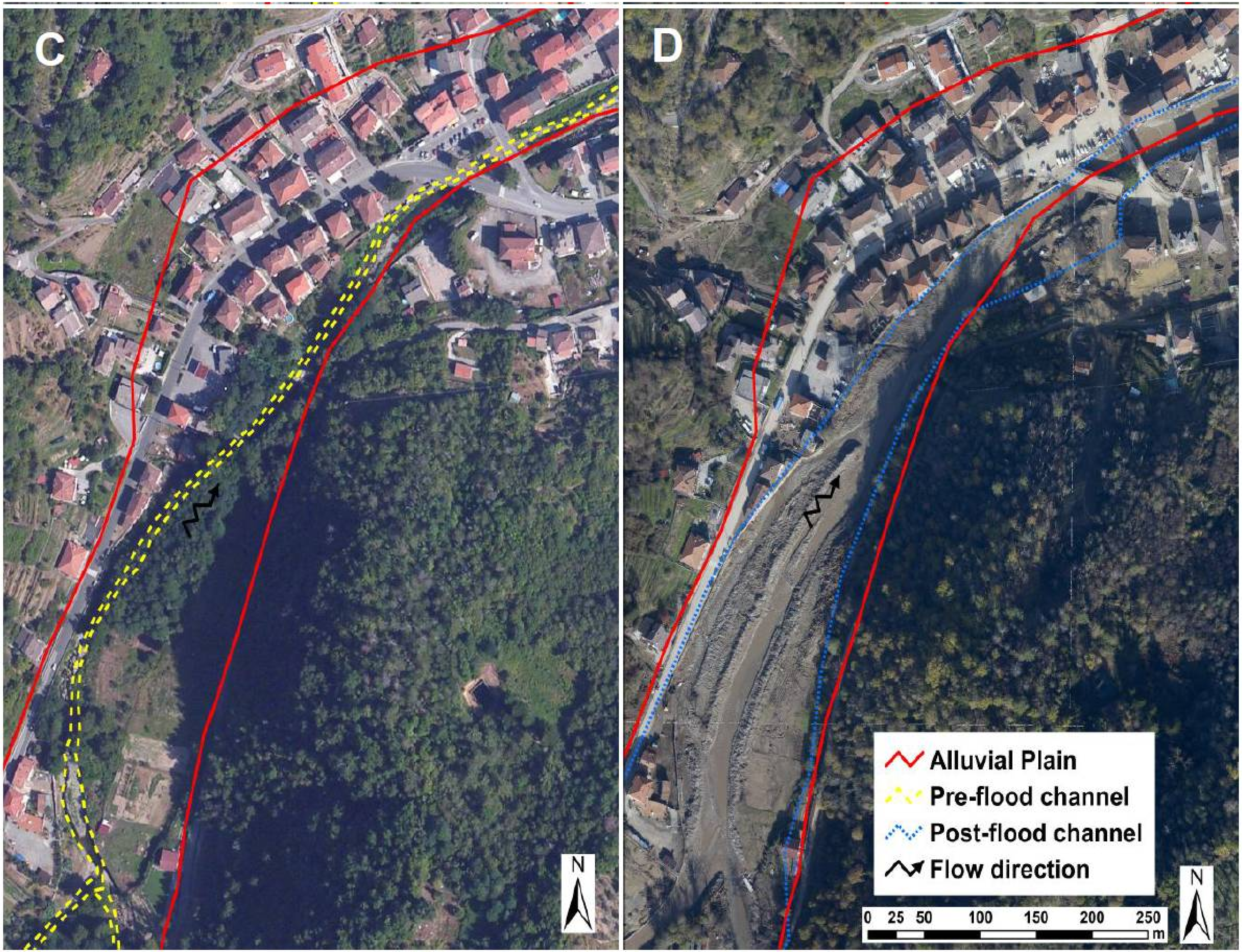
Before the flood



After the flood





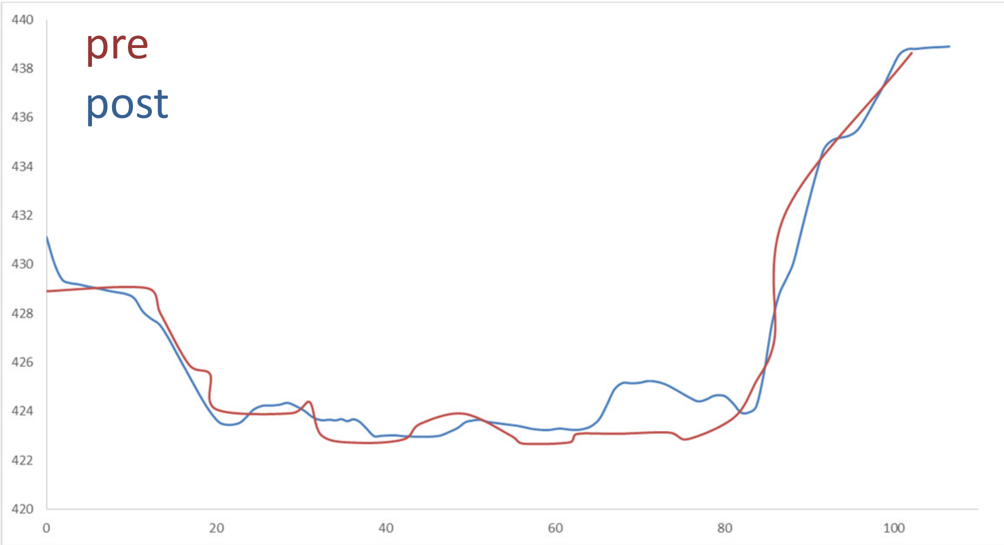

C
D
Alluvial Plain
Pre-flood channel
Post-flood channel
Flow direction
0 25 50 100 150 200 250
m
N
N

FLOOD and CHANNEL VERTICAL CHANGES

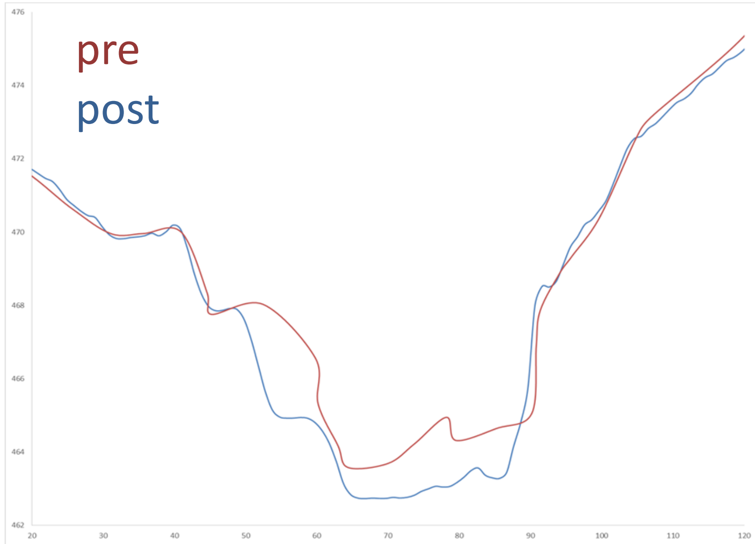
- Deposition occurs on the **bars** and on the floodplains through gravel deposition.
- Aggradation is very common immediately downstream the **tributary** junctions, where the channel bed presents **lower slope** or in areas were the **valley widens up** and channels are unconfined.
- On the floodplain, the amount of aggraded sediments tends to decrease with distance from the channel

Channel Changes: bed level

Aggradation



Incision



Aggradation: On channels (bars) and floodplains

Incision: on channels

Stream power

Channel changes only occur when the **flood power** exceeds the channel boundary resistance threshold, which depends on river bed and bank cohesive forces along the channel reach.

