MANAGEMENT OF NATURAL HAZARDS
IN MOUNTAIN BASINS

Definition and of modelling of natural risks

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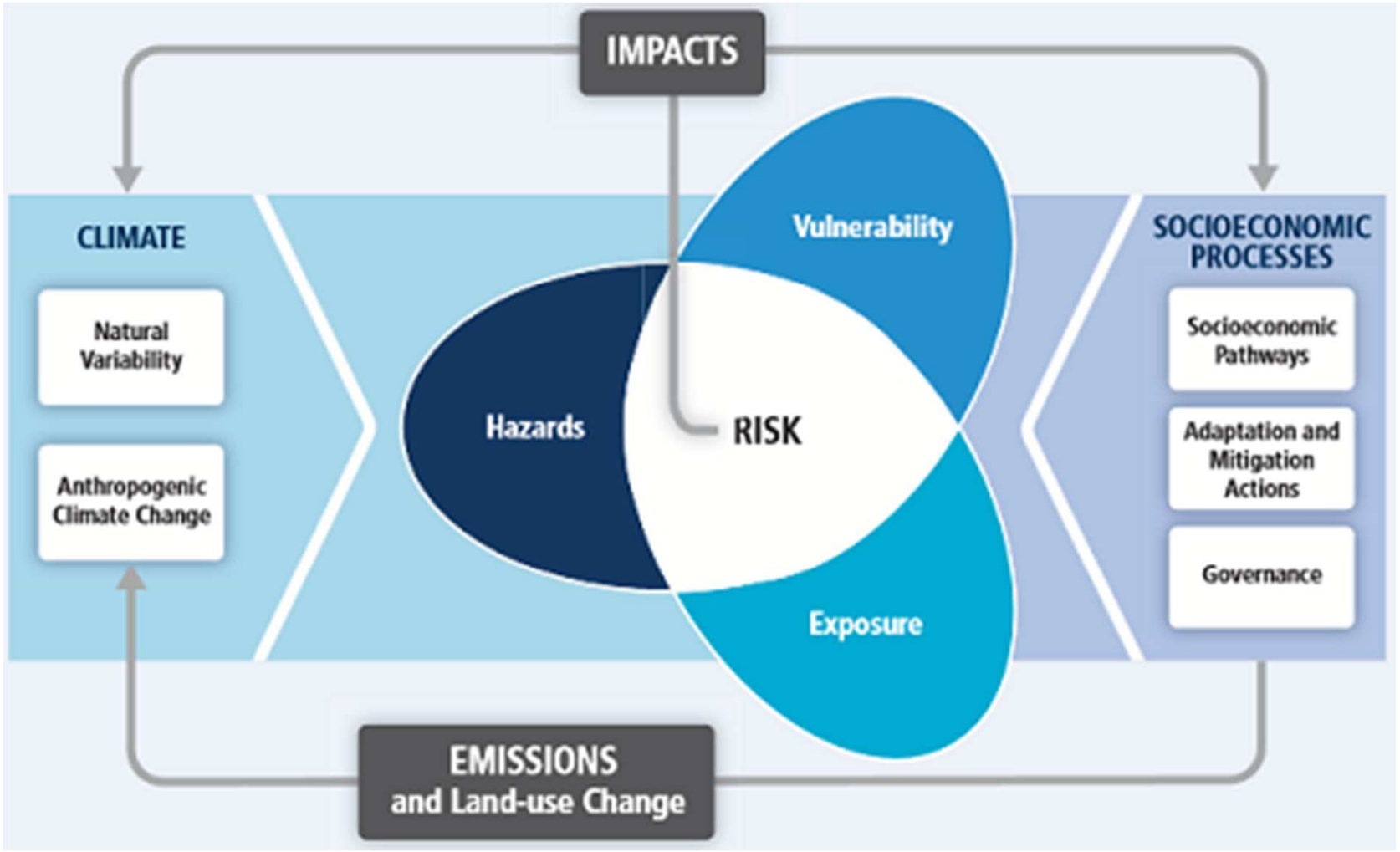
Credits to Dr. Fausto Guzzetti (CNR-IRPI)

What is risk ?

Risk = Hazard x Exposure x Vulnerability



What is the hazard of a natural process ?

- Combination of the magnitude (e.g. intensity) of a natural process and its frequency of occurrence (recurrence interval)

Magnitude-frequency relationship !

