IRASMOS SYMPOSIUM 2008

Integral Risk Management of Natural Hazards
" A Merge of Theory and Practice"

State of the Art of Prediction Techniques

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WHAT DO WE MEAN BY PREDICTION?

PREDICTING THE OCCURRENCE OF AN EVENT MEANS PROVIDING THE

LOCATION WHERE

- SCALE => RESOLUTION
- HETEROGENEITY

  f(x,y,z) ?= f(i,j,l)

AND THE

MOMENT WHEN

- TIME RESOLUTION
- TIME SPAN

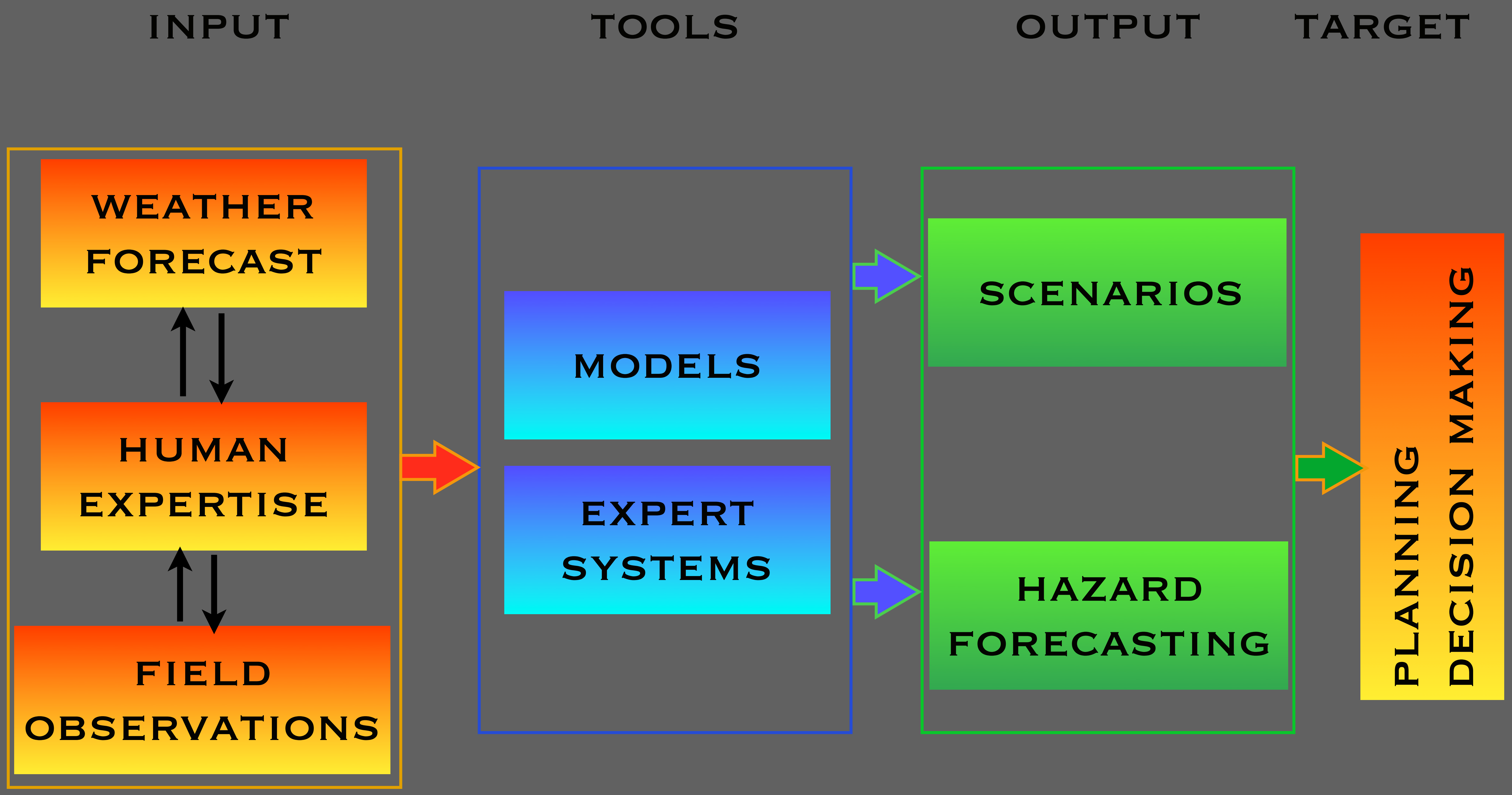
  hours
  days
  more?

IT HAS A FAIRLY HIGH PROBABILITY OF HAPPENING.

ALSO A PREDICTION SHOULD PROVIDE A

QUANTIFICATION AND THE **PROBABILITY**

2 THE "FORECASTING CHAIN"



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…. THE TRIGGERING QUESTIONS

THE NATIONAL RESEARCH COUNCIL [2004] IDENTIFIED FIVE RESEARCH QUESTIONS THAT MUST BE ADDRESSED BEFORE RELIABLE WARNINGS CAN BE ISSUED AND EFFECTIVE MITIGATION EFFORTS APPLIED.

1. HOW WOULD THE LANDSLIDE BE INITIATED?

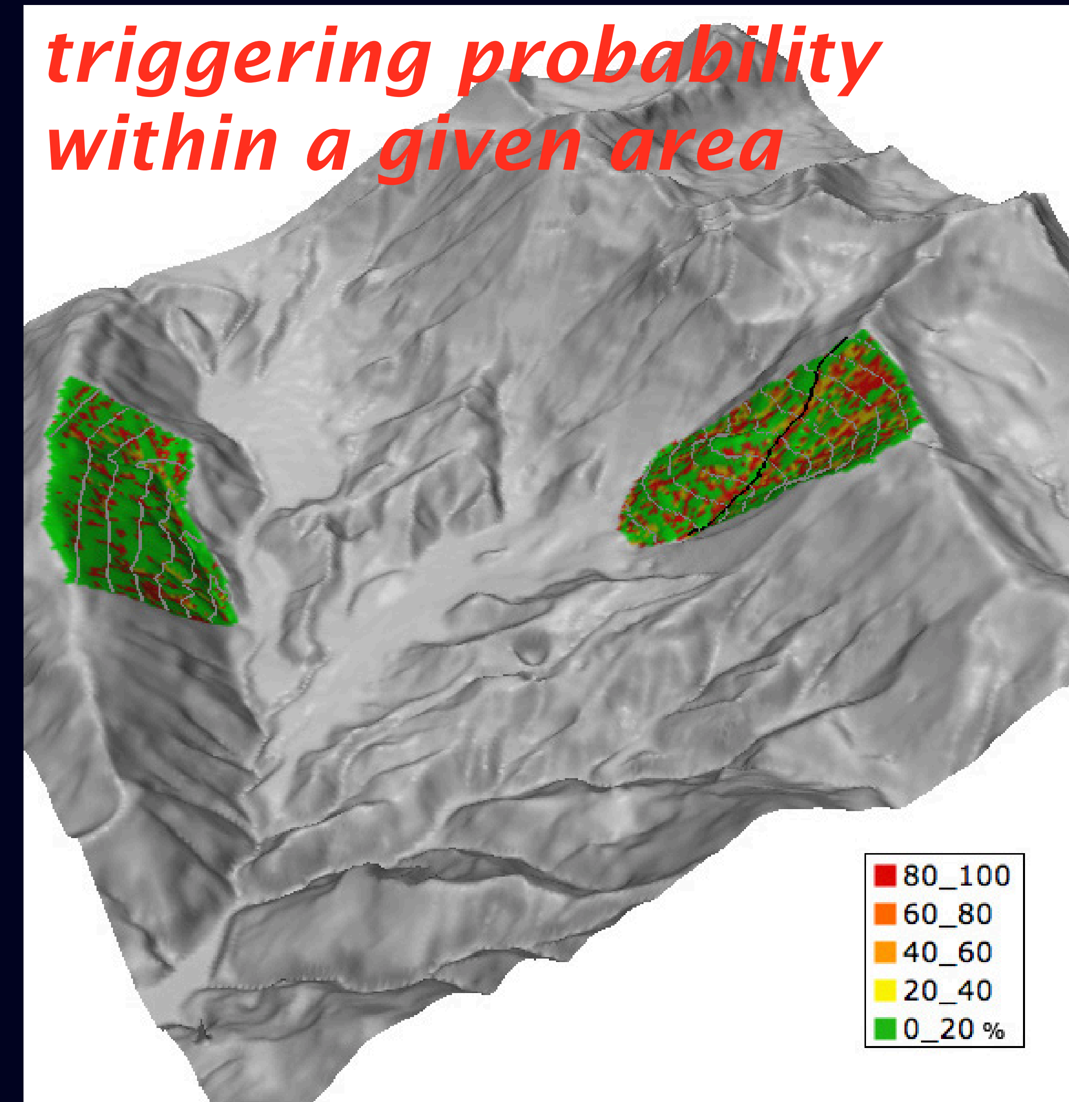
2. WHAT ARE THE WARNING SIGNS OR CONDITIONS PRIOR TO LANDSLIDE FAILURE?