Stream power has widely been used as a measure of the geomorphic effectiveness of floods because its measures quantify river energy expenditure in fluvial systems.

Stream power ‘the rate of energy supply at the channel bed that is available for overcoming friction and transporting sediments’.

STREAM POWER

$$\Omega = \rho g \, Q \, S$$

where Q [$m^3 \, s^{-1}$] is the flood discharge

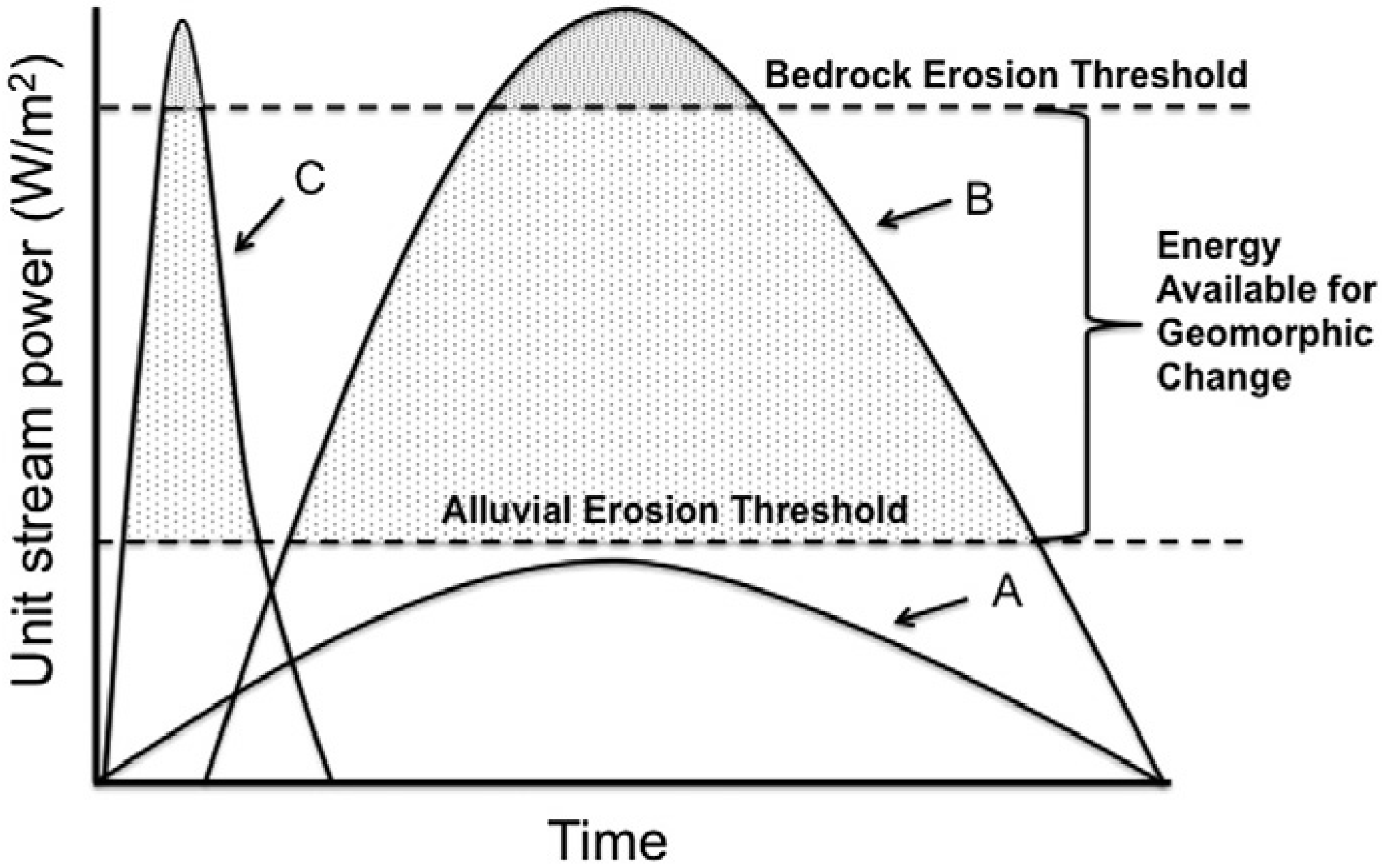
UNIT STREAM POWER

Stream power per unit-wetted area is termed unit stream power, ω [$W \, m^{-2}$] and expressed as:

$\omega = \Omega / w$

where w [m] is the top channel width corresponding to the flood level

Role of unit stream power and flow duration on geomorphic change



(Costa & O'Connor, 1995)

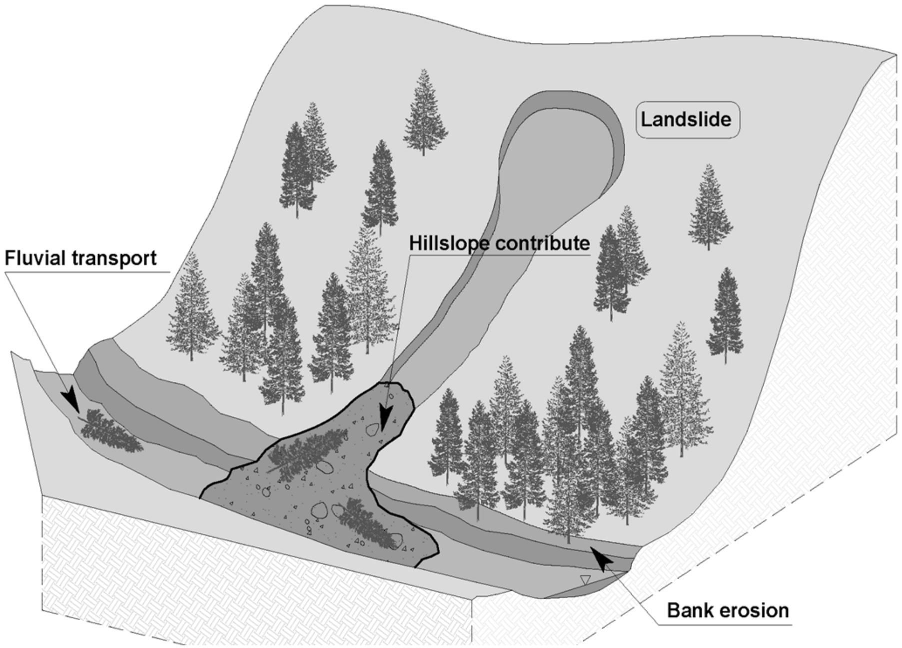
Unit Stream Power: ω = ṗgQS / w

Additional factors, besides hydraulic variables, should be incorporated to explain channel and floodplain response:

- ✓ **Bed-load supply** (e.g. Dean & Schmidt, 2013, Geomorphology)
- ✓ **Lateral confinement** (e.g. Thompson & Croke, 2013, Geomorphology)
- ✓ **Artificial structures** (e.g. Langhammer, 2010, Natural Hazards)

«Despite decades of work in geomorphology on flood effectiveness, we still generally **lack ability to predict** sites of major geomorphic changes during extreme flow events» (Buraas et al., 2014; ESPL)

