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LANDSLIDE INTENSITY ASSESSMENT

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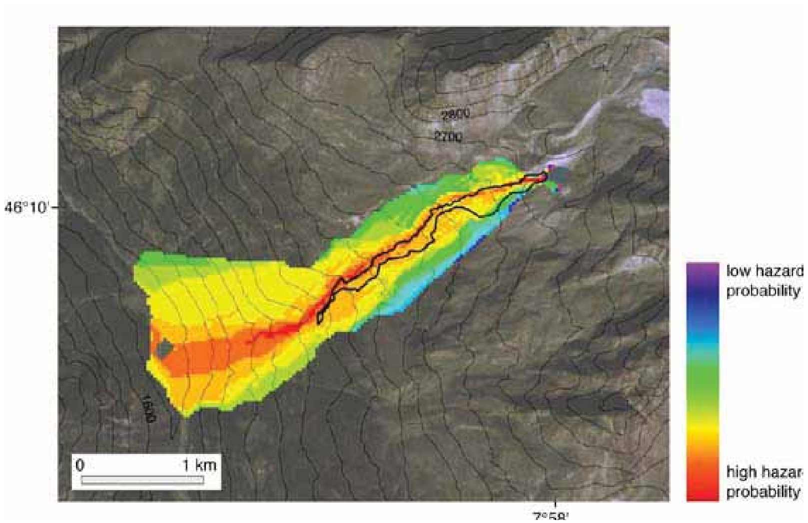


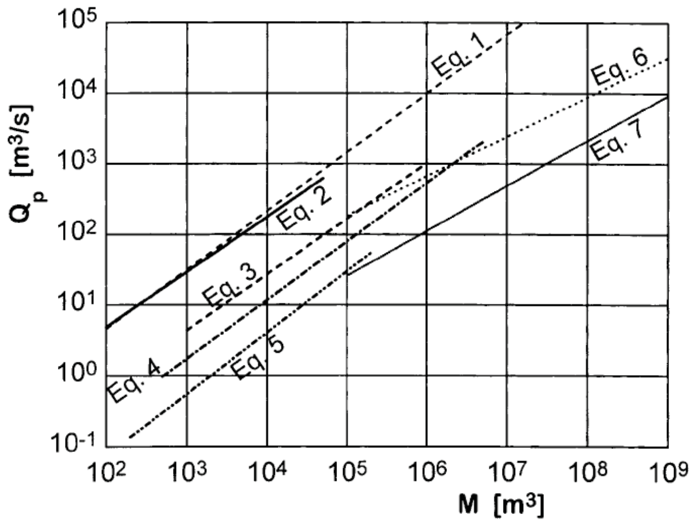
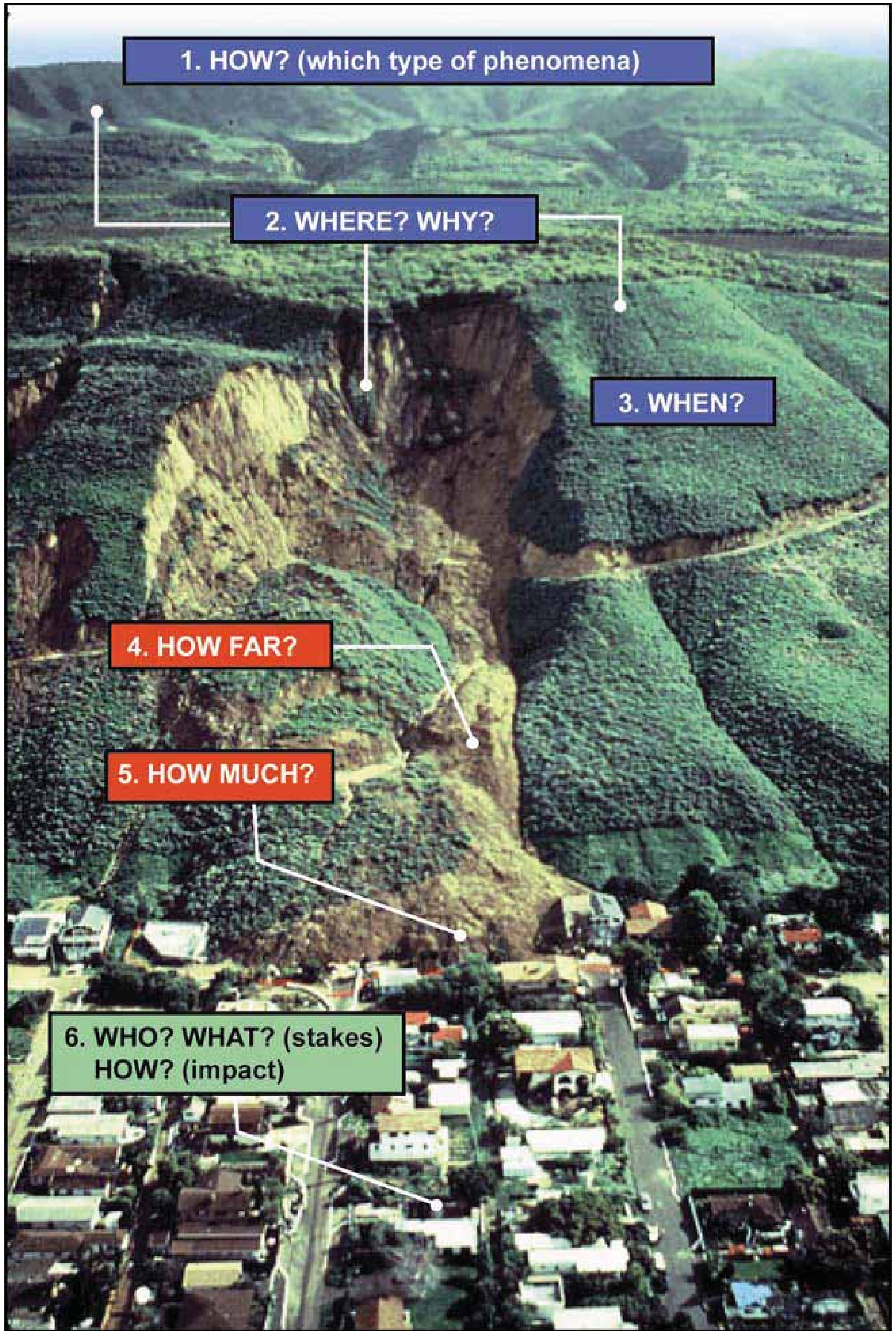


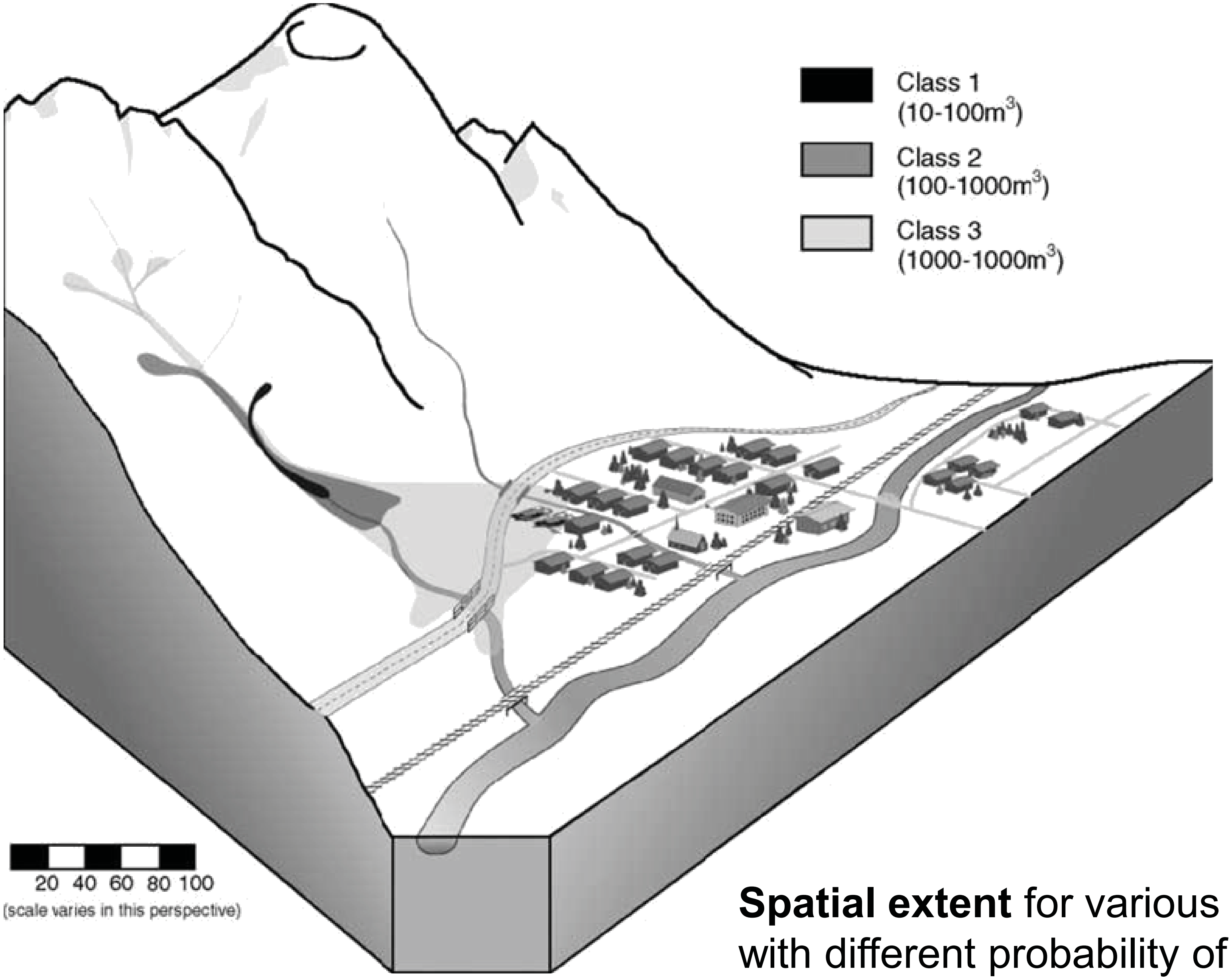
Table of content

What are the QRA stages?



- Location, geometry and classification of existing or potential landslides ?
- Estimated frequency (annual, decennal, ... probabilities) ?
- Estimated magnitude (intensity) ?
- Magnitude (intensity) – Frequency relationships ?
- Elements at risk and associated vulnerability ?
- Spatial and temporal probability ?
- Potential damage (scenarios) ?

Hazard analysis for different magnitudes (scenarios)



Spatial extent for various scenarios with different probability of occurrence

Jakob (2005)

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Hazard analysis for different magnitudes (scenarios)

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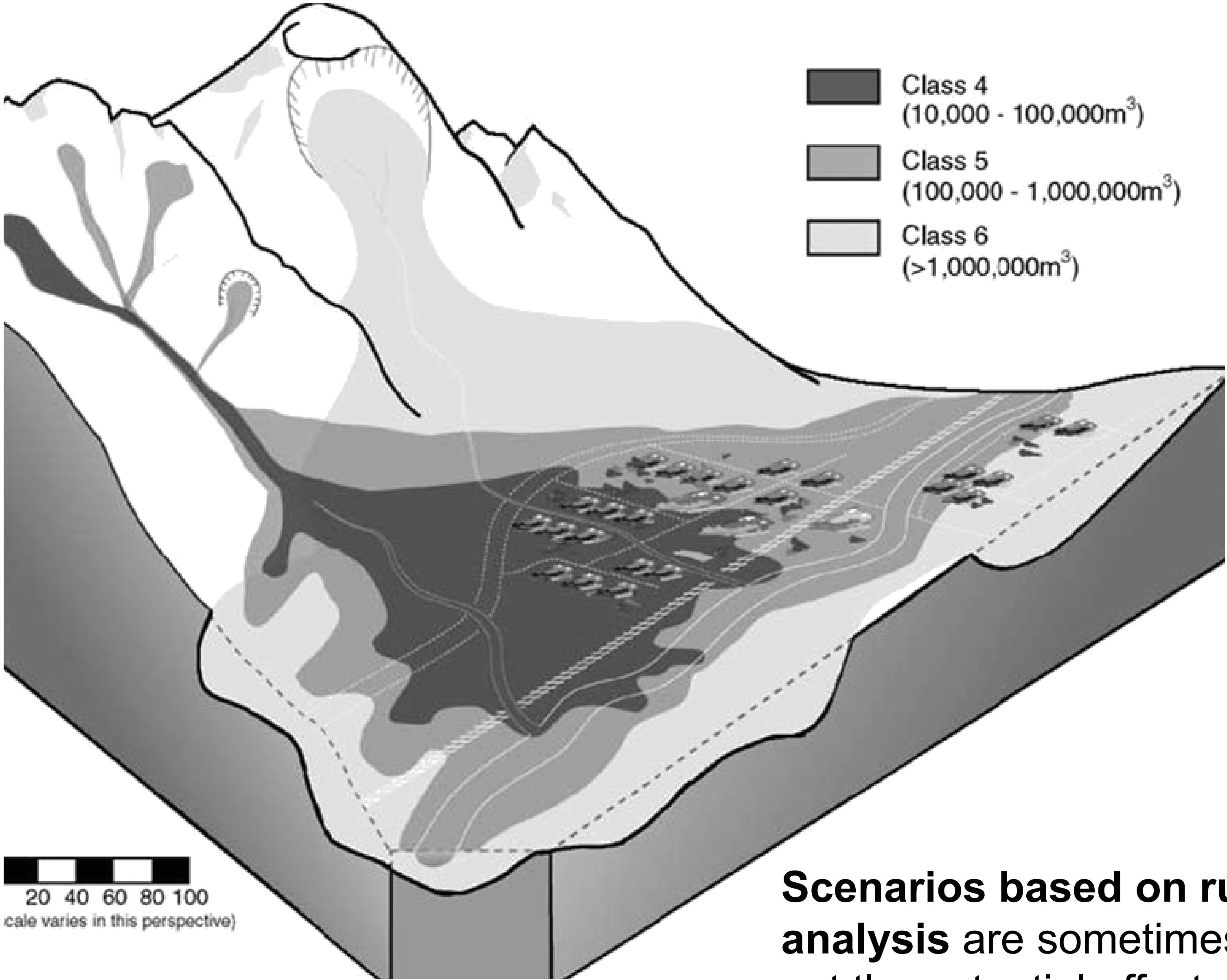

Scenarios based on runout analysis are sometimes sufficient to get the potential affected areas …

Jakob (2005)

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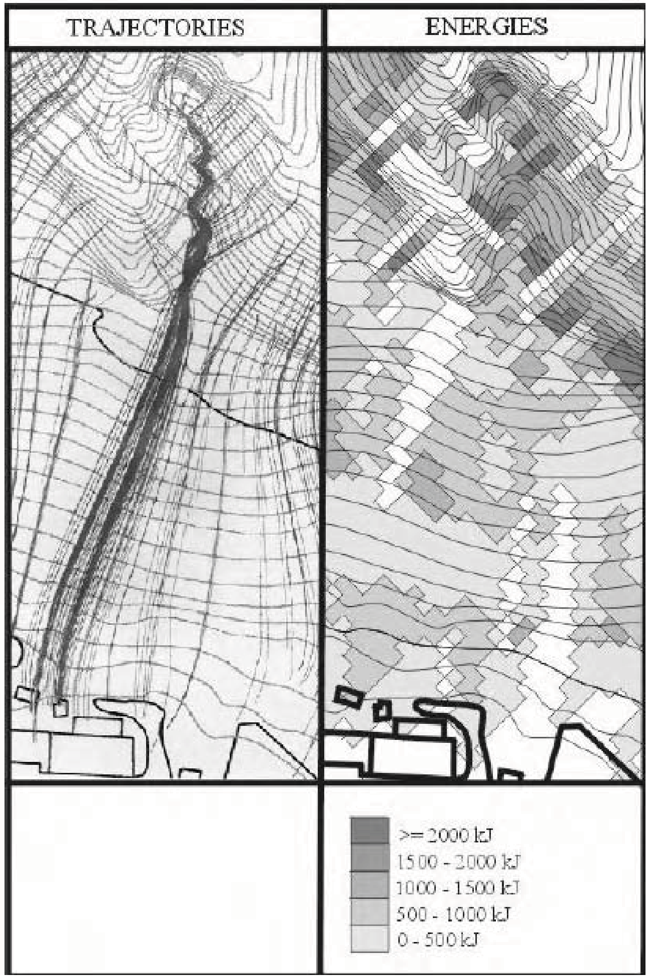
Hazard analysis for different magnitudes (scenarios)

Small size landslides: Intensity is more appropriate than the magnitude (it is a spatially distributed parameter)



Design of remedial and protective measures are based on landslide intensity calculations !

