



**FRANE INDOTTE DA  
PRECIPITAZIONI: PREVISIONE  
E PREVENZIONE**

*Politecnico di Torino  
30 Ottobre 2009*

**RICOSTRUZIONE E MESSA  
IN SICUREZZA A SARNO  
11 ANNI DOPO**

Pasquale Versace

L'evento

# Sarno 1998



















OR  
OU

PREYAN

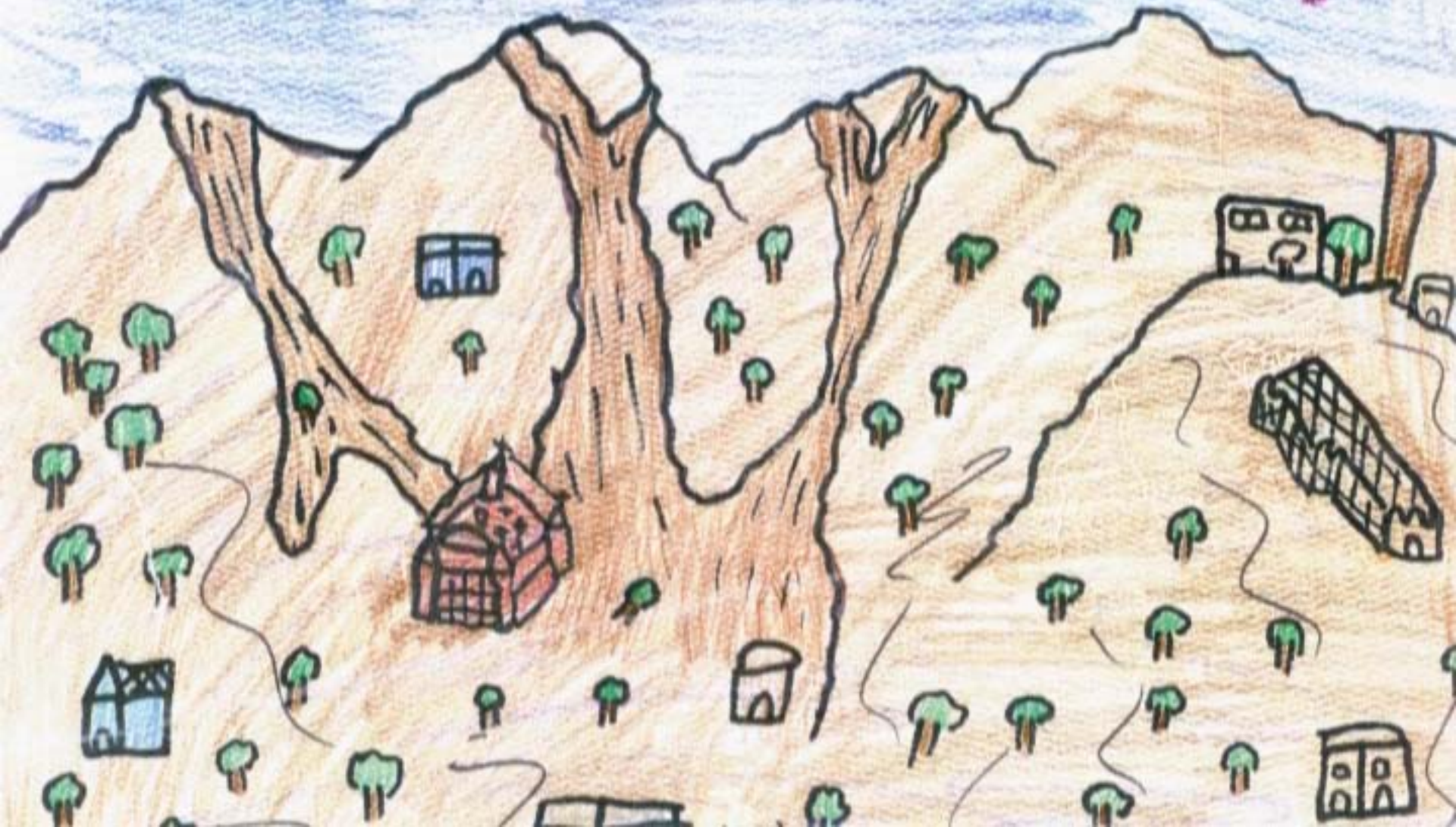




ANTONIO - PAPPENA - SCUOLABORGO - CLASSE II B

ALLUVIONE DEL 5 MAGGIO 1998 - A - SARNO.

CLASSE  
278.



**5 Maggio 1998**

**Sarno, Siano, Quindici, Bracigliano**

**142 frane**

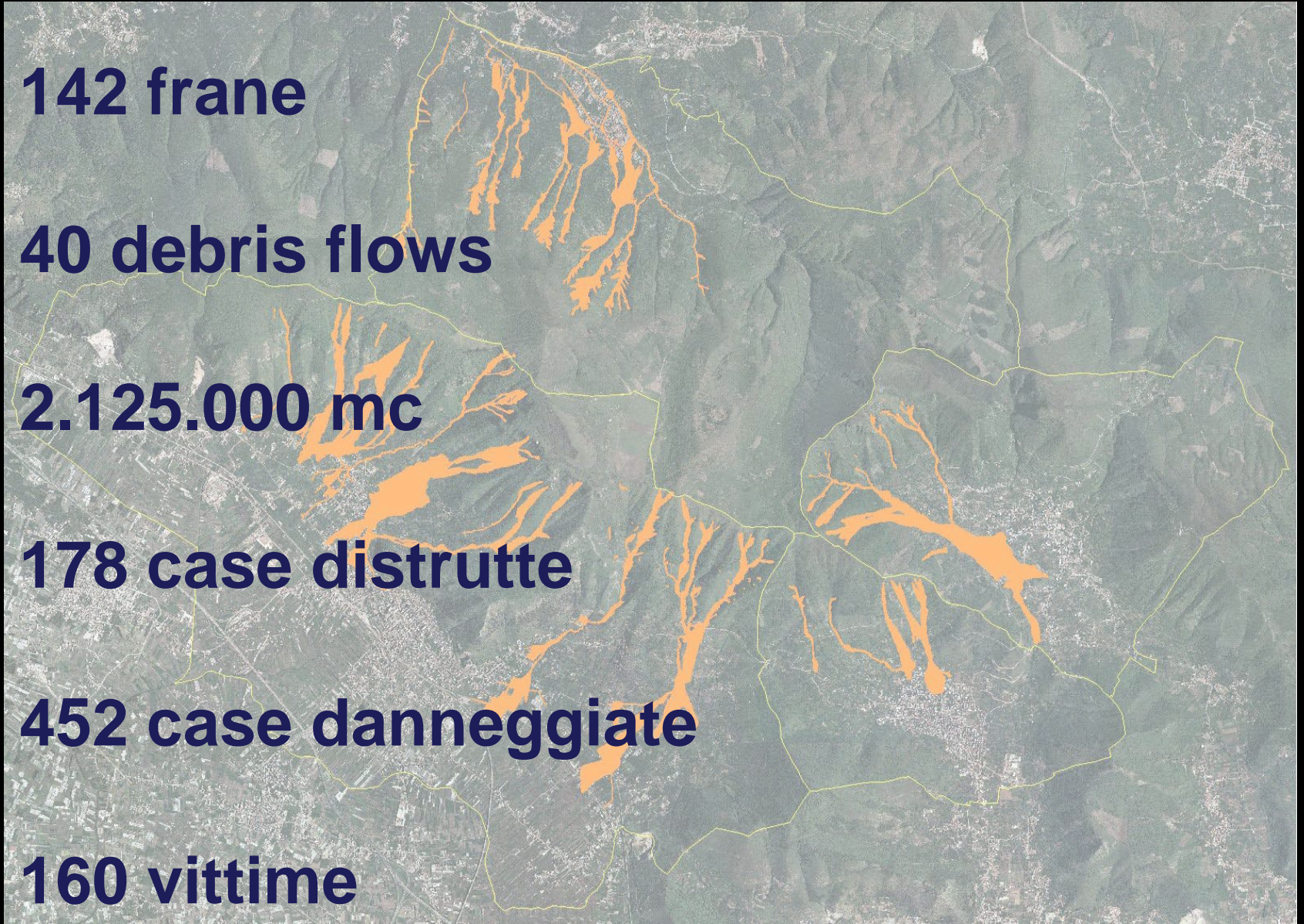
**40 debris flows**

**2.125.000 mc**

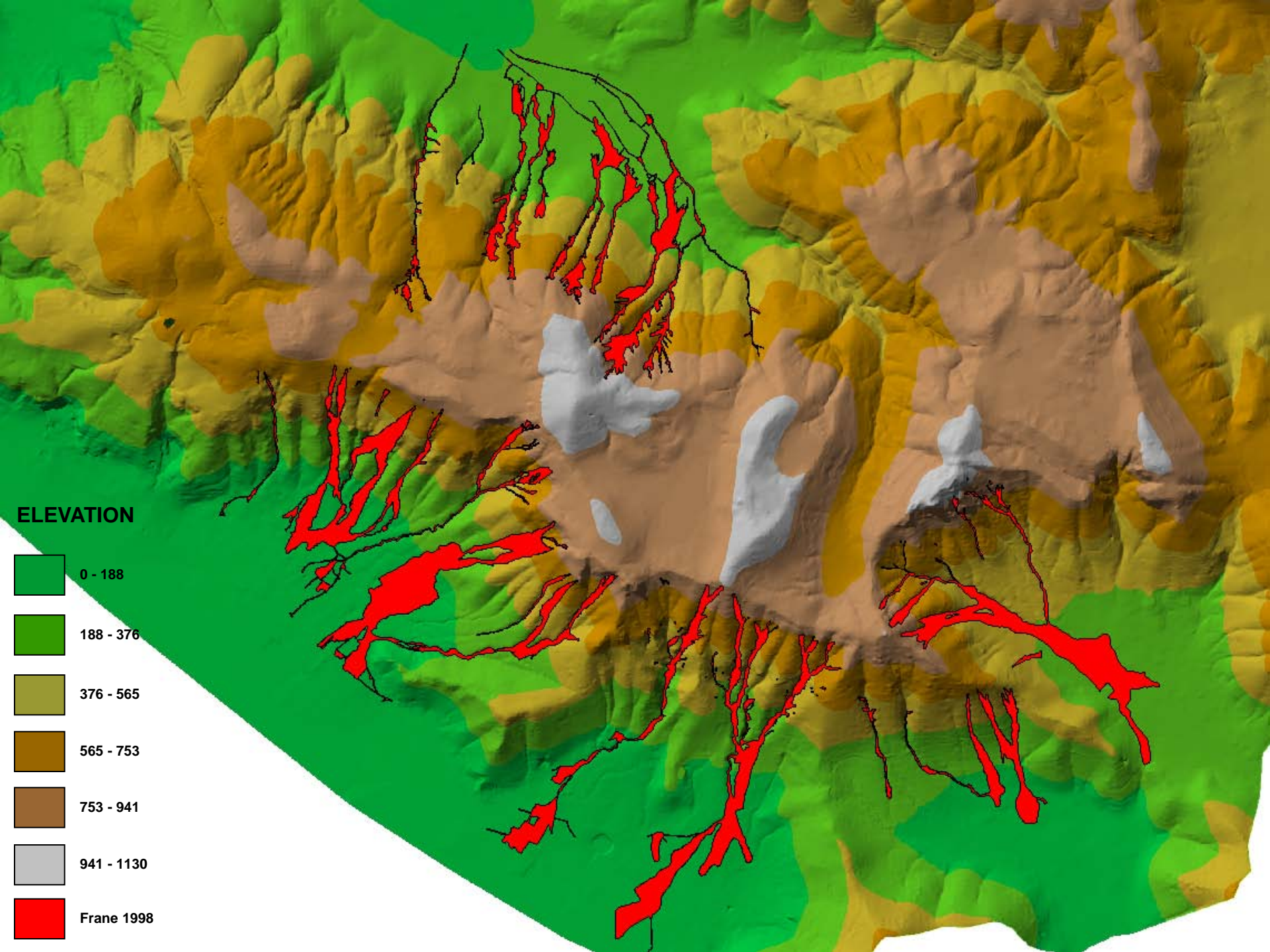
**178 case distrutte**

**452 case danneggiate**

**160 vittime**



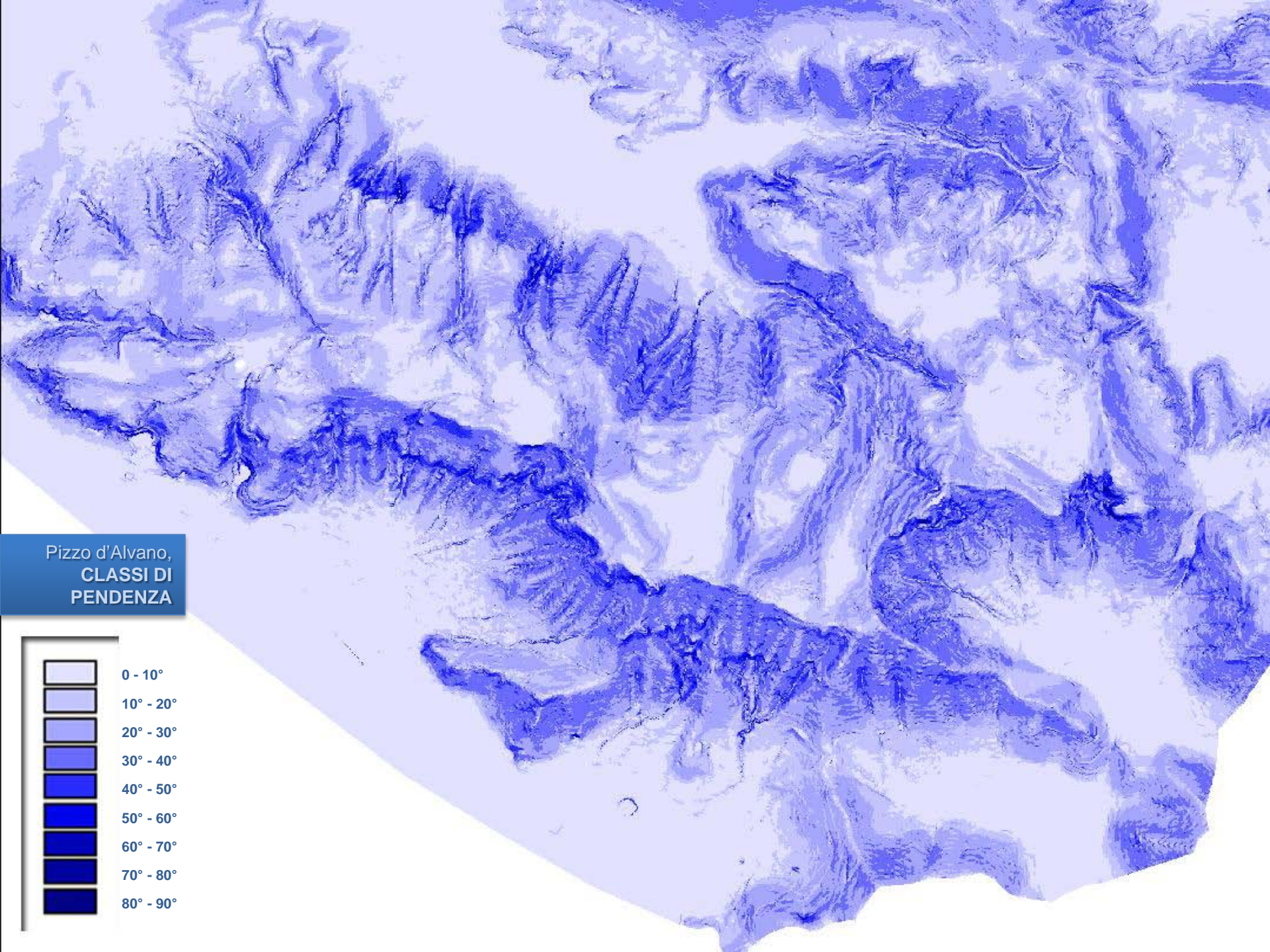




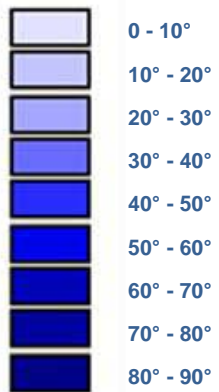
**ELEVATION**

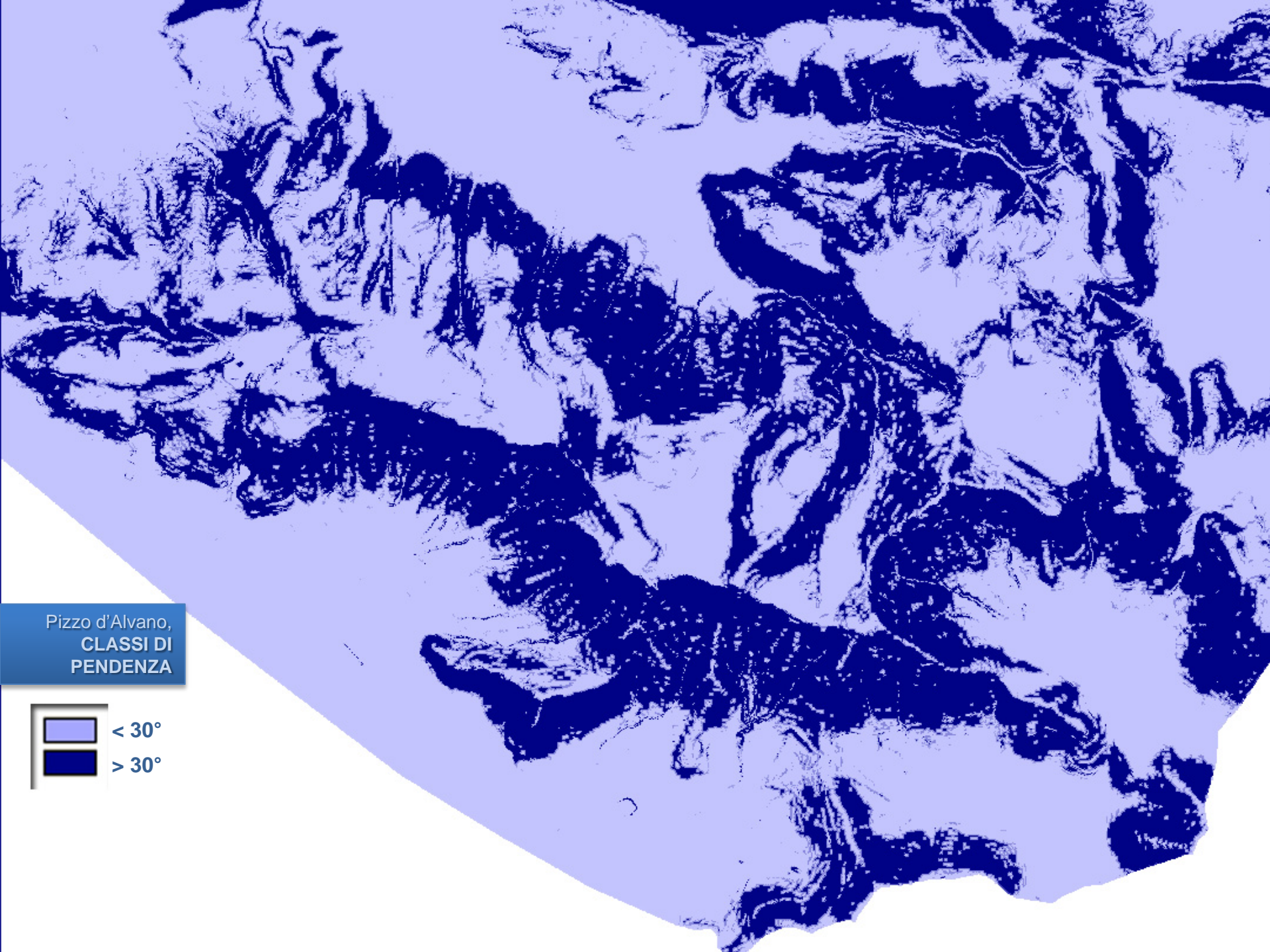
- 0 - 188
- 188 - 376
- 376 - 565
- 565 - 753
- 753 - 941
- 941 - 1130
- Frane 1998



