17 ottobre 2019

Leonardo Cascini

METTIAMOCI IN RIGA

Landslides risk zoning and management

UNIONE EUROPEA
Fondo Sociale Europeo
Fondo Europeo di Sviluppo Regionale

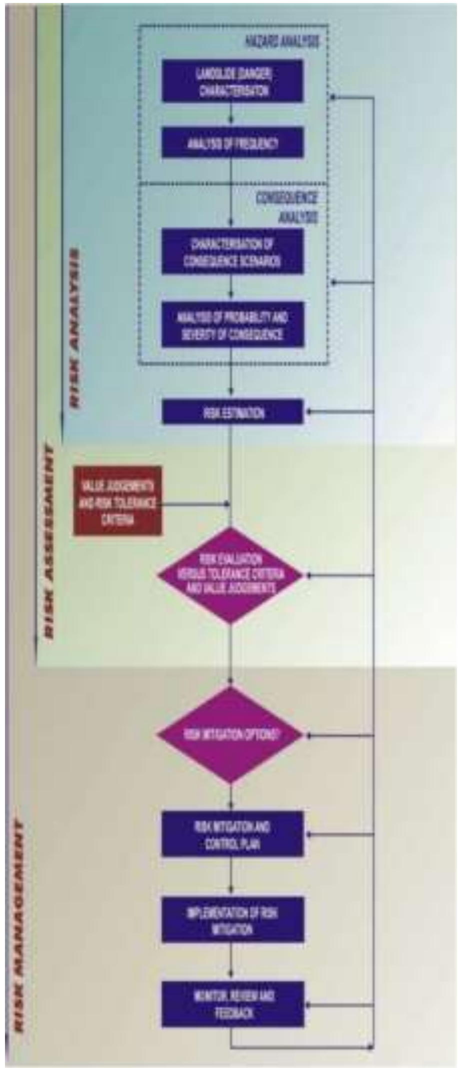
Agenzia per la Coesione Territoriale

MINISTERO DELL'AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE

PON GOVERNANCE E CAPACITÀ ISTITUZIONALE 2014-2020

SOGESID SPA INGEGNERIA TERRITORIO AMBIENTE

Risk management process and risk estimation



$$R = (H \times V) \times E = R_S \times E$$

(Varnes, 1988; Fell et al., 2005)

Natural hazard (H): means the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon.

Elements at risk (E): means the population, properties, economic activities, including public services, etc., at risk in a given area.

Vulnerability (V): means the degree of loss to a given element or set of elements at risk (see below) resulting from the occurrence of a natural phenomenon of a given magnitude. It is expressed on a scale from 0 (no damage) to 1 (total loss).

Specific risk (Rs): means the expected degree of loss due to a particular natural phenomenon. It may be expressed by the product of H times V.

Total risk (R): means the expected number of lives lost, person injured, damage to property, or distruption of economic activity due to a particular natural phenomenon, and is therefore the product of specific risk (RS) and elements at risk (E).

Other risk formulas

EINSTEIN (1988)
RISK= HAZARD x POTENTIAL WORTH OF LOSS

FELL (1994)

$R = \sum (E \times Rs) = \sum (E \times P \times V)$

LEROI (1997)

R = f [Pe, Pt, P’e (MVT, I, X, Y, Z, t, D, V, a, %, C)]

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Suggestions provided by International Guidelines

Type, level and scale of the zoning maps depend on the purposes to which the landslide zoning is applied.

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Guidelines for landslide susceptibility, hazard and risk zoning for land use planning

Robin Fell, Jordi Corominas, Christophe Bonnard, Leonardo Cascini, Eric Leroi, William Z. Savage on behalf of the JTC-1 Joint Technical Committee on Landslides and Engineered Slopes

Scale description	Indicative range of scales	Examples of zoning application	Typical area of zoning
Small	<1:100,000	Landslide inventory and susceptibility to inform policy makers and the general public	>10,000 km² square kilometres
Medium	1:100,000 to 1:25,000	Landslide inventory and susceptibility zoning for regional development; or very large scale engineering projects. Preliminary level hazard mapping for local areas Preliminary level hazard mapping for local areas	1000–10,000 km² square kilometres
Large	1:25,000 to 1:5000	Landslide inventory, susceptibility and hazard zoning for local areas Intermediate to advanced level hazard zoning for regional development. Preliminary to intermediate level risk zoning for local areas and the advanced stages of planning for large engineering structures, roads and railways Preliminary to intermediate level risk zoning for local areas and the advanced stages of planning for large engineering structures, roads and railways	10–1000 km² square kilometres
Detailed	>5000	Intermediate and advanced level hazard and risk zoning for local and site-specific areas and for the design phase of large engineering structures, roads and railways	Several hectares to tens of square kilometres

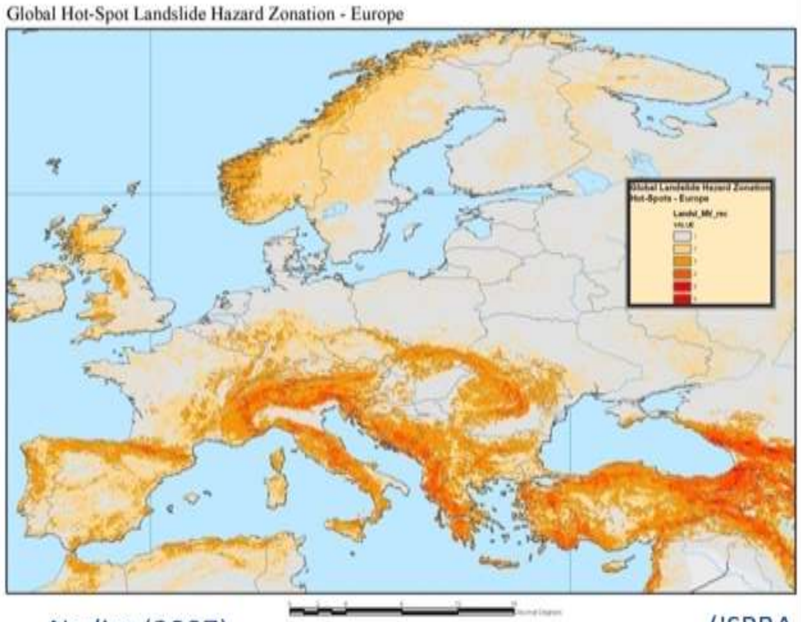
Landslide zoning/mapping scales and their application Fell et al. (2008)

Activity required for different levels of zoning

Type of zoning	Risk zoning Hazard zoning Susceptibility zoning Inventory mapping						
Zoning level	Inventory of existing landslides	Characterization of potential landslides	Travel distance and velocity	Frequency assessment	Temporal–spatial probability	Elements at risk	Vulnerability
Preliminary Intermediate Advanced	Basic[(1),(2)] Intermediate Advanced	Basic[(1),(2)] Intermediate Advanced to intermediate	Basic[(1)] Intermediate[(2)] Intermediate Intermediate to advanced	Basic[(1,2)] Intermediate Intermediate to advanced	Basic[(1,2)] Intermediate Advanced	Basic[(1,2)] Intermediate Advanced	Basic[(1,2)] Intermediate to basic Intermediate to advanced

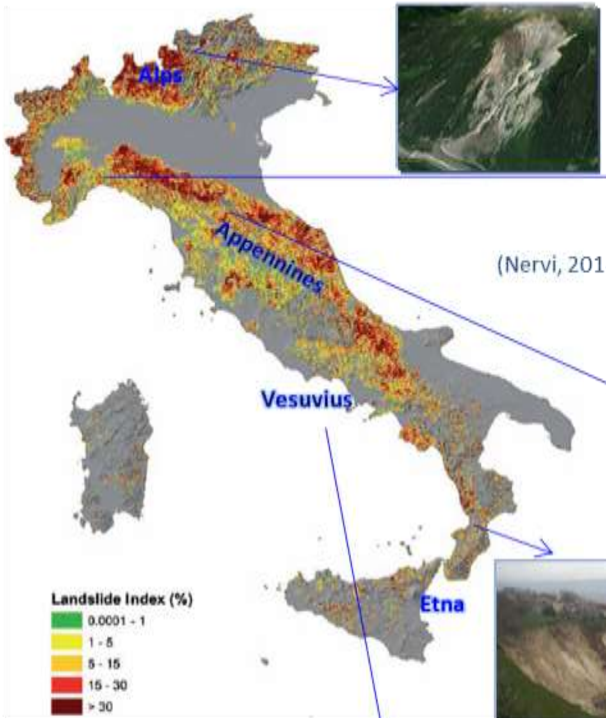
Notes
(1) For qualitative zoning.
(2) For quantitative zoning.

The Italian case study



Nadim (2007)

(ISPRA, 2008)



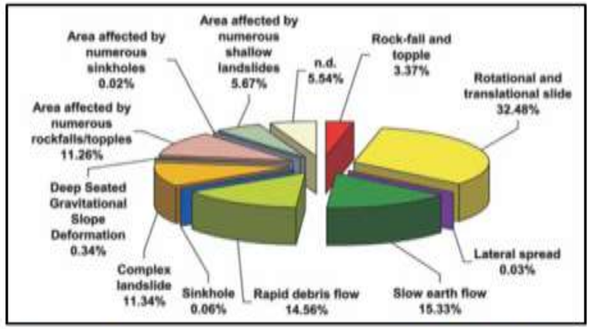
(Val Pola, 1987)

(Nervi, 2014)

(Pietta, 2013)

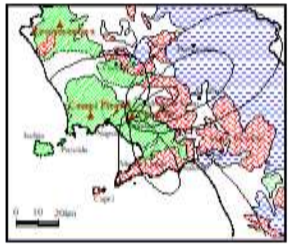
(Maierato, 2010)

The Italian territory is affected by slow moving landslides and first failure phenomena.
Damages to properties are usually the consequence of slow moving landslides while victims and huge economic damages are often caused by fast landslides, essentially when they affect large areas during a single event.



Type of movements in Italy (ISPRA, 2008)

Vesuvius volcano



(Sarno, 1998)

Air-fall pyroclastic deposits

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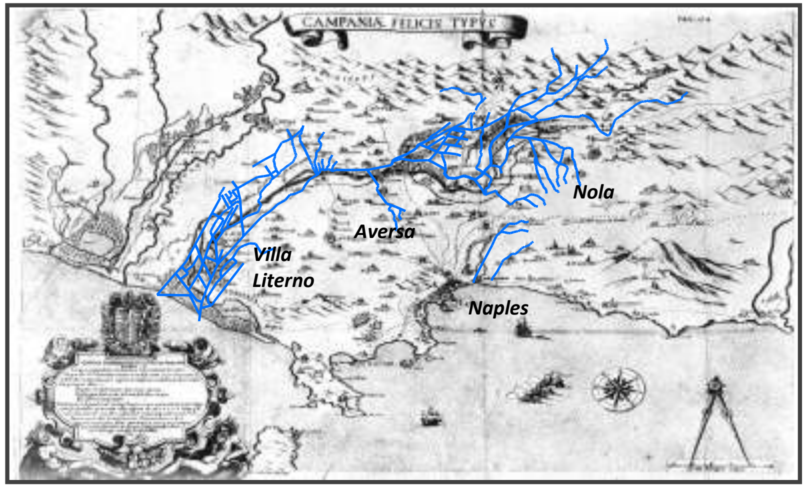
The adopted strategy up to XXth century

Until the XIXth century, the main strategy was aimed at reclaiming the plain zones threatened by landslides: *“The Regi Lagni Channels”*



Regi Lagni Channels at the present

• Project starting: XVIIth century

www.iststudiatell.org

Straight artificial channels of about 56 km collecting rain and spring water.

www.cesbim.it

In the XXth century the attention moves from the lowland areas to the mountain

Royal Legislative Decree n. 3267 of 30 December 1923
“Reorganization and reform of legislation relating to woodland and mountainous terrain”

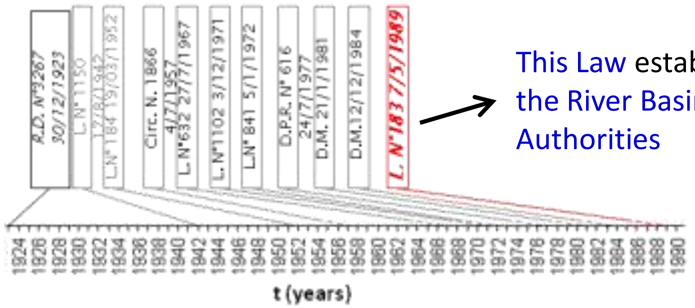
Stringent constraints on the slopes affected by landslides.

www.riservacalanchidiatri.it

METTIAMOCI **IN RIGA**

The River Basin Authorities

The Flood of Florence in the 1966: an occasion to restart the Italian legislation on soil defense



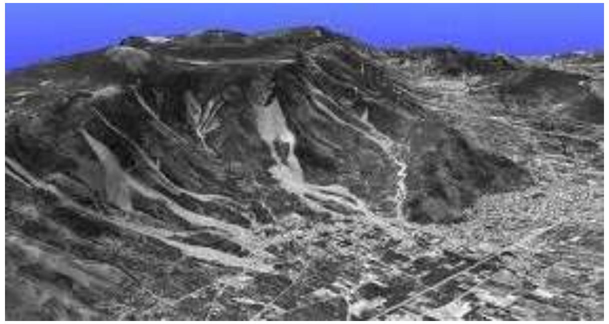
This Law established the River Basin Authorities

The National Law 183/1989

- Defines the Hydrographic Basin as the reference terrain unit within which each planning action must be concentrated;
- introduces the Basin Plan containing information on physiographic outlines and land-use planning;
- entrusts the preparation of the Basin Plan and, among these, of the landslides risk zoning to the River Basin Authorities.

