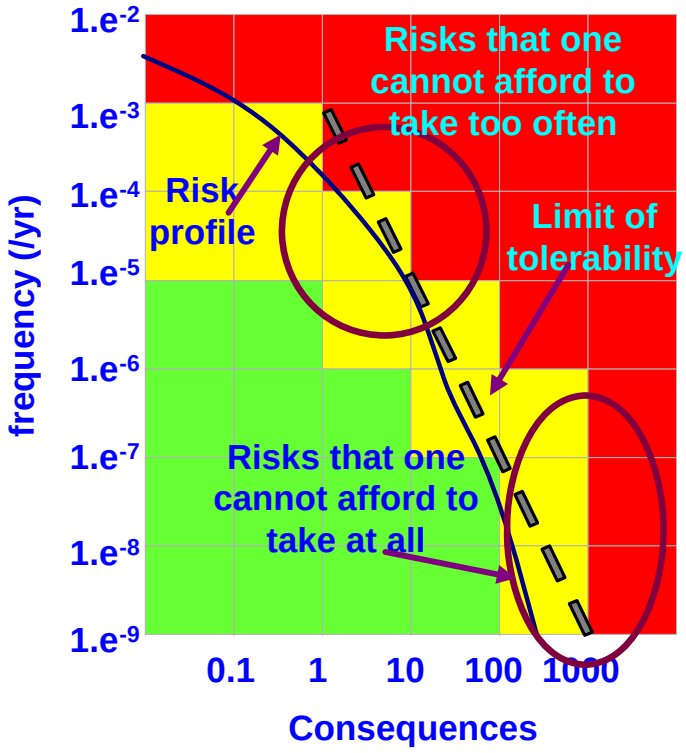


RISK MANAGEMENT OF DAMS SUBJECTED TO EXTREME NATURAL HAZARDS

analytical, policy and quality assurance considerations

Des Hartford

BC hydro

Uncertain!

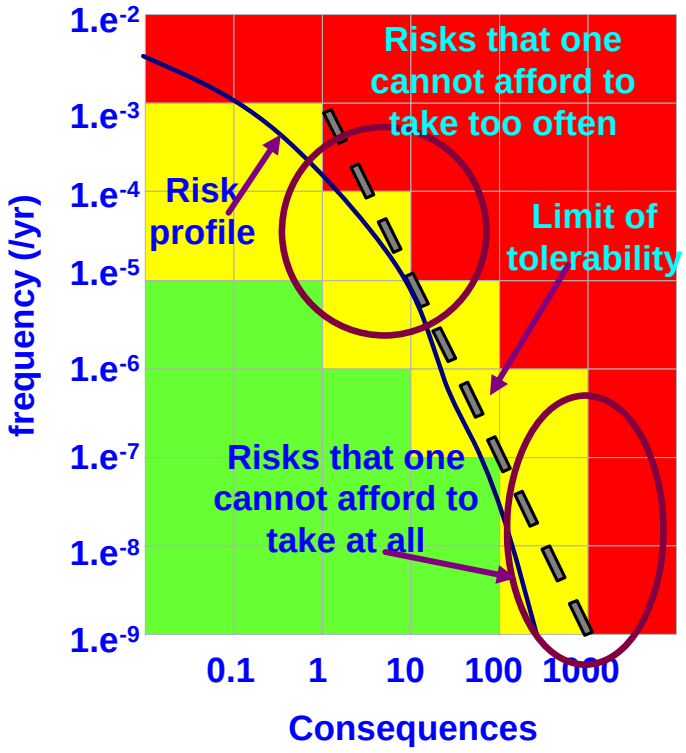
- The domain of dam safety involves much uncertainty
  - > Uncertainty in:
    - loads
      - natural hazards
      - design loads
    - dam performance
    - dam failure consequences
- All of which should be characterised probabilistically
  - > But are generally dealt with deterministically

Dimensions of Dam Safety

- Safety Policy
  - > the job of government
    - through regulators
- Safety Analysis
  - > the job of engineers and scientists
    - existing methods and new approaches derived from research
- Safety Assessment
  - > Traditionally the job of owners - to convince the regulator that the dam is “safe”
    - more realistically that the dam is *safe enough*
      - – but few want to admit to this!

Owner–regulator–engineer challenge

- To state precisely what the endeavour of dam safety assurance entails
  - > Is it the avoidance of dam failure at all costs?
    - "Absolute Safety"
  - > Is it the avoidance of dam failure at "reasonable" cost
    - "Safe Enough"
      - – What constitutes "reasonable" cost?
        - » The answer to this question is a policy/political matter.
- How do we measure "safety"?
  - > The ability to "measure" being fundamental to engineering science and engineering practice



