GUIDELINES ON LANDSLIDE ZONING

A COMMON LANGUAGE ON LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK EVALUATION, ASSESSMENT AND MANAGEMENT

Guidelines on Landslide Susceptibility, Hazard and Risk Zoning

Joint Technical Committee 1

ISSMGE, ISRM and IAEG

GUIDELINES ON LANDSLIDE ZONING

PURPOSE OF THE GUIDELINES

Need of harmonisation

- Definitions and common terminology
- Guidance on what should be included in landslide susceptibility and hazard zoning and risk zoning schemes
- Recommendation on levels of zoning and scale of zoning maps based on the users needs
- Guidance on information required for different levels of zoning taking into account the landslide type
- Guidance on the reliability, validity and limitations of the methods.

No absolute statements are given

STRUCTURE OF THE GUIDELINES

Two documents:

Guidelines

Commentaries

- Provide background notes to explain the reasons for adopting the provisions of the guideline.
- Elaborate on some parts of the guideline
- Provide references for additional reading.

GUIDELINES ON LANDSLIDE ZONING

CONTENT OF THE GUIDELINES

- Definitions, classification & terminology (section 2)
- Risk management framework (section 3)
- Types of landslide zoning (section 4)
- When zoning is necessary (section 5)
- Zoning levels, scales and descriptors (section 6)
- Landslide zoning map scales (section 7)
- Methods for landslide susceptibility, hazard and risk mapping (section 8)
- Reliability and validation of zoning (section 9)

DEFINITIONS AND TERMINOLOGY

Landslide Susceptibility. The classification, volume (or area), and spatial distribution of landslides which exist or potentially may occur in an area.

DEFINITIONS AND TERMINOLOGY

Hazard The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the likelihood of their occurrence within a given period of time.

DEFINITIONS AND TERMINOLOGY

Risk – A measure of the probability and severity of an adverse effect to health, property or the environment. (a) *For life loss*, the annual probability that the person most at risk in the risk zone will lose his or her life taking account of the landslide hazard, and the temporal spatial probability and vulnerability of the person (b) *For property loss*, the annual probability of the consequence or the annualised loss taking account of the elements at risk, their temporal spatial probability and vulnerability

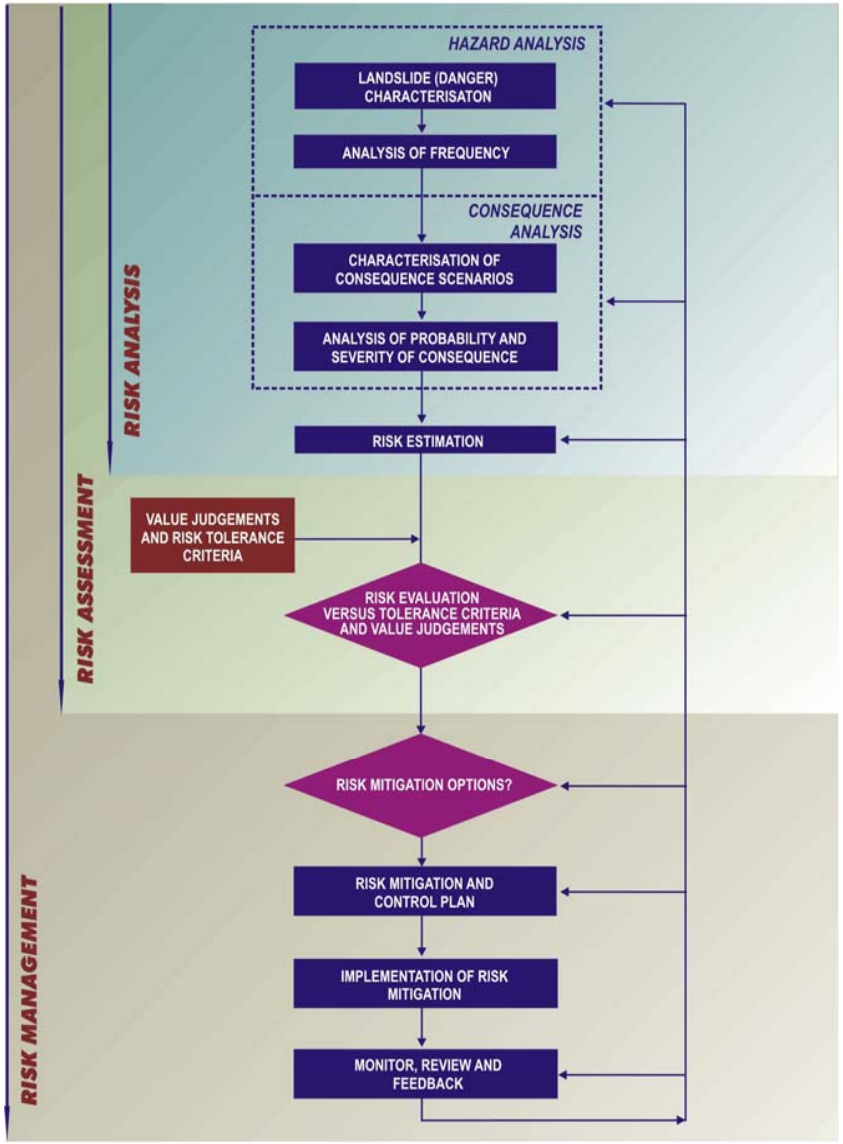
DEFINITIONS AND TERMINOLOGY

Elements at Risk – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by the landslide hazard

Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss).

Zoning: The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk.

RISK MANAGEMENT FRAMEWORK



Fell et al. 2005

GUIDELINES ON LANDSLIDE ZONING

LANDSLIDE ZONING

Location, volume and classification of existing landslides

Location, volume and classification of potential landslides

Areas with a potential to experience landsliding in the future (travel distance – head retreat)

Landslide inventory map

↓

Landslide susceptibility map

Estimated frequency (annual probability)

