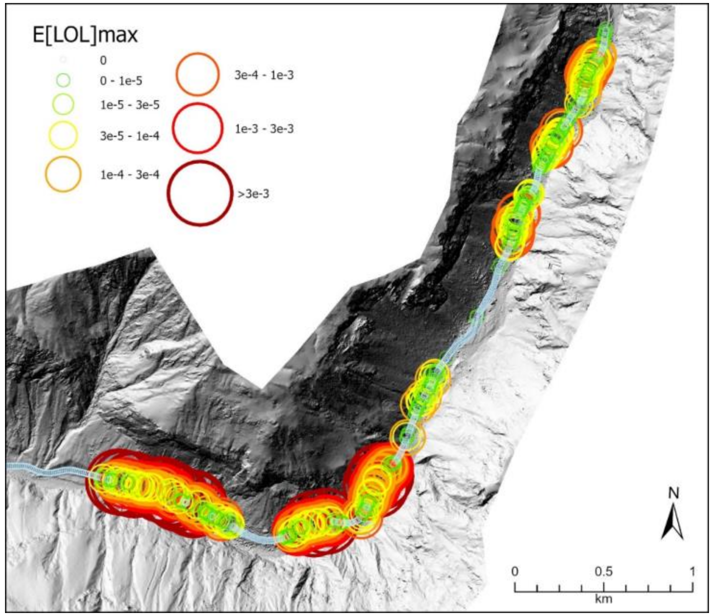
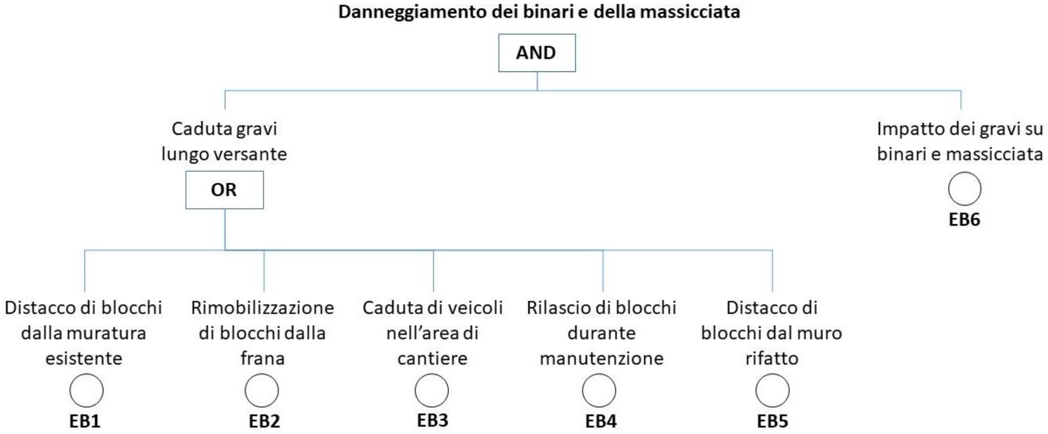
Landslide risk and acceptability

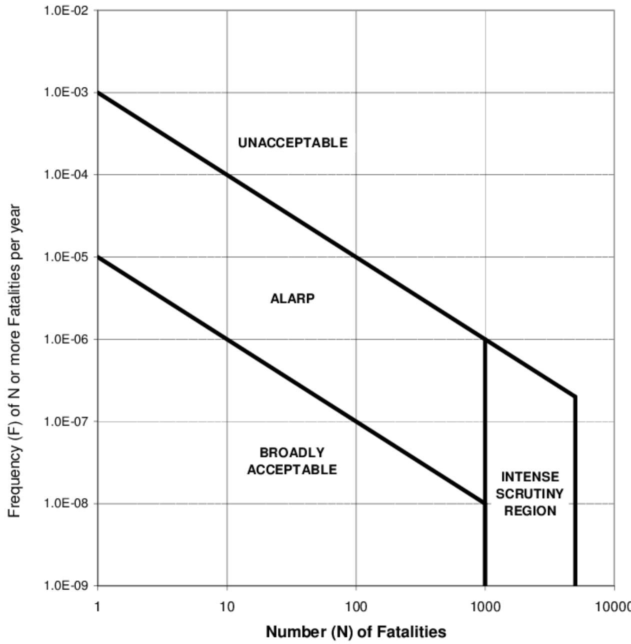
Paolo Frattini, Giovanni Crosta, Federico Agliardi





Scenari

EP1: *EB1*EB6*
EP2: *EB2*EB6*
EP3: *EB3*EB6*
EP4: *EB4*EB6*
EP5: *EB5*EB6*



Landslide Risk

A unique definition of **risk** is not available.

In general, risk is the **probability**, **P**, that an adverse event occurs, giving rise to a **loss**, **L**.

It can be also expressed in terms of **expected loss**, **E(C)**, within a given time period.

R = f(P,L) = E(L)

In geological and engineering practice, risk is defined as:

R = H x V x W

- H = hazard
- V = vulnerability
- W = worth (value) of the elements at risk

Heuristic landslide hazard and analysis

Based on a practical method involving a subject judgment based on experience. Examples of this methods include **rule of thumb**, an **educated guess**, an **intuitive judgment**, **guesstimate**, or **common sense**.

Applications and limits

- Probability is not estimated in a **rigorous way**
- Usually, intensity is not accounted for
- Large uncertainties

				Probability of occurrence, *P*		
	BUWAL (1997)	Rickenmann (2005b)		High	Medium	Low
Intensity, *I*	$h > 1.0$ m and $v > 1.0$ m/s	$h > 1.0$ m or $v > 1.5$ m/s	High	**High**	**High**	**Moderate**
Intensity, *I*	$h < 1.0$ m or $v < 1.0$ m/s	$h < 1.0$ m and 0.4 m/s $< v < 1.5$ m/s	Medium	**Moderate**	**Moderate**	**Low**
Intensity, *I*	non existent	$h < 0.4$ m and $v < 0.4$ m/s	Low	**Low**	**Low**	**Very Low**
Not affected areas				**Very Low**	**Very Low**	**Very Low**

Hürlimann, M., Rickenmann, D., Medina, V., & Bateman, A. (2008). Evaluation of approaches to calculate debris-flow parameters for hazard assessment. Engineering Geology, 102(3-4), 152-163.