Sediment sources and delivery

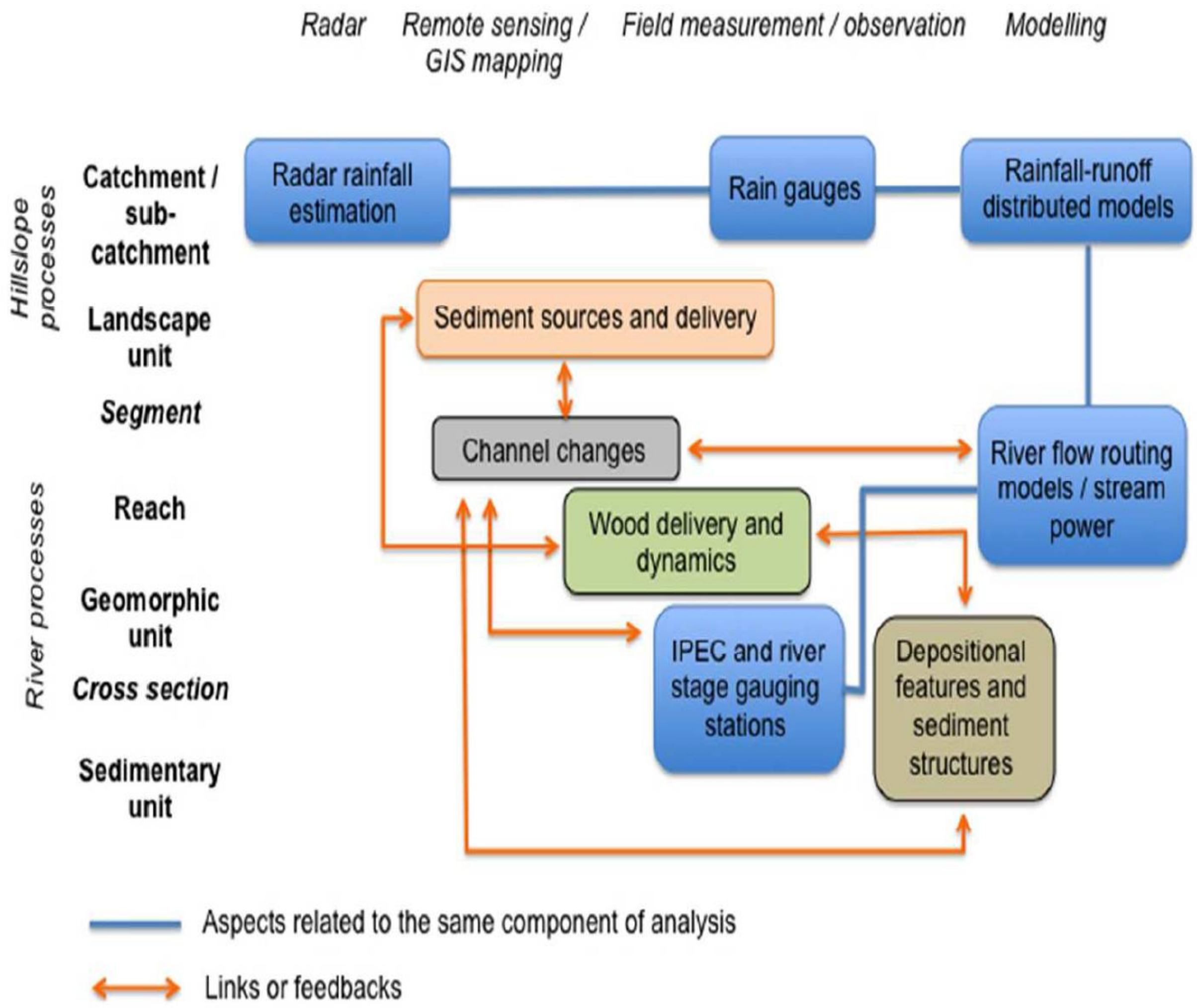


1-Landslides mapping → Field surveys; remote sensing

2- Coupled Landslides → Connectivity index (Cavalli et al., 2013)

3- Sediment Supply

Integrated approach for investigating geomorphic response to an extreme flood



Rinaldi et al., 2016, ESPL

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An integrated approach for investigating geomorphic response to extreme events: methodological framework and application to the October 2011 flood in the Magra River catchment, Italy