River Basin Authority	Total number	Area [km^2]
International	1	675,66
National	6	143.019,48
Interregional	13	52.951,68
Regional	15	110.065,52
Pilot	1	1.625,81
TOTAL	36	308.338,15

However, the complexity of the procedures introduced by the law, together with the absence of a well-estabilished culture in the landslide risk field, caused a huge delay in the preparation of the landslide risk zoning.



… indeed, a catastrophic event of May 1998 found everyone totally unprepared …

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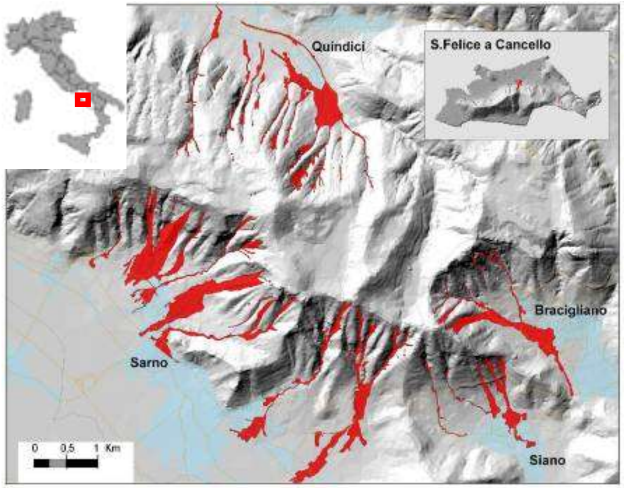
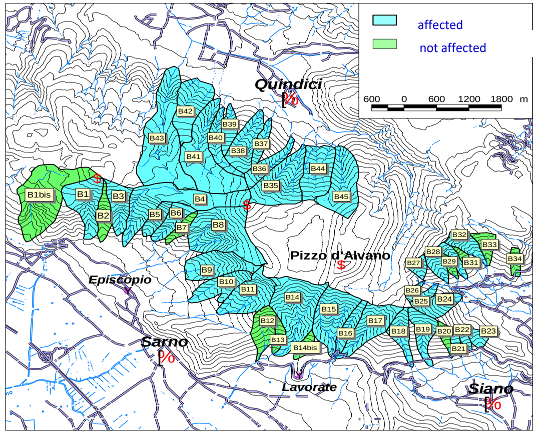
The flowslide disaster of May 1998





Fatalities:

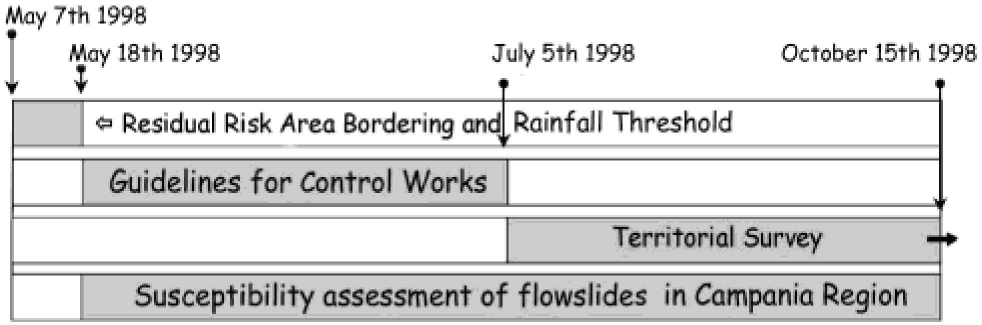
Sarno	137
- Quindici	11
- Bracigliano	6
- Siano	5
- S. Felice a Cancello	1

- Mobilised volumes ≈ 2.000.000m^3;
- 36 out of a total 47 basins affected by landslides.

http://www.repubblica.it/

http://news.bbc.co.uk/1/hi/world/europe/88932.stm

Scheduled activities of the University of Salerno (U.O. 2.38 GNDCI)



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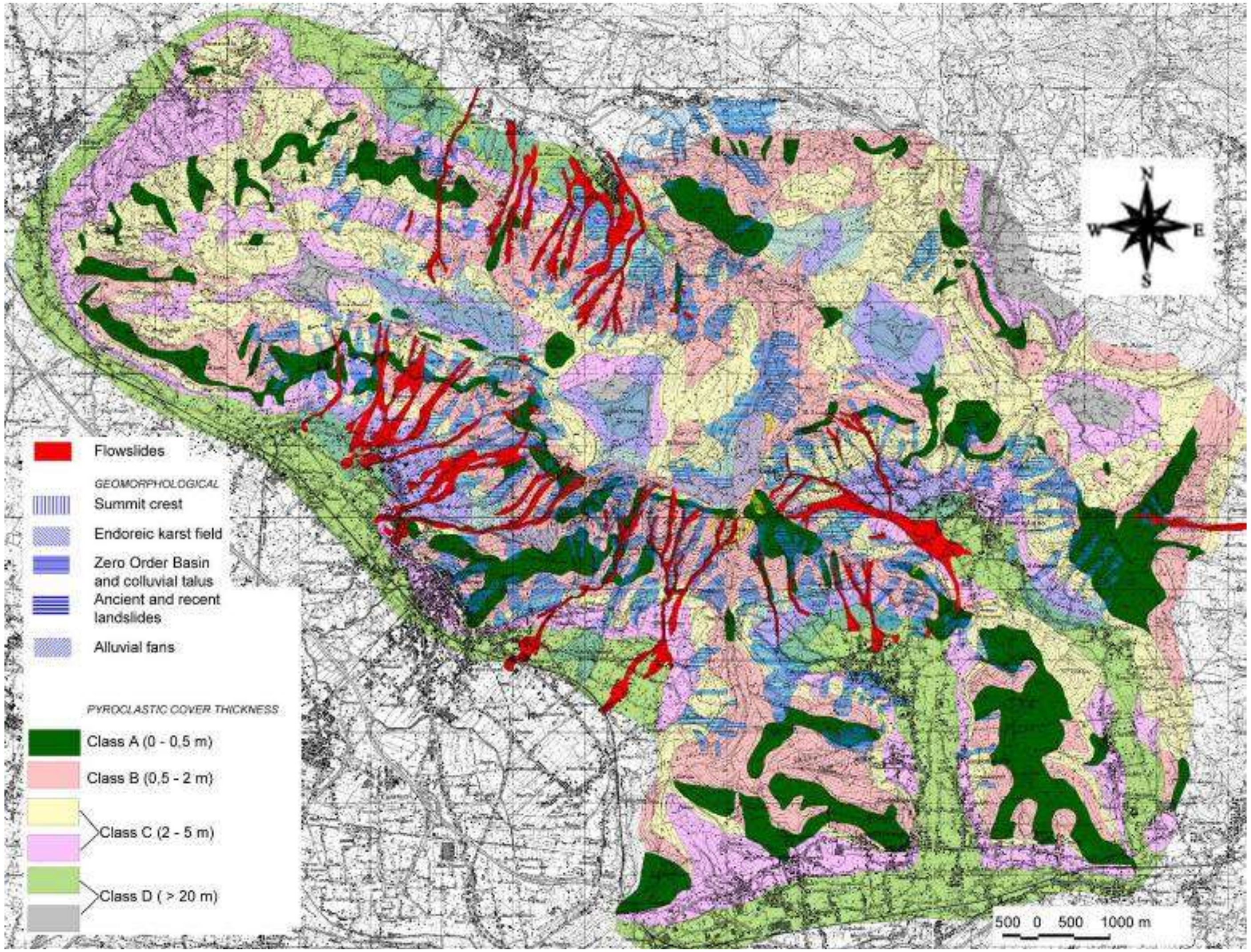
The database acquired after the 1st week



Overlay of the geological, geomorphological and landslides maps (scale 1:25,000)

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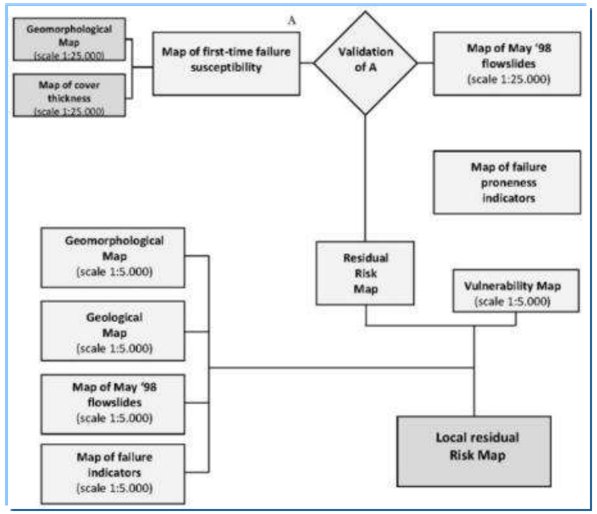
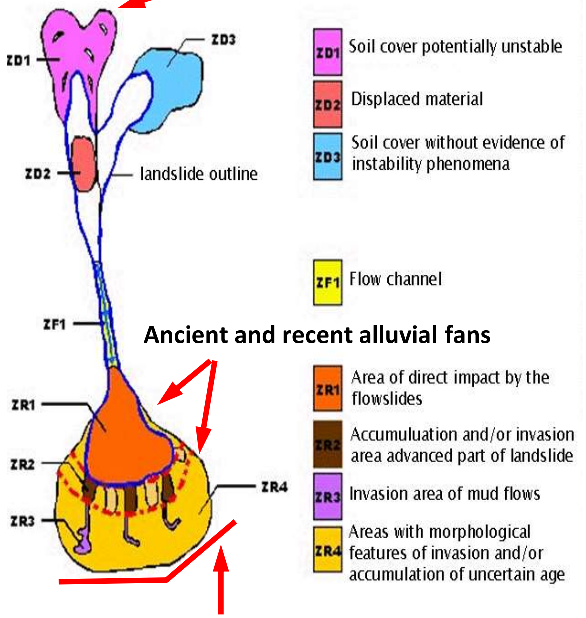
Adopted criteria for the residual risk zoning



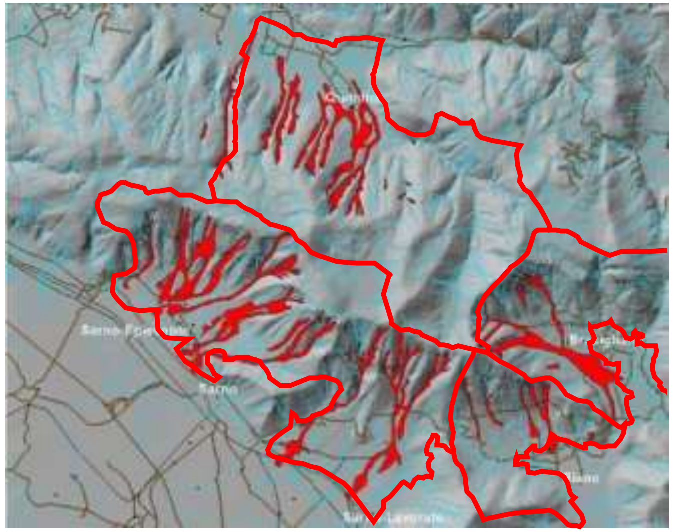
Methodological scheme for the evaluation of the residual risk areas (1:25,000 scale)

The risk zoning



Limit of the landslide affected areas

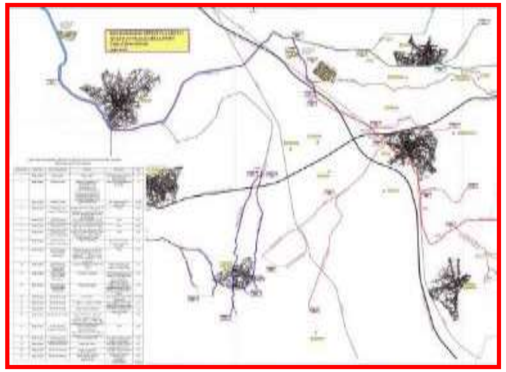
(assumed coincident with the longest run-out distance of recent and ancient alluvial fan)



After only **11 days**, by using basic methods, a team of about 100 technicians developed **the risk zoning** over an area **of 60 km^2.**

(Cascini, 2005)