3. WHEN AND WHERE WILL IT OCCUR?

4. HOW LARGE WILL THE LANDSLIDE BE?

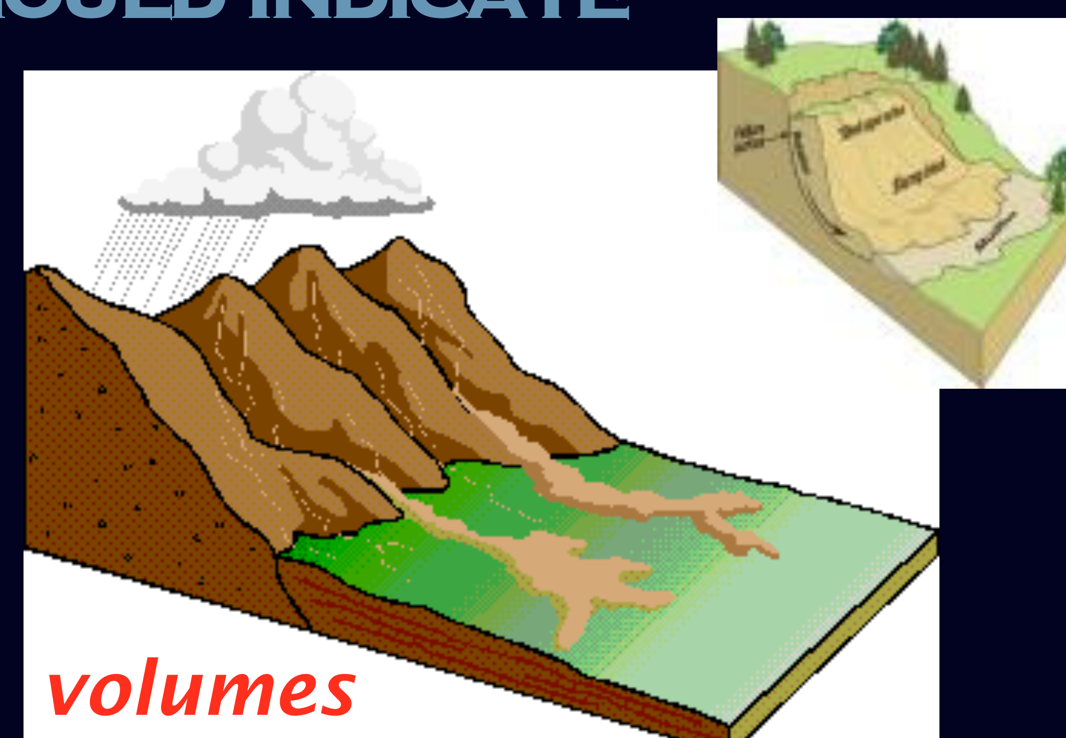
5. HOW FAR WILL THE LANDSLIDE TRAVEL?

6. HOW FAST WILL THE LANDSLIDE TRAVEL?



A RELIABLE PREDICTION SHOULD INDICATE

timing

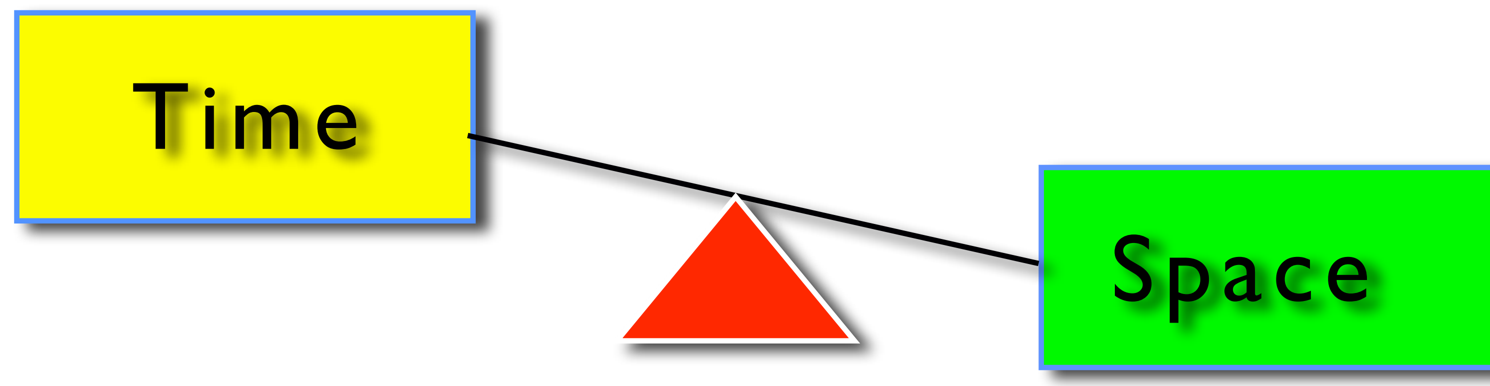


…. THE APPROACH

An effective approach should deal with:

Time and Space

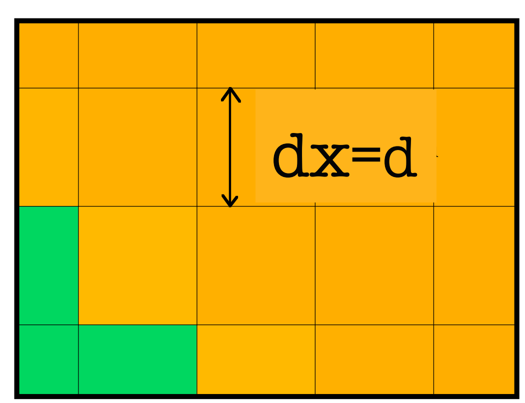
triggering = f(x,y,z,t)



Scale

→ **Adequate tools**

regional => 10 - 100 km²
catchment => 1 - 10 km²
hillslope => 10 - 1000 m²



AVAILABLE TECHNIQUES TO FORECAST RAPID MASS MOVEMENTS

1. Statistical and inferential methods

a. Susceptibility maps *(Coe et al., 2004; Guzzetti et al., 1999)*

b. Methods based on rainfall intensity-duration thresholds *(Godt et al., 2005)*

c. Historical Inventories (landslides, avalanches, rock avalanches)

2. Deterministic methods

d. Simplified distributed models with steady-state subsurface hydrology
(SHALSTAB, Montgomery and Dietrich 1994; SINMAP, Pack and Tarboton 1997)

e. Real time distributed model accounting for transient infiltration and subsurface hydrology *(TRIGRS, Baum et al., 2004; CHASM, Wilkinson et al., 2002; GEOtop, Rigon et al., 2006; SIM: - SAFRAN Durand et al., 1993 - ISBA - MODCOU)*

f. SNOW models *(SNOWPACK Lehning et al., 2000; CROCUS Brun et al., 1989, Endrizzi 2007)*

3. EMPIRICAL METHODS

g. Snowpack Tests *(Colbeck et al., 1990; Barbolini 2005)*

h. Warning systems based on realistic monitoring thresholds *(Crosta et al., 2003)*

4. OTHER SUPPORTING TOOLS (SNOW AVALANCHE FORECASTING)

i. Synoptic technique *(Shweizer and Fohn, 1996)*

j. Expert systems *(MEPRA - Giraud et al., 1991; Brun et al., 1992, AVALOG - Bolognesi 1993)*

STATISTICAL & INFERENTIAL METHODS (1/2)

