From Abstraction to Reality

Or what happens when a statistical life becomes a real person?

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13-07-2015

Some BC Hydro dams

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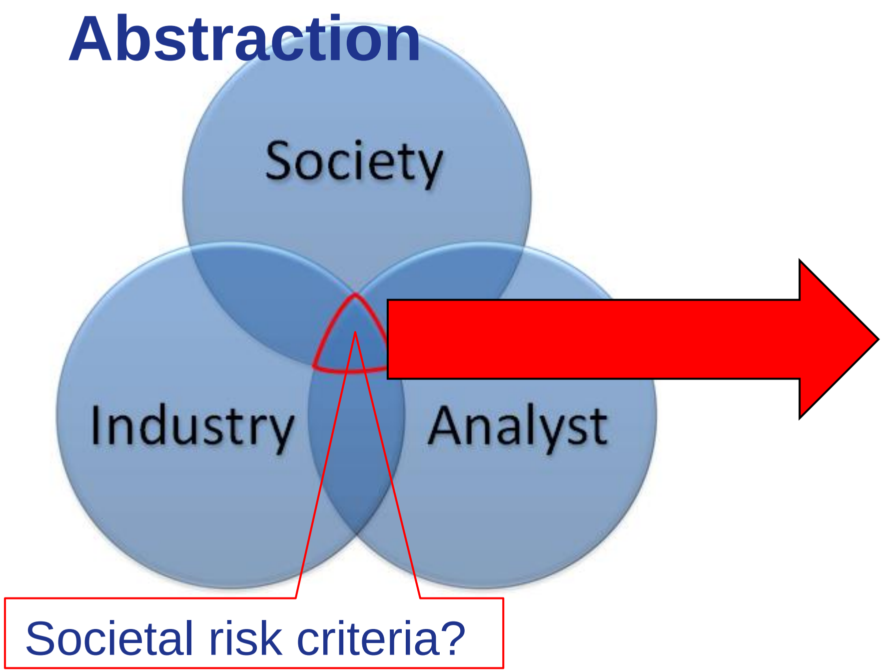
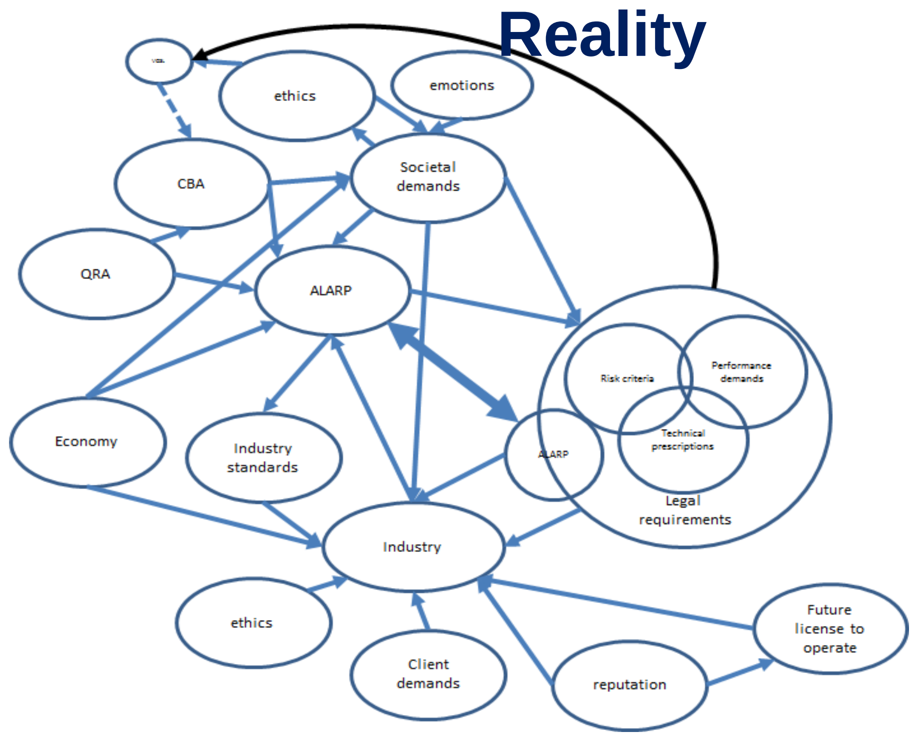
MICA DAM
Height: 242 m
Length of Crest: 792 m
Gross Capacity of Reservoir: 14,800,000,000 m^3
Maximum Flood Discharge Capacity: 4,248 m^3/s

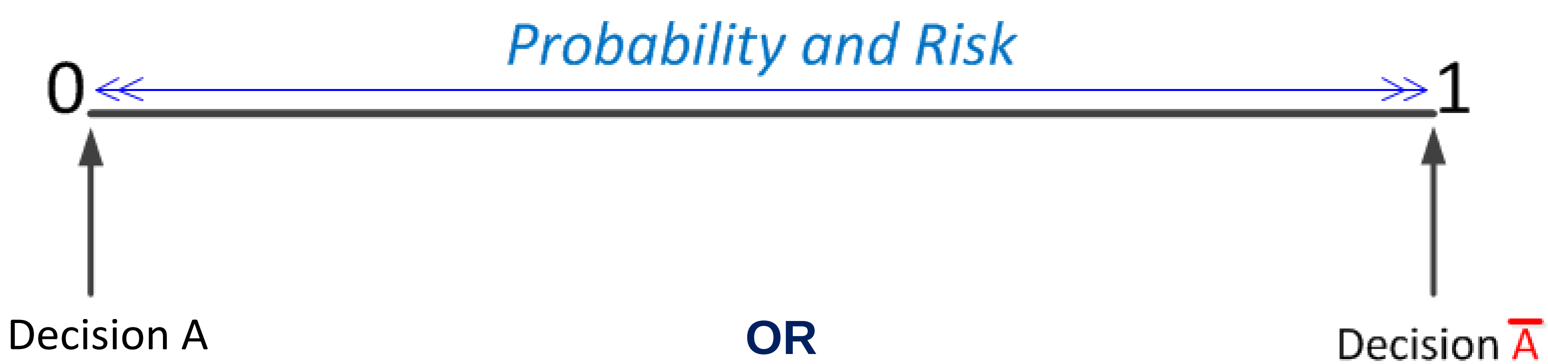
REVELSTOKE DAM
Height: 175 m
Length of Crest: 1630 m
Gross Capacity of Reservoir: 5,304,000,000 m^3
Maximum Discharge Capacity: 6,510 m^3/s

Height : 52 m
Length of Crest: 800 m
Gross Capacity of Reservoir: 10,300,000,000 m^3
Maximum Discharge Capacity of Spillways: 7,760 m^3/s

Risk decisions and the “infinite risk fence”







Launching the Malibamatso River bridge

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Monte Carlo Simulation of rock joints

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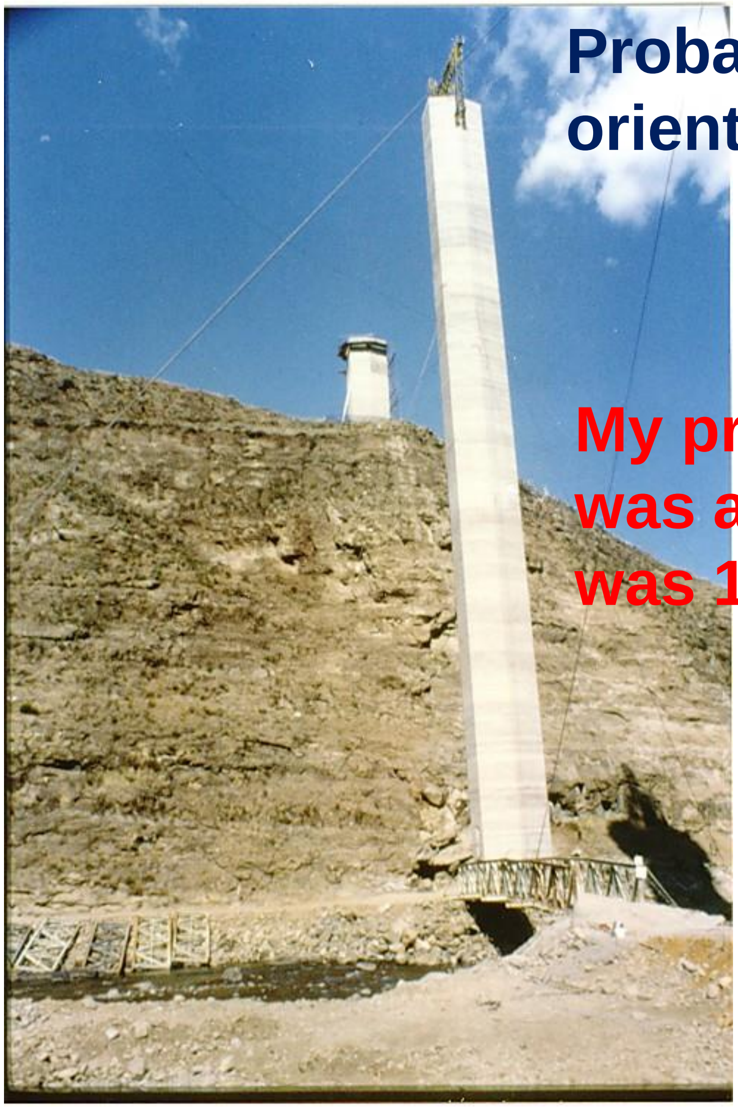

Probability of adversely orientated joints = 0.125

My probability that there was a stability problem was 1.0!

1st sign of trouble!

And stress relief!