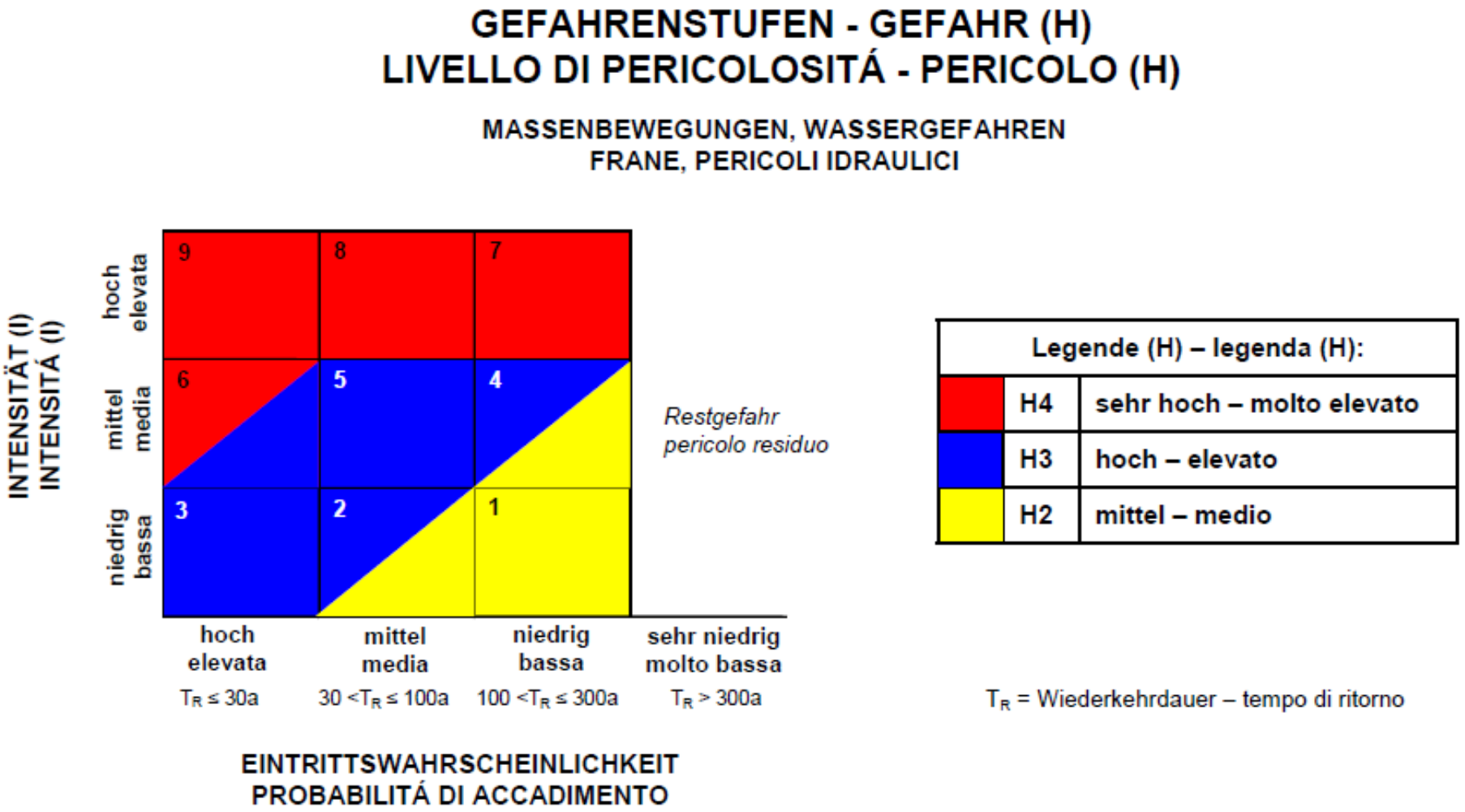
✓ Related only to climatic and geological characteristics of an area

Assessment of intensity differs for each natural process

- Floods
- Landslides
- Debris flows
- Avalanches
- Earthquakes
- Volcanic eruptions
- Wind storms
- Tsunamis

What is the hazard of a natural process ?

- The Swiss Intensity-Frequency matrix (BUWAL, 1998):



What is the hazard of a natural process ?

- Flood and debris flow hazards

Intensity classes are based on *water depth* (h) and *velocity* (v) for a flood, and on *deposition depth* (M) and/or *velocity* for debris flows. Lateral erosion depth (d) has also to be considered