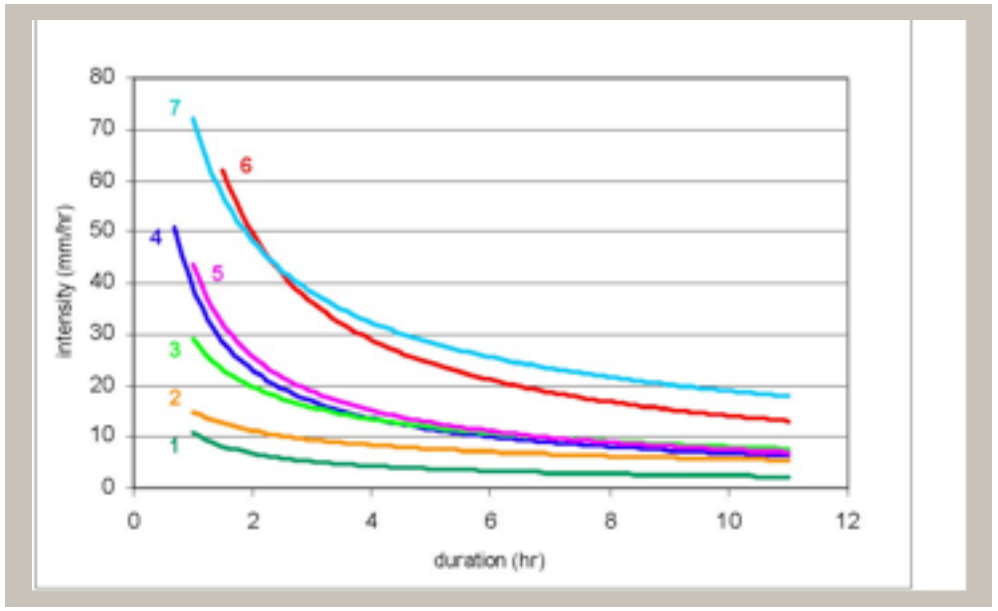
SUSCEPTIBILITY MAPS

IDENTIFY AREAS PRONE TO LANDSLIDE

ARE BASED ON QUALITATIVE OBSERVATIONS OF SOIL MOVEMENTS + MULTIVARIATE STATISTICAL ANALYSES

DO NOT ACCOUNT FOR HYDROLOGY AND SOIL MECHANICS

NO TIME SPECIFICATION



RAINFALL INTENSITY-DURATION THRESHOLDS

THE APPLICATION OF RAINFALL THRESHOLDS FOR FORECASTING PURPOSES IS BASED ON THE ASSUMPTION THAT PAST RAINFALL CONDITIONS ASSOCIATED WITH SHALLOW SLOPE FAILURES ARE LIKELY TO TRIGGER LANDSLIDES IN THE FUTURE.

THESE RAINFALL THRESHOLDS ARE REGIONALLY SPECIFIC

THEIR APPLICATION FOR FORECASTING REQUIRES HISTORICAL DATA OF LANDSLIDE, NOT AVAILABLE EVERYWHERE

Statistical & inferential Methods (2/2)

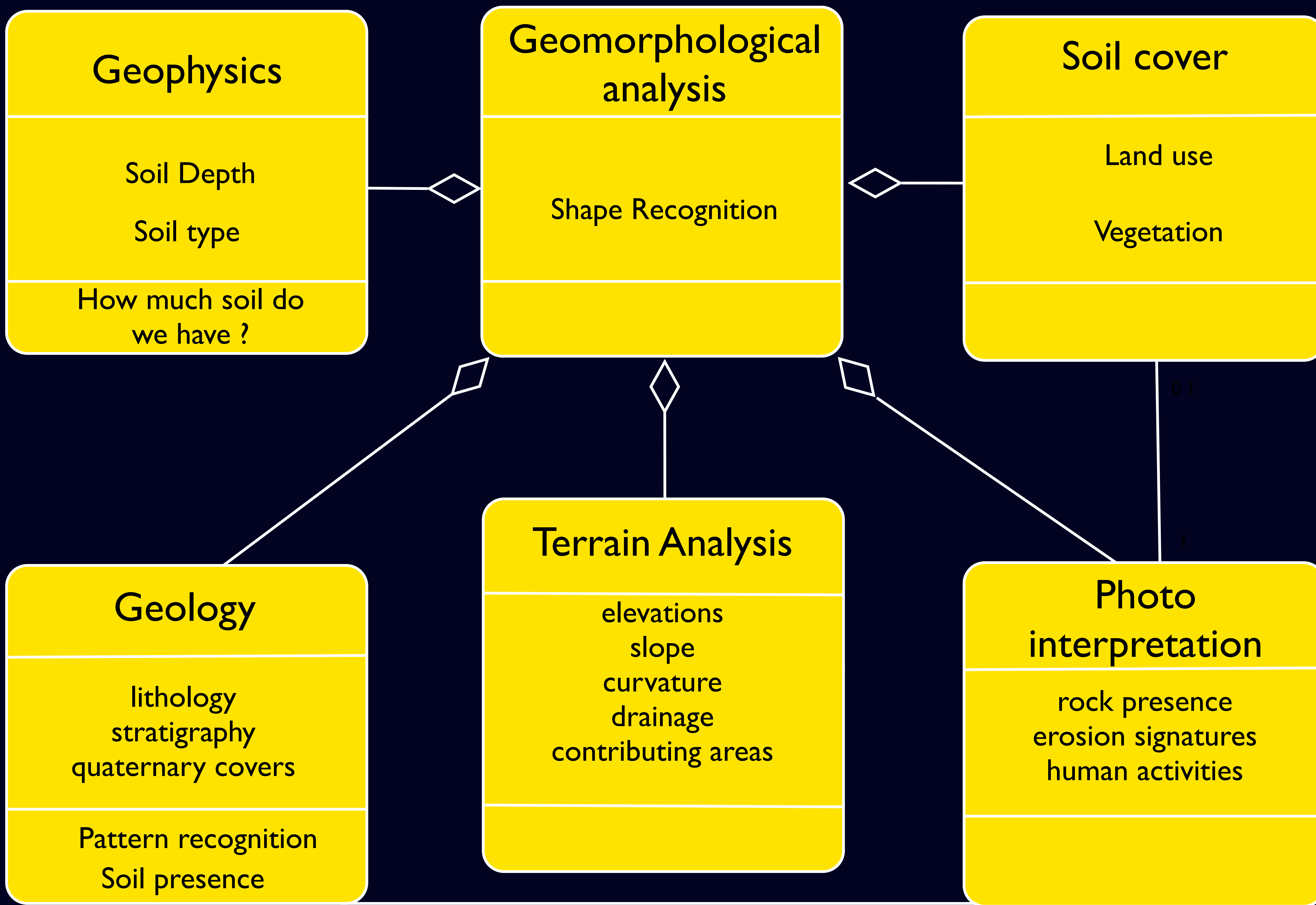
HISTORICAL INVENTORIES

IDENTIFY SPATIAL DISTRIBUTION OF MASS MOVEMENTS

MASS MOVEMENTS ARE MAPPED USING SEVERAL TECHNIQUES:

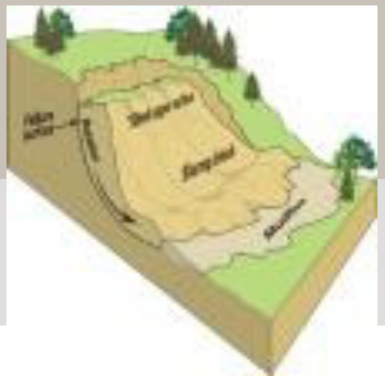
- AIRPHOTO INTERPRETATION
- MULTISPECTRAL DIGITAL IMAGERY
- LOCAL SURVEYS

GEOMORPHOLOGICAL ANALYSES ALLOW FOR SHAPE RECOGNITION AND SOIL MOVEMENT CLASSIFICATION



Geophysics
Soil Depth
Soil type
How much soil do
we have ?
Geomorphological
analysis
Shape Recognition
Soil cover
Land use
Vegetation
Geology
lithology
stratigraphy
quaternary covers
Pattern recognition
Soil presence
Terrain Analysis
elevations
slope
curvature
drainage
contributing areas
Photo
interpretation
rock presence
erosion signatures
human activities

11 DETERMINISTIC METHODS



INCLUDE DISTRIBUTED AND PHYSICALLY BASED MODELS WHICH AIM AT CAPTURING REAL TRIGGERING MECHANISMS

DIFFERENCES AMONG THEM DEPEND ON THE ASSUMPTIONS

HYDROLOGICAL SIMPLIFIED DISTRIBUTED MODELS FOR SLOPE STABILITY ANALYSES

HYDROLOGY IS LIMITED TO A STEADY STATE DESCRIPTION OF SUBSURFACE FLOWS => THESE MODELS ARE INTRINSICALLY UNABLE TO FORECAST THE TIMING OF THE TRIGGERING

E.G. SHALSTAB, MONTGOMERY AND DIETRICH 1994; SINMAP, PACK AND TARBOTON 1997

HYDROLOGICAL DYNAMIC MODELS

ACCOUNT FOR DISTRIBUTED TRANSIENT INFILTRATION AND SOIL MOISTURE REDISTRIBUTION

WORK ON A SPATIAL GRID WHOSE RESOLUTION DEPENDS ON THE INVESTIGATED SCALE

INTEGRATE METEOROLOGICAL AND EO (EARTH OBSERVATION) DATA

E.G. CHASM (WILKINSON ET AL., 2002), TRIGRS (BAUM ET AL., 2002), IDSSM (DHAKAL AND SIDLE, 2004), SNOWPACK (LEHNING ET AL., 2003).