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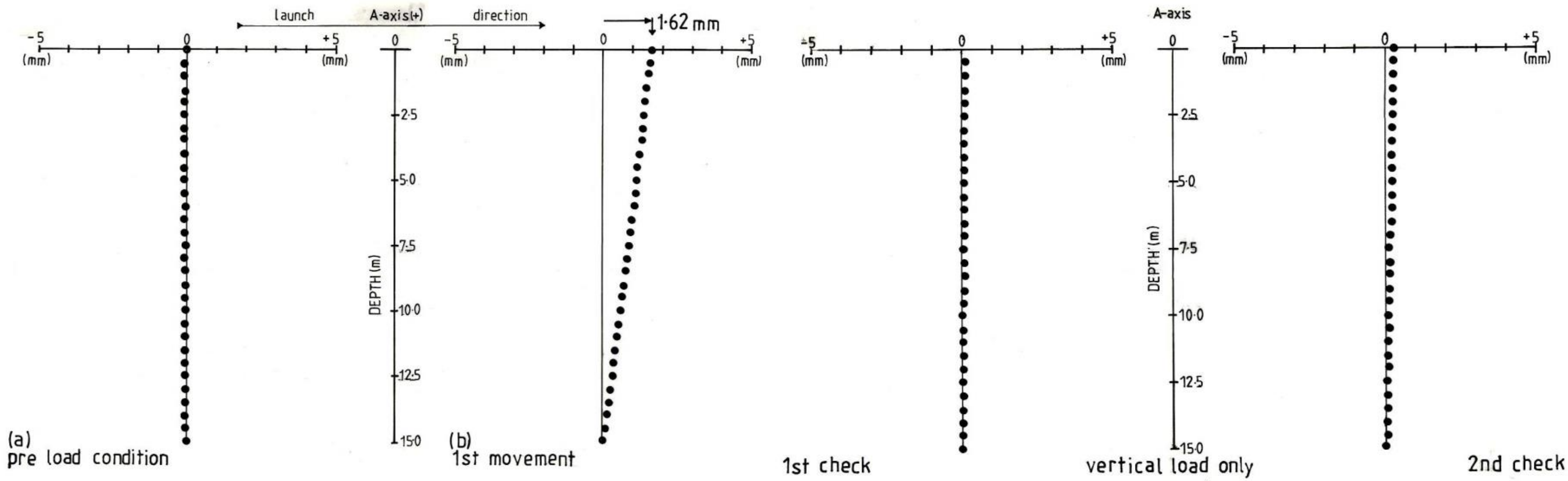
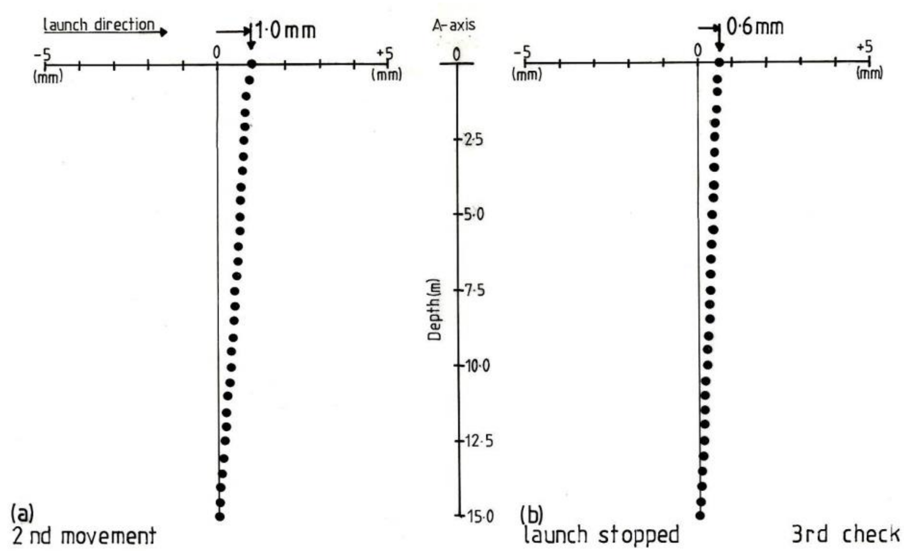


And re-stress at 50% horizontal velocity!



Traditionally...

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Engineers took it upon themselves to be the guardians of the safety of engineered systems

- The engineers gave an assurance that people could go about their daily lives in the knowledge that the engineered works did not pose a threat to their safety or to the many things that they value

But no more….*not in the societal risk context*

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In the modern context the "Engineer" no longer determines the safety of many engineered systems

- Societal values and expectations have changed
  - Despite what professional "Codes of Ethics" might state
- *The safety of people, property and the environment are highly political issues*

Distribution of risk

- *It is the nature of risk that, frequently, those who create the risk do not bear its consequences nor its wider costs. So the market does not function properly as a distributive mechanism. The State must intervene to regulate risk.*

(J. Bacon, UK Health and Safety Executive, Forum Engelberg Lecture, 1997)

Risk assessment promises...

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A rational basis for decisions

- But *rational* in whose paradigm?
  - The risk taker?
  - The target?
  - The adjudicator?
    - (a.k.a. the Regulator)

Risk decisions often emerge through a different rationality than “decision-theoretic” rationality

- Of the type that is the subject of so many scientific papers

Perhaps with the view to reducing risk “As Low as Reasonably Practicable”

3 Types of risk

Risks one can’t afford to take

- But you may be stuck with them

Risks one can’t afford to take too often

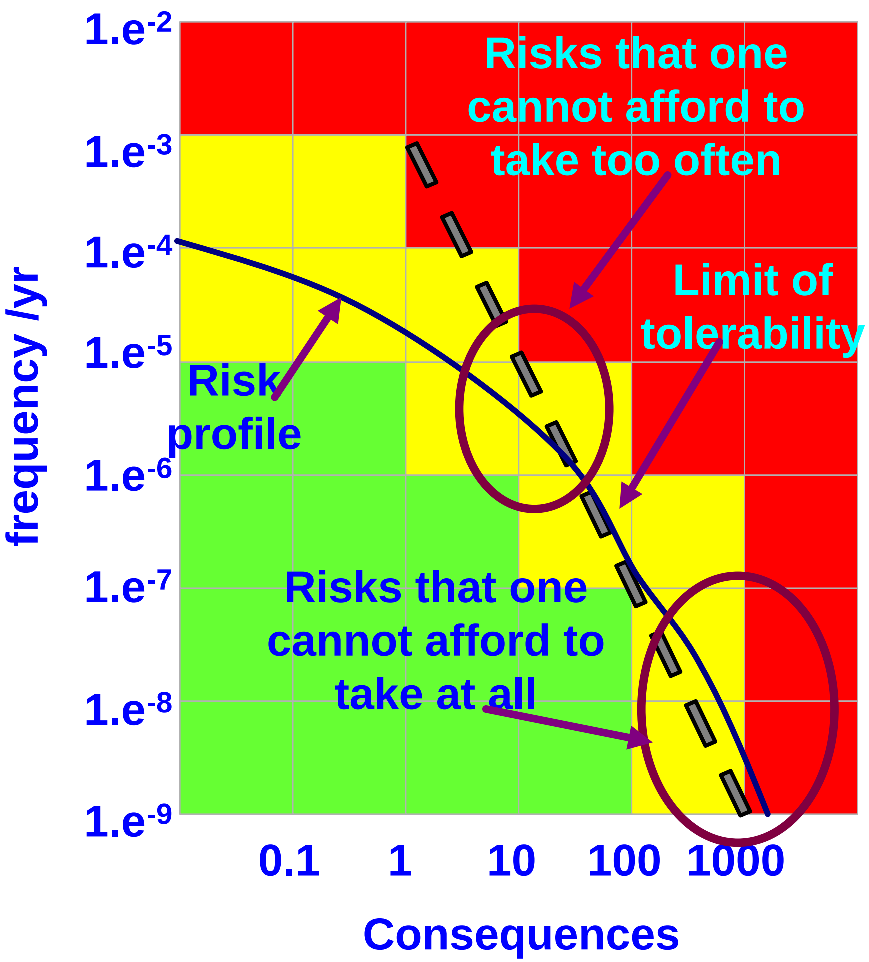
- But will take more often than you think

Risks that one can afford to take

- But often won’t

And of course “who” is “one” ?

- And what is the decision context”



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The probability that the model is right is zero!

Some models are useful

Many models are incredibly complicated - and often without proper grounding in reality

INFORMATION, MODELS AND SPECIALISATION

Knowledge

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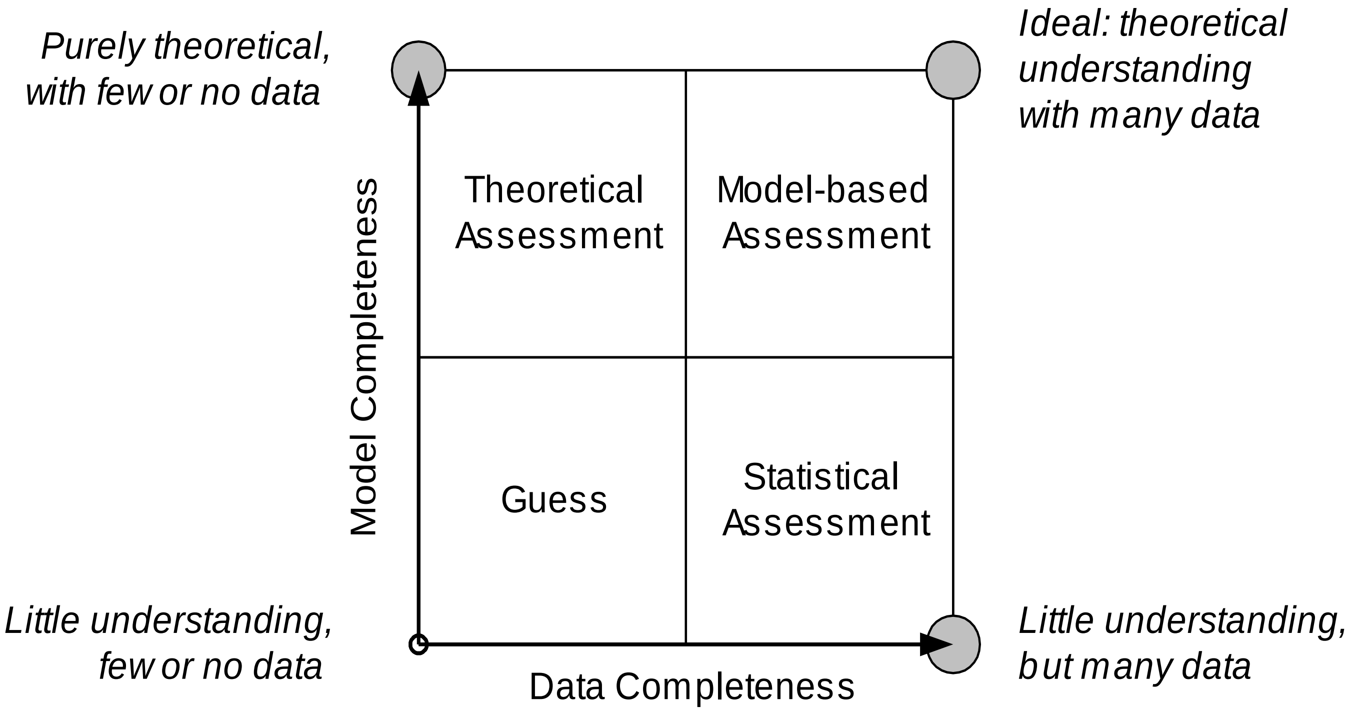
In dealing with risk, the first thing that we must accept is:

We don’t actually know!

