Acceptable risk for critical facilities subjected to geohazards

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Open questions

- **What is risk?**
- **Can we measure it?**
- **If we understand it, can we manage it better?**

"Risk" is an abstract, forward-looking concept and has different definitions in different disciplines. However, regardless of its definition, risk is closely related to uncertainty and is not static.

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Risk and uncertainty in geosciences

In any geotechnical and geological assessment, one must deal with uncertainties, eith… implicitly … tly.

ISO's definition of risk: Risk is the *effect of uncertainty on objectives*

Quantification of Risk (from an engineer's viewpoint)

Risk = f(Hazard, Consequences)

or Risk = f(H, V, (E), U)

- **H** **=** Hazard (temporal probability of a threat)
- **V** **=** Vulnerability of element(s) at risk,
- (**E** **=** Exposure of element(s) at risk)
- **U** **=** Utility (or value) of element(s) at risk

To quantify risk, one should quantify hazard, vulnerability, exposure and value of the elements at risk.

Risk Assessment and Risk Management

What can cause harm? →	**Danger** identification
How often can the event(s) occur (frequency/ magnitude)? →	**Hazard** assessment
What is at risk? →	**Elements at risk** identification
What is the potential for damage? →	**Vulnerability** assessment
What is the probability of damage? →	**Risk** estimation
What is the significance of the estimated risk? →	**Risk evaluation** (acceptable/tolerable risk)
What should be done? →	**Decision-making** on risk treatment (mitigation)

Risk Assessment

Risk Management

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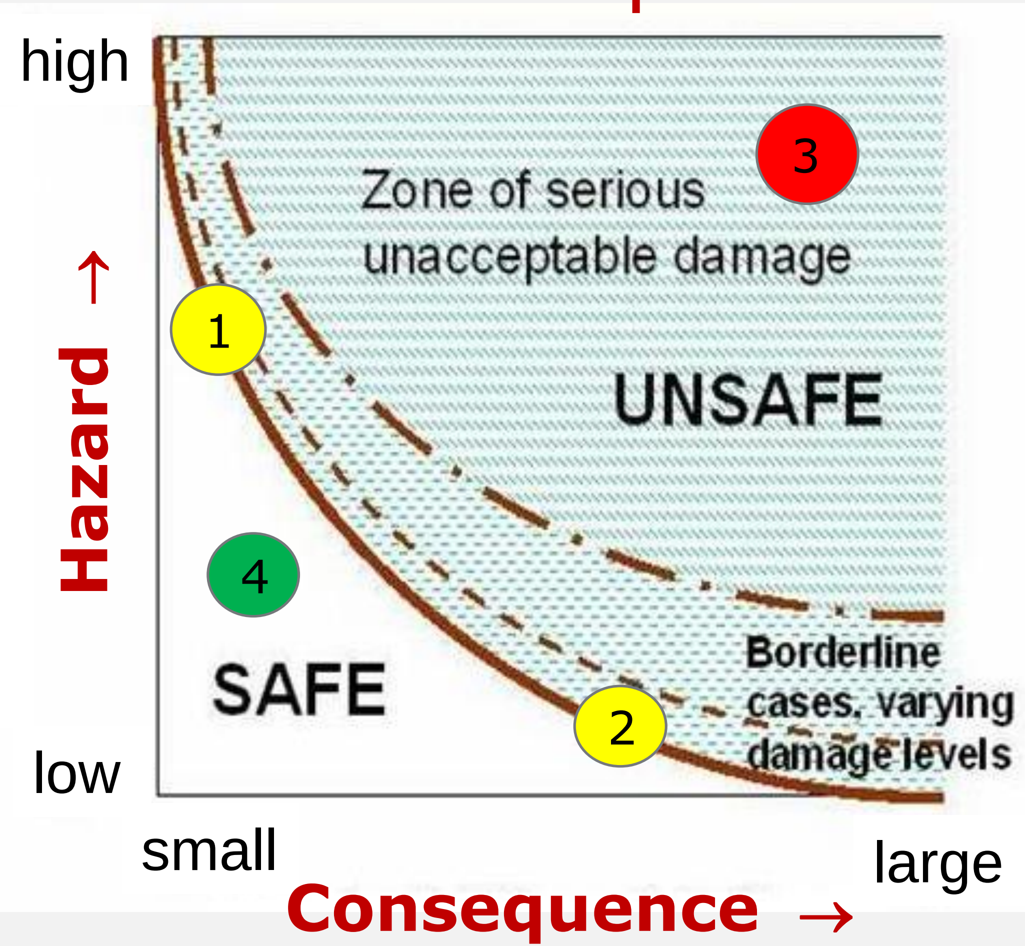
Risk acceptance



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How much risk is acceptable?

How much risk are we willing to accept?

Depends on whether the situation is voluntary or imposed.

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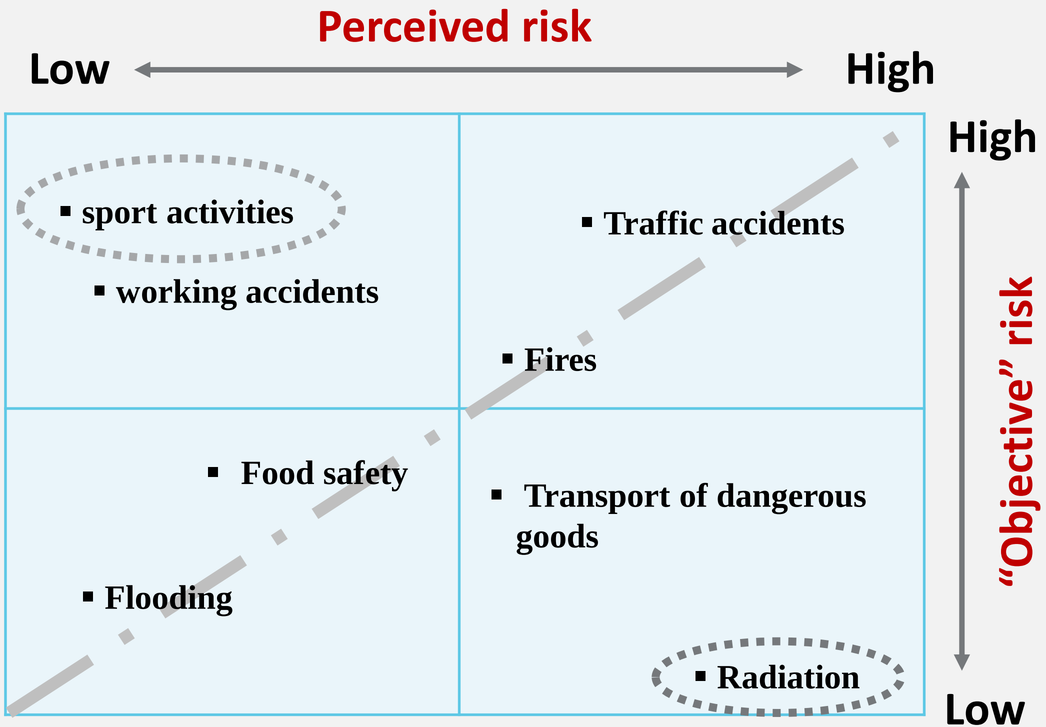
Snow avalanches in Norway:

(1500 deaths in past 150 years)

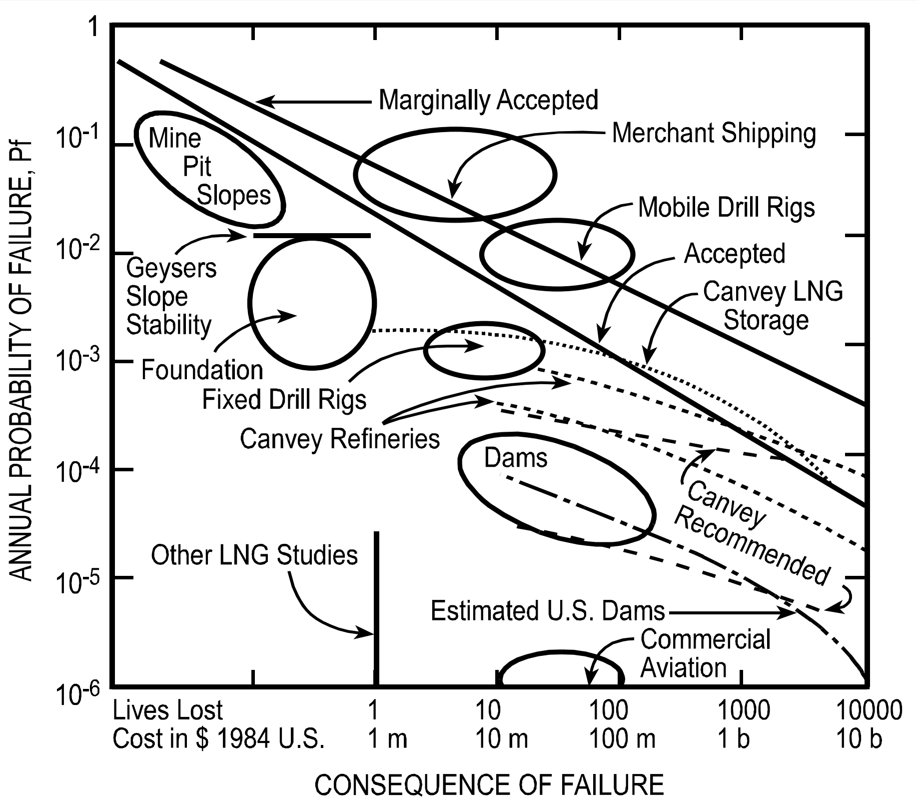
- **Before 1950s:** most casualties were people residing in buildings
- **After 1950s:** most casualties are skiers, who often trigger the avalanche themselves. Only 1 - 2 casualties per year for people inside buildings.