Empirical Methods

AIM AT ASSESSING THOSE VARIABLES WHICH ARE HARDLY DETERMINED BY DETERMINISTIC METHODS AND NUMERICAL SIMULATIONS

SNOWPACK TESTS

EMPIRICAL MEASUREMENTS OF SURFACE DEFORMATION RATES

MONITORING THRESHOLDS => WARNING SYSTEM

! ISSUE: OPERATOR ARBITRARINESS !

SEVERAL OF THESE OBSERVATION ARE INTEGRATED IN MODELS

DETERMINISTIC TOOLS + EMPIRICAL OBSERVATIONS + DATA

Empirical Observations

Geomorphology =>
shape recognition

snowpack tests

site characterization

Physical Approach

Transient hydrology

Geomechanics

Terrain analyses

Weather Data

spatial density of the stations

reliability of the data

recording time step

Operator Expertise

Monitoring and Warning

surface deformation rates

displacement

defining reliable monitoring thresholds

INTEGRATED APPROACH

DATA AVAILABILITY AND SITE CHARACTERIZATION

EXAMPLE GEOtop-FS, Simoni et al., 2007

Input
Meteo data
Topography
Hydraulic characterization
Hydrological characterization

Hydrological model
GEOtop 0.875
Rigon et al. 2006

Output
Soil moisture
Pore water pressure
Soil temperature
Snow melting

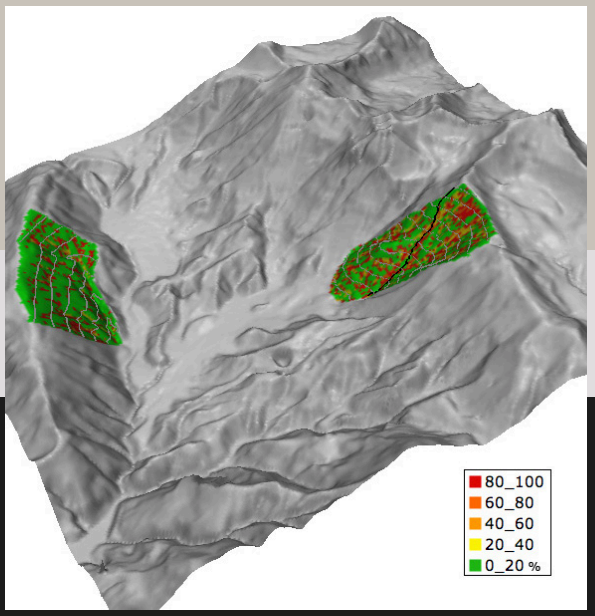
Input
Soil characterization
Soil strength parameters
Vegetation cover

Stability model
GEOtop-FS
Simoni et al. 2007

Output
1. Factor of Safety maps
2. Failure Probability maps
3. Suction stress maps

Soil Measures
1. Soil Suction
2. Soil Moisture
3. Soil Temperature

Dealing with Heterogeneity



A probabilistic approach

Parameter pdfs

$$\hat{f}_{C'} = \frac{e^{-\frac{\left(c'-\mu_{c'}\right)^2}{2\cdot\sigma_{c'}^2}}}{\sqrt{2\cdot\pi}\cdot\sigma_{c'}} \qquad \hat{f}_{\Delta_v} = \frac{e^{-\frac{\left(\Delta_v-\mu_{\Delta_v}\right)^2}{2\cdot\sigma_{\Delta_v}^2}}}{\sqrt{2\cdot\pi}\cdot\sigma_{\Delta_v}} \qquad \hat{f}_{\tan\phi} = \frac{e^{-\frac{\left(\tan\phi-\mu_{\tan\phi}\right)^2}{2\cdot\sigma_{\tan\phi}^2}}}{\sqrt{2\cdot\pi}\cdot\sigma_{\tan\phi}}$$

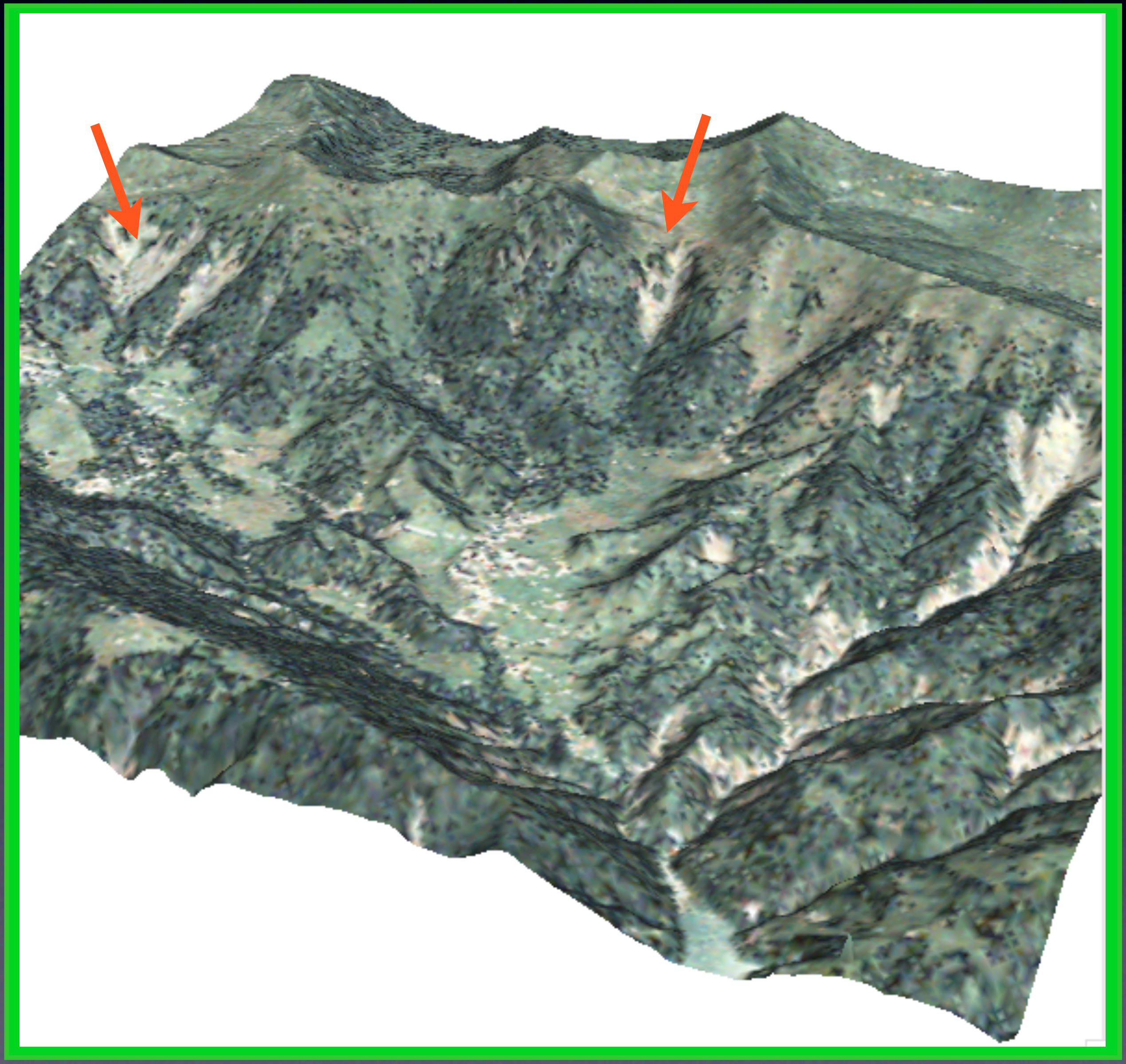
Factor of safety pdf

$$\hat{f}^{n}_{FS(i,j,k)} = \left.\frac{A\cdot D\cdot e^{-\frac{\left[A\cdot\left(D\cdot fs-\mu_{\tan\Phi}\right)-D\cdot\left(\mu_{C'}+\mu_{\Delta_V}\right)\right]^2}{2\cdot\left[A^2\cdot\sigma^2_{\tan\Phi}+D^2\cdot\left(\sigma'^2_{C}+\sigma^2_{\Delta_V}\right)\right]}}}{\sqrt{2\cdot\pi}\cdot\sqrt{A^2\cdot\sigma^2_{\tan\Phi}+D^2\cdot\left(\sigma^2_{C'}+\sigma^2_{\Delta_V}\right)}}\right|^{n}$$