Landslide Hazard and Risk

Event-tree landslide hazard and risk analysis

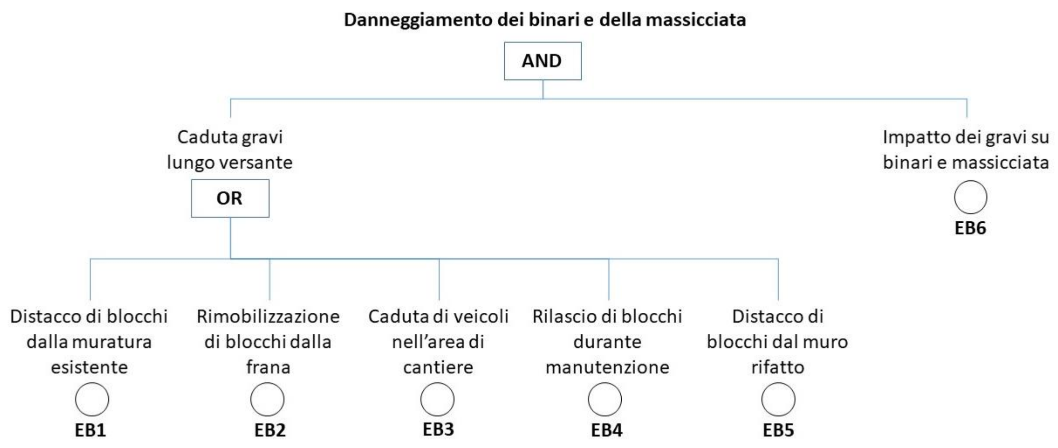
It derives from fault tree approach, used in engineering for the assessment of potential failures of an engineering systems.

- initial event, characterized by a certain probability of occurrence
- nodes with a series of effects (branches), each with a conditional probability

The probability of each final leaf, can be expressed as a joint probability (of dependent events)

Applications and limits

- Suitable for threats characterized by few discrete possible scenarios
- Unsuitable for threats that may occur with different intensities (earthquakes, …)



__*Scenari*__ *EP1*: *EB1*EB6* *EP2*: *EB2*EB6* *EP3*: *EB3*EB6* *EP4*: *EB4*EB6* *EP5*: *EB5*EB6*

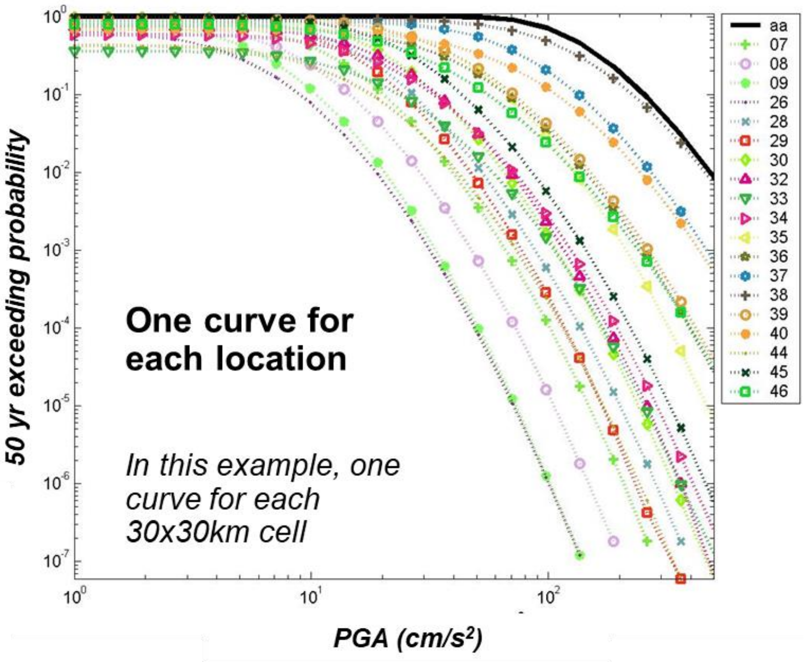
Frequenza di accadimento	Livello di rischio e accettabilità			
Frequente		EP1, EP2		
Probabile				
Occasionale		EP4, EP5		
Remoto				
Improbabile		EP3		
Inverosimile				
	Insignificante	Marginale	Critico	Catastrofico
	Livello di gravità			

Analisi del rischio per gli eventi pericolosi. Il livello di accettabilità deriva dalla disposizione RFI 51/07 (le classi sono riscalate in modo conservativo rispetto alla CEI EN 50126).

Landslide Hazard and Risk

Probabilistic landslide hazard and risk analysis

Reports the probability of exceeding a certain intensity in a given period of time, as a function of intensity