Risk perception



Max Geldens Stichting, 2002

Examples of F-N curves (Whitman, 1984)



Acceptable / Tolerable Risk

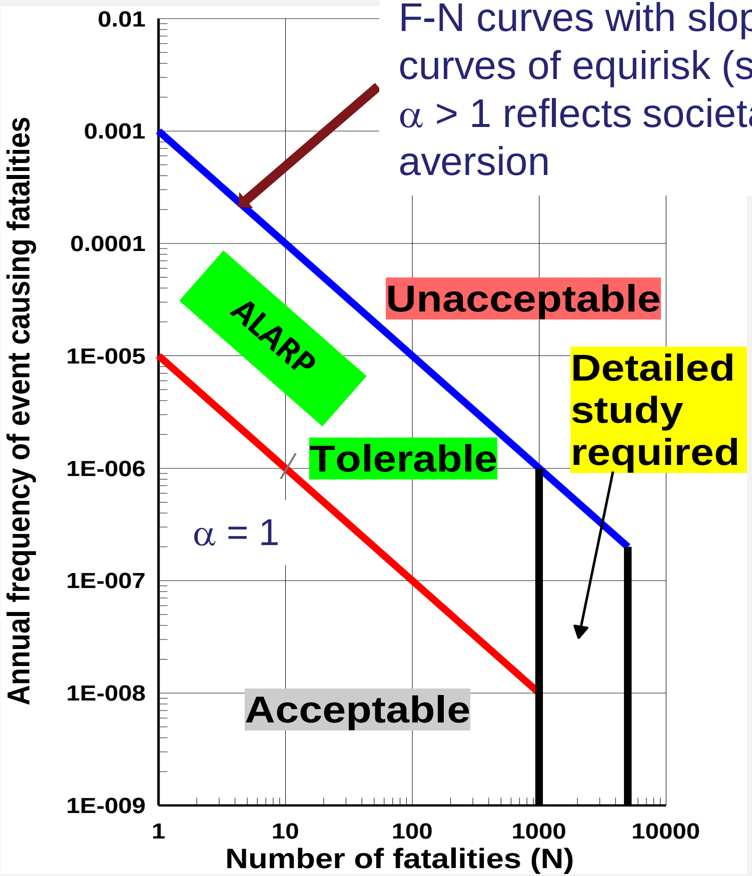
Example of Acceptable Societal Risk for slopes from Hong Kong:

Use of **F - N** Charts & **ALARP** principle

$$\mathbf{F \cdot N^{\alpha} = k}$$

k = 0.001, α = 1 (blue curve)

ALARP = As Low As Reasonably Practicable



F-N curves with slope α = 1 are curves of equirisk (same risk); α > 1 reflects societal risk aversion

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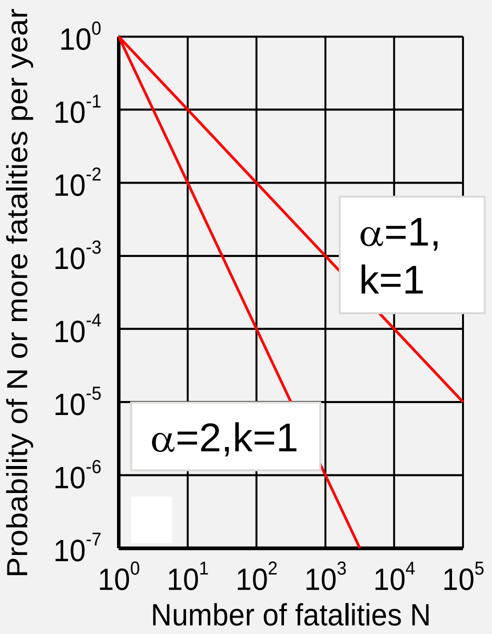
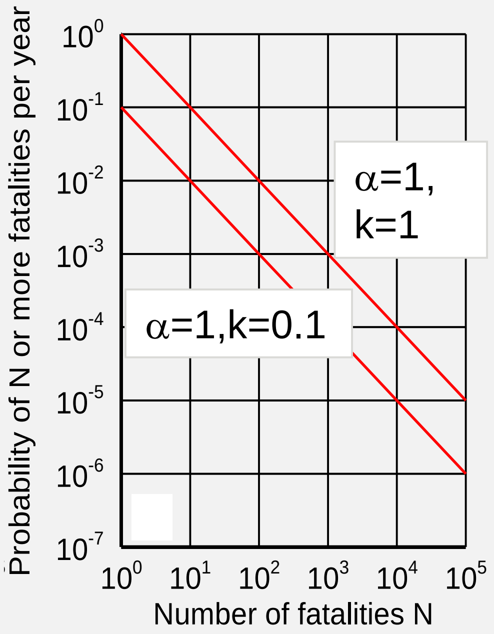
F-N curves $F \cdot N^{\alpha} = k$
Exponent α and intercept k





F-N curves with slope $\alpha = 1$ are curves of equi-risk (same risk); $\alpha > 1$ reflects societal risk aversion

Risk Acceptance Criteria reviewed:

PIR
(Personal Individual Risk)
(i.e. account for temporal factors and protection)

- Hong Kong
- Australia
- UK
- Denmark
- European Commission
- Czech Republic
- Hungary

IR (Individual Risk)

(i.e. 100% of time exposed to a hazard)

- Canada
- Netherlands
- Belgium
- Norway

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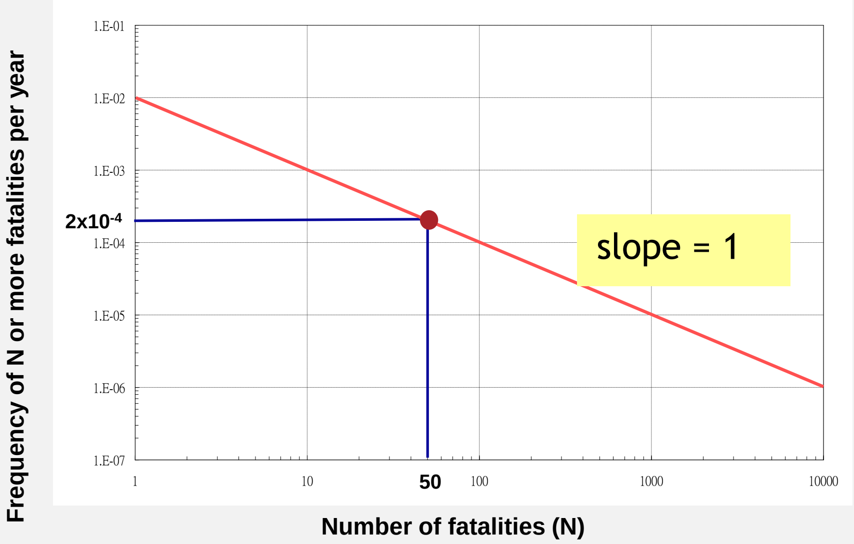
United Kingdom, 2007 - Societal Risk (Land Use)

In 2001, HSE proposed a societal risk criterion that said that:

"The risk of an accident causing the death of 50 or more people in a single event should be regarded as intolerable if the frequency is estimated to be more than one in five thousand per annum"



Proposals for revised policies to address societal risk around onshore non-nuclear major hazard installations (HSE, 2007)
Impact of HSE PADHI policy proposals on LDA & GLA (Capita Symonds, 2007)