Stability Index

$$F^{n}_{FS_{(i,j,k)}} = p\left(FS\le 1\right) = \int_{-\infty}^{1}\hat{f}^{n}_{FS(i,j,k)}\cdot \mathrm{d}fs_{(i,j,k)}$$

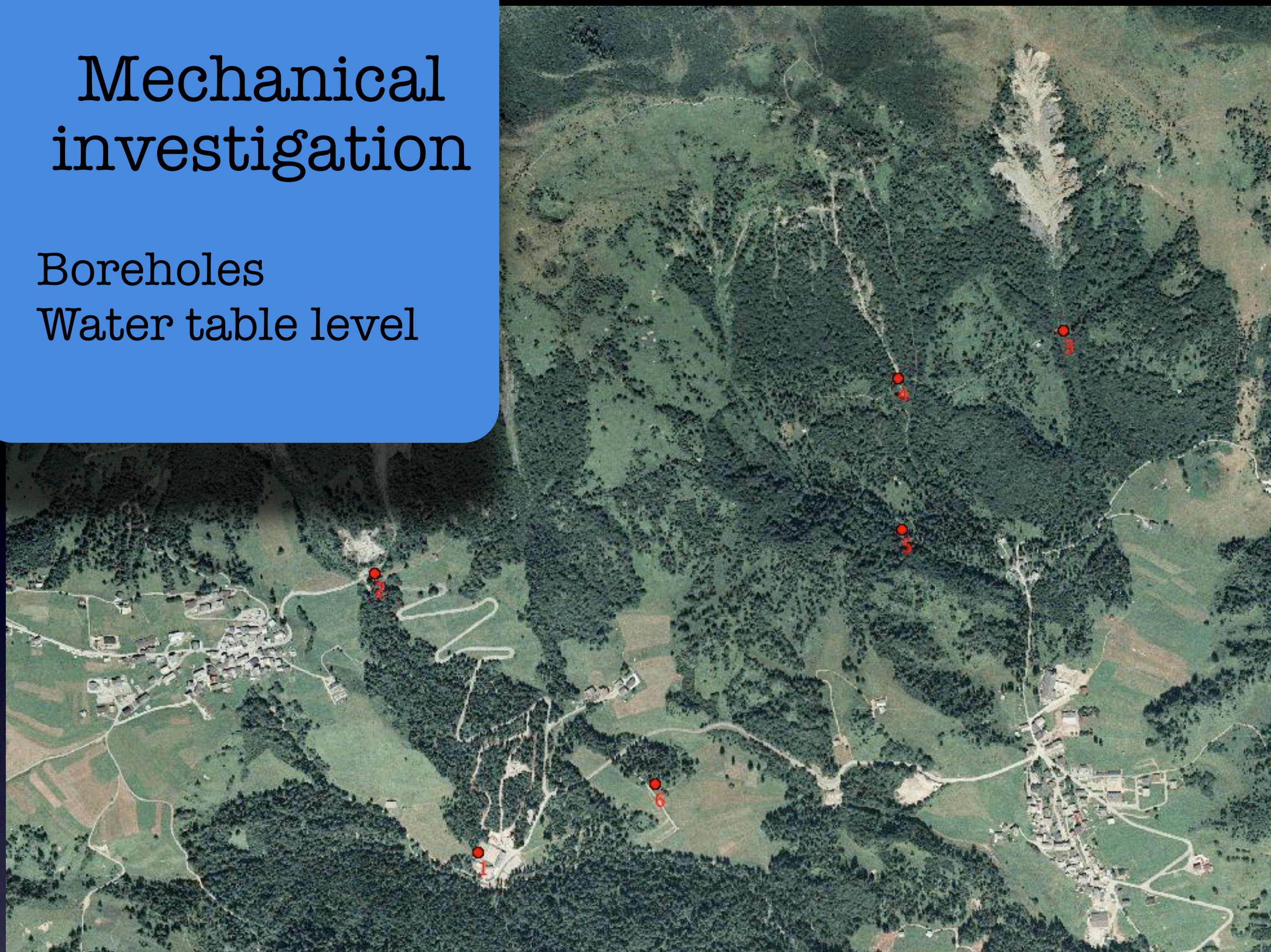
Kortol Catchment, Sauris,UD, Italy

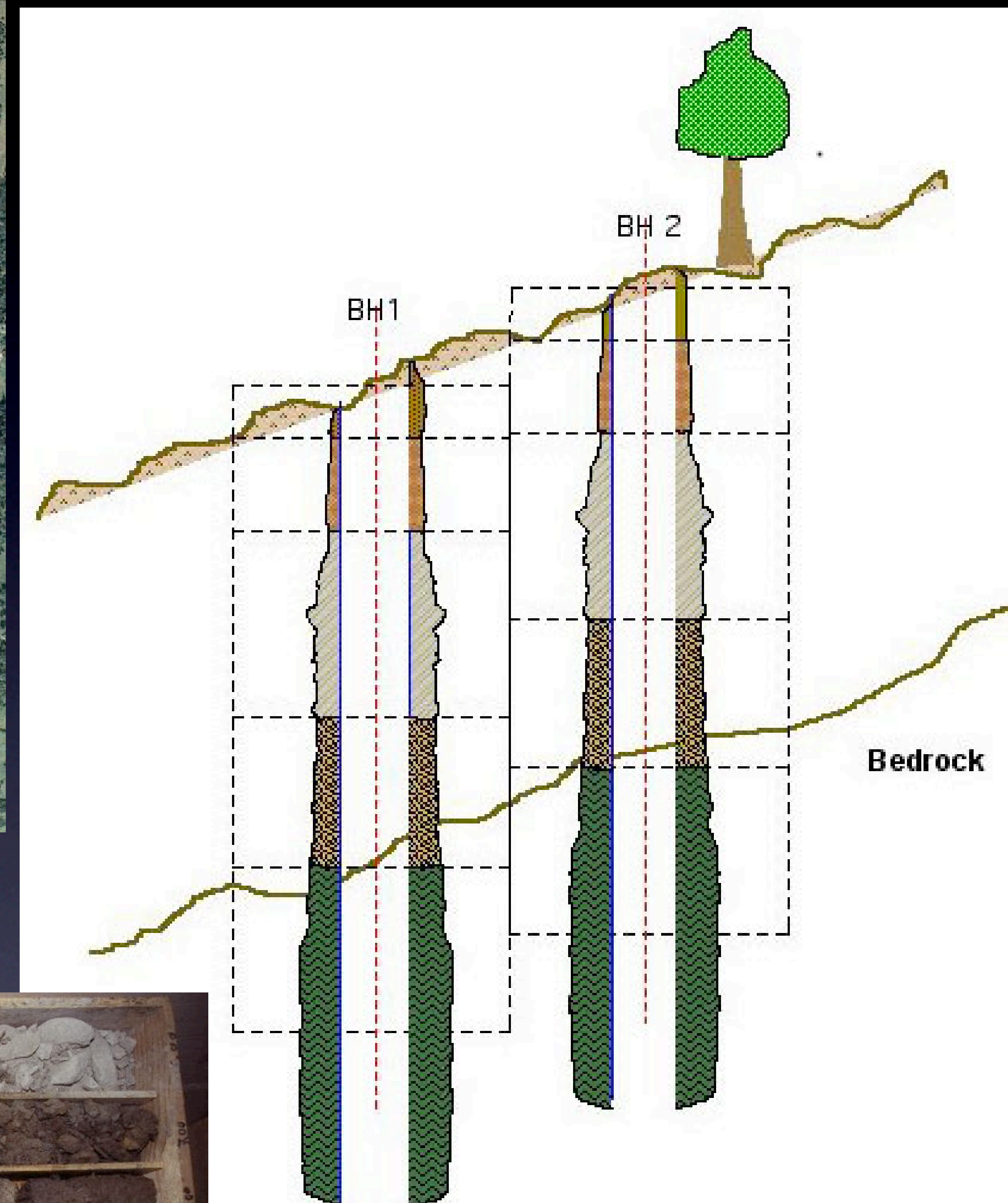


Sauris landscape, UD, Italy (Simoni & Zanotti, 2005).