Intensity – frequency relationships

↓

Landslide hazard map

Elements at risk

Vulnerabillity

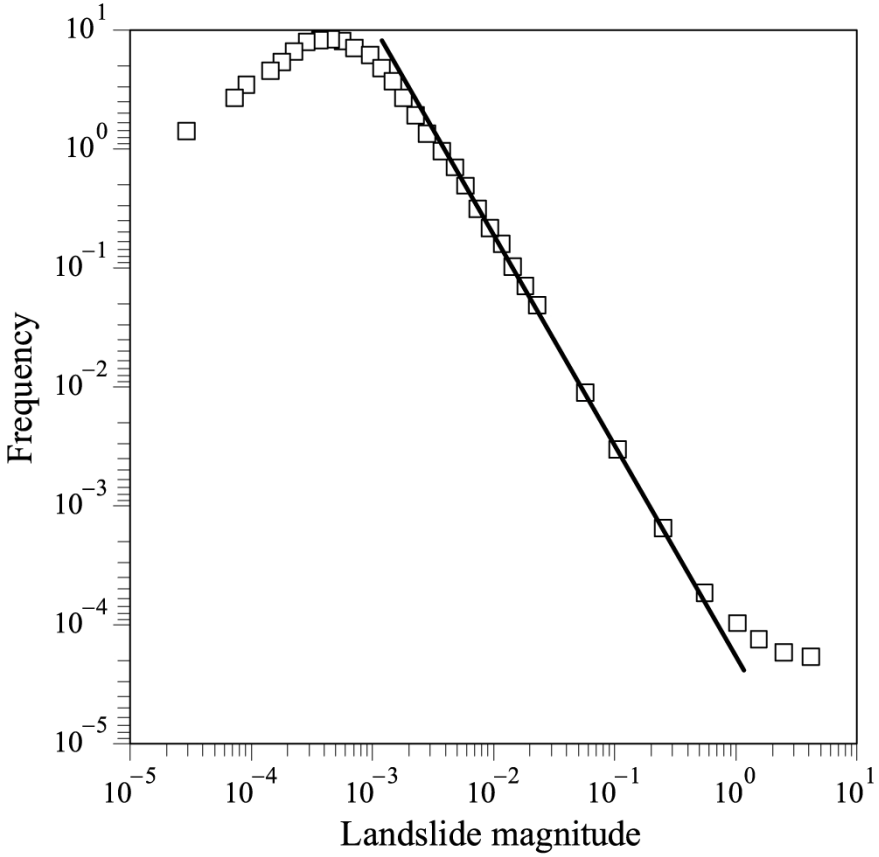
Spatial and temporal probability

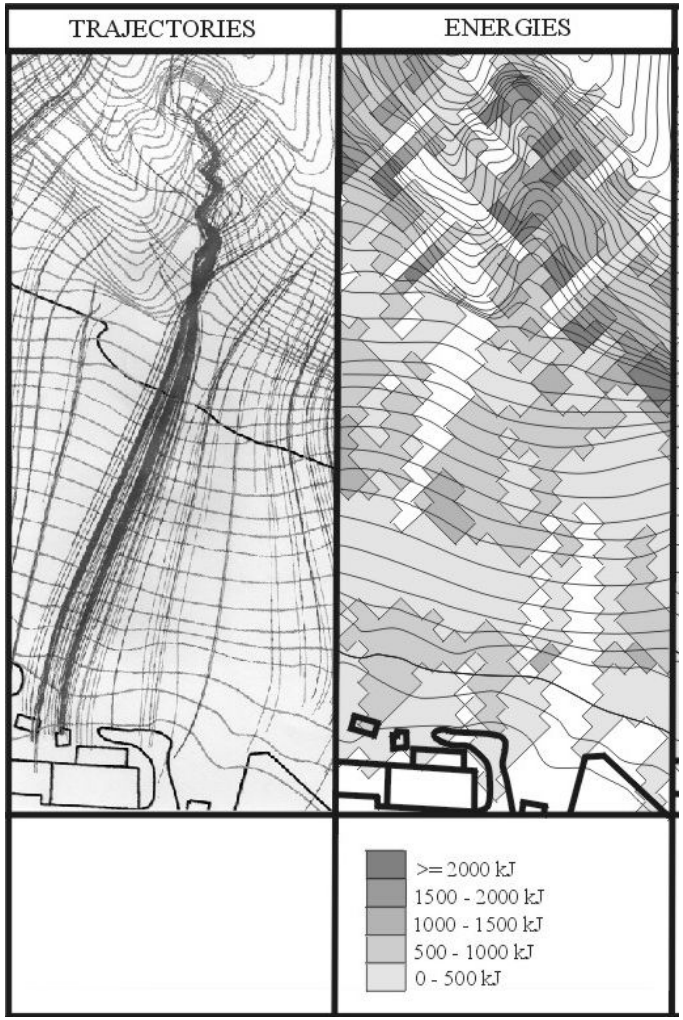
Potential damage

↓

Landslide risk map

Hazard zoning: Intensity (magnitude) – frequency relationship





Hazard zoning: Intensity (magnitude) – frequency relationship

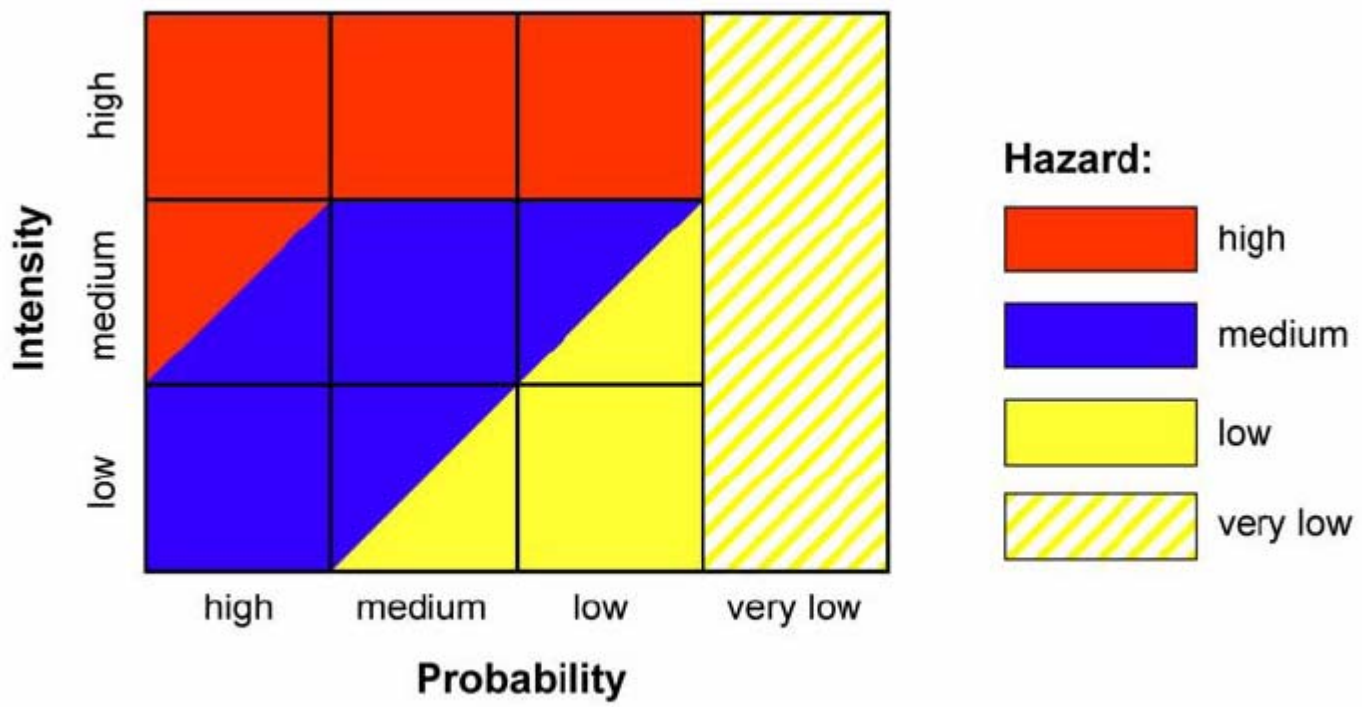


Figure 3. Diagram of hazard levels as a function of probability and intensity.

LANDSLIDE RISK ZONING

What should be taken into account

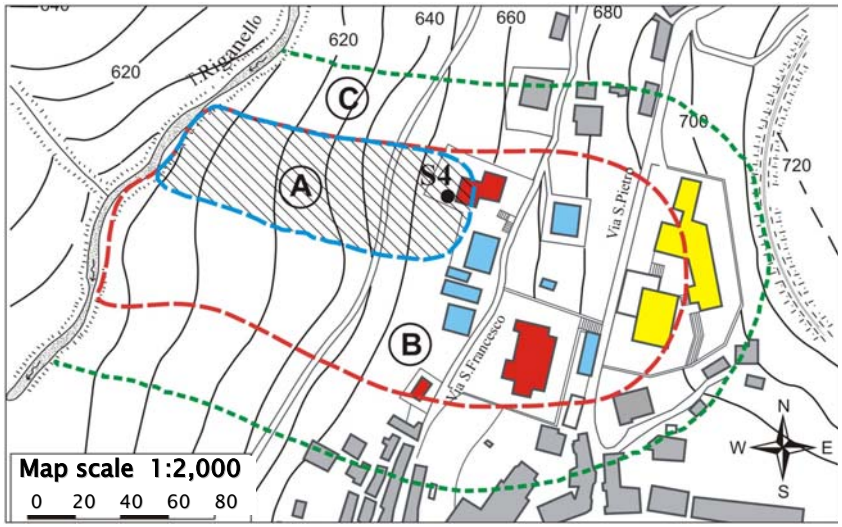
- The elements at risk
- The vulnerability of the elements at risk (different vulnerabilities)
- The expected damages for given scenarios :

  - Triggering events of a given magnitude (i.e. rainfall, earthquake, etc)
  - Landslides with a given probability of occurrence
  - Cascading effects (i.e. valley damming)
  - Risk remaining after protection works have been completed
  - Risk transfer