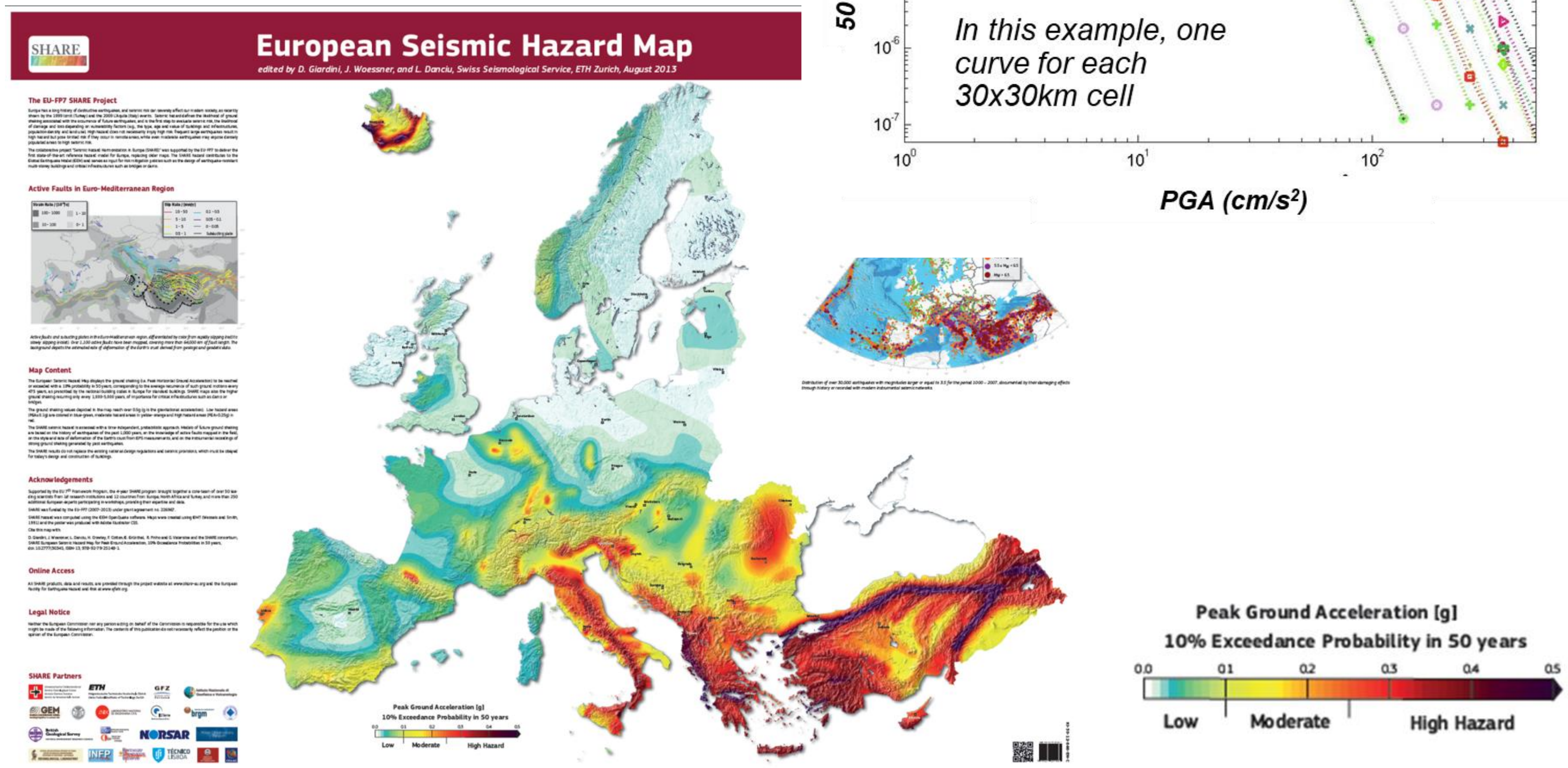


To produce a hazard map, we need to reduce the hazard curves (one at each location) to a single value that can be represented in a map.

This can be done by :

- selecting certain level of intensity, to represent the exceedance probability (or T)

- selecting a certain level of probability of exceedance to represent the intensity



Probabilistic Risk for people

Quantitative risk for casualties of people can be expressed as the possible **yearly number of casualties (or loss of life), E[LOL]**

$$E[LOL] = \underbrace{P_L(M) \cdot P_{S|L}(I|M)}_{\text{Hazard}} \cdot P_{T|S} \cdot V_{D|T}(I)$$

Hazard

$P_L(M)$: onset probability of a landslide with a certain magnitude (i.e., volume)

$P_{S|L}(I|M)$: transit probability --> probability that a landslide reaches a certain point along the slope with a certain local intensity I (i.e., kinetic energy) given the onset magnitude

} *Hazard*

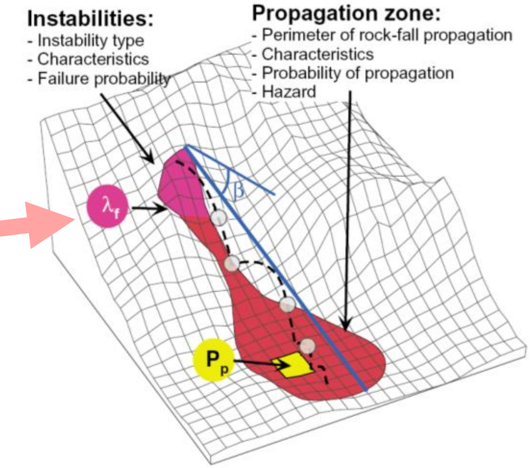
P(S|I>i): probability that the landslide impacts an element at risk. Temporal-spatial probability → *Exposure*

V(I<i): vulnerability of the element at risk for a certain intensity (i.e, loss of life probability) → *Vulnerability*

Onset probability, $P_L(M)$

$$E[LOL] = P_L(M) \cdot P_{S|L}(I|M) \cdot P_{T|S} \cdot V_{D|T}(I)$$

$P_L(M)$: onset probability of a landslide with a certain magnitude (i.e., volume) → **Onset frequency = f_0**



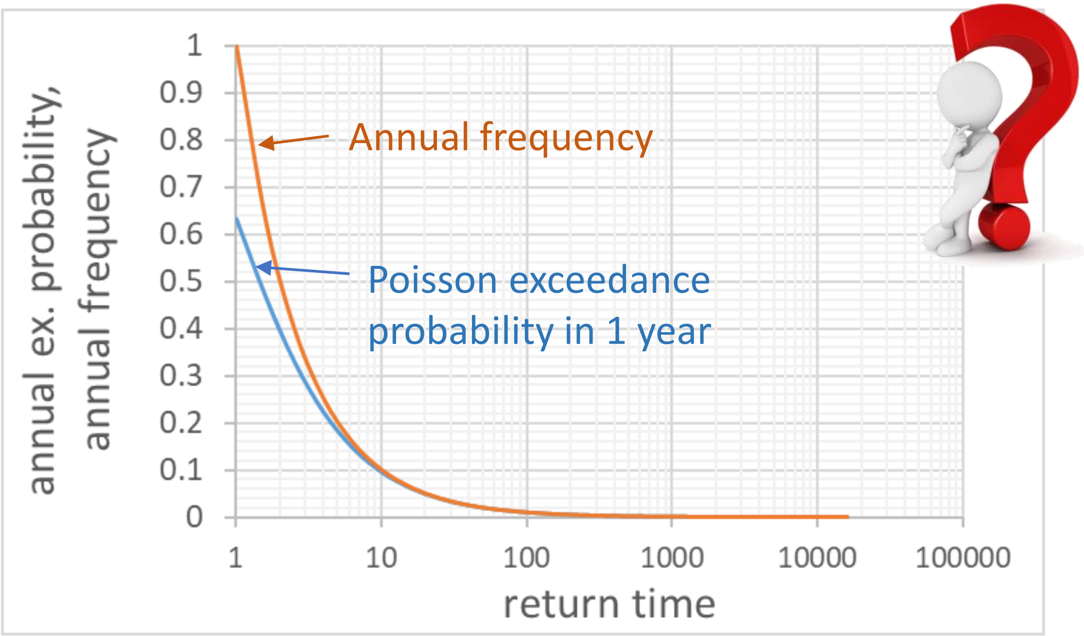
Annual frequency instead of exceedance probability (appropriate for low frequency events)