Mechanical investigation

Boreholes
Water table level

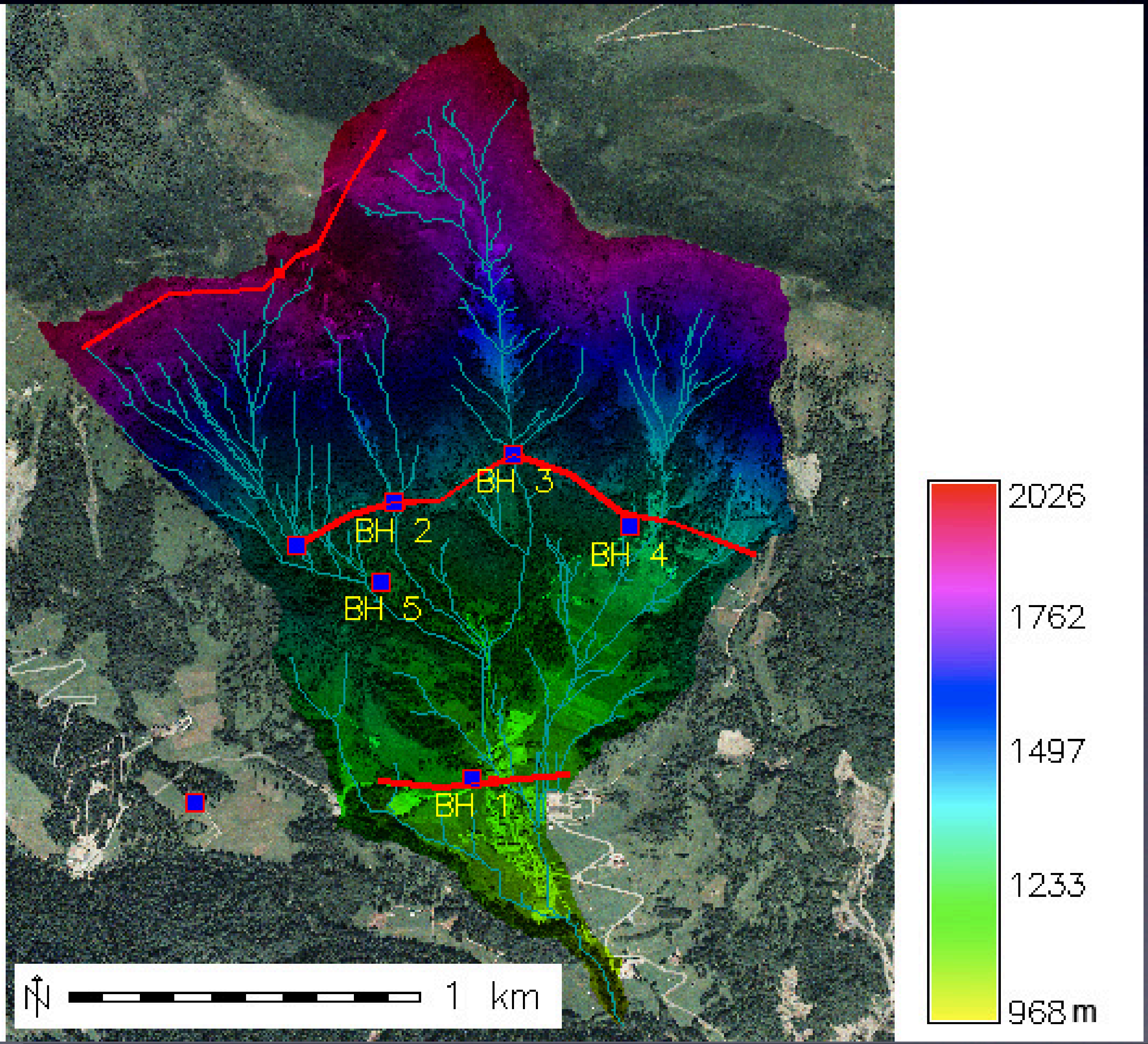




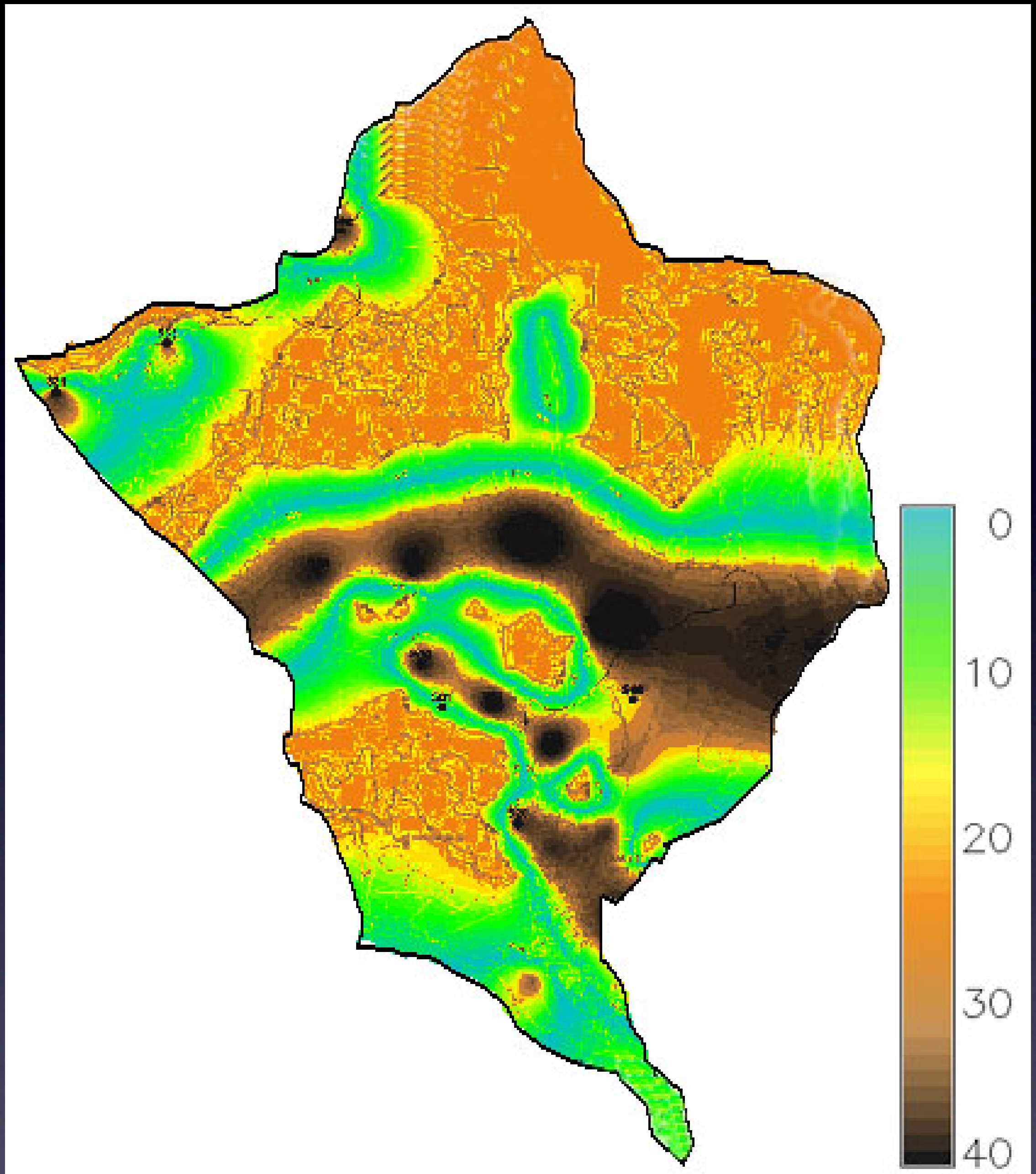
Geophisycal Analysis

Soil Depth
Stratigraphy