Safety policy

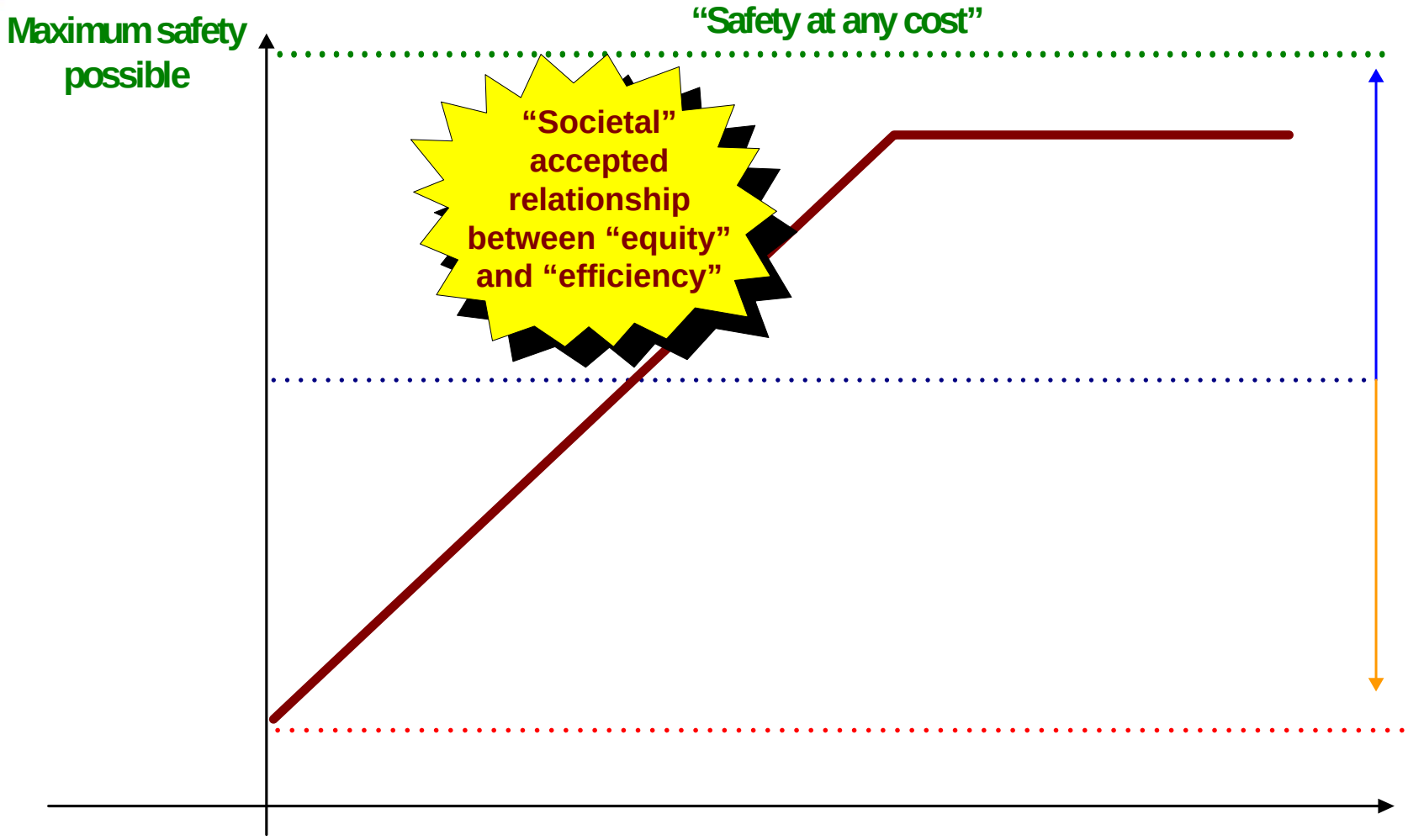
A matter for owners and regulators

BC hydro

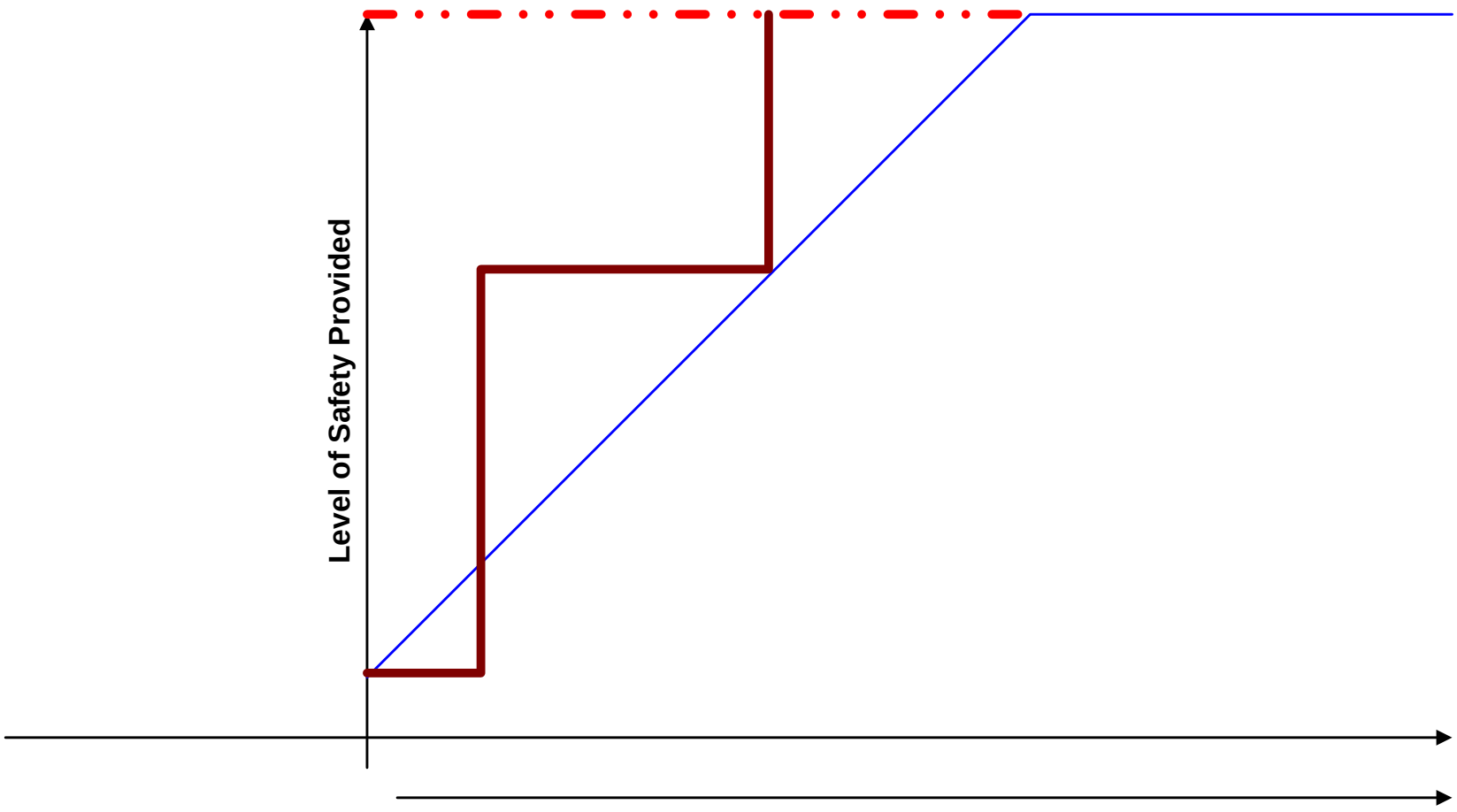
Safe enough or absolutely safe?