- We sort of know with some probability of being right
- We need to know where we are in "knowledge space”
- Judgement is interwoven across the knowledge space



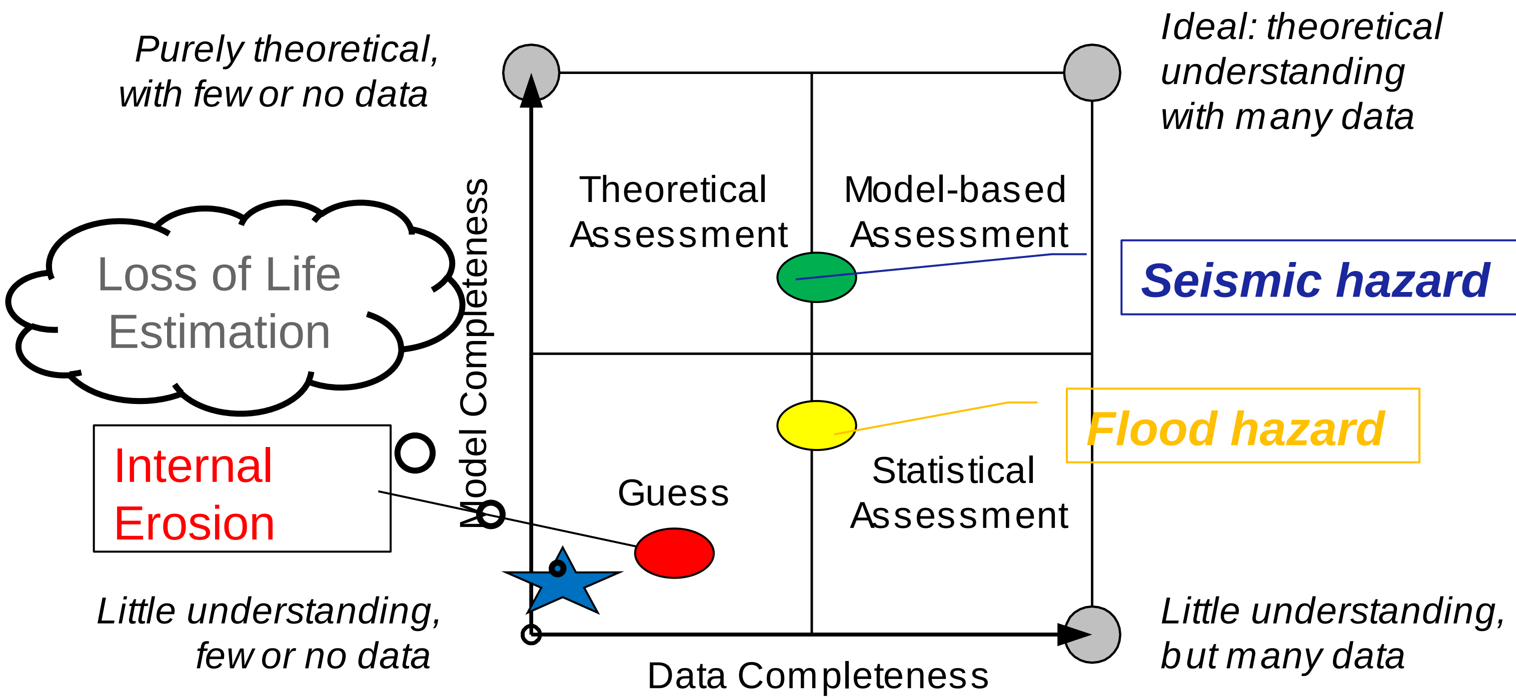
The "Risk Information" Problem

- The information you have is not the information you want
- The information you want is not the information you need
- The information you need is not the information that you can obtain
- The information you can obtain costs more than you want to pay
    - *Against the Gods, the remarkable story of risk, Peter Bernstein, 1996, Wiley*

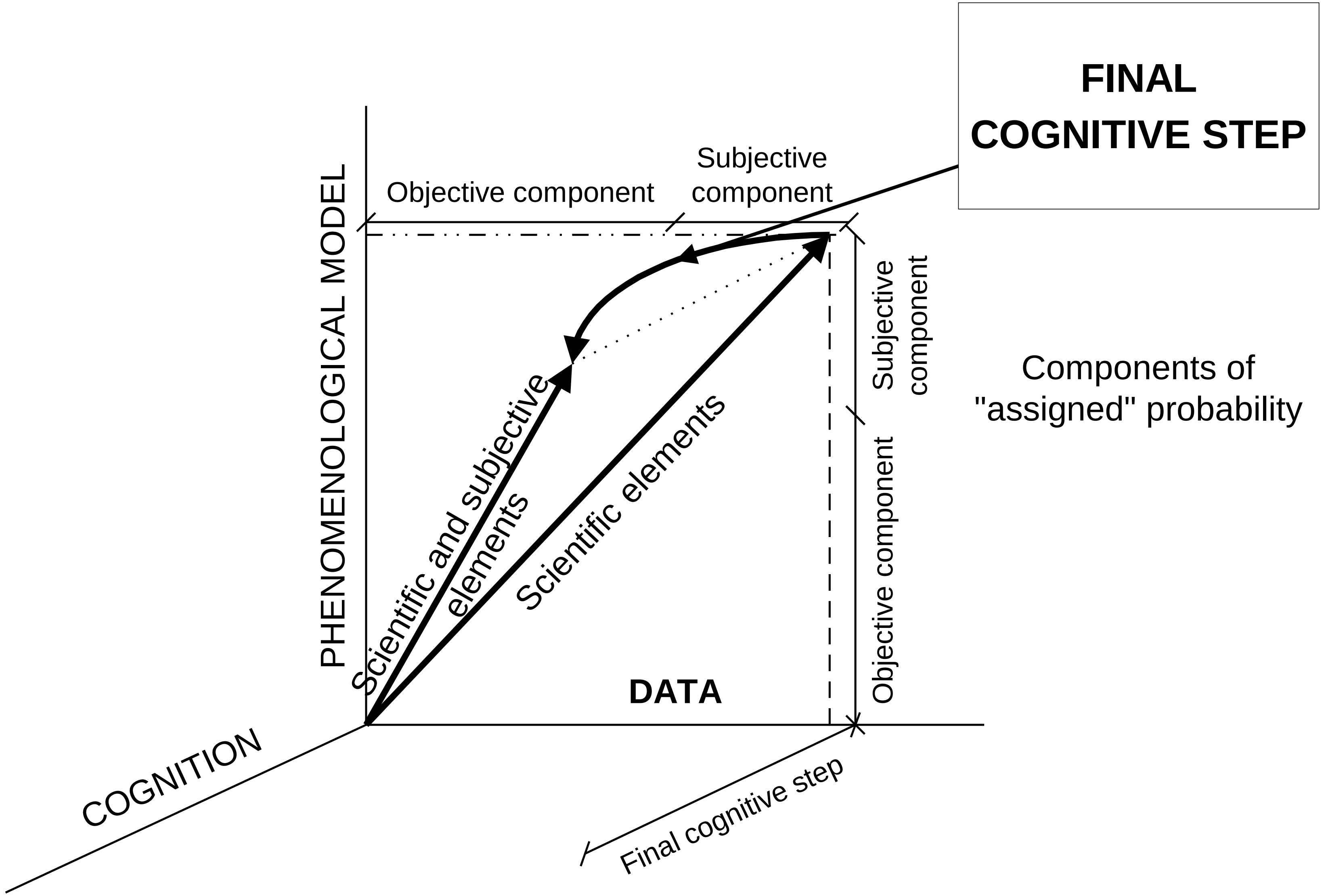
Uncertainty

- Cannot be eliminated – may be reduced – at a cost
- Cannot be avoided!

Analytical knowledge in risk analysis of dams



Subjectivity cannot be eliminated



Justifying the “judgements”?

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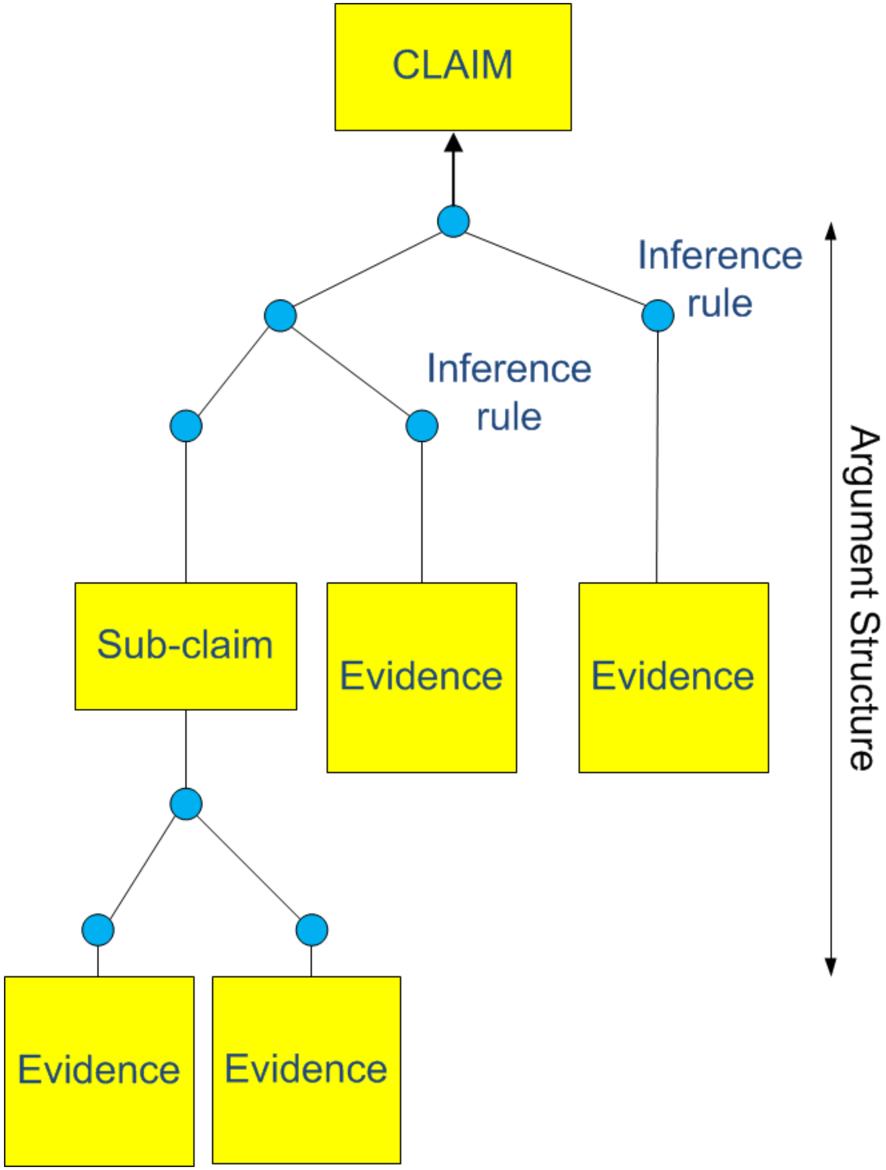

Reductionism doesn’t cut it

- Analysis is the process of breaking a complex topic or substance into smaller parts to gain a better understanding of it. “The whole” is constituted, and re-constituted, from the parts put together

2 fundamental assumptions

- The interaction between parts is non-existent, or so weak that it can be neglected
  - This is the essential condition such that the parts can be “worked out” actually, logically and mathematically and then “put back together”
- The relations describing the behaviour of parts is linear
  - Only then is the condition of summation given
    - An equation describing the behaviour of the total is of the same form as the equations describing the behaviour of the parts
    - Partial processes can be superimposed to obtain the total process.
      - The Principle of Superposition