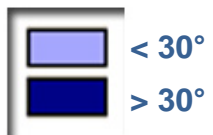


Pizzo d'Alvano,  
**CLASSI DI  
PENDENZA**





Pizzo d'Alvano,  
**CLASSI DI  
PENDENZA**





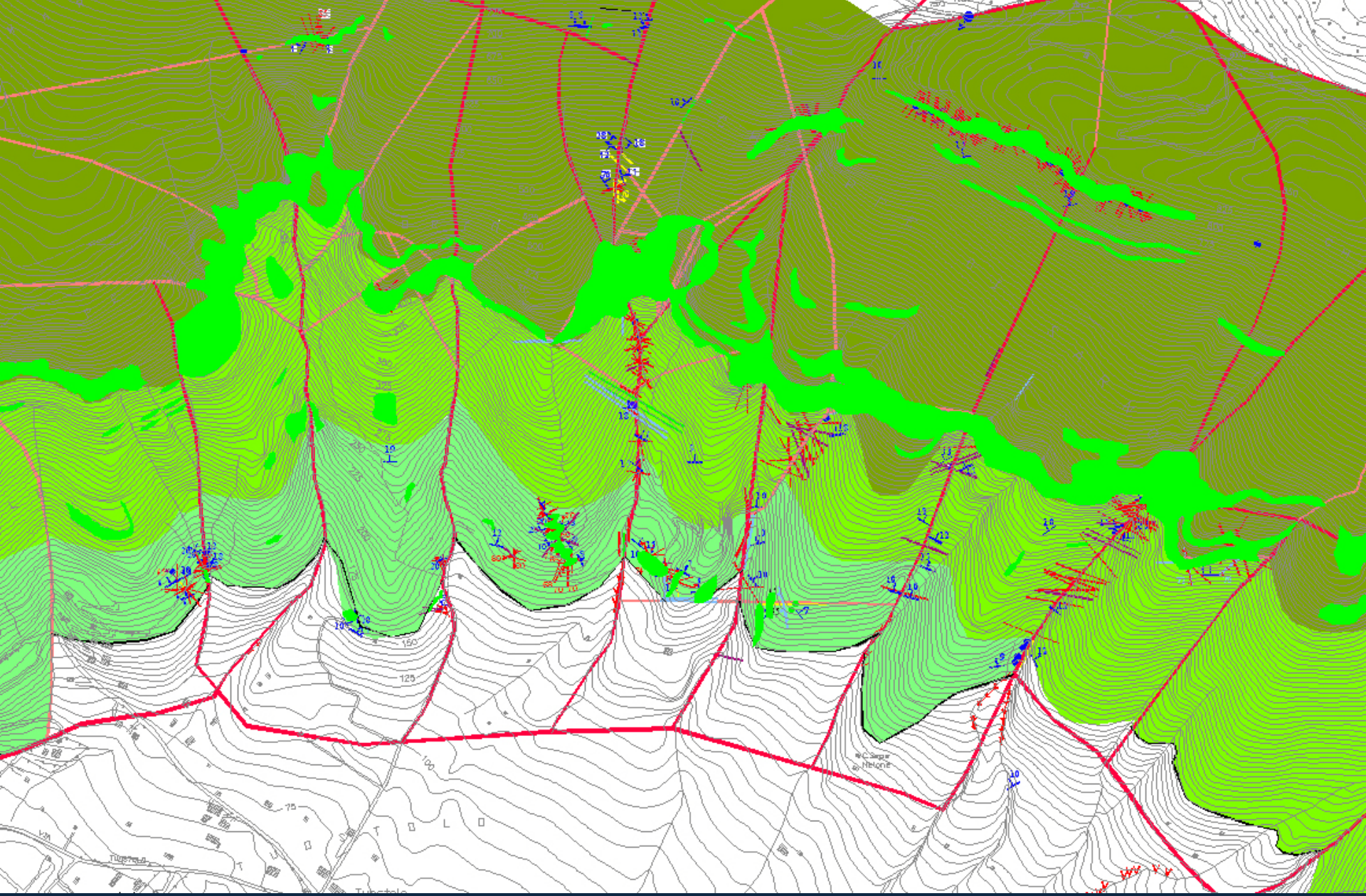
Quindici

**EPISCOPIO**

Sarno

Siano

Bracigliano



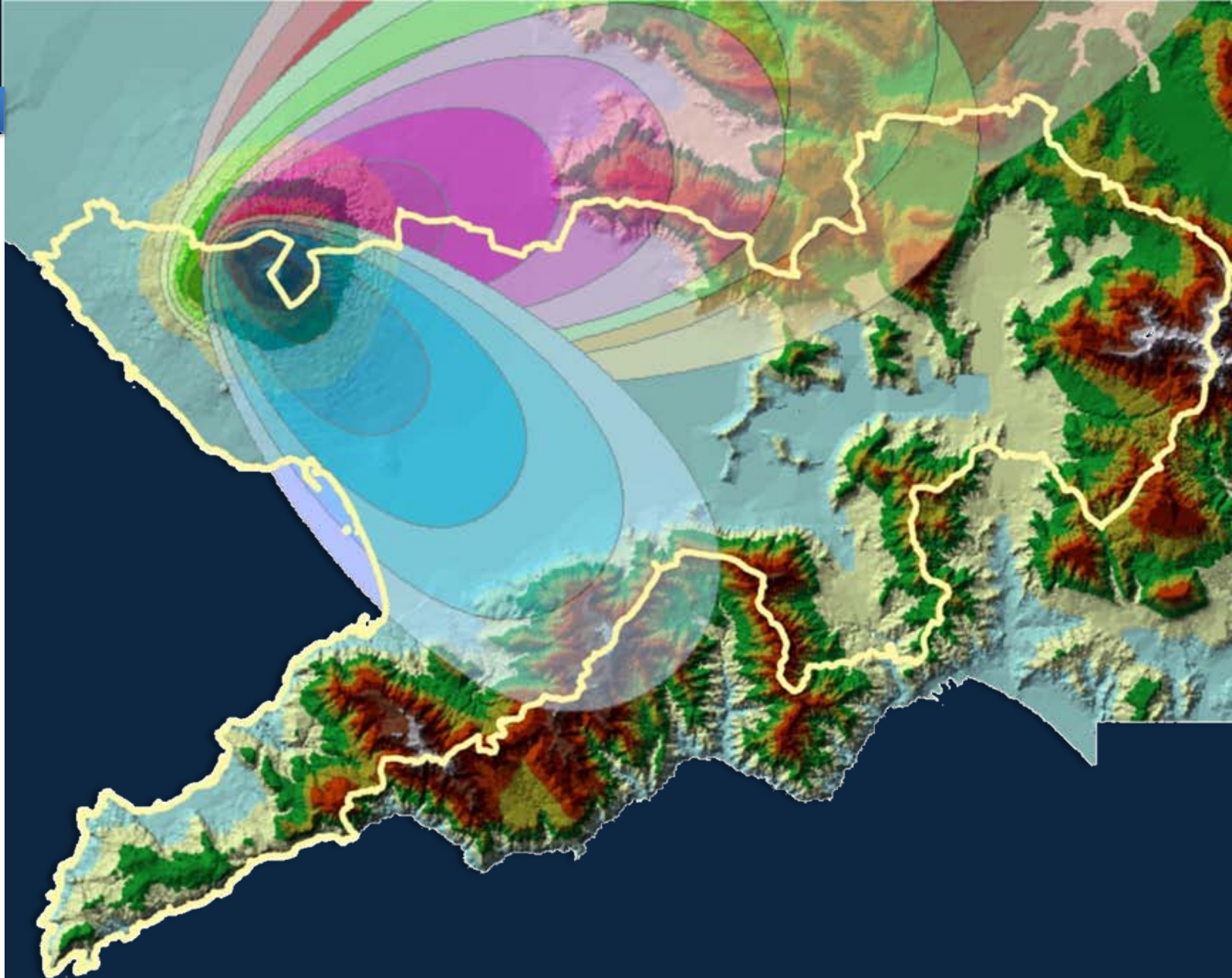
Limestone - Dolomitic complex

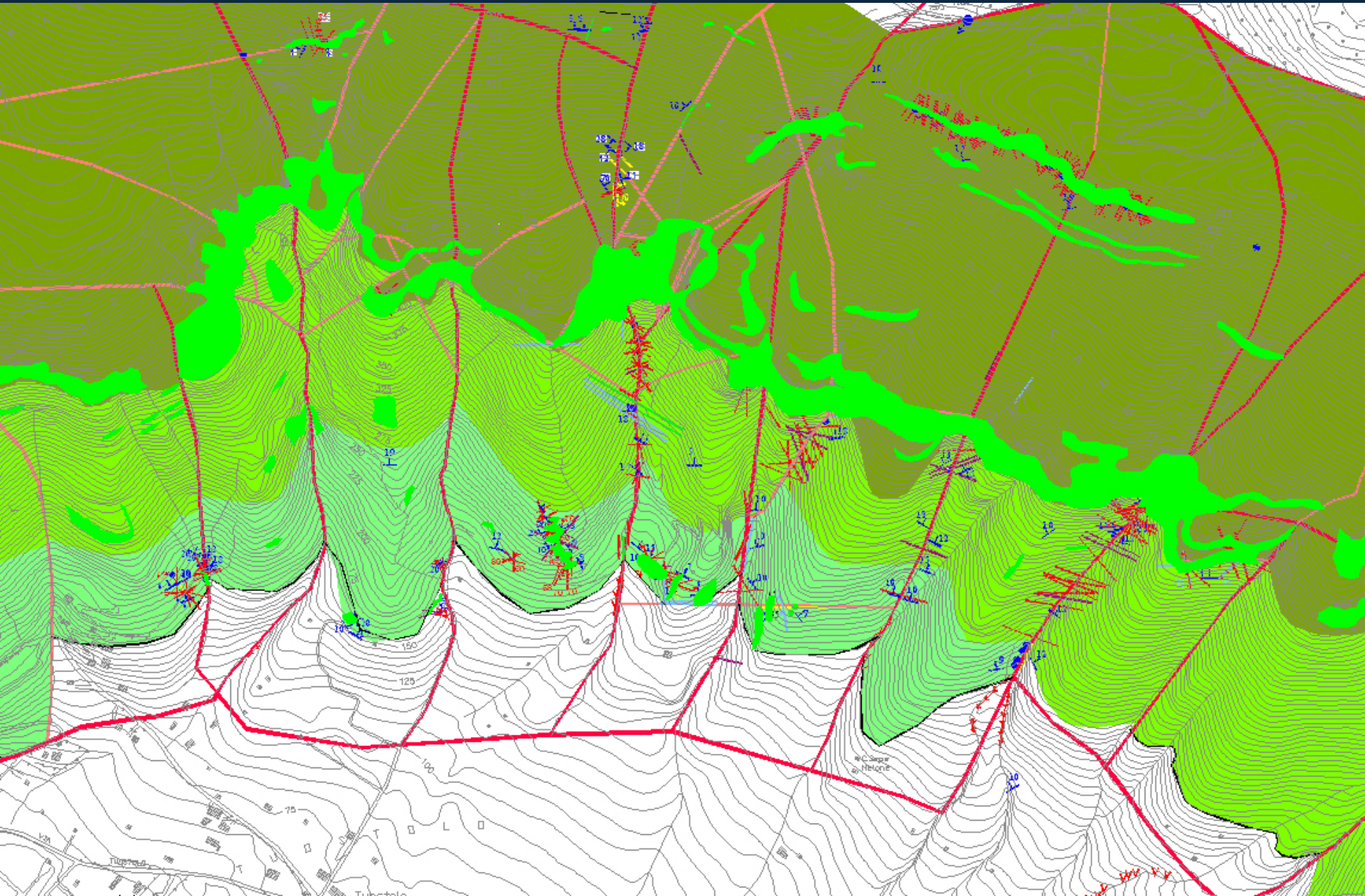




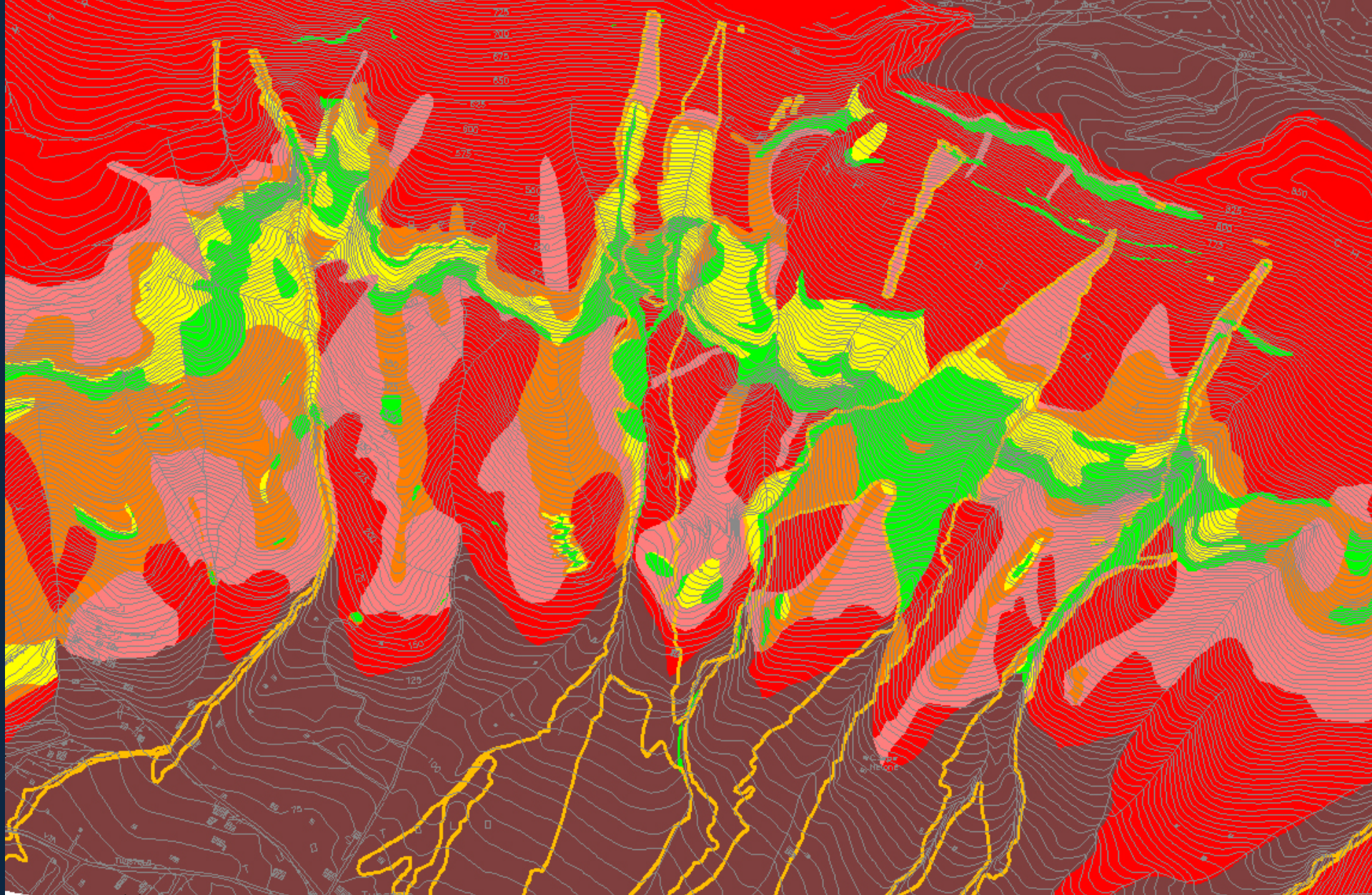
# ISOPACHE

- avellino, 1
- avellino, 2
- avellino, 3
- avellino, 4
- avellino, 5
- ottaviano, 1
- ottaviano, 2
- ottaviano, 3
- ottaviano, 4
- ottaviano, 5
- pollena, 1
- pollena, 2
- pollena, 3
- pollena, 4
- pollena, 5
- pompei, 1
- pompei, 2
- pompei, 3
- pompei, 4
- pompei, 5
- sarno, 1
- sarno, 2
- sarno, 3
- sarno, 4
- sarno, 5













 Calcare

 0.5 – 1 m

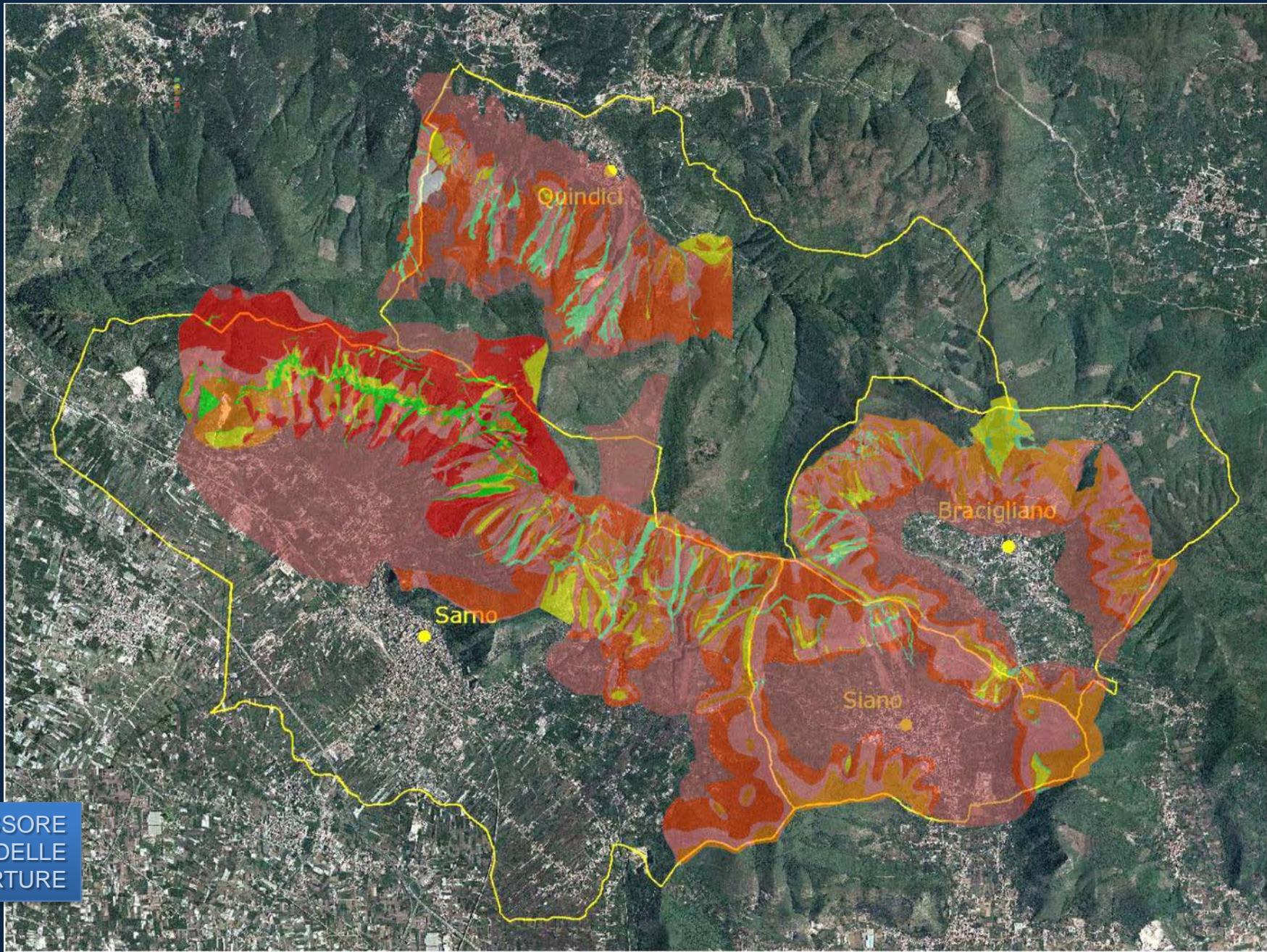
 2 – 5 m

 Frane del maggio 1998

 0 - 0.50 m

 1 – 2 m

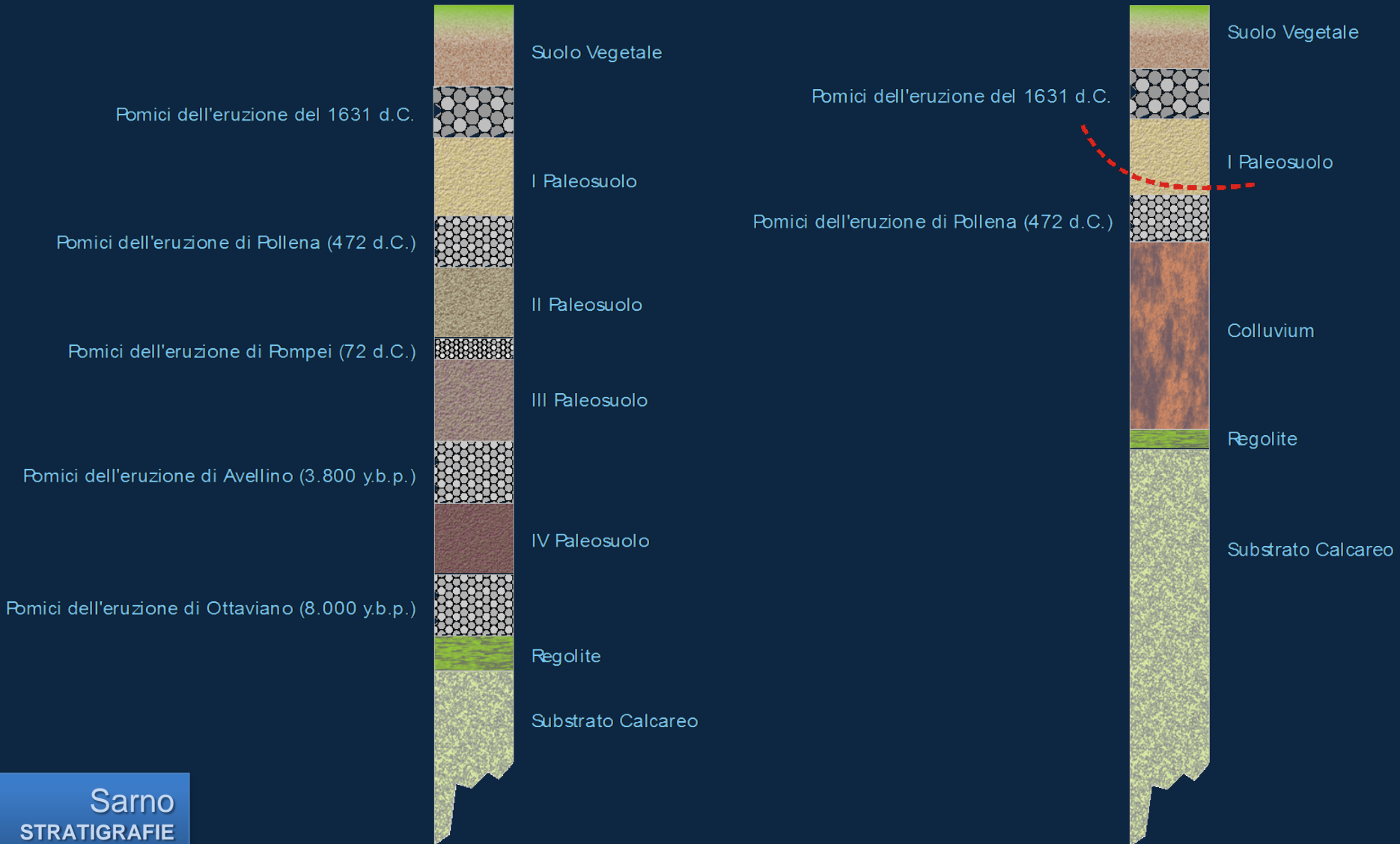
 > 5 m

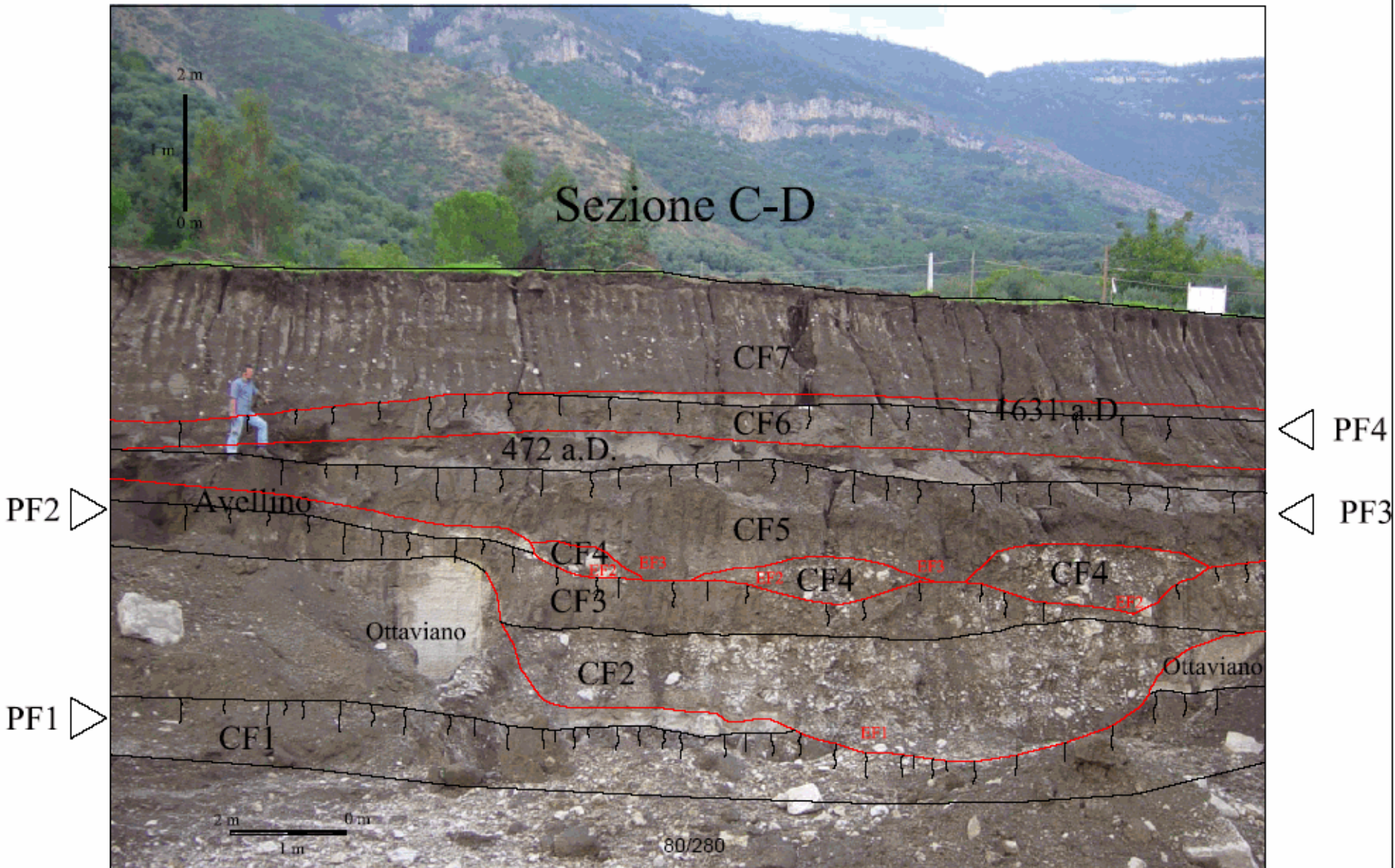


SPESSORE  
DELLE  
COPERTURE

IN POSTO

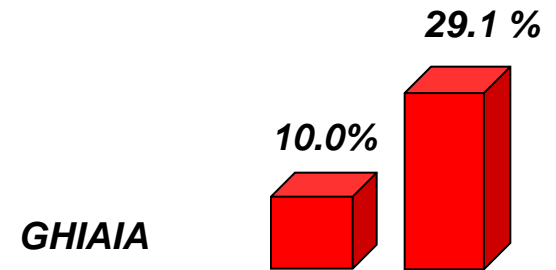
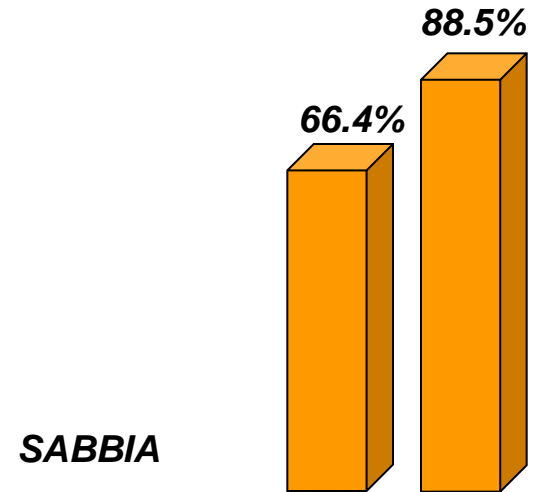
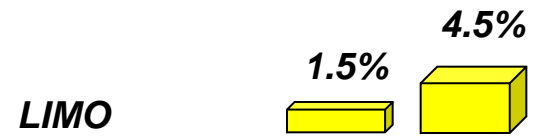
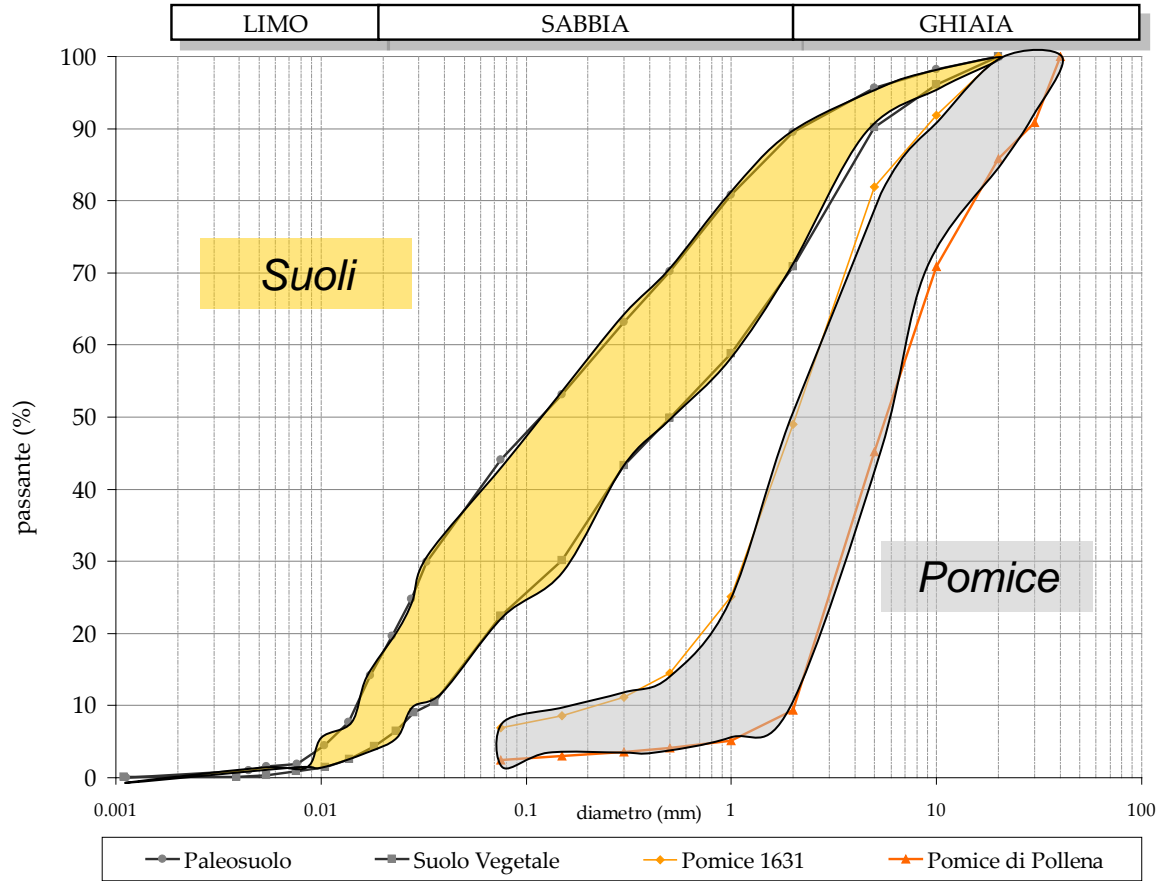
Vallone CURTI