- Dam owners who are liable for the consequences of dam failure, and
- Dam regulators who are responsible for safeguarding the interests of the public
  - > should have a rational and transparent means of explaining what is meant by a *"safe dam"*
    - definitions of what constitute a "safe dam" are difficult to find
      - perhaps look outside the dams community
        - » where the myth of absolute safety dominates
      - and see that safety is defined in terms of risk
  - > Conclusion is that *Safe Enough* is the goal to be striven for
    - absolute safety is unachievable

Societal safety in general

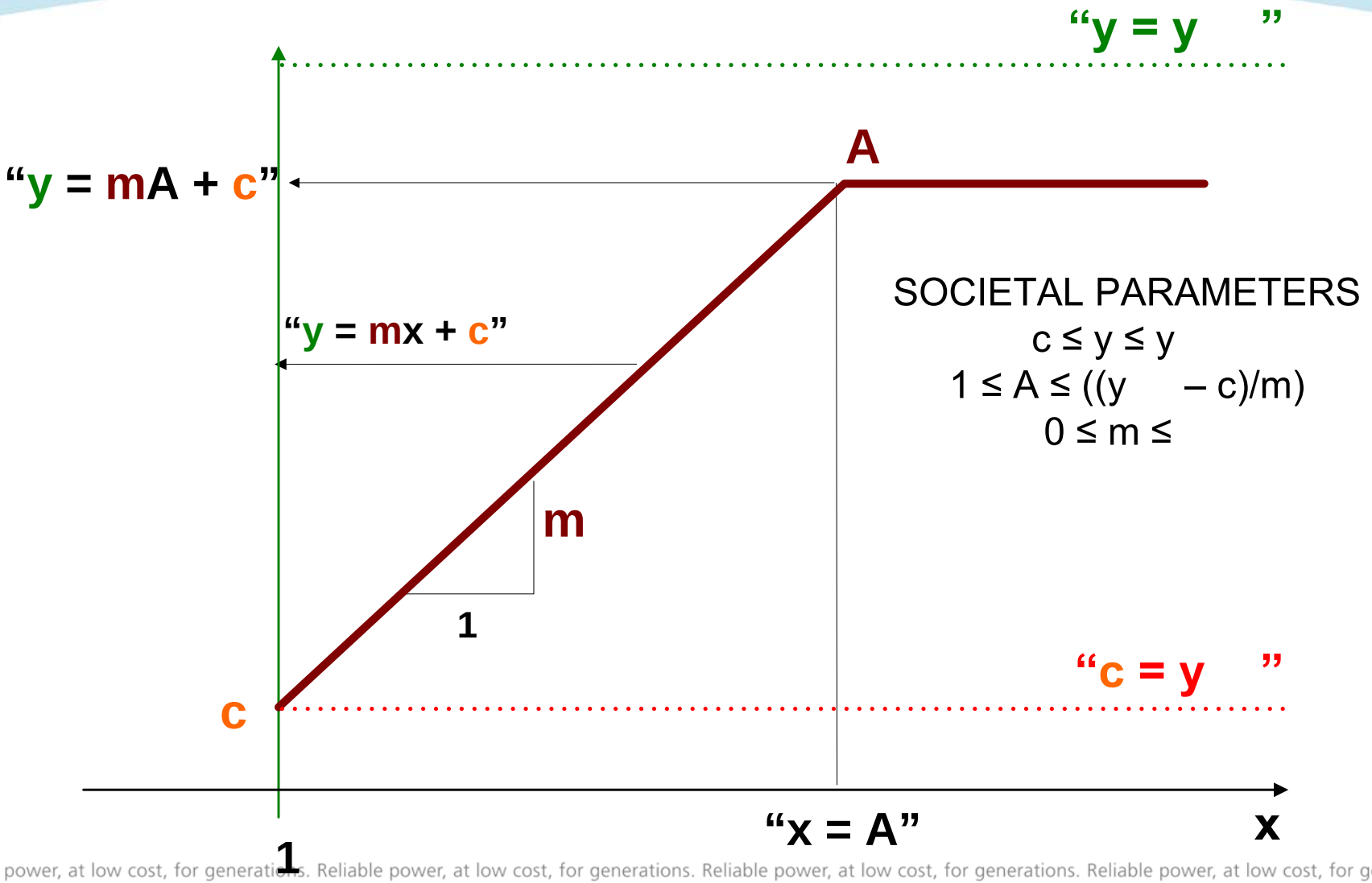


Dams in the context of societal safety

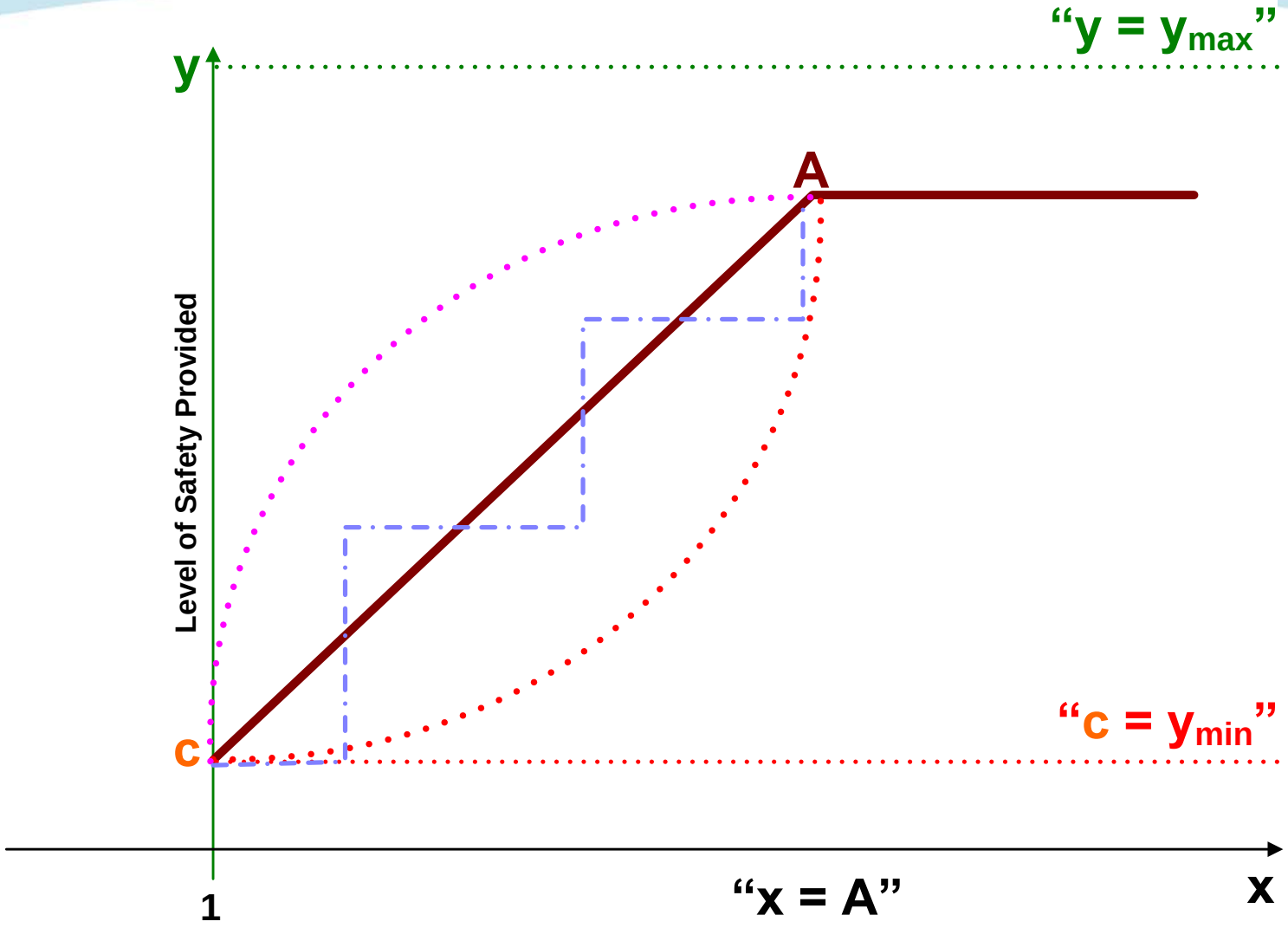


Reliable power, at low cost, for generations. Reliable power, at low cost, for generations. Reliable power, at low cost, for generations. Reliable power, at low cost, for generations.