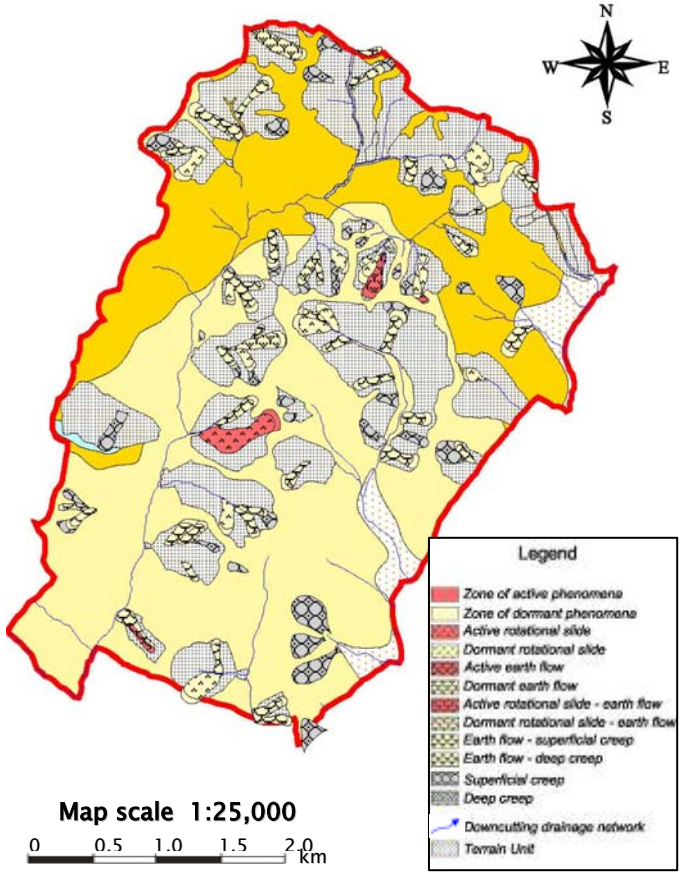
DIFFERENT VULNERABILITIES TO LANDSLIDING

GUIDELINES ON LANDSLIDE ZONING

RECOMMENDED TYPES AND LEVELS OF ZONING AND MAP SCALES



Cascini, 2006



RECOMMENDED TYPES AND LEVELS OF ZONING AND MAP SCALES

Purpose	Type of Zoning				Zoning Level			Applicable Map Scales
	Inventory	Suscept-ibility	Hazard	Risk	Preliminary	Intermediate	Advanced	
Regional Zoning								
Information	X	X			X			1:25,000 to 1:250,000
Advisory	X	X	(X)		X	(X)		
Statutory	NOT RECOMMENDED							
Local Zoning								
Information	X	X	X	(X)	X	(X)		1:5,000 to 1:25,000
Advisory	(X)	X	X	X	X	X	X	
Statutory		(X)	X	(X)		X	X	
Site Specific Zoning								
Information	NOT RECOMMENDED							1:5,000 to 1:1,000
Advisory	NOT COMMONLY USED							
Statutory		(X)	X	X		X	X	
Design			(X)	X		(X)	X	

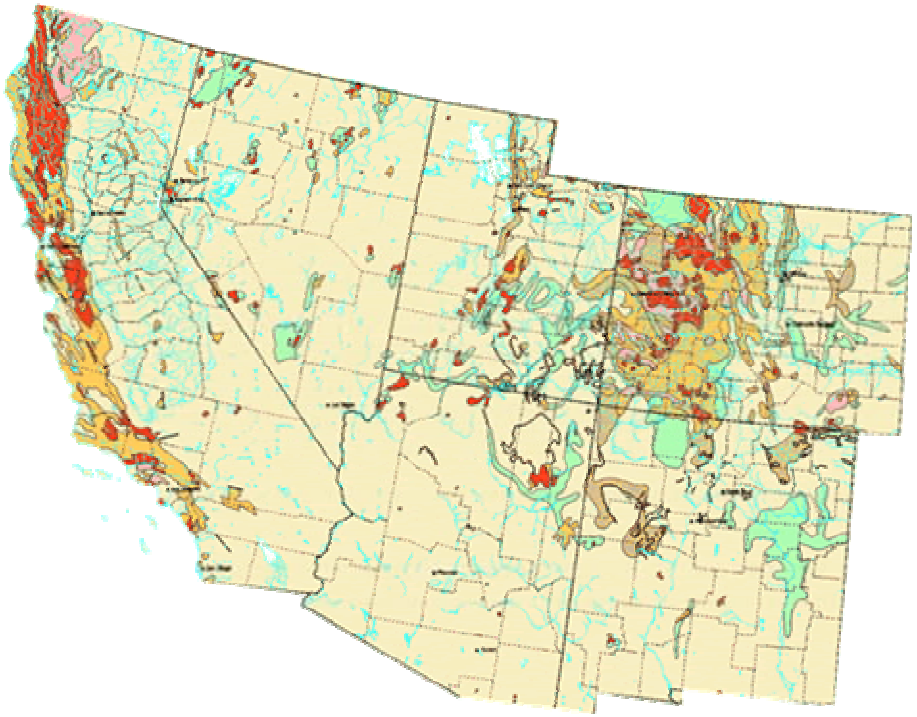
Notes: X= applicable; (X) = may be applicable

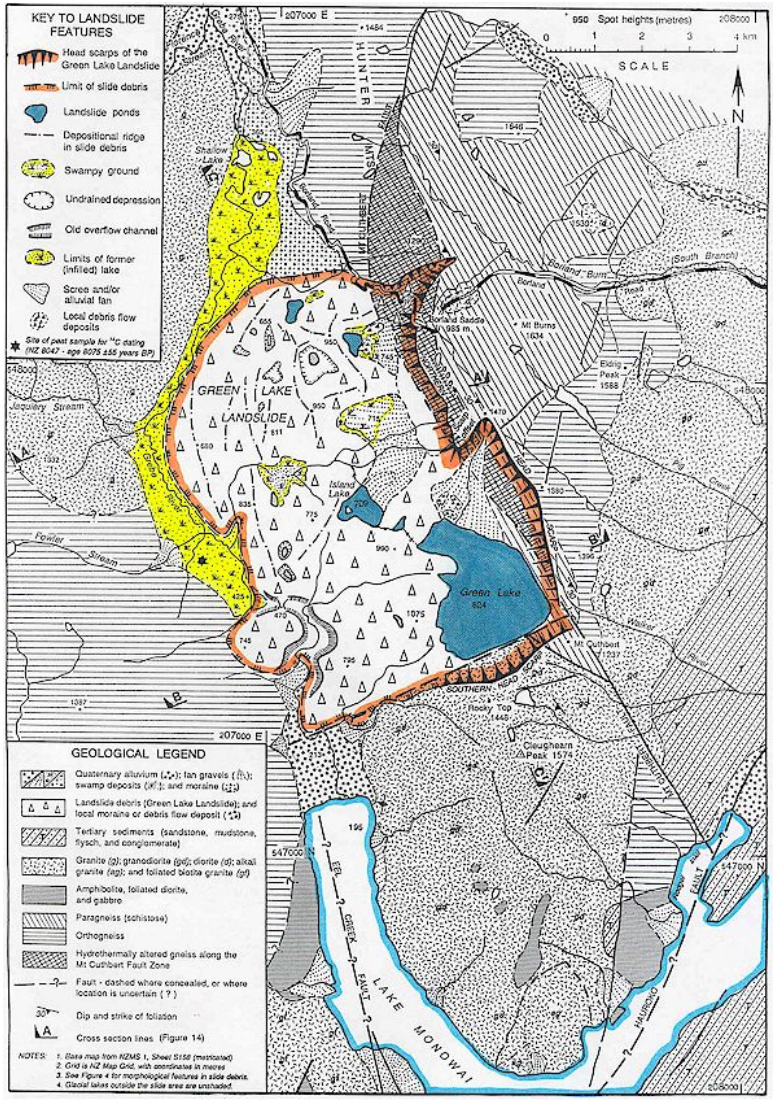
SCALE OF MAPPING

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 square kilometres
Medium	1:100,000 to 1:25,000	Landslide inventory and susceptibility zoning for regional and local development; or very large scale engineering projects. Preliminary level hazard mapping for local areas	1000 – 10,000 square kilometres
Large	1:25,000 to 1:5,000	Landslide inventory, susceptibility and hazard zoning for local areas Preliminary level risk zoning for local areas and the advanced stages of planning for large engineering structures, roads and railways	10-1000 square kilometres
Detailed	> 5,000	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

GUIDELINES ON LANDSLIDE ZONING

ACTIVITIES FOR PREPARING A LANDSLIDE INVENTORY





ACTIVITIES FOR PREPARING A LANDSLIDE INVENTORY

Characterisation Method	Activities
Basic	Prepare an inventory of landslides in the area from aerial photographs and by mapping and from historic records.
	Identify the relationship to topography, geology and geomorphology
	Show this information on inventory maps
Intermediate	**The same activities as Basic plus**
	Distinguish different parts of the landslides
	Map landslide features and boundaries
	Collect and assess historical information on the activity of landsliding.
	Increased time and resources in the research phase of the inventory compilation resulting in more rigor and extended coverage
Advanced	**The same activities as Intermediate plus**
	Prepare an inventory of geotechnical data
	Geotechnical analysis to understand slope instability processes
	Analyse the past evolution of the land use to know whether human activities have had an influence on the incidence of landslides
	Advanced temporal cataloguing of periodic reactivations of the same hazard and temporal windowing of specific triggering events to provide periodic inventory data sets which can then be used in advanced validation approaches.