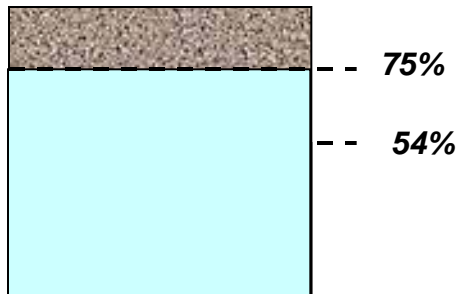


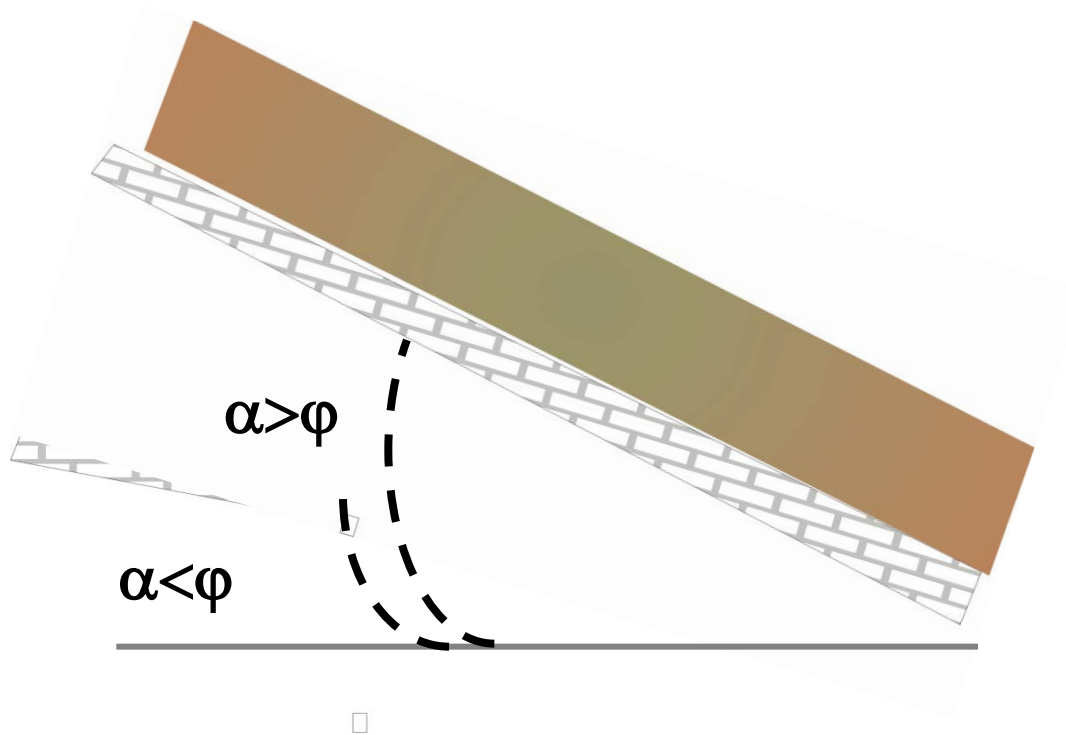
# SARNO: Fusi granulometrici



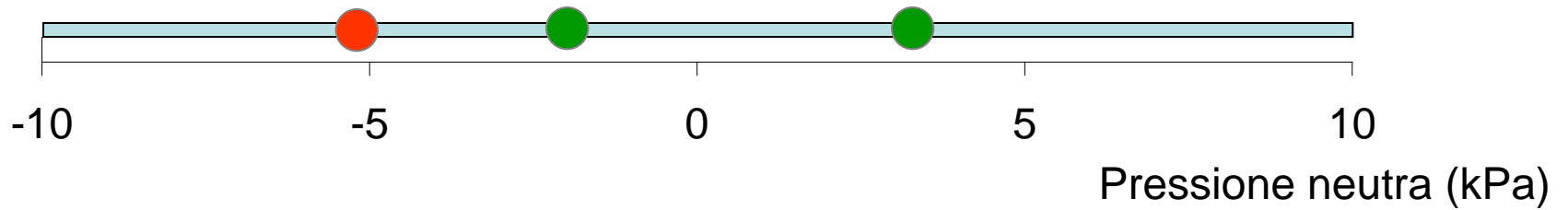
**COESIONE  $\approx 0$**

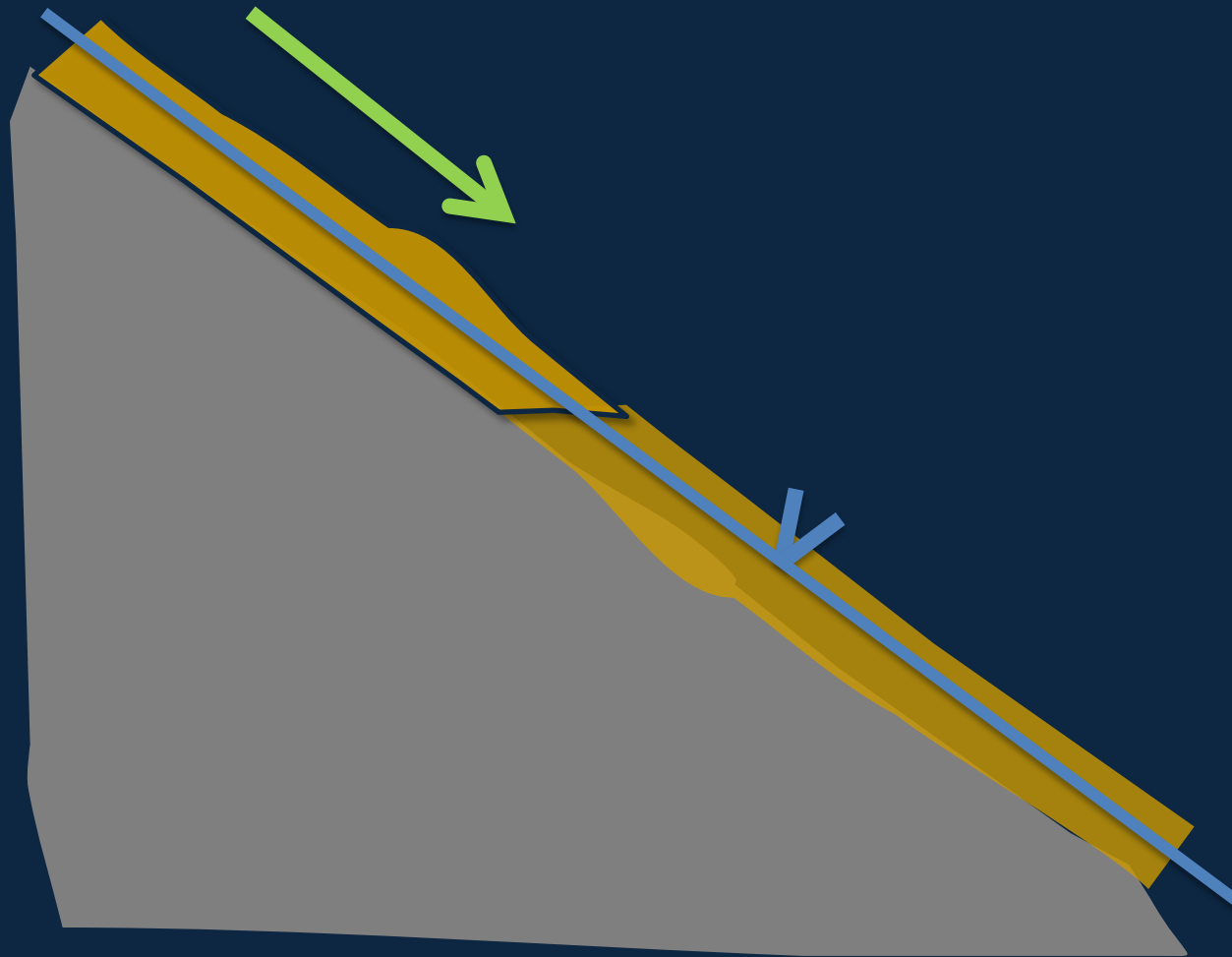
**POROSITA'**





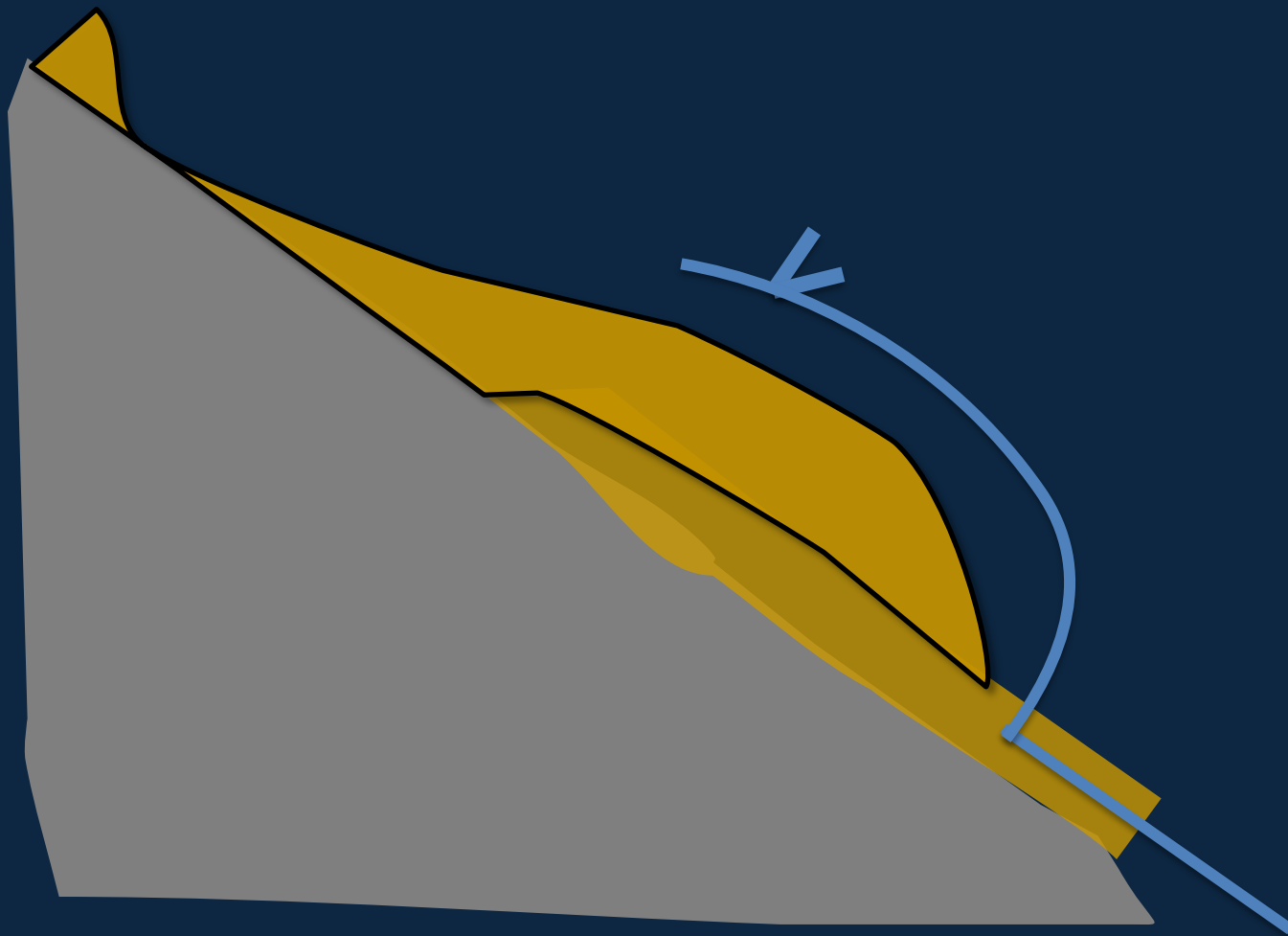
$C \text{ (kPa)} = 0$   
 $\phi = 30-38^\circ$



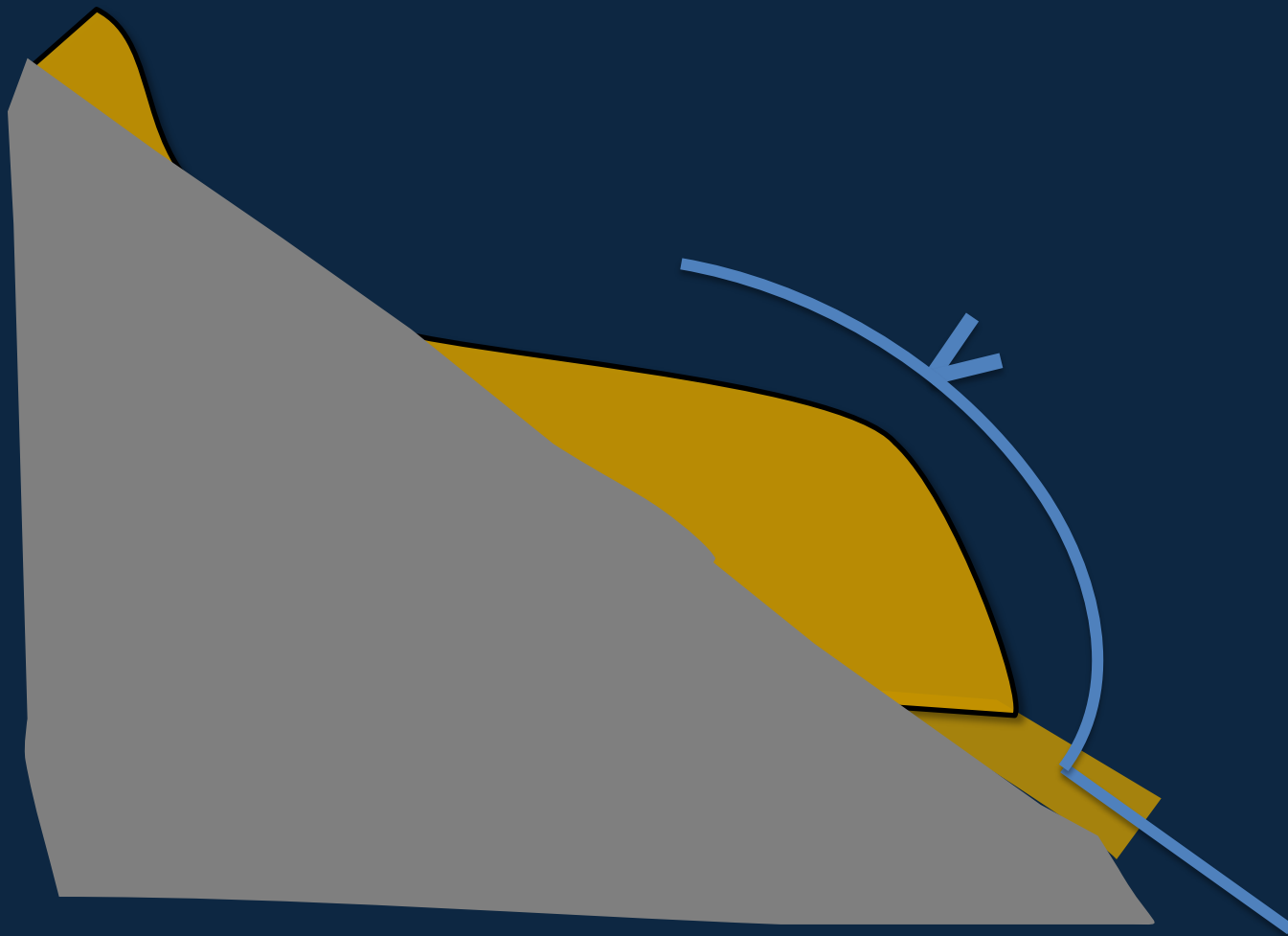


*Hutchinson & Bhandari (1971), Sassa (1985)*

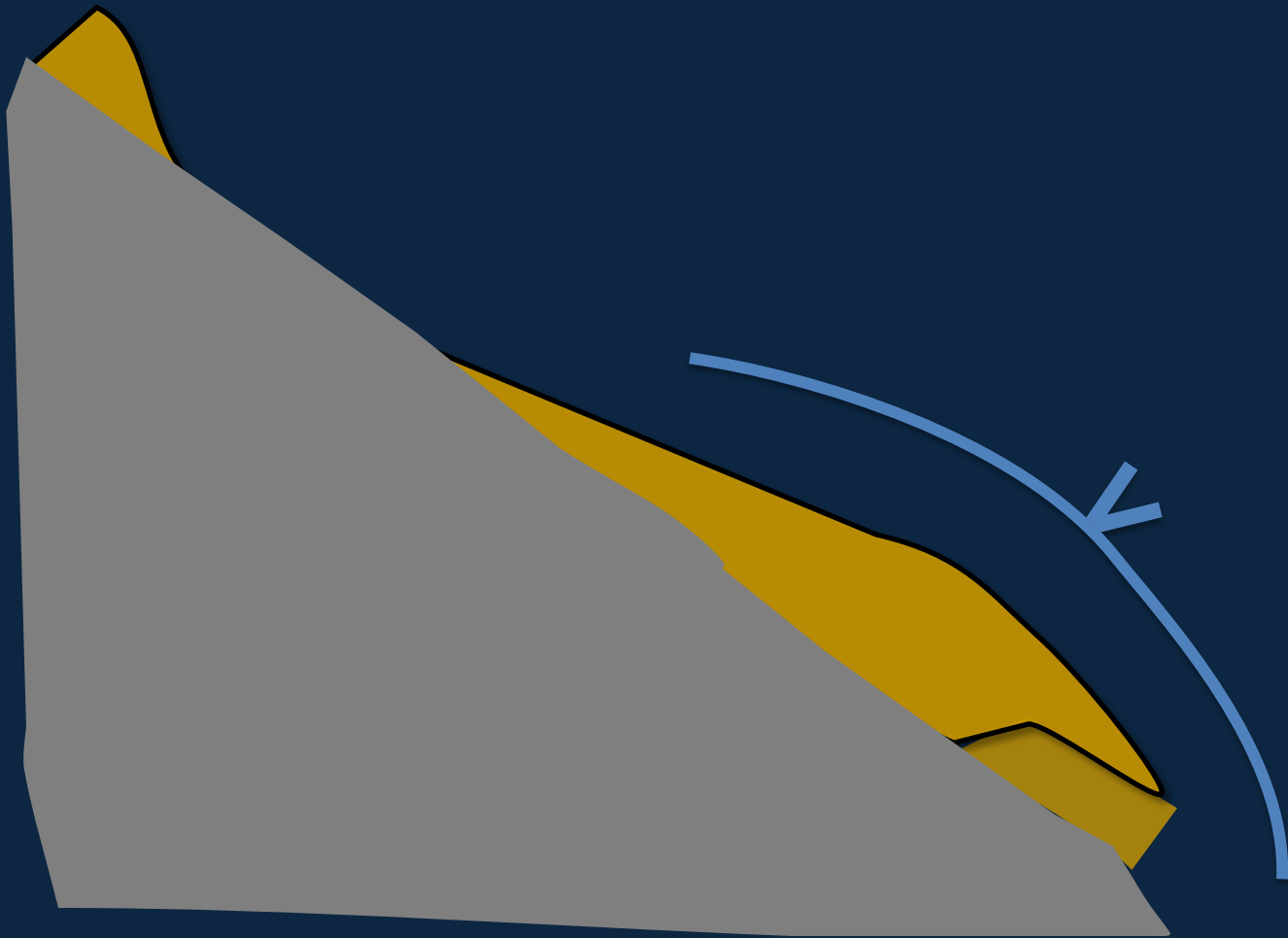




*Hutchinson & Bhandari (1971), Sassa (1985)*

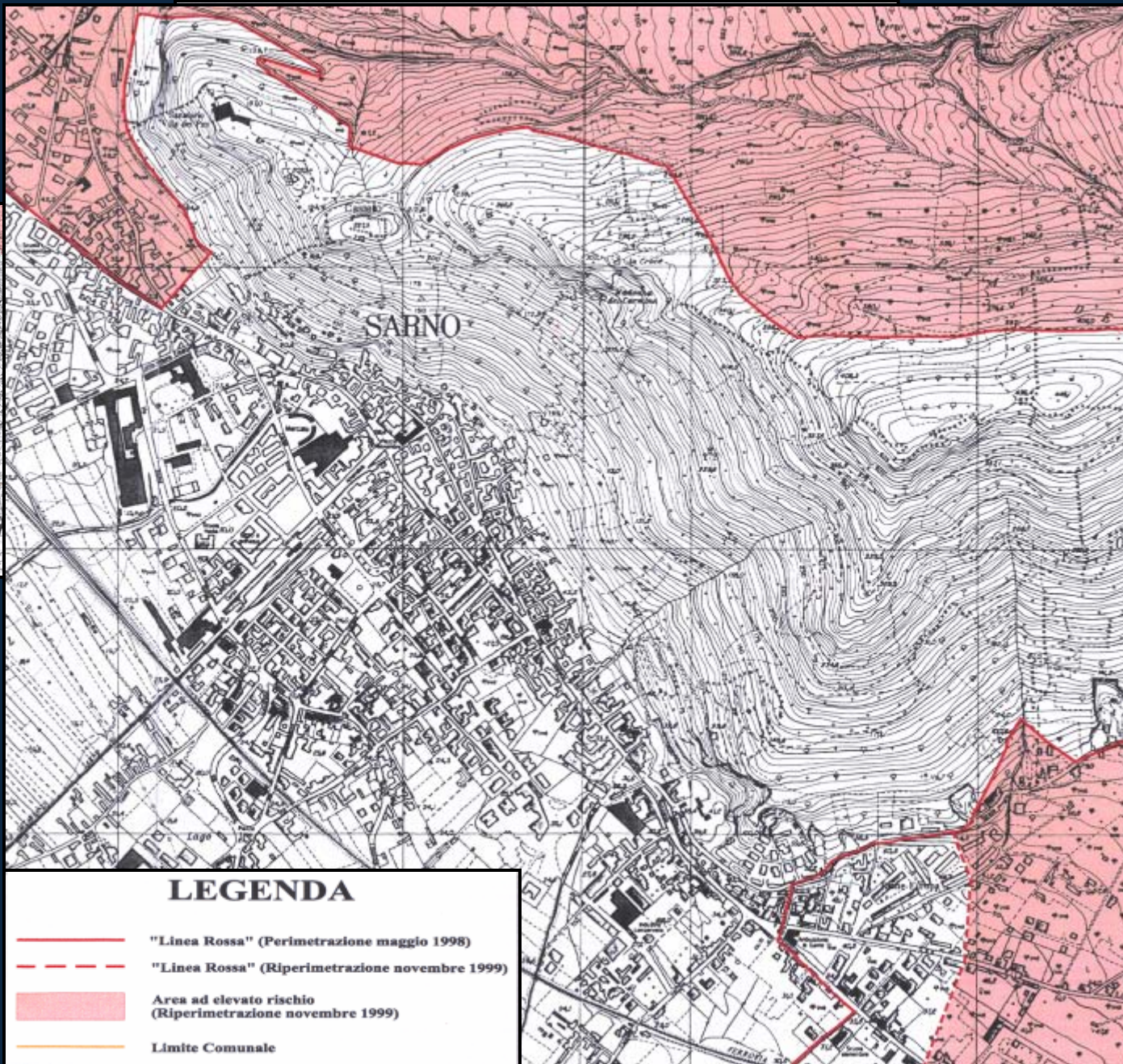


*Hutchinson & Bhandari (1971), Sassa (1985)*







*Hutchinson & Bhandari (1971), Sassa (1985)*





## LEGENDA

-  "Linea Rossa" (Perimetrazione maggio 1998)
-  "Linea Rossa" (Riperimetrazione novembre 1999)
-  Area ad elevato rischio (Riperimetrazione novembre 1999)
-  Limite Comunale

# Risk Mitigation

Structural measures

17



CURTI

EPISCOPIO

Sarno

vasca Episcopio

feb 04 – gen 06

13,7 Meuro



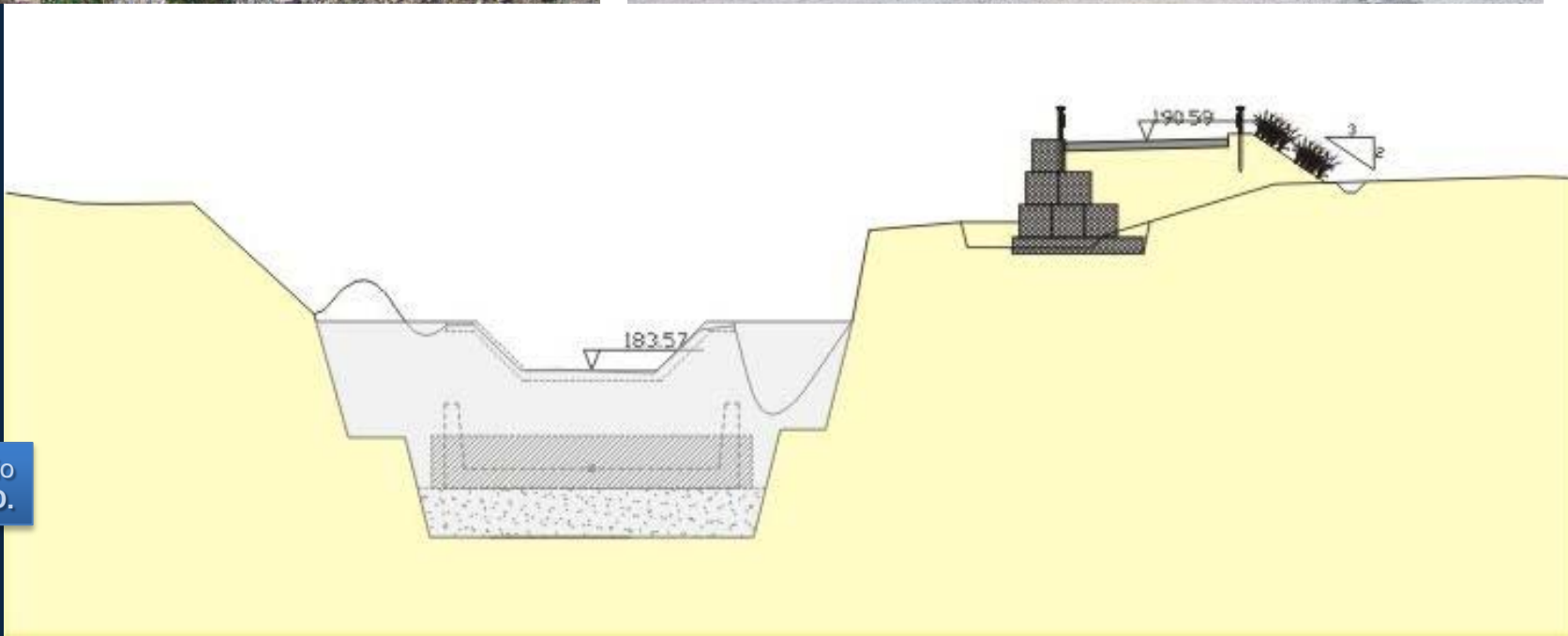




Sarno Episcopo  
MAGGIO 1988



Vasca Episcopio  
MAGGIO 2007



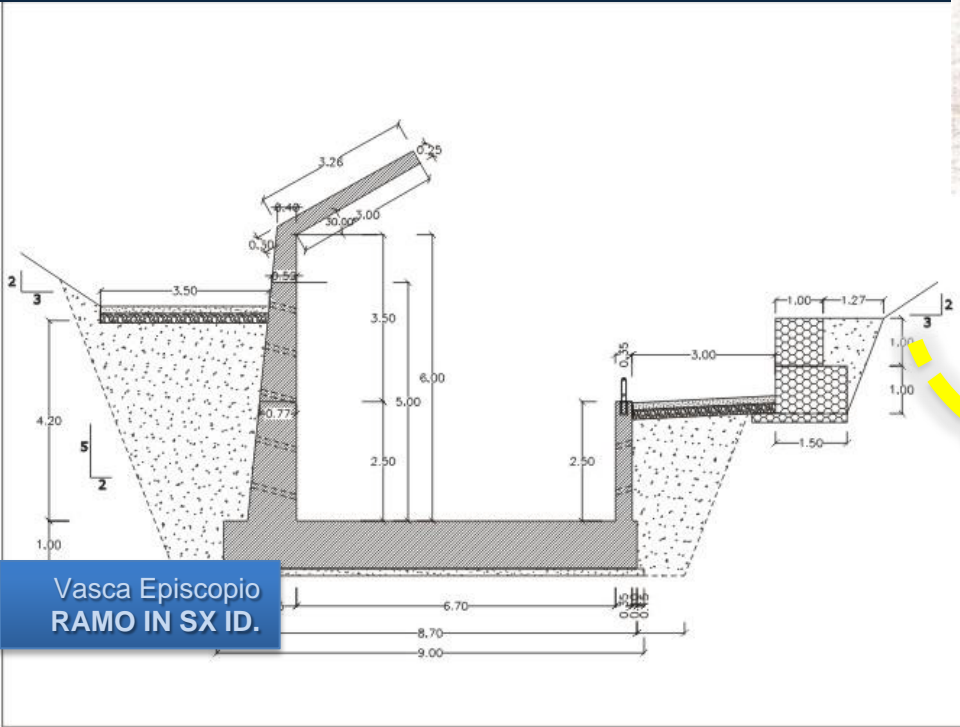
Vasca Episcopio  
RAMO IN DX ID.