Corominas (2008)

Hazard matrix: intensity – frequency relationship

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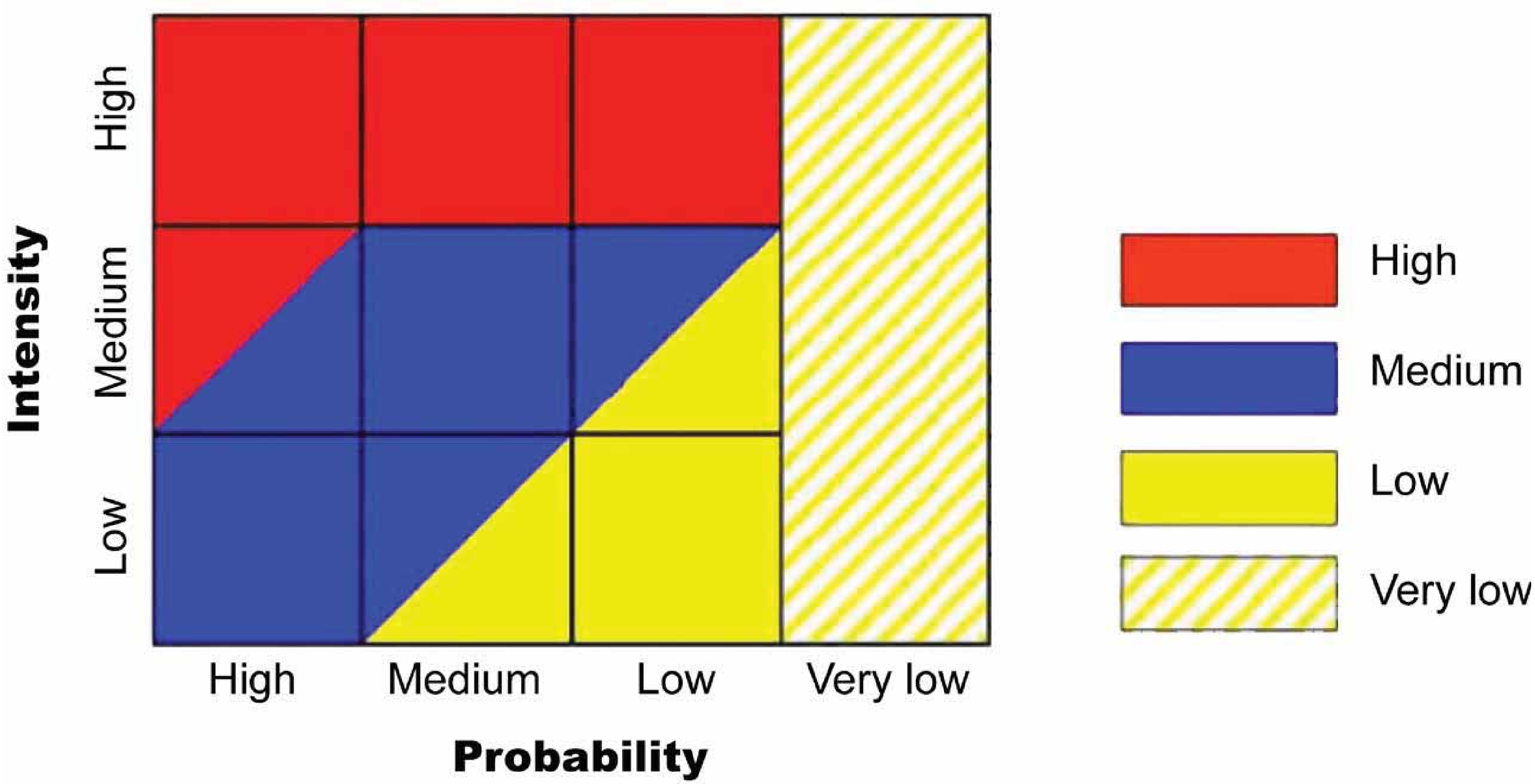
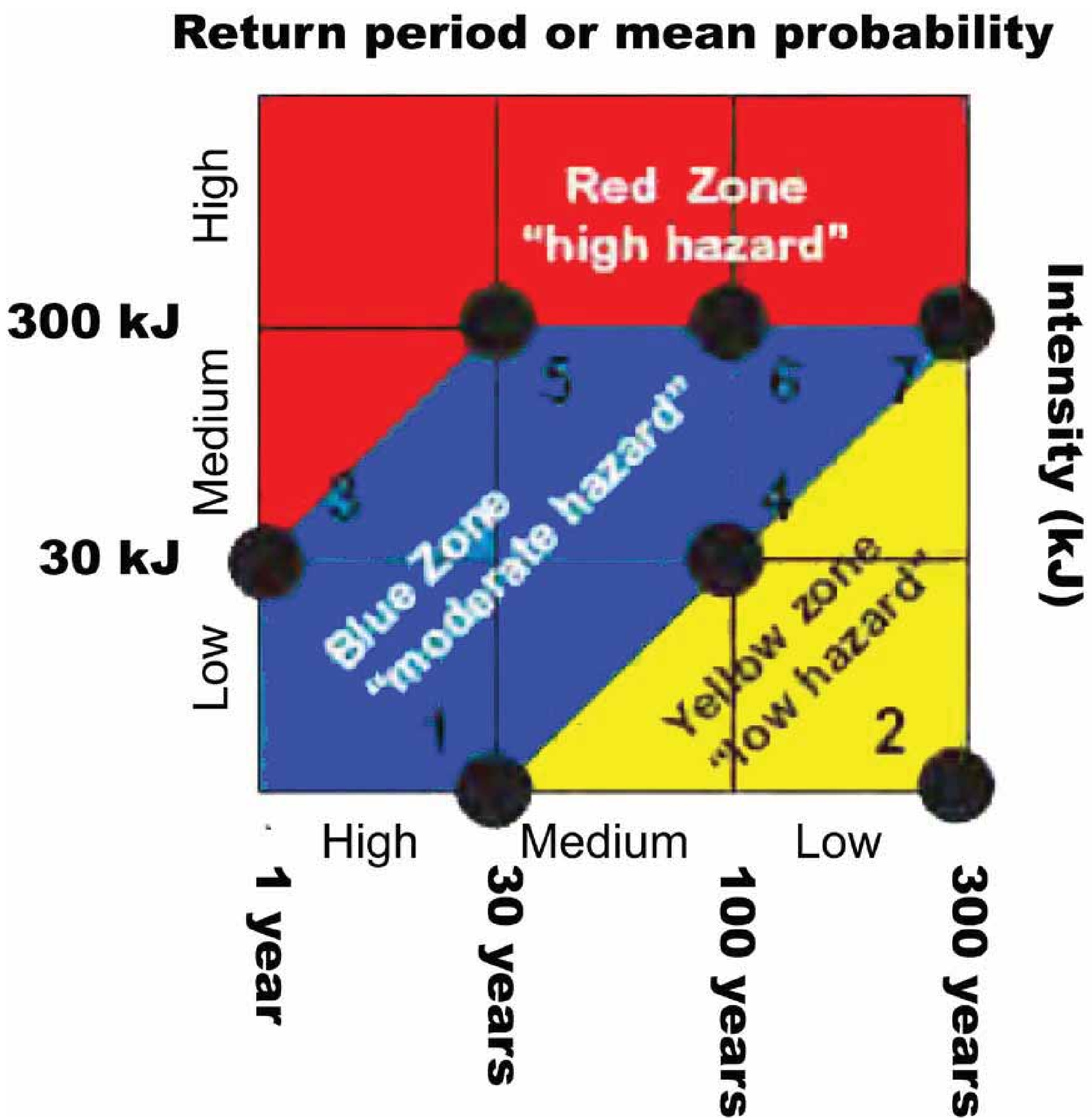


Diagram of hazard levels as a function of intensity and probability

Corominas (2008)

Hazard matrix: intensity – frequency relationship



Corominas (2008)

Landslide intensity

+ Intensity: a set of spatially distributed parameters describing the destructiveness of a given landslide (Hungr, 1997) ;

i.e. velocity, kinetic energy, total displacement, flow discharge, etc.

+ The landslide mechanism has a strong influence on the consequences and damages. Large landslides are not necessarily more damaging than small ones !

+ The expected damage depends on the location of the exposed elements in relation to the landslide.

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Landslide intensity descriptors

I = the highest expected velocity	
I	**Landslide types**
High	Flow slides, Rapid earth and debris flows, Rock falls, Rock avalanches, Rock slides
Medium	Slides and slow earth flows (Occasional reactivation and Active landslides) First failure in brittle materials
Low	Deep-Seated Gravitational Slope Deformation (DSGSD), Sackung, Lateral spreads and Creep zones

Cascini (2003)

Landslide intensity descriptors

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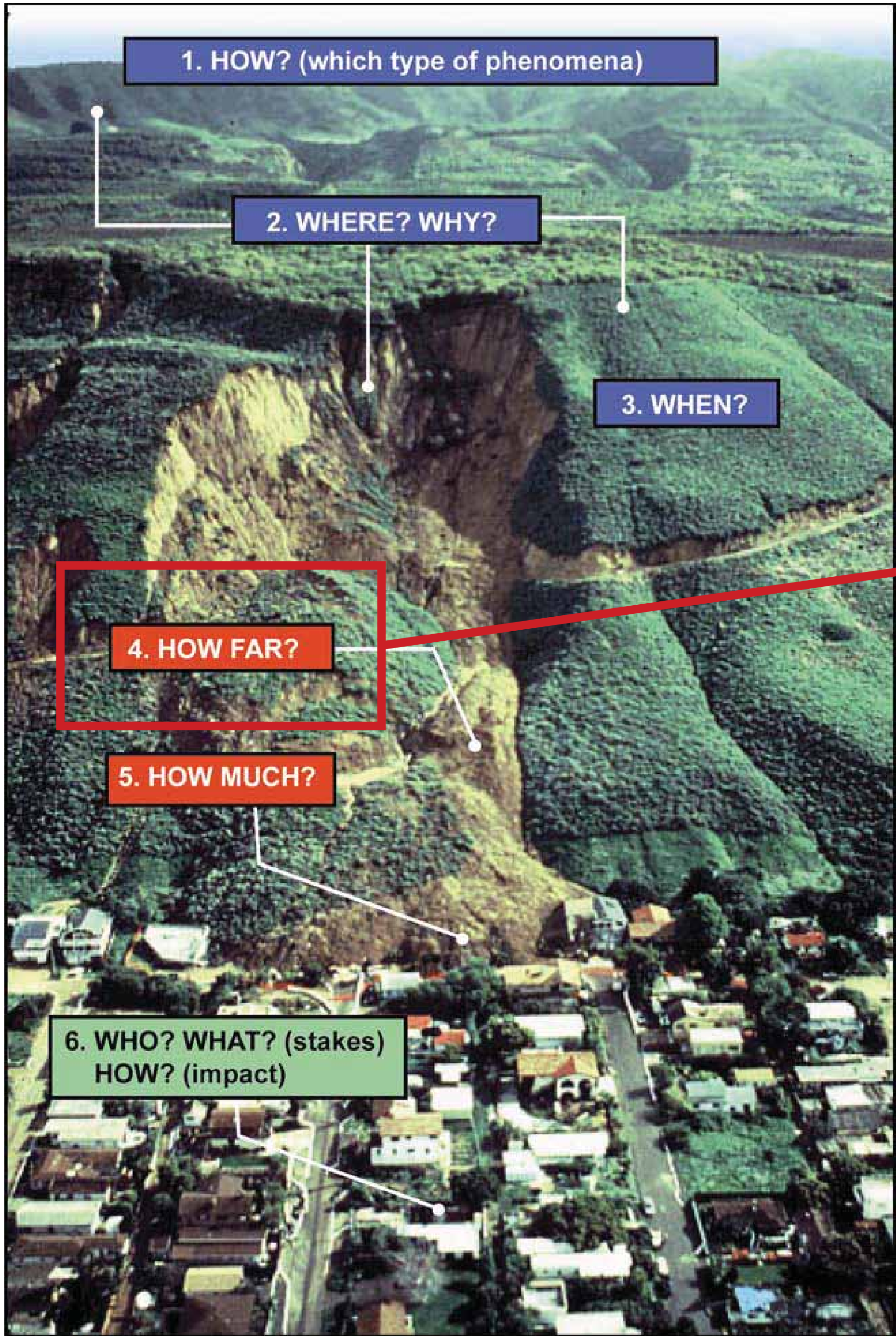
Process	Low intensity	Medium intensity	High intensity
Rock falls	E < 30 kJ	30 kJ < E < 300 kJ	E > 300 kJ
Slides	Vs < 2cm/year	Vs : dm/year	Vs > dm/day ;
			Displacement
			> 1 m per event
Debris flow	-	D < 1 m and	D > 1 m and
		V < 1 m/s	V > 1 m/s
	E < 0.5 m (potential)	0.5 < e < 2 m (potential)	e > 2 m (potential)
E = kinetic energy ; Vs = mean annual velocity of slide ; D=thickness of debris front ; V=debris flow velocity ; e= depth of soil material (potential debris flows)			

Rock avalanches *or large* ***rock slides*** *will be always ranked as very intense event (****catastrophic events****)*

Lateltin et al. (2005)

How far ? (Travel distances)

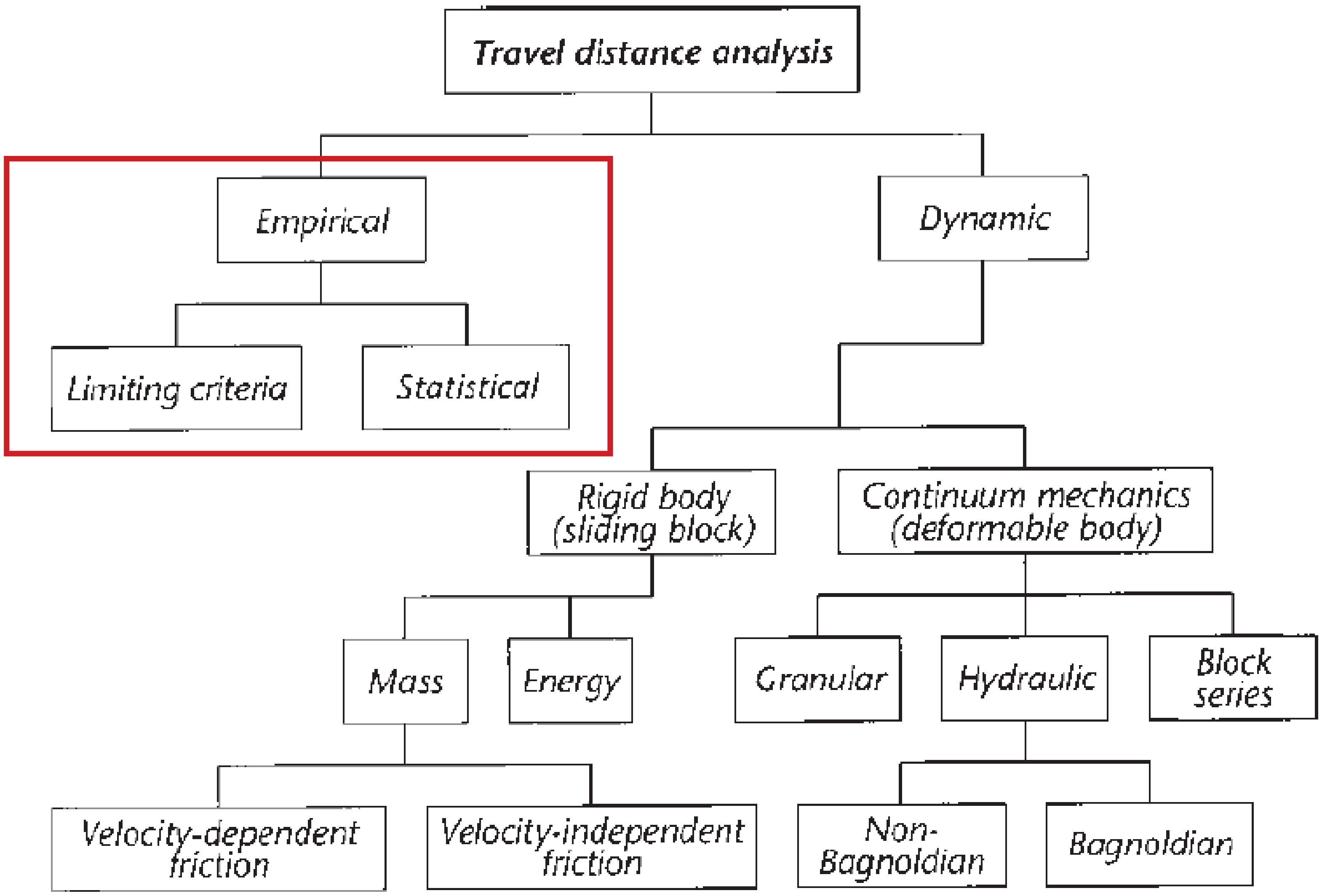


+ **Empirical approaches** (based on previous obervations in a given study area, historical databases) ;

+ **Numerical approaches** (statistical models, physically-based models, etc.).