Poisson probabilistic model

- The event are independent
- The events can take any energy level

$$P[I > i] = 1 - e^{-\lambda t} = 1 - e^{-\frac{t}{T}}$$

When T > 10 , $P[I > i] \approx \frac{1}{T}$



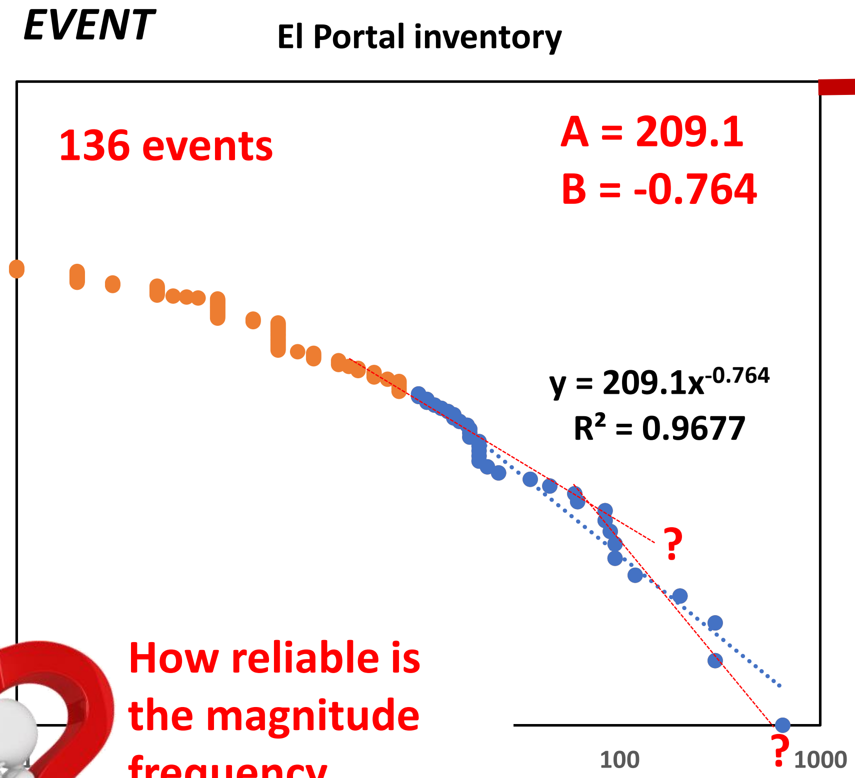
How appropriate is a stationary probabilistic model with Climate Change?

Onset frequency, f_0

Onset frequency depends on magnitude! The large the event, the smaller the frequency

$$f_0 = N(V > v) = \frac{N_0}{T}\left(\frac{V}{V_0}\right)^{-b}$$

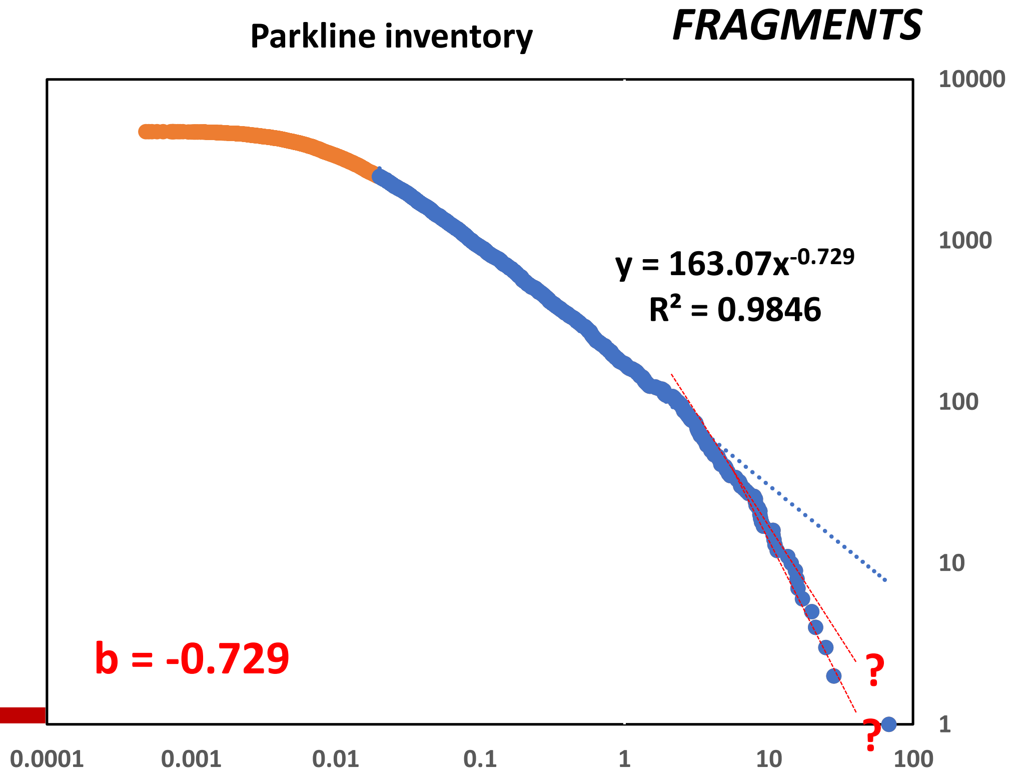
with $N(V > v)$ and N_0 respectively cumulative and total number of events with V>v



$$N(V) = N_1 V^{-B}$$

$$a = \frac{(1-b)V_t}{v_{max}^{1-b} - b v_{min}^{1-b}}$$

$$n(v) = av^{-b}$$



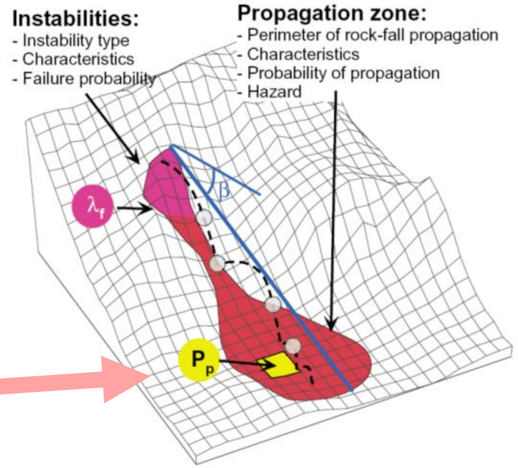
How reliable is the magnitude frequency distribution based on historical data?