GUIDELINES ON LANDSLIDE ZONING

ACTIVITIES FOR ASSESSING LANDSLIDE SUSCEPTIBILITY

Characterisation Method	Activities
Basic	Prepare a geomorphologic map
	Prepare a landslide inventory
	Calculate the % of the total landslide count for each susceptibility class, the % of the area affected by landslides for each class and the % of each class in comparison to the total study area.
	Correlate the incidence of landsliding with the geology and slope to delineate areas susceptible to landsliding.
	Prepare the landslide susceptibility zoning map superimposed on the topography with a suitable legend.
	Implement the data and the maps in a GIS (recommended)
Intermediate	**The same activities as basic plus**
	Qualitative rating of landslide susceptible areas based on overlapping techniques
	Perform data treatment analysis (discriminate; neural networks; fuzzy logic; logistic regression; etc) and develop quantitative ratings to obtain susceptibility classes
	Implement the data and the maps in a GIS (recommended)
Advanced	**The same activities as Intermediate plus**
	Detailed mapping and geotechnical investigations to develop an understanding of the mechanics of landsliding, hydrogeology and stability analyses.
	Perform stability analyses

EXAMPLES OF SUSCEPTIBILITY MAPPING DESCRIPTORS

Susceptibility Descriptors	Rock Falls	Small Landslides on Natural Slopes	Large Landslides on Natural Slopes
(a) Quantitative susceptibility descriptors			
Relative	Geomechanical ratings (SMR, RMS)	Scores of contributing factors obtained from data treatment techniques	
Absolute	Factor of safety values from stability models	Factor of safety values from stability models	Factor of safety values from stability models
(b) Qualitative susceptibility descriptors			
Field geomorphological analysis	Presence of absence of potential instability factors (cracks, dipping joints)	# of landslides per square kilometer	Presence or absence of landslides and their degree of preservation
	Density of scars on a rock slope	% of area covered by landslide deposits	Presence or absence of activity indicators
Index map or parameter map	Overlapping of index maps with or without weighting	Overlapping of index maps with or without weighting	

GUIDELINES ON LANDSLIDE ZONING

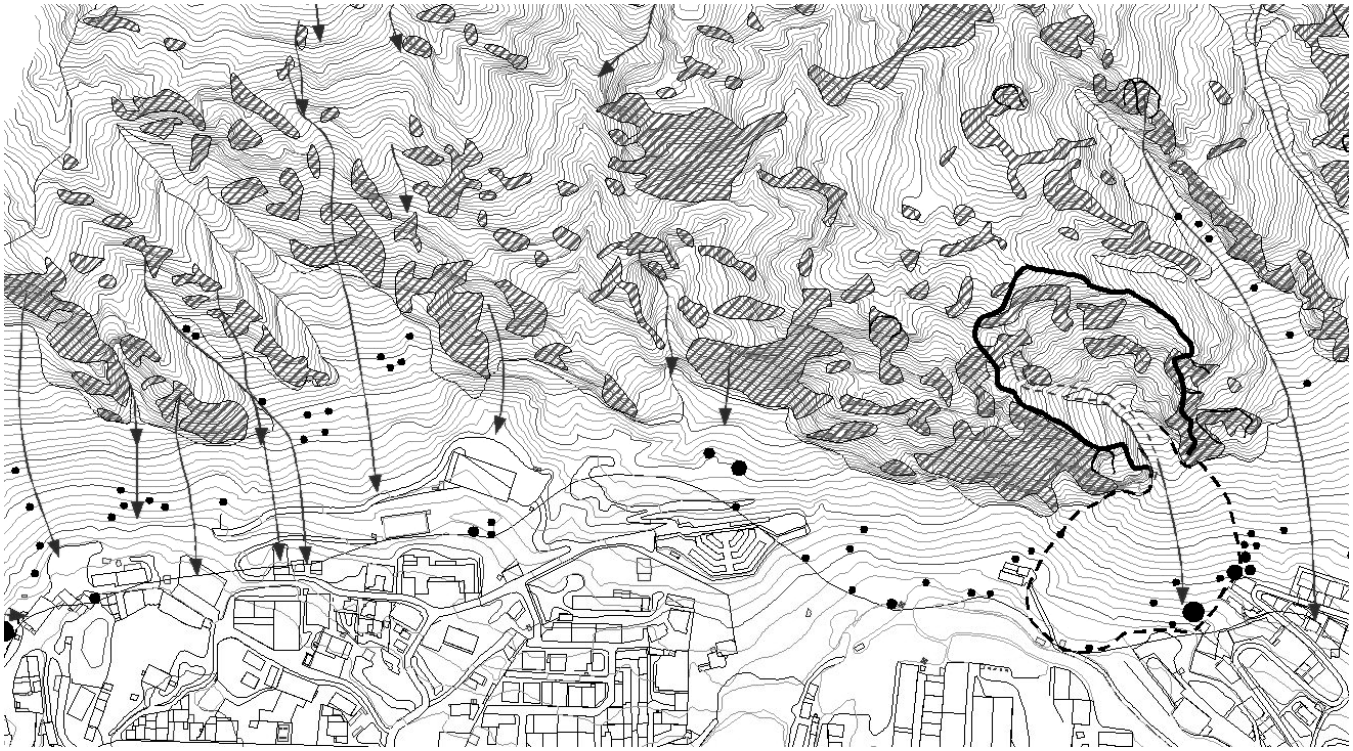
ACTIVITIES FOR ASSESSING TRAVEL DISTANCE AND VELOCITY

	Activities
Basic	Collect and assess historical information on travel distances and velocity.
	Assess limiting travel distances from geomorphologic data and old landslide deposits.
	Assess the likely travel distance and velocity from consideration of the classification of the potential landslides, geology and topography.
	Based on this information assess the limit (greatest) likely travel distance for each classification of potential landslide.
Intermediate	**The same activities as Basic plus**
	Assess likely landslide mechanisms and soil classification
	Use empirical methods based on travel distance angle or shadow angle to assess travel distance accounting for the uncertainty in the empirical methods and data in puts.
	Assess velocity using simple sliding block models.
Advanced	**The same activities as Intermediate plus**
	Investigate geotechnical properties of the sliding materials as required by numerical models
	Use numerical models to model travel distance and velocity.