Massimo Rinaldi,[1]* William Amponsah,[2] Marco Benvenuti,[1] Marco Borga,[3] Francesco Comiti,[4] Ana Lucía,[4] Lorenzo Marchi,[2] Laura Nardi,[1] Margherita Righini[5] and Nicola Surian[5]
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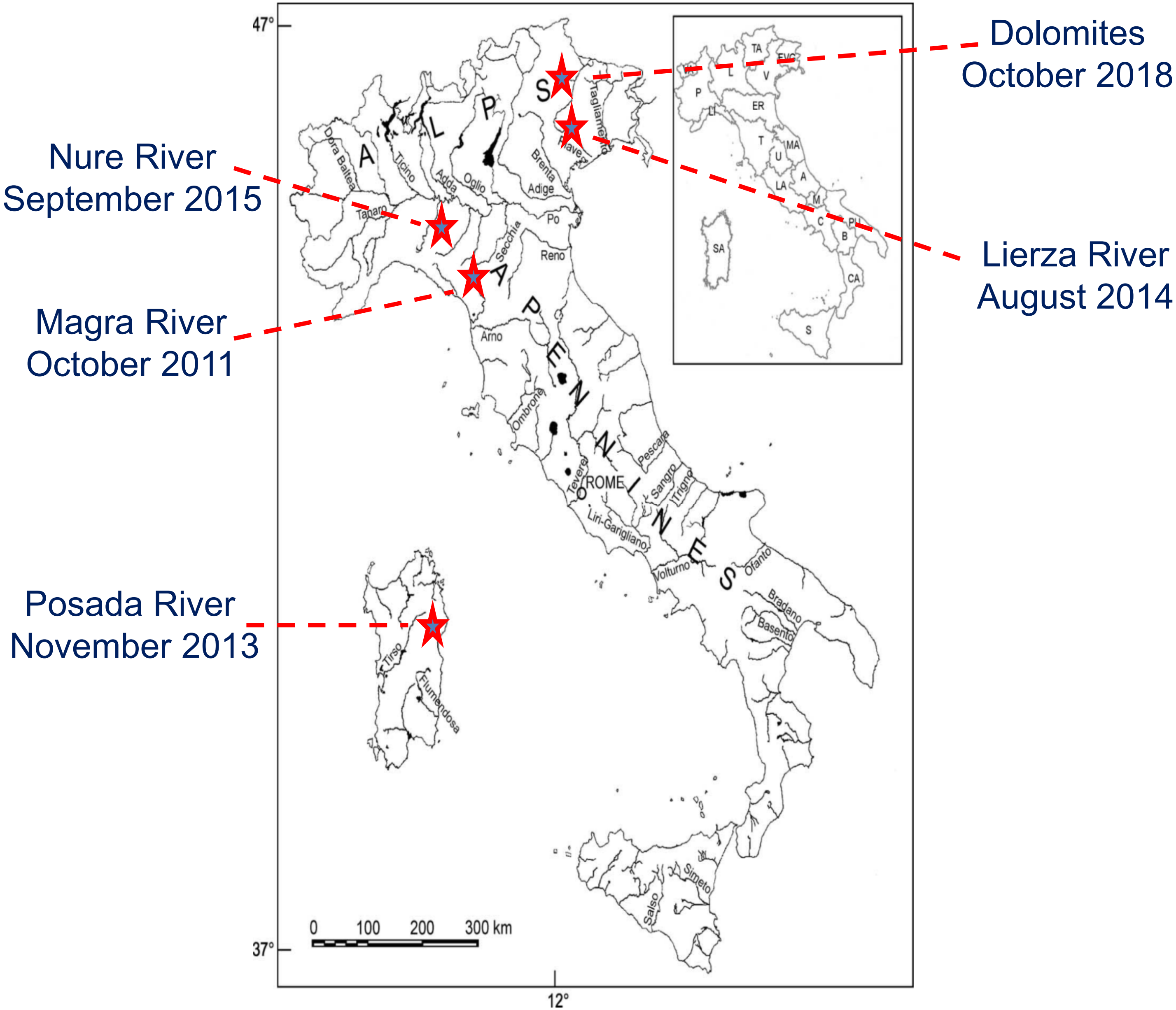
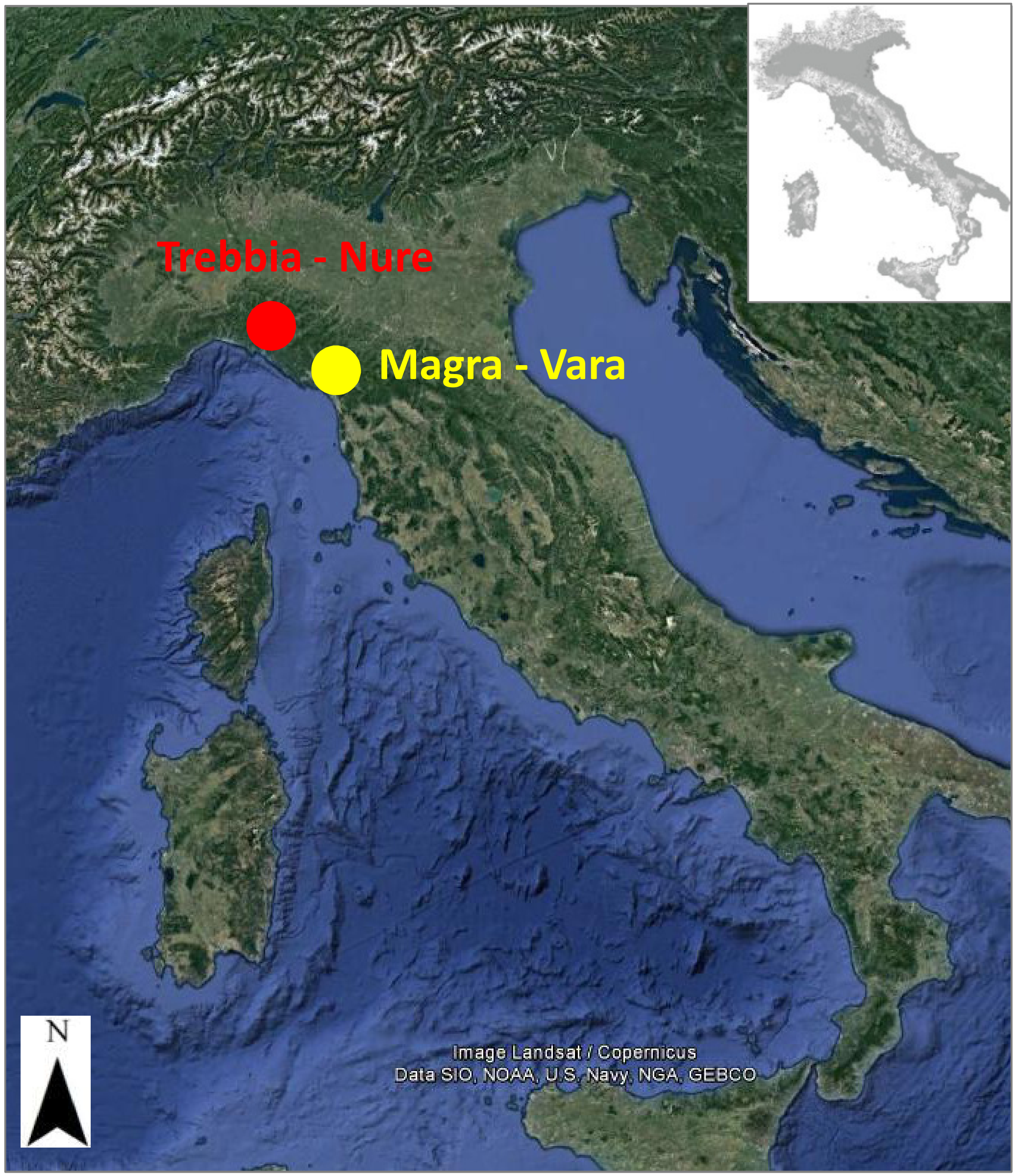
Case studies



Extreme flood event in the Magra and Vara basins

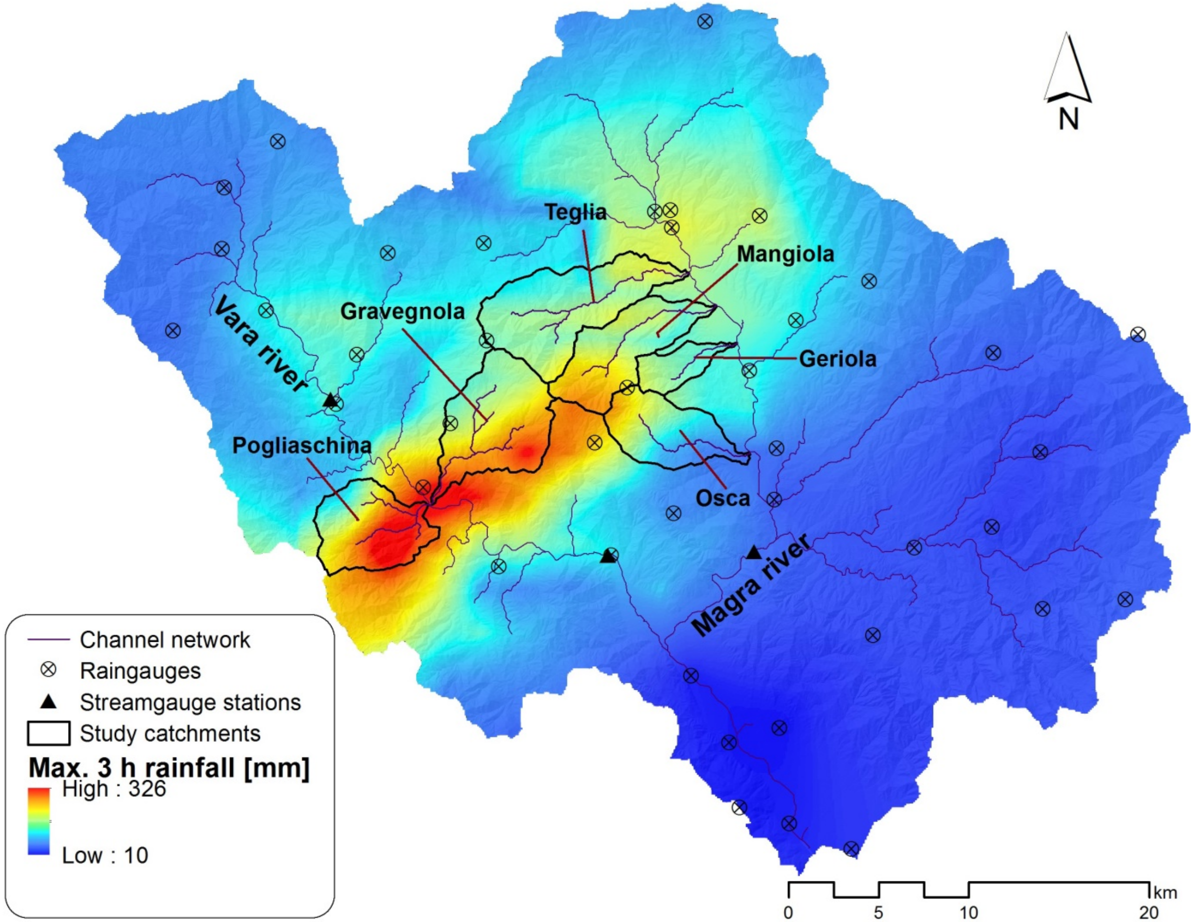


MAGRA and VARA
October 25th 2011

Nardi and Rinaldi, 2015 - ESPL;
Rinaldi et al., 2016 – ESPL;
Surian et al., 2016 - Geomorphology