How far ? (Travel distances)

Fig. 1. Modelling techniques for determining travel distance.



Fannin & Wise (2003)

How far ? (Travel distances)

Table 13.1. Overview of runout prediction methods discussed in the text.

General approach	Keywords to characterize method	Main references
Total travel distance (entire path length)		
Travel distance and event magnitude	Travel angle	Corominas (1996)
	Volume and descent height	Rickenmann (1999)
Volume balance	Without entrainment	Cannon (1993)
	With entrainment	Fannin and Wise (2001)
Mass point models	Voellmy approach	Zimmermann et al. (1997)
	Iverson approach	Lancaster et al. (2003)
Limiting criteria	Critical slope and junction angle	Benda and Cundy (1990)
Runout length (depositional part of flow)		
Critical slope and deposition on fan	Several empirical methods	VanDine (1996); Bathurst et al. (1997)
Volume balance	Deposition area and flow cross section	Iverson et al. (1988); Crosta et al. (2003)
Analytical approaches	Mass point models	Körner (1980); Perla et al. (1980)
	Constant discharge model	Hungr et al. (1984); Takahashi (1991)
Runout distance (entire path or depositional part only)		
Continuum based simulation models	Various constitutive equations	Iverson (1997); McDougall and Hungr (2003)

Rickenmann (2005)

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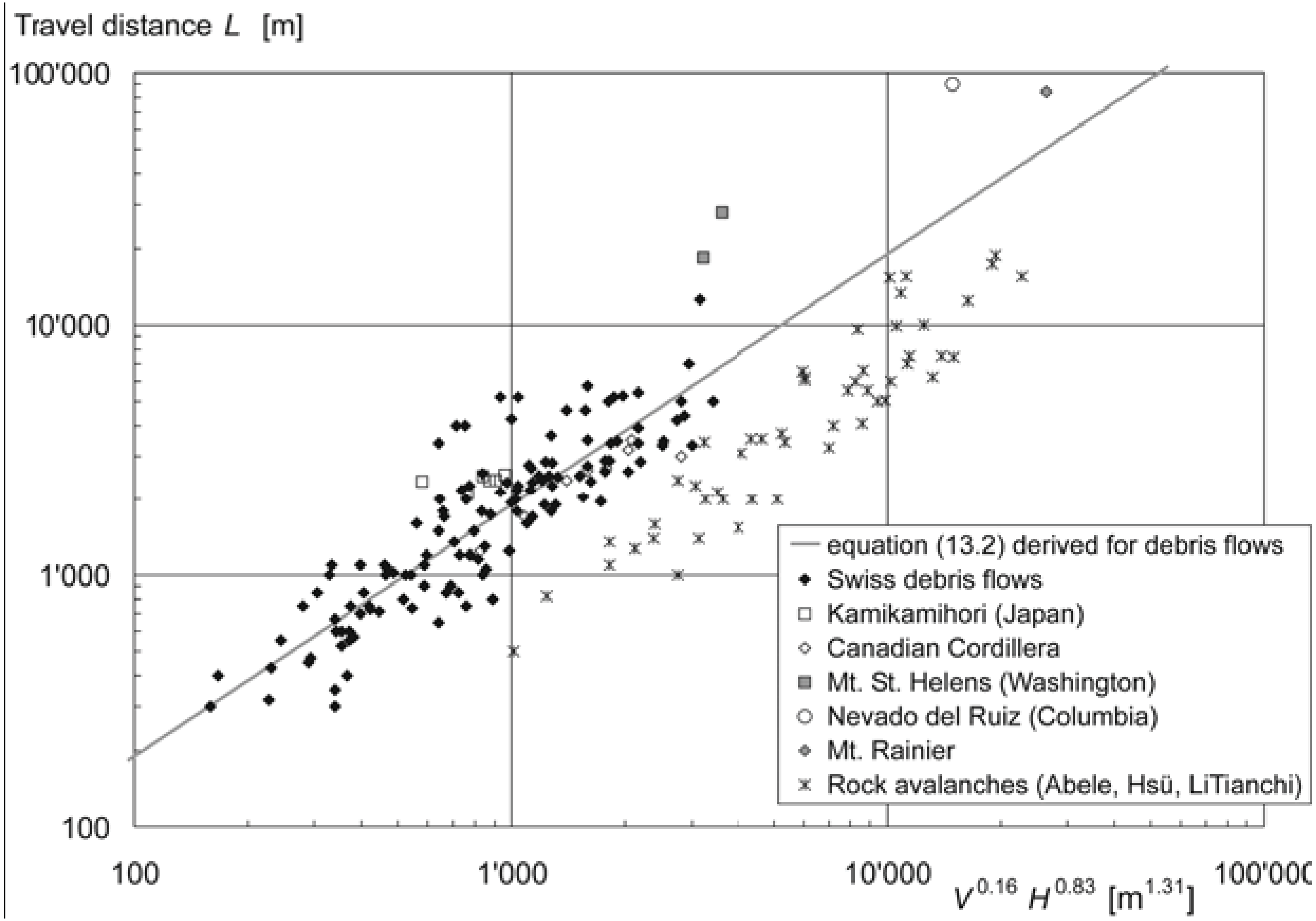
How far ? (Travel distances) … Empirical

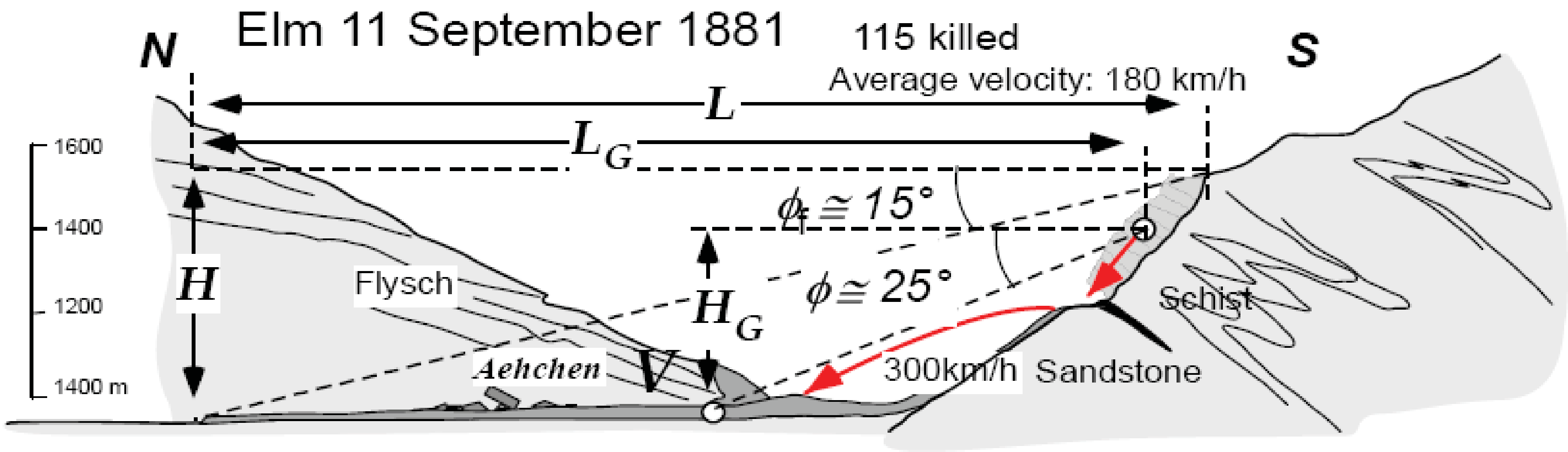
+ Travel distances for various fast mass movements



Rickenmann (2005)

How far ? (Travel distances) … Empirical

+ Travel distances for rock avalanches ;



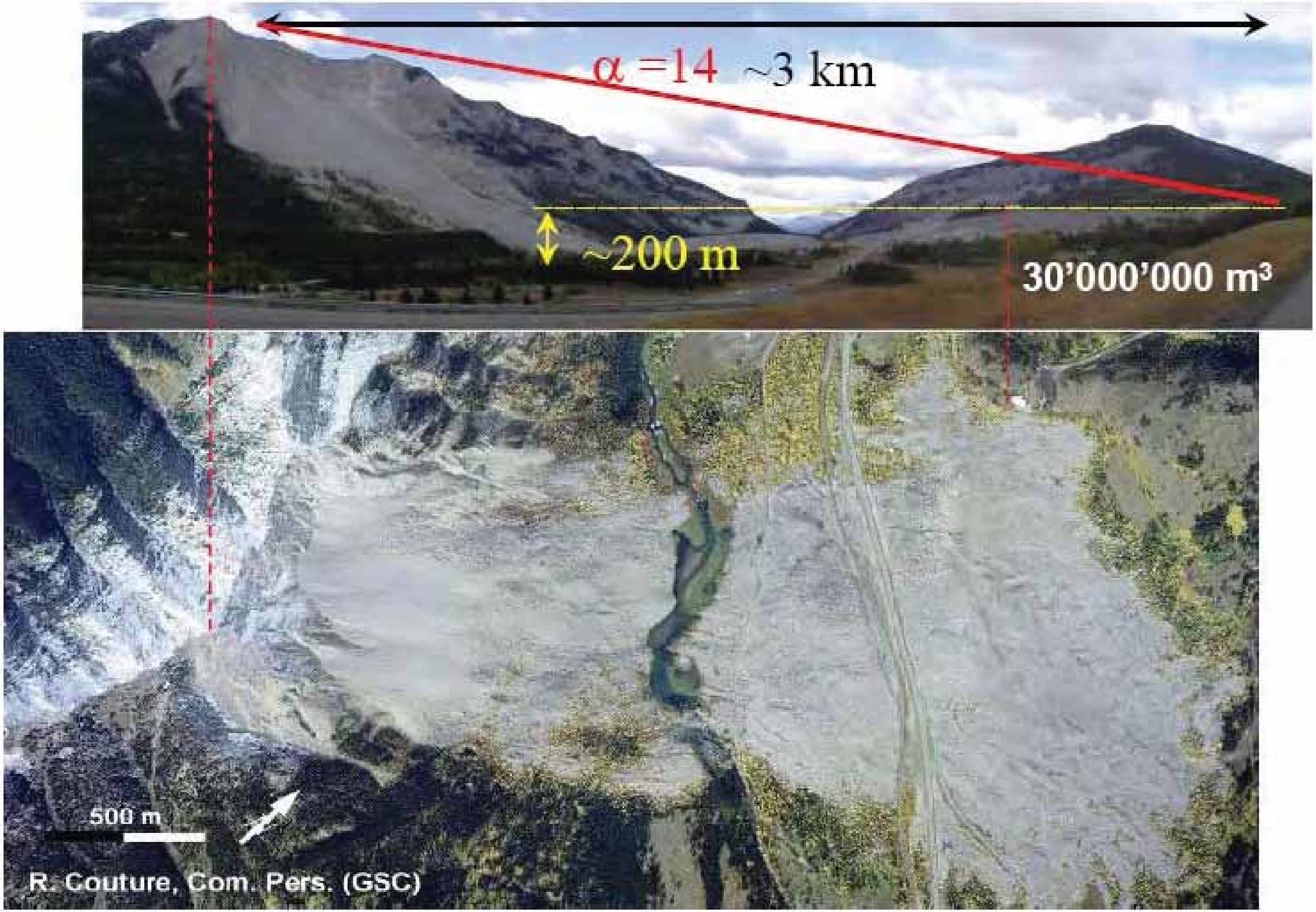
Elm rock avalanches modified after Heim (1932)

- L: horizontal distance of travel from top of the scar to end of deposit
- H: Vertical distance corresponding to L
- L_G: horizontal distance of travel between centre of mass of the top of the scar to end of deposit
- H_G: Vertical distance corresponding to L_G
- V: volume of the deposit
- $\mu = f = \tan \phi = (L_G/H_G)$
- $f = \tan \phi_f = (L/H)$
- ϕ_f = Farböschung

Jaboyedoff & Labiouse (2001)

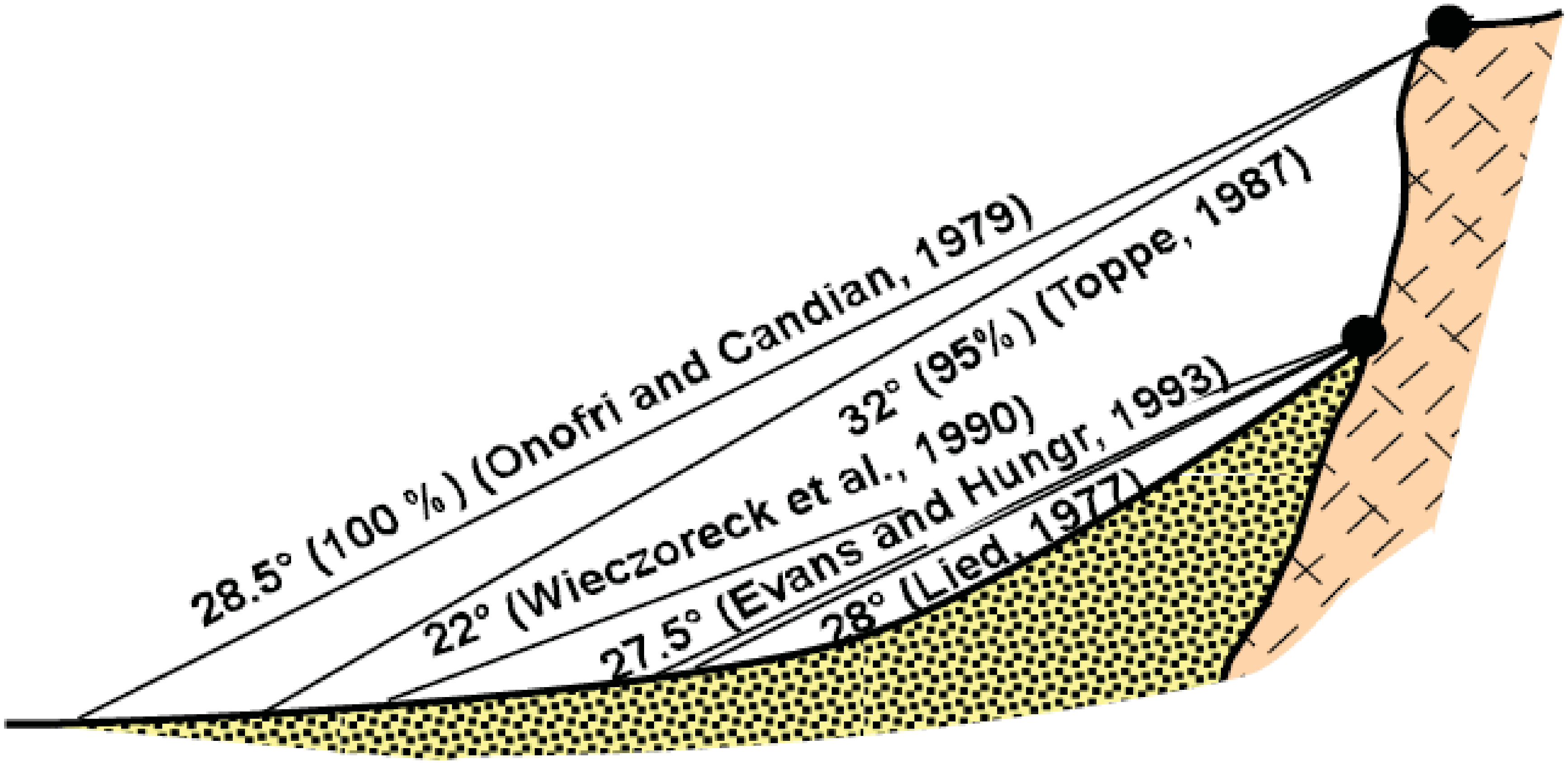
How far ? (Travel distances) … Empirical