Risk reduction strategy during the emergency phase



Completed in three months

Completed in six months

First Phase Works

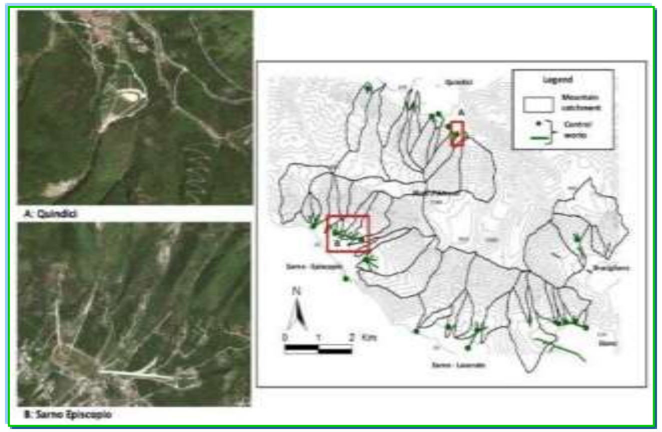
- Cleaning of the drainage channel network inside and outside the risk zones
- Urgent countermeasures for local risk mitigation

Second Phase Works

- New arrangement of the drainage channel network inside the risk zones

Third Phase Works

- Structural control works aimed at risk mitigation



Completed in eight years

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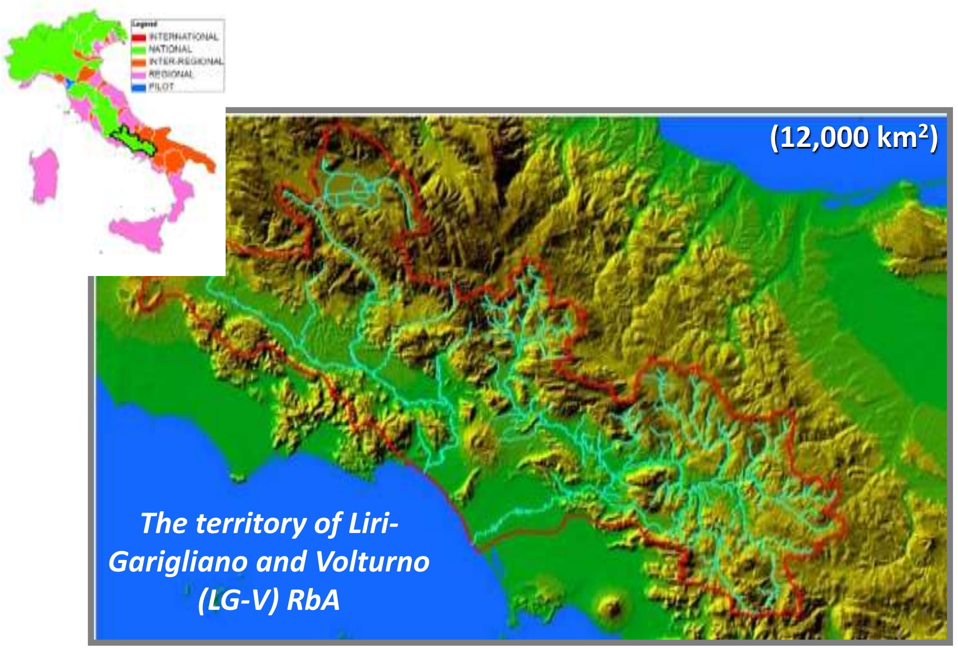
From the Sarno's emergency phase to the Law 365/2000

The landslide risk classes established by the law

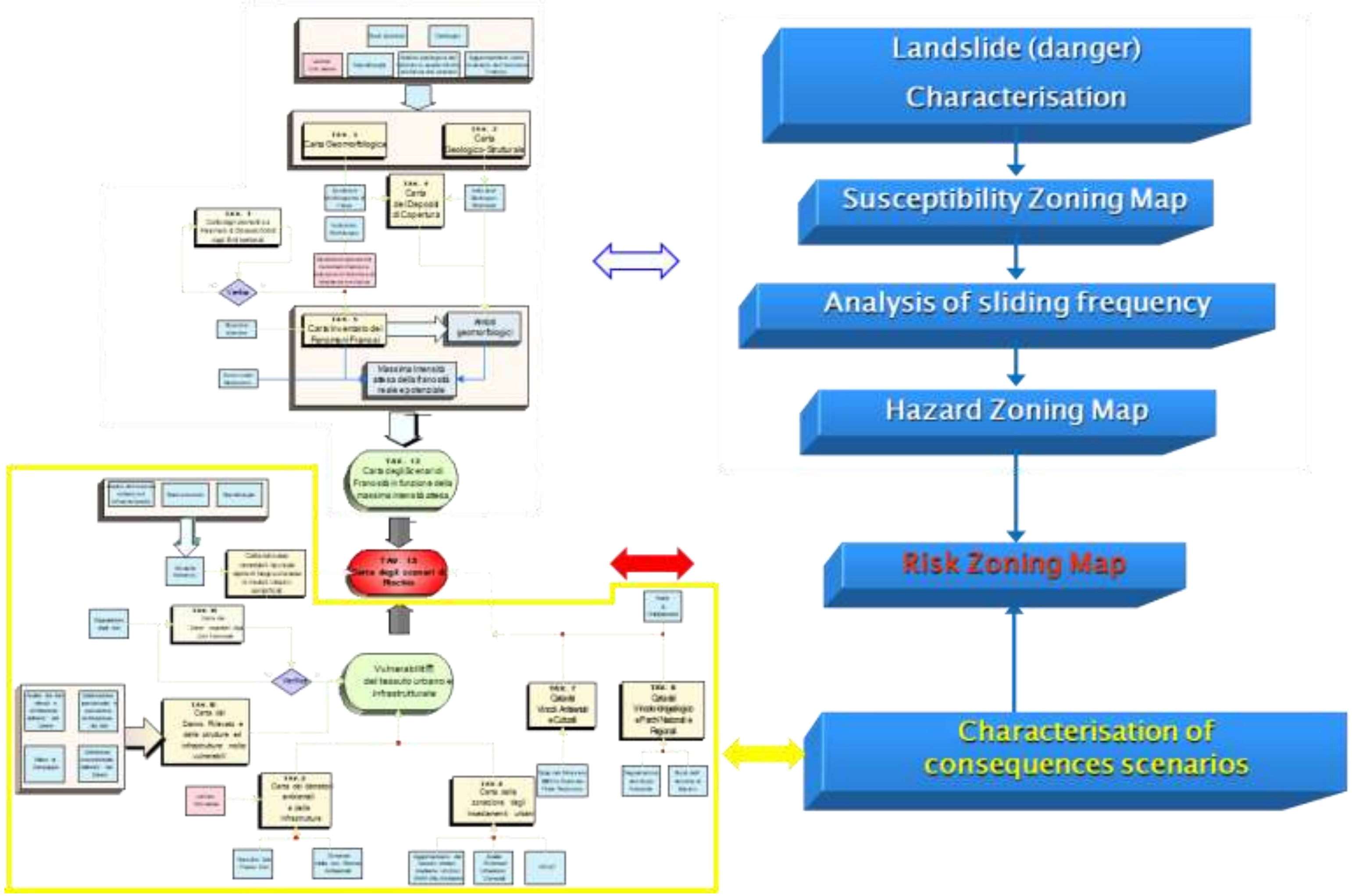
R4	Human life loss and destruction of buildings, infrastructures and environmental as well as interruption of economic activities are expected.
R3	Possible victims and high damages to properties.
R2	Possible victims and high damages to properties.
R1	Limited damages to properties.

Furthermore, some River Basin Authorities, in preparing the landslide zoning, identified the so called Attention Areas" (hazard areas).



	Liri-Garigliano	Volturno	Total
	Area (km^2) %	Area (km^2) %	Area (km^2) %
Plans	926 18	1522 24	2448 21.3
Hills	1954 38	2790 44	4744 41.3
Mountains	2263 44	2030 32	4293 37.4

The framework for risk zoning at medium scale



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Adopted landslide intensity classes

I ≡ the highest expected velocity

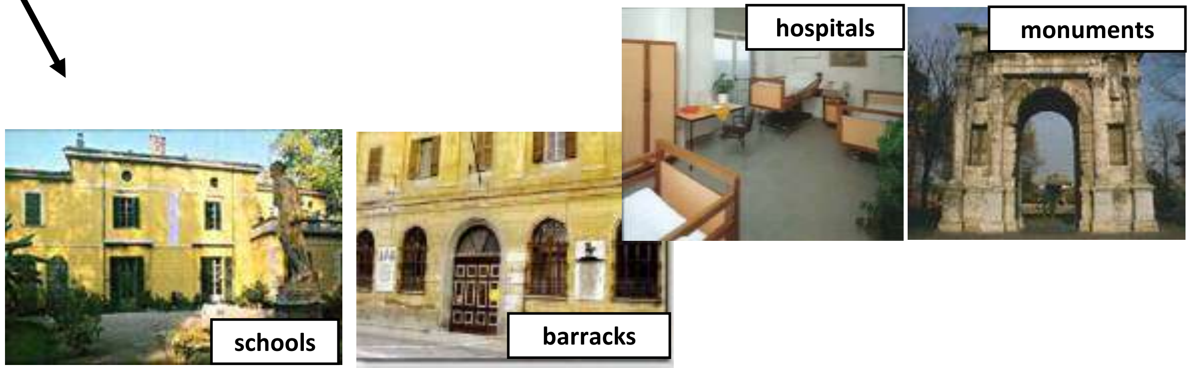
I	Landslide type
High	**Flowslides, Debris flow, First failure in brittle materials**
Medium	**Slow moving earthflows, Translational and Rotational slides**
Low	**Deep-Seated Gravitational (Slope) Deformation, Lateral spreads**

Nominal scales for hazard, element at risk and their vulnerability

$$R = H \cdot E \cdot V$$

I	Building type	Observed damages	VULNERABILITY
HIGH	All	Not considered	HIGH
MEDIUM	Strategical building	Not considered	HIGH
	Common building	YES	
	Common building	NO	MEDIUM
LOW	Strategical building	Not considered	MODERATE
	Common building	YES	
	Common building	NO	LOW

I	HAZARD	Landslide activity
HIGH	HIGH	Active
		Quiescent
MEDIUM	HIGH	Active
	MEDIUM	Quiescent
LOW	HIGH	Active
	MEDIUM	Quiescent



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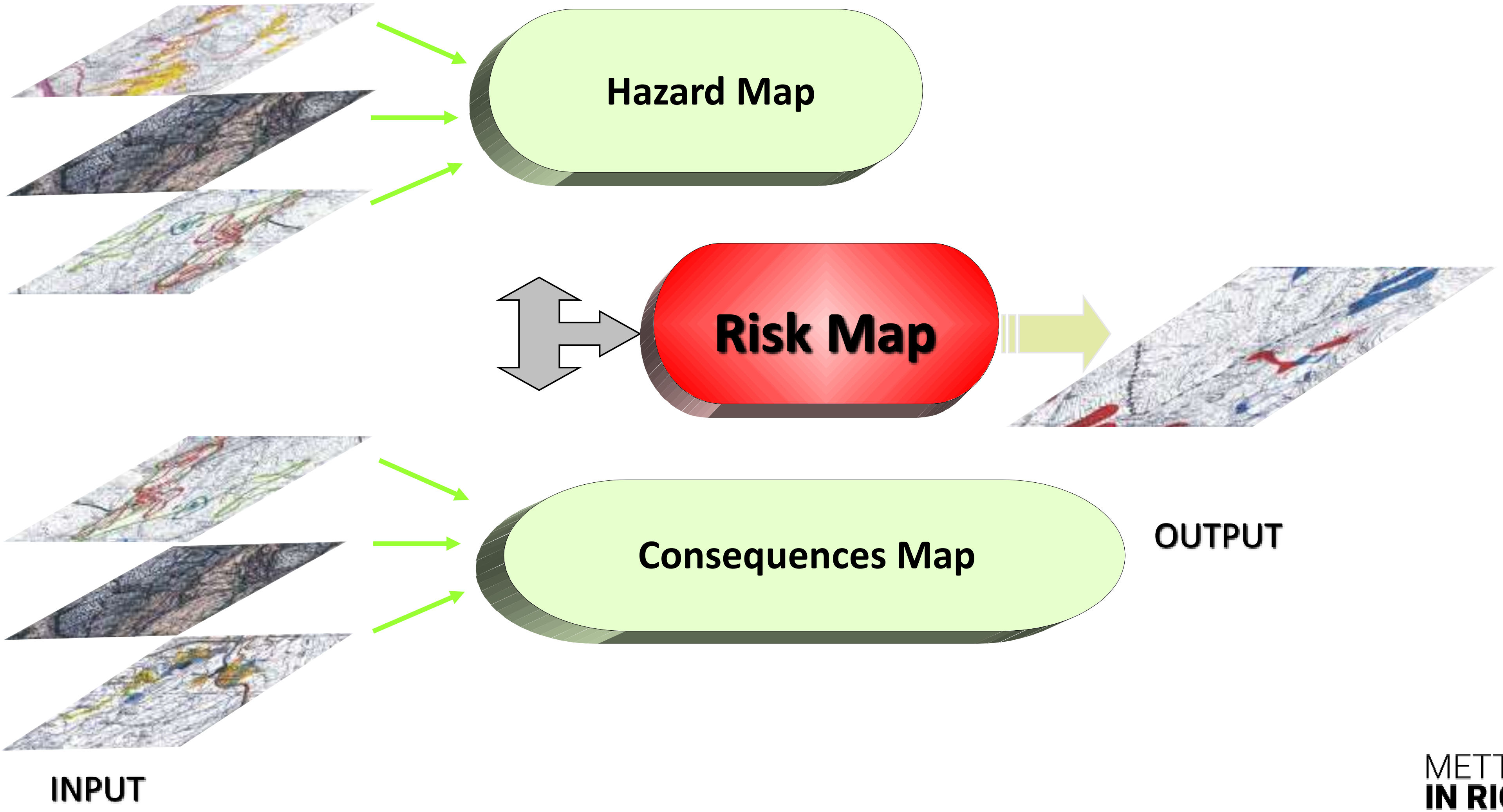
Risk zoning at medium scale