Need systems thinking to get at risk

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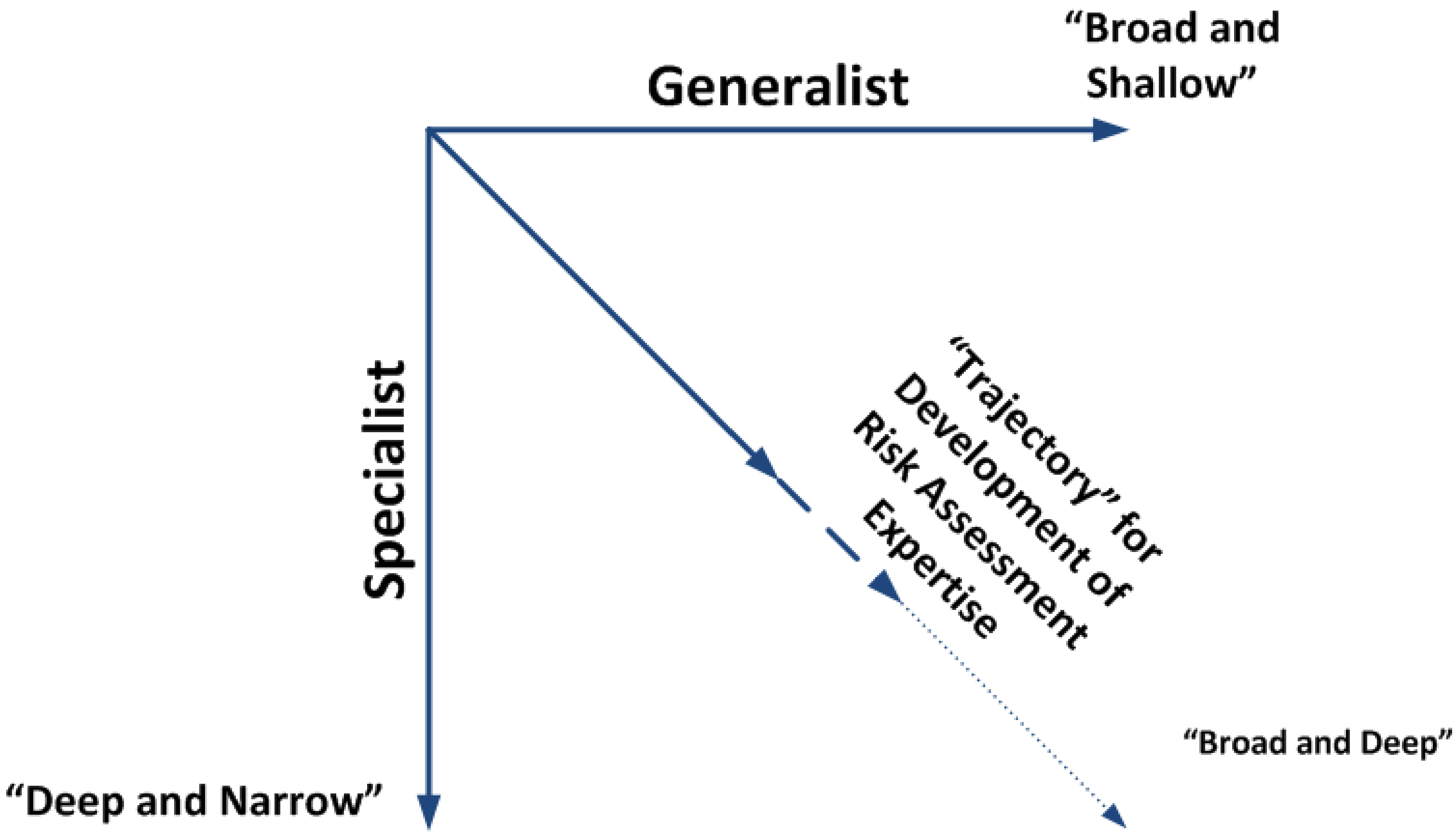
Systems:- Parts in interaction

- A “System” (or “organised complexity”) may be characterised in part by the existence of:
  - “strong interactions between parts”, or,
  - interactions that are “non-trivial”
    - i.e. non-linear
- The methodological concern of systems theory is to provide approaches to problems which, compared to the “analytical-summative” problems of classical science, are of a more general nature
- Need to be able to deal with risks that arise from
  - Unusual combinations of usual conditions

Specialisation and Generalisation

In the limits

- The generalist knows nothing about everything!
- The specialist knows everything about nothing!



Engineering Replacement of Factor of Safety?

A silver bullet?

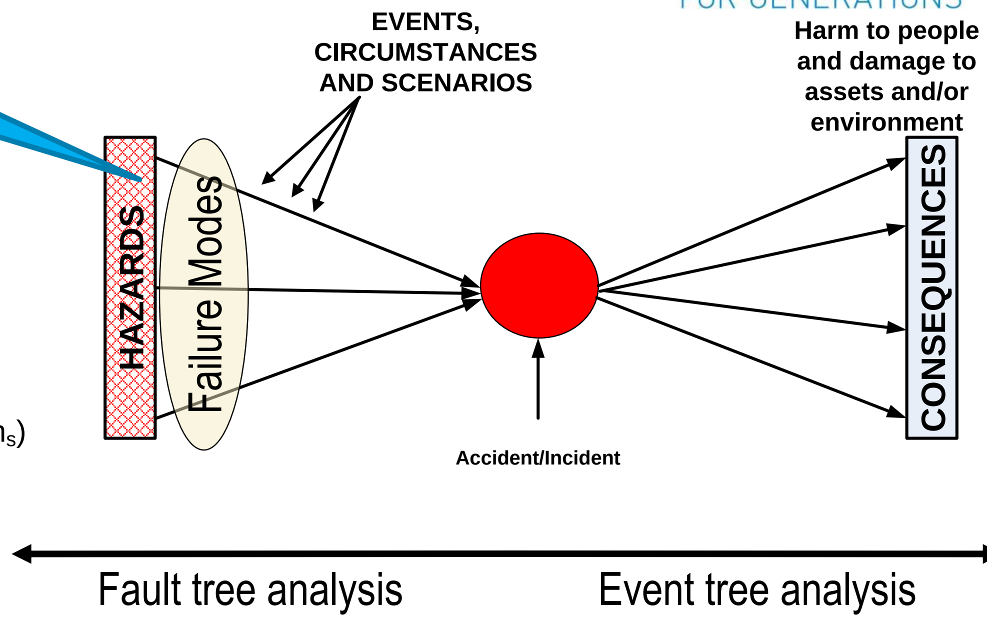
A “pipe dream”?

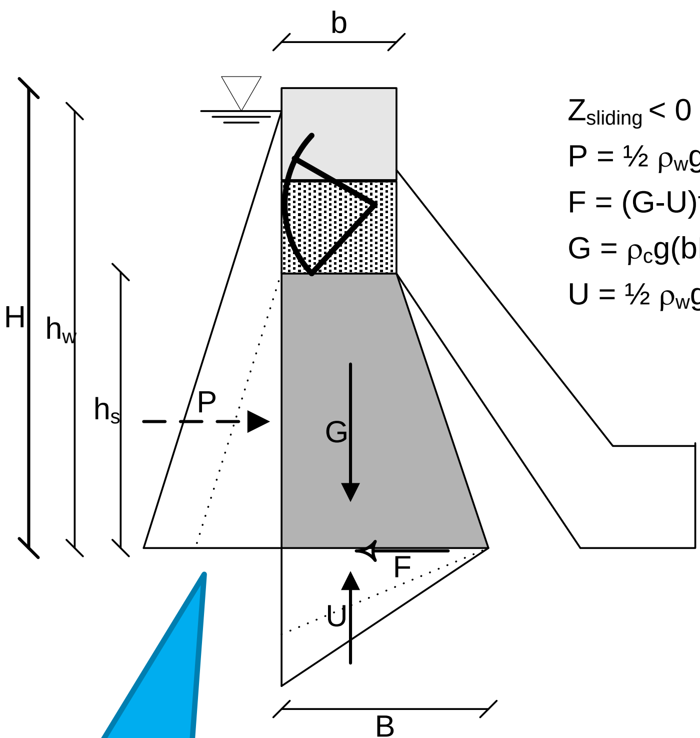
Not as straightforward as portrayed in the engineering literature!

RISK CRITERIA

Abstract view of "safe"

Risk Analysis





$Z_{sliding} < 0$ (F-P < 0)