Hantz D., Ventroux Q., Rossetti J.P. & Berger F. (2018) http://dx.doi.org/10.1201/b21520-127

Transit probability, $P_{S|L}(I|M)$

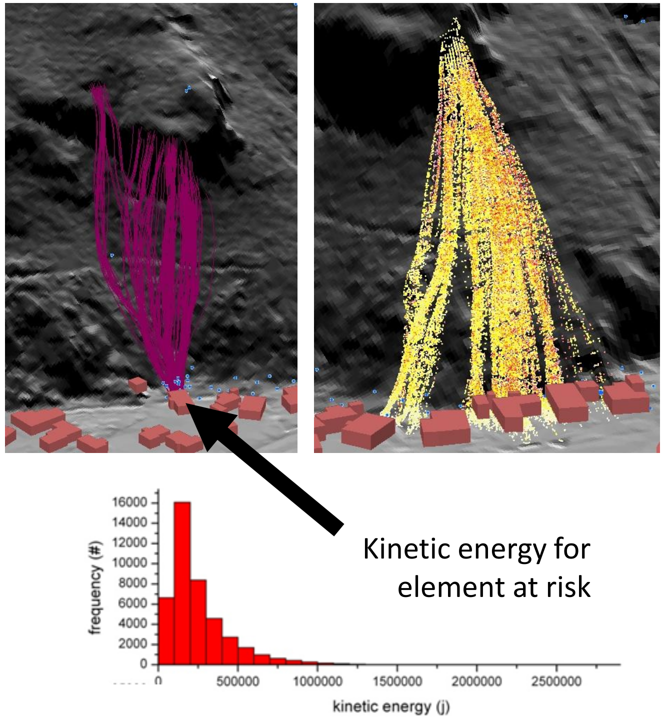
$$E[LOL] = P_L(M) \cdot P_{S|L}(I|M) \cdot P_{T|S} \cdot V_{D|T}(I)$$

$P_{S|L}(I|M)$: transit probability --> probability that a landslide reaches a certain point along the slope with **a certain local intensity I** (i.e., kinetic energy) given the onset magnitude → **Transit frequency = f_t**

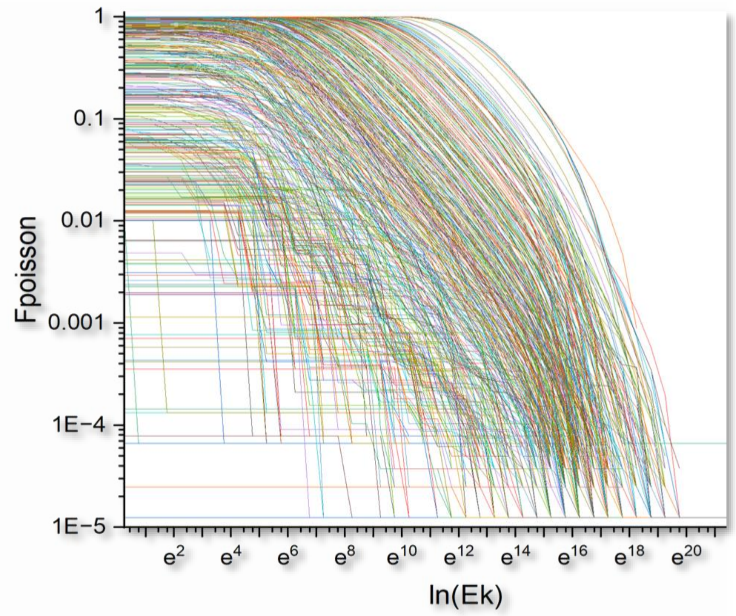


The quantification of transit frequency and related energies requires:

1) a **model** to simulate the propagation
2) an appropriate **local intensity parameter** that is related to the damaging potential of the landslide *(depends on the landside type: kinetic energy, velocity, impact pressure, depth, displacement rate)*
3) a **method to combine the different intensities** derived from different source areas and/or from uncertainty about the propagation



Hazard Curve (PRHA)



- **P** of **exceeding** a value ***i*** of **kinetic energy (E_k)** *(scenario)*

$$Ps(I > i) = \int_{I_c}^{\infty} p(I)\, dI$$

$Ps(I)$: PDF of kinetic E at position z (**MODEL**)

- Annual **frequency of exceedance** of ***i*** *(scenario)*

$$Fs(I > i) = f \cdot Ps(I > i)$$

where f is the annual frequency of occurrence

Annual **frequency of occurrence**: *(scenario)*

$$f = f_0 \cdot f_r = f_0 \left(\frac{t}{t_{tot}}\right)$$

FREQUENCY OF REACH (MODEL)

ONSET FREQUENCY (INVENTORY)

- **Total** annual **frequency of exceedance** *(integrated over all scenarios)*

$$F_{tot}(I > i) = \sum_{s=1}^{N} F_s\, P_s(I > i)$$

with s: magnitude scenario

- **P of exceedance of *i* in *T* years** - stationary Poisson process *(integrated over all scenarios)*

$$P_{poisson}(I > i, T) = 1 - e^{-F_{tot} \cdot T}$$

Lari S., Frattini P. & Crosta G.B. (2014) A probabilistic approach for landslide hazard analysis. *Engineering Geology 182 (A), 3-14.*