Safety parameters

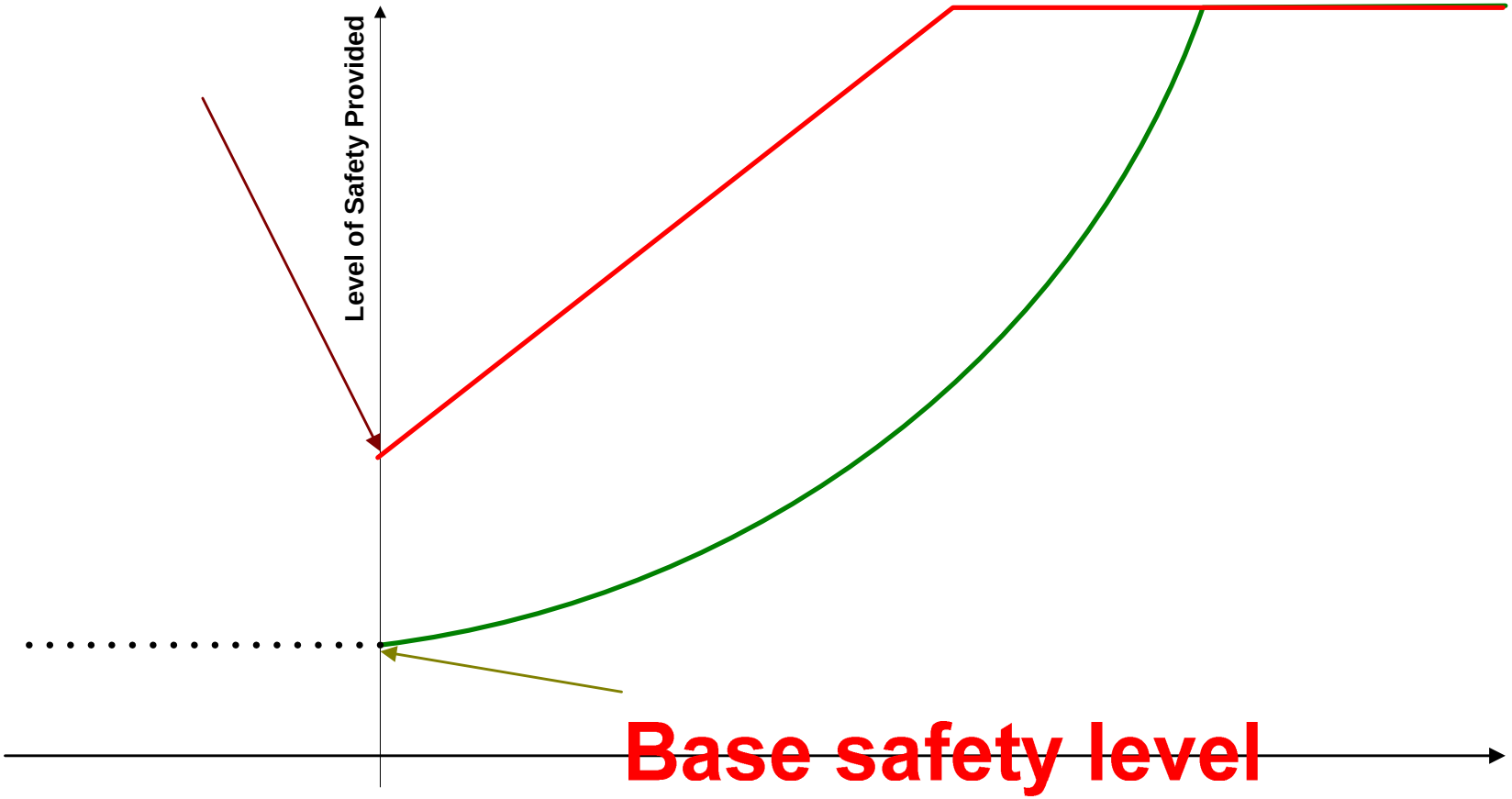


Alternative policy parameters



Reliable power, at low cost, for generations. Reliable power, at low cost, for generations. Reliable power, at low cost, for generations. Reliable power, at low cost, for generations.

Generalised safety framework for dams



Policy reality

- Risk assessment provides the most complete characterisation of the safety issue
  > It is also the most complex way to characterise safety
- Designing for the “hazard” with no “factors of safety” on the response is an option
  > Generally not done
- Designing to the “hazard” with “factors of safety” on the response is another option
  > Traditional practice

Policy challenge

- Decide whether safety of dams should be assessed in terms of:
  - > Deterministic standards (PMF, MCE, design rules)
    - Possibly linked to the consequences of dam failure
      - – Linear or non-linear way?
  - > Probability of hazard
    - e.g. 100 year flood or the 10^{-4}/yr natural hazard event
      - – Consider the design parameters for levees post Hurricane Katrina
  - > Probability of failure
    - Integrated over the full ranges of hazard loads and dam responses
  - > Risk
    - Full probabilistic characterisation of the combinations of hazards, dam responses and failure consequences