$P = ½ \rho_w g(h_w)^2$

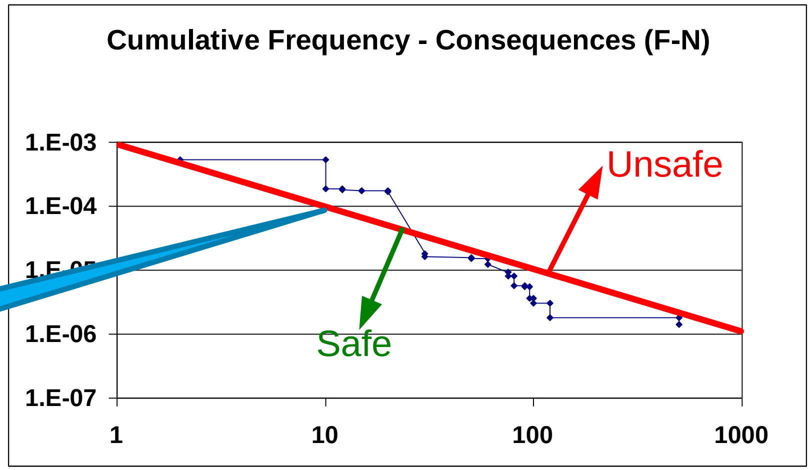
$F = (G-U)\tan \delta$

$G = \rho_c g(bH + ½(B-b)h_s)$

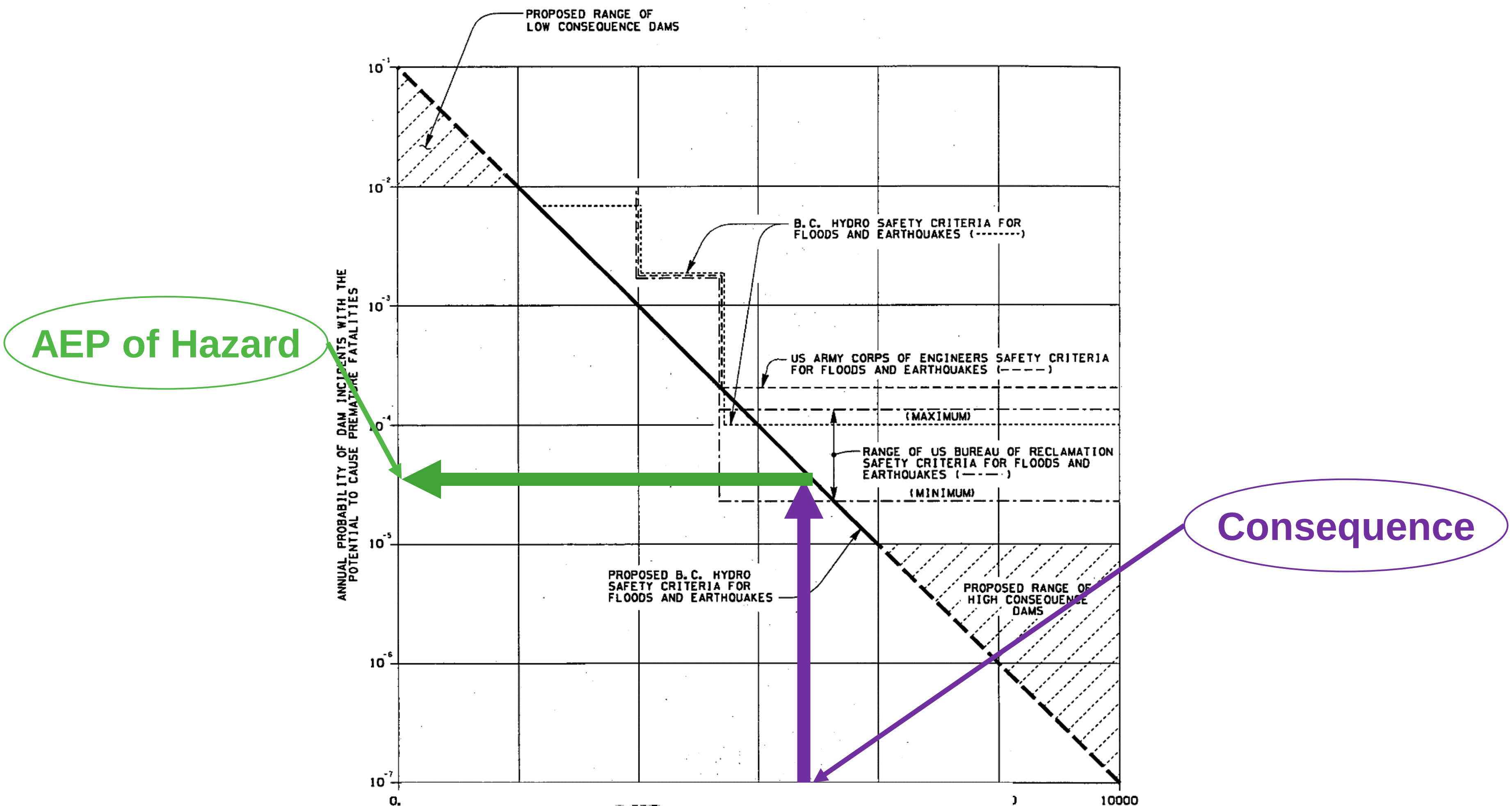
$U = ½ \rho_w g h_w B$

Models

Safety Criterion



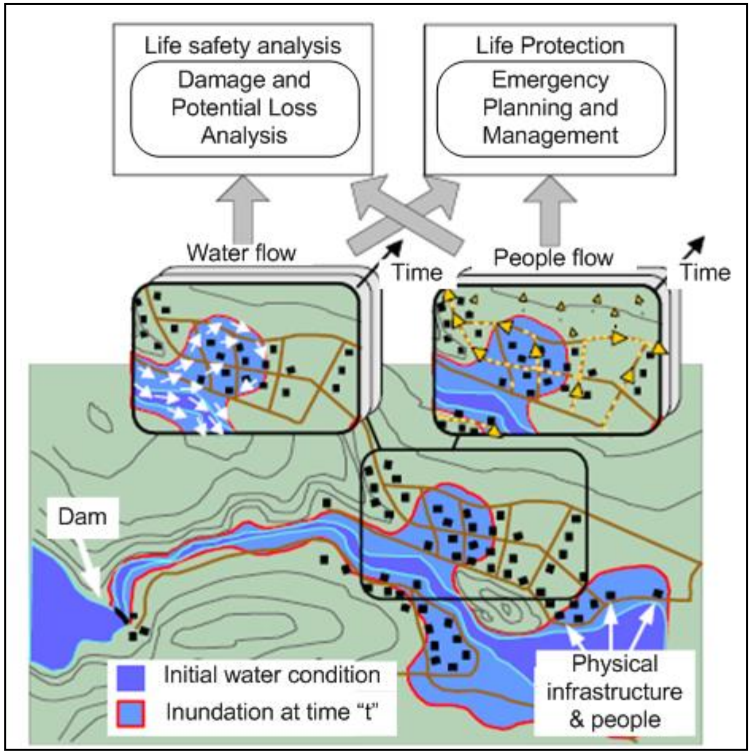
Expected value of risk-based hazard selection



$$L = 1.896(Par^{0.527})\exp[-1.819(Wt)] - 0.5$$

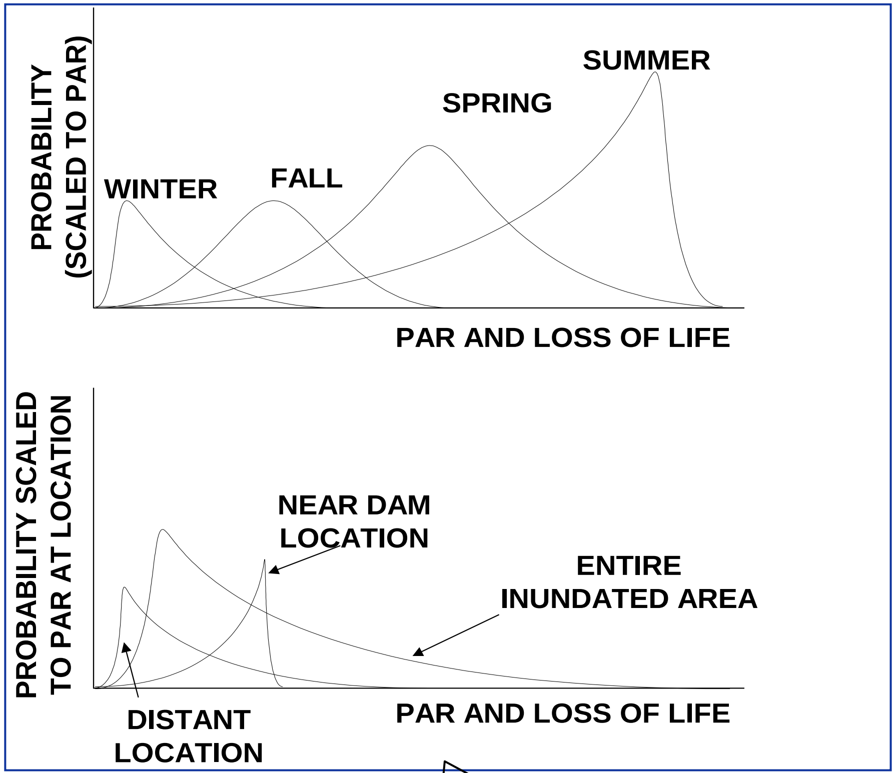
F ... ITERIA AND
PROPOSED RISK-BASED SAFETY CRITERIA FOR PROTECTION AGAINST PREMATURE LOSS OF LIFE

Flood flow – People flow interactions



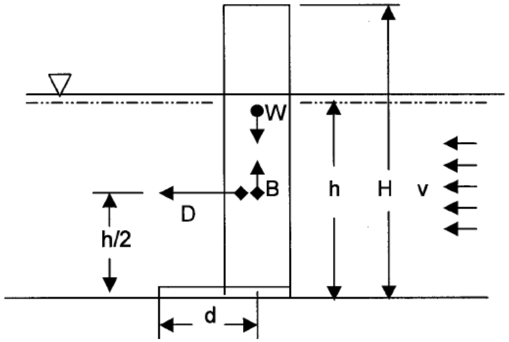
"Water Flows In" –
"People Flow Out"

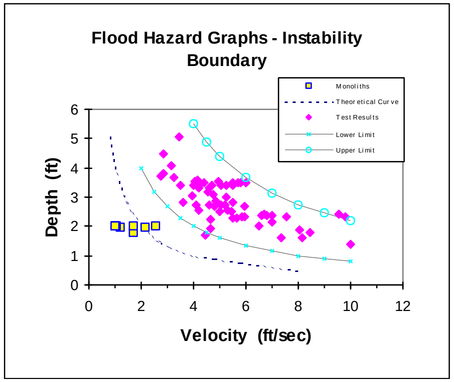
Simple concept



Complex Problem

Models of human stability





Simulations

Numerous “wrinkles” in societal risk

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Dam safety “standards” depend on the resilience of the downstream community to respond to and withstand the effects of a dam breach flood:

- This essentially means that
- similar dams with
- similar stored volumes and
- similar proximities to communities of similar sizes and environs
  - could be designed to different performance expectations.
- Simply because one community has the capacity to “run for high ground” and the other one does not
- This begs questions as to how should the resilience of a downstream community be characterised:

Emergency plans that are not matched to the characteristics and response capabilities of the people at risk are simply plans that may not work as intended

In reality

SAFETY DECISIONS

Coquitlam Dam and Reservoir

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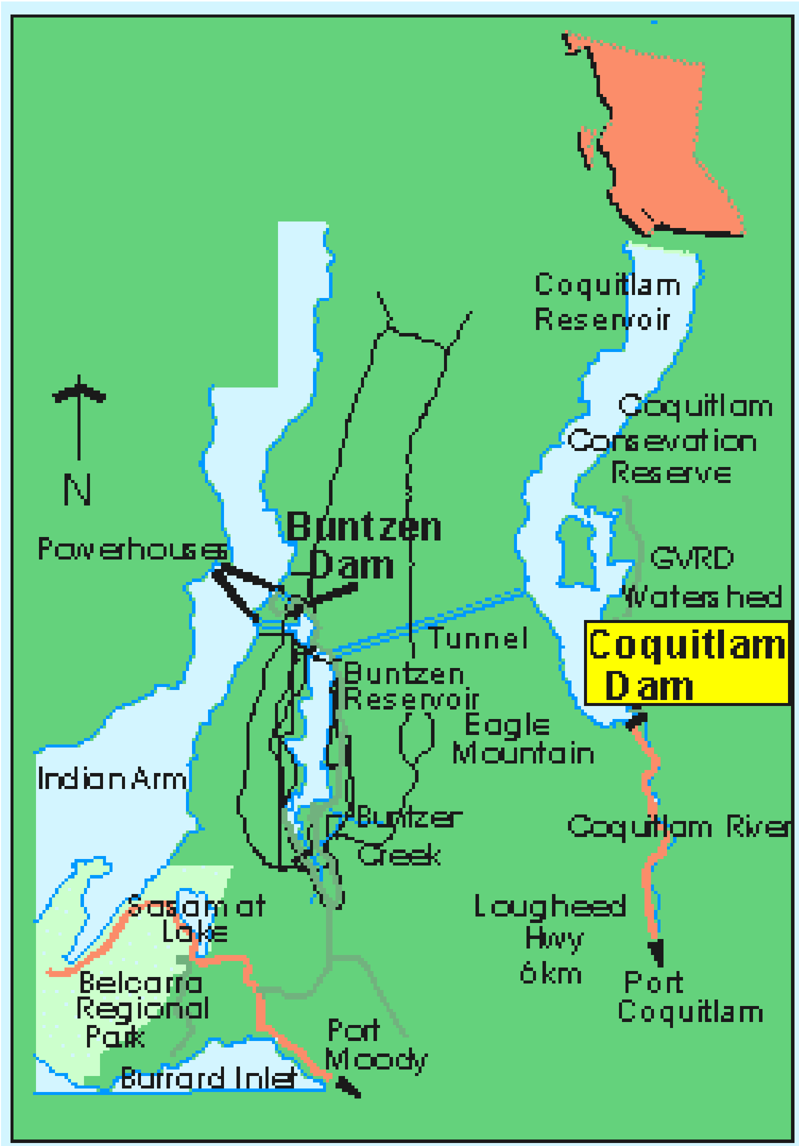
Coquitlam Dam & Lake



Reservoir Area 12.5 km^2 (El. 154.86 m)