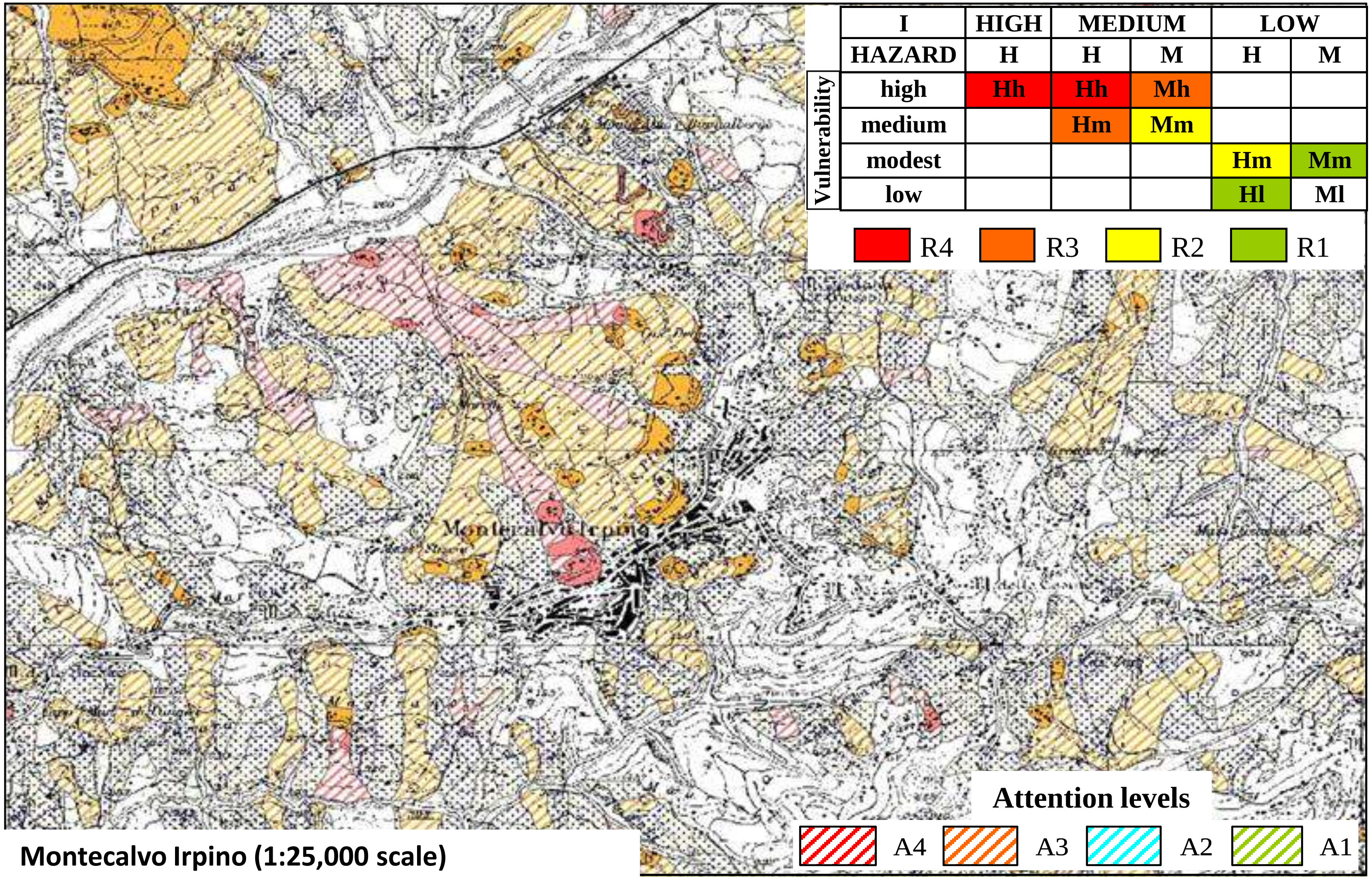


Adopted levels for qualitative risk estimation

	I	HIGH	MEDIUM		LOW	
	HAZARD	H	H	M	H	M
VULNERABILITY	high	Hh	Hh	Mh		
	medium		Hm	Mm		
	modest				Hm	Mm
	Low				Hl	Ml

R4	
R3	
R2	
R1	

An example of hazard and risk maps (L. 365/2000)



	I	HIGH	MEDIUM		LOW	
	HAZARD	H	H	M	H	M
Vulnerability	high	Hh	Hh	Mh		
	medium		Hm	Mm		
	modest				Hm	Mm
	low				Hl	Ml

Montecalvo Irpino (1:25,000 scale)

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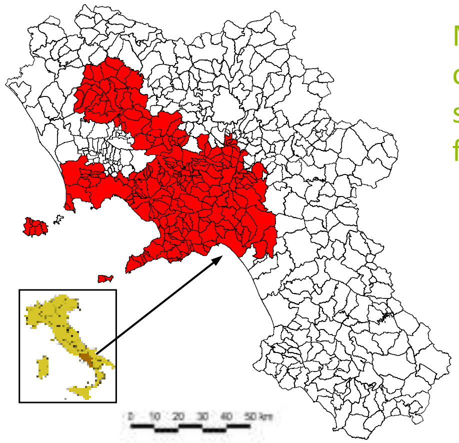
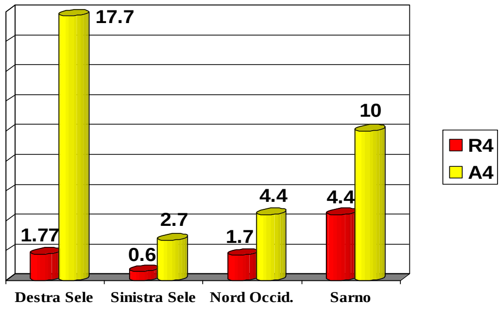
Limits of the current landslide risk zoning

Fast moving landslide



Municipal territories (212) of the Campania region sistematically affected by flowslides

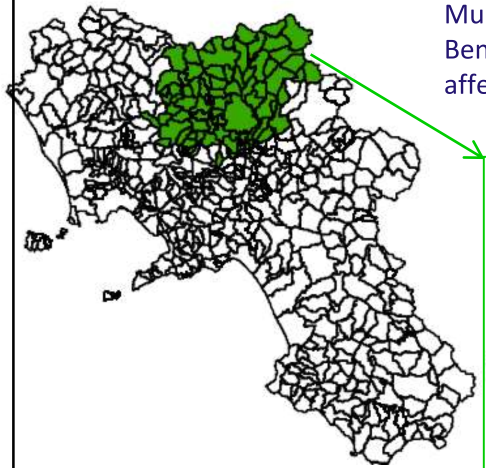
Risk and attention areas inside the 212 Municipalities of Campania region .

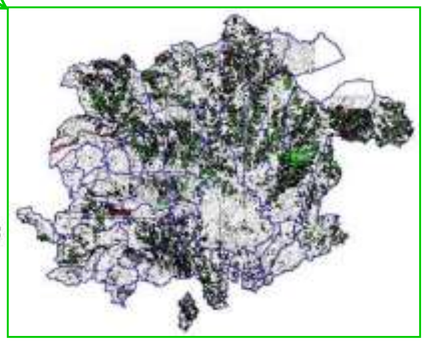


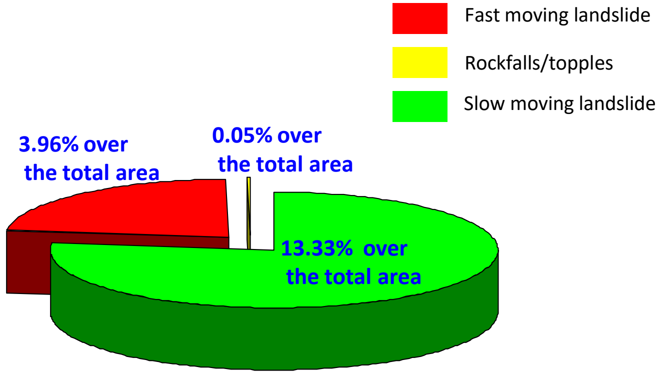
The level of risk cannot be ranked in 212 towns since the territory at landslide risk is everywhere classified at R4 class.

Slow moving landslide

Municipal territories (78) of the Benevento Province sistematically affected byslow moving landslides





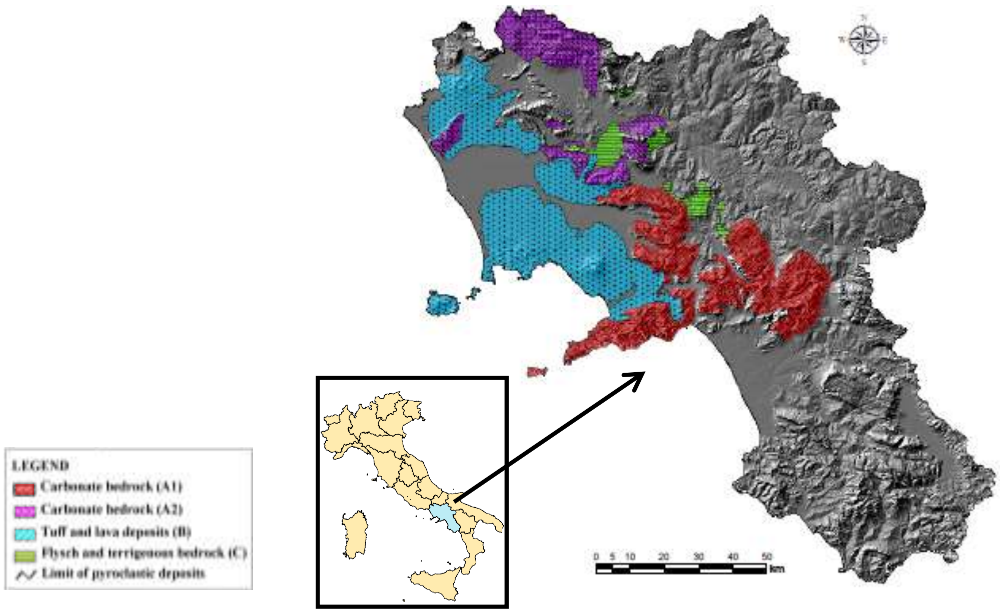


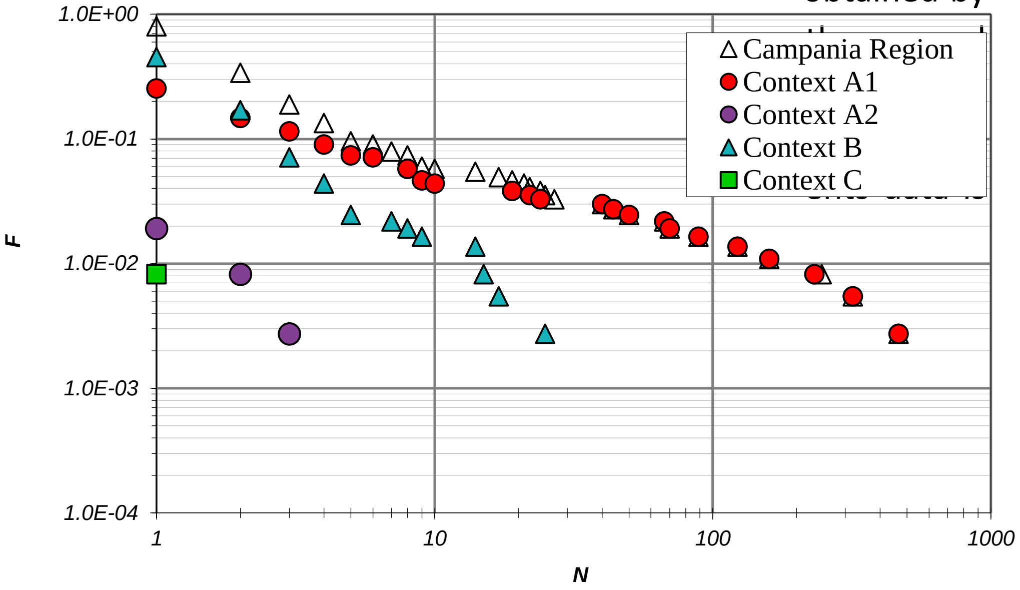
The level of risk cannot be ranked for hundreds of landslides since the territory at landslide risk is everywhere classified at R2 class.