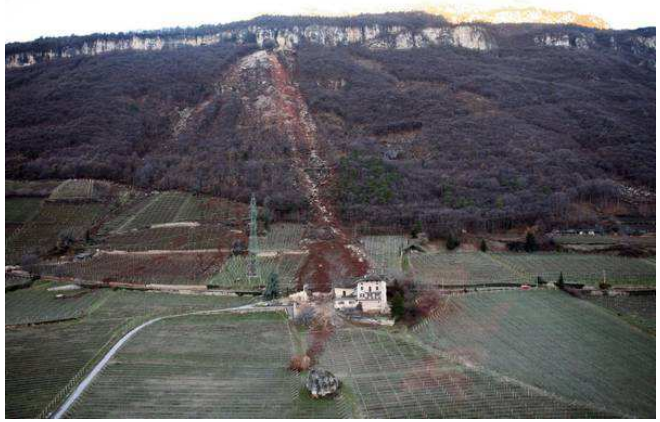
Values used in the Province of Bolzano

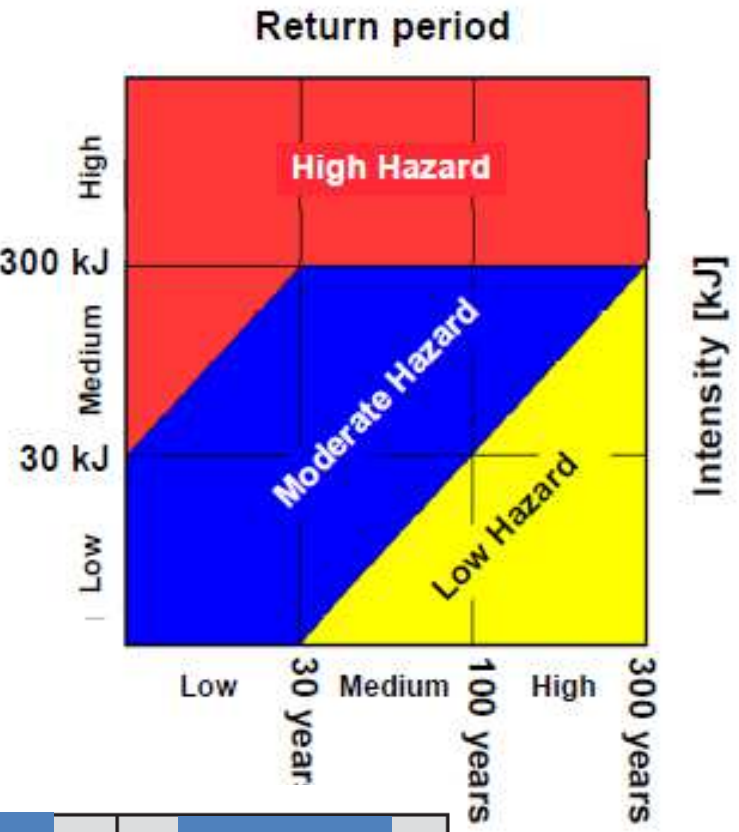
	Low intensity	Medium intensity	High intensity
	Intensità bassa	*Intensità media*	*Intensità alta*
Flood	h < 0,5 m opp. v x h < 0,5 m²/s	h = 0,5–2 m opp. v x h = 0,5–2 m²/s	h > 2 m opp. v x h > 2 m²/s
Debris flow	non noto	M ≤ 1 m opp. v ≤ 1 m/s	M > 1 m e v > 1 m/s
Erosion depth	d < 0,5 m	d = 0,5–2 m	d > 2 m

What is the hazard of a natural process ?

- Rockfall hazard

Intensity classes are based on the *kinetic energy* (E) of the rock fragments and on their *dimensions* (D)





Rockfall	High intensity	Medium intensity	Low intensity
Rocks D<2m	E > 300 kJ	300 kJ > E > 30 kJ	E < 30 kJ
Rocks D>2m	E > 300 kJ	---	---

Values used in the Province of Bolzano

What is the hazard of a natural process ?

- Landslide hazard

Intensity classes are based on the combination of *velocity* and *geometric severity* (slide thickness)

Velocity classes:

- < 13 m/month (ca. 45 cm/day)
- 13 m/month ÷ 3 m/min
- > 3 m/min

Thickness classes:

- < 2m
- 2 – 10 m
- > 10 m

Values used in the Province of Bolzano

Approach taken from Cruden & Varnes (1996) and BUWAL (1998)

What is the hazard of a natural process ?

- Snow avalanche hazard

Intensity classes are based on the *pressure* (p) exerted by the avalanche to a large surface normal to the direction of propagation

Low intensity	Medium intensity	High intensity
Intensità bassa	*Intensità media*	*Intensità alta*
$p < 3$ kN/m²	$3 \leq p \leq 30$ kN/m²	$p > 30$ kN/m²

Values used in the Province of Bolzano

What is exposure ?

- People, assets and activities potentially threatened by a hazard
- Measured in number (of people, of cultural/natural heritage sites) and in monetary terms (objects)

What is vulnerability ?

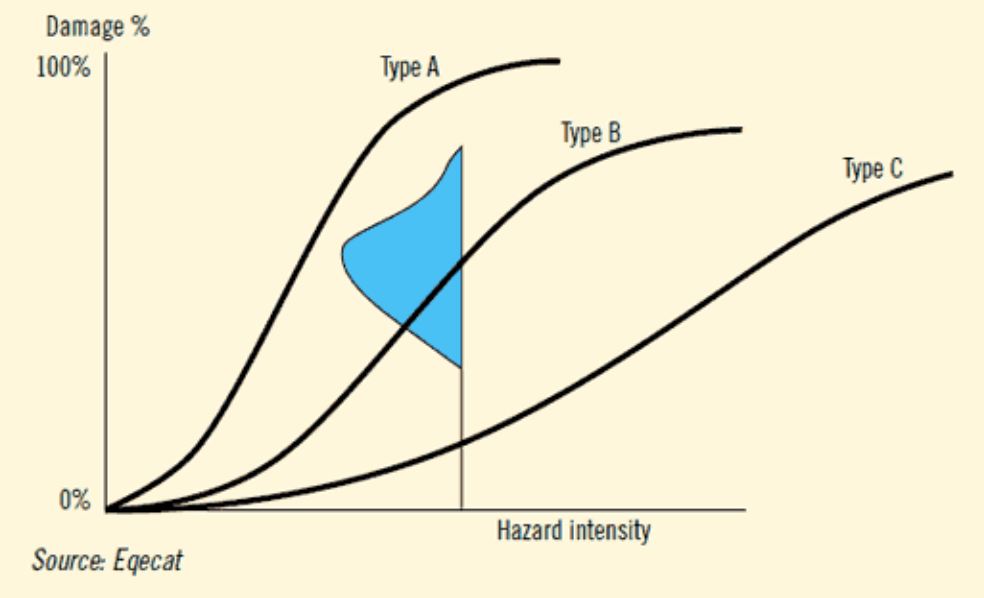
➢ Physical vulnerability

- Degree (from 0 to 1) of damage/loss of a certain exposed object

- Vulnerability is zero if the exposed object is able to resist without any damage or loss of functionality a given hazard

- Vulnerability is equal to 1 (100%) if the object completely loses its value

- Vulnerability is a function of:
  - ✓ Hazard type
  - ✓ Hazard intensity and duration
  - ✓ Object typology
  - ✓ Object maintenance



What is vulnerability ?