+ Travel distances for rock avalanches ;



How far ? (Travel distances) … Empirical

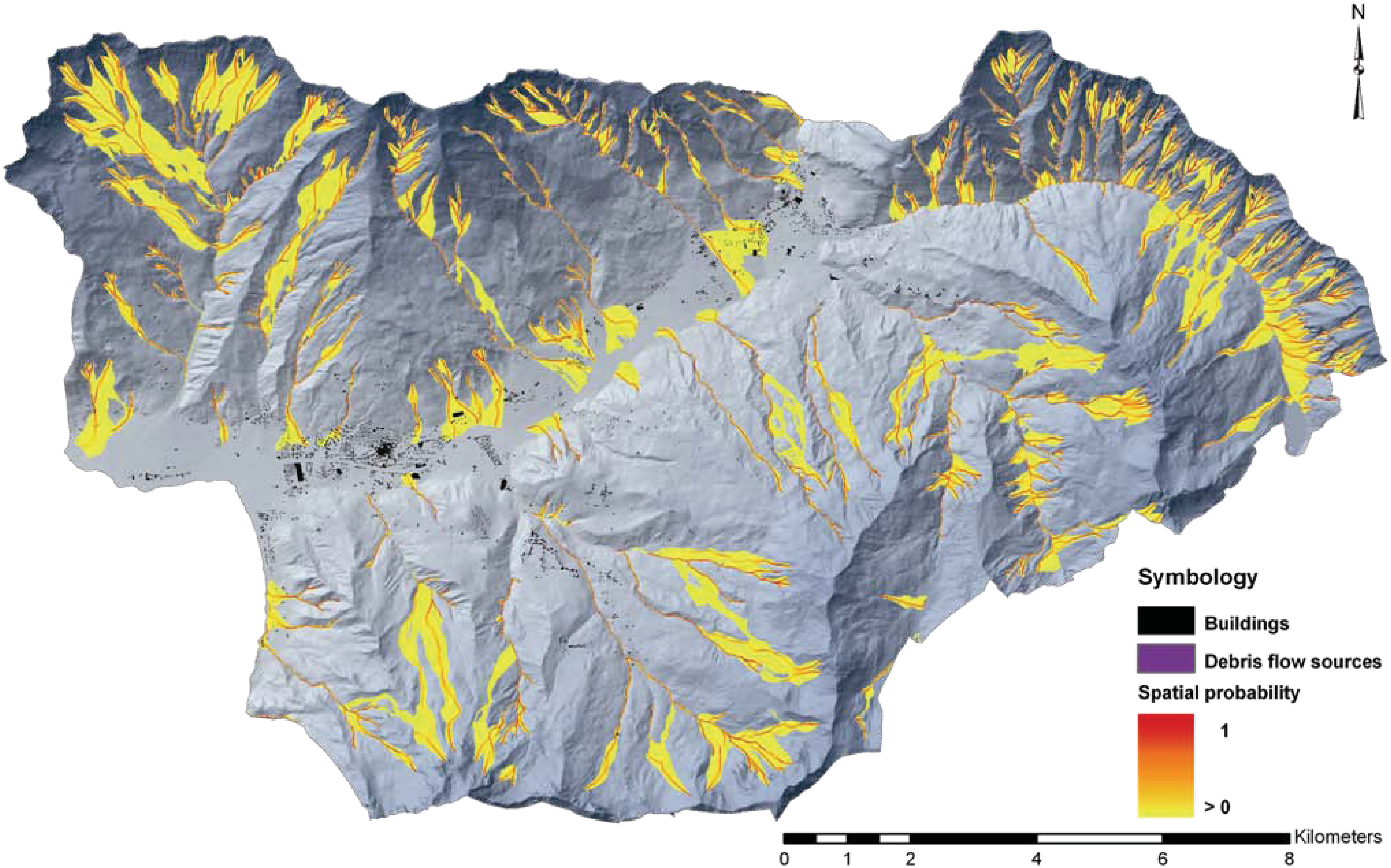
+ Travel distances for rock avalanches ;



Jaboyedoff & Labiouse (2001)

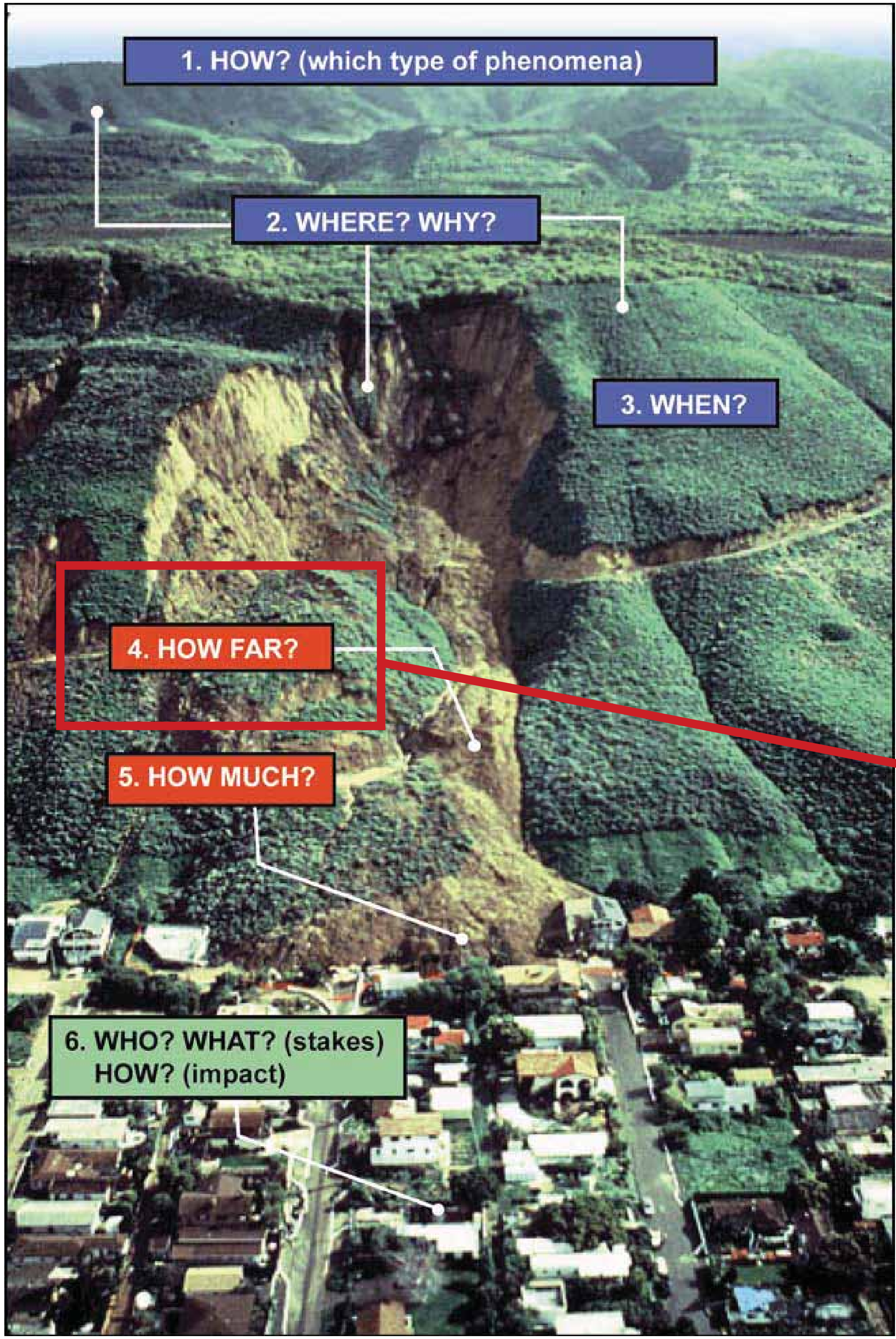
How far ? (Travel distances) … Empirical

+ Travel distances and spreading for debris flows (at a risk basin scale)



Kappes et al. (2009)

How far ? (Travel distances)

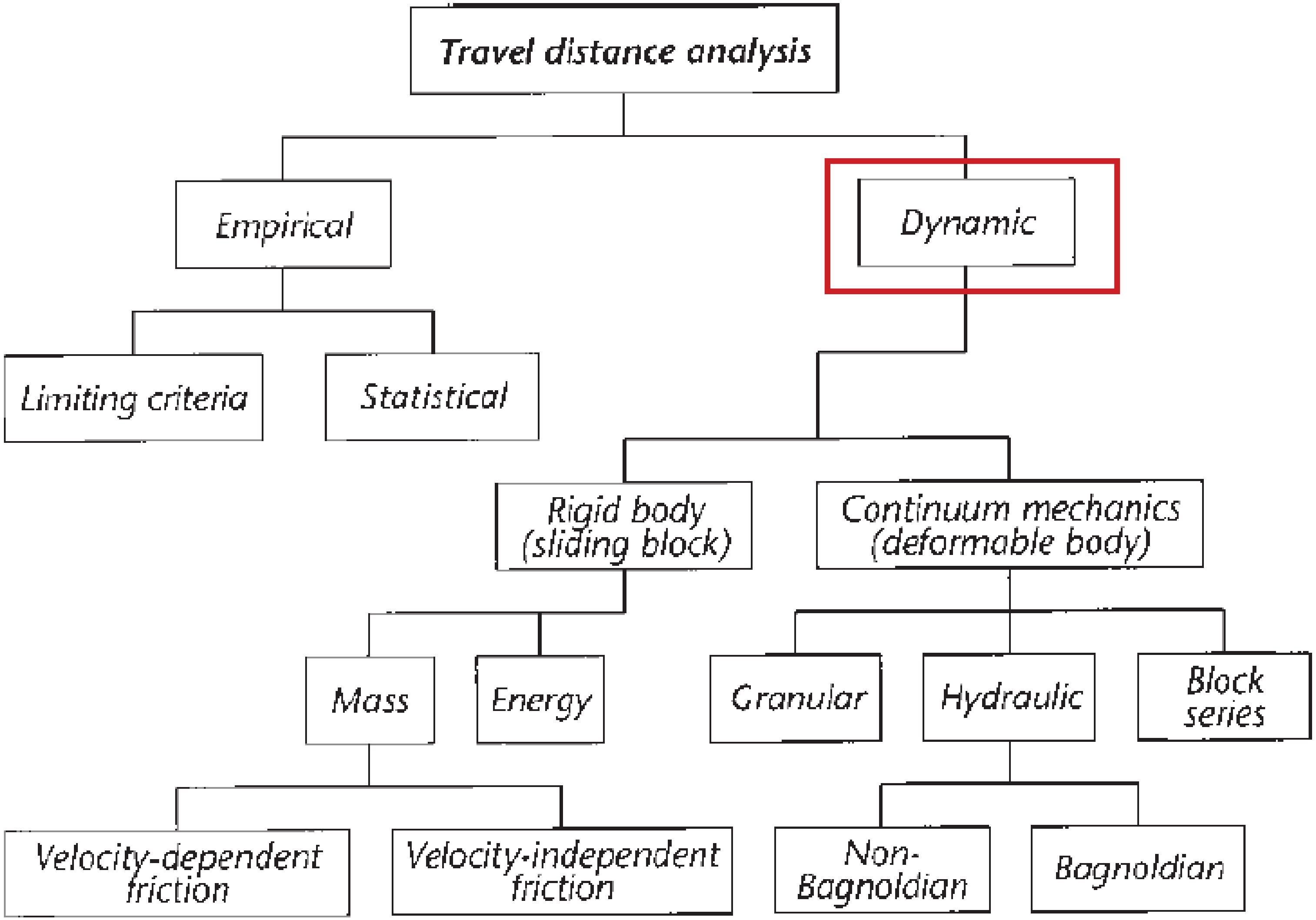


+ **Empirical approaches**
  (based on previous obervations in a given study area, historical databases) ;

+ **Numerical approaches**
  (statistical models, physically-based models, etc.).

How far ? (Travel distances)

Fig. 1. Modelling techniques for determining travel distance.



Fannin & Wise (2003)

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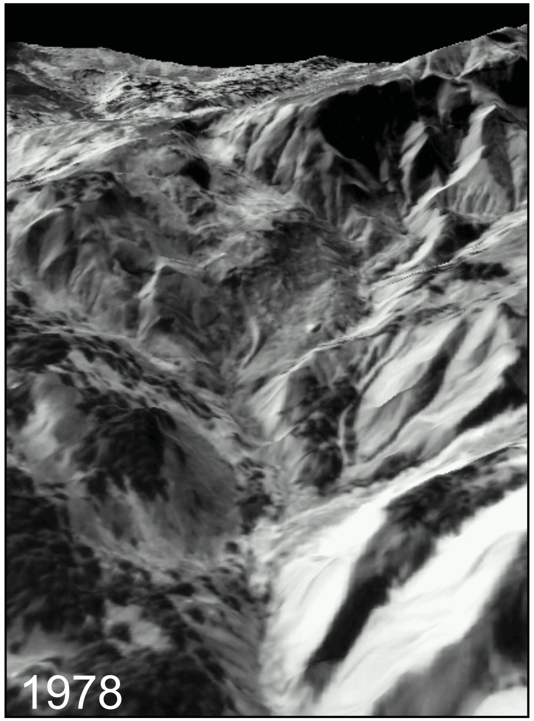
How far ? (Travel distances) … Numerical for slow M.M.

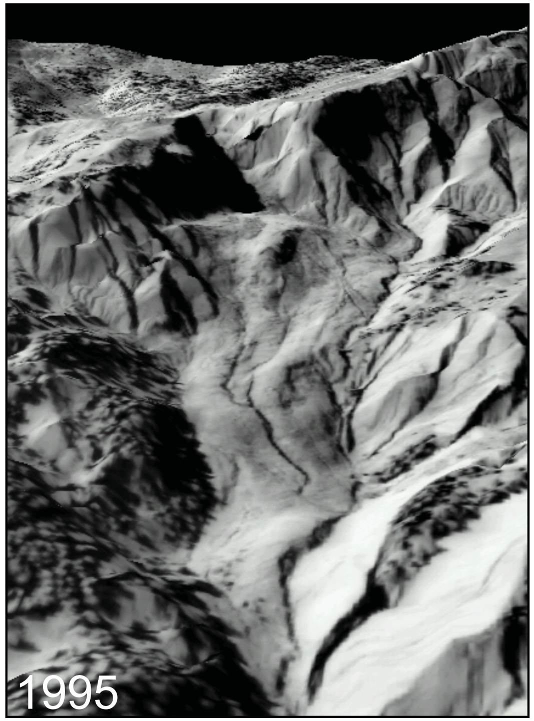
Coupling a hydrological model to a displacement model (transport and routing of material)

Calculation of the mechanical stresses within the material

Use of a rheological model (Bingham, Voelmy, etc)

Application: long-term kinematics of the Super-Sauze mudslide





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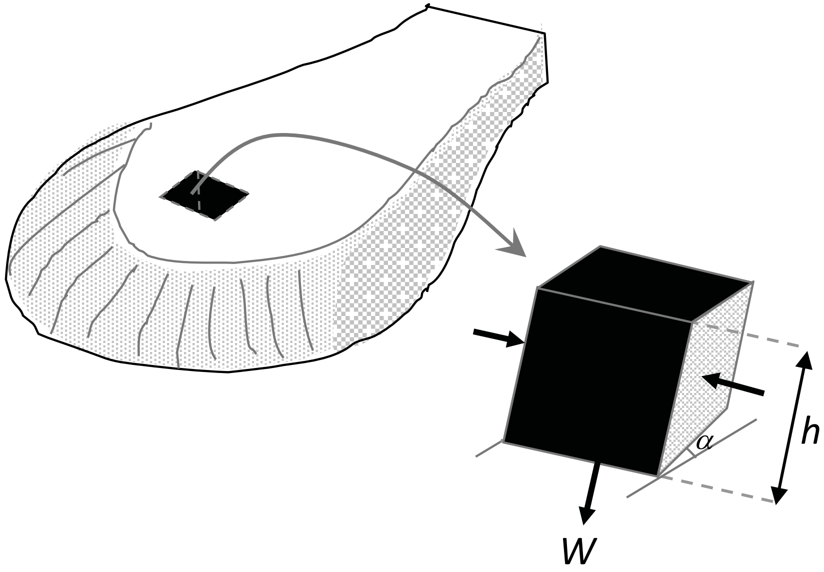
How far ? (Travel distances) … Numerical for slow M.M.