Reservoir Storage 220 million m^3

Power Generation at Buntzen **(76.7 MW)**

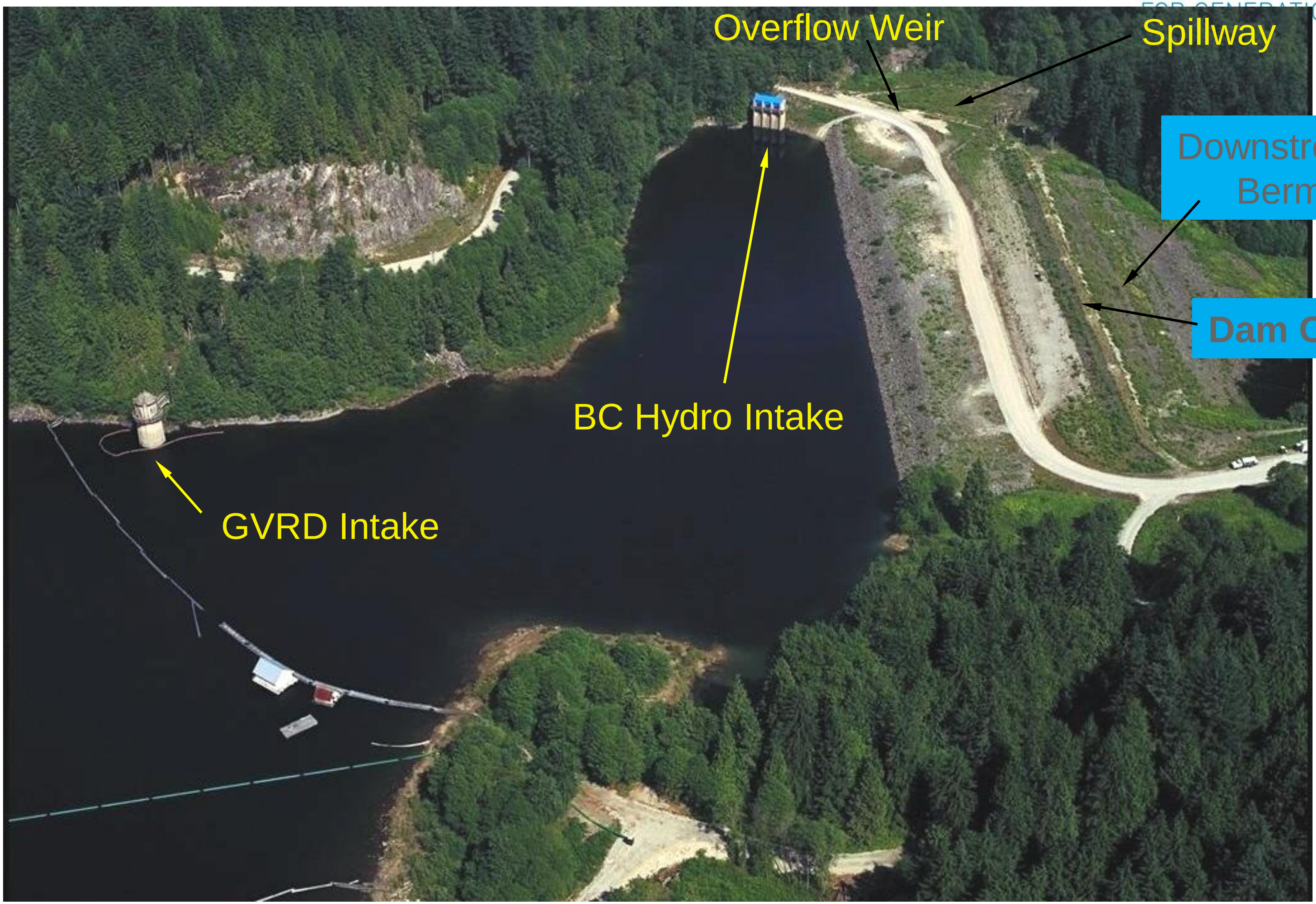
Water Supply for Greater Vancouver **(0.2 to 7.9 m^3/s)**

Fish Release (minimum 0.57 m^3/s)

Small dam (30m high) and reservoir in the BC Hydro context

Extremely severe consequences of failure

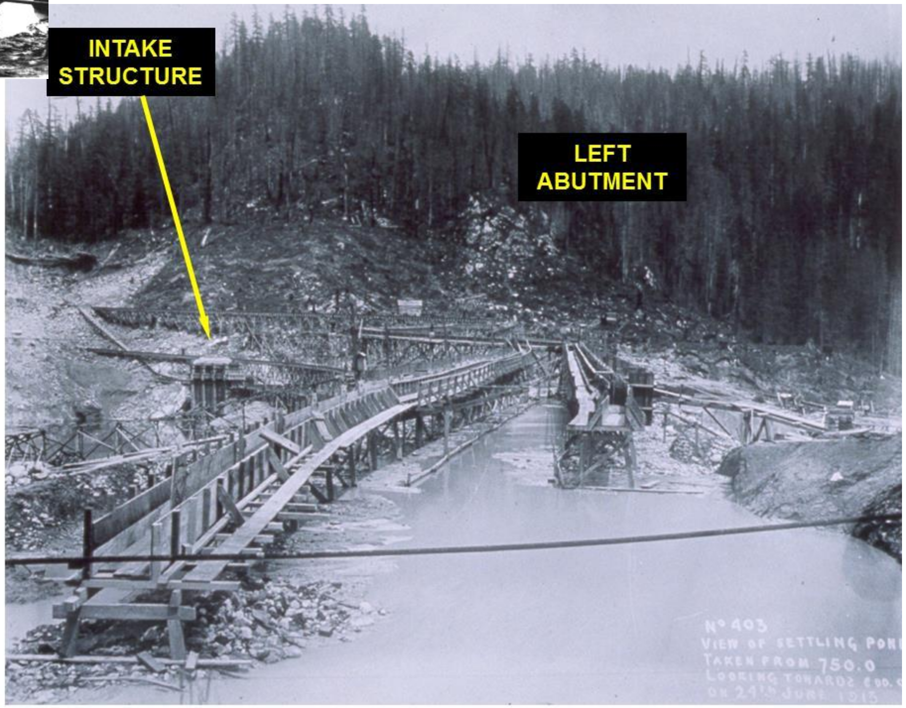
Coquitlam Dam



Coquitlam Dam - Original Construction

u/s BORROW AREA

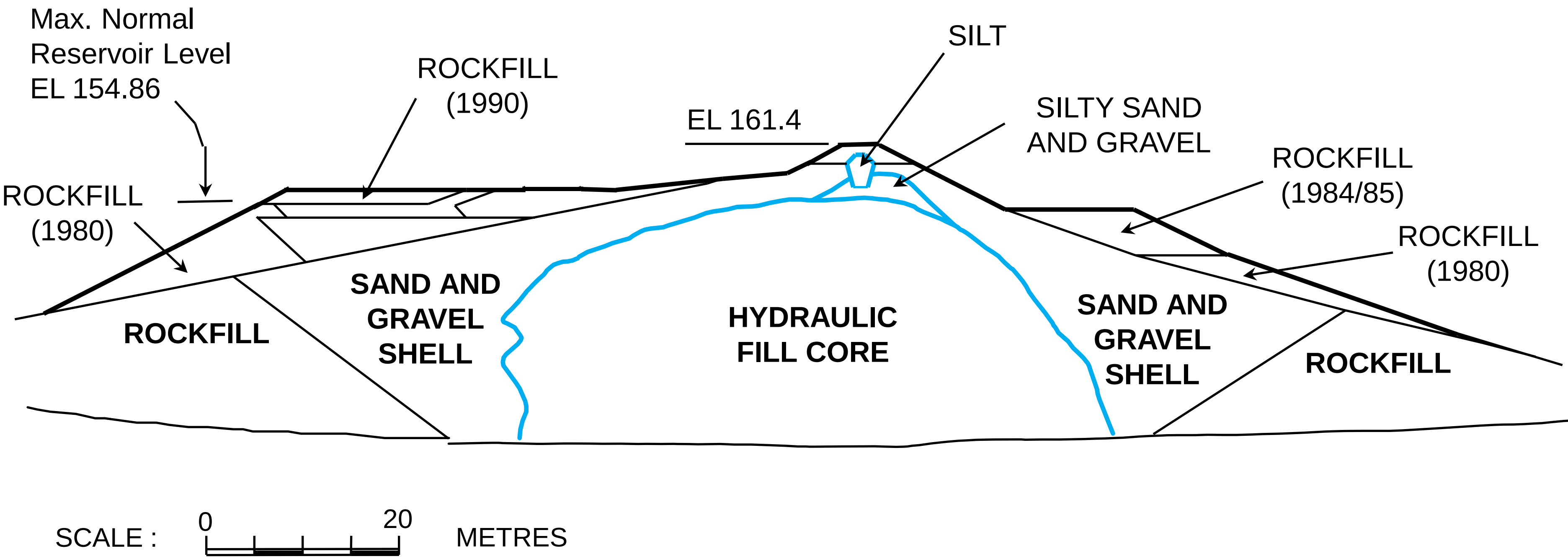
Note :
u/s and d/s
flumes come
close to each
other near top
of dam.