➢ Social vulnerability

pre-existing condition that affects a society's ability to withstand (resistance) and recover (resilience) from a disruptive event

- Social vulnerability is a function of:

  - ✓ Hazard type and intensity
  - ✓ Hazard period of occurrence
  - ✓ Prior risk perception
  - ✓ Preparedness to the event
  - ✓ Demography (age and gender)
  - ✓ Economic and education levels
  - ✓ Social structure

https://www.youtube.com/watch?v=gkybZKVYMWc

https://www.youtube.com/watch?v=kIZS3rDjJjg

https://www.youtube.com/watch?v=z6PmR2hYW3E

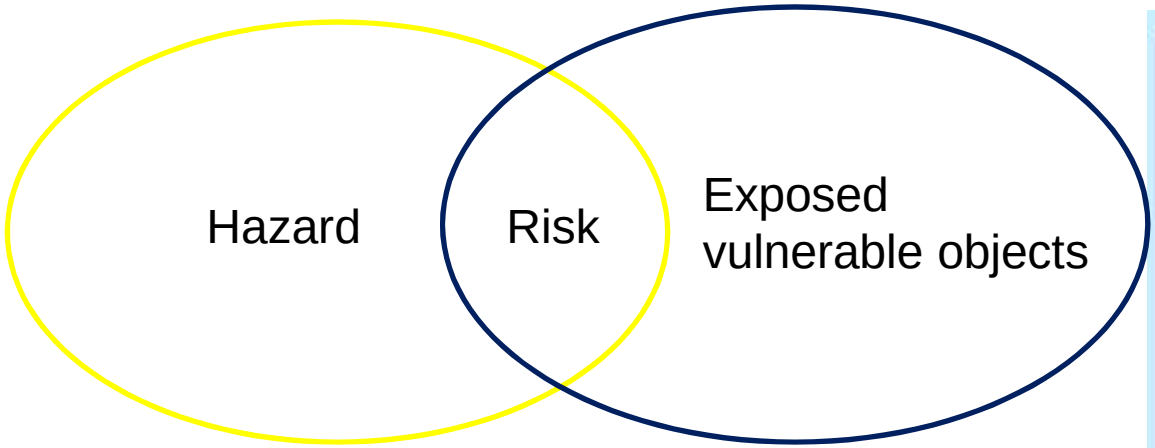
Time-dependance of risk

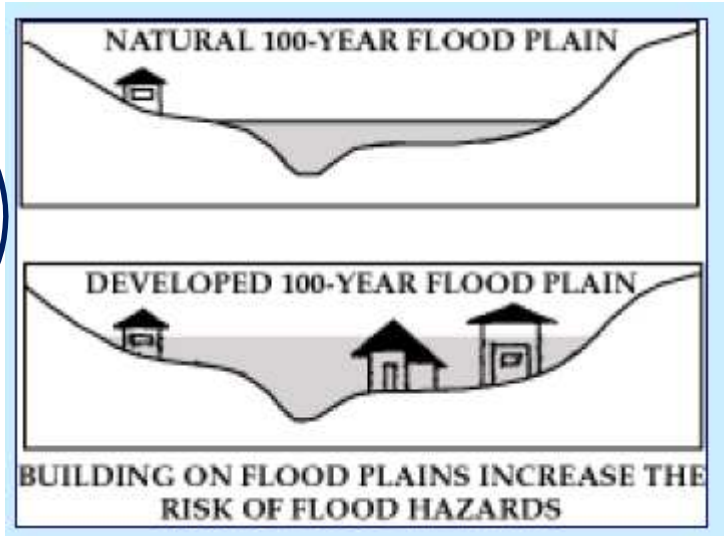
- Most hazards can be considered to be invariant with time over relatively short periods (if external conditions remain constant)

- Exposure and vulnerability vary with time, even at the daily scale !

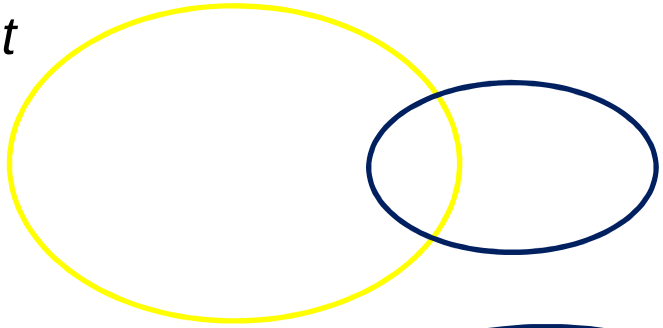
Risk is strongly time-dependent !

General historical change in natural risks



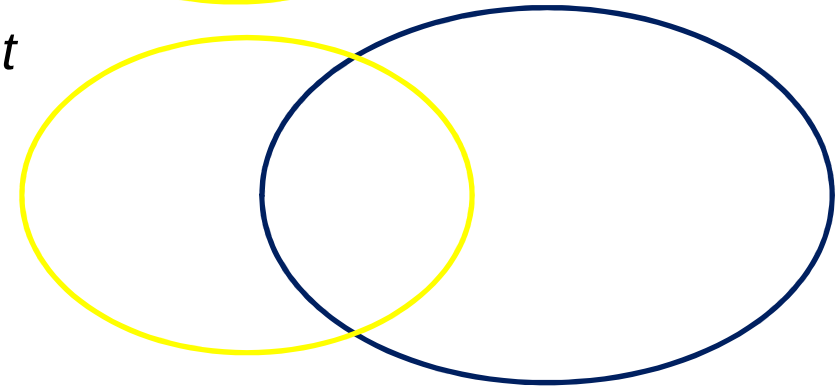


In the past



Exposure greatly increased !