Vasca Episcopio  
RAMO IN DX ID.



Vasca Episcopo  
RAMO IN SX ID.



Vasca Episcopio  
RAMO IN SX ID.





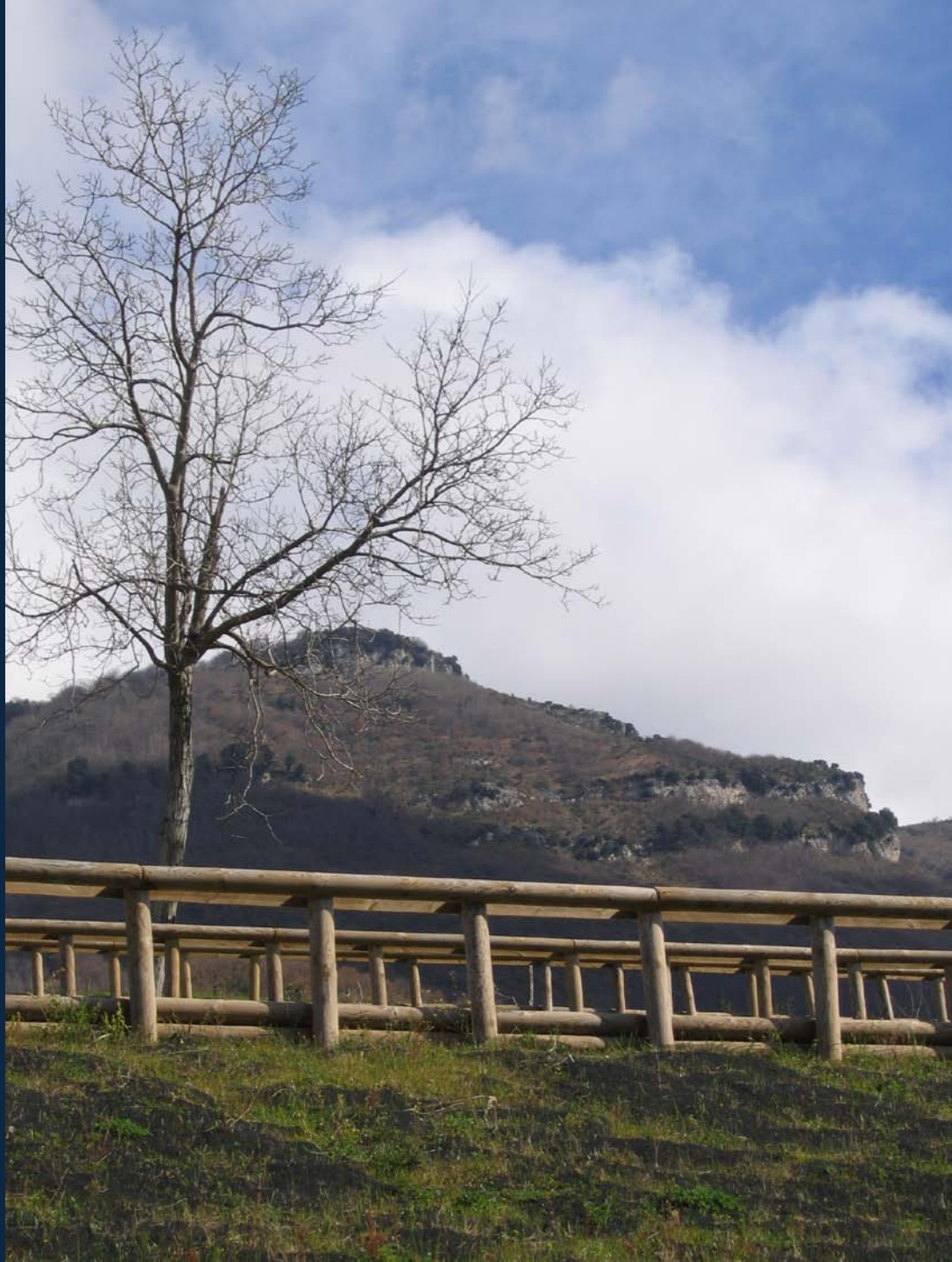
















Vasca Episcopo  
CANTARIELLO





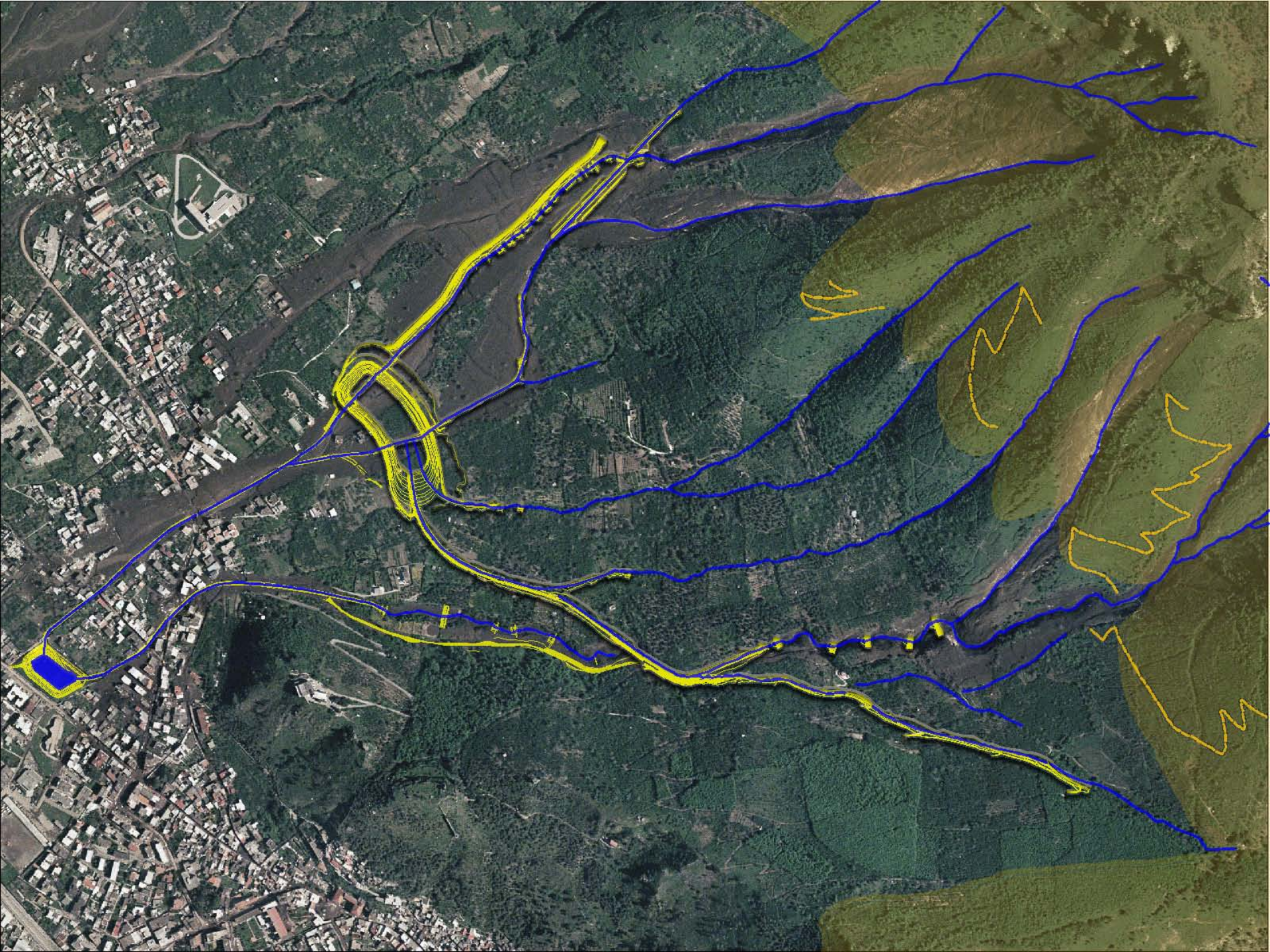
Vasca Episcopo  
**CANTARIELLO**

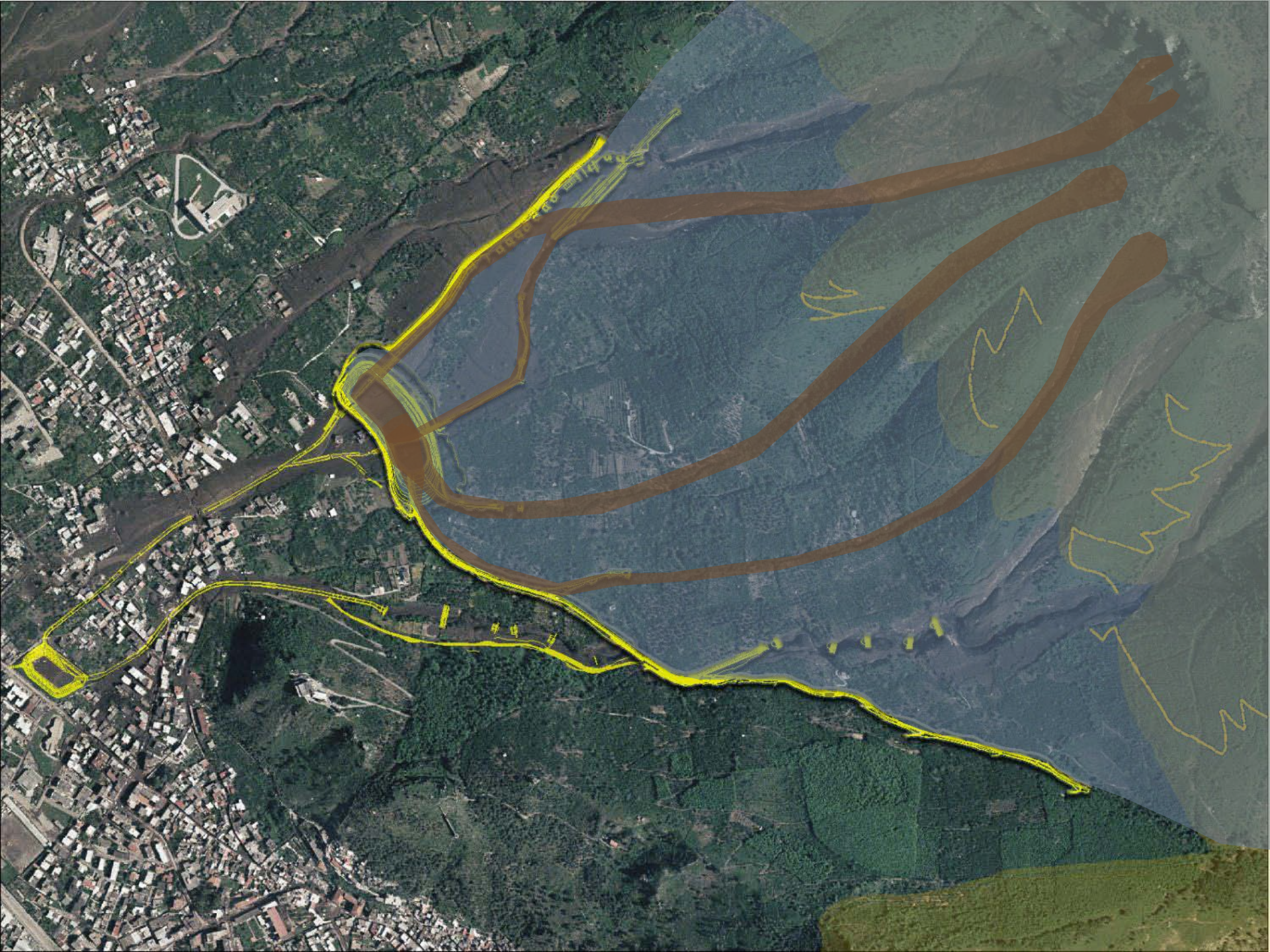


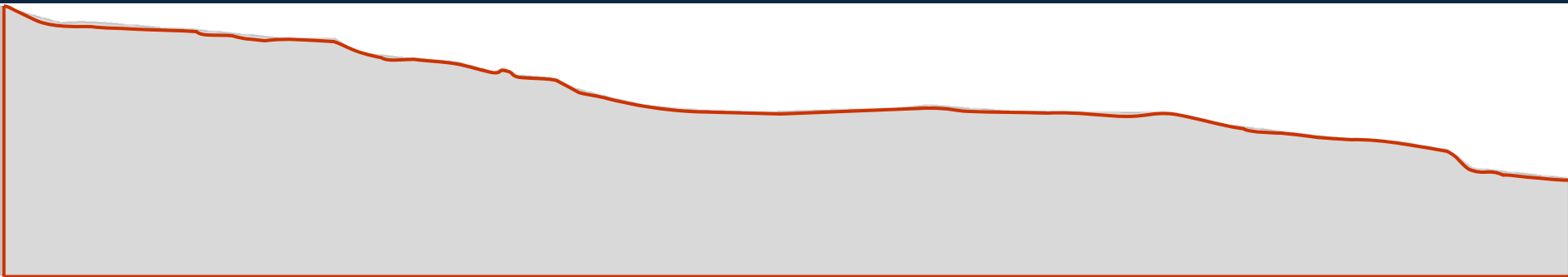
Vasca Episcopio  
**CANTARIELLO**

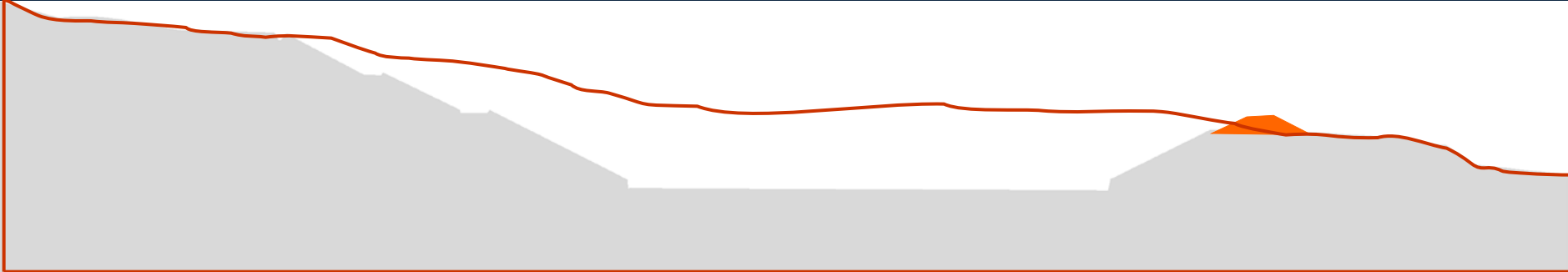


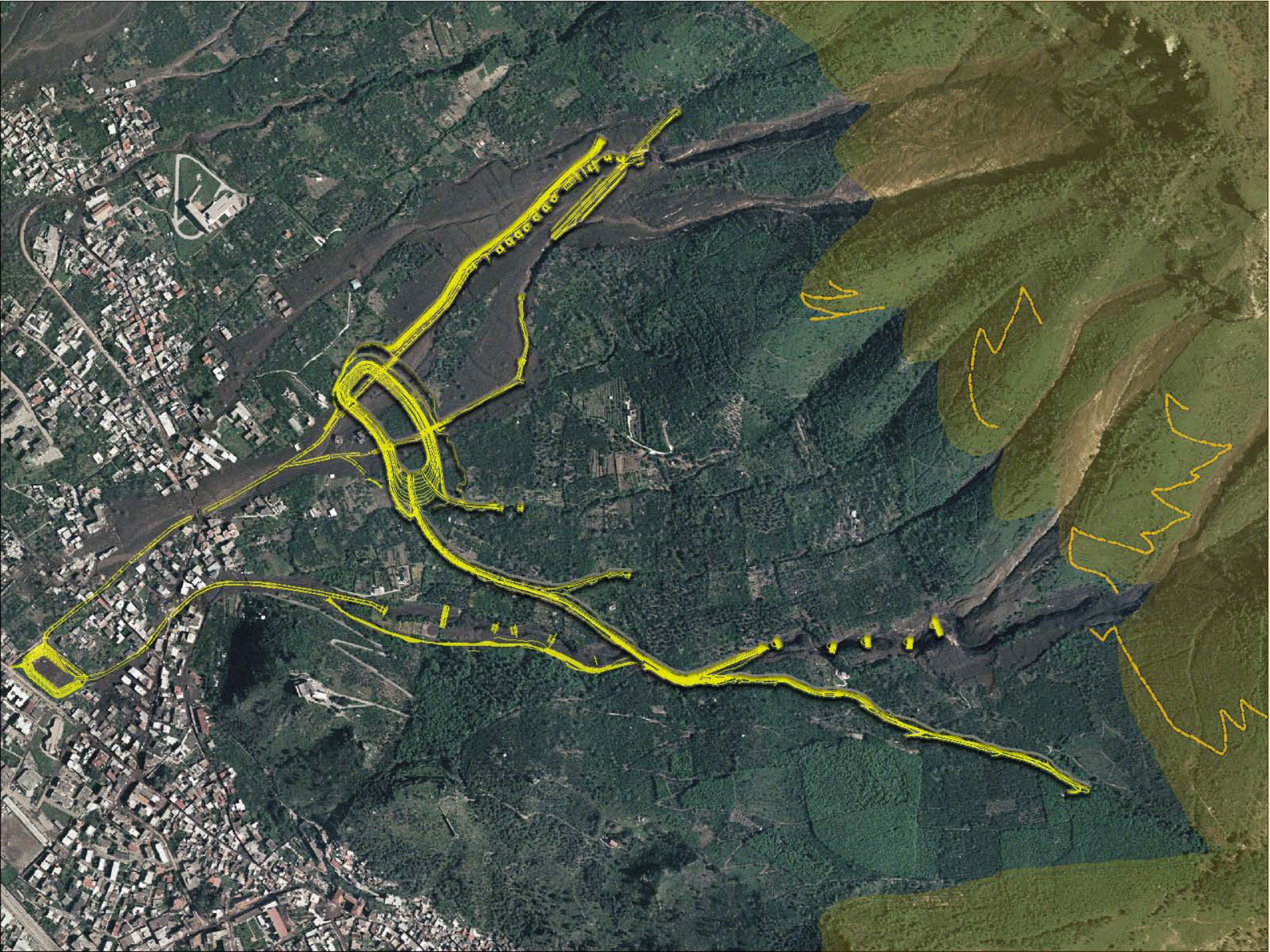
Vasca Episcopo  
**CANTARIELLO**













Quindici

vasca Connola

giu 04 – dic 06

9,5 Meuro





Quindici  
**VASCA CONNOLA**  
Ultimata









VASCO CONNOLA  
Quindici

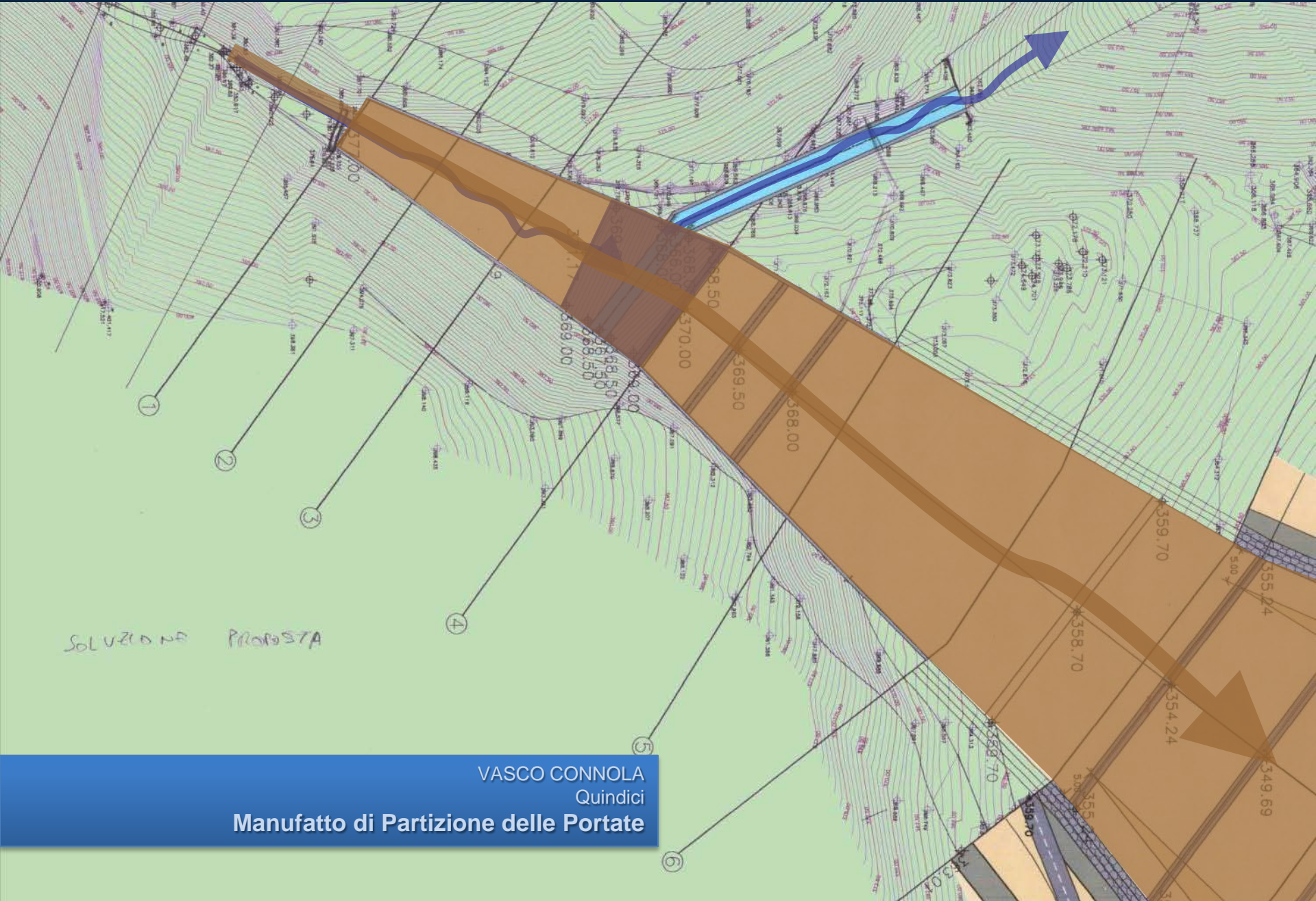
**Manufatto di Deviazione delle Portate**