Two parameters Bingham rheology

$$V = K \cdot (\tau - \tau_0)$$



Yield strength (resisting force T): Coulomb viscous-cohesive

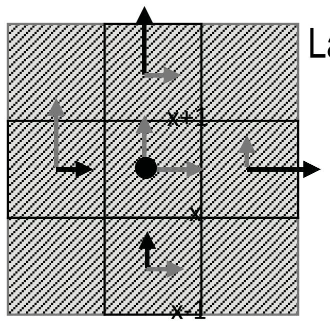
$$\tau_0 = coh + h \cdot \gamma_d \cdot (1 - r_u) \cdot \cos\alpha \cdot \tan\varphi'$$

$$r_u = \left(\frac{\gamma_w}{\gamma_d}\right) \cdot \cos^2\alpha$$

Shear stress (driving force G+P): gravity and pressure terms
(derived as in Hungr, 1995; Hutter & Koch, 1991)

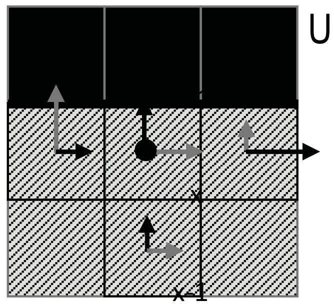
$$\tau = G + P \qquad G = -W \sin\alpha \qquad P = -W \; K_{act/pas} \frac{\Delta h}{\Delta s} \cos\alpha$$

Pore pressures (U): only for the calculation of the normal stress (pore pressure ratio)


Lax

Mass balance equation:

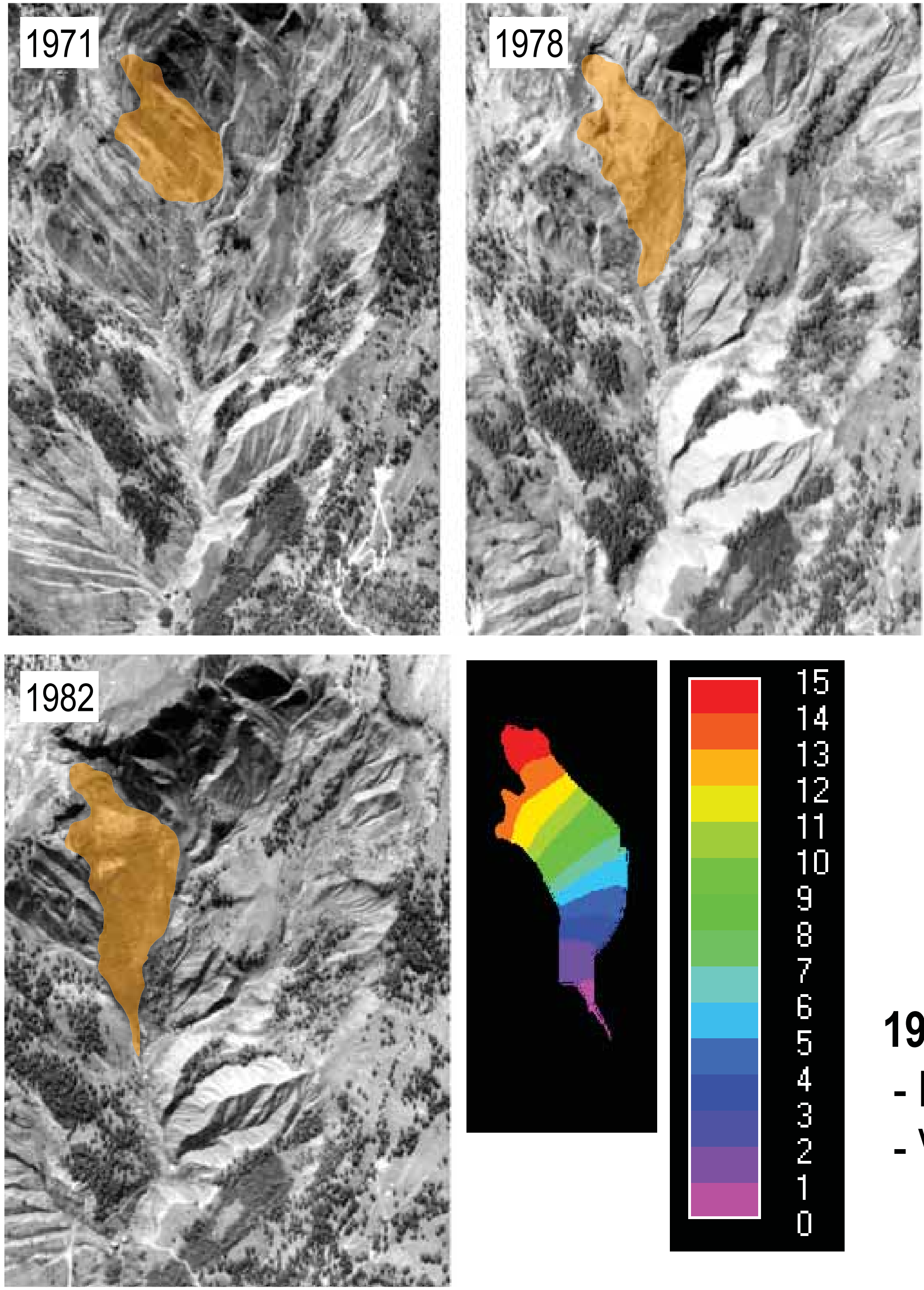
$$\frac{\partial h}{\partial t} + \frac{\partial (h\bar{u})}{\partial x} + \frac{\partial (h\bar{v})}{\partial y} = 0$$


Upwind

Numerical scheme (2 step fully explicit finite difference solution):
- Lax (explicit, finite central difference scheme) for the mudslide body
- Upwind (explicit, backward difference scheme) for the mudslide front & laterals

Malet (2005)

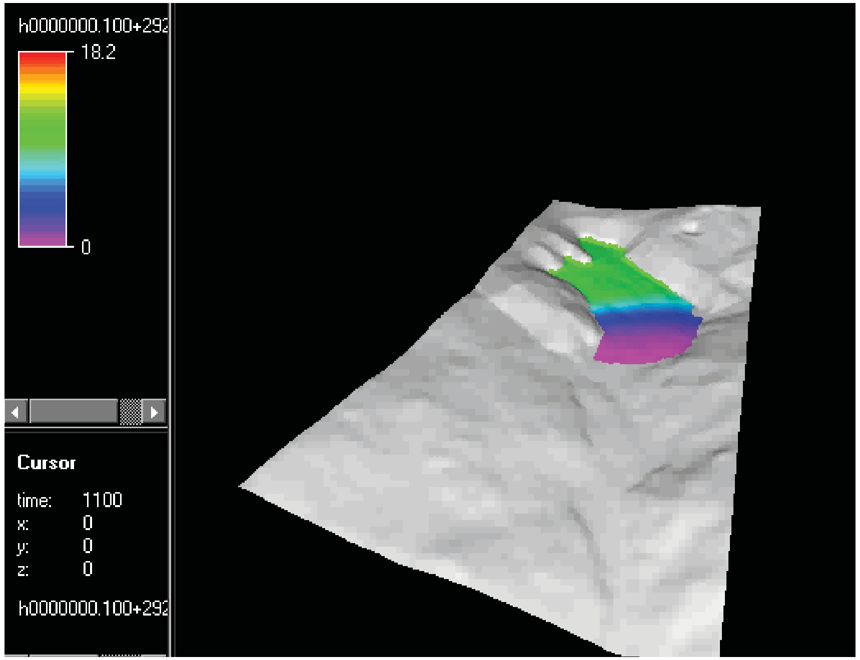
How far ? (Travel distances) … Numerical for slow M.M.



Period 1971-1982:

- V_1 = 300,000 m^3
- Rheology: c' = 2 kPa ; ϕ' = 23° μ = 10,000 kPa.s

1971 ➔ 1982



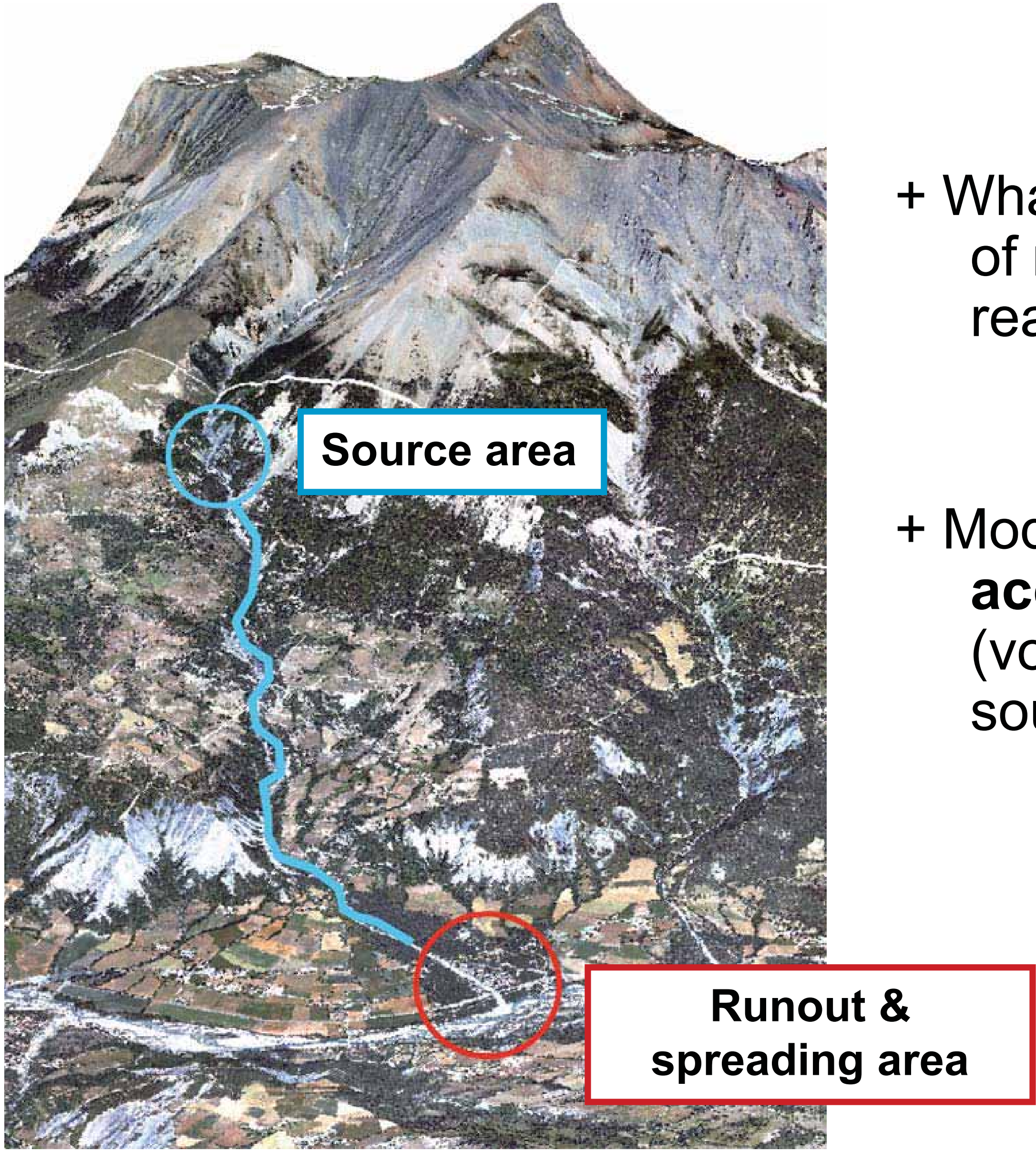
1982:

- Runout distance: D_{obs} = 653m ; D_{sim} = 681m
- Velocity: V_{sim} = 0.04 – 0.08 $m.day^{-1}$

Malet (2005)

How far ? (Travel distances) … Numerical for fast M.M.

+ Travel distances for debris flows (at the catchment scale)



+ What is the **minimal volume** of material (source area) to reach the fan (**stakes**) ?

+ Modeling of DF runout **according scenarios** (volume and rheology of the source material)

How far ? (Travel distances) … Numerical for fast M.M.

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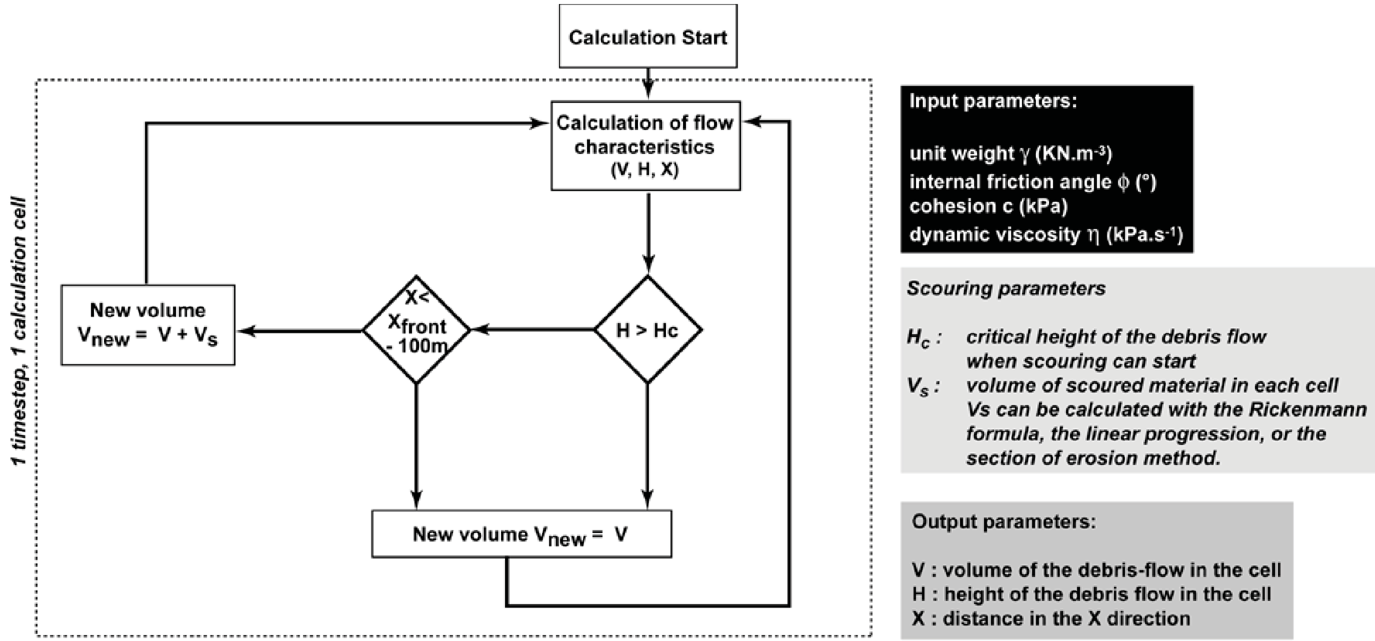
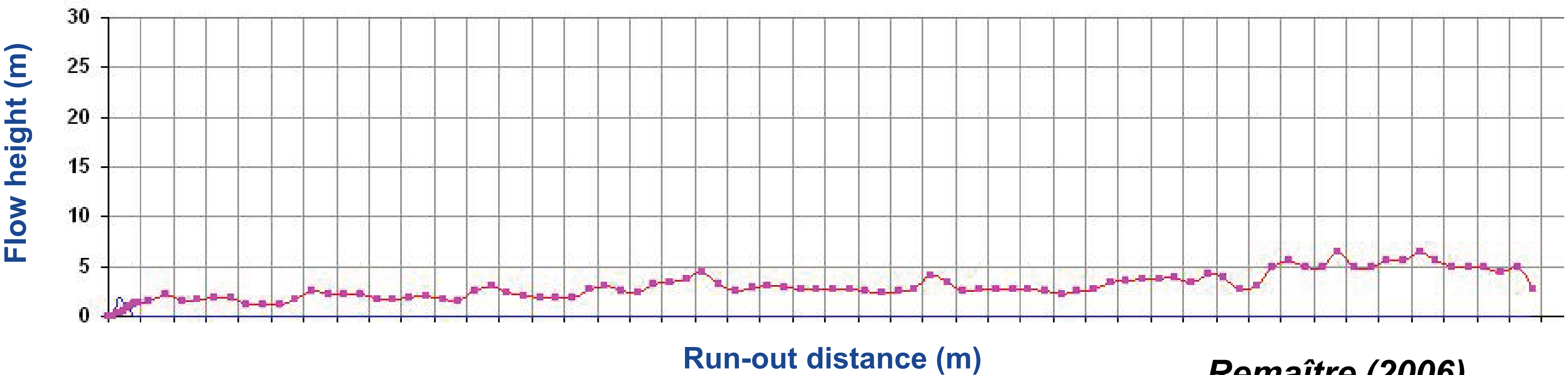
+ Travel distances for debris flows (at the catchment scale)





Remaître (2006)

How far ? (Travel distances) … Numerical for fast M.M.