ACTIVITIES FOR ASSESSING TRAVEL DISTANCE AND VELOCITY

Basic level

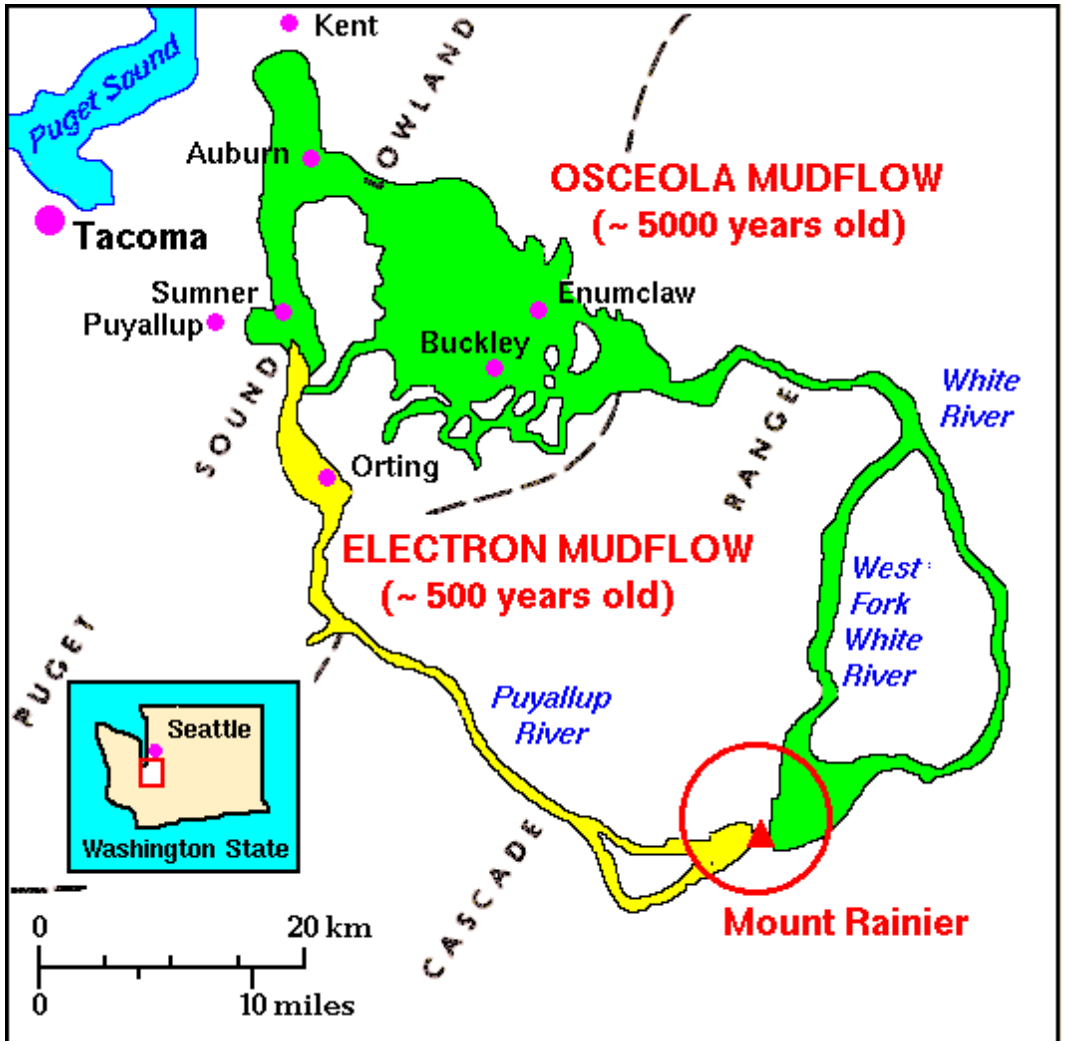
Geomorphological approach



Copons, 2004

ACTIVITIES FOR ASSESSING TRAVEL DISTANCE AND VELOCITY

Basic level



Crandell et al. 1979

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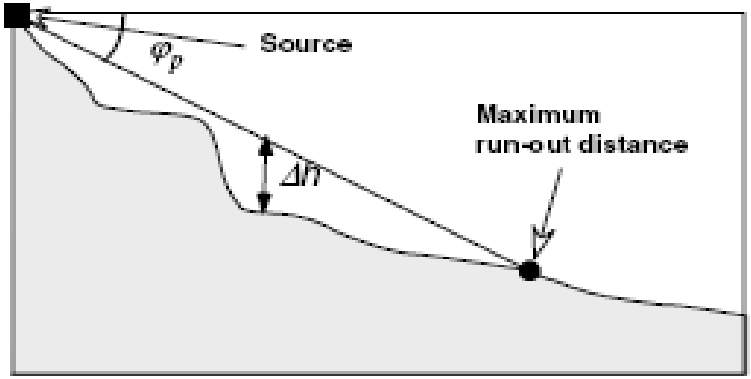
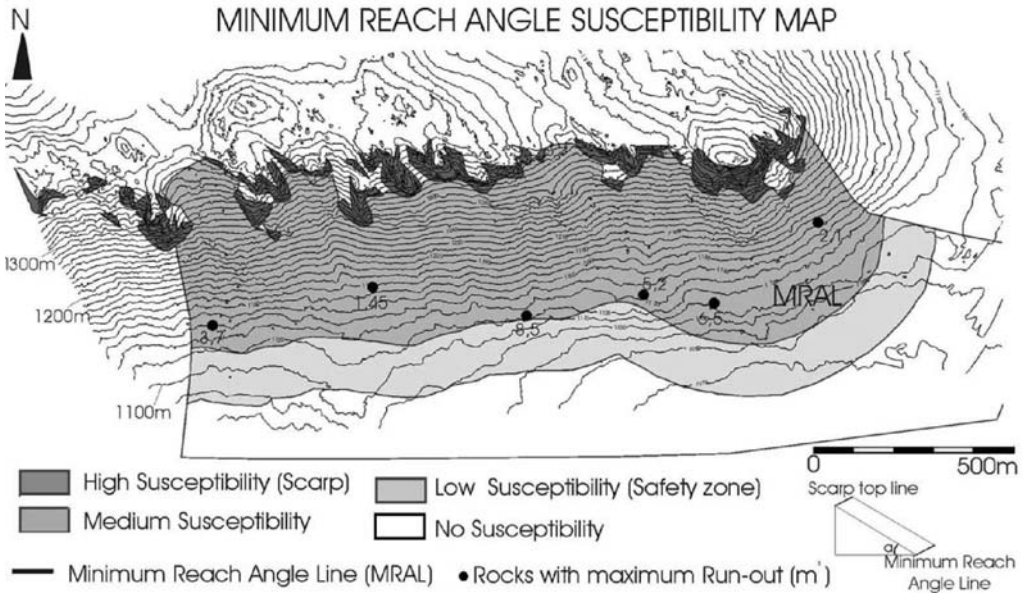
ACTIVITIES FOR ASSESSING TRAVEL DISTANCE AND VELOCITY

Intermediate level

empirical methods



Reach angle



Ayala et al. 2003

GUIDELINES ON LANDSLIDE ZONING

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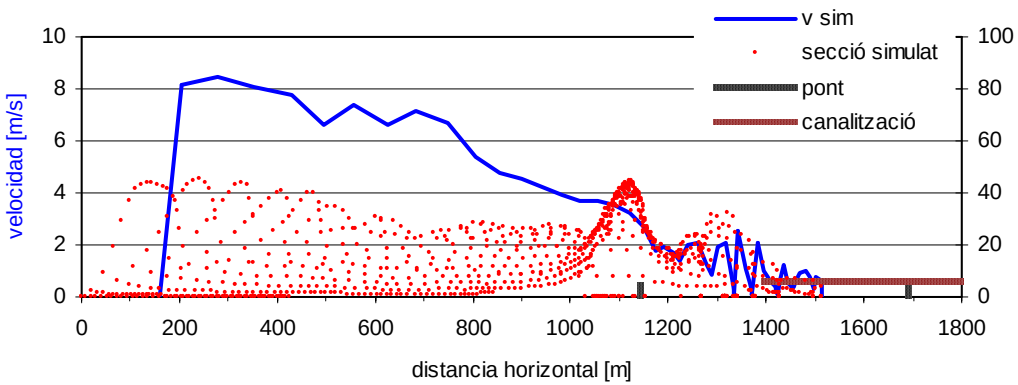
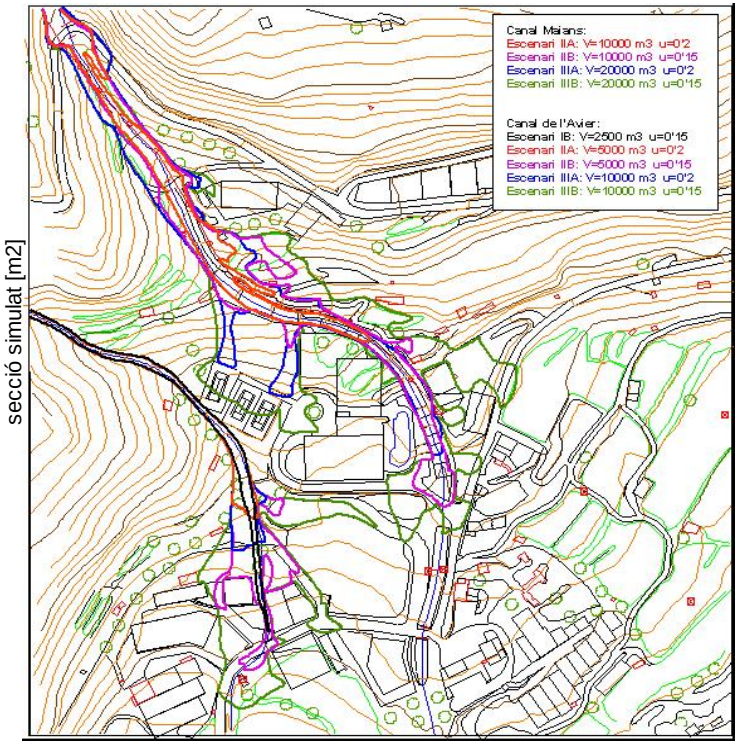
ACTIVITIES FOR ASSESSING TRAVEL DISTANCE AND VELOCITY

Advanced level

Numerical methods





Scenario IIb: V = 10000 m³ ; μ = 0.15; C = 9 m$^{1/2}$/s

GUIDELINES ON LANDSLIDE ZONING

ACTIVITIES FOR ASSESSING FREQUENCY OF LANDSLIDES

	Activities
Basic	relative freshness of the morphological features of the scars and landside deposits taking into account the presence of active geomorphic events
	number of landslides from aerial photographs taken at known time intervals
	Assess the historic frequency from basic incident databases
Intermediate	**The same activities as Basic plus**
	Relate to slope characteristics such as topography (slope angle, elevation, aspect), geology, geomorphology using multi-variate analyses.
	Assess the historic frequency from incident databases: develop and use frequency volume curves.
	Use proxy data such as silent witnesses (e.g. damage to trees), dendrochronology.
	Analysis of rainfall including the effects of antecedent rainfall For seismically induced landsliding, relate sliding to seismic loading including the peak ground acceleration and magnitude of the earthquake using empirical methods.
Advanced	**The same activities as Intermediate plus**
	Assess geotechnical parameters of the soils. Model slope factors of safety from geotechnical parameters and rainfall frequency or piezometric data. For seismically-induced landslides, analyse displacements using 'Newmark' type analyses and for liquefiable soils, the likelihood of liquefaction and flow sliding.