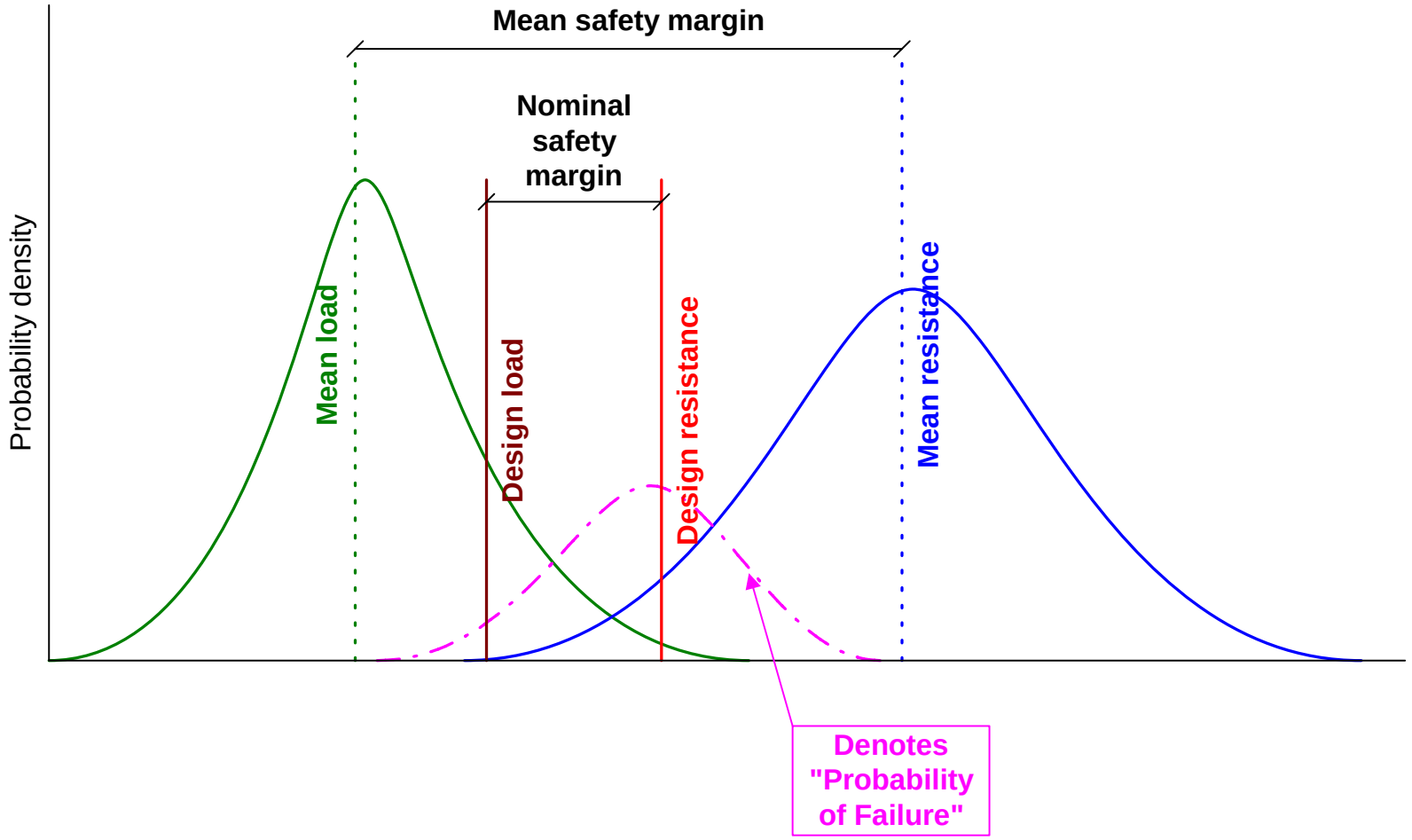
PMF and MCE

- The PMF is simply a large flood
- The MCE is simply a large earthquake
  - > May be very conservative in the local context
    - **<u>May not</u>** be very large by global standards
  - > Are not the physical maxima
  - > Are not invariant instruments of public safety policy with respect to
    - Location
    - The state of scientific knowledge or, the people developing them
  - > Are not strictly “deterministic” constructs
    - The extent of probabilistic characterisation varies with the extent of the scientific knowledge available
  - > Do not necessarily provide the upper bound of “achievable safety”
  - > Do not necessarily lead to consistently high levels of safety in different parts of the same jurisdiction

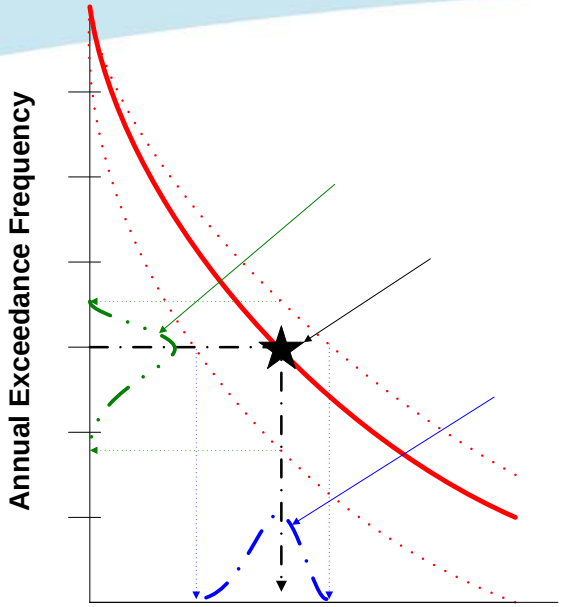
ALARP considerations

- PMF and MCE do not necessarily maximise safety by reducing risk “As Low As Reasonably Practicable”
  - > If it is reasonably practicable to provide performance capacity that exceeds the PMF and/or MCE performance than the additional capacity should be provided.
    - e.g. concrete dam with PMF spillway designed to withstand overtopping
    - e.g. earthfill dam with liquefaction failure mode eliminated
      - Such a dam could well withstand earthquakes larger than the site specific MCE
- The ALARP demonstration requires joint consideration of all “hazards”, and the associated “dam response”