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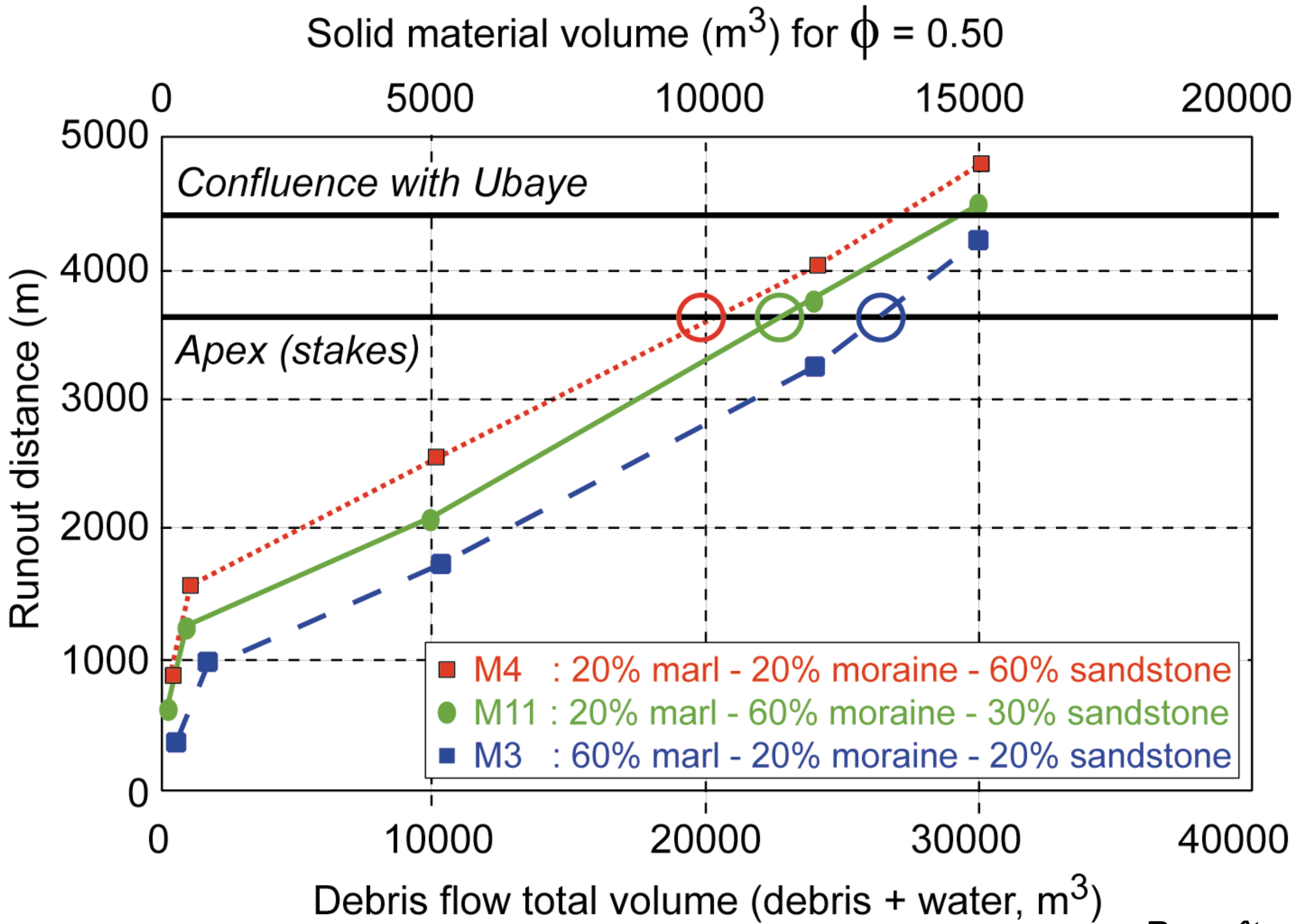
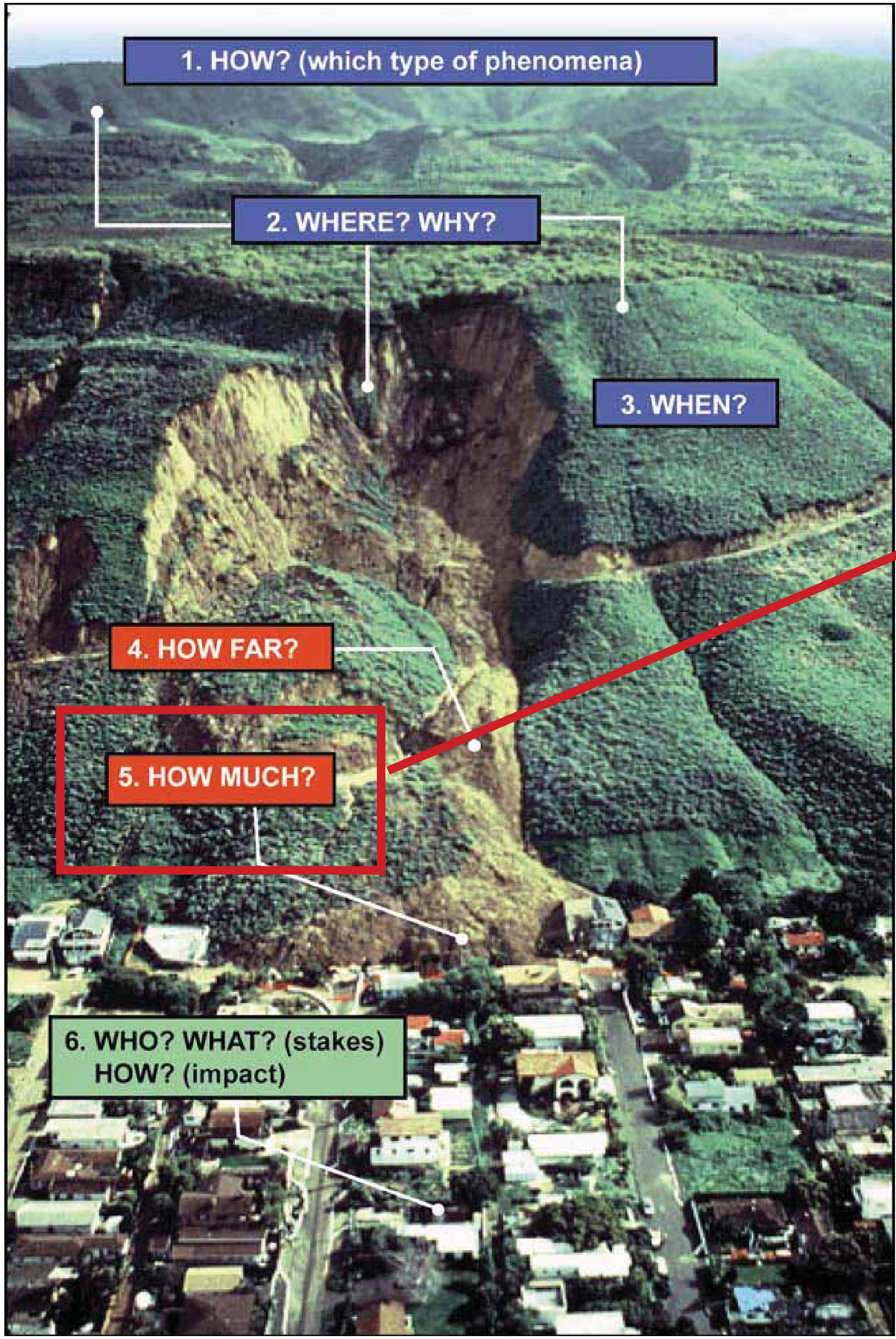
+ Travel distances for debris flows (at the catchment scale)



Remaître (2006)

How much ? (dynamic, impact…)



+ **Empirical approaches** (based on previous obervations in a given study area, historical databases) ;

+ **Numerical approaches** (statistical models, physically-based models, etc.).

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How much ? (dynamic, impact…) … Empirical

Table 17.4. Equations for indirect determination of debris-flow velocities.

Equations	Author	Equation number
$v = (gr_c \cos\Theta \tan\alpha)^{0.5}$	Chow (1959)	(17.4)
$v = (2g\Delta h)^{0.5}$	Chow (1959)	(17.5)
$v = (1.21g\Delta h)$	Wigmosta (1983)	(17.6)
$v = (\gamma S/K\mu)H^2$	Hungr et al. (1984)	(17.7)
$v = 2.1Q^{0.33}\,S^{0.33}$	Rickenmann (1999)	(17.8)
$v = (\gamma S/K\mu_B)H^2F$	Jordan (1994)	(17.9)

v is debris-flow velocity, r is radius of curvature of the channel bend, α is the channel gradient, Θ is the superelevation gradient, Δh is the runup height, g is the mass acceleration constant, μ is the dynamic viscosity of the debris flow, μ_B is the Bingham viscosity, S is the channel slope, γ is the unit weight, H is the flow thickness, and K is a shape factor for various channel forms.

Table 17.5. Equations for indirect determination of debris-flow peak discharge, Q_p.

Equation	Author	Equation number
$Q_p = 0.135V^{0.78}$ (bouldery debris flows)	Mizuyama et al. (1992)	(17.11)
$Q_p = 0.019V^{0.79}$ (muddy debris flows)	Mizuyama et al. (1992)	(17.12)
$Q_p = 0.006V^{0.83}$ (volcanic debris flows)	Jitousono et al. (1996)	(17.13)
$Q_p = 0.04V^{0.90}$ (bouldery debris flows)	Bovis and Jakob (1999)	(17.14)
$Q_p = 0.003V^{1.01}$ (volcanic debris flows)	Bovis and Jakob (1999)	(17.15)
$Q_p = 0.293V_w^{0.56}$	Costa (1988)	(17.16)
$Q_p = 0.016V_w^{0.64}$	Costa (1988)	(17.17)
$Q_p = 0.1V^{0.83}$	Rickenmann (1999)	(17.18)

V is debris-flow volume and V_w is the water volume behind the natural dam.

Jakob (2005)

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How much ? (dynamic, impact…) … Empirical

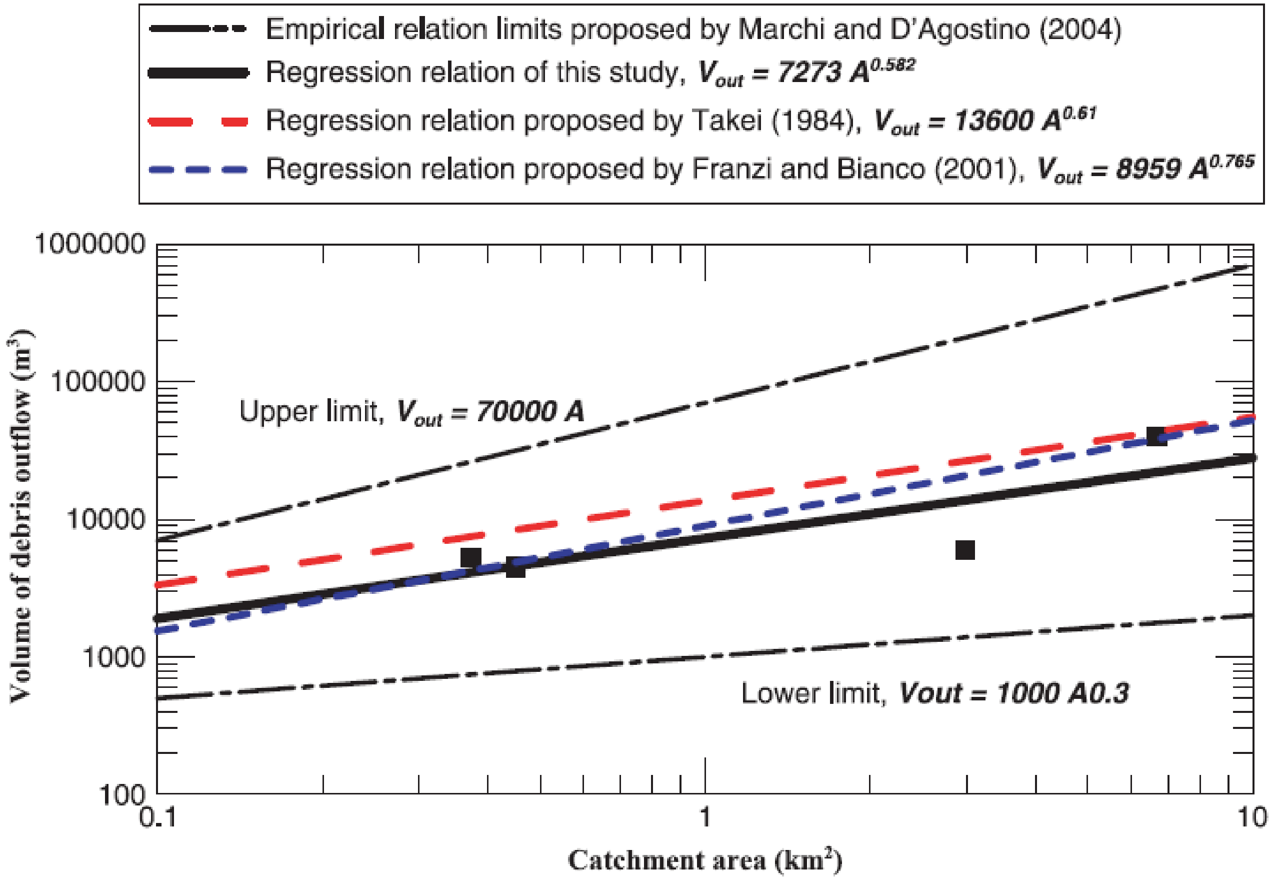

Figure 4. Empirical relations between the catchment area and the volume of the debris outflow. The four data points collected during Typhoon T are indicated as black solid squares. This figure is available in colour online at www.interscience.wiley.com/journal/espl

Dong et al. (2009)