ACTIVITIES FOR ASSESSING FREQUENCY OF LANDSLIDES

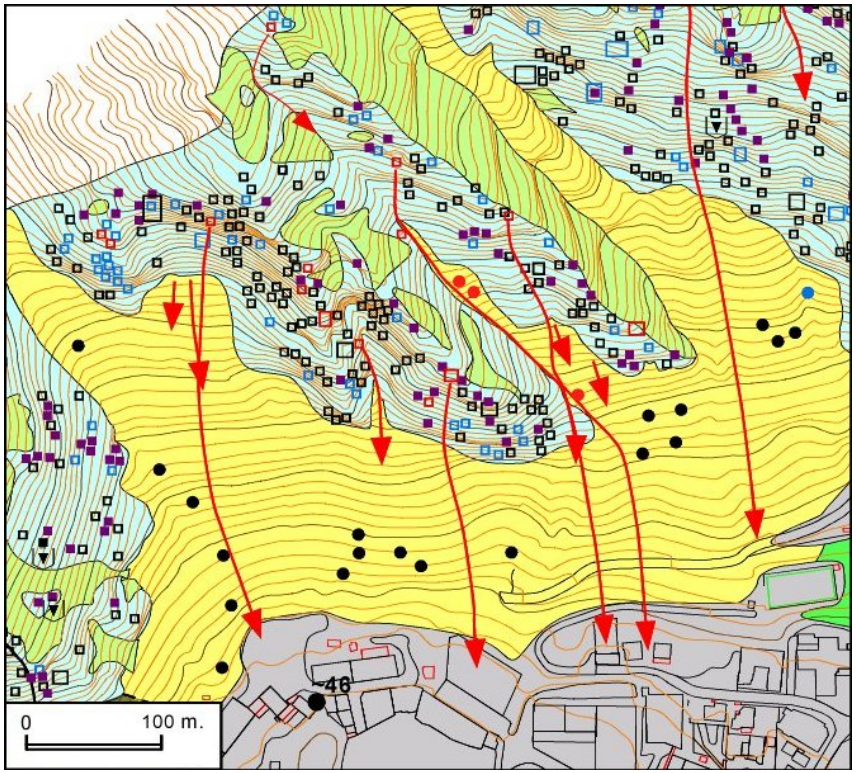
Basic level

Geomorphological approach

ACTIVITIES FOR ASSESSING FREQUENCY OF LANDSLIDES

Basic level

Geomorphological approach



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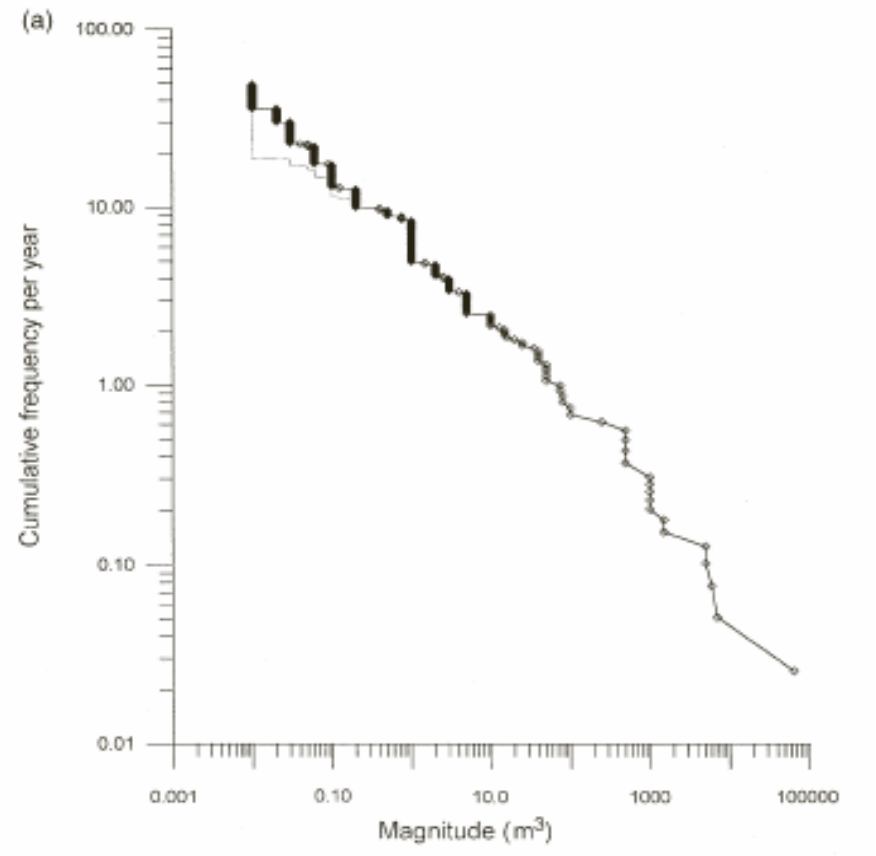
ACTIVITIES FOR ASSESSING FREQUENCY OF LANDSLIDES