At present



Prediction of natural risk

For all the possible hazards within a given region, managers have to assess the following:

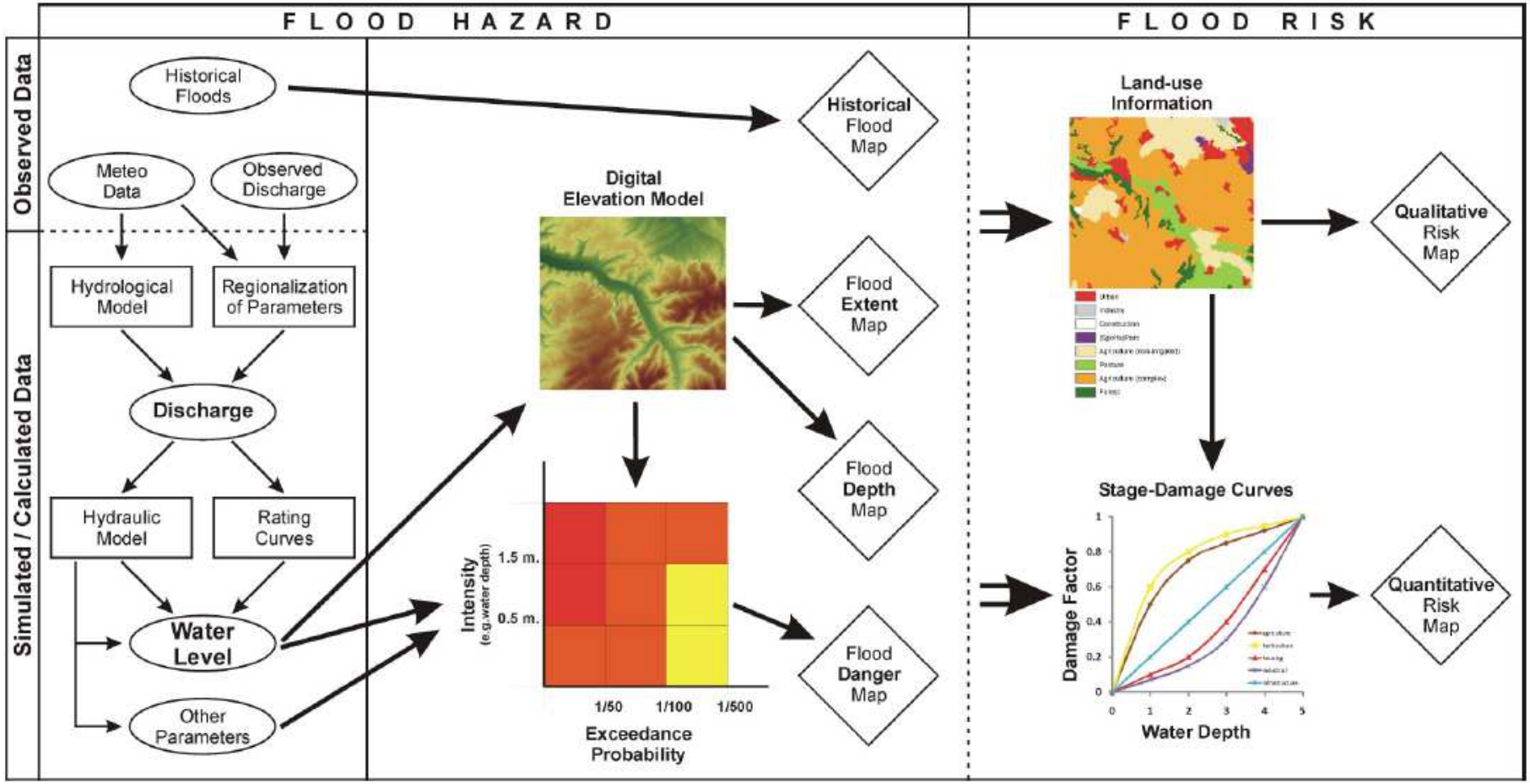
- Location (geographical extension)
- Magnitude (intensity)
- Frequency (recurrence interval)

Hazard mapping

- Season/period of occurrence
- Potential direct damages/victims
- Indirect consequences