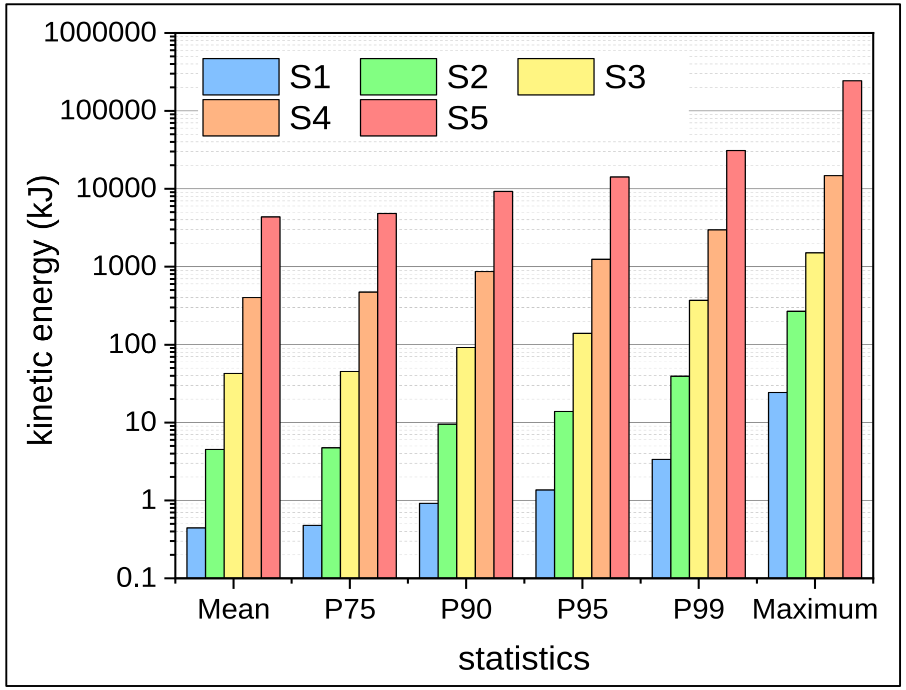
Kinetic energy for vulnerability

Two approaches:

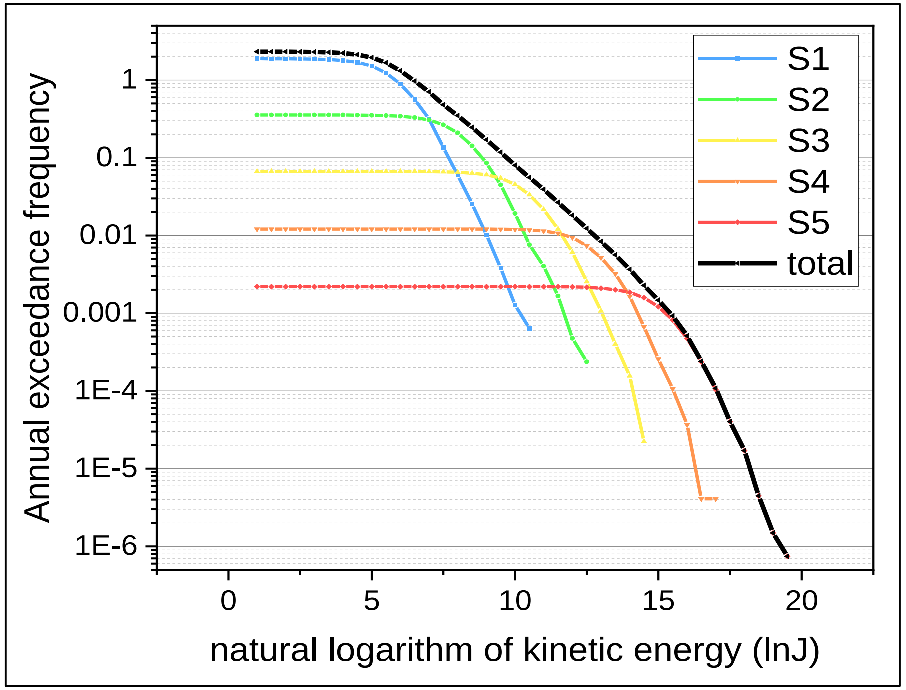
Statistical approach: for each scenario, a statistic of the kinetic energy is used (mean, max, percentiles)

Frequency-curve: for each scenario, the frequency curve of the kinetic energy is used. Each class of intensity has an associated annual frequency

How reliable is the kinetic energy used for the analysis?



Statistical approach: kinetic energy changes up to almost two order of magnitude



Frequency-curve approach: exceedance frequency of kinetic energy for each scenario

→ The total frequency is NOT used because each scenario has to be considered independently for exposure and vulnerability analysis

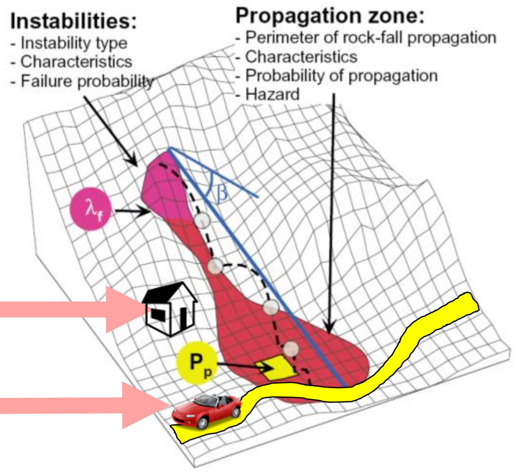
Temporal-spatial probability, $P_{T|S}$

$$E[LOL] = P_L(M) \cdot P_{S|L}(I|M) \cdot P_{T|S} \cdot V_{D|T}(I)$$

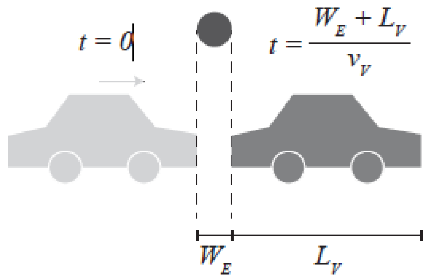
$P_{T|S}$: probability that the landslide impacts an element at risk. Temporal-spatial probability

For static elements= 1 (e.g., houses)

For mobile elements = variable



The temporal spatial probability (i.e., the probability of a vehicle being in the path of the landslide when it transits) depends on the velocity of the vehicle, its size, and the size of the falling rock block (Nicolet et al, 2016):



$$P_{T|S} = \frac{f_V(W_E + L_V)}{v_V}$$

where f_V is the daily number of vehicle of length L_V, moving with a velocity v_V, and W_E is the size of the landslide/block