Australia - AGS, 2007 (Landslides)
Australia - ANCOLD, 2003 (Dams)

Existing Dams / Slopes:

$IR < 10^{-4}$ / yr

New Dams / Slopes:

$IR < 10^{-5}$ / yr

Tolerable Risk Criteria – The ANCOLD Guidance (AGS, 2007)
Guidelines on Risk Management (ANCOLD, 2003)

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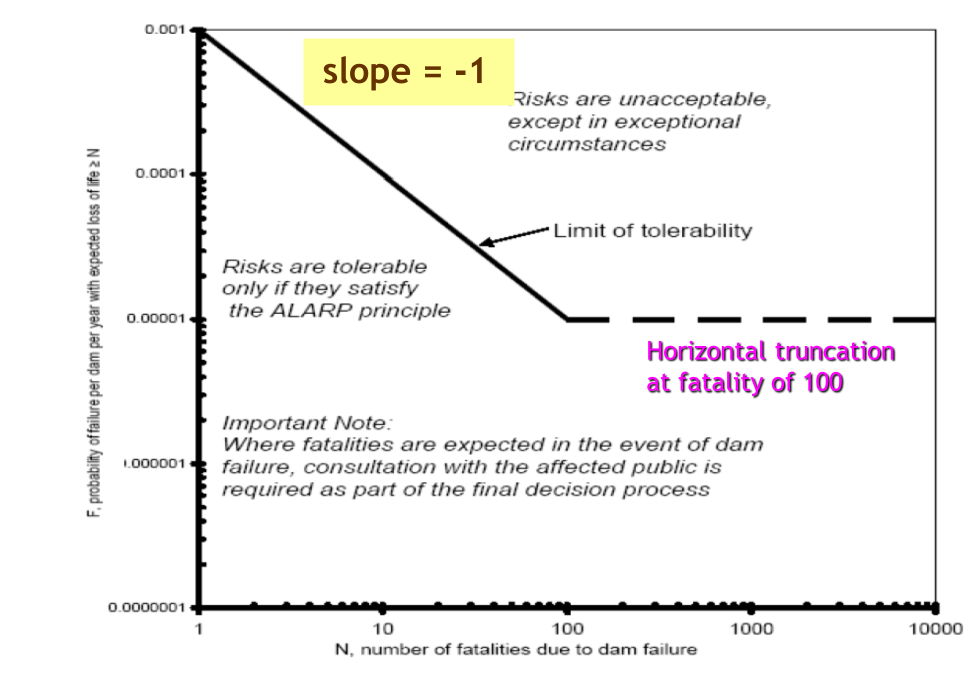
Australia – ANCOLD, 2003 (Dams)



Tolerable Risk Criteria – The ANCOLD Guidance (AGS, 2007)
Guidelines on Risk Management (ANCOLD, 2003)

Australia – New South Wales, 1992-2008 (Land Use)

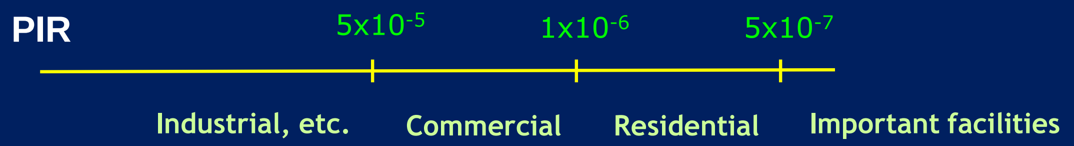


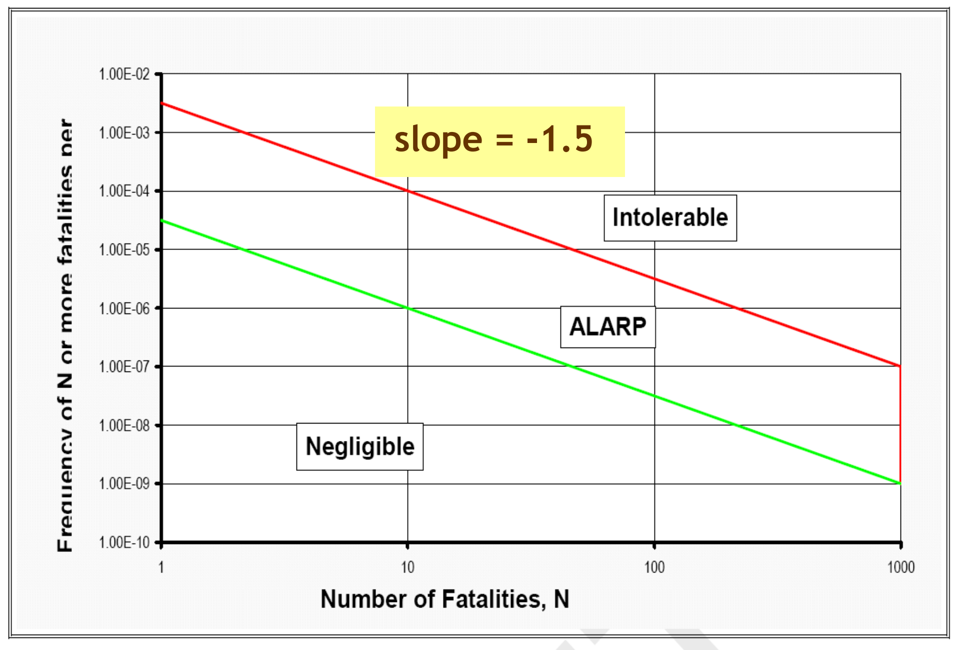
Table 2: Individual Fatality Risk Criteria

Land Use	Suggested Criteria (risk in a million per year)
Hospitals, schools, child-care facilities, old age housing	0.5
Residential, hotels, motels, tourist resorts	1
Commercial developments including retail centres, offices and entertainment centres	5
Sporting complexes and active open space	10
Industrial	50

PIR – the risk of death to a person at a particular point (it is necessary to account for variations in the duration of exposure to that risk at any particular point by any one individual)

Risk Criteria for Land Use Safety Planning (NSW Govt, 2008)

Australia - New South Wales, 1992-2008 (Land Use)



Risk Criteria for Land Use Safety Planning - consultation draft (NSW Govt, 2008)

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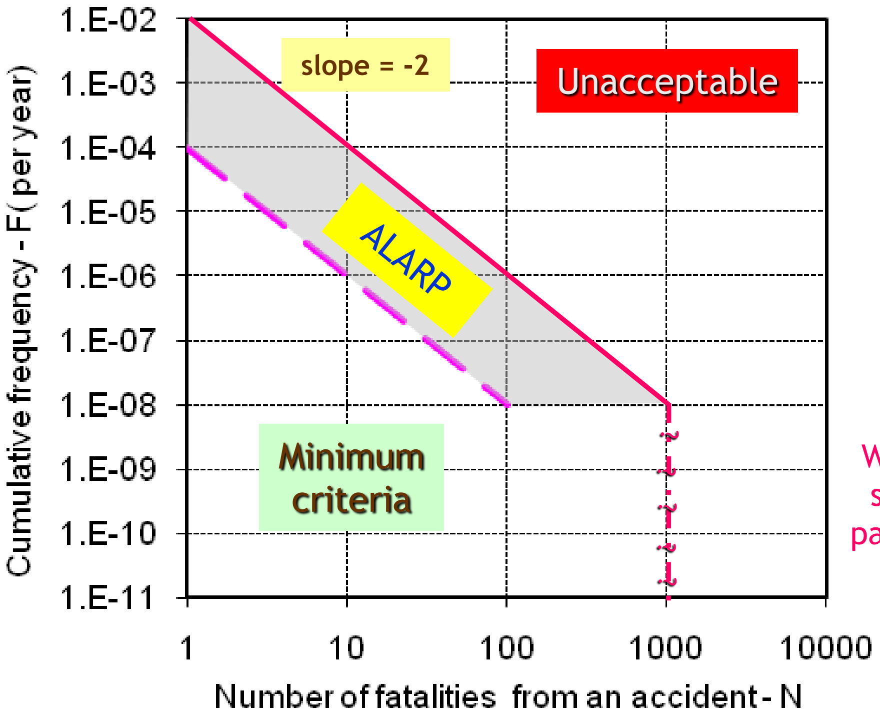
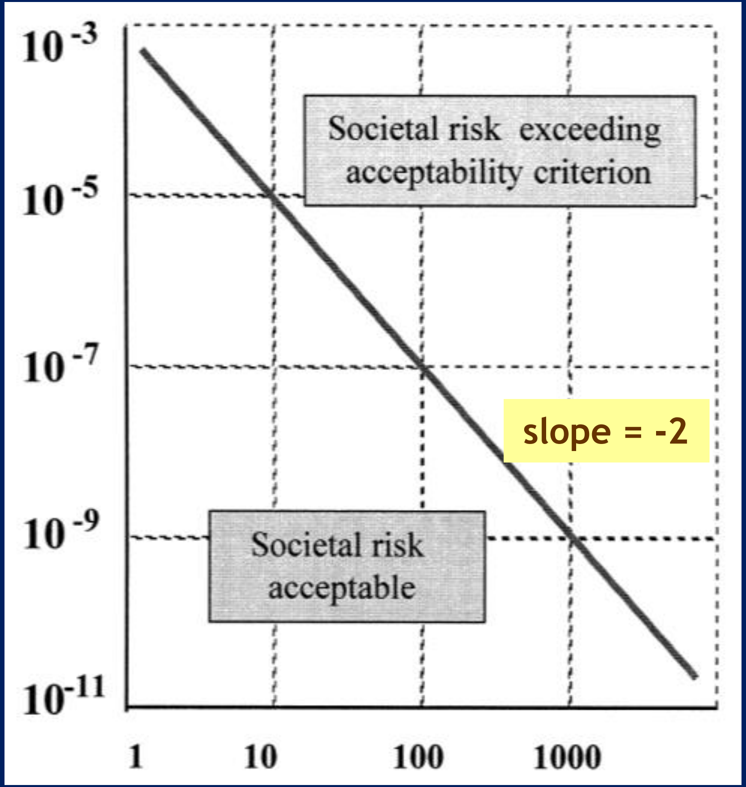
Denmark, 2003 - Societal Risk (Land Use)