VASCO CONNOLA  
Quindici

## Manufatto di Deviazione delle Portate







SOLUZIONE PROPOSTA

VASCO CONNOLA  
Quindici  
Manufatto di Partizione delle Portate

Siano

vallo trasversale

# DIVERSION STRUCTURE / Siano

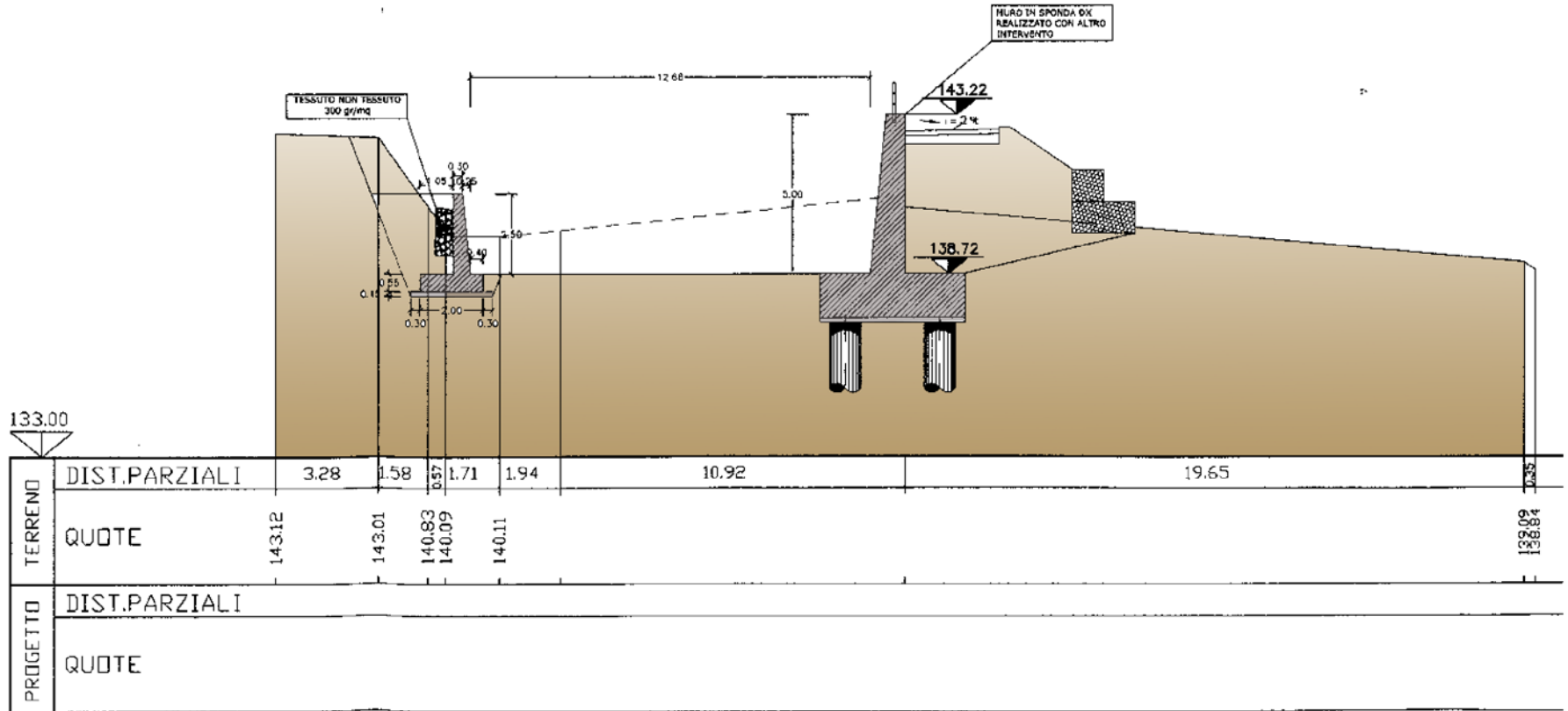


# DIVERSION STRUCTURE / Siano



SEZ.NUM. 99

PROGR. 360.15  
PARZ. 21.64





# DIVERSION STRUCTURE / Siano



Ingegneria

naturalistica





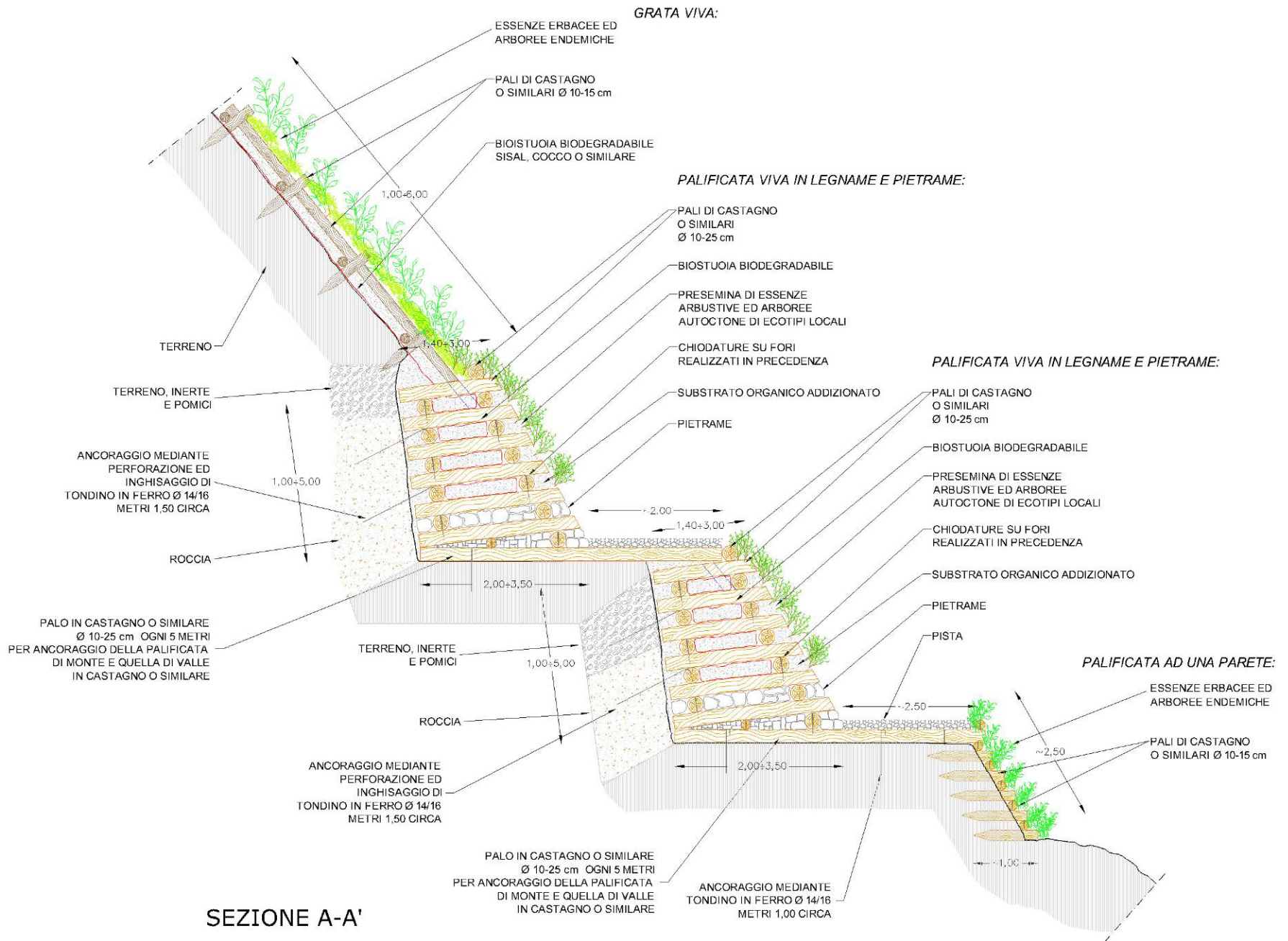


9. 11. 2004





INTERVENTI DI  
INGEGNERIA  
NATURALISTICA  
Fasi





INTERVENTI DI  
INGEGNERIA  
NATURALISTICA  
Fasi



INTERVENTI DI  
INGEGNERIA  
NATURALISTICA  
Fasi



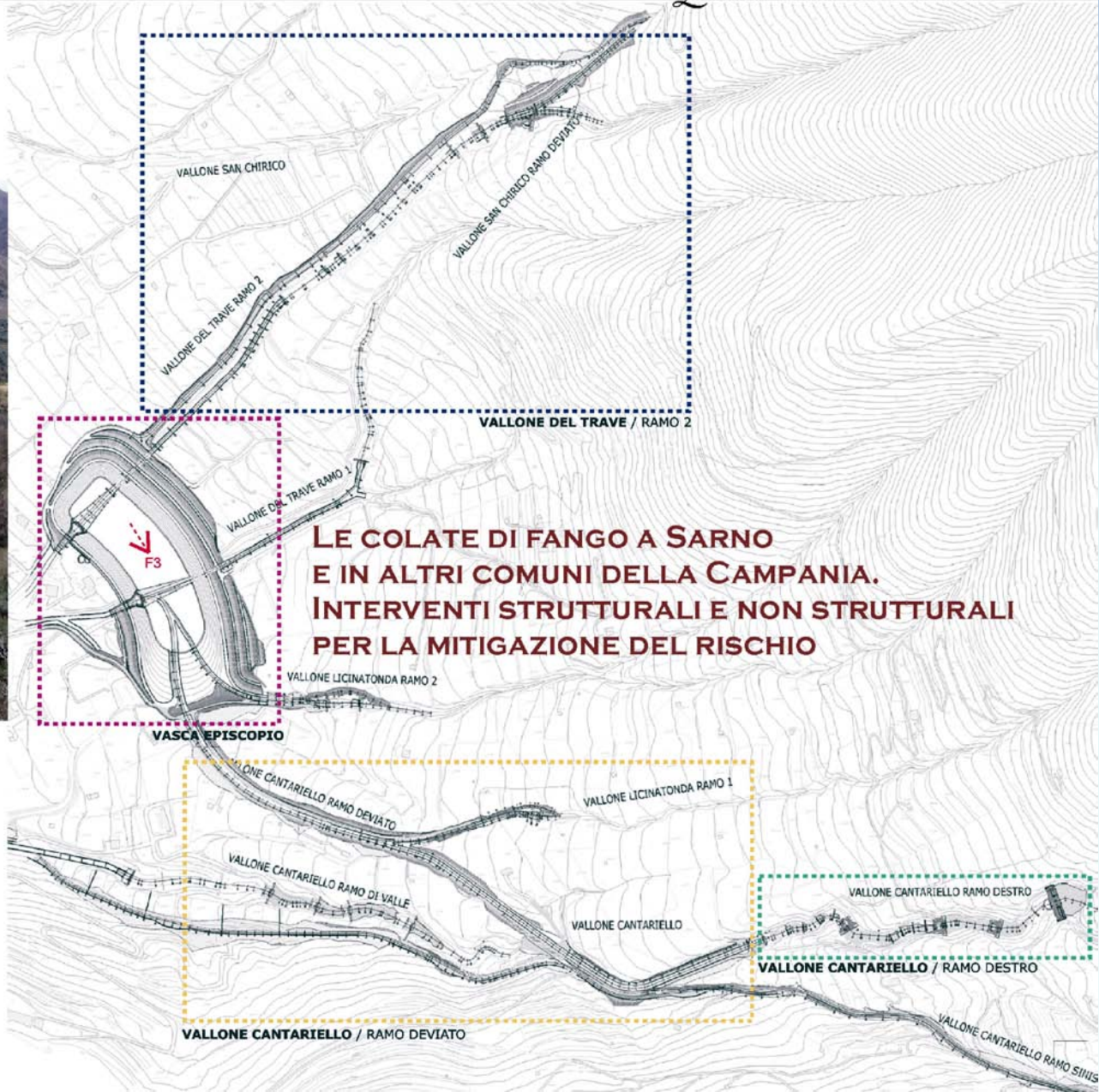
INTERVENTI DI  
INGEGNERIA  
NATURALISTICA  
Fasi

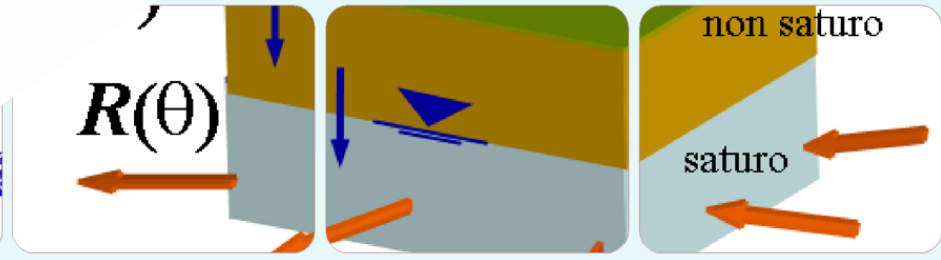
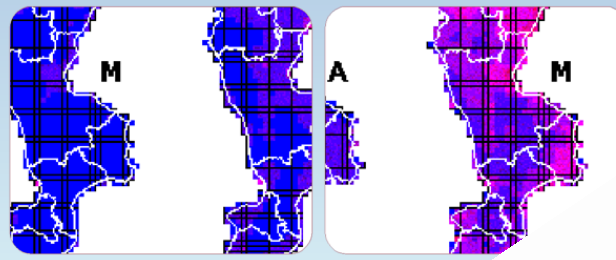
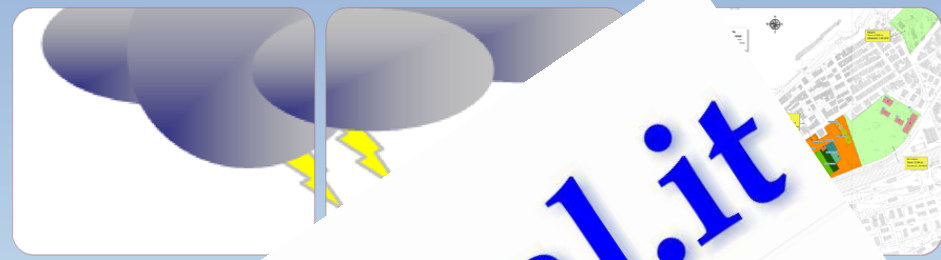
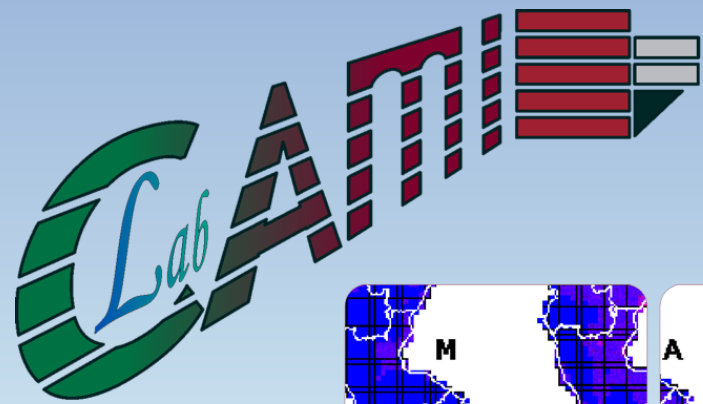
2008 9 4





INTERVENTI DI  
INGEGNERIA  
NATURALISTICA  
Fasi



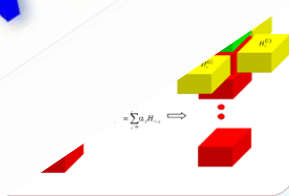


[www.camilab.unical.it](http://www.camilab.unical.it)

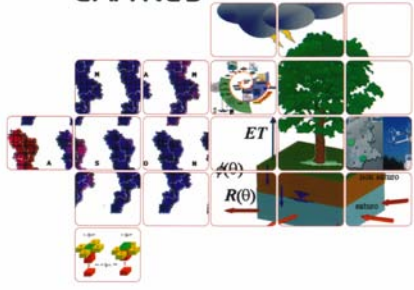
### CAMILAB

Laboratorio di **C**artografia **A**mbientale e **M**odellistica **I**drogeologica  
Università della Calabria - Dipartimento Difesa del Suolo "V.Marone"

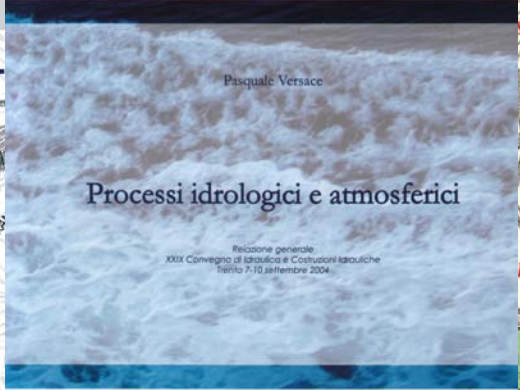
Centro di Competenza del Dipartimento di Protezione Civile  
(Decreto del 26/01/2005 emanato ai sensi della Direttiva del 25/02/2004)



### CAMilab



Laboratorio di Cartografia Ambientale e Modellistica Idrogeologica  
 UNIVERSITÀ DELLA CALABRIA - Dipartimento Difesa del Suolo "V. Marone"



## Processi idrologici e atmosferici

Relazione generale  
 XXX Convegno di Idraulica e Costruzioni Idrauliche  
 Tenuto 7-10 settembre 2004.

Laboratorio di Cartografia Ambientale e Modellistica Idrogeologica  
 UNIVERSITÀ DELLA CALABRIA - Dipartimento Difesa del Suolo "V. Marone"

OLIVA POSTALE ITALIANA  
 (CARTE POSTALE D'ITALIE).

**Università della Calabria**  
**Osservatorio di Documentazione Ambientale**  
**Archivio di Stato di Cosenza**

**FRANE E ALLUVIONI**  
**IN PROVINCIA DI COSENZA**  
**AGLI INIZI DEL '900.**  
 ricerche storiche nella documentazione  
 del Genio Civile

UNA POSTALE ITALIANA  
 (CARTE POSTALE D'ITALIE).

**Università della Calabria**  
**Osservatorio di Documentazione Ambientale**  
**CNR-IRPI (Cosenza)**

**E ALLUVIONI**  
**IN PROVINCIA DI COSENZA**  
**1930 E IL 1950:**  
 le ricerche nella documentazione  
 del Genio Civile

**UCCI P. VERSACE**

**CNR-GNDCI**  
 pubblicazione nel 2013

NOVA BIOS

HONG KONG 2007 - INTERNATIONAL FORUM  
 ON LANDSLIDE DISASTER MANAGEMENT

The CAMilab and CIRIAM contribution



Laboratorio di Cartografia Ambientale e Modellistica Idrogeologica  
 UNIVERSITÀ DELLA CALABRIA - Dipartimento Difesa del Suolo "V. Marone"

### FRANCESCO IOVINO

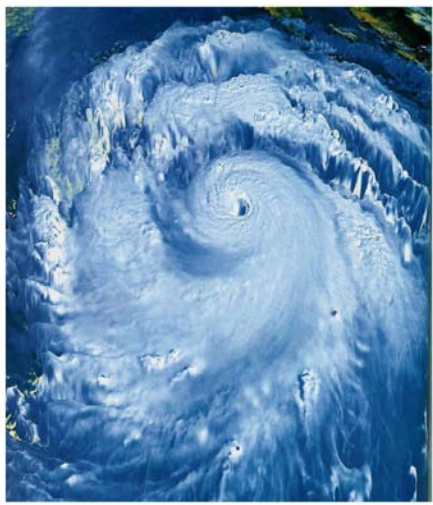
**Analisi dell'uso del suolo e linee operative di gestione forestale sostenibile per mitigare la vulnerabilità del territorio di Pizzo d'Alvano (Campania)**



Laboratorio di Cartografia Ambientale e Modellistica Idrogeologica  
 UNIVERSITÀ DELLA CALABRIA - Dipartimento Difesa del Suolo "V. Marone"

LA MODELLAZIONE MATEMATICA  
 DEI FENOMENI IDROLOGICI

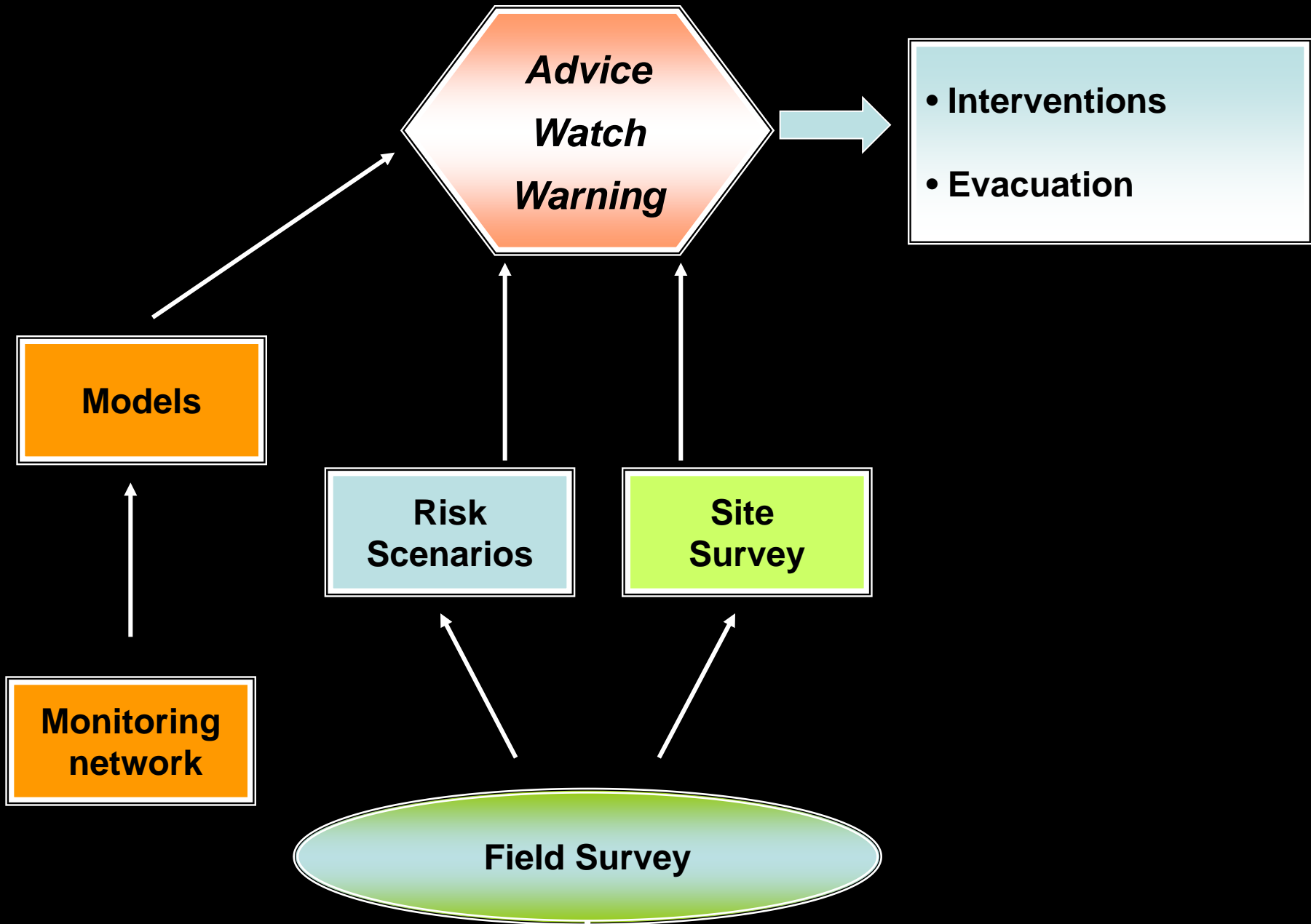
Il contributo del CAMilab al XXXI Convegno di Idraulica e costruzioni Idrauliche



Laboratorio di Cartografia Ambientale e Modellistica Idrogeologica  
 UNIVERSITÀ DELLA CALABRIA - Dipartimento Difesa del Suolo "V. Marone"