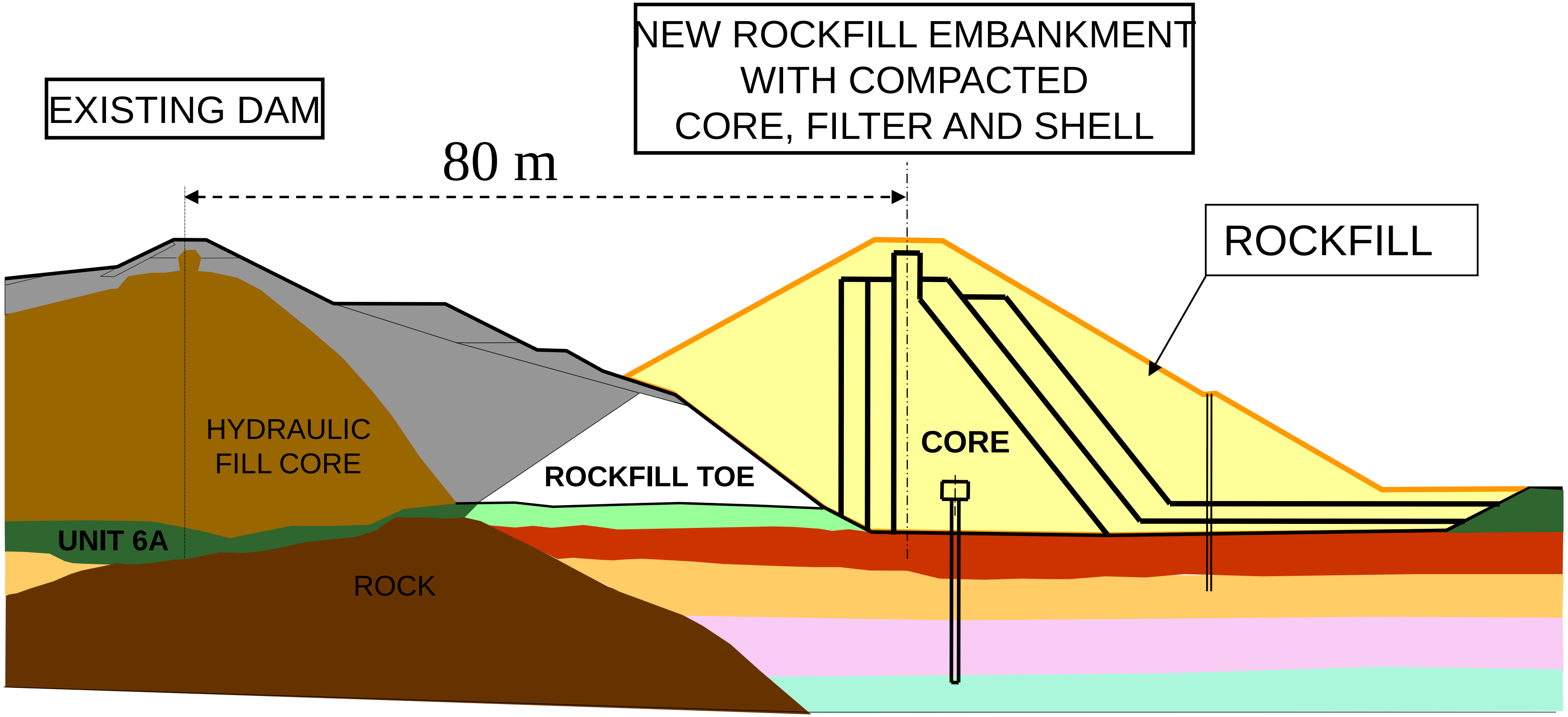
VIEW FROM RIGHT TOWARDS LEFT ABUTMENT

Coquitlam Dam Cross Section

- Hydraulic fill dam (1911-1913)
- 30 m high



Coquitlam Buttress Dam



“Forces” around a hazardous activity

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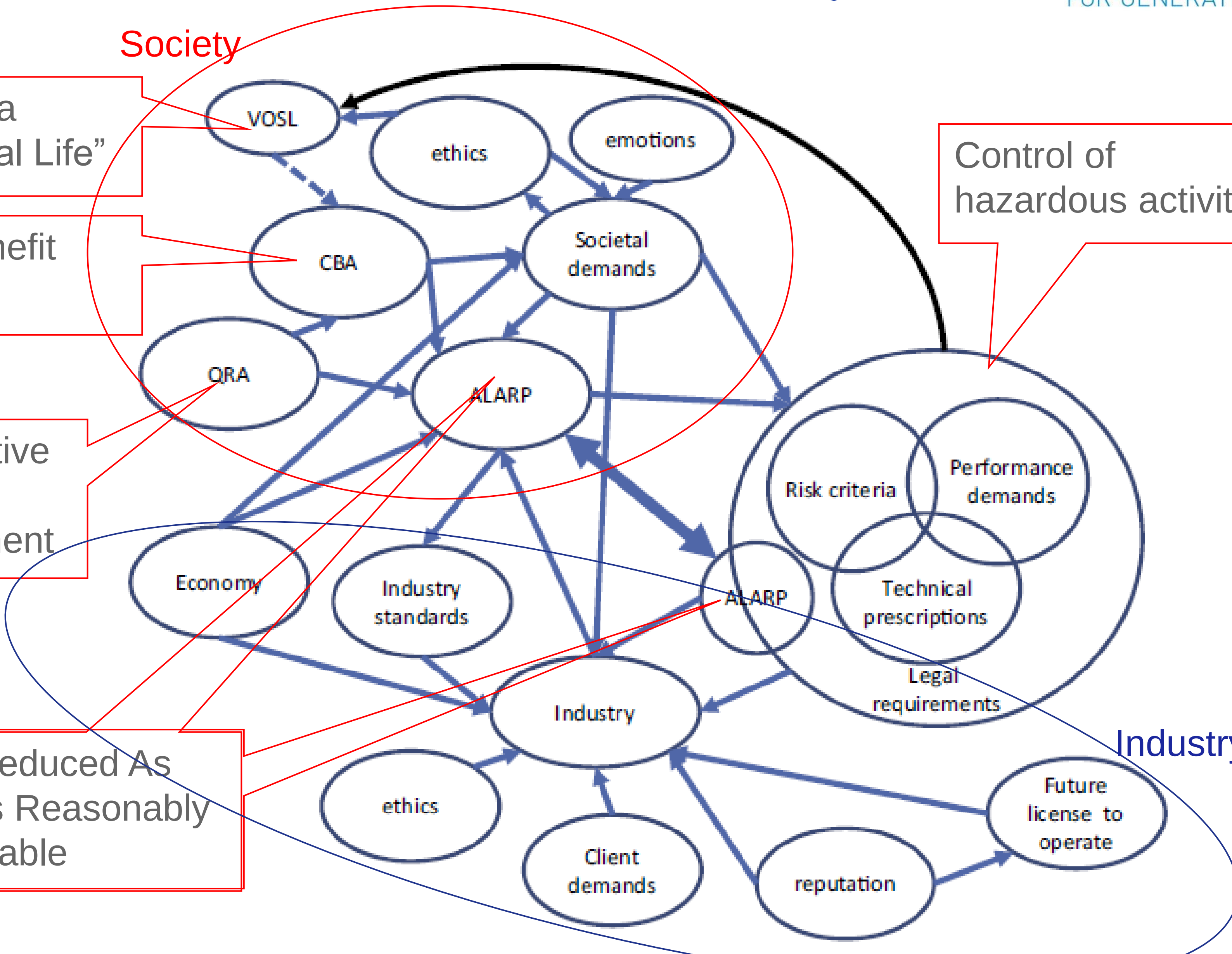
Value of a “Statistical Life”

Cost-Benefit Analysis

Quantitative Risk Assessment

Control of hazardous activity

Risks reduced As Low As Reasonably Practicable



ALAP and ALARA (origins in USA)

As Low as Practicable

- Radiation Protection in the 1950's in the USA
  - In 1970 title 10 of the Code of Federal Regulation Parts 20 and 50 specified that exposure to radiation should be kept as far below the limits as was reasonably practicable

ALARA

- Radiation Limits
  - By 1970 the notion of limits, to be used also as reference, was part of the protection construct. In 1979 ALAP changed in to As Low As Reasonably Achievable
  - In radiation protection the ALARA principle is used as a ratchet mechanism to update – i.e. lower – the radiation exposure limits as a function of the developments in science and technology. When the limit technically can be set lower it will.

ALARP and SFAIRP (origins in UK)

- As Low as Reasonably Practicable
  - Reduce Risk As Low As Reasonably Practicable
- So Far as is Reasonably Practicable
  - Control danger in So Far as is Reasonably Practicable

Have different origins (the UK)

- The principle that measures should be reasonable and practicable was already used earlier in the United Kingdom in the Electricity Regulations 1908, in the Spinning by Self-acting Mules Regulations of 1905 reg 3 and in Section 5 of the Salmon Fishery Act 1861. Another early use was found in the Chaffing Machines Act 1897, the Threshing Machines Act 1878 and the Alkali Act Amendment Act 1874.

Not the same

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ALARP and SFAIRP are not the same

- even if an authoritative source suggests that they are
  - The important point here, that is generally not made, is that the two qualifications are applied to quite different properties.
    - ALARP is applied to the level of 'risk'
    - SFAIRP is applied to being 'safe' from the danger or the hazard
  - The key question is whether being 'safe' is determined solely by the level of 'risk'.
    - Safety is relative and influenced by values whereas risk is quasi-objective and held to be value-free. The numbers mean the same to everyone, which of course is why risk became the parameter or property of choice.
    - In practice, the difference means that the requirement 'safe SFAIRP' focuses on reducing the hazard. This is what the law requires and on which the courts pass judgement.
      - But do the numbers really mean the same to everybody?

ALARA and ALARP

ALARA seems to imply that achievable includes that it could be theoretically possible to go lower even if it has not been demonstrated in any way to be feasible in practice.

- ALARA then demands to do work, research, engineering to make it work.

Practicable seems to indicate that the technical feasibility needs to have been demonstrated.

- Whether this also means that the technical implementation of the possibility should have been realised in practice and that practicable means the same as available technology is unclear.

Costs and benefits

VALUING LIFE IN SAFETY DECISIONS

Valuing Life

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A problem going back centuries before

- Dr. Jonathan Swift tackled the problem as far back as 1729
  - *A modest proposal (an essay)*
- *I have already computed the charge of nursing a beggar's child (in which list I reckon all cottagers, labourers, and four-fifths of the farmers) to be about <u>two shillings per annum</u>, rags included; and I believe no gentleman would repine to give <u>ten shillings</u> for the carcass of a good fat child, which, as I have said, will make four dishes of excellent nutritive meat, when he hath only some particular friend, or his own family to dine with him. Thus the squire will learn to be a good landlord, and grow popular among his tenants, the mother will have eight shillings neat profit, and be fit for work till she produces another child.*

Today the moral and ethical dimensions of valuing the lives of people are assuaged by the use of "statistical lives"

Abstract lives

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In a relevant paper;

"...and how much for your grandmother?"

Adams remarks:

- *The removal of the need to talk about specific lives has thus removed a serious impediment to the rational discussion about sacrifice; although our ethical tradition strongly disapproves of the taking of life in the particular, there is nothing in this tradition that particularly opposes the taking of life in the abstract, so long as the price is right*.
  - Adams, J.G.U., Environment and Planning, A, Vol.6., 1974, pp. 619-626

The problem of costs and benefits

Probability and Risk are abstract concepts

- The idea of “statistical lives”

Consequences when they happen are real

- Valuation of costs is relatively straightforward for physical objects
  - Notoriously difficult for other objects

Valuation of benefits is fraught with difficulty even impossible

- Especially safety benefits.

- Hardly surprising that it is a problem – a threat by one party and the fear of a loss by the other

Decisions based on CBA

- Its primary merit is that it is precisely defined and the decision is predictable.
- Its disadvantage is that it does not take into account the imponderables that more often than not weigh into the decision.
  - Using CBA also suggests that the Value of Life is a known and universal constant
    - There is no scientific evidence other than that the VOSL varies over a large range and highly depends on the circumstances and on the method used to determine it.
  - What seems to have emerged is that decisions on statistical human lives and anonymous future victims are much easier than on real human beings.

Decisions based on ALARP

- The advantage of a qualitative somewhat vague concept, and decision-making that depends on a to a large extent subjective value judgement by a decision maker, lies in that it avoids questions that are difficult to answer.
- It also avoids questions that have ethical connotations.
  - The stinging problem of the monetary value of a human life is avoided.
  - By demanding substantial disproportionality or gross disproportionality of costs before refraining from a risk reducing measure, the problem of precisely setting a value on a human need not be addressed.

What constitutes Reasonable?

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Is central to the whole endeavour.

- The use of the term reasonable suggests that it is not sufficient to just adhere to some limit, if it exists, and that the reasonability of performing or refraining from an action is not just a matter of money.
- The term expresses that there are aspects that do not have such a monetary value, or such a value cannot be established with reasonable accuracy.
  - The aspects may comprise such things as equity, sociality and even maybe beauty – even if it is only in the eye of the beholder.
- Reasonability is only loosely defined.
  - It is what those who happen to make a decision consider reasonable.
    - *Is it really?*

Reasonableness permeates the entire analytical process

- *Models, data, computational effort, interpretation*

Gets us to somewhere between …

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BAT

- Best Available Technology and…

CATNIP

- Cheapest Available Technology Not Inviting Prosecution

- BAT implies that the costs are not considered. Then BAT means the same as ALAP.
- ALARP apparently means that the technology not only should be available, but also that the costs should be reasonable.