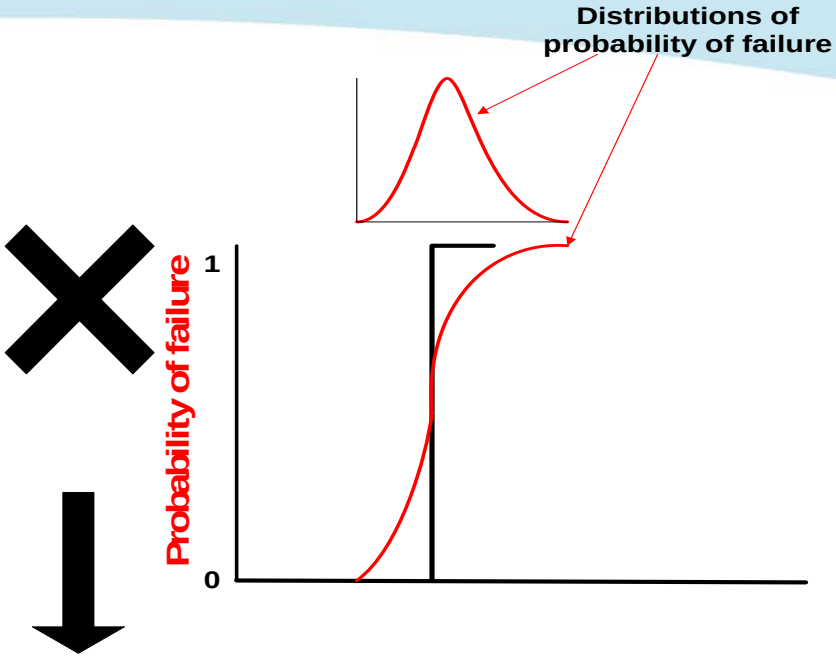
“Hazard” and “Dam Response”