Whether the F-N curve should be cut off at a particular accident size? (being considered)

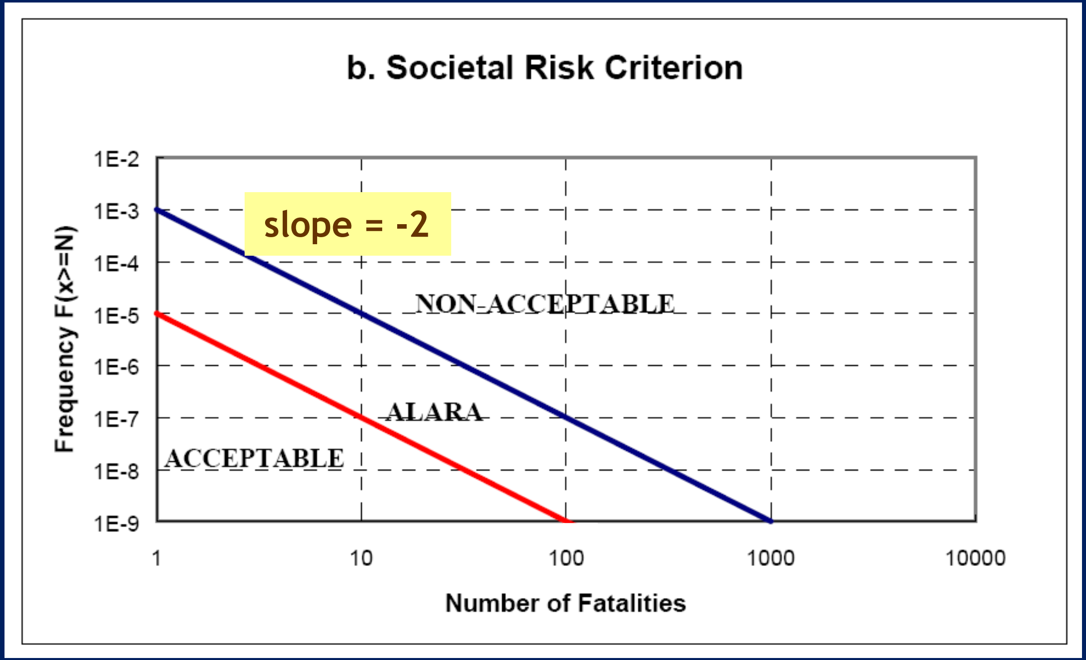
Acceptance criteria in Denmark and the EU (Danish Ministry of the Environment, after 2003)

Netherlands, 2003 (Land Use)



Risk analysis and safety policy developments in the Netherlands (Bottelberghs, 2000)

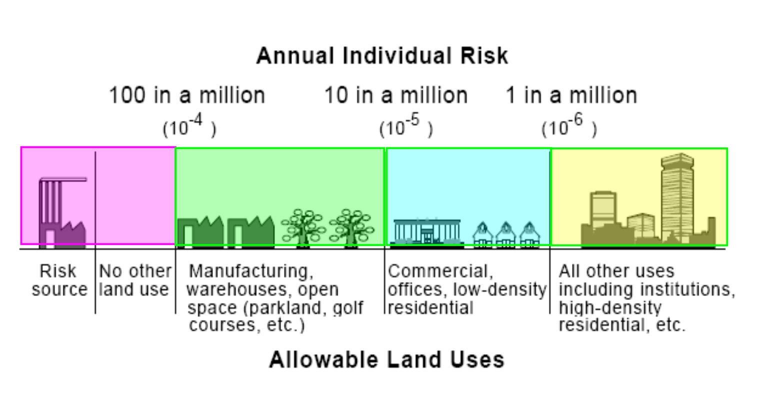
European Commission, 2006 (Land Use)



Land use planning guidelines (European Commission, 2006)
Guidance on Land Use Planning (European Communities, 1999)

Canada, 2004 (Land Use and Industrial)

$10^{-4} < IR$
No other land use but the risk source and the on-site personnel



$10^{-5} < IR < 10^{-4}$
Presence of limited number of people but easy evacuation

$10^{-6} < IR < 10^{-5}$
Continuous access but easy evacuation

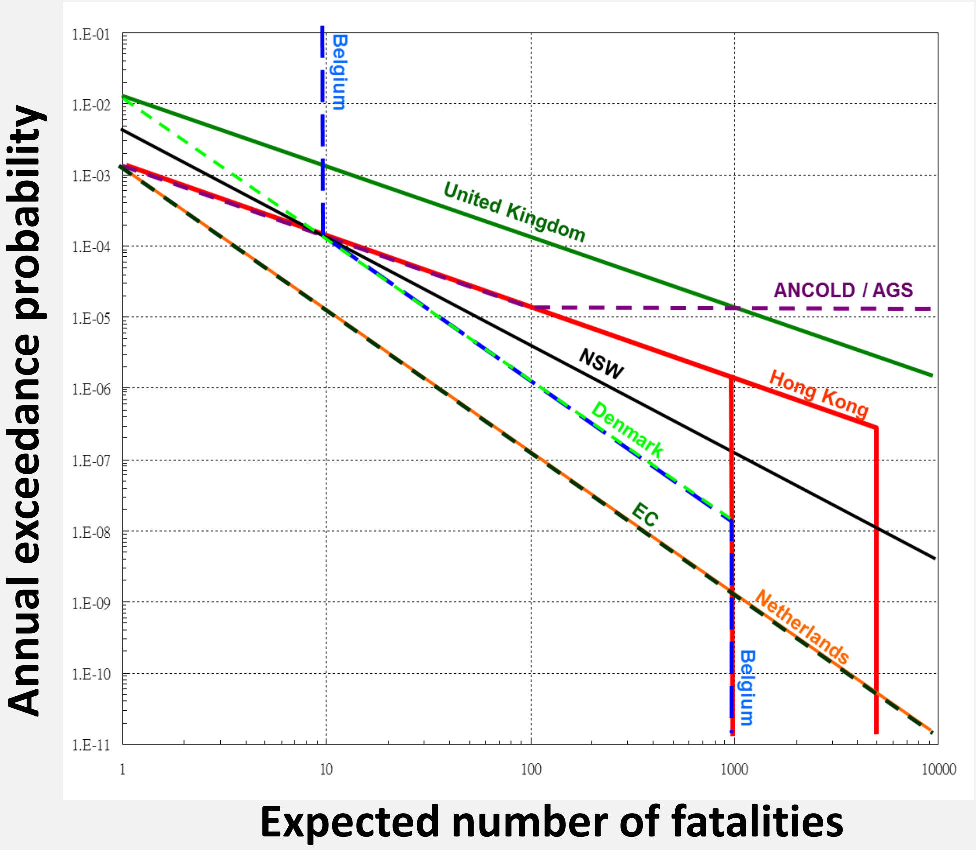
$IR < 10^{-6}$
Development is not restricted

IR – the chance that a person near a hazardous facility might die due to potential accidents in that facility. This person is usually assumed to remain at the same unsheltered location.