Intermediate level

Landslide incident records



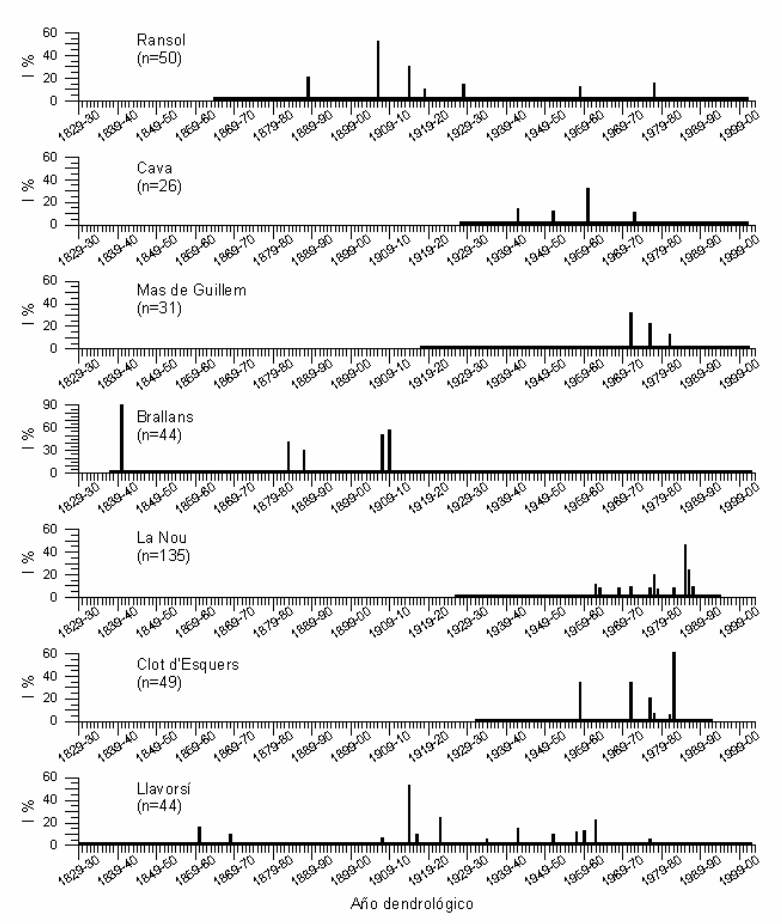
Hungr et al. 1998

GUIDELINES ON LANDSLIDE ZONING

ACTIVITIES FOR ASSESSING FREQUENCY OF LANDSLIDES

Intermediate level

Reconstructed landslide series



Corominas & Moya 1999

GUIDELINES ON LANDSLIDE ZONING

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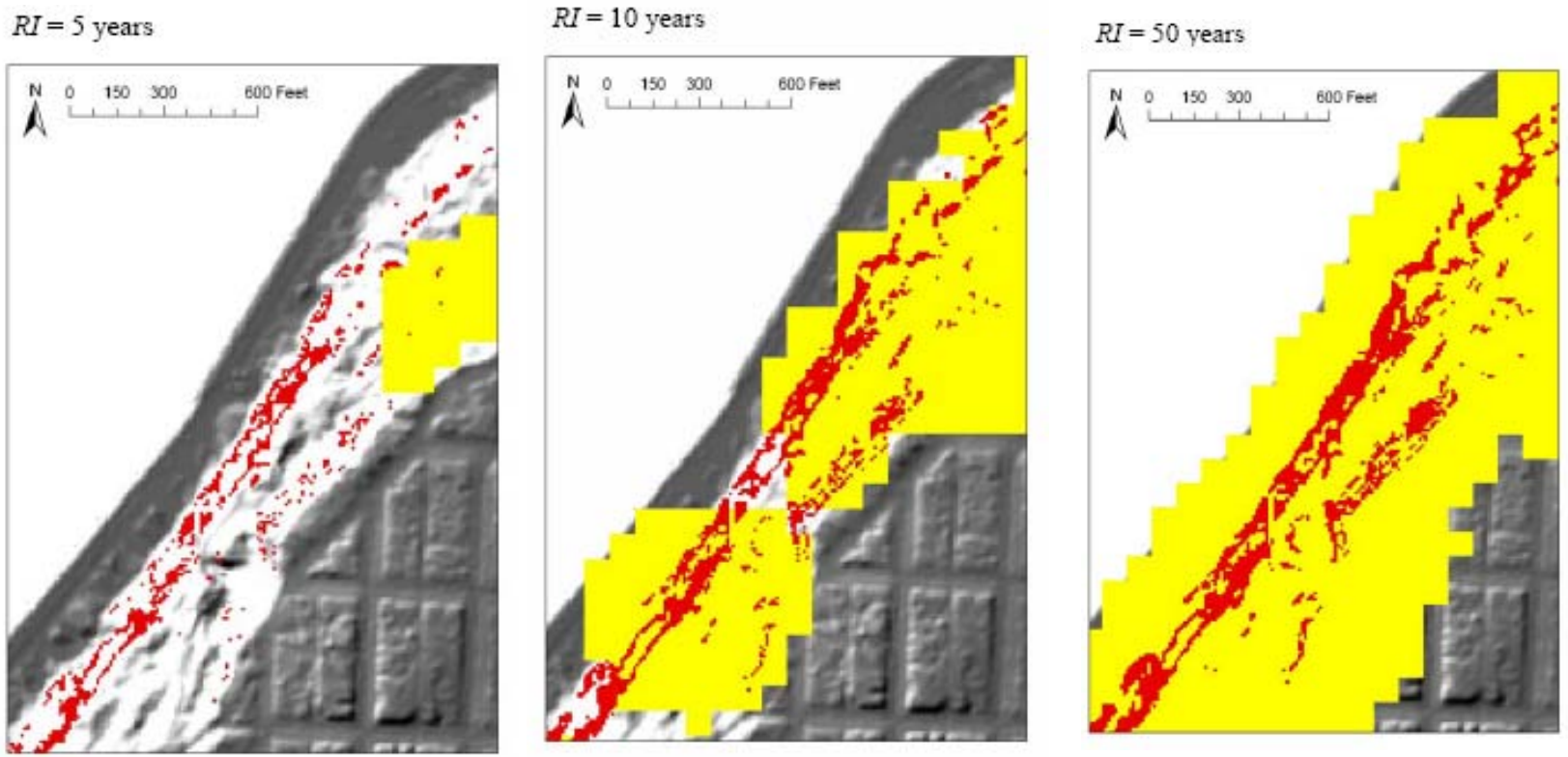
ACTIVITIES FOR ASSESSING FREQUENCY OF LANDSLIDES

Advanced level

Probabilistic models



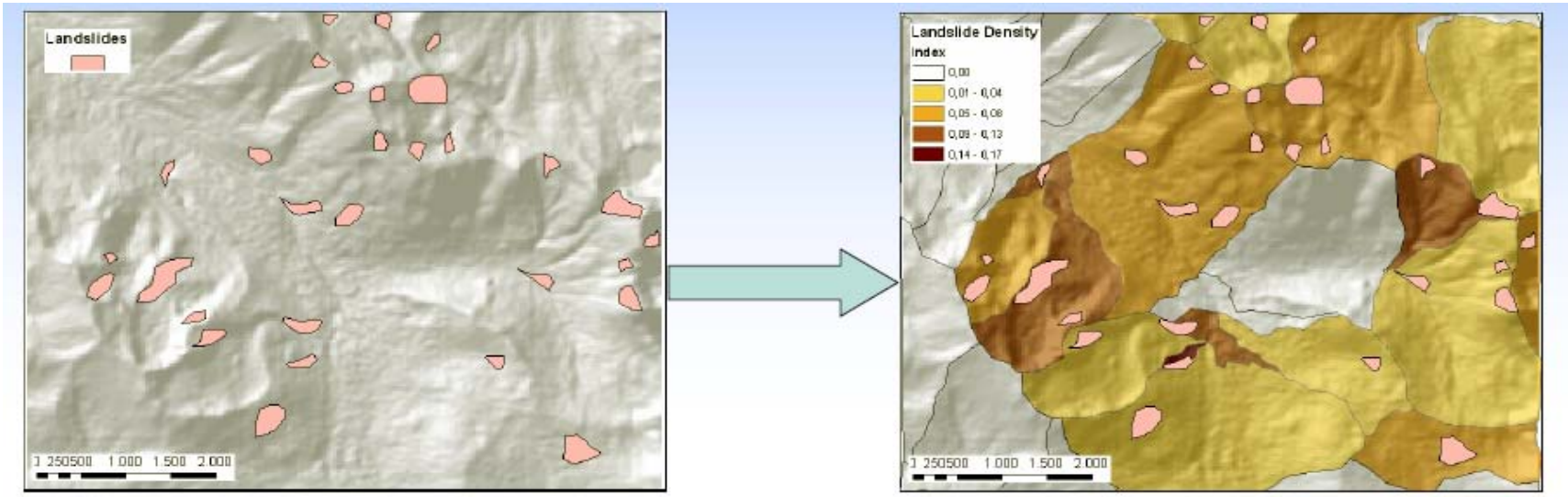
Salciarini et al. 2007

COMMENTARY: ACTIVITIES TO CHARACTERIZE AND EVALUATE THE SPATIAL DISTRIBUTION OF LANDSLIDES

Small landslides

Characterisation method	Activity	References
Basic	Map historic landslides from air photography, preferably photographs taken at different times some years apart, and using some surface mapping.	Evans and King, 1998 Dai and Lee, 2002
	Prepare isopleth maps	Wright et al. 1974
	Relate landslide occurrence to topography (e.g. slope, elevation, aspect) and lithology using simple correlation of single variables and judgement.	Nilsen et al., 1979 Brabb, 1984
Intermediate	**The same activities as Basic plus**	Van Westen, 1994 Carrara et al., 1995 Baynes and Lee, 1998; Whitworth et al. 2005
	Carry out more detailed surface mapping of the incidence of landslides, and geomorphology mapping using air photographs, remote sensors and/or by surface mapping.	
	Relate landslide occurrence to topography, geology, type and depth of soils and geomorphology using statistical analysis techniques..	
	Prepare landslide magnitude-frequency relations	Guzzetti et al. 2002; Reid and Page, 2002; Guthrie and Evans 2004
Advanced	**The same activities as Intermediate plus**	Baum et al., 2005, Xie et al. 2003
	Detailed surface mapping and aerial photo interpretation, geotechnical and hydrological investigations. Relate landsliding with coupled slope stability models implemented in a GIS.	

COMMENTARY: ACTIVITIES TO CHARACTERIZE AND EVALUATE THE SPATIAL DISTRIBUTION OF LANDSLIDES



Landslide inventory map

Landslide density map of terrain units (watersheds)

Günther, 2007

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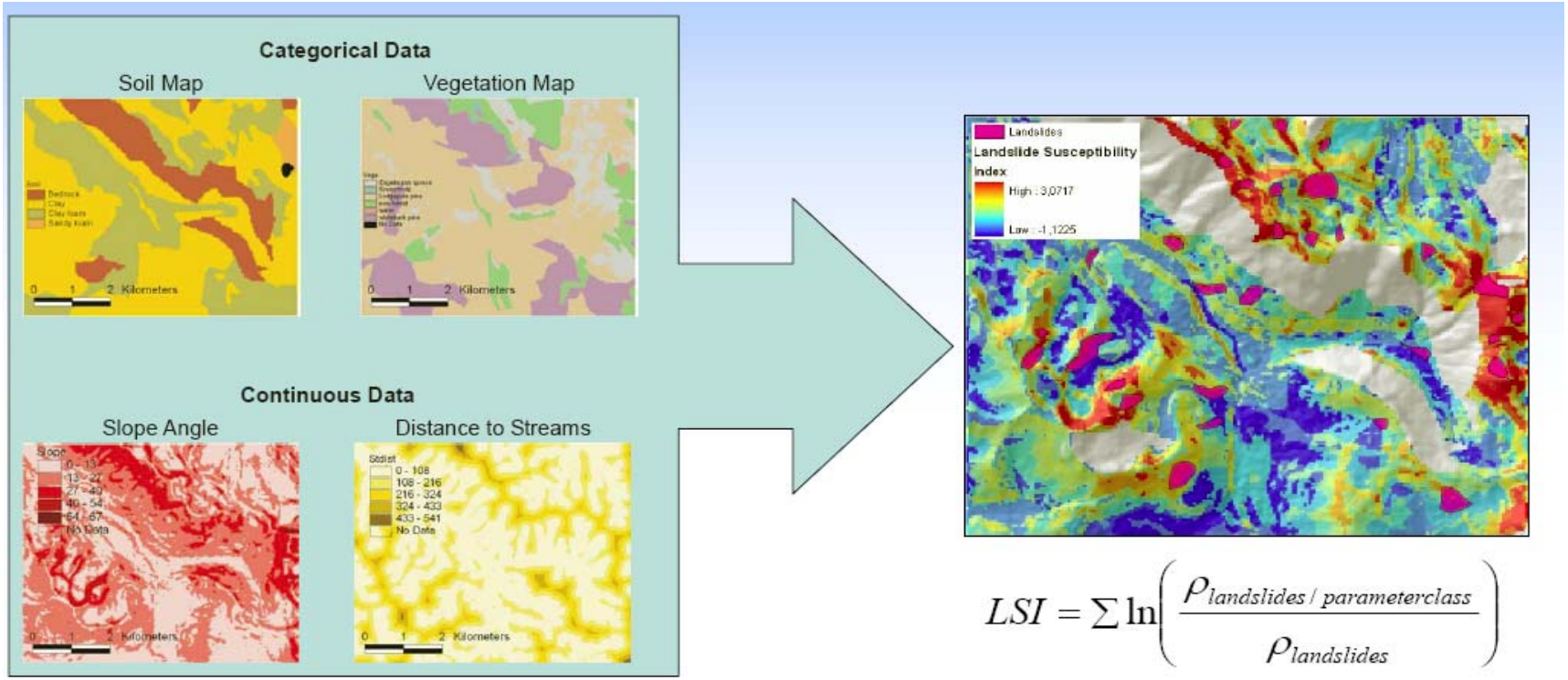