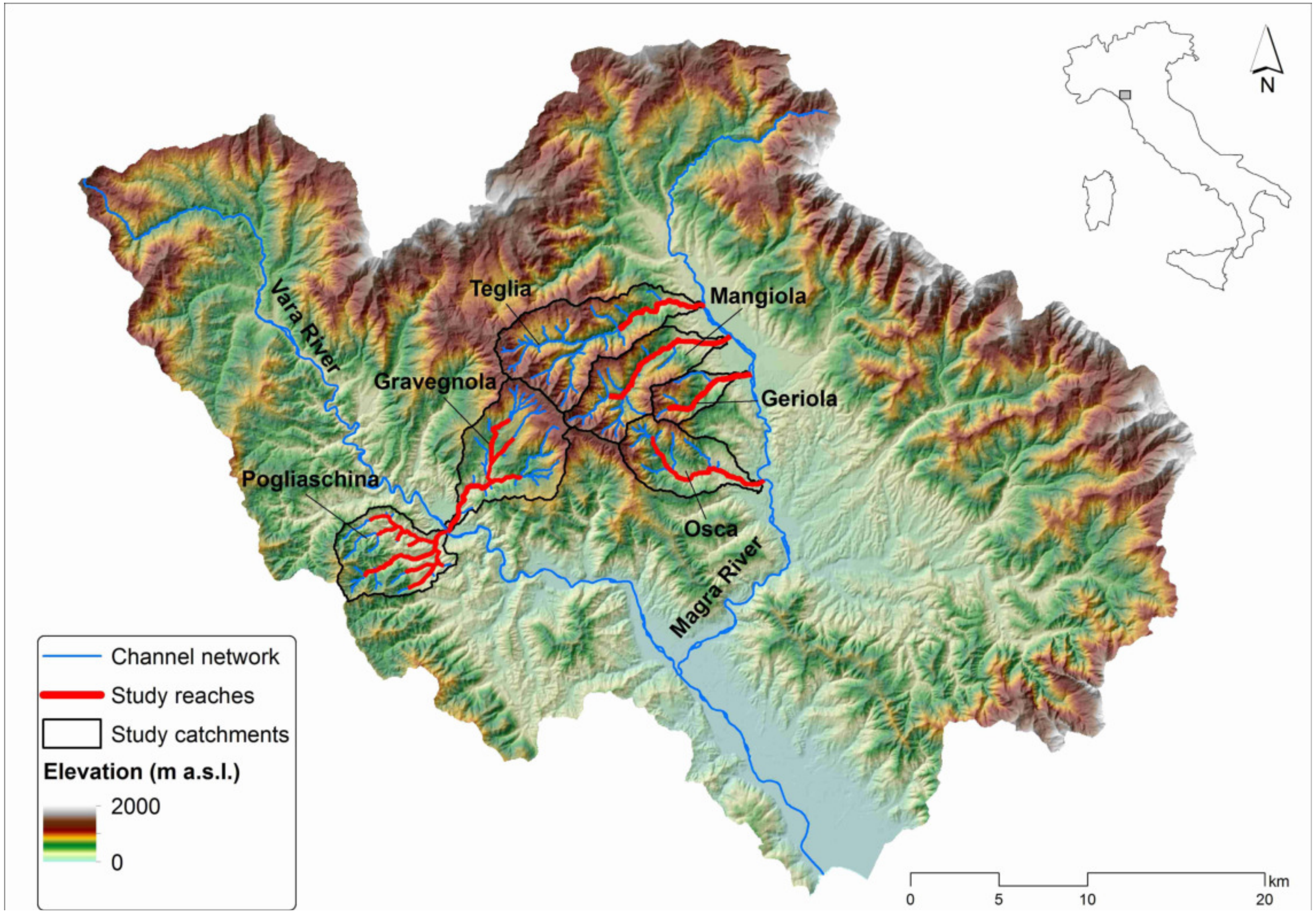
MAIN CHANNELS	MAGRA	VARA
Catchment area (km^2)	1146	571
Catchment max elevation (m)	1901	1404
Channel length (km)	70	58
Main Catchment Geology	Sandstones Mudstones	

The 25th October 2011 event in the Magra River catchment: spatial distribution of rainfall maxima corresponding to three-hours rainfall duration



(Surian et al., 2016, Geomorphology)

Maximum hourly rates: up to 149 mm/hr,
Event-accumulation maxima were up 500 mm (RI up to 300 yr)



Stream	Drainage area (km^2)	Basin relief (m)	Stream length (km)	Channel slope (%)	D_{50} (mm)	Total rainfall (mm)	3 h max rainfall (mm)	Runoff ratio	Q_{pk} ($m^3\ s^{-1}$)	Unit Q_{pk} ($m^3\ s^{-1}\ km^{-2}$)
Teglia	38.8	1035	14.8	4.9	47-69	335	116	0.53	538	13.9
Mangiola	26.2	1012	12.9	6.6	41-95	376	148	0.57	406	15.5
Geriola	8.5	884	7.2	8.8	n.a.	267	116	0.51	121	14.2
Osca	21.8	962	9.9	4.1	44-65	243	125	0.52	279	12.8
Gravegnola	34.6	1106	12.8	7.0	33-79	387	176	0.62	523	15.1
Pogliaschina	25.1	625	9.1	5.6	24-36	387	209	0.61	595	23.7