Improving the landslide risk management at regional and national scales

F-N curves for fatal landslides occurred in Campania region.

obtained by





(Cascini et al., 2008)

Historical period	Documentary sources
15th - 18th Centuries	Literary works and Parish archives
19th Century	Intendenza del Regno delle Due Sicilie (Sezione Opere Pubbliche) - founded by the Bourbons in 1806 and housed in the State Archive of Salerno
	Archives of the Genio Civile (dating back to 1816)
	Archives of the Prefettura di Gabinetto (founded in 1861)
	Documents labelled Protocolli Notarili
20th Century	Historical literature
	Scientific books
	Local and national newspaper kept in the Provincial Library of Salerno
	National research Council's AVI Special Project archive
	Essays written following the events of May 1998

Geological context	*Number of Municipalities*	*Number of Municipalities threatened by fatal landslides*	*Recorded number of deaths*
A1	121	57	1790
A2	70	7	11
B	157	39	301
C	66	3	3

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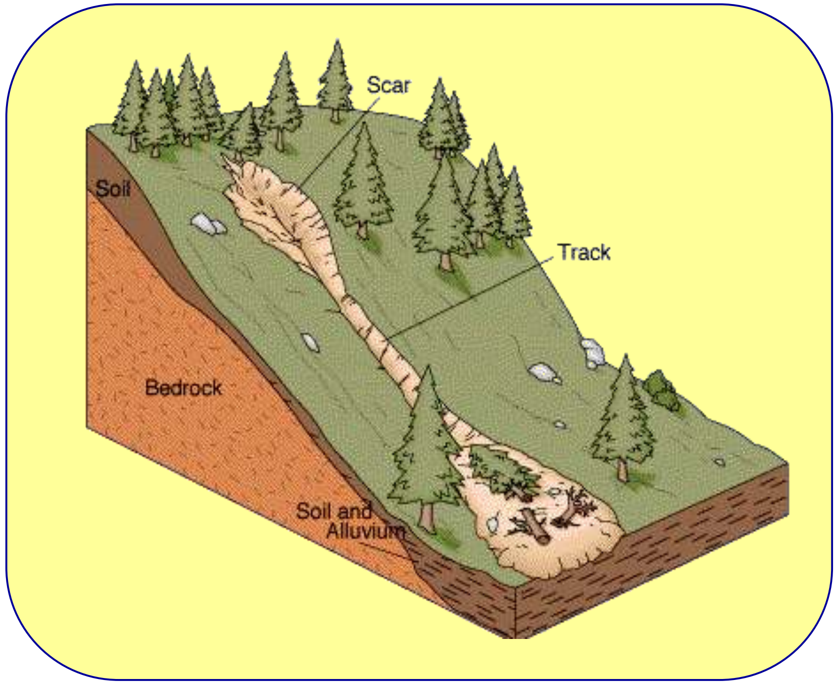
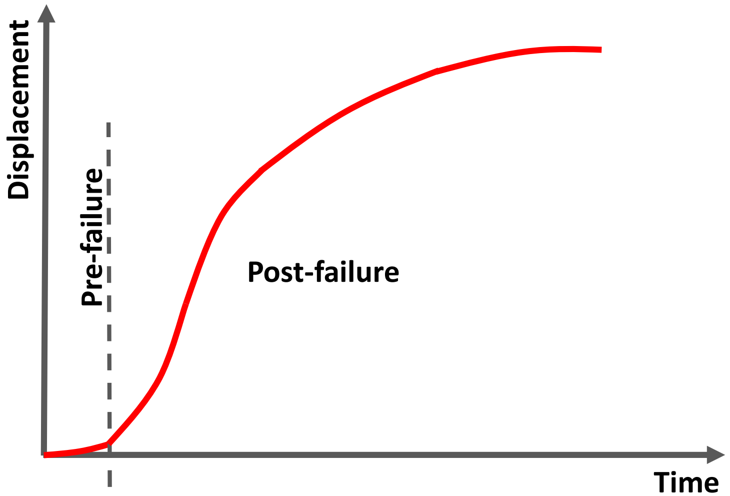
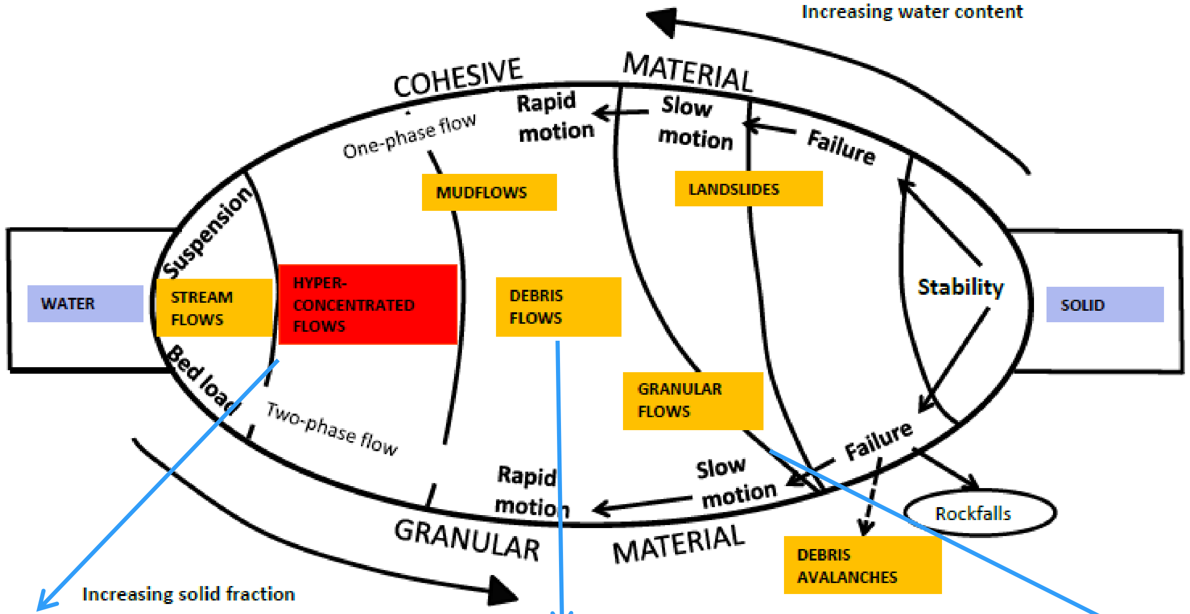
Improving the landslide risk management at slope scale





Classification of flow-like landslides



Classification of mass movements on steep slopes as a function of solid fraction and material type (Coussot & Meunier, 1996 mod.)

Atrani (2010)

Quindici, 1998
(Cascini et al., 2005)

Acquabona, 2001
(Tecca et al., 2009)

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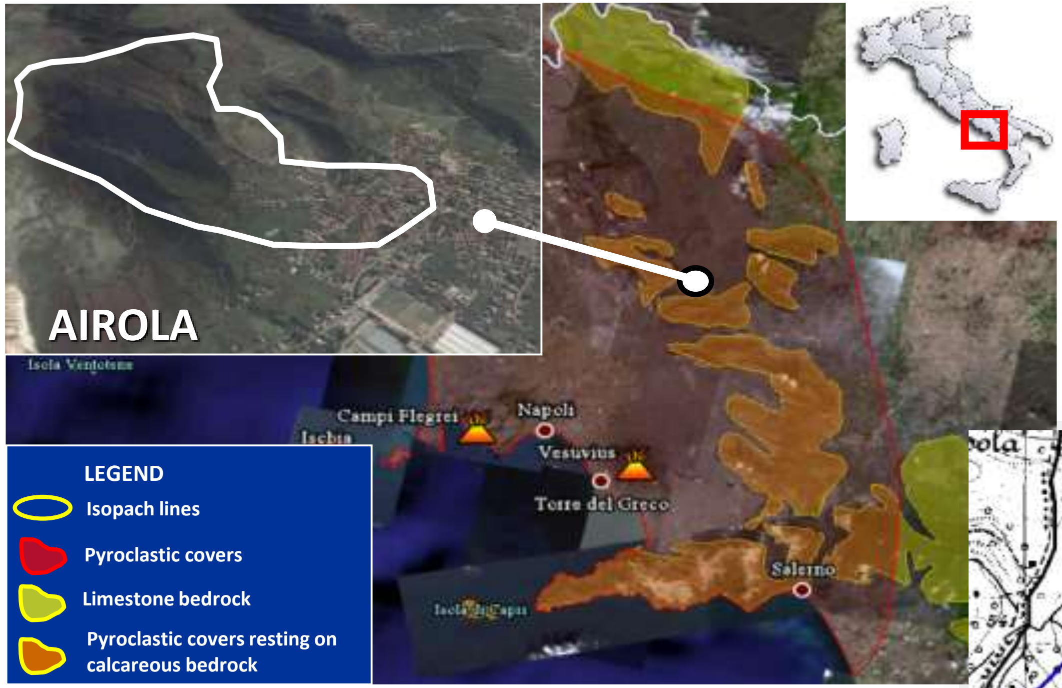
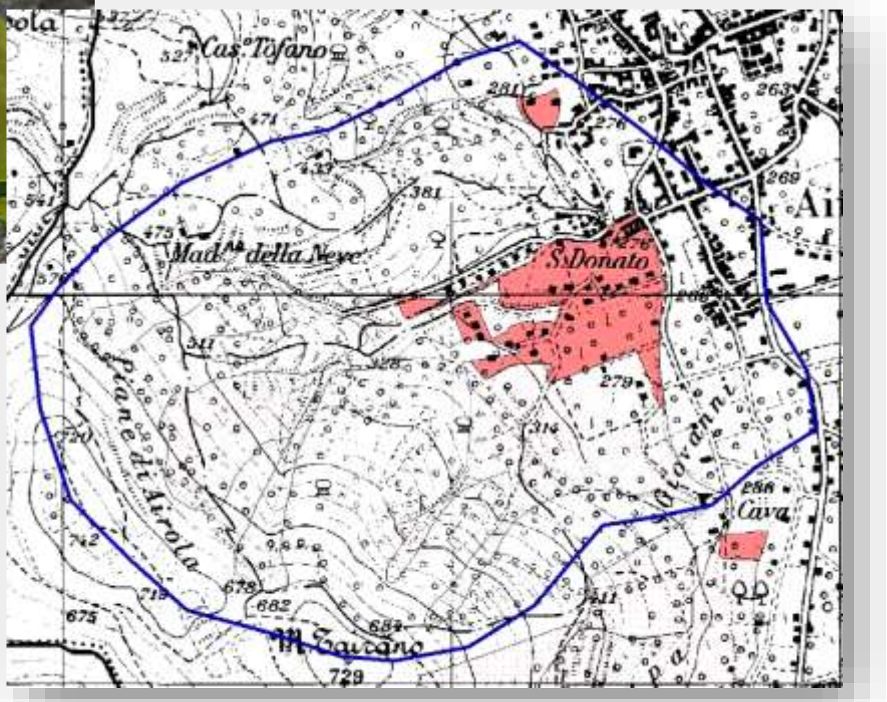
A case study in Campania region



The current landslides risk zoning has been developed at a preliminary level by using only basic methods. As a consequence the landslides triggering areas and the alluvial fans are not validated by a comparison with other methods

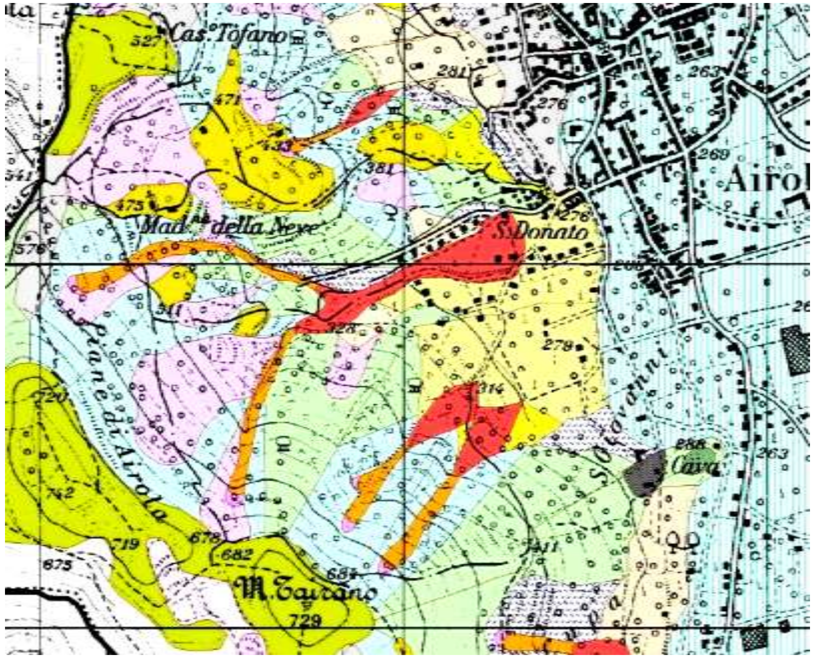
The current landslide risk zoning



AIROLA **1:25,000 scale**

Improving the basic zoning maps

1:25,000 scale

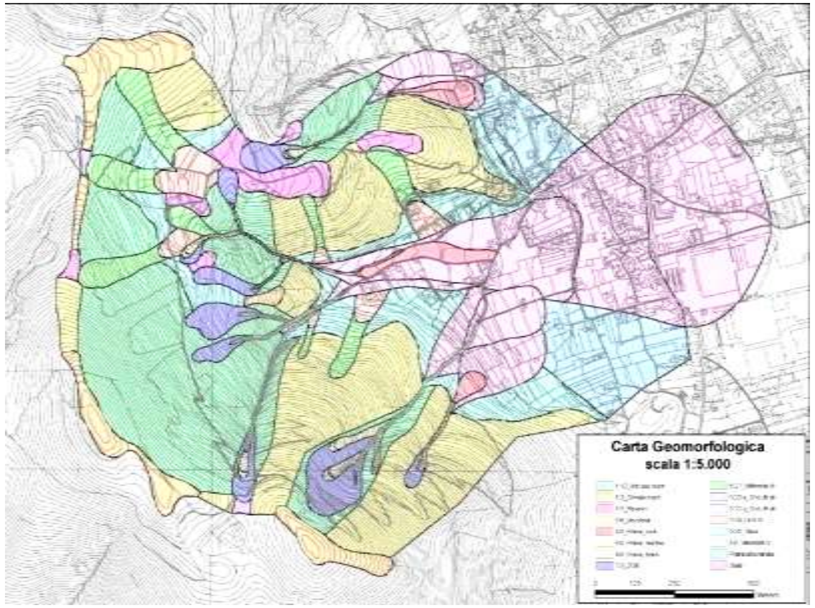


In the current risk zoning maps (1:25,000) the basic data were obtained at the same scale (1:25,000);

eventhough the risk zoning improvement was planned at the same scale (1:25,000), the basic zoning maps were developed at 1:5,000 scale;

This allows a comparison of the triggering and flooded area with those calculated using advanced methods.