# Risk Mitigation

Non structural measures



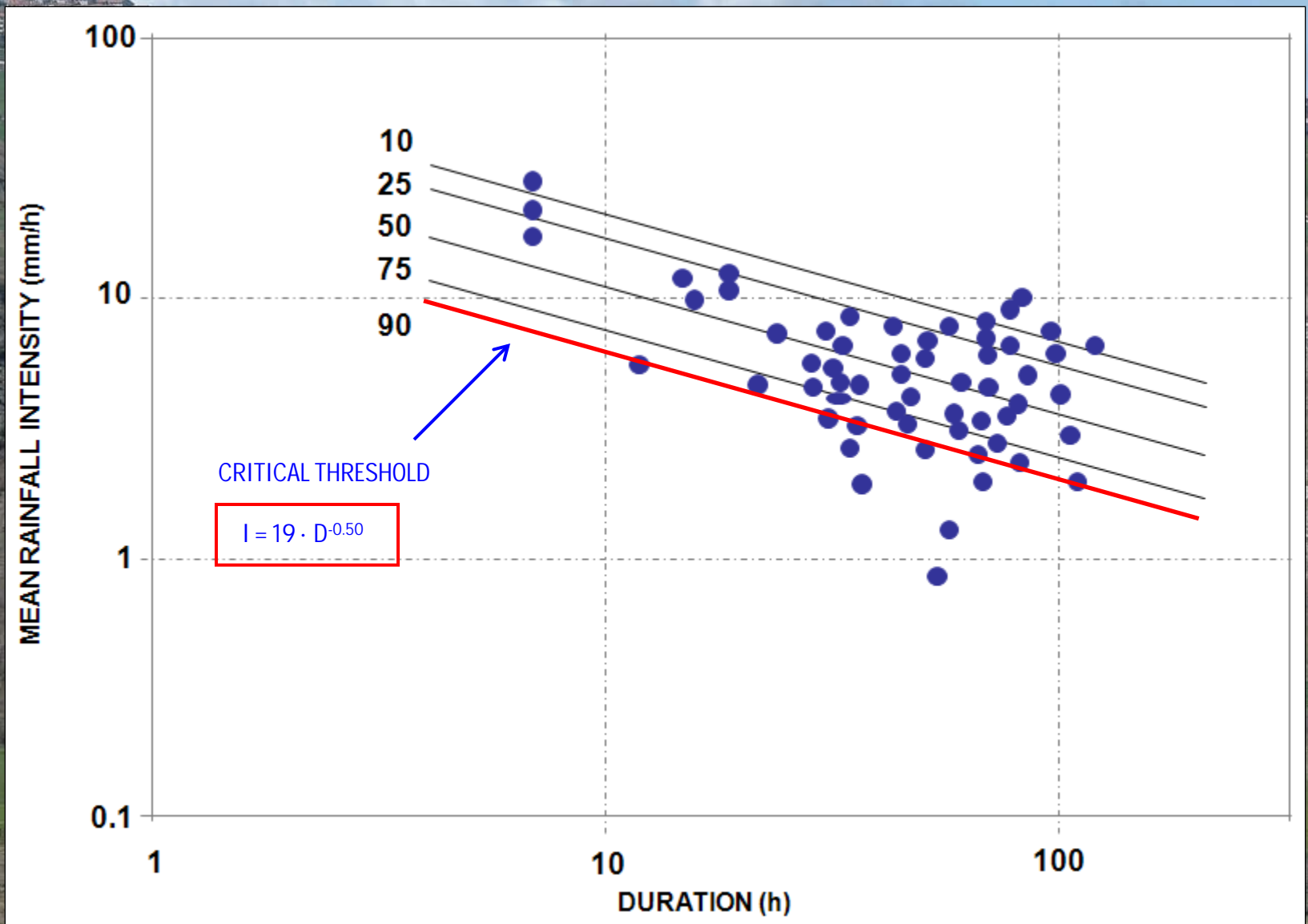
# RELAZIONI TRA PIOGGE E FRANE

*Modelli empirici*

*Modelli completi di versante*

# RELAZIONI TRA PIOGGE E FRANE I MODELLI EMPIRICI





## GUZZETTI 2008

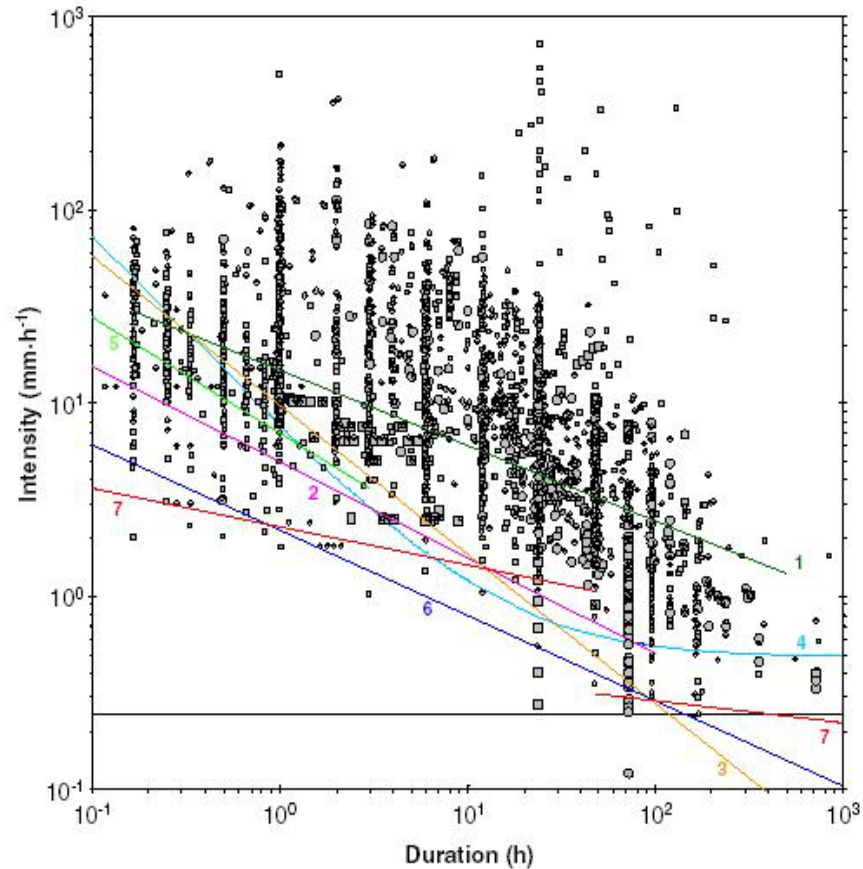
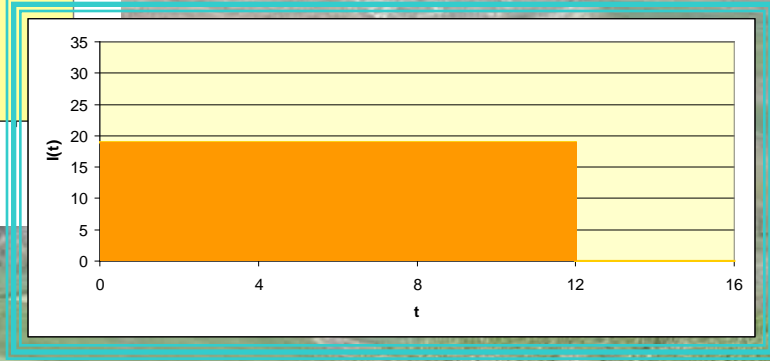
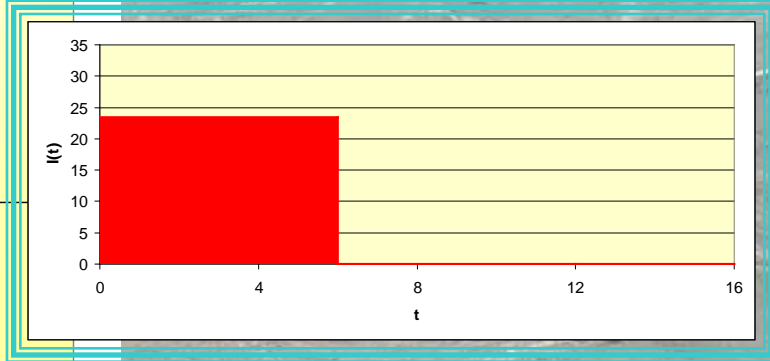
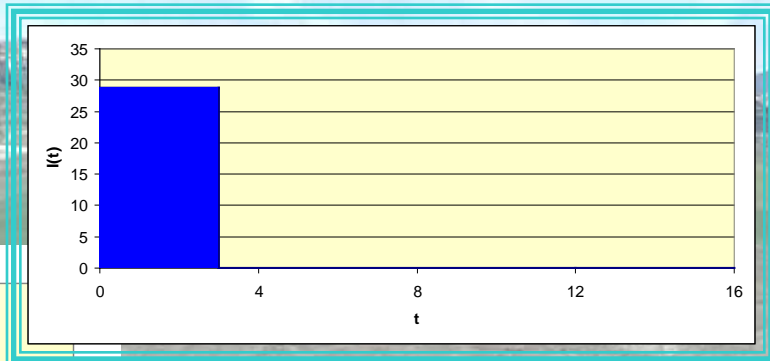
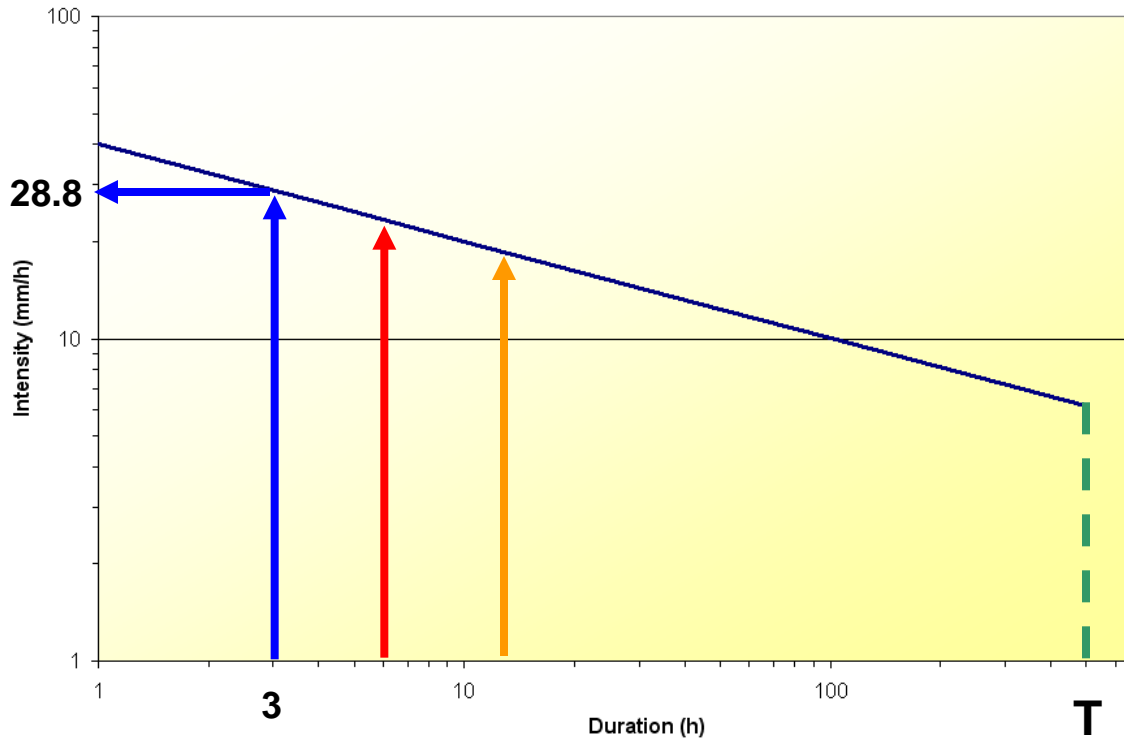
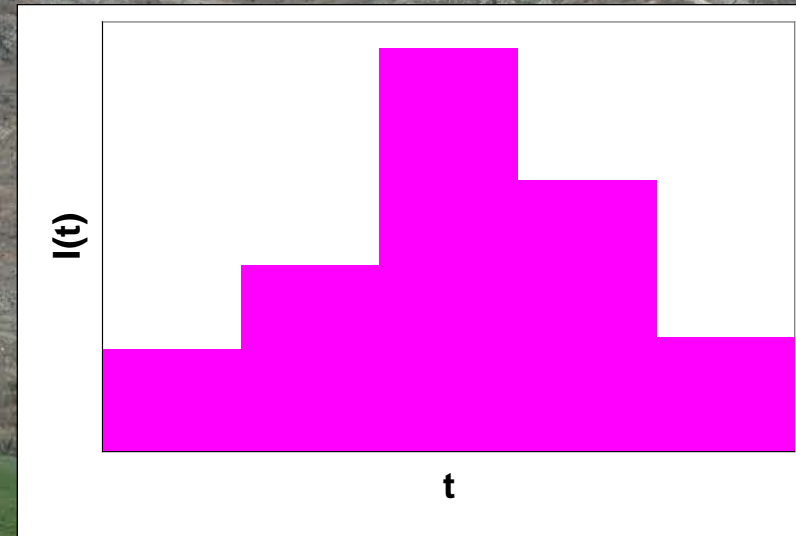
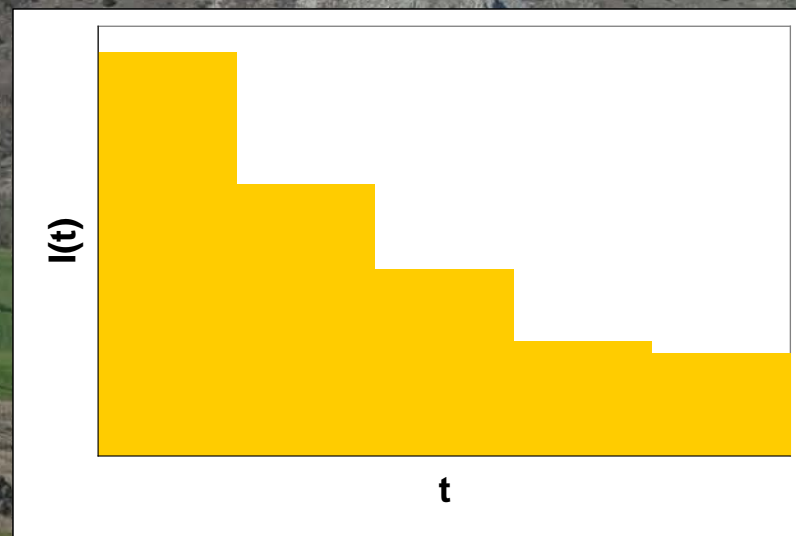
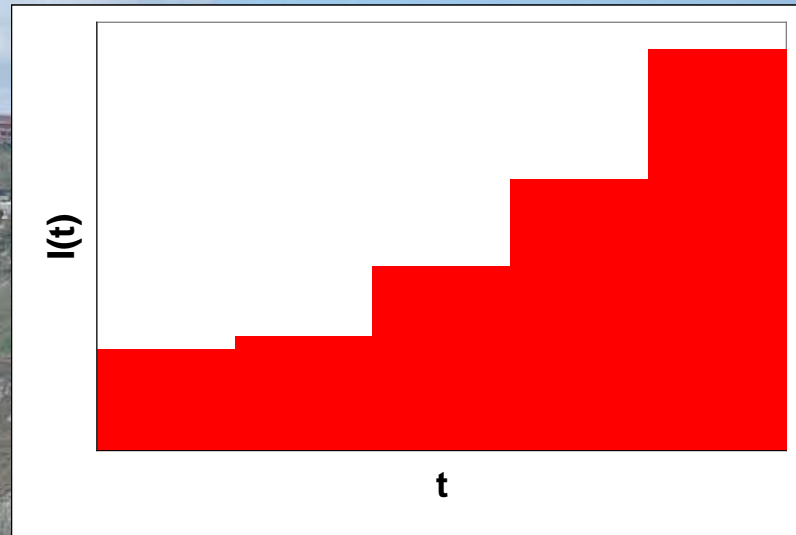
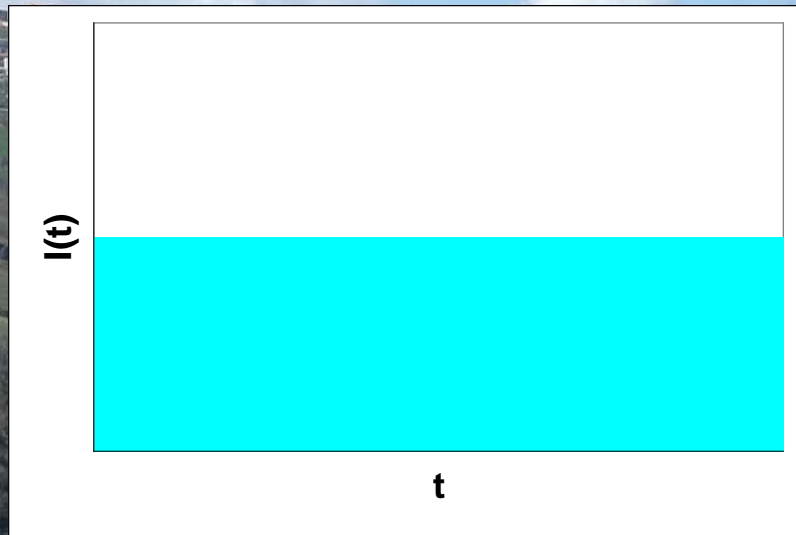


Fig. 7 Comparison between the global ID thresholds defined in this study and published global (worldwide) ID rainfall thresholds. 1 Caine (1980); 2 Innes (1983); 3 Clarizia et al. (1996); 4 Crosta and Frattini (2001); 5 Cannon and Gartner (2005); 6 I-D THRESHOLD inferred from the entire set of ID rainfall data (this work); 7 thresholds inferred from the probability estimates of the rainfall conditions, for two different rainfall periods ( $D < 48$  h, and  $D \geq 48$  h) (this work). Dashed line shows 0.25 mm h<sup>-1</sup> rainfall intensity

# MODELLI I-D

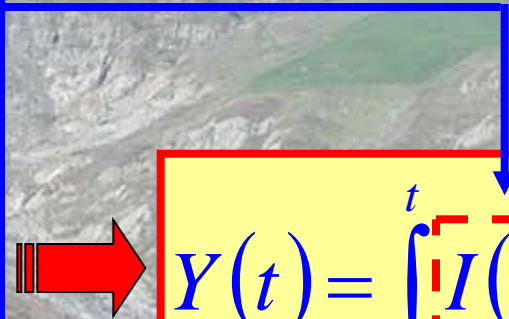
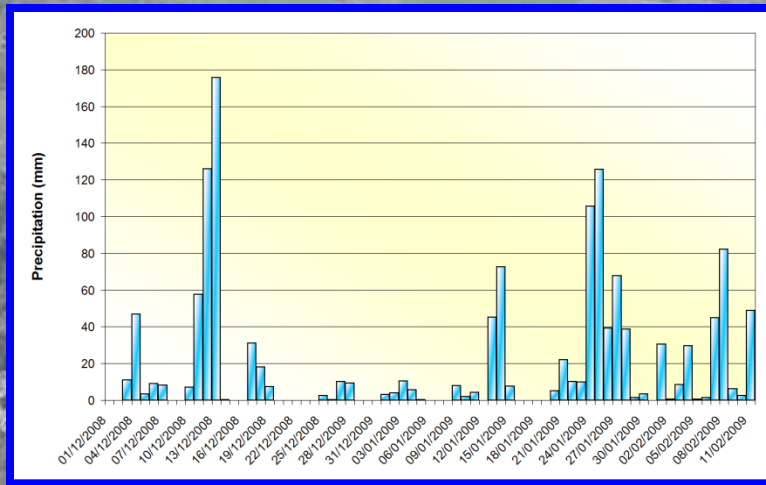
$$I_{cr}(D) = a D^{-b}$$





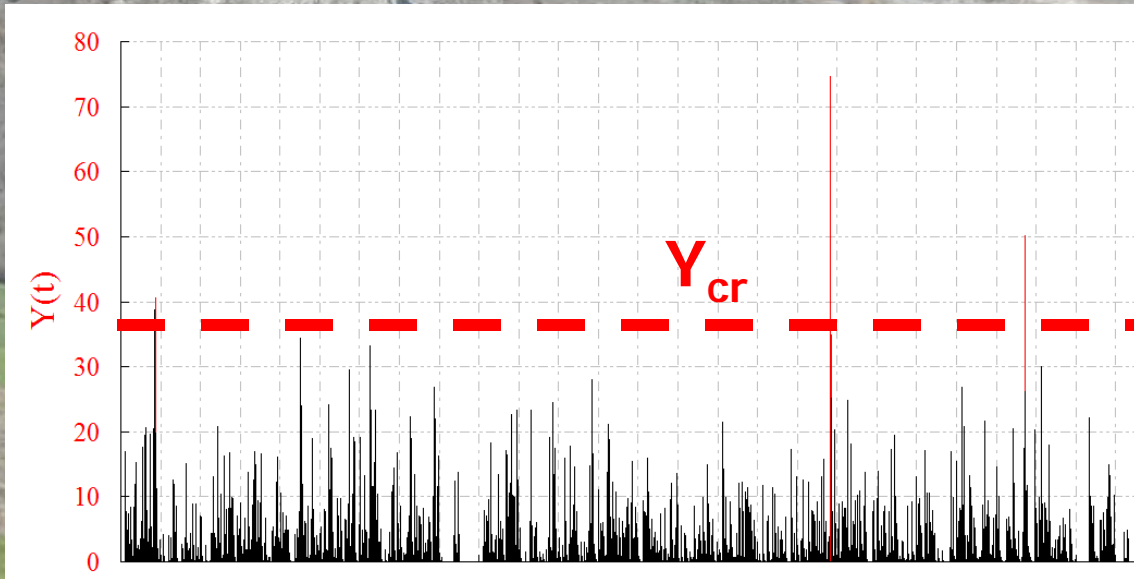
# FLaIR

(Forecasting Landslide Induced by Rainfall,  
Sirangelo & Versace, 1992)



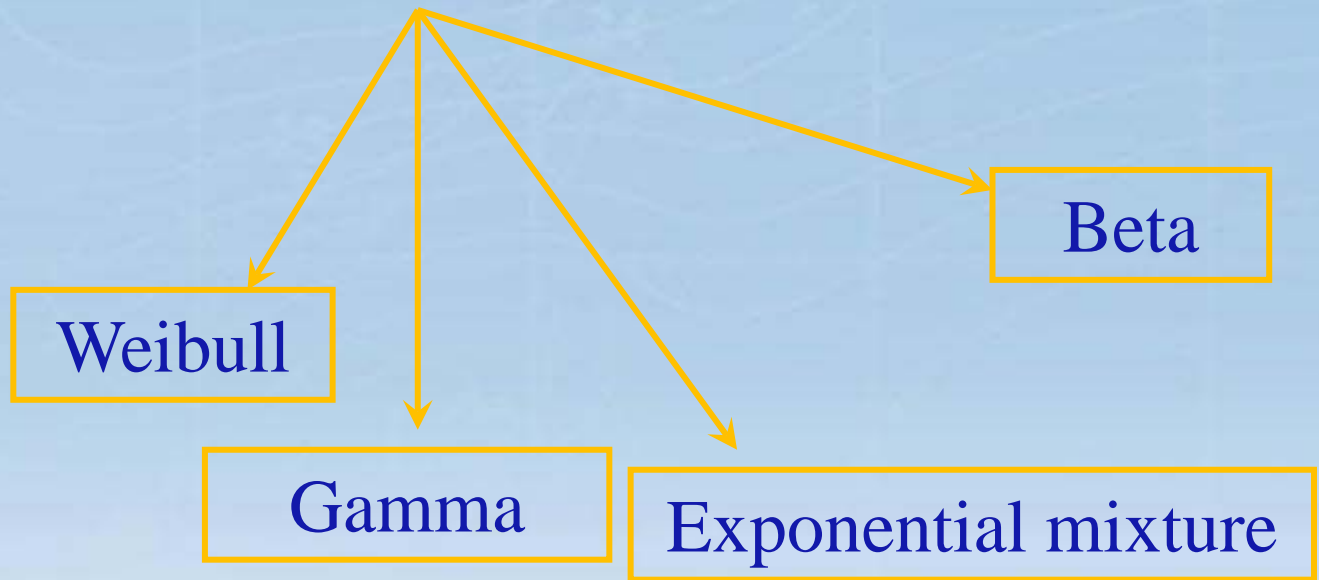
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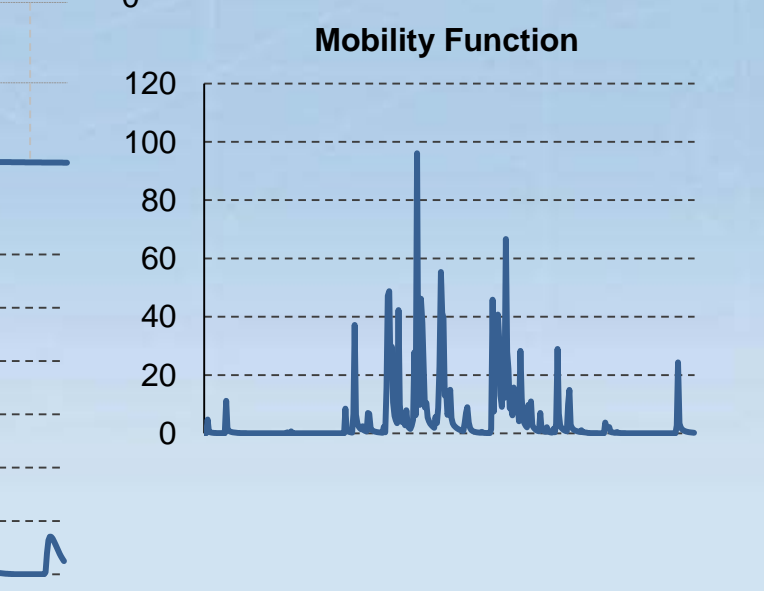
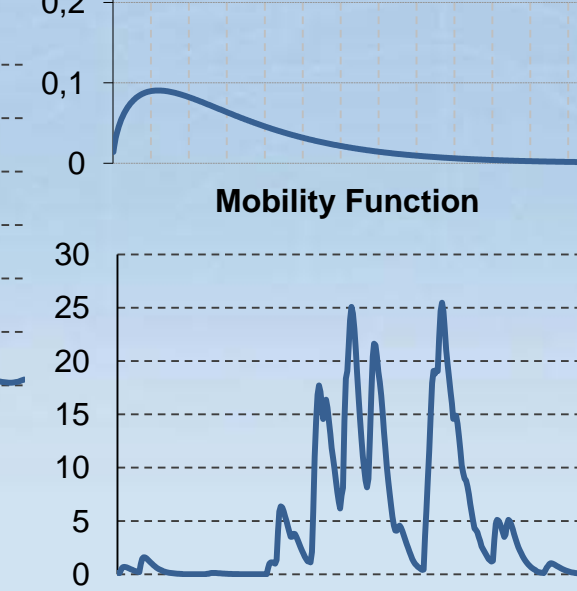
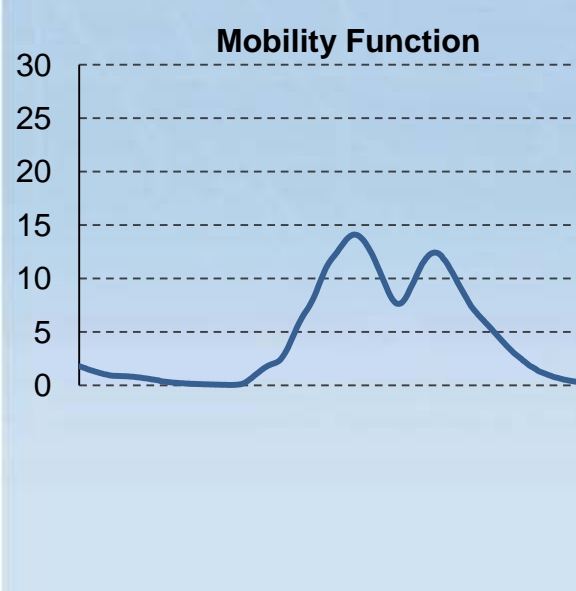
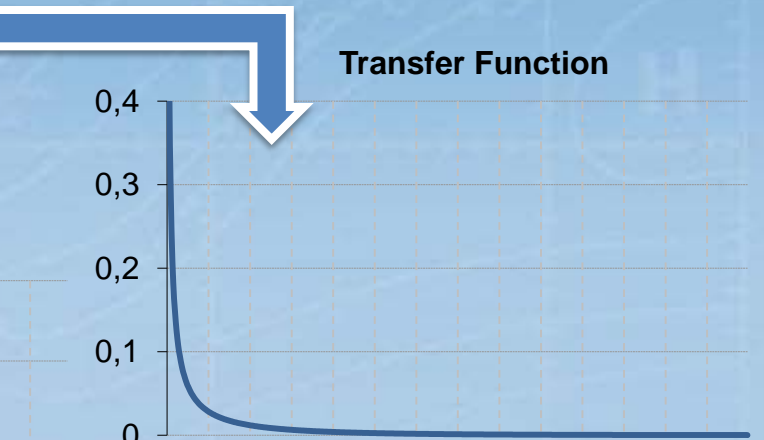
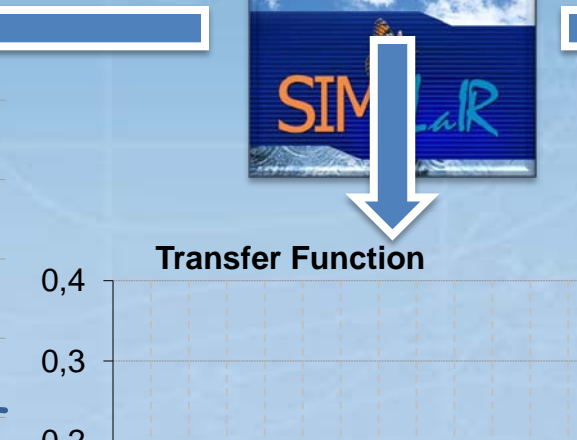
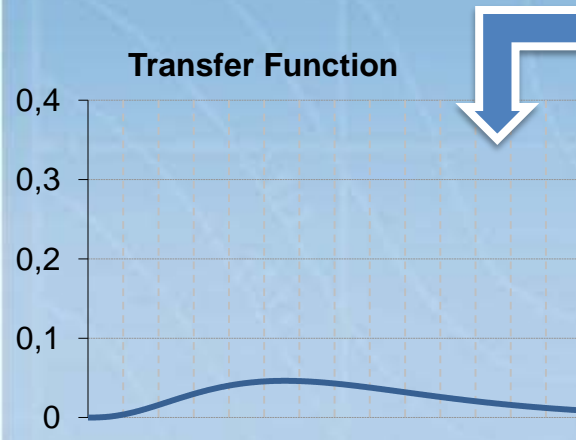
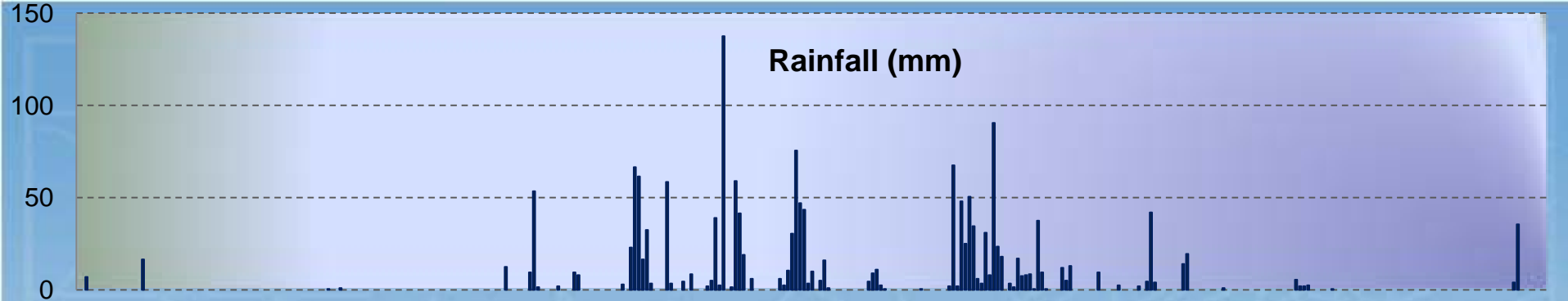
$$Y(t) = \int_0^t I(\tau) \psi(t-\tau) d\tau$$



$$Y(t) = k_d \int_{-\infty}^t \psi(t - \tau) p(\tau) d\tau$$

Transfer Function  $\psi(t)$

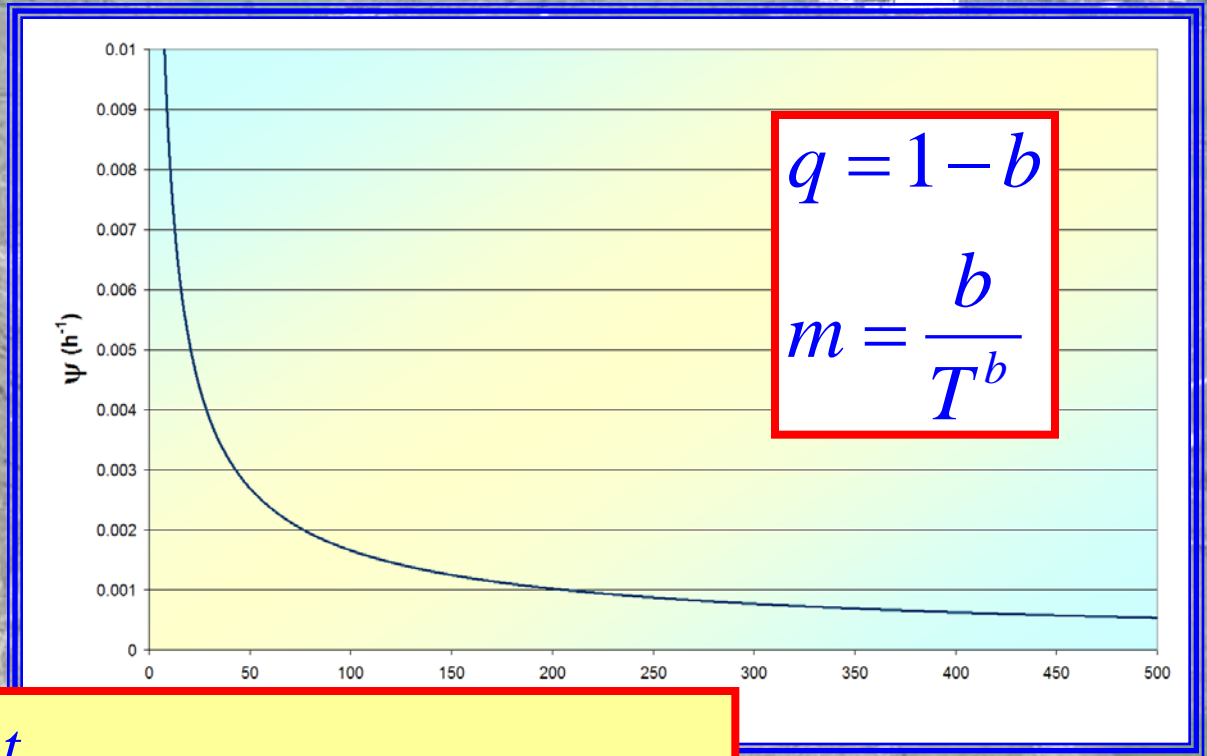
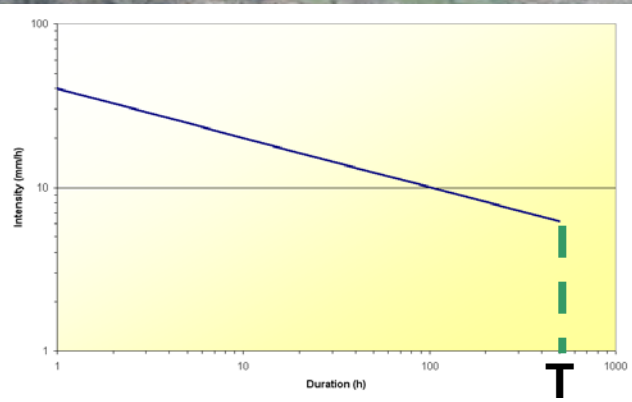