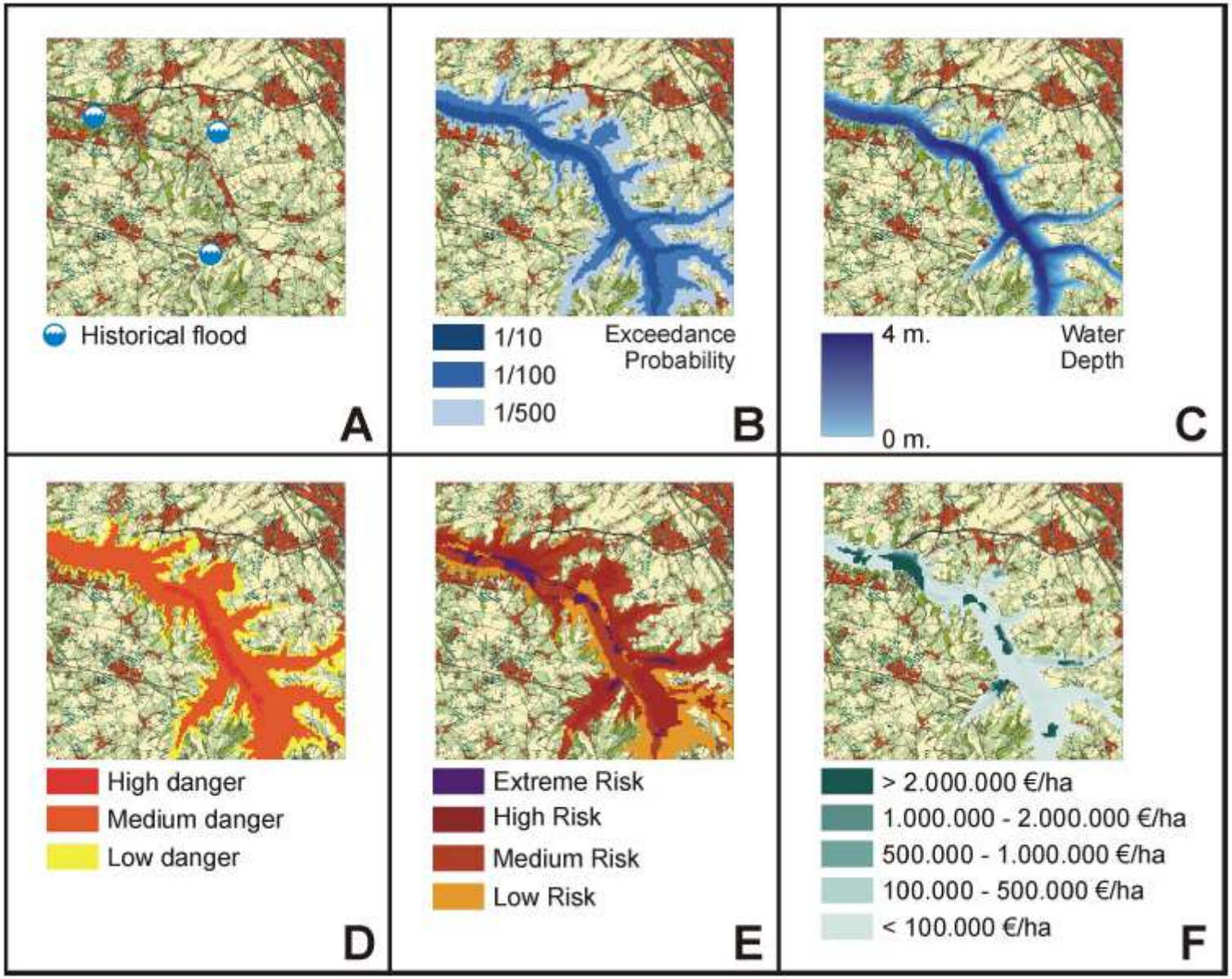
Potential damage (or vulnerability) mapping

Example: flood risk maps



De Moel et al (2009)

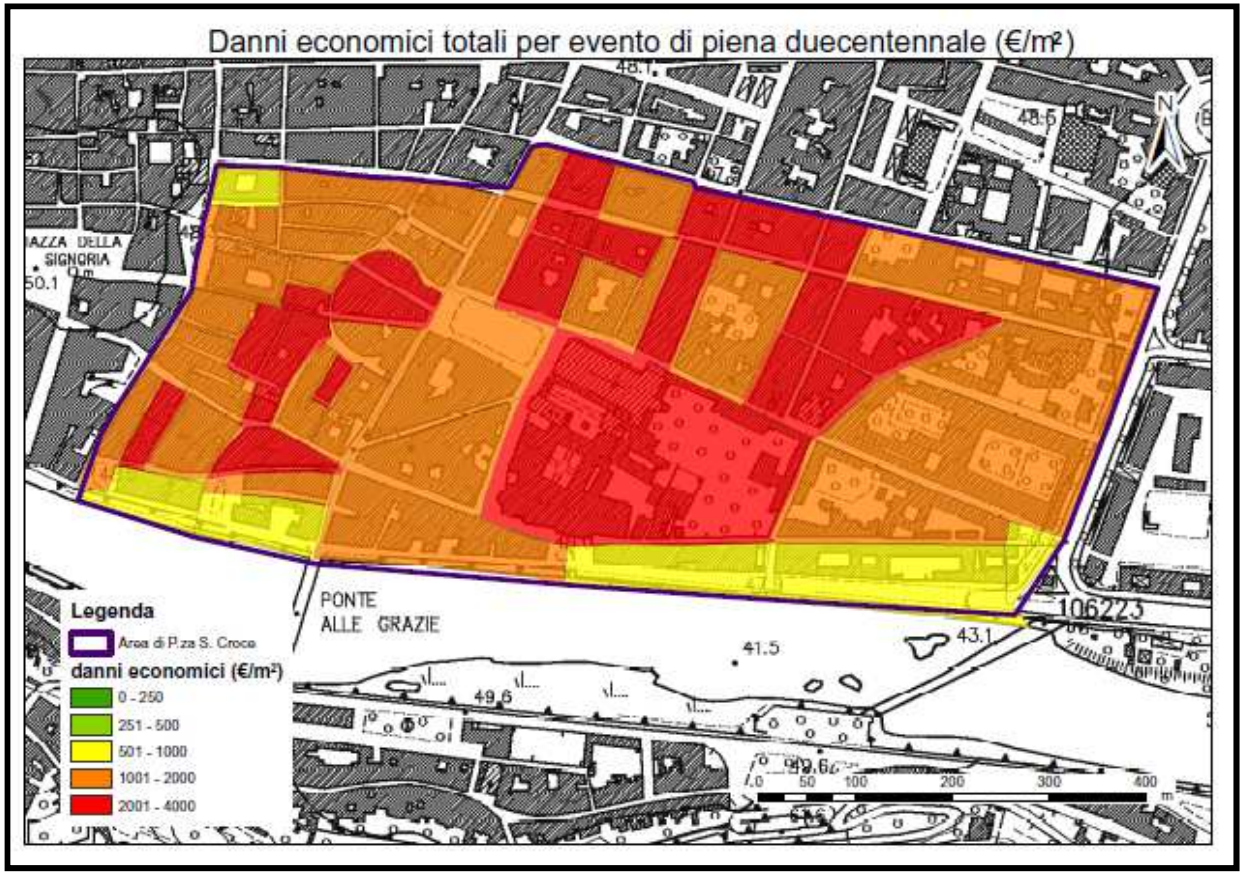
Example: flood risk maps



De Moel et al (2009)