Geomorphic effects in the Magra River catchment

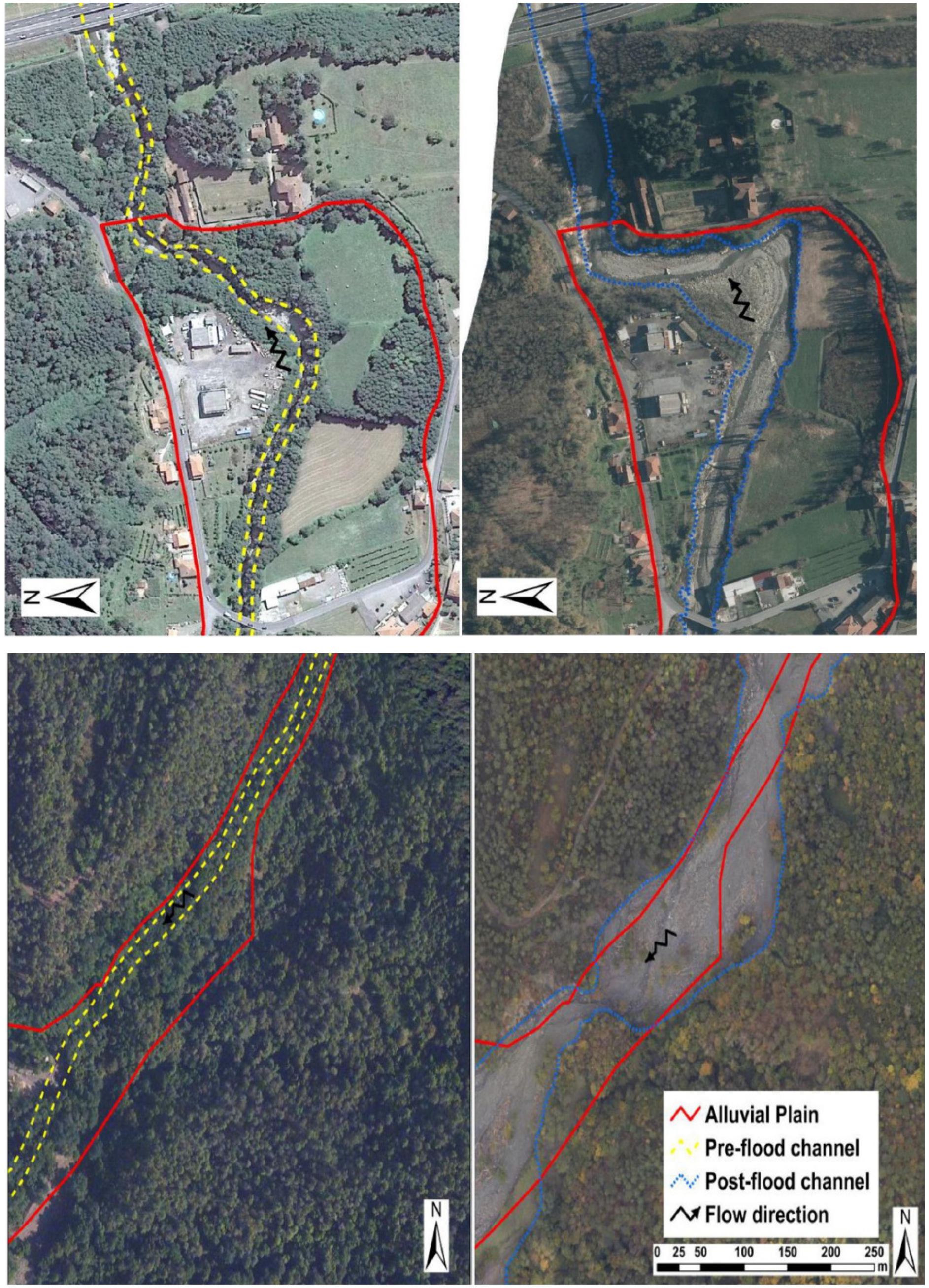
Teglia River

Pre-flood

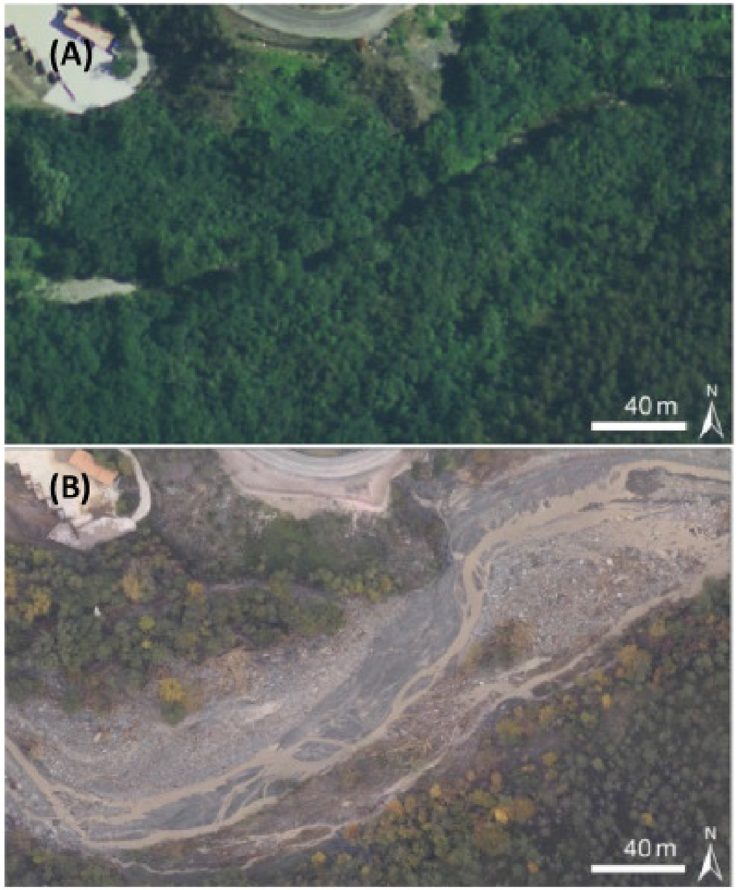
Post-flood

(Rinaldi et al., 2016, ESPL)

Widening observed in the study channels



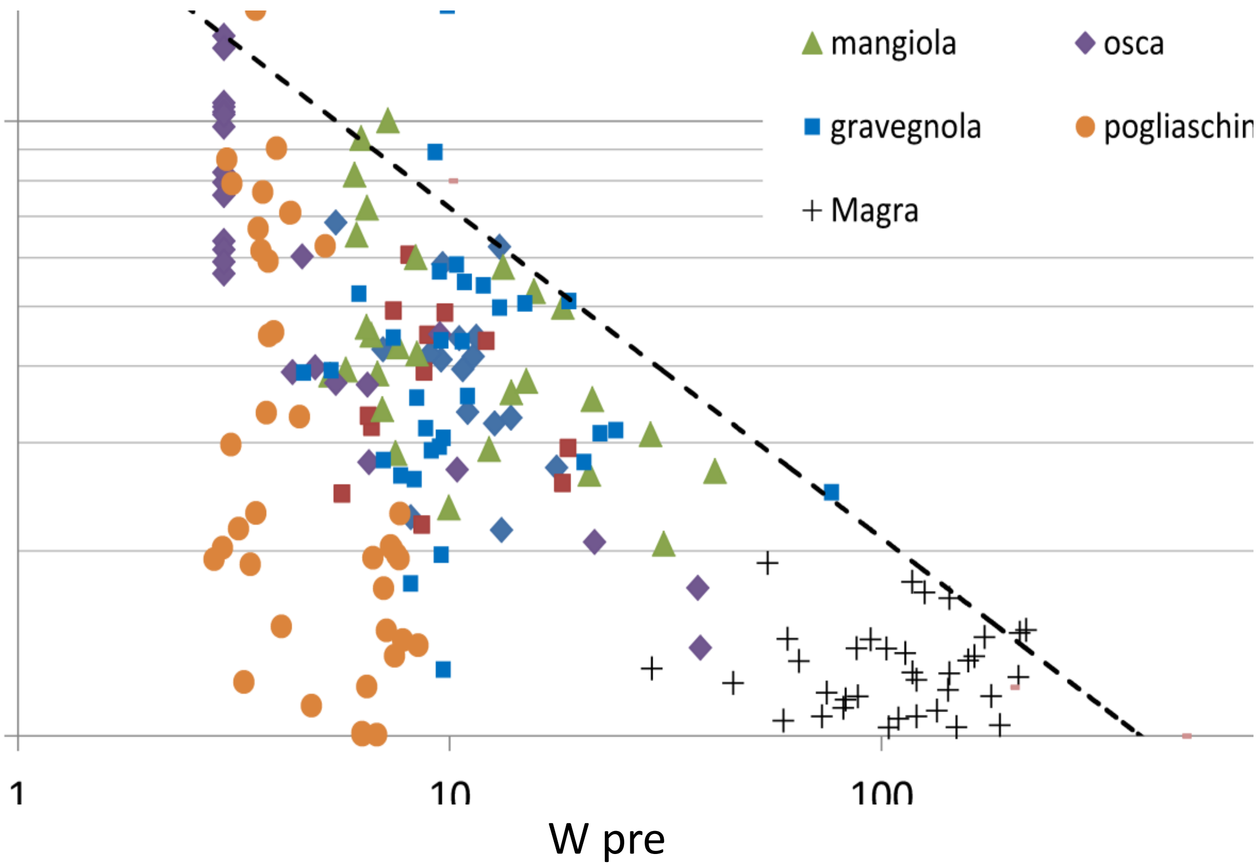
Average Width before flood =17m
Average Width after flood = 43m
Average Wratio = 4.3
Average Widening = 27m