1:5,000 scale



A comparison between the two different maps clearly highlights the significant improvement obtained at 1:5,000 scale for both landslides triggering areas and alluvial fans at the toe of the hillslopes.

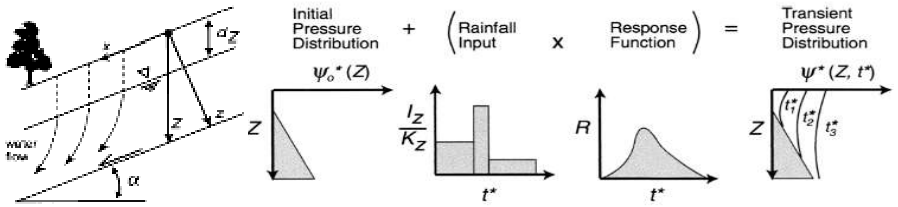
METTIAMOCI IN RIGA

Improving the basic zoning maps

TRIGRS
(Baum et al., 2002)

- Transient hydrological conditions
- Fully Saturated conditions
- Slope-parallel watertable
- Homogeneous soil with spatial variability
- Impermeable or infinite basal boundary

Infiltration model



Linearised solution of Richards equation

↓

$$\psi(z,t)$$

↓

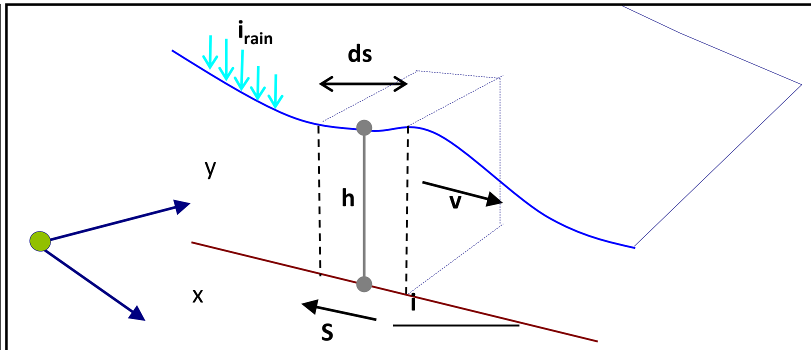
Infinite slope

↓

Safety factor

$$FS(z,t)$$

FLO-2D model
(O'Brien, 1993)



- Continuity equation :

$$\frac{\partial h}{\partial t} + \frac{\partial hV_x}{\partial x} + \frac{\partial hV_y}{\partial y} = i_{rain}$$

- Dynamic wave momentum equation along x,y directions:

$$S_{fx} = i_x - \frac{\partial h}{\partial x} - \frac{V_x}{g}\frac{\partial V_x}{\partial x} - \frac{V_y}{g}\frac{\partial V_x}{\partial y} - \frac{1}{g}\frac{\partial V_x}{\partial t}$$

$$S_{fy} = i_y - \frac{\partial h}{\partial y} - \frac{V_y}{g}\frac{\partial V_y}{\partial y} - \frac{V_x}{g}\frac{\partial V_y}{\partial x} - \frac{1}{g}\frac{\partial V_y}{\partial t}$$

CARATTERISTICHE:
- BI-DIMENSIONAL MODEL
- EULERIAN INTEGRATION

SHEAR STRESS RELATIONSHIP

$$S_f = S_y + S_v + S_{td}$$

YIELD SLOPE

$$S_y = \frac{\tau_y}{\gamma_m h}$$

VISCOUS SLOPE

$$S_v = \frac{K\eta}{8\gamma_m}\frac{V}{h^2}$$

TURBOLENT-DISPERSIVE SLOPE

$$S_{td} = \frac{n_{td}^2 V^2}{h^{4/3}}$$

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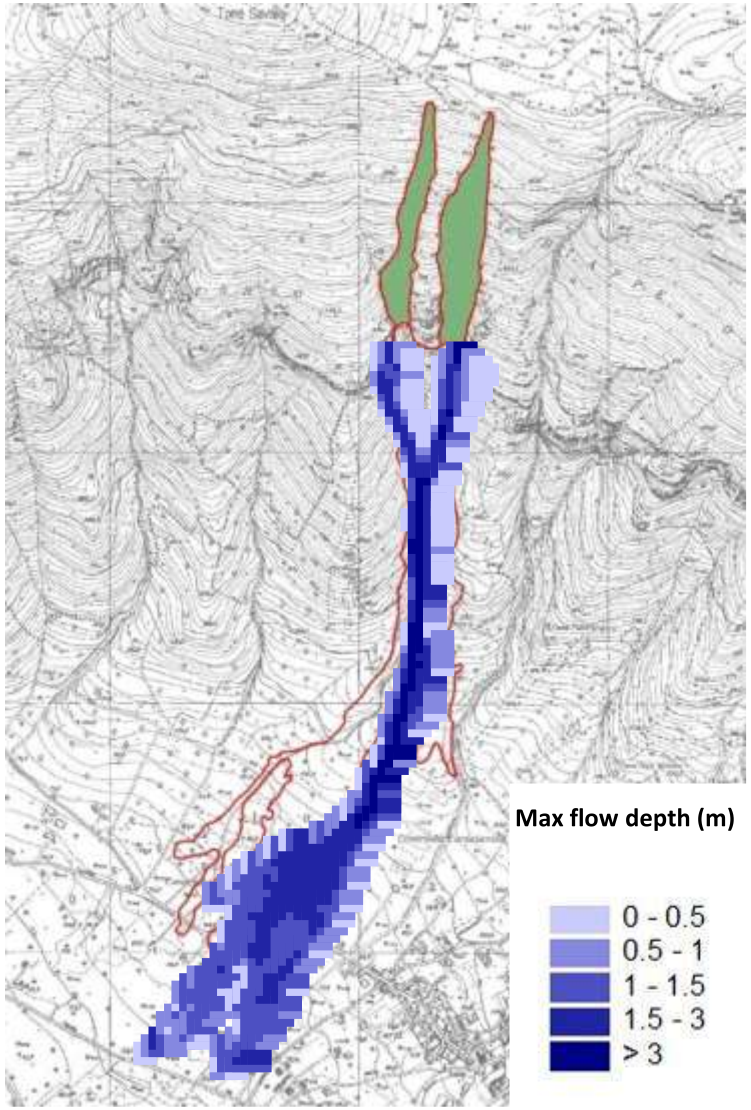
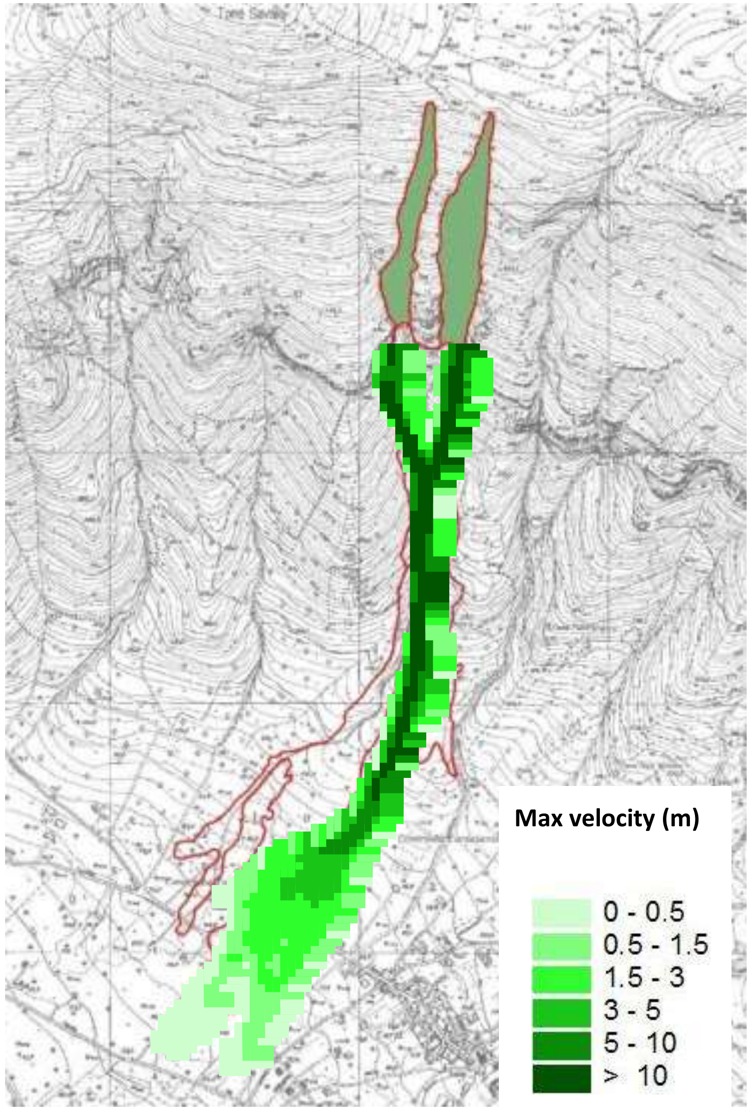
Validation of model and parameters





A proper use of advanced models necessarily requires a satisfactory calibration of the input parameters