Risk Assessment – Recommended Practices for Municipalities and Industry (Canadian Society for Chemical Engineering, 2004)

Comparison of Acceptable Societal Risk criteria in different countries

(Ken Ho 2009; Government of Hong Kong SAR, CEDD, Geotechnical Engineering Office, Personal communication)



What is the implicit level of acceptable risk in Norway?

- **No official value for acceptable IR or PIR in Norway.**
- **Traffic:**

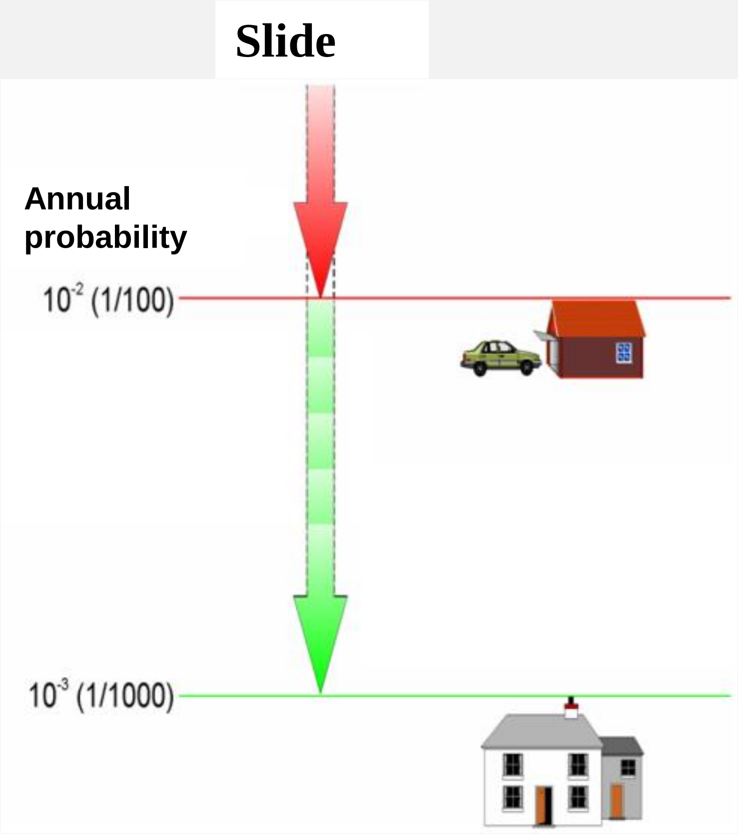
Every year 200 – 250 are killed in traffic accidents in Norway

$\Rightarrow$ **PIR $\approx 5 \cdot 10^{-5}$ / year**

The Norwegian Plan and Building Act

Definition of acceptable hazard levels for different activities / types of infrastructure

Acceptability based on frequency of exposure (rather than forces on the structure and consequences)



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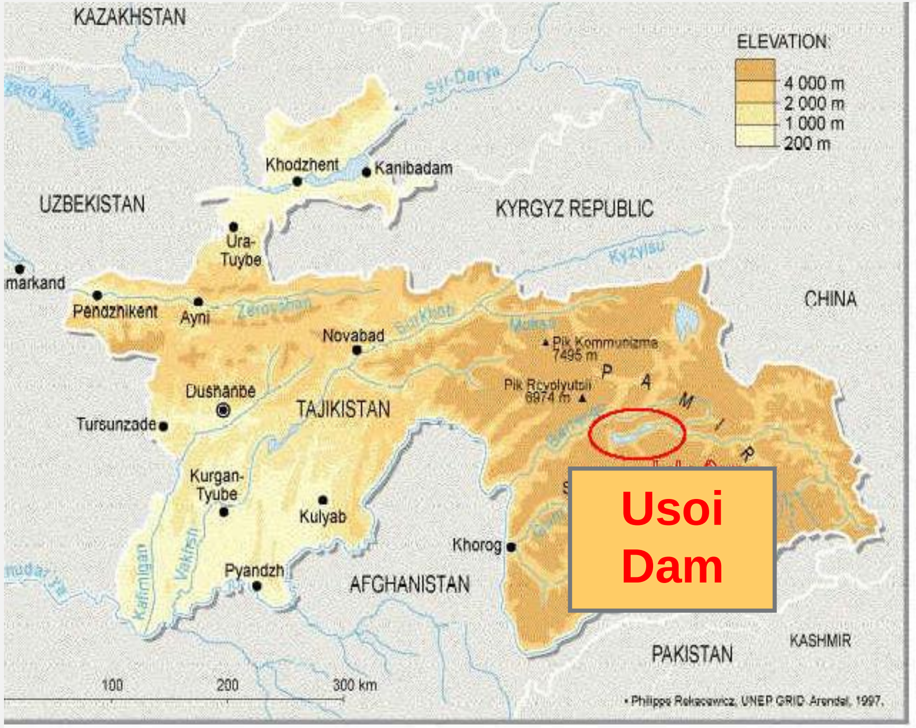
Example application of F-N curves for assessment of acceptability of risk level

Usoi Dam on Lake Sarez in Tajikistan

Usoi Dam is a 600 m high <u>landslide dam</u>.

It is the largest dam in the world!

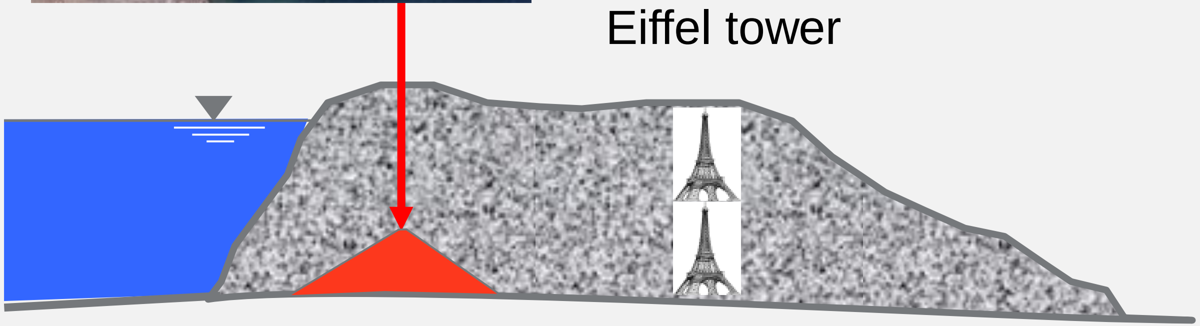


Usoi dam

The volume of the landslide was 2.2 km^3

How big is Usoi dam?

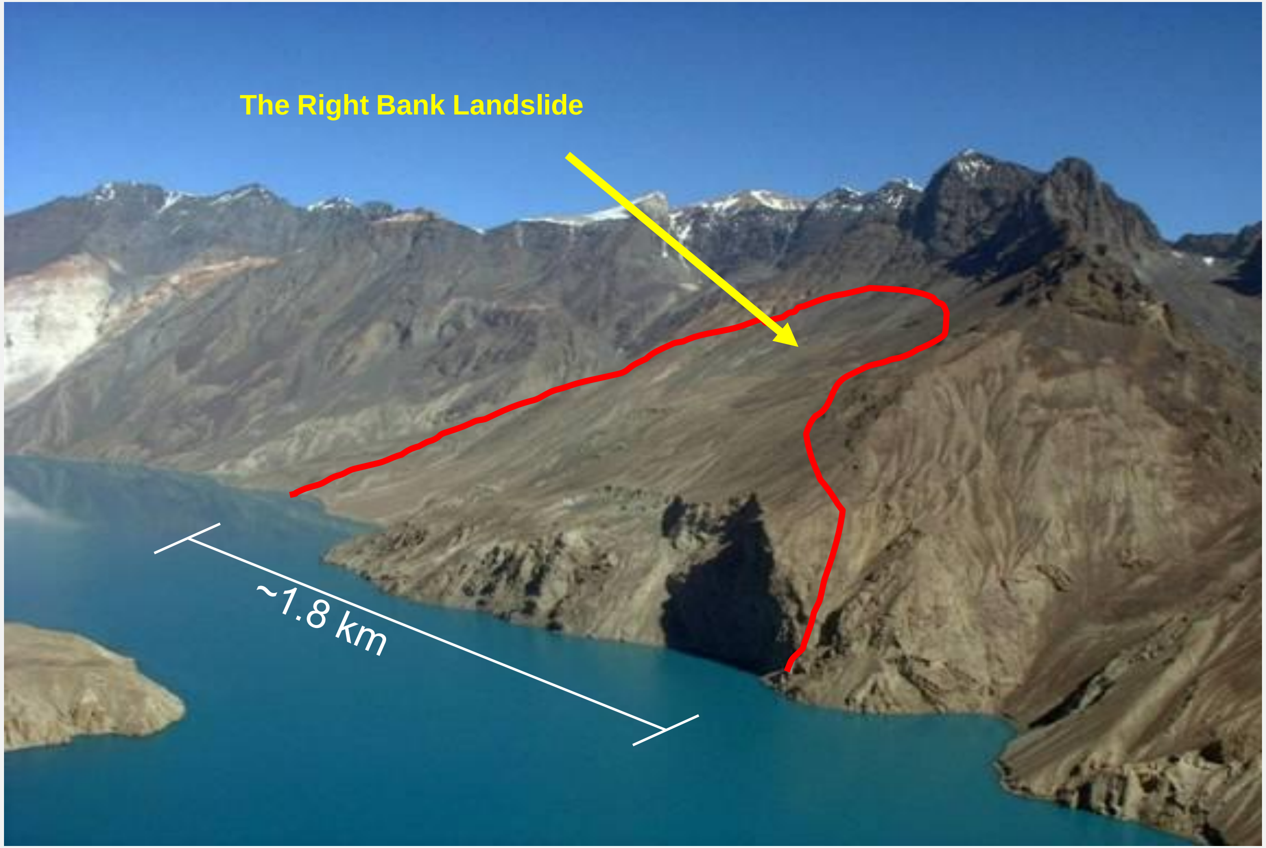
Bennett dam, 183 m high
One of the largest dams in North America