Potential damage maps

- Different spatial scales (from continental to regional to municipal)
- Often based on land use categories (qualitative, at regional scale)
- Expressed in monetary terms (civil/rural appraisal, at local scale)
- Generally static (do not account for fluxes of people/vehicles)
- Vulnerability often assigned to 1 in cases of high-energy processes



Arrighi (2012)

Hazard maps

- Different spatial scales (from continental to regional to municipal
- Different spatial resolution (from to tens of meters to few meters)
- Different objectives (regional to municipal land planning, emergency plans)

Regional scale

- Increased spatial and temporal resolution
- Increased need for accurate data
- Increased legal value of the map

Local scale

Hazard maps: «Floods» Directive

«Floods» EU Directive (2007)

Article 6

Flood hazard maps shall cover the geographical areas which could be flooded according to the following scenarios:

- floods with a low probability, or extreme event scenarios;
- floods with a medium probability (likely return period ≥ 100 years);
- floods with a high probability, where appropriate.

For each scenario the following elements shall be shown:

- the flood **extent**;
- water **depths** or water level, as appropriate;
- where appropriate, the flow **velocity** or the relevant water flow.

Risk maps: «Floods» Directive

Article 6

Flood risk maps shall show the potential adverse consequences associated with flood scenarios and expressed in terms of the following:

(a) the indicative **number of inhabitants** potentially affected;

(b) **type of economic activity** of the area potentially affected;

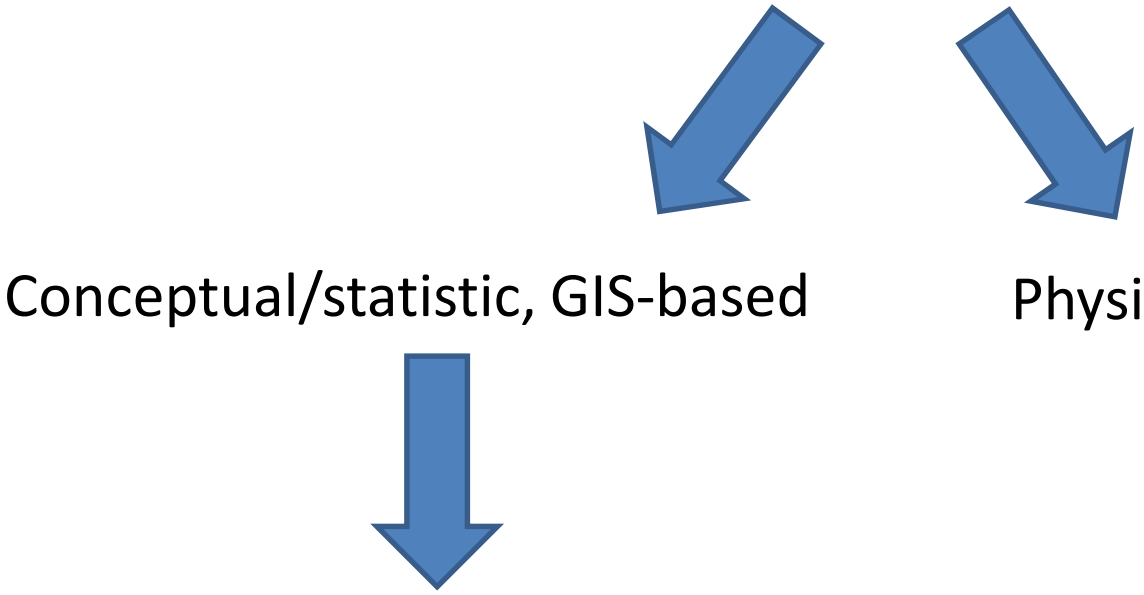
(c) installations as referred to (…) concerning integrated pollution prevention and control which might cause **accidental pollution** in case of flooding and potentially affected protected areas (…)

d) other information (…) useful such as the indication of areas where floods with a high content of **transported sediments and debris floods** can occur and information on other significant sources of pollution.

Modelling tools for hazard mapping

- A model is a simplification of reality, useful to make predictions testing different scenarios

- Physical (laboratory) and **numerical** (computer) models



- For large areas (fast runs)
- Preliminary mapping
- Hazard susceptibility

- For small areas (long run time)
- Detailed mapping
- Hazard intensity

Modelling tools for hazard mapping

- Hydrological models (rainfall – runoff transformation)
- Hydrodynamic models (inundation maps)

Floods

- Morphodynamic models (bedload transport)

- Debris flow models
- Snow avalanche models

Often a single model used with different parameters

- Landslide models (susceptibility and geotechnical)
- Rockfall models (trajectoies, energies)