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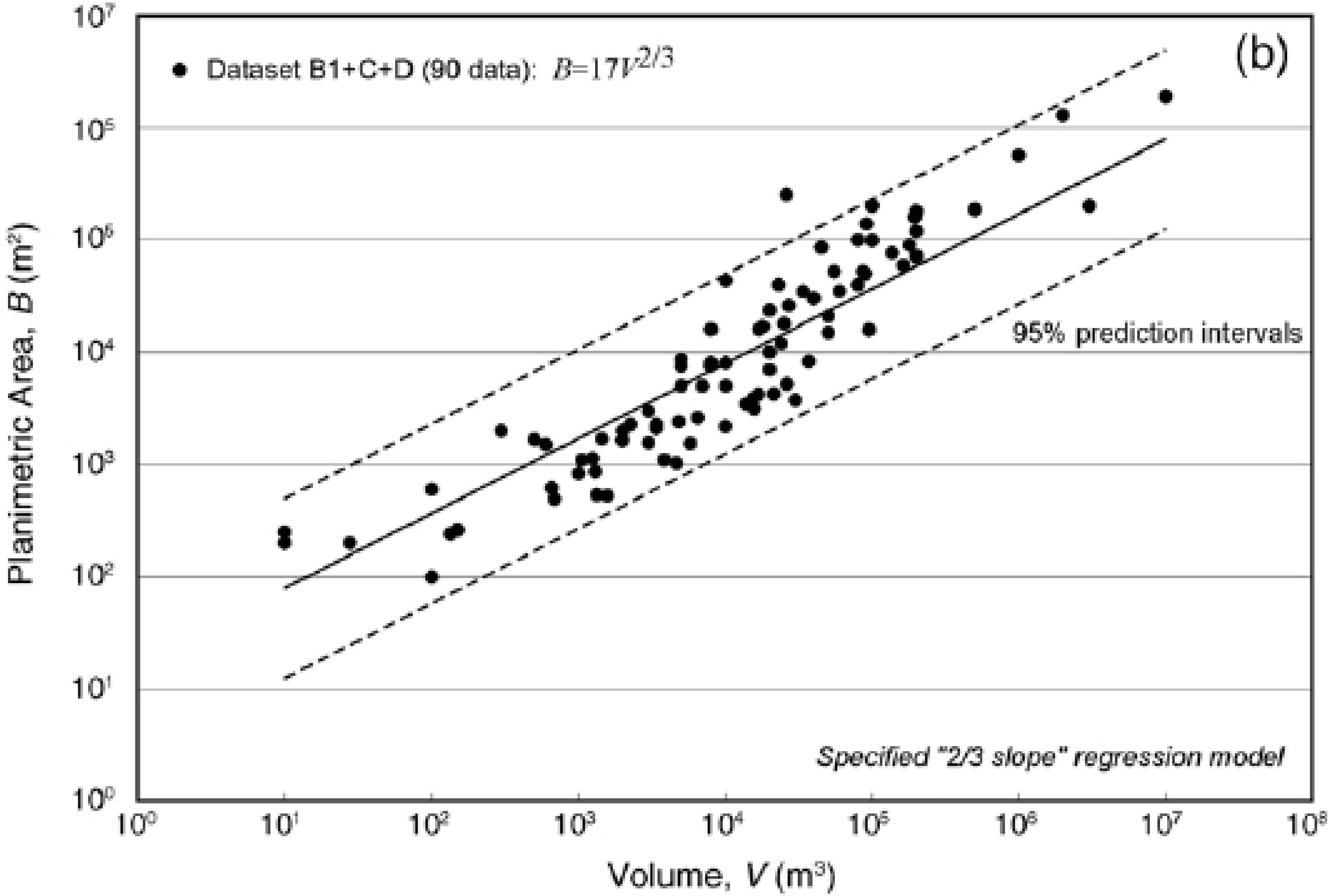
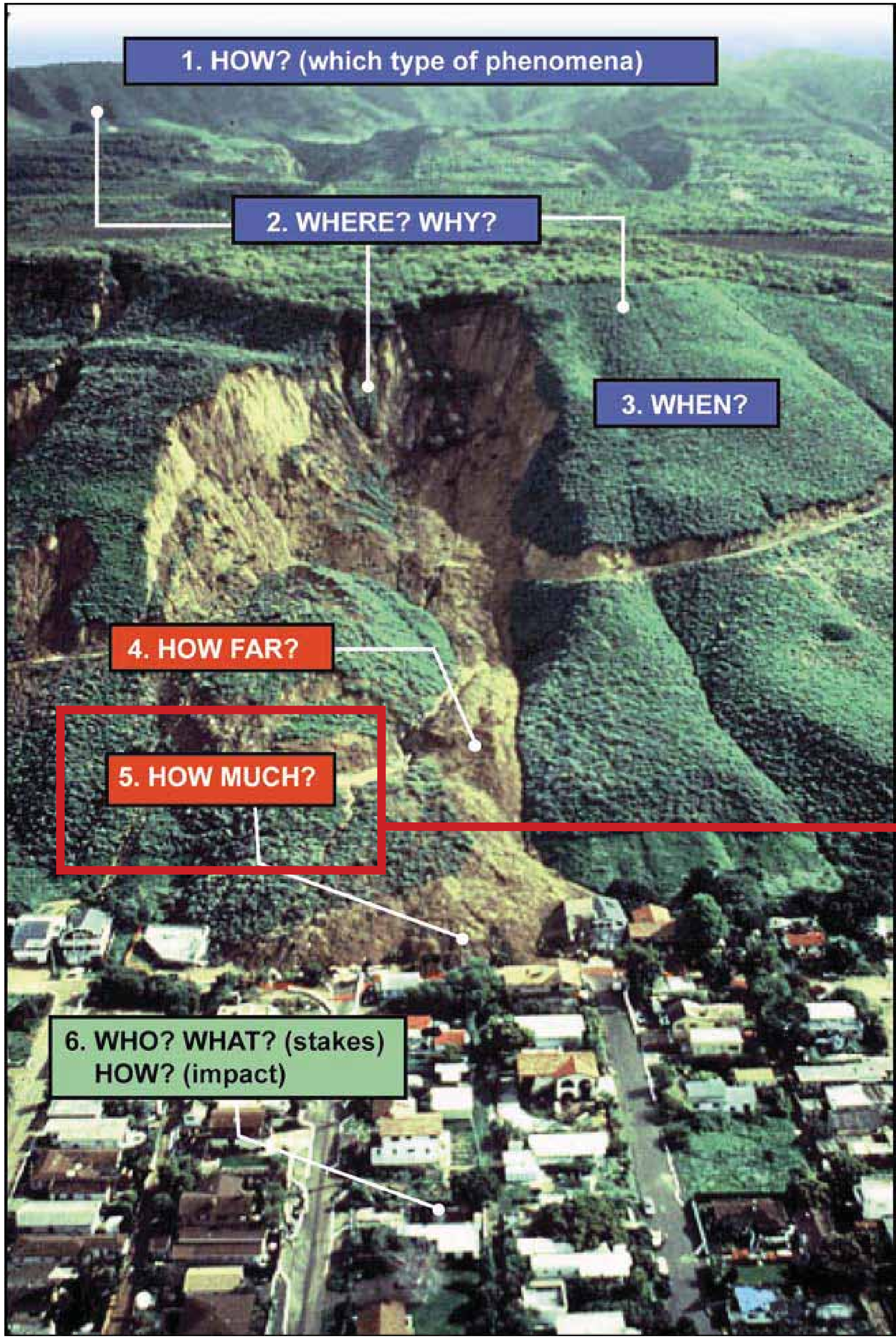
How much ? (dynamic, impact…) … Empirical



Berti & Simoni (2007)

How much ? (dynamic, impact…)



+ **Empirical approaches** (based on previous obervations in a given study area, historical databases) ;

+ **Numerical approaches** (process-based models, etc.).

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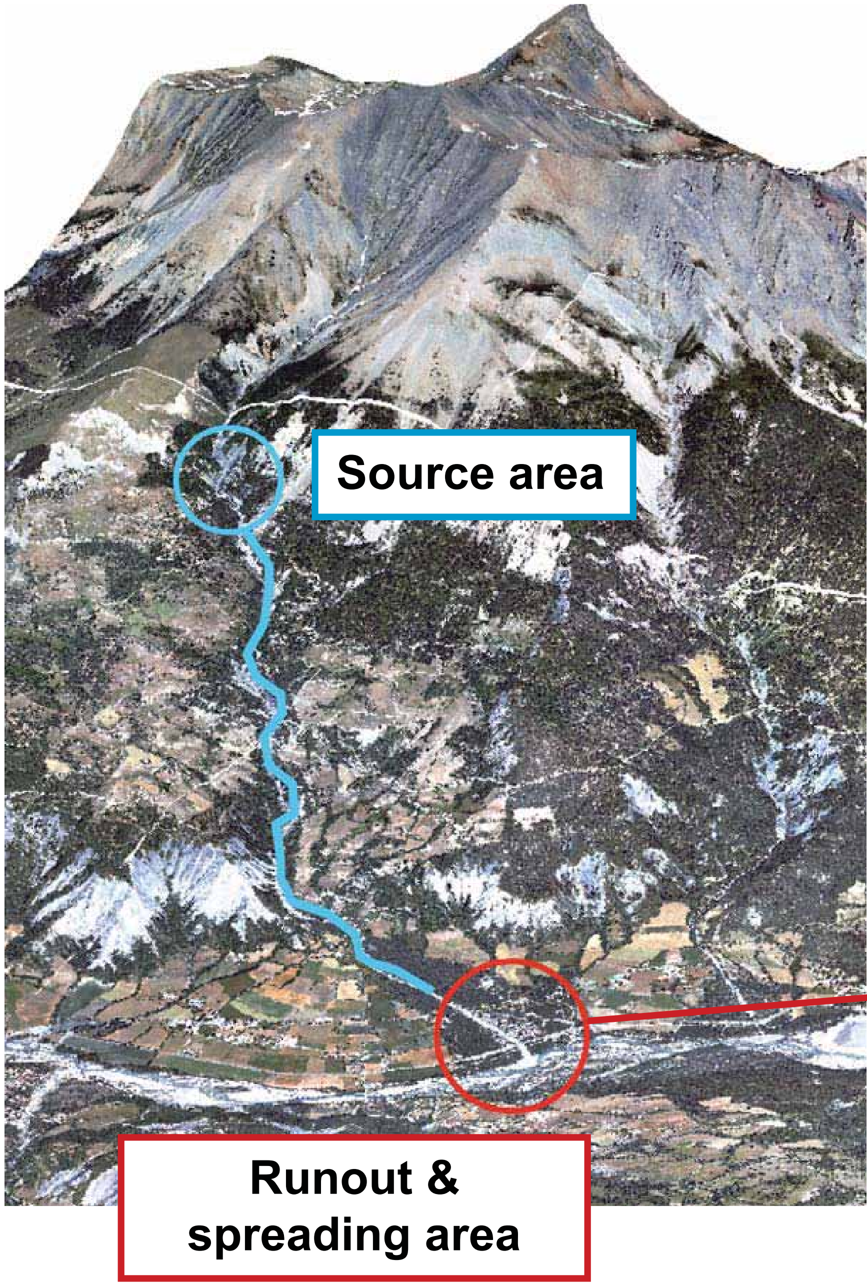
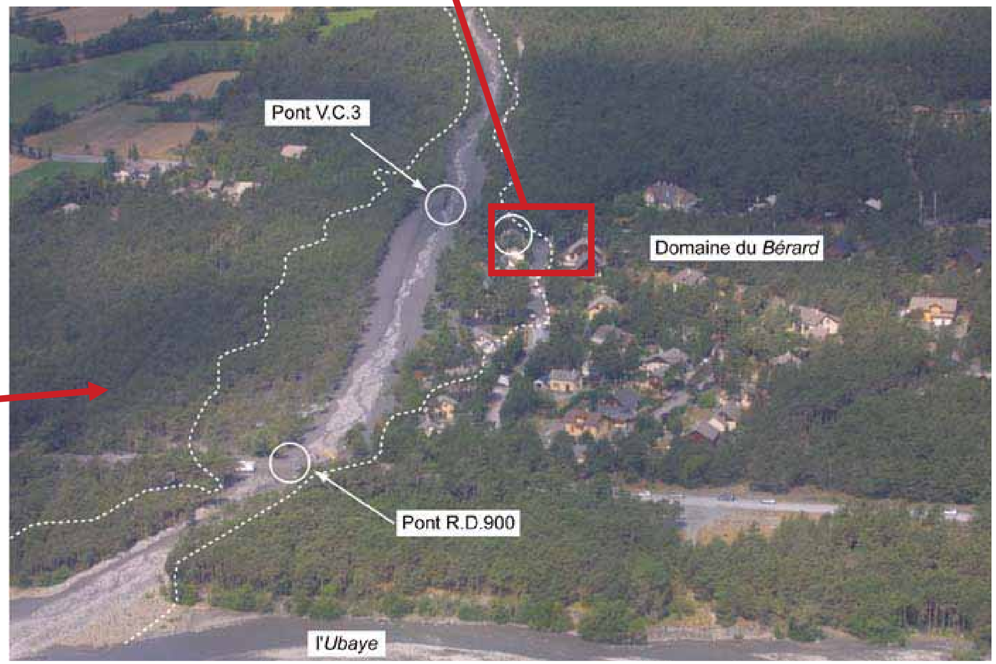
How much ? (dynamic, impact…) … Numerical





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How much ? (dynamic, impact…) … Numerical

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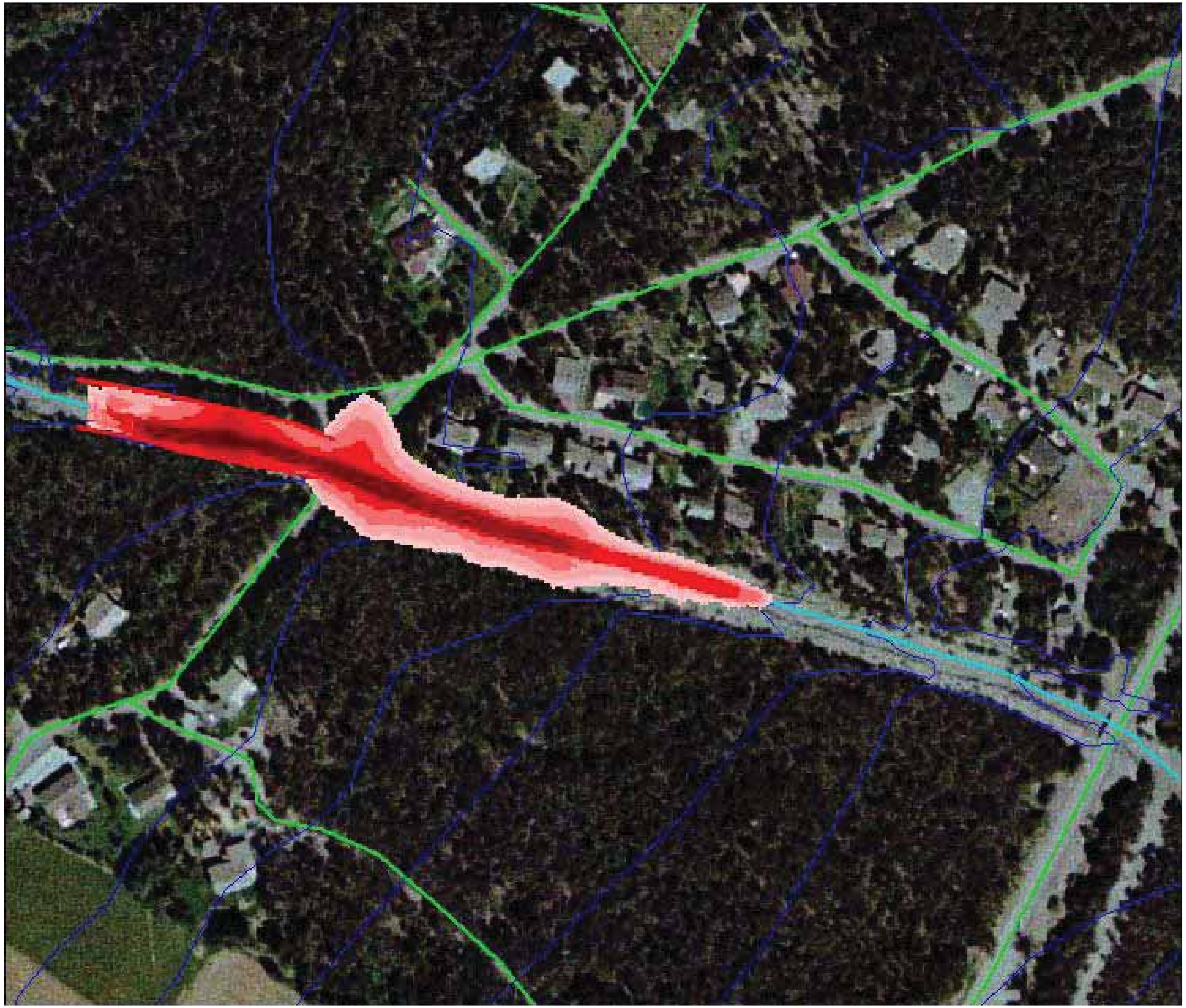