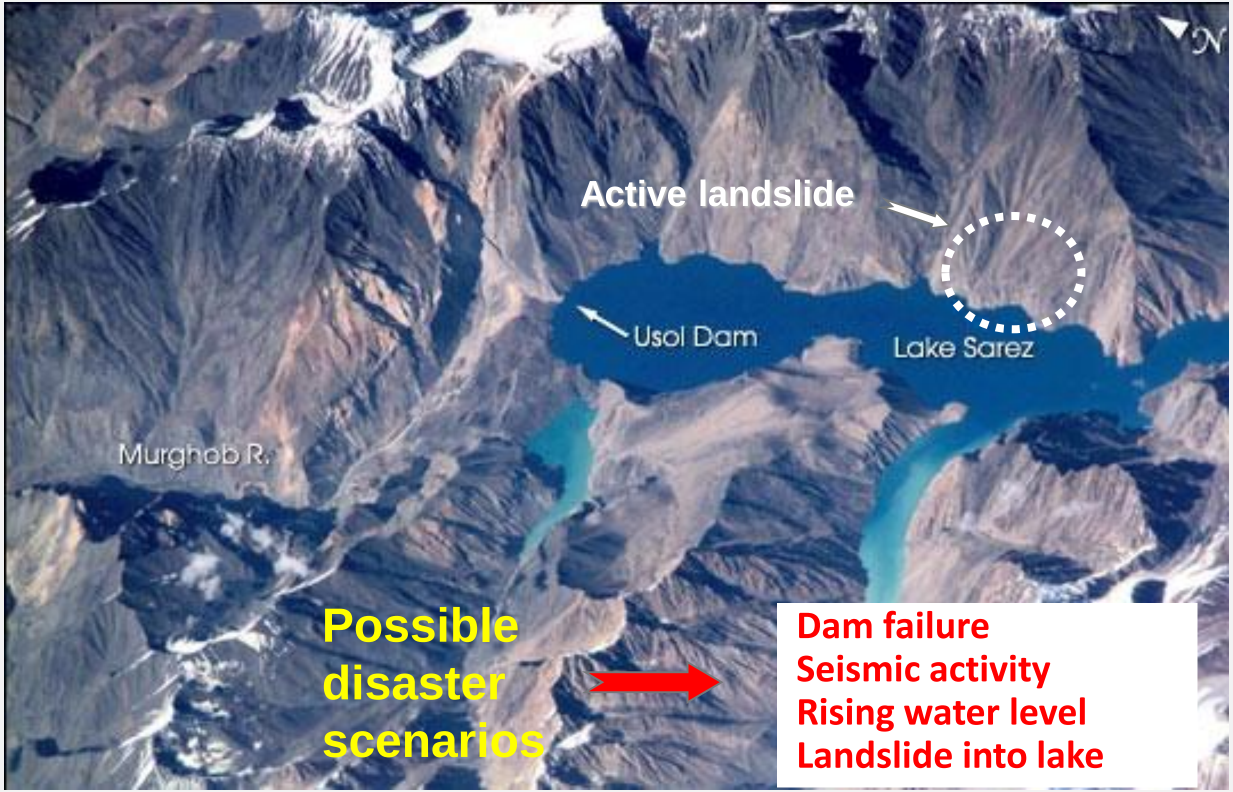
Horizontal scale of Usoi Dam is compressed

Right bank active landslide

Current rate of movement is ~15 mm/year



Disaster scenarios at Lake Sarez



Threat and consequences

- Lake Sarez behind the dam currently holds 17 km^3 of water
- If the dam fails, the flood would be a catastrophe of inconceivable