Velocity changes along the road, and was assumed equal to the speed limit
For the **queue**, the velocity is calculated by considering the distance divided by expected time to the entrance

→ This only considers a direct impact on the vehicle, not the impact of the vehicle on the landslide

Vulnerability, $V_{D|T}(I)$

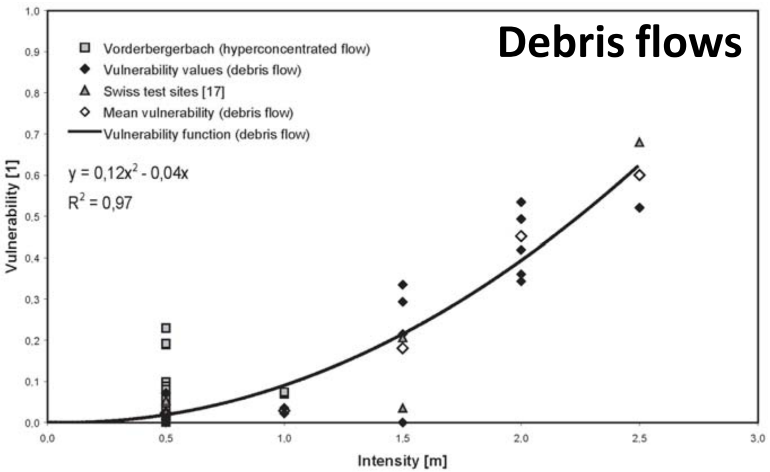
$$E[LOL] = P_L(M) \cdot P_{S|L}(I|M) \cdot P_{T|S} \cdot V_{D|T}(I)$$

Different landslide types are characterized by different physical mechanisms that can cause damages (pressures, forces, differential displacements, fluidification, …) making vulnerability assessment extremely uncertain.

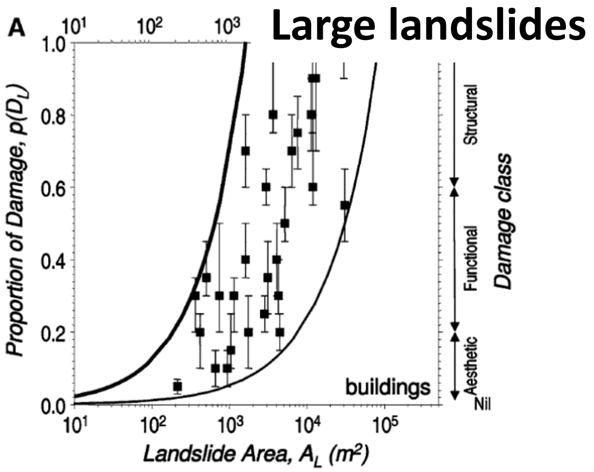
Reliable vulnerabity curves do not exist.

For people, casualty probability is normally assumed as 1 in case of impact (Farvacque et al, 2023), which is very conservative.

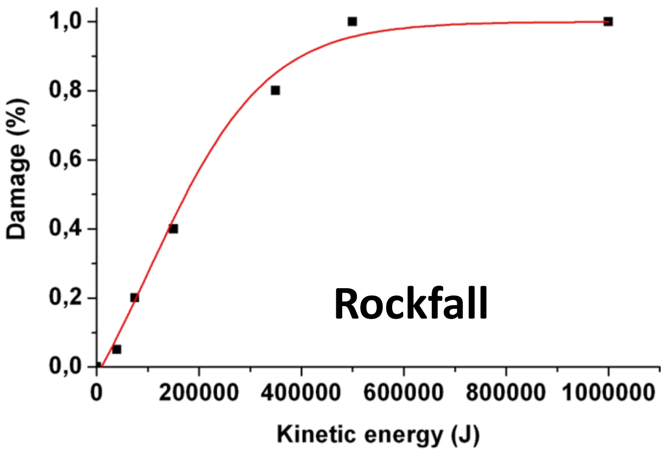
How reliable is the assessment of vulnerability



Fuchs, S. (2008): Vulnerability to torrent processes, WIT Trans. on Inf. and Comm. Tech, 39, 289-298.



Galli M., Guzzetti F., 2007, Landslide vulnerability criteria: A case study from Umbria, central Italy, Env. Man. 40 (4), pp. 649-664



Agliardi F., Crosta G.B., Frattini P., (2009), Natural Hazard and Earth System Science

Risk acceptability

“The risk with which the society is willing to live to ensure certain benefits, in the awareness that the risk level is controlled, updated and, if possible, reduced” (*IUGS Commission on Risk Assessment, 1997*)

Acceptance of a risk is a function of several factors *(Finlay e Fell, 1997; IUGS, 1997)*:

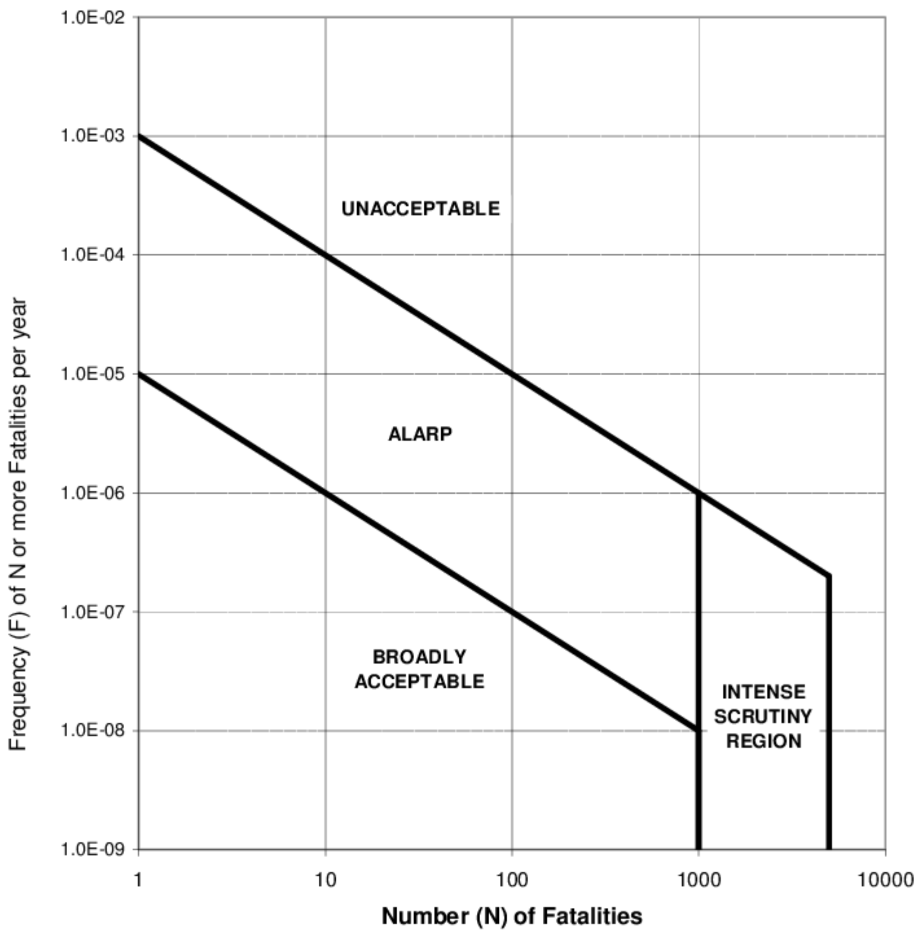
- risk type *(natural o man-made)*
- voluntariness of exposure to risk *(volunteer and non-volunteer)*
- consciousness of risk *(perception)*
- expected cost *(individual or societal risk)*
- mitigation *(implemented or perceived)*