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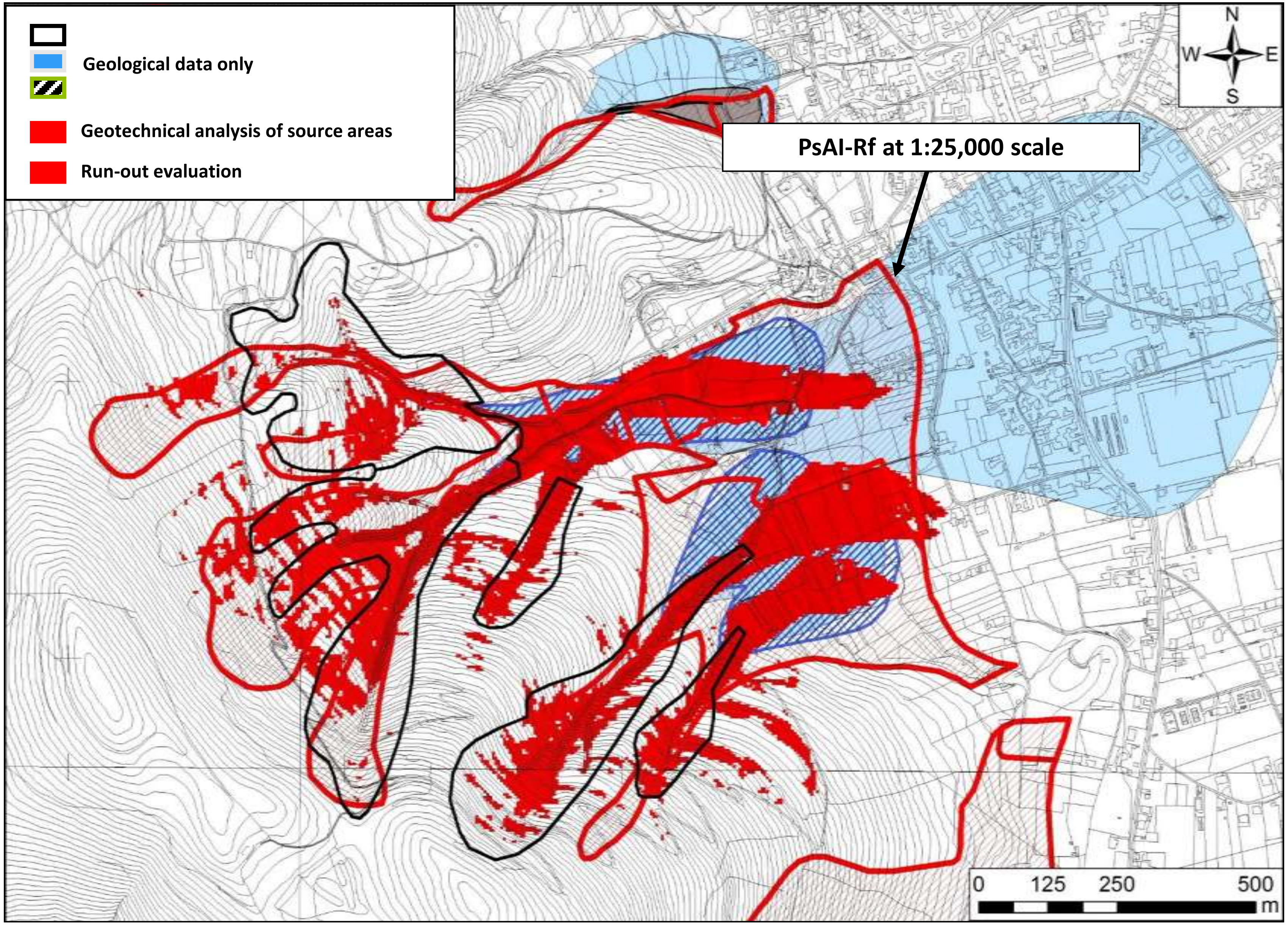
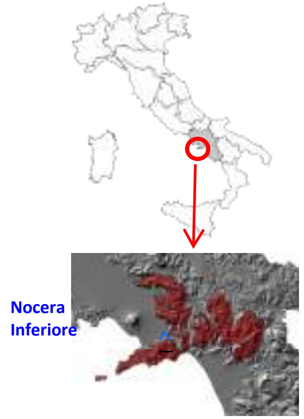
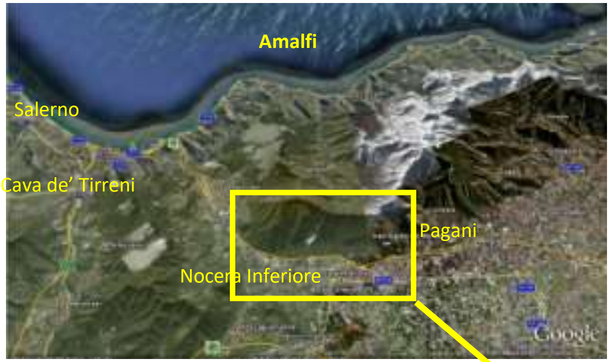
Improving the landslide risk zoning

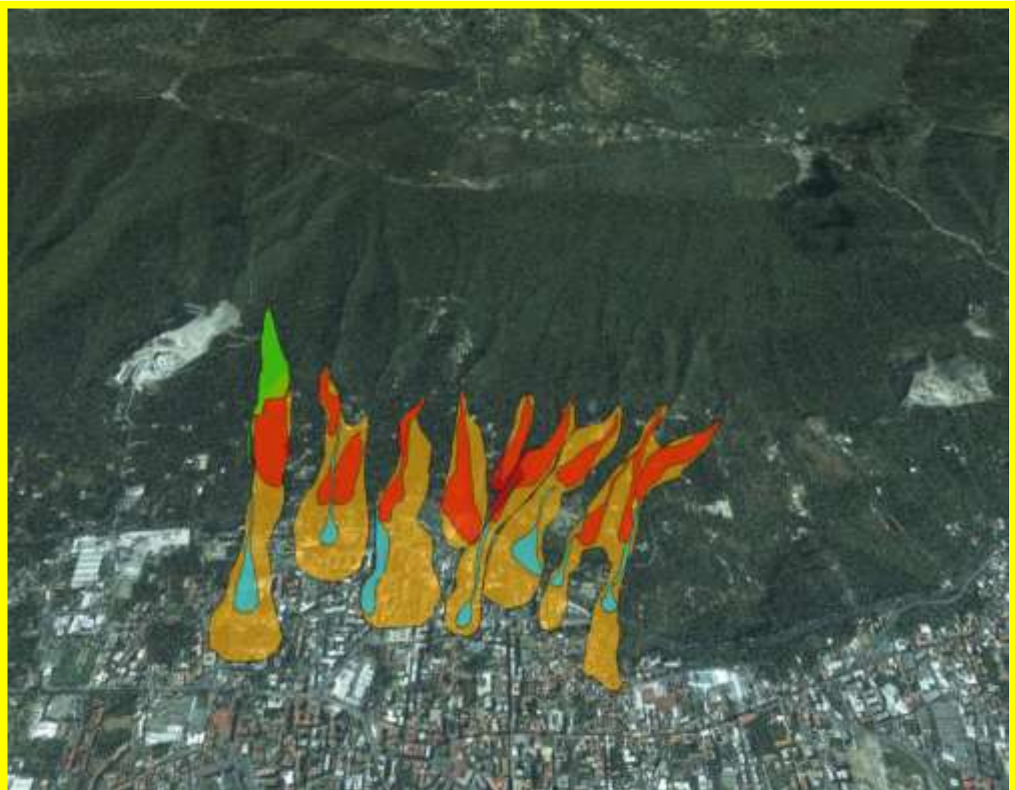


A new frontier for the landslide risk management: the QRA





- ➢ **DEBRIS FLOWS**
- ➢ **HYPERCONCENTRATED FLOWS**
- ➢ **LANDSLIDES ON OPEN SLOPES**
- ➢ **FLOODS**



Frontal view of the debris avalanche occurred on March 2005.

Classification of flow-like phenomena

Flow	Sediment concentration	Bulk Density [g/cm^3]	Shear Strength [dyne/cm^2]	Fluid Type
Water flood	1 – 40 % by wt. 0.4 – 20 % by vol.	1.01–1.33	0 - 100	Newtonian
Hypercon centred flow	40 – 70 % by wt. 20 – 47 % by vol.	1.33 – 1.80	100 - 400	Non-Newtonian (?)
Debris flow	70 – 90 % by wt. 47 – 77 % by vol.	1.80 – 2.30	>400	Viscoplastic (?)

(Costa, 1988)

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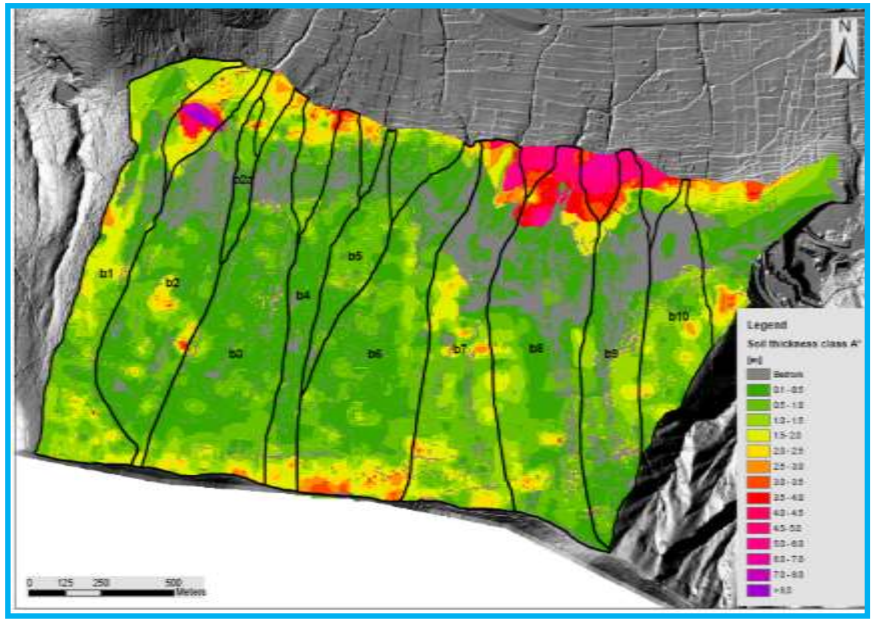
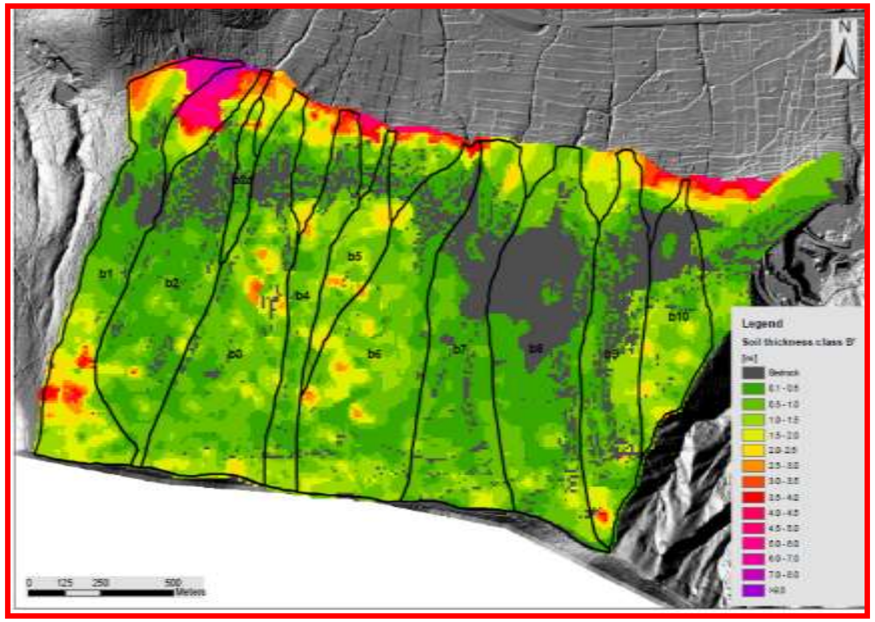
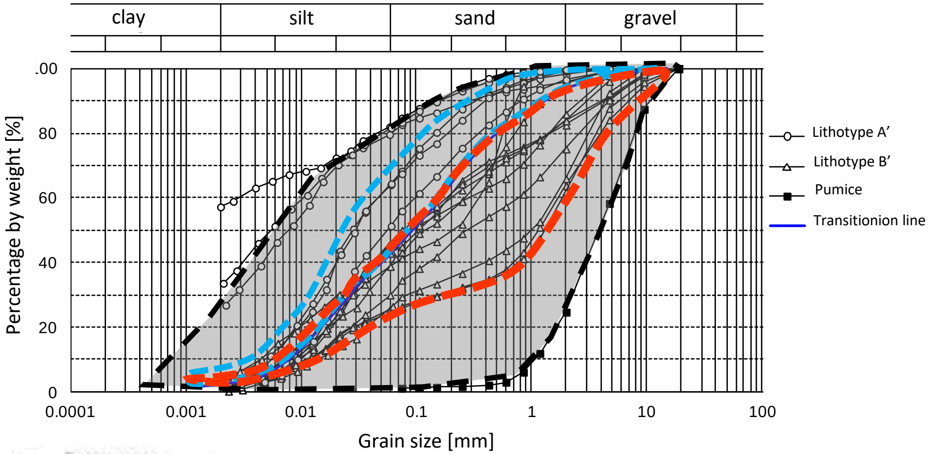
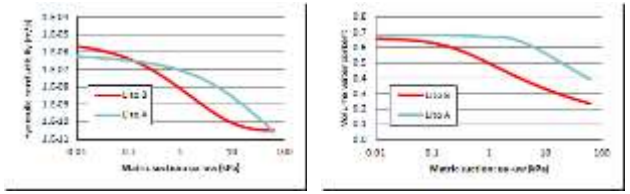
Detailed in situ and laboratory investigations







Soil water characteristic curves



(Bilotta et al., 2005 modified)

Physical properties of A' and B' ashy soils

Lithotype	γ_s (kN/m³)		γ (kN/m³)		γ_d (kN/m³)		e	
	min	max	min	max	min	max	min	max
A'	25.1	26.3	10.1	15.7	6.8	10.8	1.42	2.84
B'	25.5	27.3	11.8	13.4	7.5	9.7	1.67	2.44

Average values of shear strength parameters of A' and B' ashy soils

Lithotype	c' (kPa)	φ' (°)
A'	6.1	30.7
B'	4.1	37.3

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(De Chiara, 2014)

The QRA procedure

AN EXAMPLE FOR HYPERCONCENTRATED FLOWS

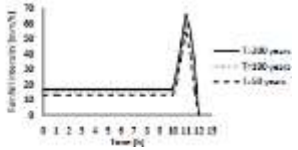
Hazard Analysis

1) **Landslide characterisation**

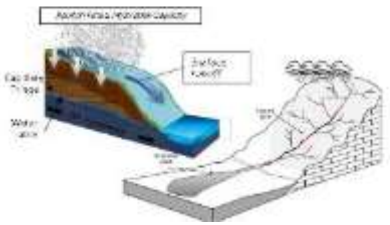
WHICH PHENOMENON?
WHERE? WHAT? WHEN?