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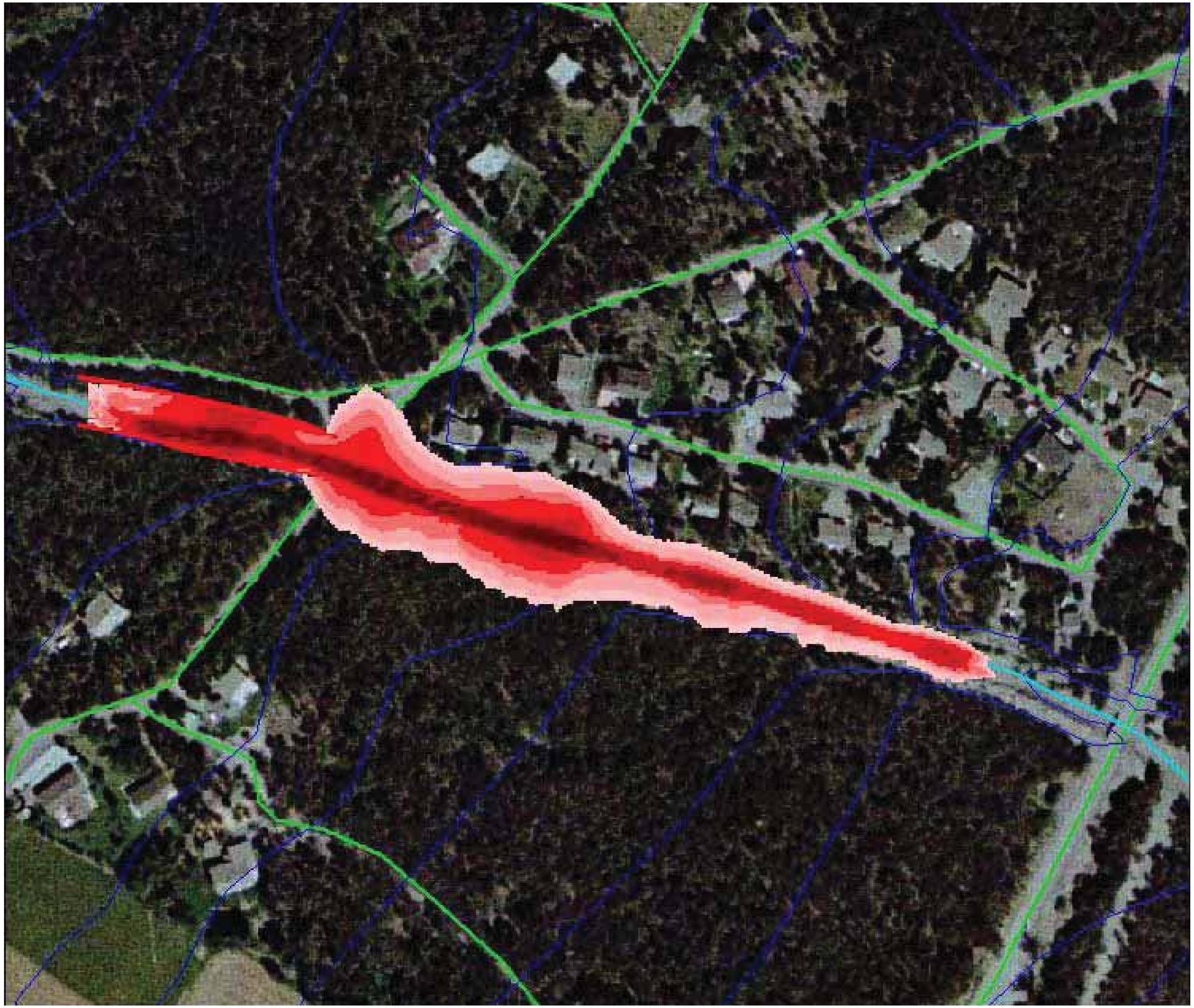

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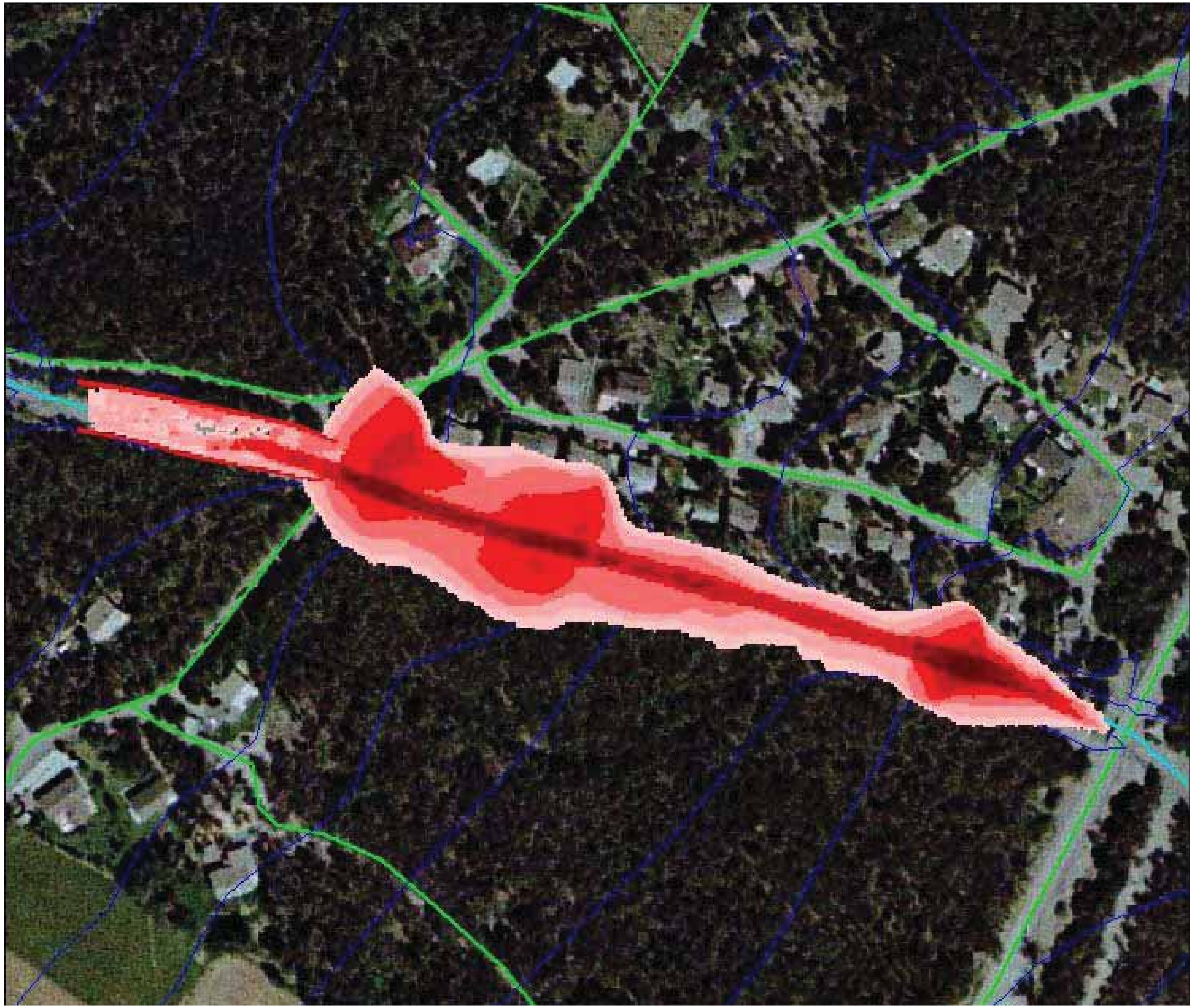

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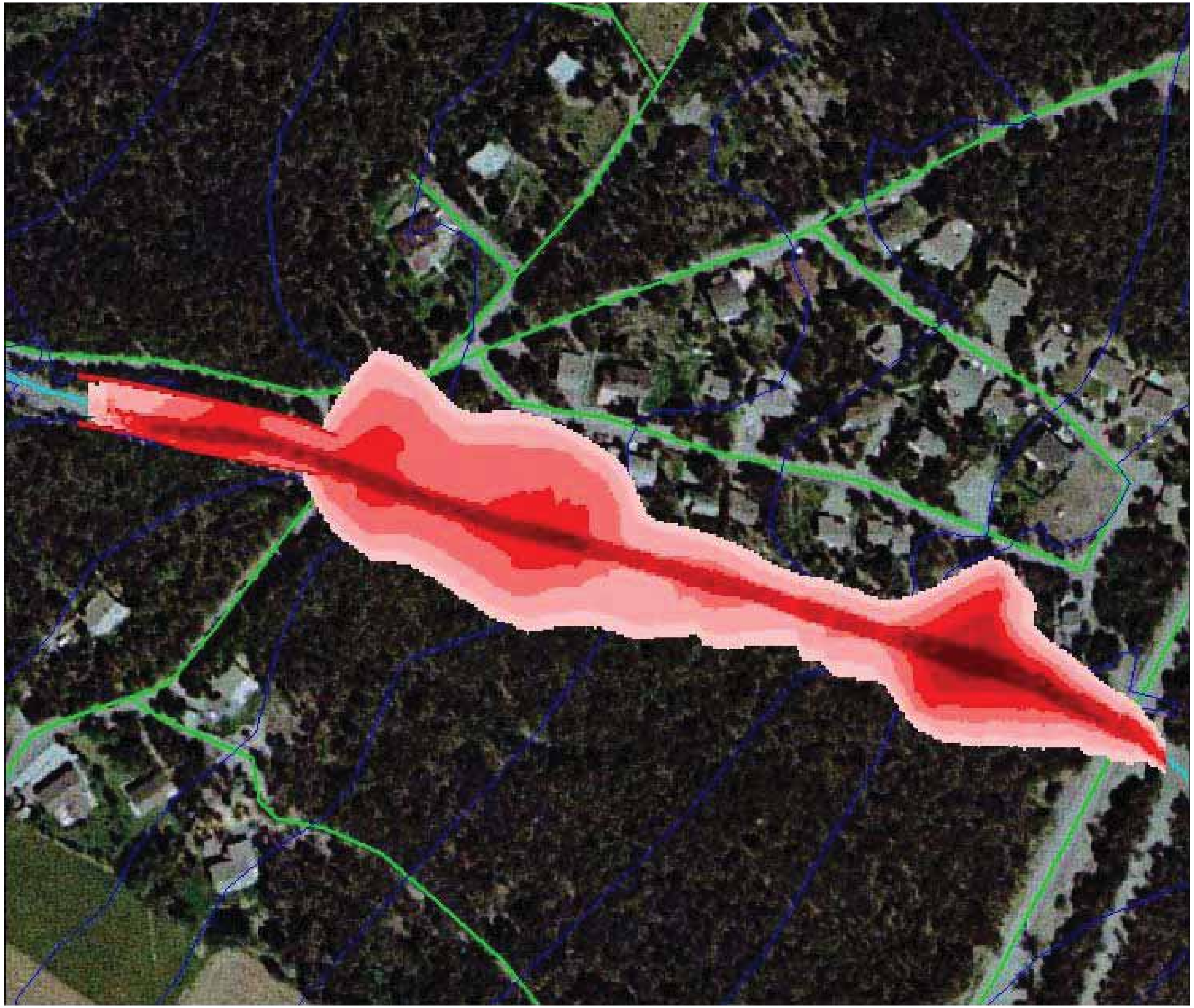

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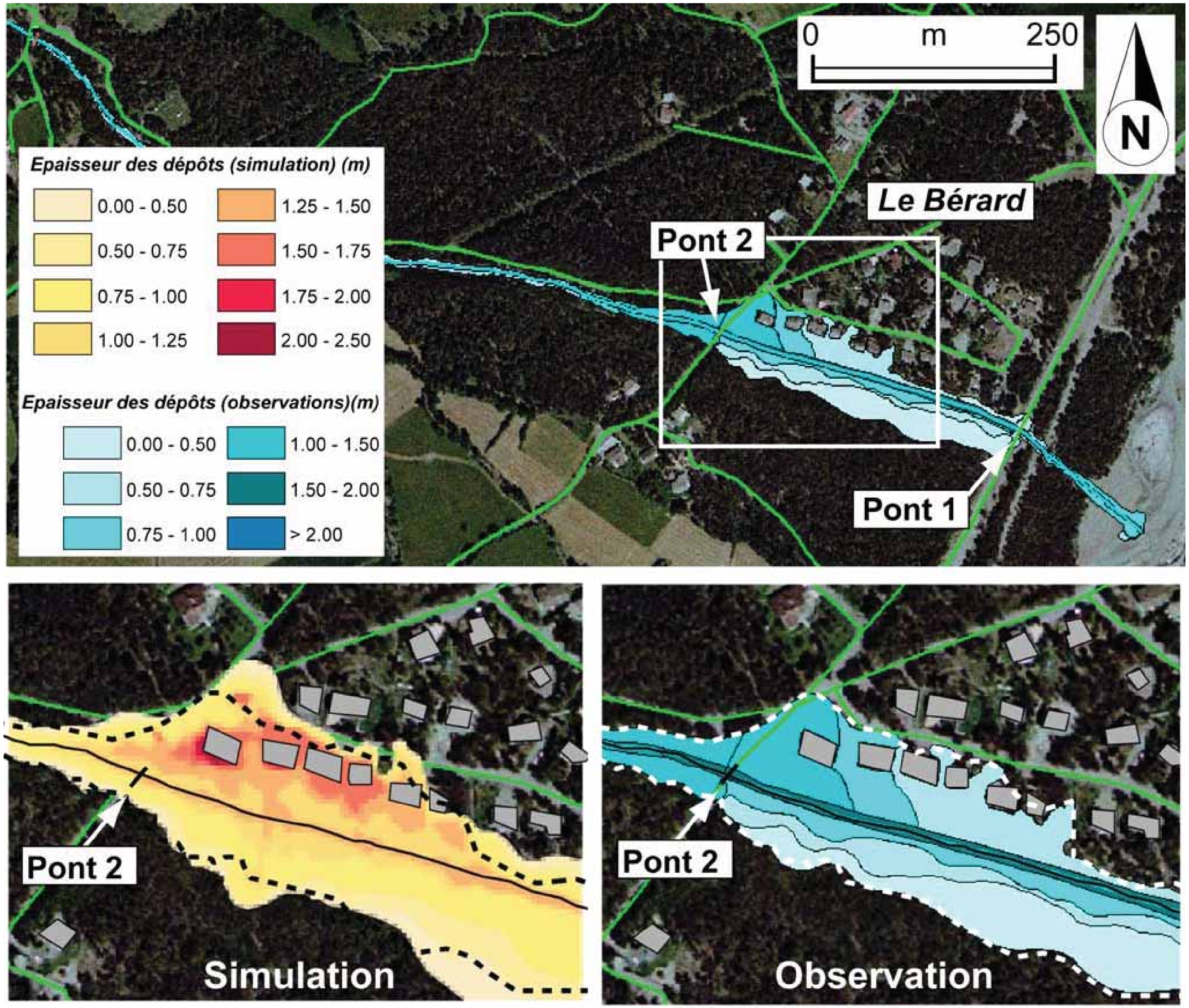

Remaître (2006)