Widening observed in the study channels

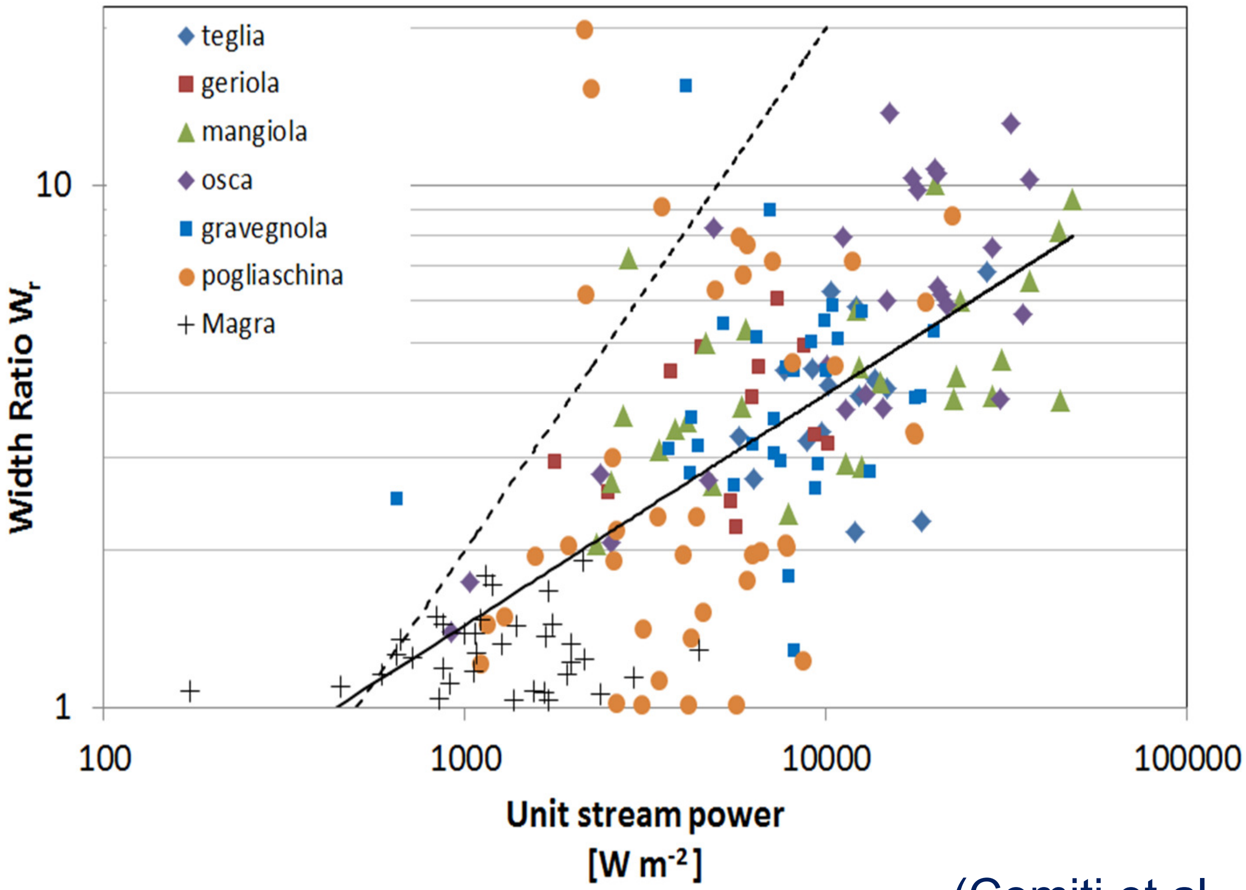
Width ratio

$$W_r = \frac{Post - flood\ width}{Pre - flood\ width}$$



- The narrower the channel, the largest the max widening
- Very large scatter for similar channel size

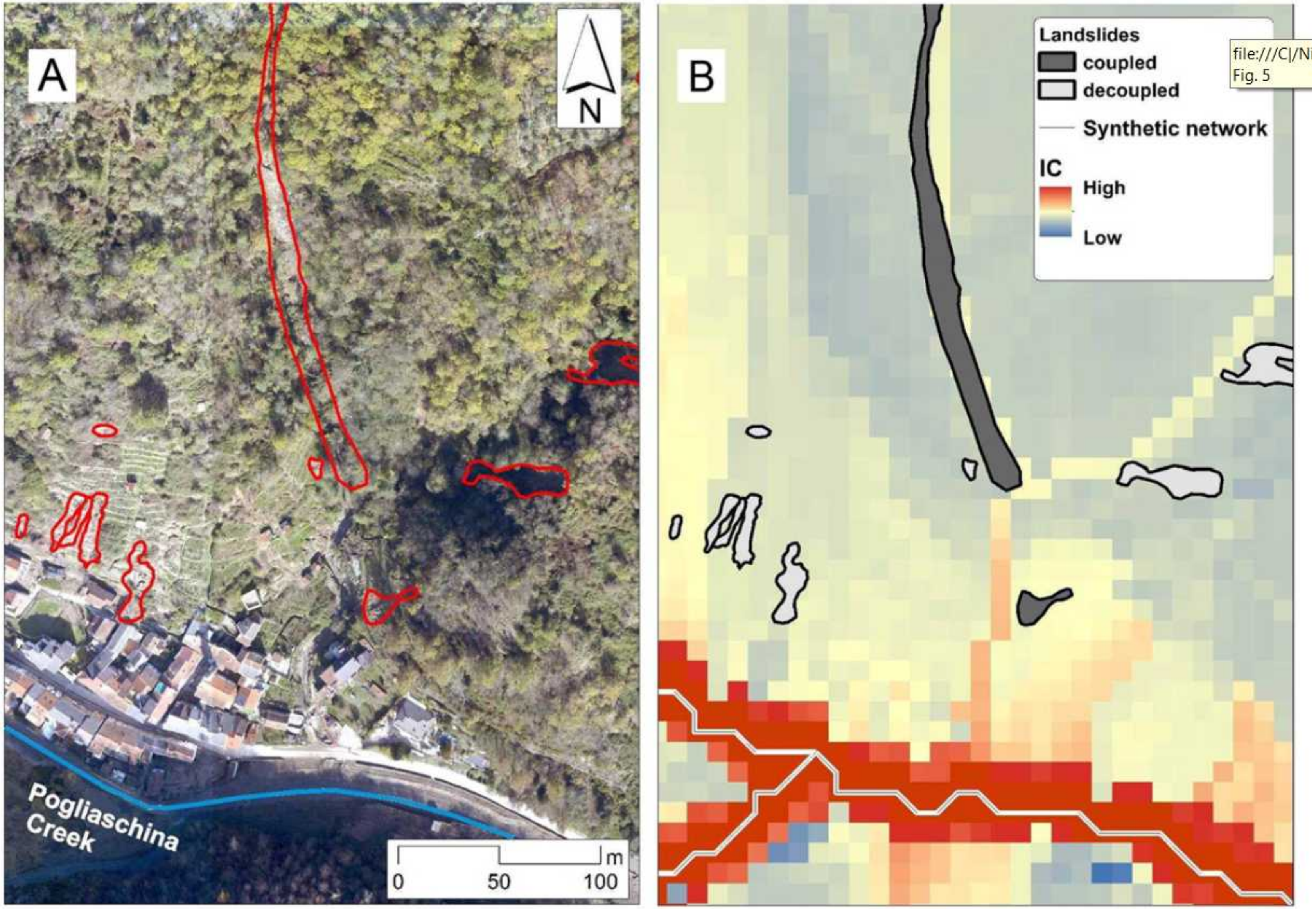
Relation between widening («width ratio») and unit stream power