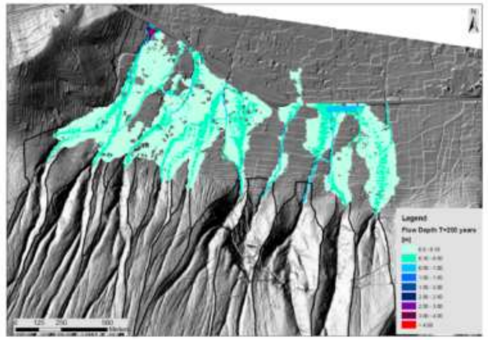
2) **Frequency analysis: P(L) estimation**

Historical occurrence	Duration [h]	Return Period [years]
02/10/1949	12	50
12/09/1955	24	200
26/09/1963	12	100



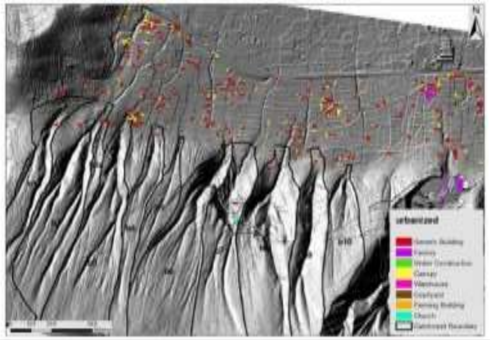
3) **Modelling the triggering stage**





Consequence Analysis

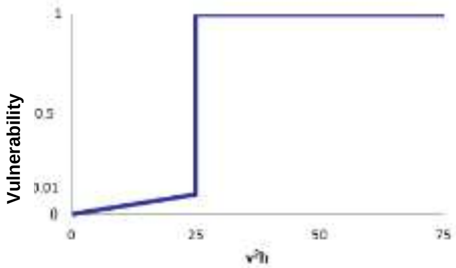
4) **Characterisation of the elements at risk**



5) **Evaluation of the temporal spatial probability of the exposed person P(S:T)**

How many people? Age? Gender? Occupation?
....

6) **Analysis of probability and severity of consequence ($V_{(D:T)}$)**



Risk estimation

(De Chiara, 2014)

Individual risk estimation

The annual probability that a particular person may lose his/her life can be calculated from (Fell et al, 2005):

$$P_{(LOL)} = P_{(L)} \times P_{(T:L)} \times P_{(S:T)} \times V_{(D:T)}$$

where

$P_{(LOL)}$ is the annual probability that the person will be killed;

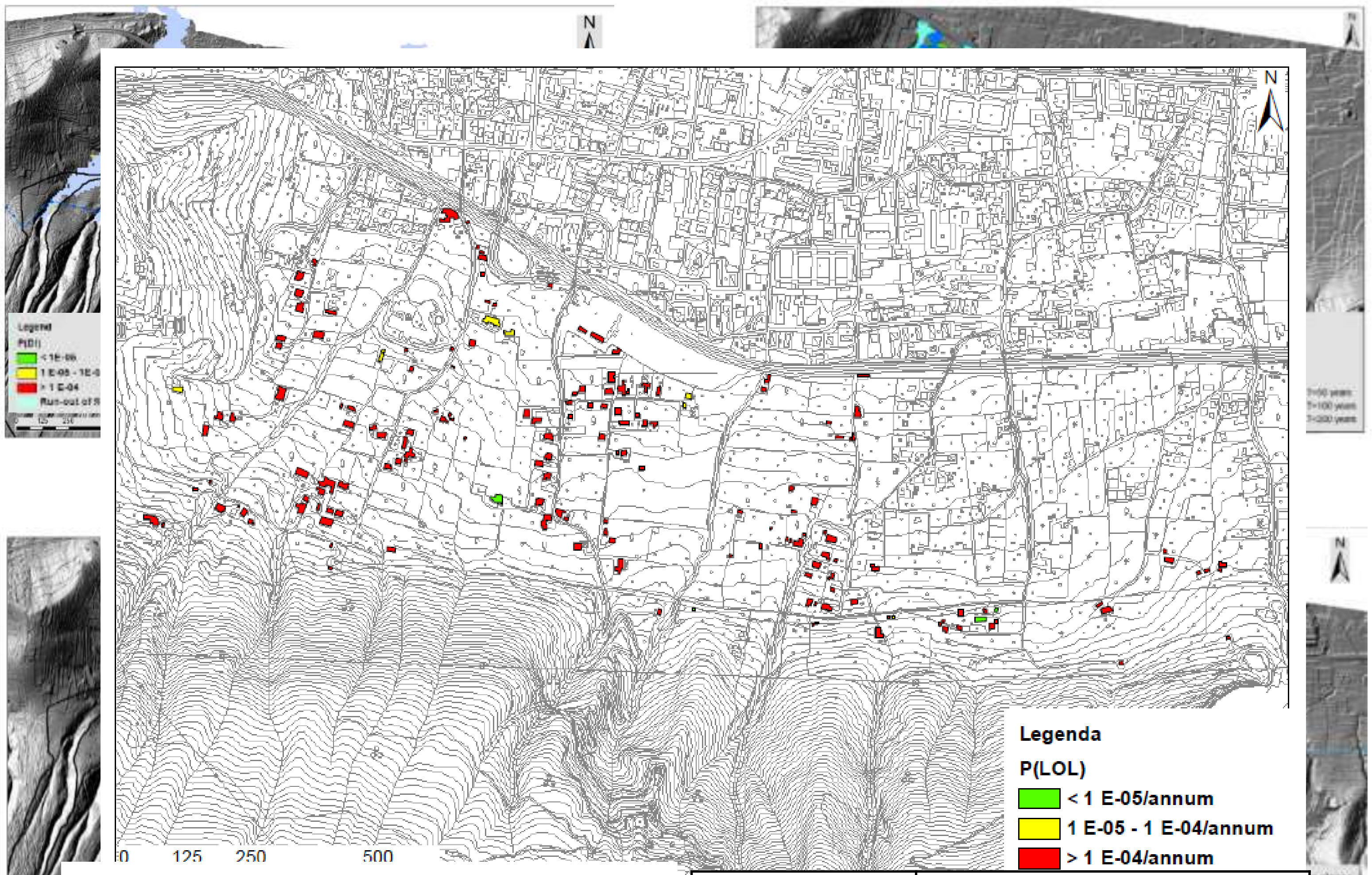
$P_{(L)}$ is the frequency of the phenomenon;

$P_{(T:L)}$ is the probability of landslide reaching the exposed person;

$P_{(S:T)}$ is the temporal spatial probability of the exposed person;

$V_{(D:T)}$ is the vulnerability of the exposed person.

Results provided by the QRA



Is it acceptable or not?

Situation	Tolerable risk for loss of life
Existing slopes	10^{-4} person most at risk 10^{-5} average of persons at risk
New slopes	10^{-5} person most at risk 10^{-6} average of persons at risk

(GEO, 1998)

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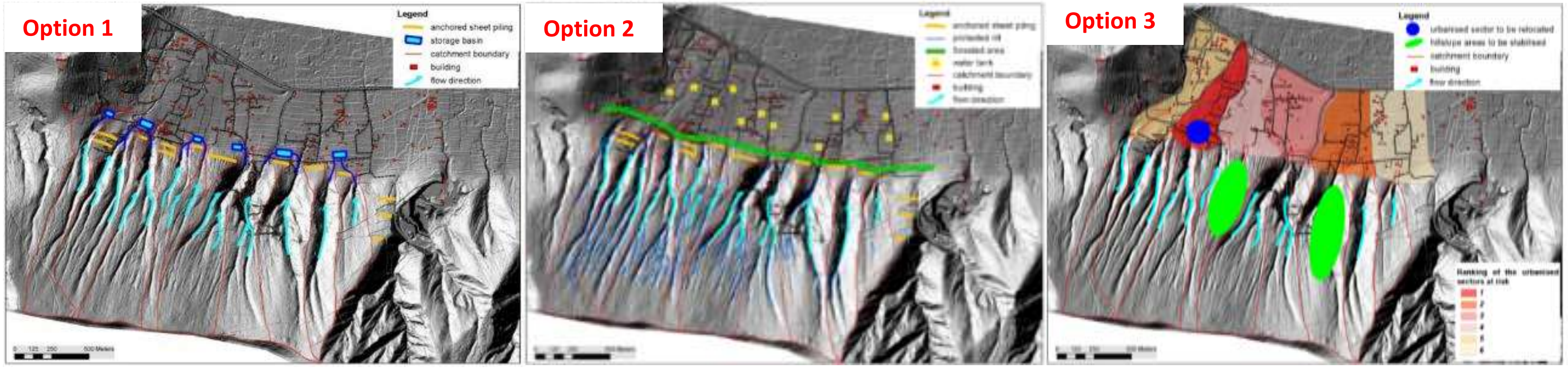
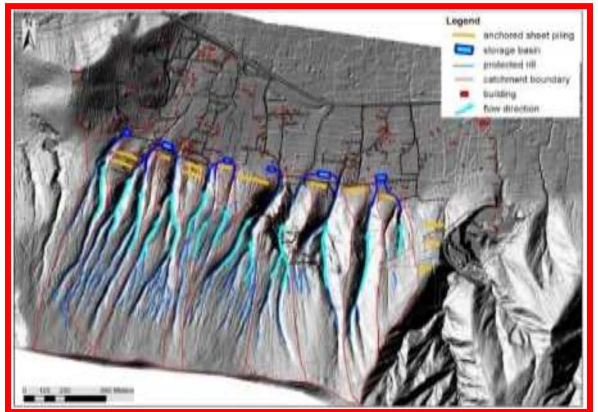
The partecipatory process



The compromise solution



During the final meeting the attendants agreed on some pillars for risk mitigation on the Monte Albino slope.

Particularly, they reached an unanimous consensus on:

- the improvement of the warning system;
- the institution of a territorial survey;
- the stabilization of the open slopes by naturalistic engineering works.

Much more debate was devoted to the relocation of residents from the most endangered areas and/or the need to build passive structural works, especially on private properties.

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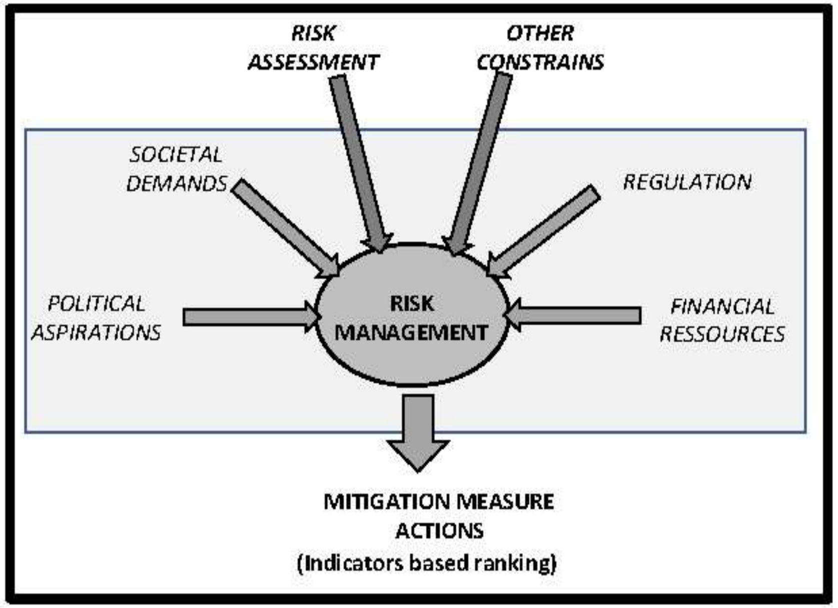
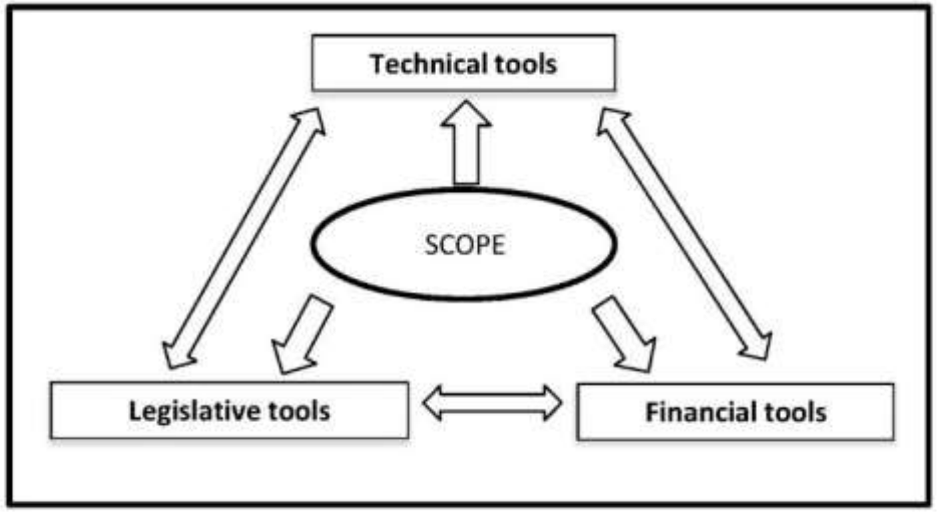
Is the risk management a purely technical issue?



(Leroi et al., 2005)



(Sacco e Cascini, 2013)