$$LSI = \sum \ln\left(\frac{\rho_{landslides\,/\,parameterclass}}{\rho_{landslides}}\right)$$

Günther, 2007

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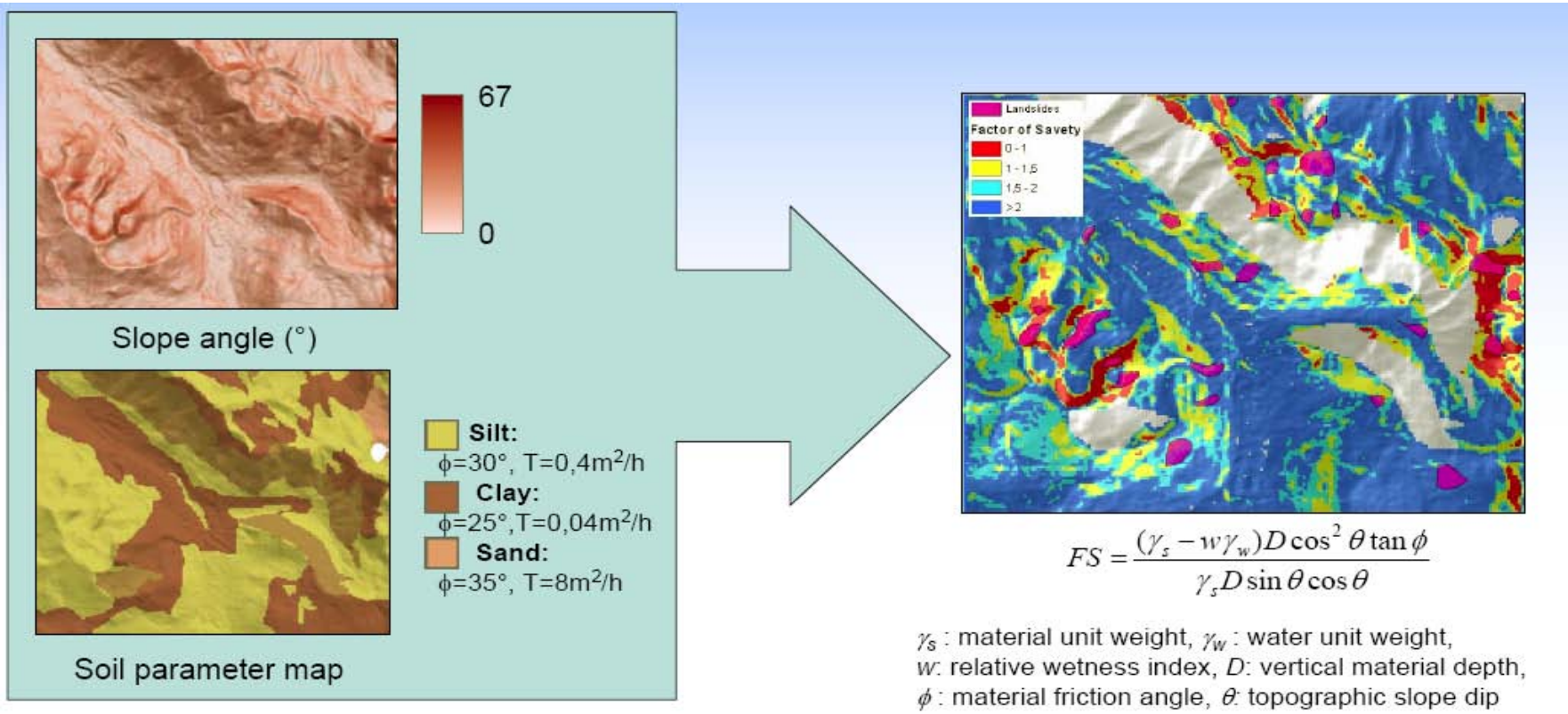
	Relate landslide occurrence to topography (e.g. slope, elevation, aspect) and lithology using simple correlation of single variables and judgement.	Nilsen et al., 1979 Brabb, 1984
Intermediate	**The same activities as Basic plus**	Van Westen, 1994 Carrara et al., 1995 Baynes and Lee, 1998; Whitworth et al. 2005
	Carry out more detailed surface mapping of the incidence of landslides, and geomorphology mapping using air photographs, remote sensors and/or by surface mapping.	
	Relate landslide occurrence to topography, geology, type and depth of soils and geomorphology using statistical analysis techniques..	
	Prepare landslide magnitude-frequency relations	Guzzetti et al. 2002; Reid and Page, 2002; Guthrie and Evans 2004
Advanced	**The same activities as Intermediate plus**	Baum et al., 2005, Xie et al. 2003
	Detailed surface mapping and aerial photo interpretation, geotechnical and hydrological investigations. Relate landsliding with coupled slope stability models implemented in a GIS.	

COMMENTARY: ACTIVITIES TO CHARACTERIZE AND EVALUATE THE SPATIAL DISTRIBUTION OF LANDSLIDES



$$FS = \frac{(\gamma_s - w\gamma_w) D \cos^2\theta \tan\phi}{\gamma_s D \sin\theta \cos\theta}$$

γ_s : material unit weight, γ_w : water unit weight,
w: relative wetness index, D: vertical material depth,
ϕ : material friction angle, θ: topographic slope dip

Günther, 2007

SCIENTIFIC COMMITTEE

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Eric Leroi, Urbater, France
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ATTENDEES TO WORKSHOP IN BARCELONA, 18th to 20th September 2006

Australia
Professor Robin Fell, University of New South Wales
Mr. Andrew Leventhal, GDH-LongMac, Sydney
Dr Fred Baynes, Baynes Geologic, Australia
Brasil
Professor Willy Lacerda, Federal University of Rio de Janeiro
Canada
Professor Serge Leroueil, Universite Laval, Quebec
Professor Oldrich Hungr. University of British Columbia
China
Dr. H. W. Sun, Geotechnical Engineering Office, Hong Kong.
France
Dr. Eric Leroi, Urbater
Professor Olivier Maquaire, University of Caen

Germany
Professor Thomas Glade, Department of Geography, University of Bonn
Italy
Professor Leonardo Cascini, University of Salerno
Mr. Giovanni Bertolini, Water Authority, Regione Emilia-Romagna, Bologna
Dr. Diana Salciarini, University of Perugia, Perugia
Professor Luciano Picarelli, University of Naples
Professor Claudio Scavia, Politecnico di Torino
Dr. Marina Pirulli, Politecnico di Torino
Professor Giovanni Crosta, University of Milano Biccoca, Milano
Professor Paolo Fratini, University of Milano Biccoca, Milano
New Zealand
Professor Michael Crozier, University of Wellington
Norway
Professor Farrokh Nadim, International Centre for Geohazards, Oslo
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Professor Jordi Corominas, Technical University of Catalonia, Barcelona
Dr. Mercedes Ferrer, Spanish Geological Survey, Madrid
Professor José Chacón, University of Granada, Granada
Professor Juan Remondo, University of Cantabria, Santander
Professor Marcel Hürlimann, Technical University of Catalonia, Barcelona
Professor José Moya, Technical University of Catalonia, Barcelona
Dr. Ramon Copons, University of Barcelona
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Mr. Olivier Lateltin, Federal Office for Water and Geology, Biel
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Mr. Brian Marker, Consultant London
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Dr. William Z. Savage, United States Geological Survey, Denver, Colorado
Dr. Susan Cannon, United States Geological Survey, Denver, Colorado