Geological Formation

Geophone layout



Soil depth

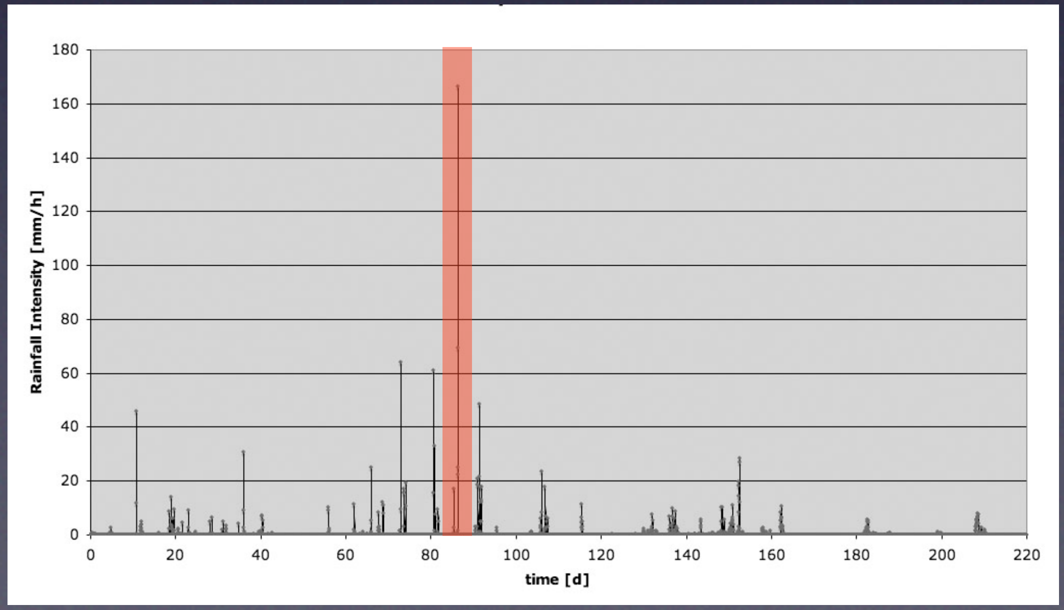


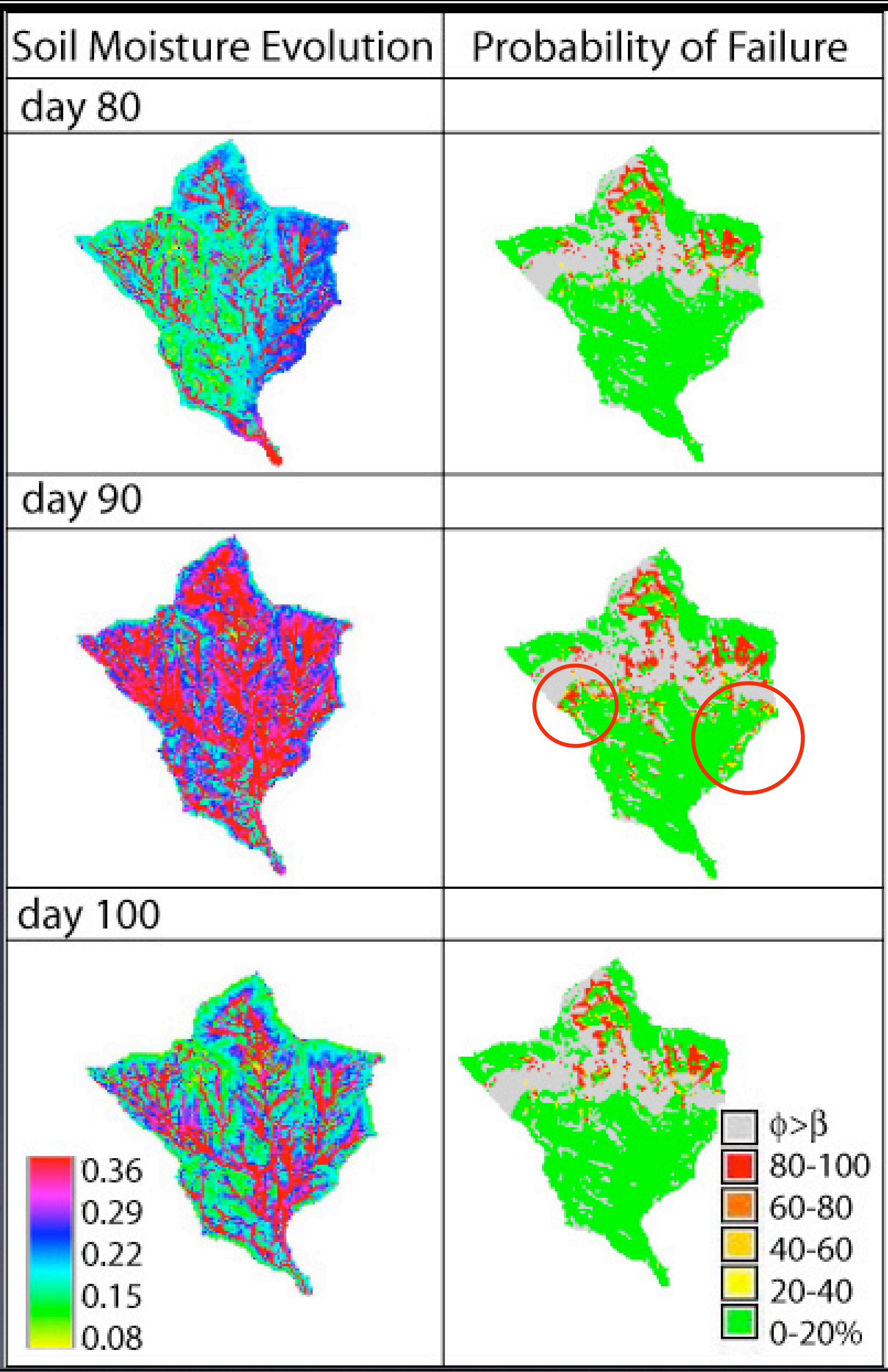
data elaboration courtesy of dr. Pivetta, 2004