Modelling tools for hazard mapping

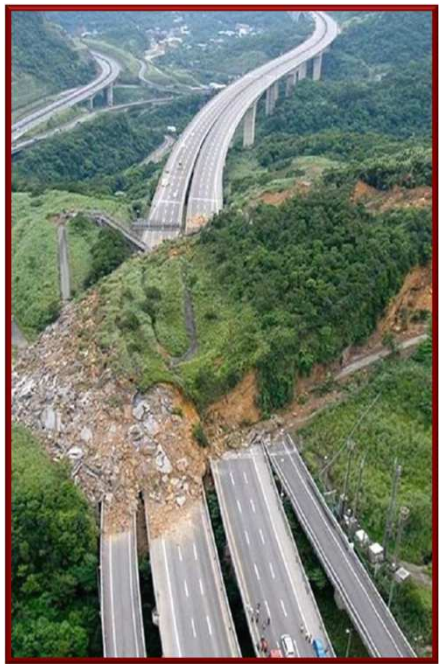
- Landslides

LANDSLIDES ARE NATURAL PHENOMENA CHARACTERIZED BY **HIGH RANDOMNESS** AND **LOW PREDICTABILITY**

LANDSLIDES ARE **PREDICTABLE**, BUT WITH SIGNIFICANT **UNCERTAINTY**

PREDICTING … WHAT?

SINGLE LANDSLIDE



MANY LANDSLIDES

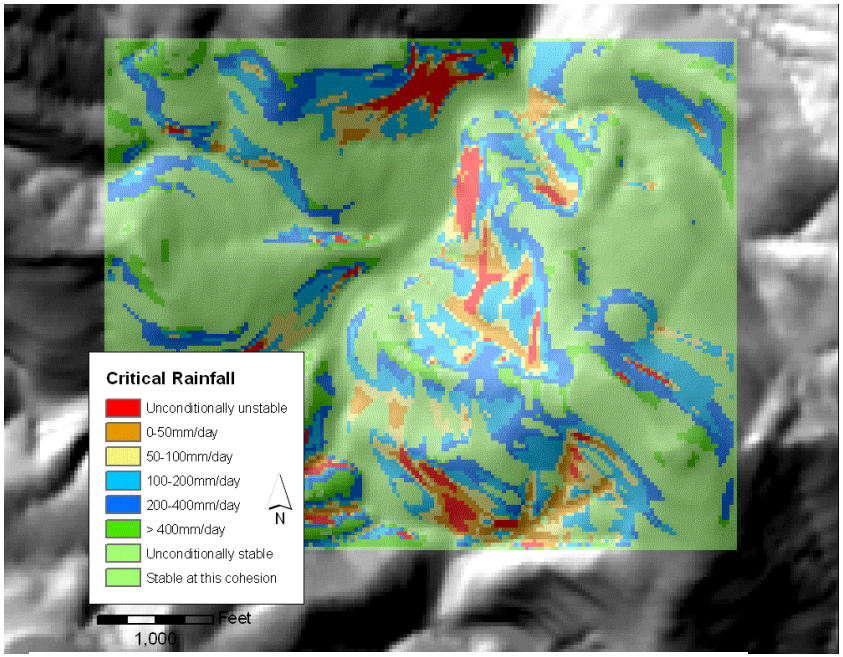
Modelling tools for hazard mapping

Landslide susceptibility maps

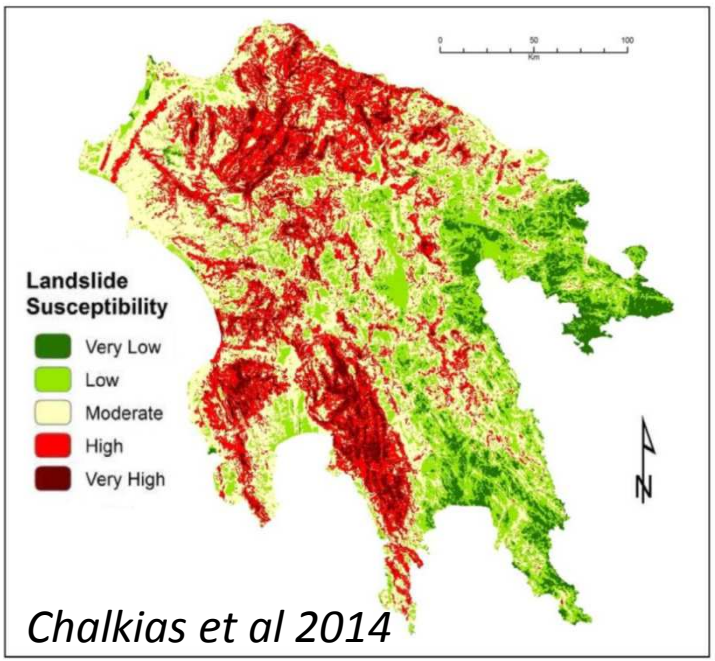
(FOR SHALLOW LANDSLIDES AT REGIONAL/LARGE BASIN SCALE)

- PHYSICALLY-BASED (OR BETTER "CONCEPTUAL")
  - INFINITE SLOPE APPROACH, CALIBRATED IF POSSIBLE AGAINST OBSERVED EVENTS (TO DETERMINE TRIGGERING RAINFALL)
- STATISTICALLY-BASED
  - BASED ON CLIMATIC, TOPOGRAPHIC, GEOLOGIC, LAND USE CHARACTERISTICS, AND LOCATION OF PAST EVENTS

Modelling tools for hazard mapping



Physically-based infinite slope model (e.g. SHALSTAB)



Chalkias et al 2014

Statistically-based
(weight from landslide inventories)

Y: Landslide vulnerability Index
Mi: Score of criterion i
wi: Weight of criteria i