Societal risk acceptability

For societal risk, acceptable risk is represented by reference levels (or thresholds):

- limit risk (upper limit: a higher risk is UNACCEPTABLE)
- objective risk (target of reference: a lower risk is ACCEPTABLE)

ALARP = As Low As Reasonably Practicable
For ALARP, it must be possible to demonstrate that the cost involved in reducing the risk further would be disproportionate to the benefit gained



Intense scrutiny region: The cut-off values adopted in Hong Kong for the area of intense scrutiny corresponds to a local policy, and its adoption needs to be based on political and social considerations

Societal Risk, SR (*Ichem, 1985*)

SR = Frequency of events x number of fatalities/event

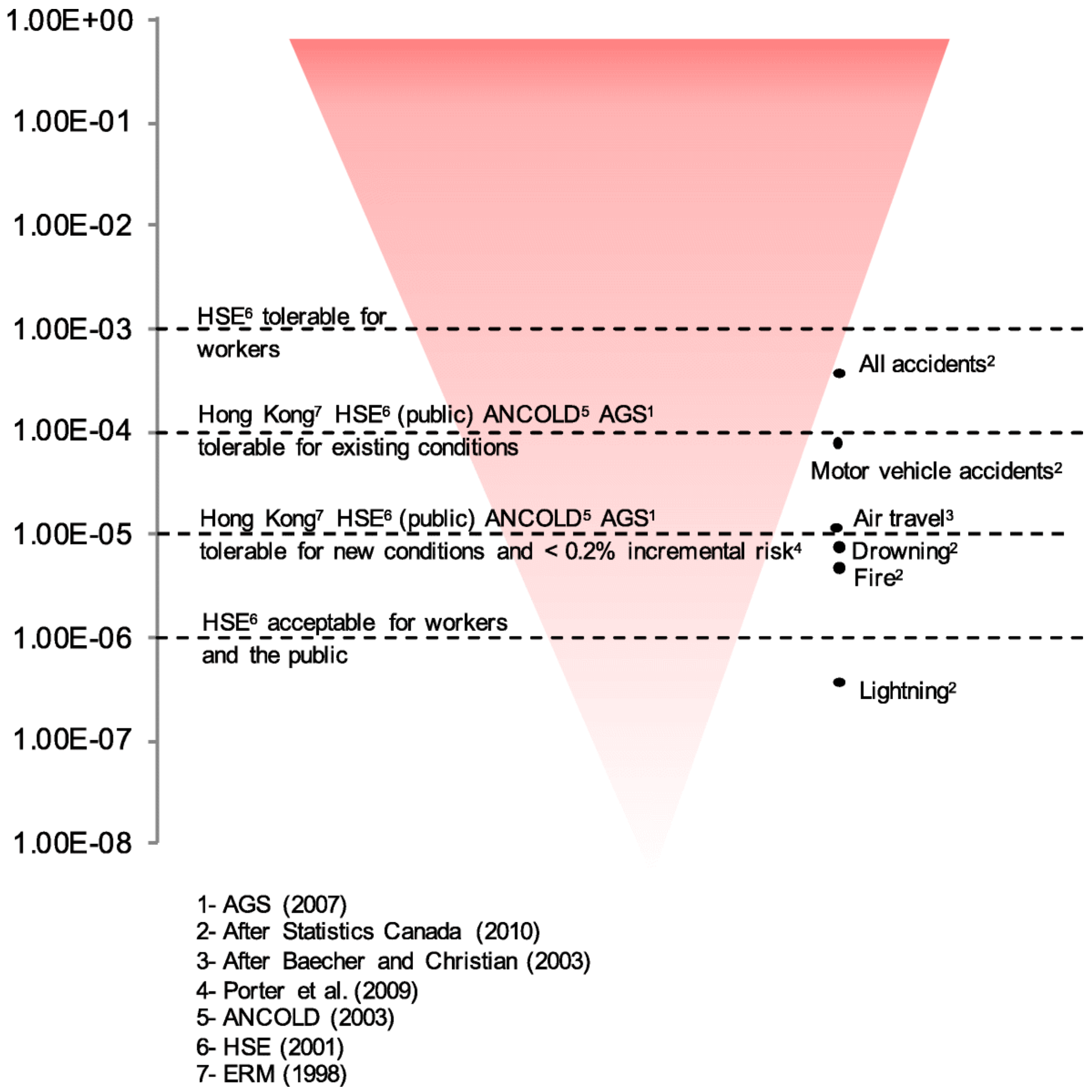
Potential Loss of Life, PLL

Expected number of fatalities within a specified population (or within a specified area A per annum).

Individual risk acceptability

For individual risk, the thresholds are different for different risks, according to the different criteria for risk acceptability.

Landslide do not have a value of defined acceptability.



Individual risk, IR (*Dutch Ministry of Housing, Spatial Planning and Environment, VROM*)

Probability that a person will be killed as a consequence of an hazard. Reported to a single year, it can be called Individual risk per annum (IRPA)