RESULTS

EVOLUTION OF SLOPE STABILITY DURING THE INVESTIGATED RAINFALL PERIOD

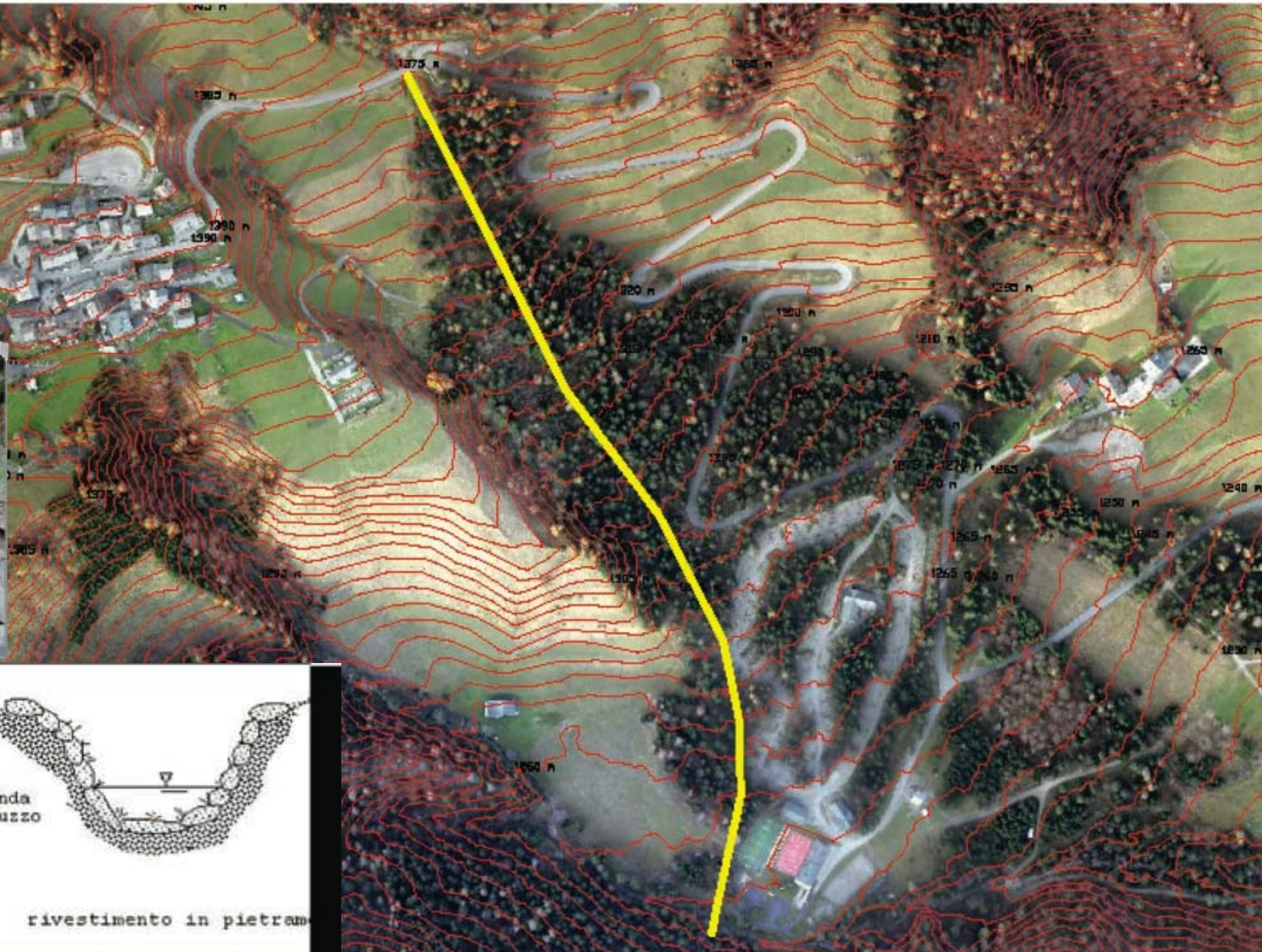
DAY 90

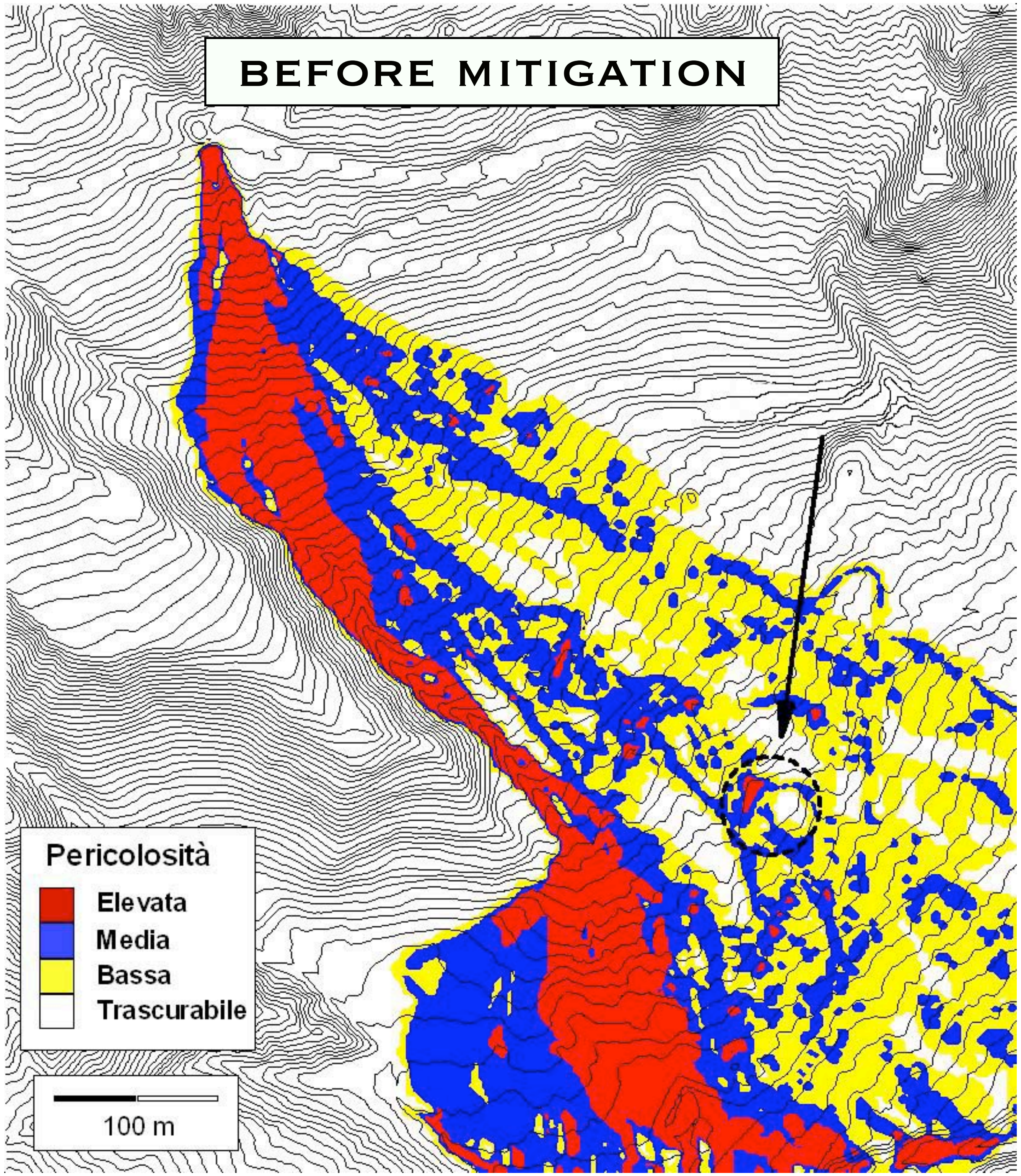


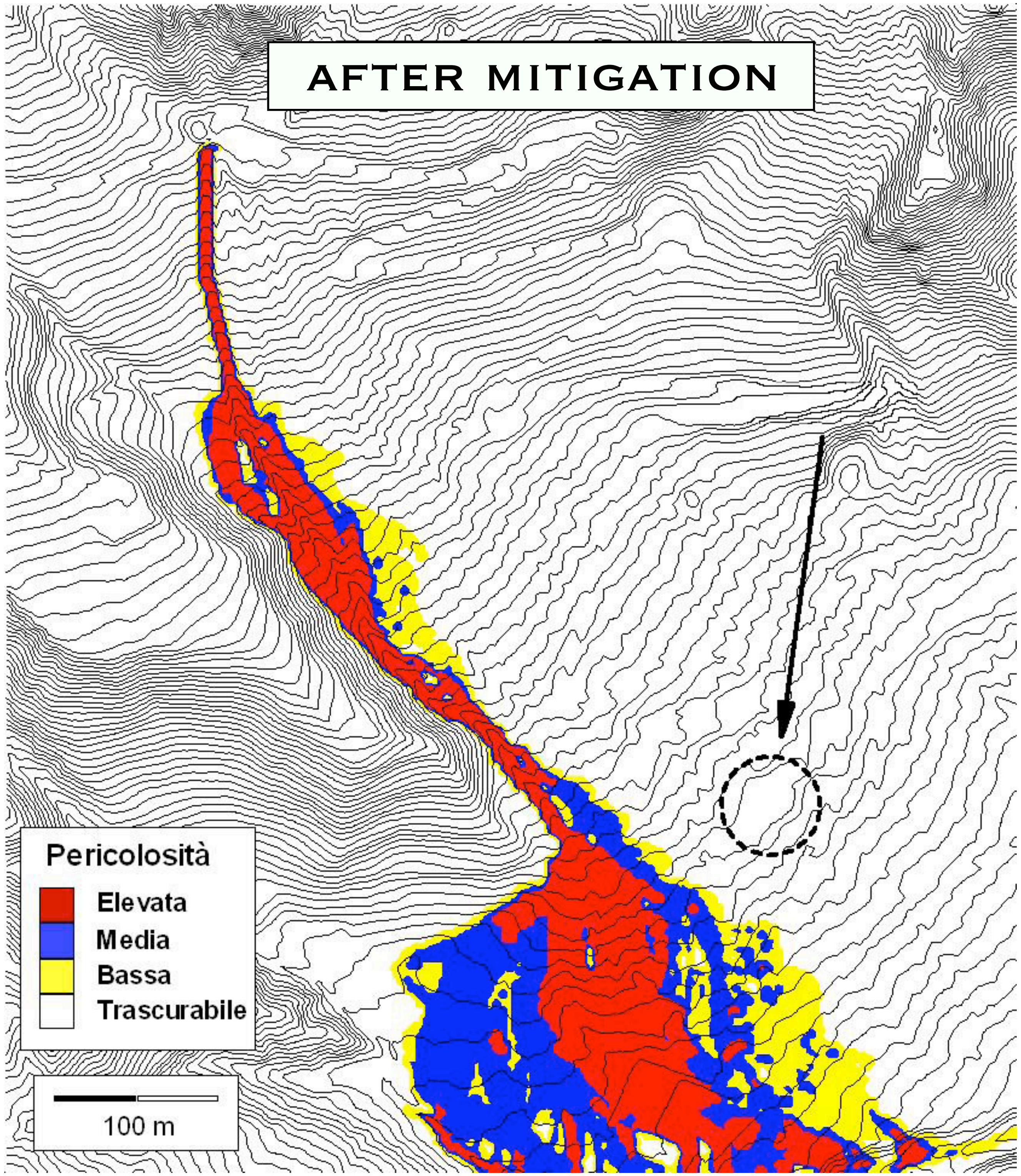


Simoni et al., Hydrological Processes, to appear 2007

DESIGN OF COUNTERMEASUREMENTS FOR RISK MITIGATION




BEFORE MITIGATION
Pericolosità
Elevata
Media
Bassa
Trascurabile
100 m


AFTER MITIGATION
Pericolosità
Elevata
Media
Bassa
Trascurabile
100 m

CONCLUSIONS

The forecasting of landslide, debris-flow and avalanche triggering is mainly characterized by two aspects: time and space; i.e. when and where a rapid mass movement will take place. Several techniques are currently available but none of them can really address the problem in real time at operational level. However the research in this field has made considerable progress.

At local scale, the most powerful tools seem to be distributed and dynamic models, physically based, which are theoretically capable of capturing the time and the location of the triggering, jointed with field observations and human expertise. Practical limitations of these tools are the availability of data and computational costs. Therefore, our current capability of predicting landslide triggering mainly relies on overcoming these challenges.