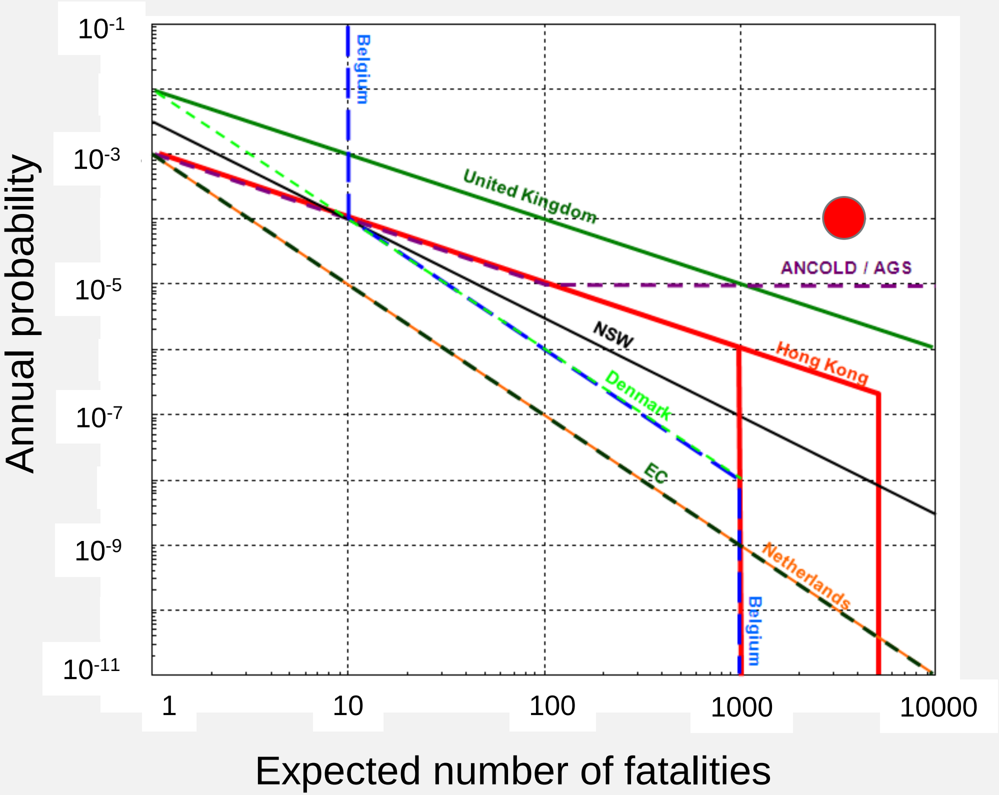
Panj valley, border to Afghanistan

Bartang Valley

Risk diagram

Annual probablility vs number of casualties

Risk with no mitigation measures



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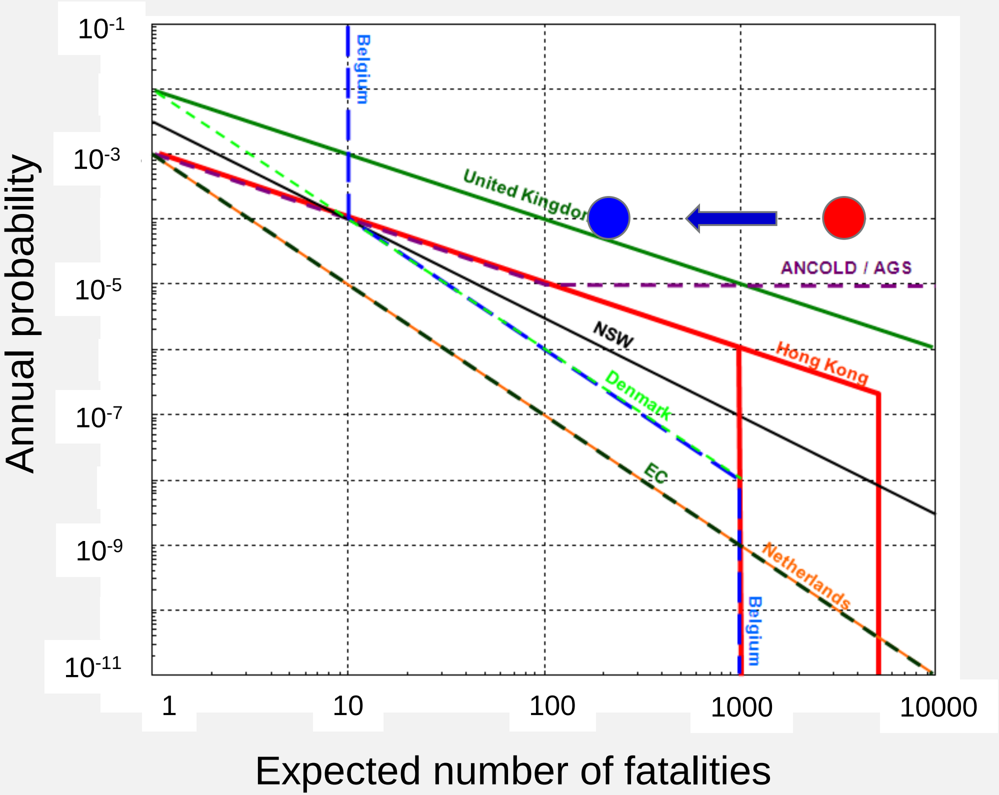
Risk diagram

Annual probablility vs number of casualties

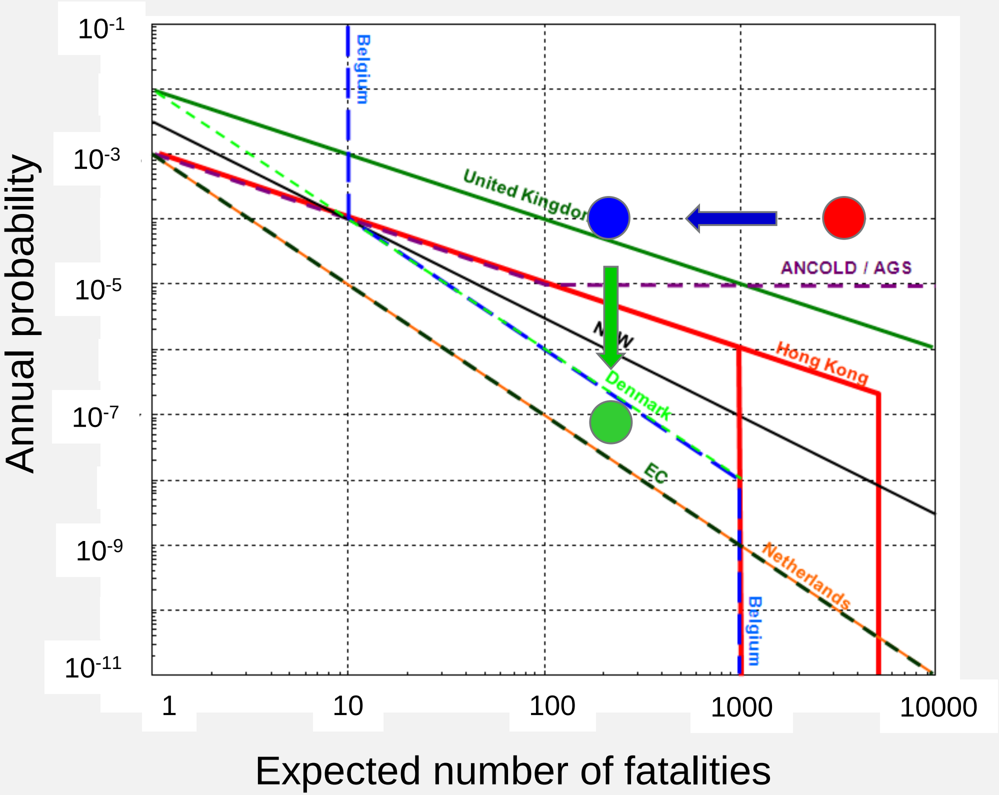
Adding an early warning system (EWS)



Risk diagram

Annual probablility vs number of casualties

Mitigation with EWS and lowering of reservoir



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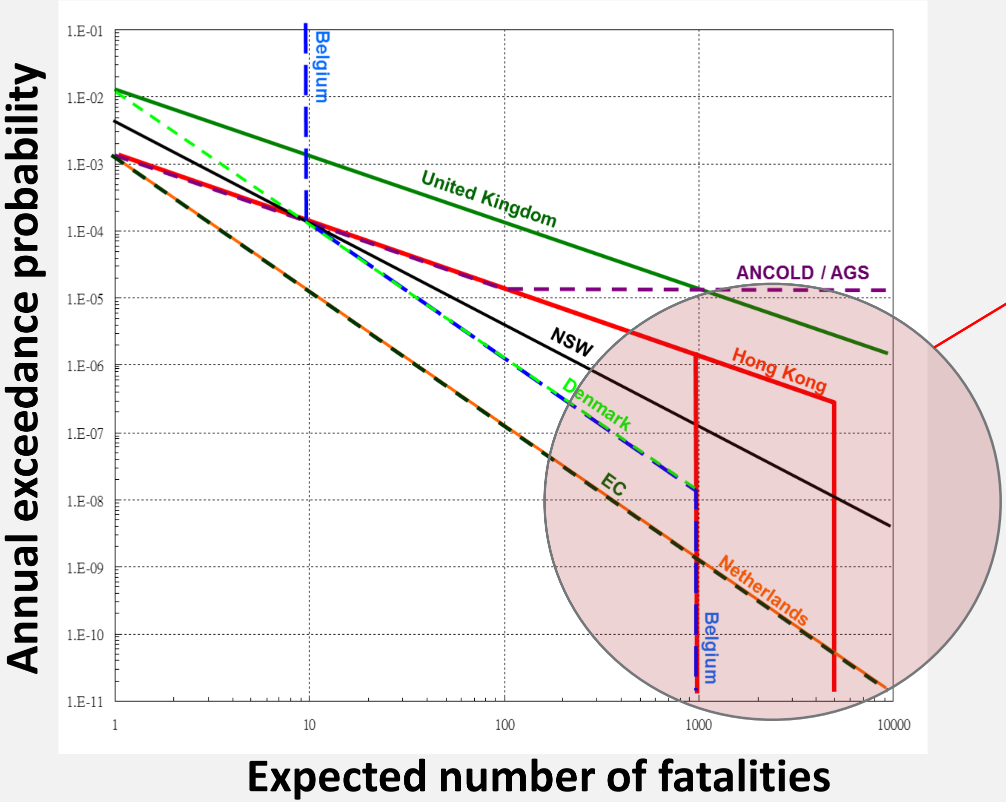
Reality check: Is Acceptable Risk concept useful as a guide for decision making?



Can we really calculate the probabilities with confidence in this region?