# MODELLI I-D e MODELLO FLAIR

$$\psi(t) = m t^{-q} \quad 0 \leq t \leq T$$

$$I_{cr}(D) = a D^{-b}$$



$$q = 1 - b$$

$$m = \frac{b}{T^b}$$

$$Y(t) = \int_0^t I(\tau) \psi(t - \tau) d\tau$$

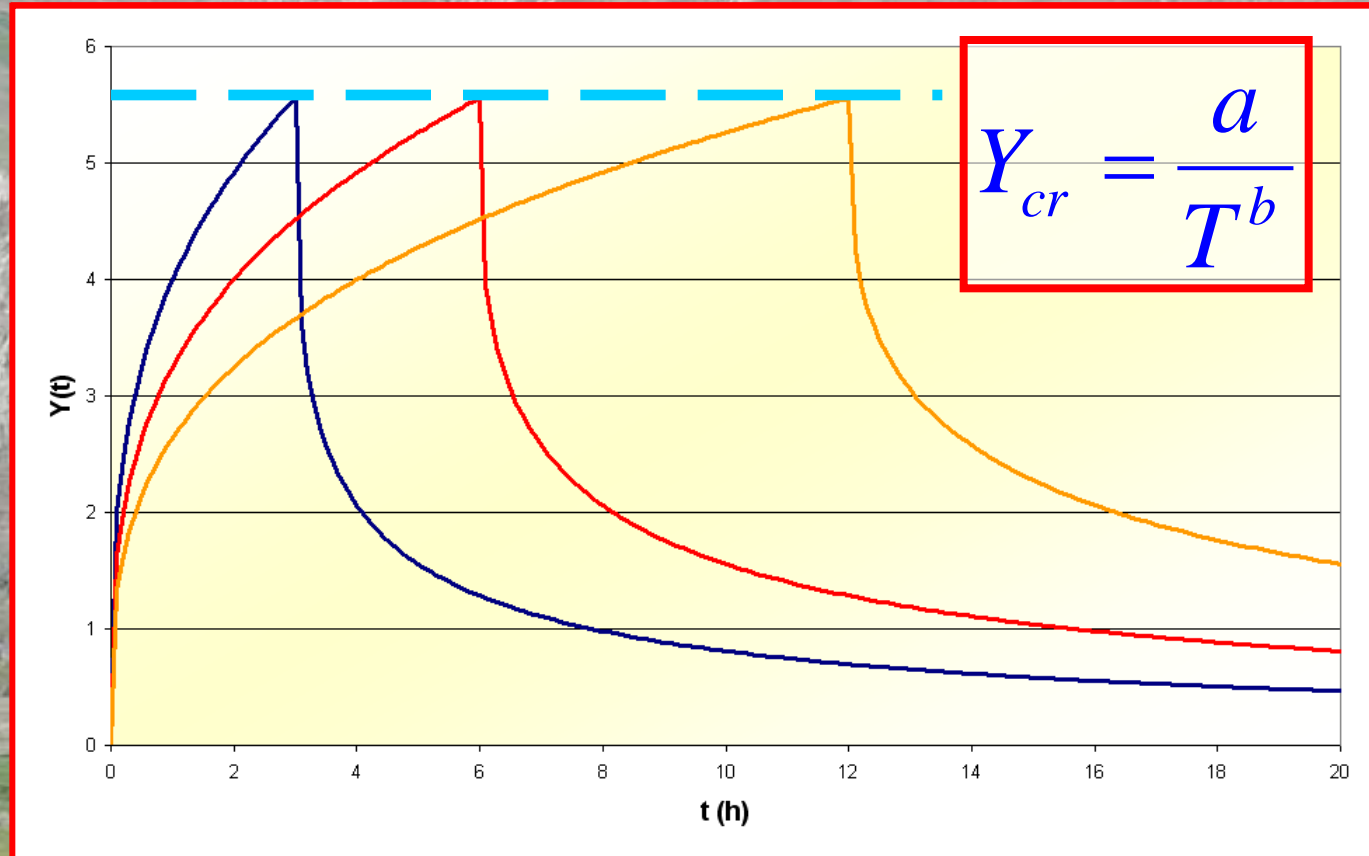
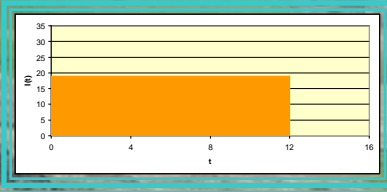
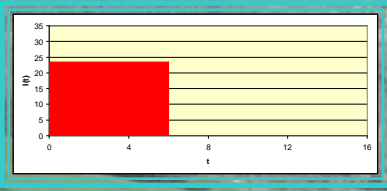
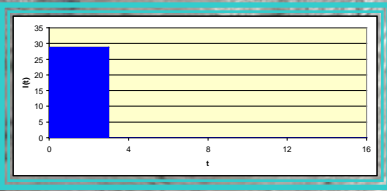
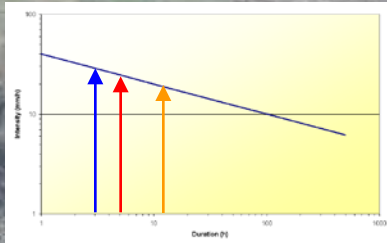


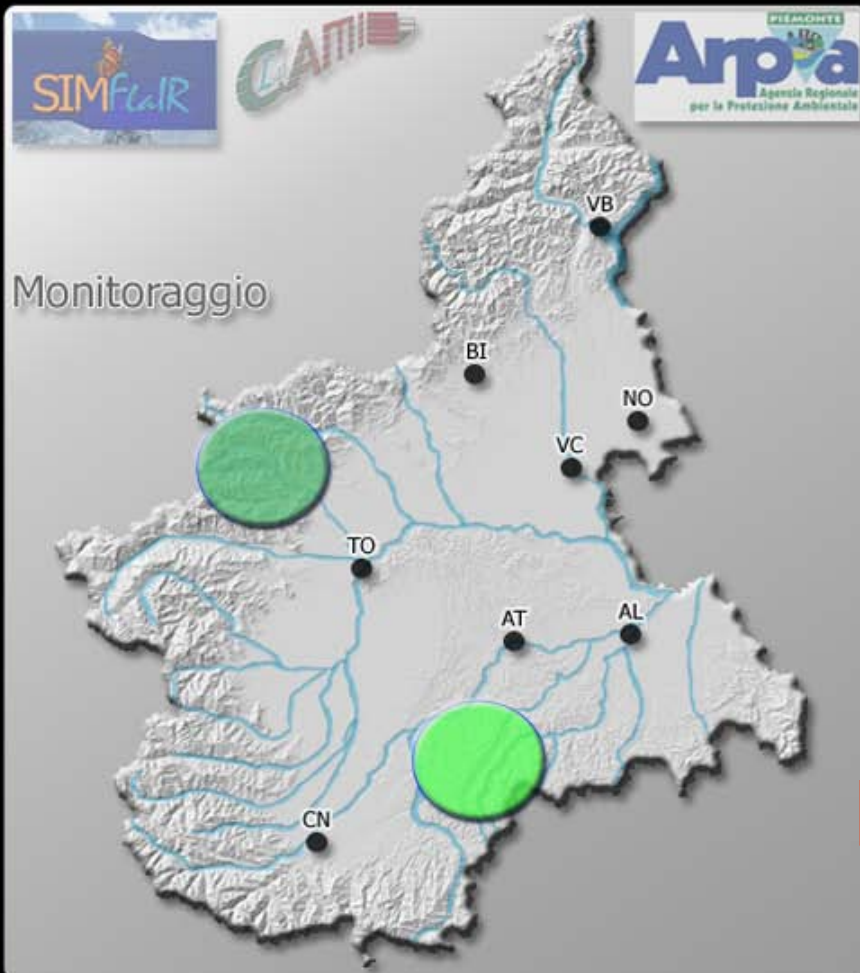
# MODELLI I-D e MODELLO FLAIR

$$Y(t) = \int_0^t I(\tau) \psi(t - \tau) d\tau$$

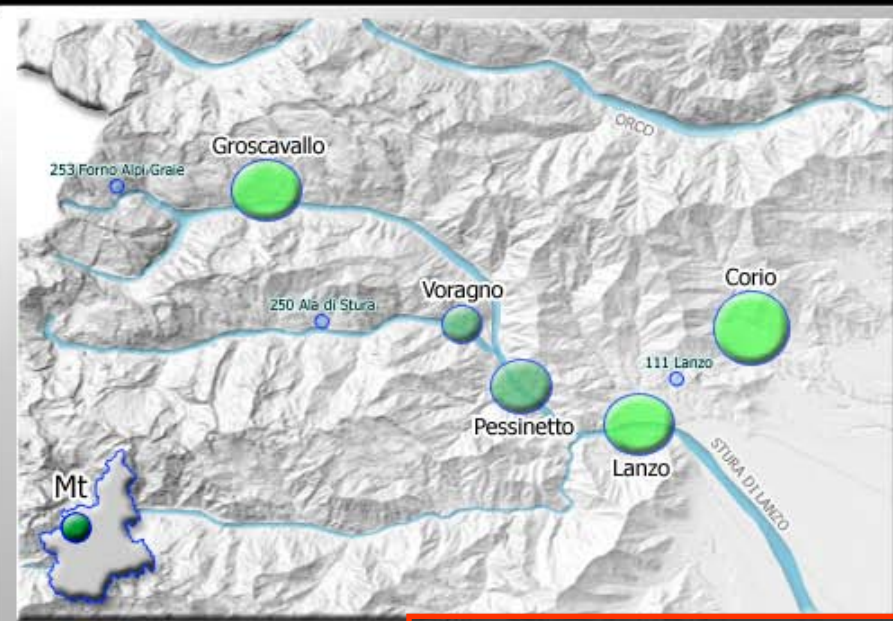
$$I_{cr}(D) = a D^{-b}$$

$$\psi(t) = m t^{-q} \quad 0 \leq t \leq T$$





Monitoraggio



Simulazione del 14/10/2000 - ore 09:30

Area 1 - Valli di Lanzo

Ambito Frana	Cod. Staz.	Ritardo trasm.	Mt		Previsione							
					+6h		+12h		+18h		+24h	
			Y	I.F.	Y	I.F.	Y	I.F.	Y	I.F.		
Groscavallo	253	00:00h	1.52	0.02	1.37	0.02	1.37	0.02	1.37	0.02	1.37	0.02
Voragno	250	00:00h	81.50	0.50	135.15	0.83	135.15	0.83	135.15	0.83	135.15	0.83
Corio	111	00:00h	1.10	0.01	0.31	0.00	1.07	0.01	1.83	0.01	2.59	0.02
Lanzo	111	00:00h	1.10	0.01	0.31	0.00	1.07	0.01	1.83	0.01	2.59	0.02
Pessinetto	250	00:00h	85.77	0.51	146.34	0.87	146.34	0.87	146.34	0.87	146.34	0.87

Area 2 - Langhe

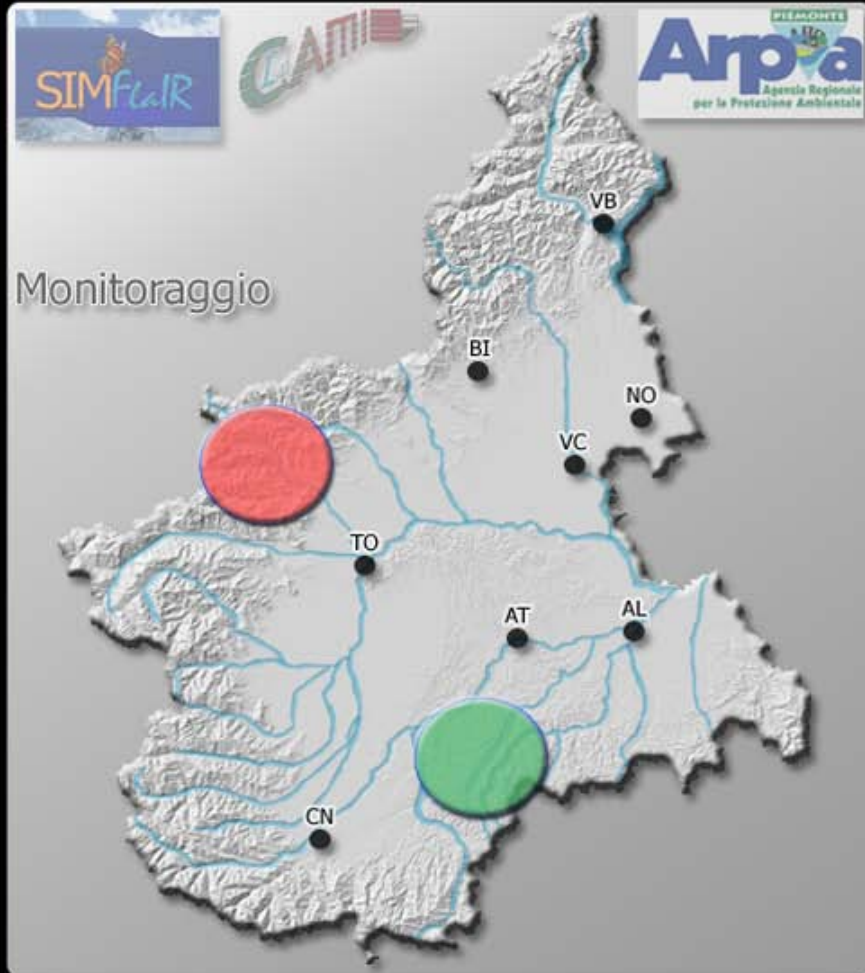
Ambito Frana	Cod. Staz.	Ritardo trasm.	Mt		Previsione							
					+6h		+12h		+18h		+24h	
			Y	I.F.	Y	I.F.	Y	I.F.	Y	I.F.		
Salicetti	137	00:00h	5.03	0.39	5.64	0.43	5.65	0.43	5.66	0.43	5.67	0.44
Bosia	135	00:00h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C. Castella	135	00:00h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monastero B.	135	00:00h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Previsione



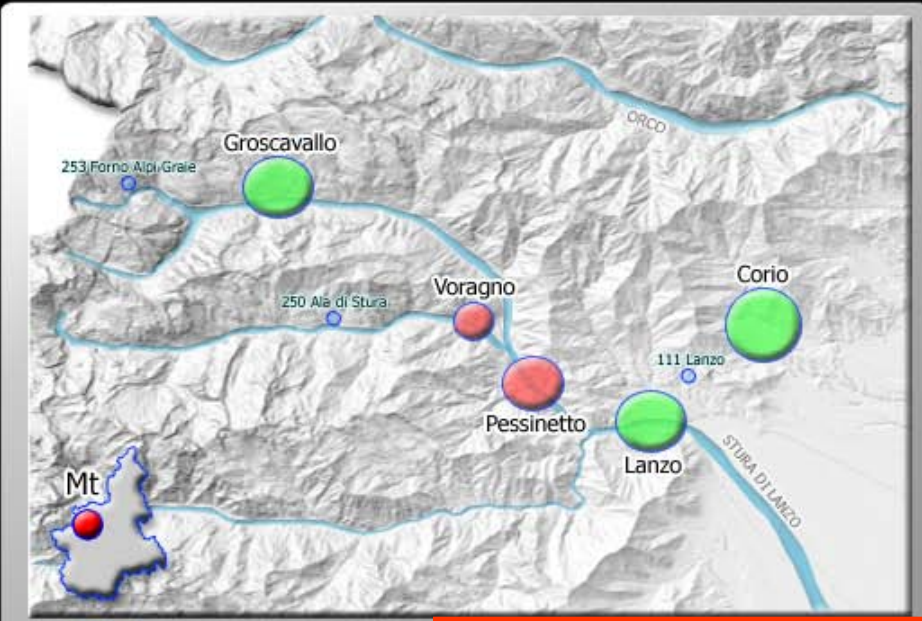
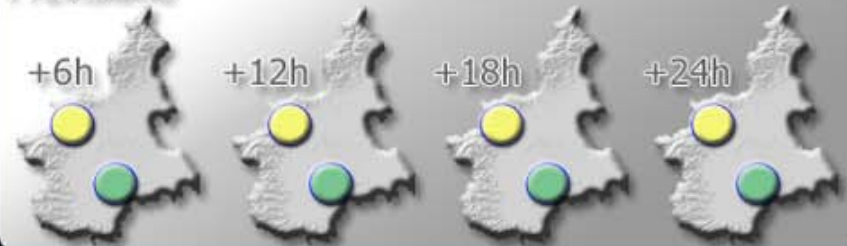
- Assenza di Criticità - I.F. ≤ 0,40
- Stato di Attenzione - 0,40 < I.F. ≤ 0,65
- Stato di Allerta - 0,65 < I.F. ≤ 0,85
- Stato di Emergenza - I.F. > 0,85





Monitoraggio

Previsione



Simulazione del 15/10/2000 - ore 05:30

Area 1 - Valli di Lanzo

Ambito Frana	Cod. Staz.	Ritardo trasm.	Mt		Previsione							
					+6h		+12h		+18h		+24h	
			Y	I.F.	Y	I.F.	Y	I.F.	Y	I.F.	Y	I.F.
Groscavallo	253	00:00h	1.07	0.02	0.90	0.01	0.80	0.01	0.90	0.01	0.90	0.01
Voragno	250	00:00h	279.27	1.70	91.04	0.56	91.04	0.56	91.04	0.56	91.04	0.56
Corio	111	00:00h	0.31	0.00	0.00	0.00	0.76	0.01	1.53	0.01	2.29	0.02
Lanzo	111	00:00h	0.31	0.00	0.00	0.00	0.76	0.01	1.53	0.01	2.29	0.02
Pessinetto	250	00:00h	294.62	1.76	109.98	0.65	109.98	0.65	109.98	0.65	109.98	0.65

Area 2 - Langhe

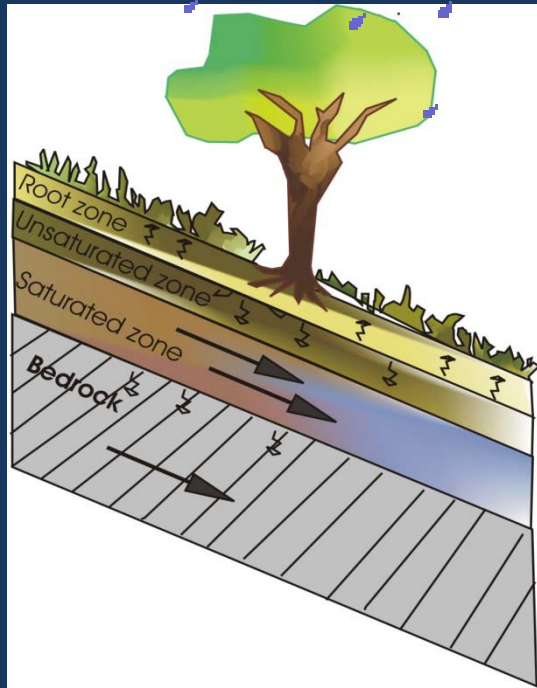
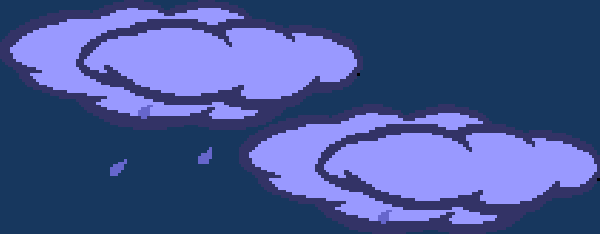
Ambito Frana	Cod. Staz.	Ritardo trasm.	Mt		Previsione							
					+6h		+12h		+18h		+24h	
			Y	I.F.	Y	I.F.	Y	I.F.	Y	I.F.	Y	I.F.
Salicetti	137	00:00h	5.63	0.43	5.86	0.45	5.87	0.45	5.88	0.45	5.89	0.45
Bosia	135	00:00h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C. Castella	135	00:00h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monastero B.	135	00:00h	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

- Assenza di Criticità - I.F. ≤ 0,40
- Stato di Attenzione - 0,40 < I.F. ≤ 0,65
- Stato di Allerta - 0,65 < I.F. ≤ 0,85
- Stato di Emergenza - I.F. > 0,85



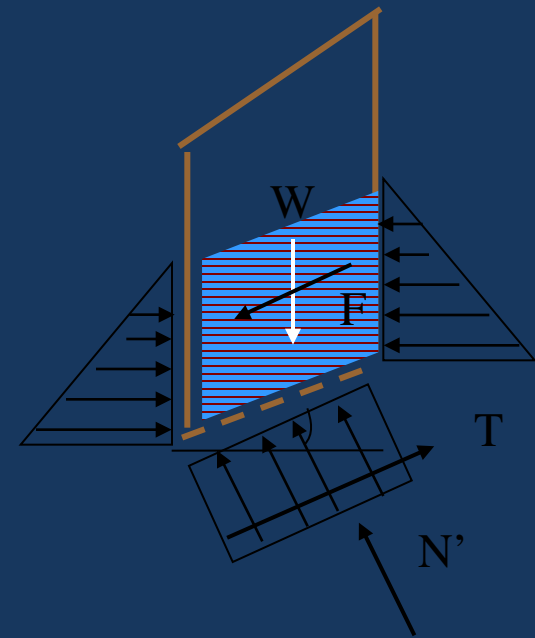
RELAZIONI TRA PIOGGE E FRANE

I MODELLI COMPLETI  
DI VERSANTE



Pore pressure  
and water content

# Geotechnical module



# Hydraulic Module

**Hydrological module**  
**Hydro sushi**

**Geotechnical module**  
**Geo sushi**

### **2-D Richards' equation**

*analysis of the saturated  
and unsaturated flows*

*applicability to :*

*layered soils*

*irregular shape domain*

*variable boundary conditions*

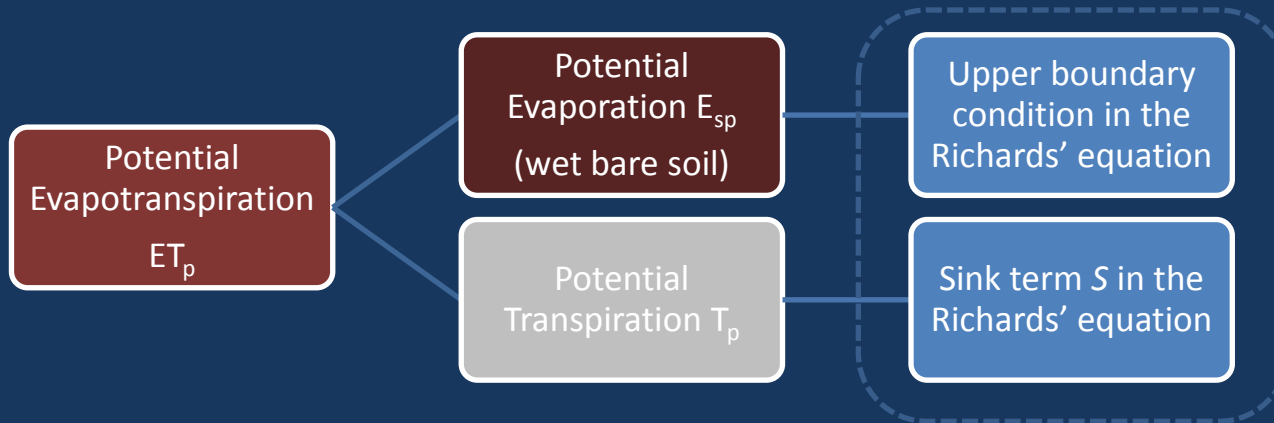
### **General Limit Equilibrium Methods**