BATNEEC

- Best Available Technology Not Entailing Excessive Cost
  - But the “NEEC” is values driven and subjective and may be anywhere within the spectrum of choices between BAT and CATNIP

Coursier Lake Dam as it was

Coursier Lake Dam as an abstraction

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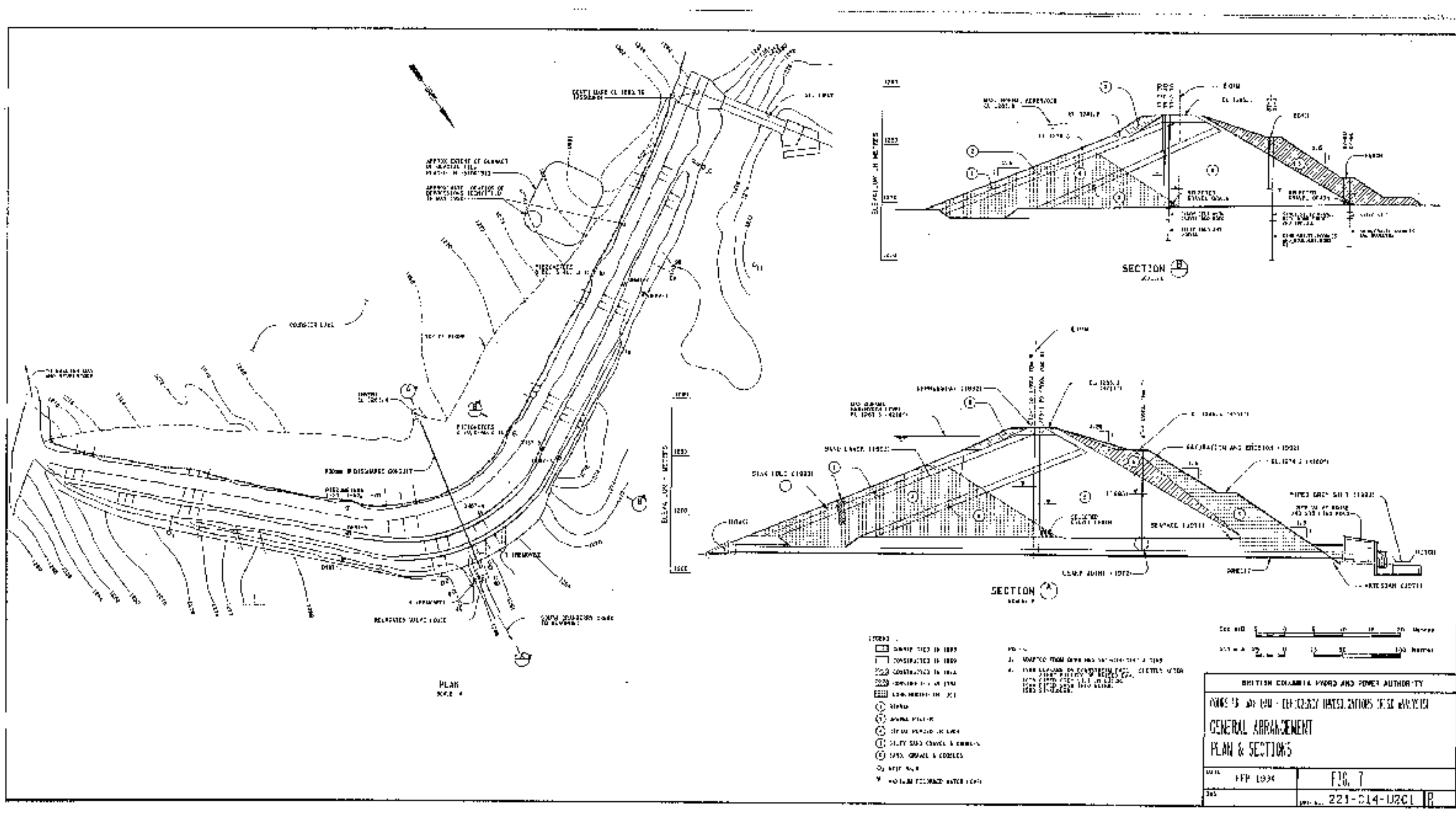
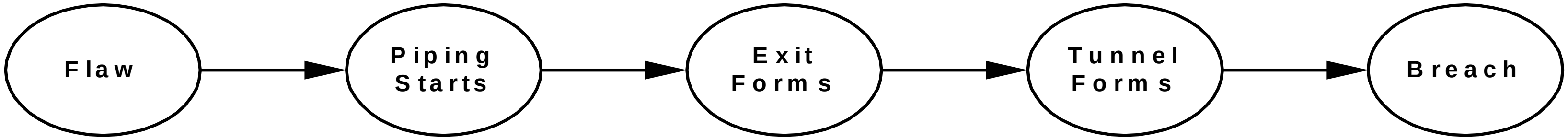


Influence diagram of failure model



Generic influence model formed basis for event tree analysis

Event tree analysis heavily dependent on:

- Past history of incidents
- Case histories of dam failures due to internal erosion
  - No soil mechanics modelling

Probabilities assigned on the basis of “engineering judgement” by BC Hydro engineers

- Using S. Vick’s “degree of belief” philosophy
- BC Hydro engineers considered to be “expert”

Sinkhole – one of many

Construction material!

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Core - just like a water-bed!

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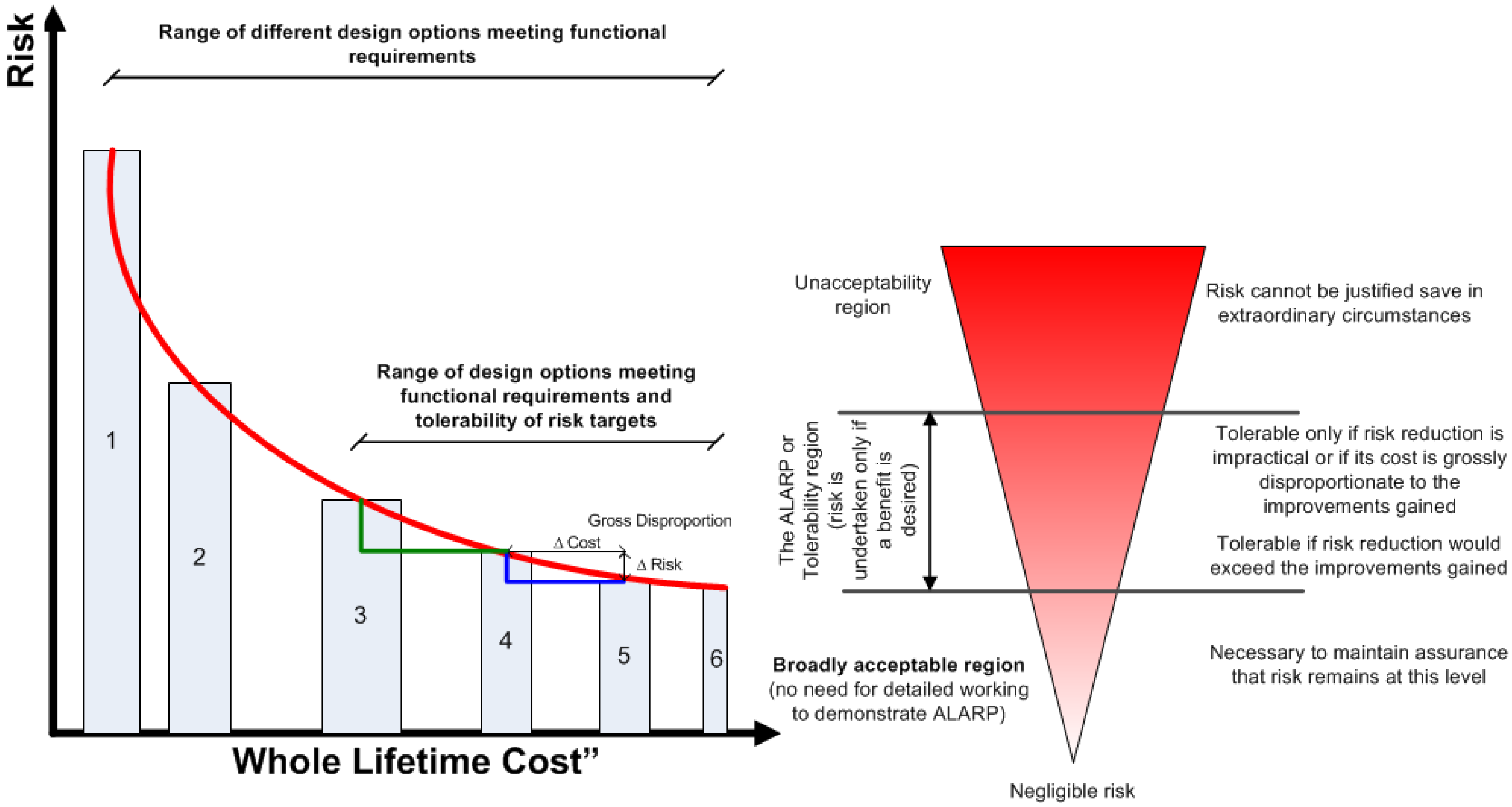
Suggested decision principles

Owners of hazardous installations should meet or exceed all:

1. General Legal Duties
2. General Duties of Ownership of hazardous installations
3. Legal Duties associated with hazardous Operation and Safety
4. Regulatory requirements with respect to Hazardous Operation and Safety
5. Conform to established engineering principles for safety of engineered systems
6. Conform to established safety standards/criteria and norms
   - And if the safety issue remains unresolved:
7. Perform quantitative risk assessment and ALARP demonstration
   - With specific consideration of totality of the consequences of failure
   - It is not simply a matter of lives lost and damage costs
8. Obtain societal consent through the political process

Risk-informed Decision Framework



So what does happen...

When a statistical life becomes a real person?

Case from the Netherlands

- In health care the Dutch Health Councils prefers a value of €80,000 per Quality Adjusted Life-year (QALY).
  - However, when the costs of medicines decreases this may lead to the conclusion that it is worthwhile to treat half of the Dutch population against hypertension even when this risk of adverse consequences is marginal.
- Recent decisions according the preference of the Health Council regarding the treatment of among other things Pompe’s disease.
  - This resulted in a parliamentary debate and in a revoking of the decision to no longer pay for this treatment under the basic health insurance system in the Netherlands.

The "Melchers' issues" (2007)

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1. Is the structural safety approach sufficiently broad to embrace and be embraced by other ways of considering safety in society
2. The perception that in relying on partial safety factors and nominal risk measures that structural engineers *"have slid out of the acceptable risk debate"*.
3. The unavoidability of both metaphysical and rational dimensions of safety
4. Defensibility of decisions concerning the safety of structural (engineered) systems
5. Decision-theoretic approaches to safety such as the use of cost-benefit analysis.
6. The role of non-technical factors in structural failures
7. Dynamics of the level of safety
8. Model verification
   - Structural reliability theory in the context of structural safety, Civ. Eng & Env. Sys., Vol 24, No.1, March 2007