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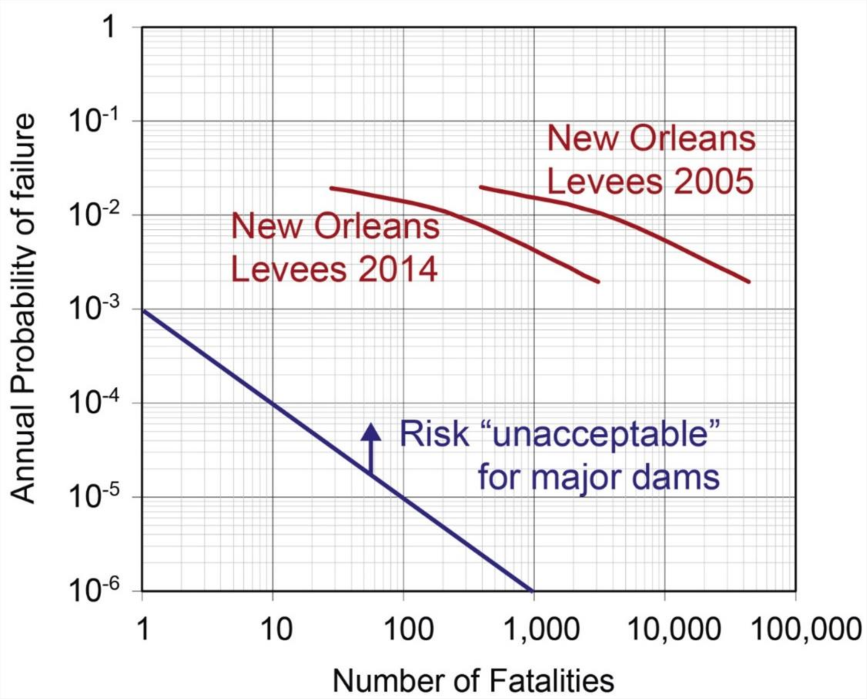
Hurricane Katrina and its impact in New Orleans

New Orleans Levees and Hurricane Katrina:
Risk diagrams (F-N curves)

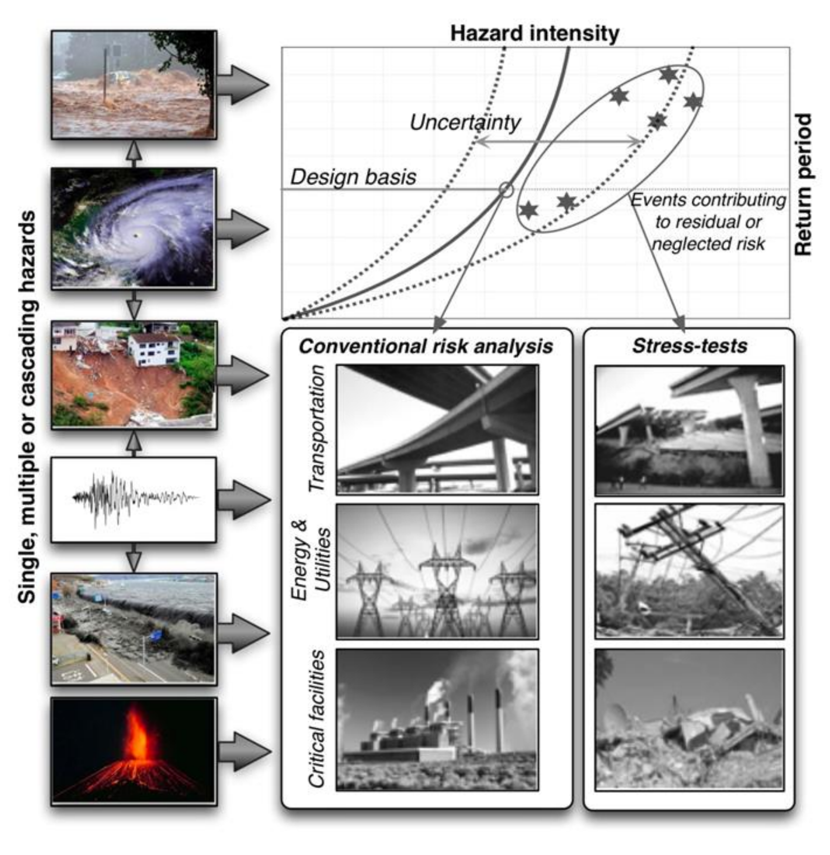
2005
"Hurricane Protection System"

2014
"Hurricane Storm Damage Risk Reduction System"



[Gilbert 2014]

Conventional risk analysis vs. stress testing for Critical Infrastructure



How can the system be made more robust under extreme events and the society be better prepared?

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Major challenges in stress testing – I. What scenario to test for?

Magnitude 9.1 earthquake in Japan

Magnitude 3.2 earthquake in Norway

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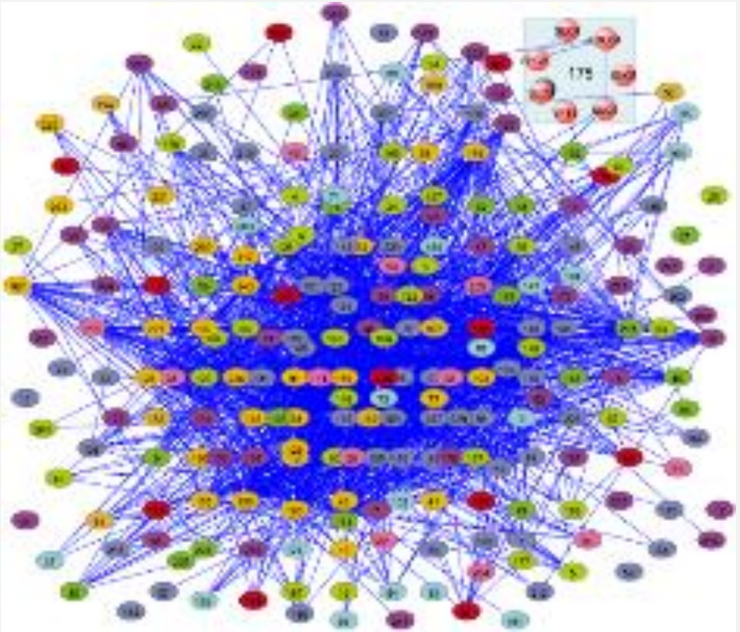
Major challenges in stress testing –
II. Coping with complex systems (and systems of systems)



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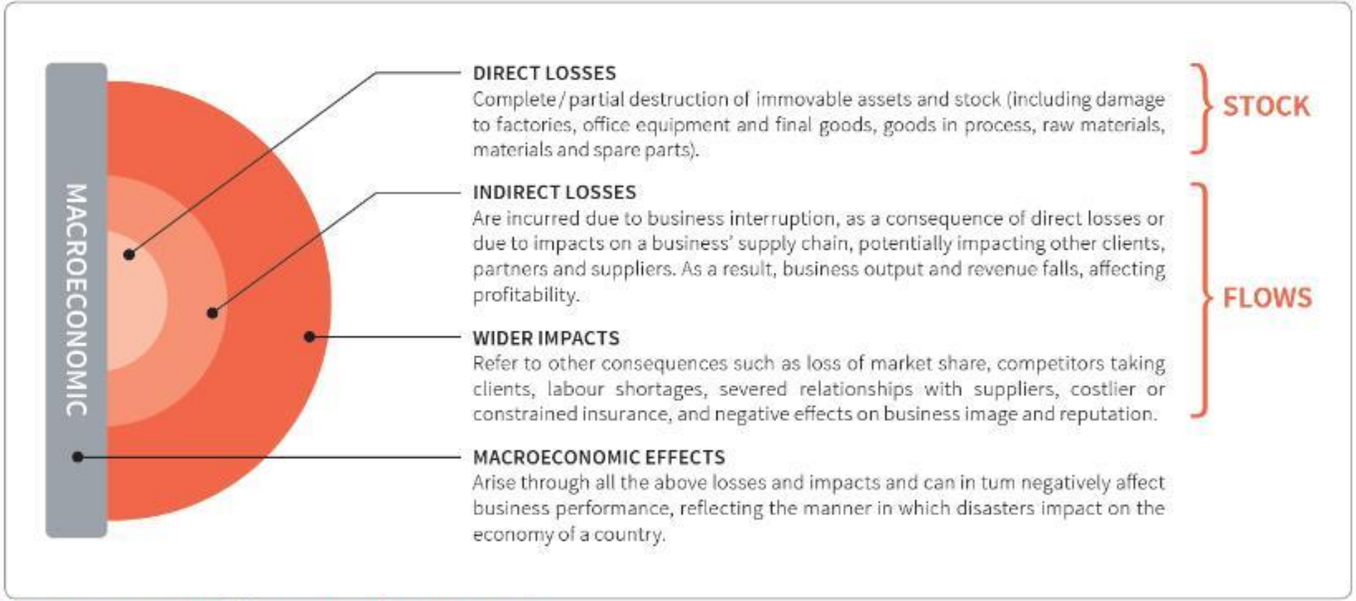
Major challenges in stress testing – III. Are we willing to accept the answers?



The growing impact of disasters on the private sector

GAR 2013 report

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On-going research in Europe on stress testing for critical infrastructure

- **STREST** (ETHZ, Switzerland) – Harmonized approach to stress tests for critical infrastructures against natural hazards. The aim of STREST is to develop appropriate stress tests for all classes of non-nuclear CIs.
- **INFRARISK** (Roughan & O'Donovan Limited, Ireland) – Novel Indicators for Identifying Critical Infrastructure at Risk from Natural Hazards. The main goal of INFRARISK is similar to that of STREST.

Thank you for your attention