*Extended Mohr-Coulomb Failure Envelope*

**SUSHI model (Capparelli, 2006)**

**(Saturated Unsaturated Simulation for Hillslope Instability)**

# General framework



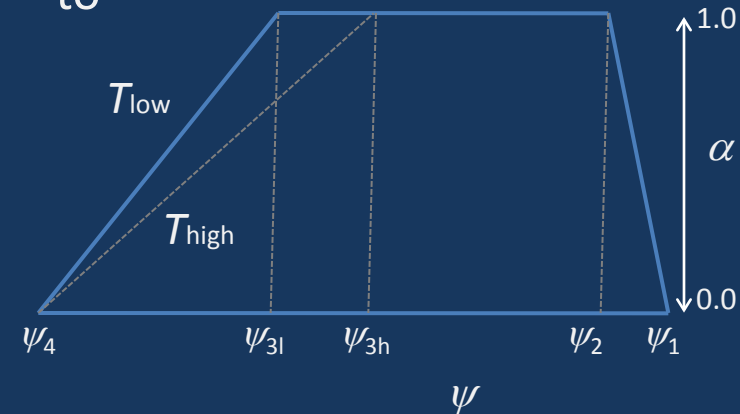
$$S(\psi) = \alpha(\psi) \frac{T_p}{|z_r|} \quad (\text{uniform root distribution})$$

(Feddes et al., 1978)

$\alpha \in [0,1]$  dimensionless reduction factor depending on the suction  $\psi$  accounting for restriction to transpiration caused by soil moisture limitations

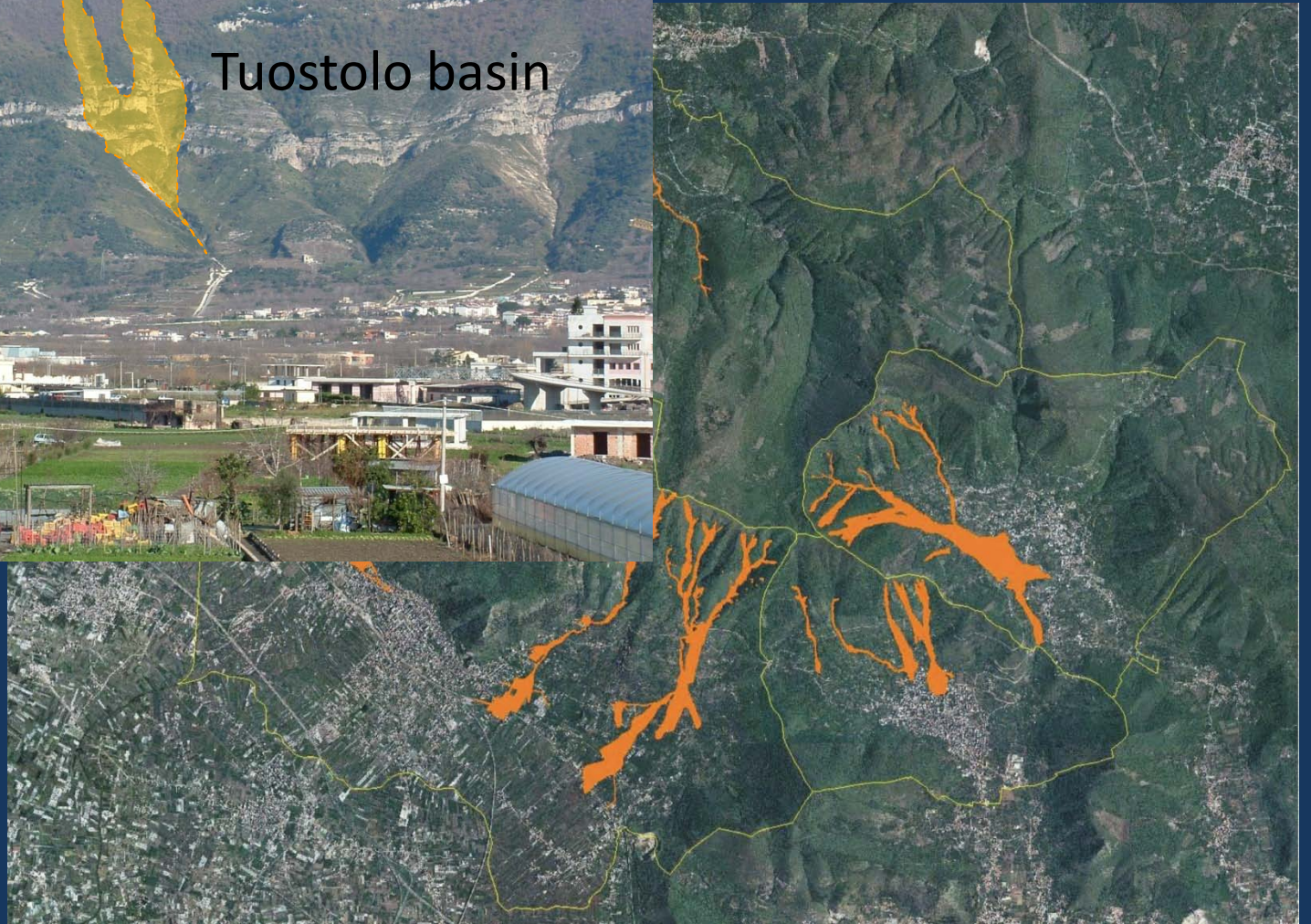
$z_r$  rooting depth

Integration of  $S(\psi)$  over the rooting depth yields the total actual transpiration  $T$

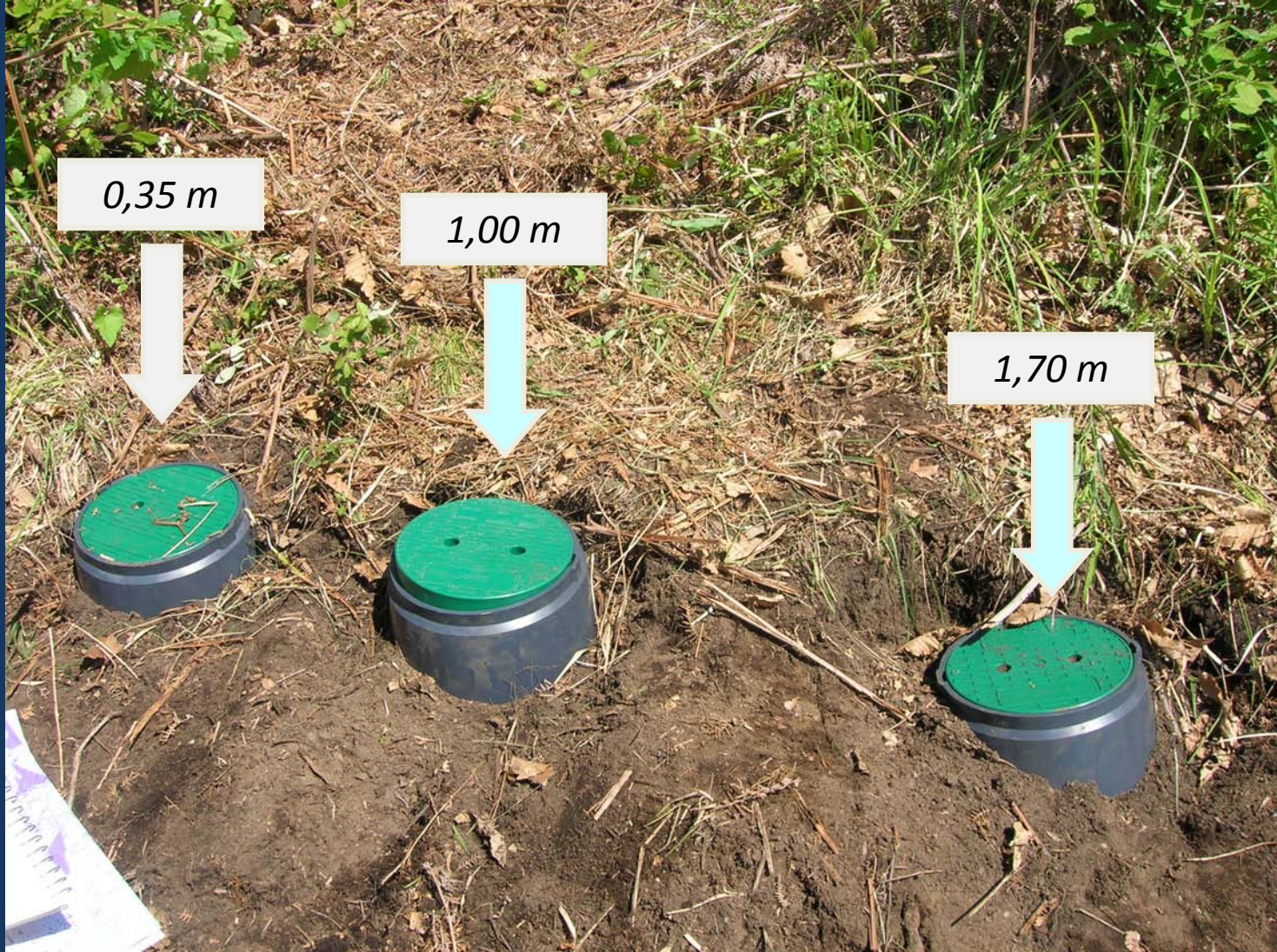


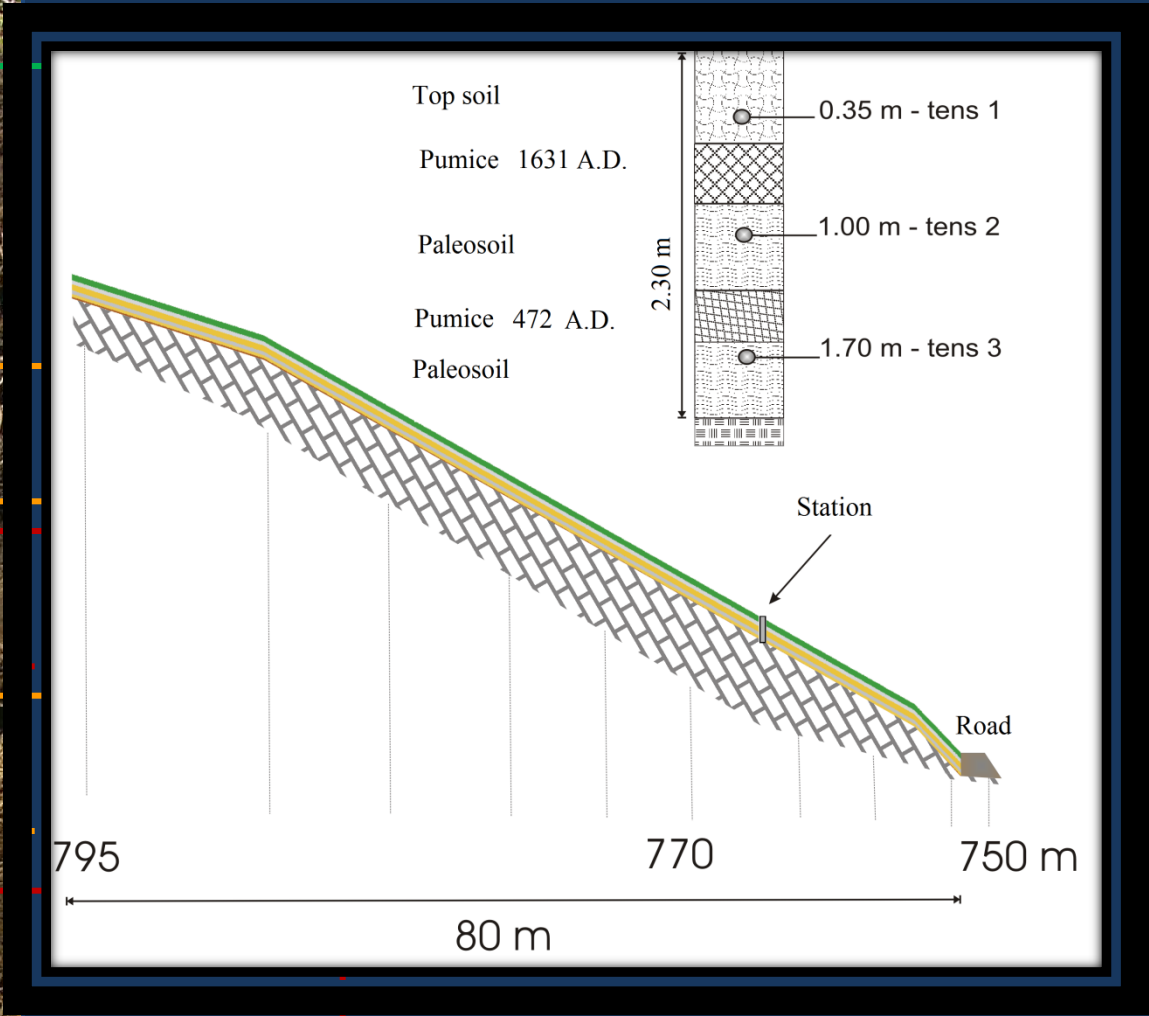
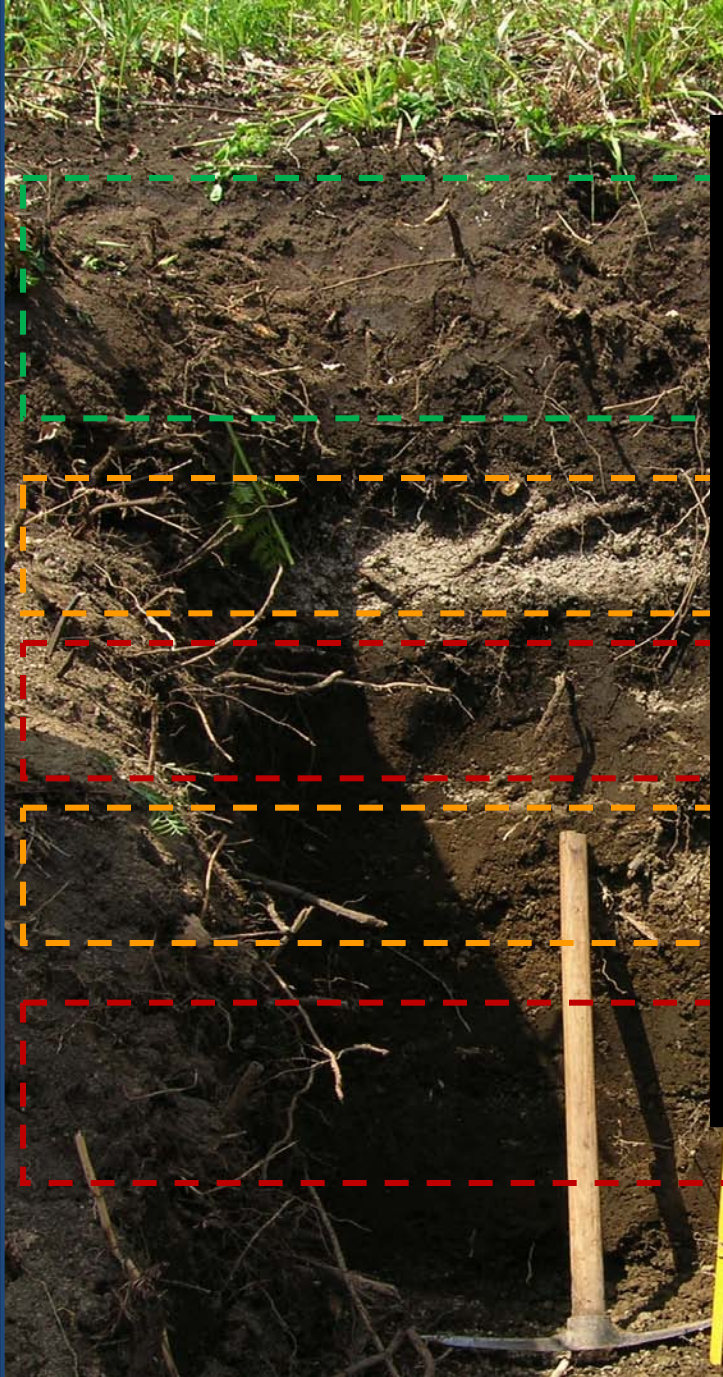


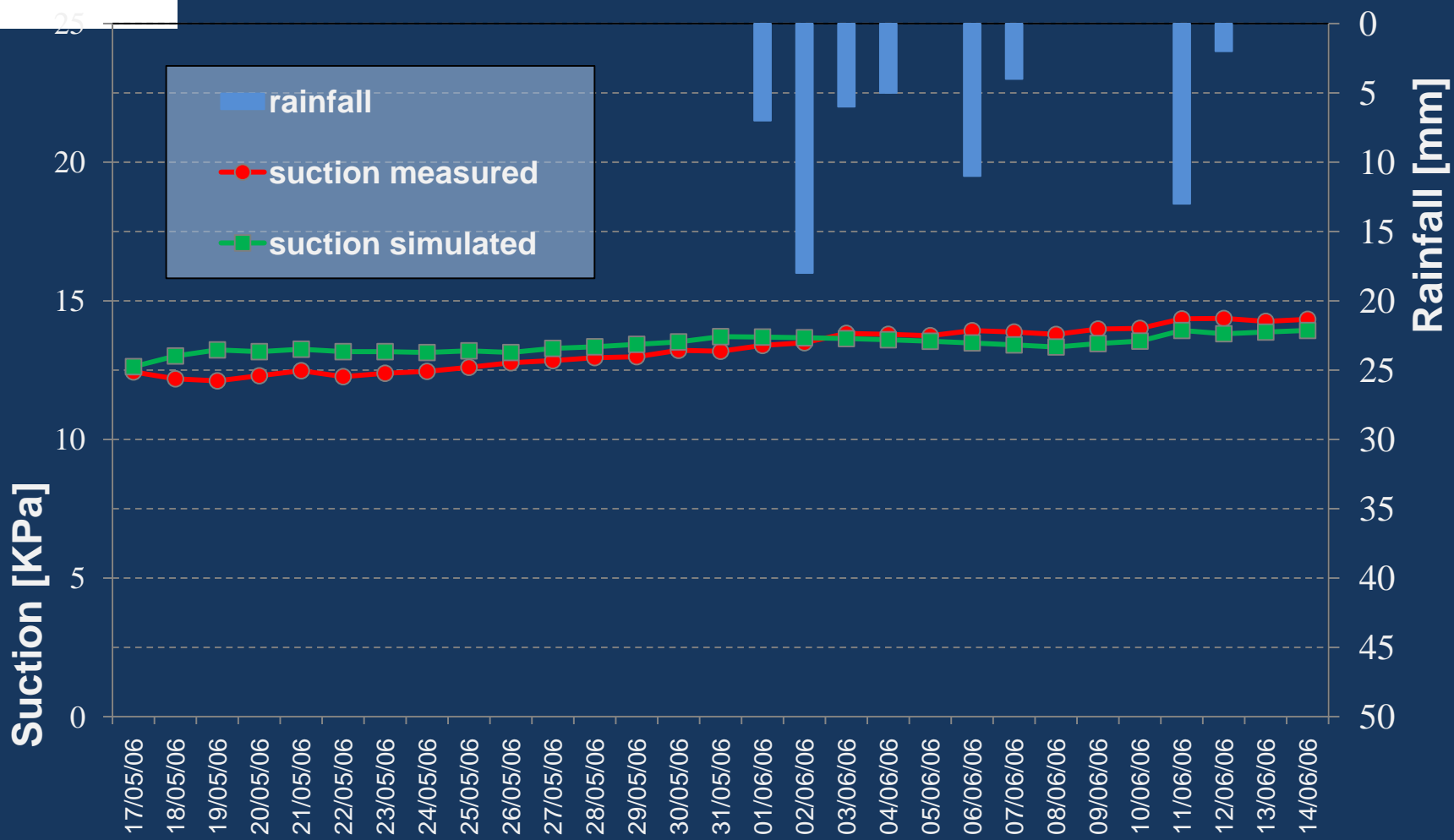
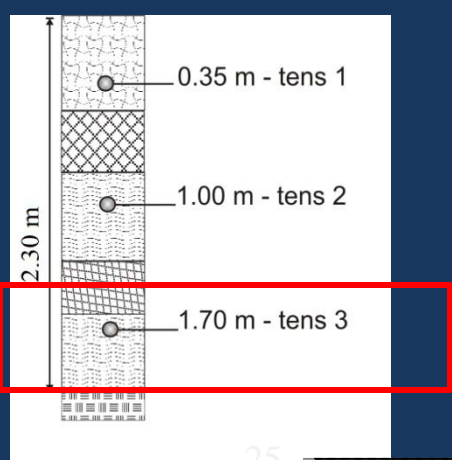
Tuostolo basin

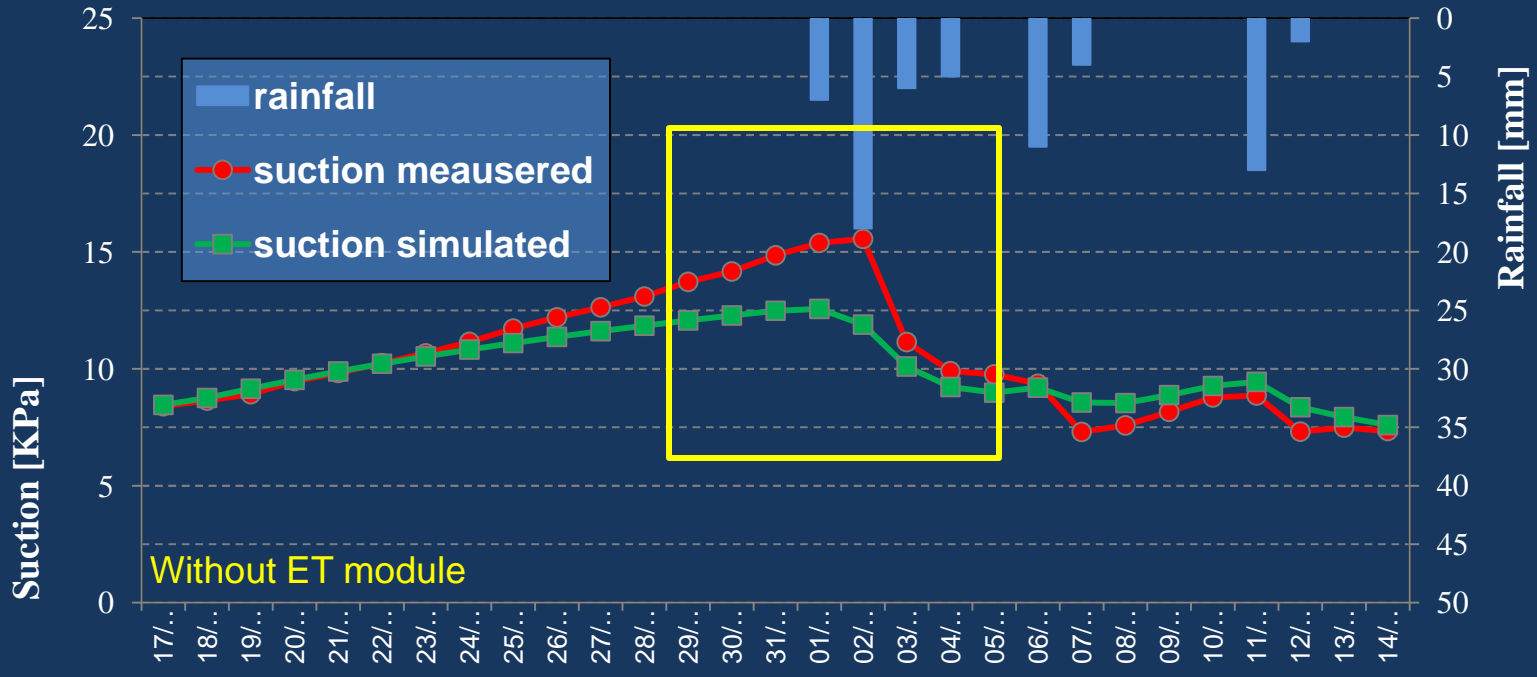
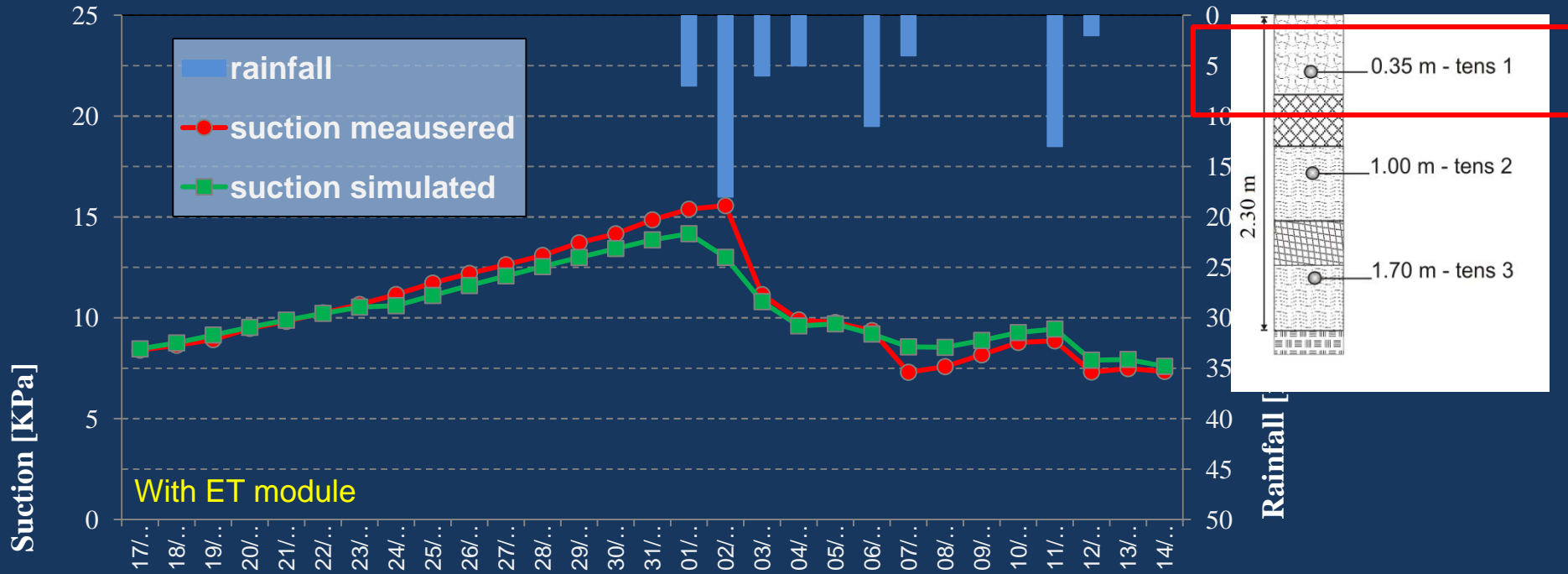












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