(Comiti et al., 2016)

width ratio = channel width after / channel width before the flood

Sediment connectivity analysis



Multiple regression models between width ratio and controlling factors for the sub-reaches characterized by no-steep slope (< 4%)

	Model 1		Model 2		Model 3		Model 4	
	R^2=0.32 R^2_{adj}=0.29 *p*-value<0.000		R^2=0.35 R^2_{adj}=0.32 *p*-value<0.000		R^2=0.40 R^2_{adj}=0.37 *p*-value<0.000		R^2=0.38 R^2_{adj}=0.35 *p*-value<0.000	
	R^2	*p*-value	R^2	*p*-value	R^2	*p*-value	R^2	*p*-value
C_i	0.23	0.0000	0.23	0.0000	0.23	0.0004	0.23	0.0000
Artificial Structures	0.05	0.4247	0.05	0.1758	0.05	0.0729	0.05	0.9186
Sediment supply	0.11	0.0022	0.11	0.0004	0.11	0.0044	0.11	0.0028
Slope	0.01	0.7999	-	-	-	-	-	-
Ω (Wm^{-1})	-	-	1.33E-06	0.0458	-	-	-	-
ω_{before} (Wm^{-2})	-	-	-	-	0.14	0.0011	-	-
ω_{after} (Wm^{-2})	-	-	-	-	-	-	0.12	0.0061

(Surian et al., in review)

Multiple regression models between width ratio and controlling factors for the sub-reaches characterized by steep slope (> 4%)

	Model 1		Model 2		Model 3		Model 4	
	R^2=0.45 R^2_{adj}=0.42 *p*-value<0.000		R^2=0.66 R^2_{adj}=0.64 *p*-value<0.000		R^2=0.67 R^2_{adj}=0.66 *p*-value<0.000		R^2=0.44 R^2_{adj}=0.42 *p*-value<0.000	
	R^2	*p*-value	R^2	*p*-value	R^2	*p*-value	R^2	*p*-value
C_i	0.43	0.0000	0.43	0.0000	0.43	0.0000	0.43	0.0000
Sediment supply	0.03	0.4226	0.03	0.1836	0.03	0.3047	0.03	0.3575
Slope	0.02	0.3389	-	-	-	-	-	-
Ω (Wm^{-1})	-	-	0.44	0.0000	-	-	-	-
ω_{before} (Wm^{-2})	-	-	-	-	0.50	0.0000	-	-
ω_{after} (Wm^{-2})	-	-	-	-	-	-	0.02	0.7305

(Surian et al., in review)

Some remarks on the Magra flood

- ✓ **magnitude of changes**: very intense channel widening (in several reaches channel widening took up most of the alluvial plain)
- ✓ **controlling factors**: besides hydraulic variables (unit stream power), channel confinement, hillslope sediment supply, artificial structures are significant
- ✓ regression models as **predictive tools** of channel widening: more reliable in the steep channels, less in the no-steep channels

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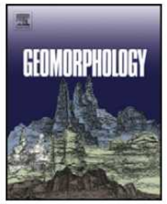

Channel response to extreme floods: Insights on controlling factors from six mountain rivers in northern Apennines, Italy

CrossMark

Nicola Surian [a,*], Margherita Righini [a], Ana Lucía [b], Laura Nardi [c], William Amponsah [d,e], Marco Benvenuti [c], Marco Borga [e], Marco Cavalli [d], Francesco Comiti [b], Lorenzo Marchi [d], Massimo Rinaldi [c], Alessia Viero [d]

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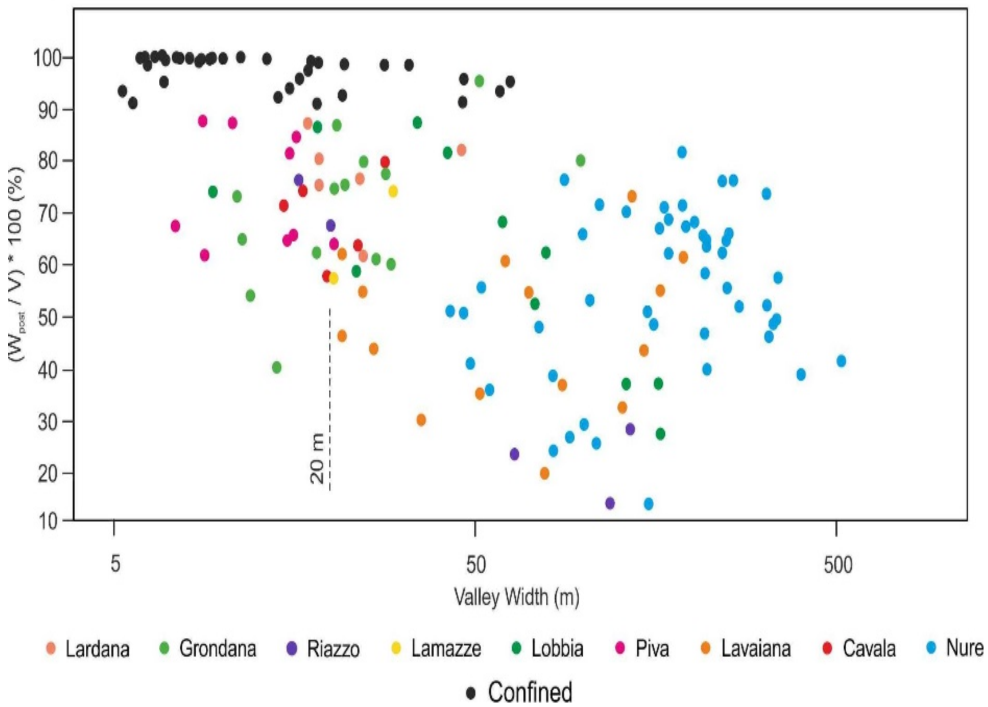
Final remarks

- ✓ *Integrated approach*: crucial for a comprehensive analysis of extreme floods
- ✓ *Complex channel response*: hydraulic variables are not sufficient to explain geomorphic response (e.g. Costa & O'Connor, 1995; Dean & Schmidt, 2013; Thompson & Croke, 2013; Buraas et al., 2014); confinement is a key factors; unit stream power calculated on pre-flood channel width

- ✓ *Hazard assessment*: channel often takes up the whole valley floor, in small streams; widening and lateral confinement are well related; widening often coupled with aggradation
- ✓ Need to include geomorphic processes in hazard assessment and mapping: inundation is not everywhere a major issue, much less relevant than channel dynamics



Credits

- ✓ Margherita Righini, Andrea Brenna, Marco Borga, William Amponsah (*Univ. Padova*)
- ✓ Lorenzo Marchi, Marco Cavalli, Stefano Crema (*CNR-IRPI, Padova*)
- ✓ Francesco Comiti, Vittoria Scorpio, Ana Lucia (*Univ. Bolzano*)
- ✓ Massimo Rinaldi, Laura Nardi, Marco Benvenuti (*Univ. Firenze*)
- ✓ Alessandro Corsini, G. Ciccarese (*Univ. Modena & Reggio Emilia*)
- ✓ Ellen Wohl (*Colorado State Univ.*)
- ✓ Francesco Marra (*Hebrew Univ. of Jerusalem*)

Main pubblications:

- ✓ Scorpio V. et al. (2018), Science of the Total Environment, 640-641, 337-351.
- ✓ Righini M. et al. (2017), Geomorphology, 290, 184-199.
- ✓ Rinaldi M. et al. (2016), Earth Surf. Process. Landf., 41, 835-846.
- ✓ Surian N. et al. (2016), Geomorphology, 272, 78-91.