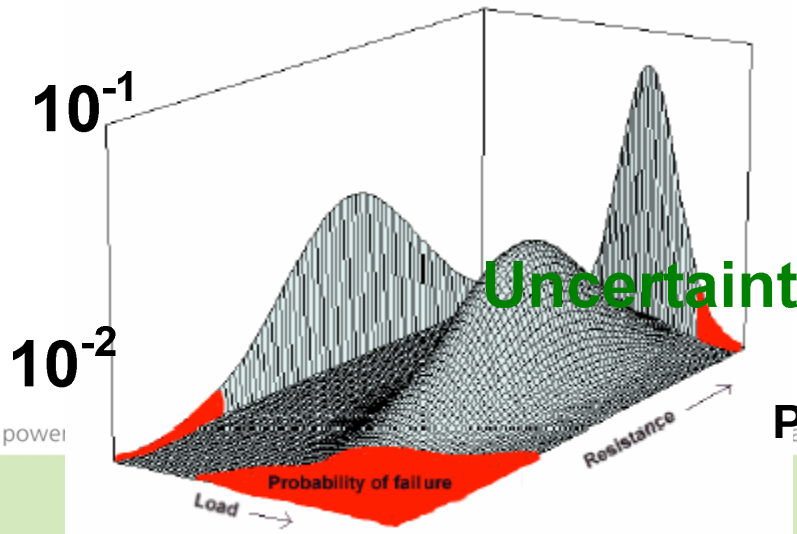


Probability of Hazard



Probability of Failure given Hazard



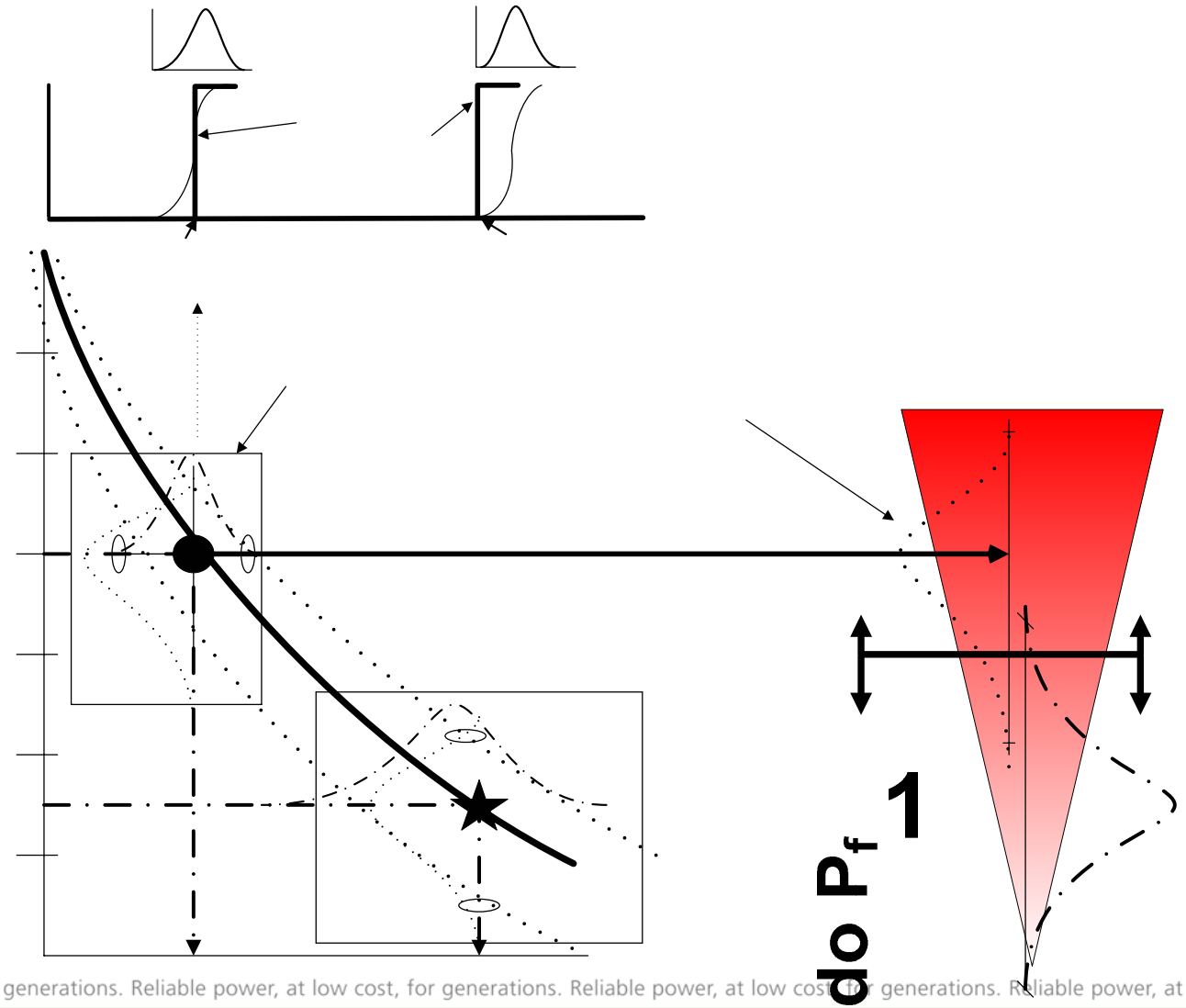


Uncertainty in Ground-motion F (Probability)

Probability of Failure

The "10,000"

Natural hazards, dam response and risk



Towards a rational approach….

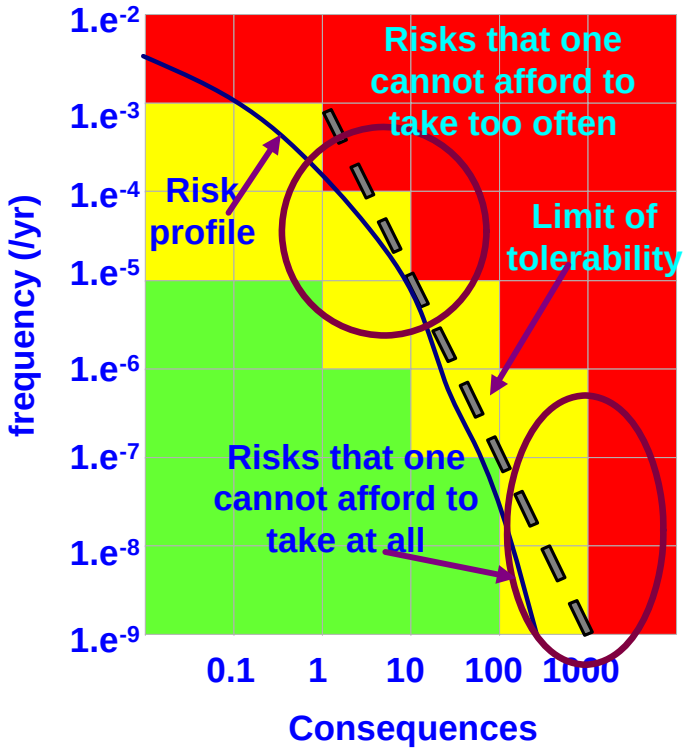
- Risk analysis
  - > Provides the most comprehensive means of characterising the safety of dams
    - Explicit treatment of all uncertainties
      - – Transparent and founded in sound science
      - – Necessarily embodies all attributes of traditional analysis
    - Goes beyond traditional analysis
      - – Traditional analysis practice is embodied in the risk analysis approach
        - » As a subset
  - > A comprehensive risk analysis will include loads and responses outside the range of traditional practice
    - Risk analysis demands more comprehensive analysis

The problem of the “unknowable”!

- Impossible to know if an estimate of risk is a good estimate
  - > If probability of event is very low and nothing happens
    - then one might be tempted to assume that it is a good estimate
      - this is not the case
      - similarly for events that occur when previously two very different estimates of the probability of the event (0.1 and 0.00001) were estimated independently
        - » impossible to determine if the event that occurred was the 0.1 or 0.00001 event!
- This problem is not unique to risk analysis
  - > same problem with traditional practice,
    - How does one assure quality of engineering judgement?

Dangers of judgements of probability

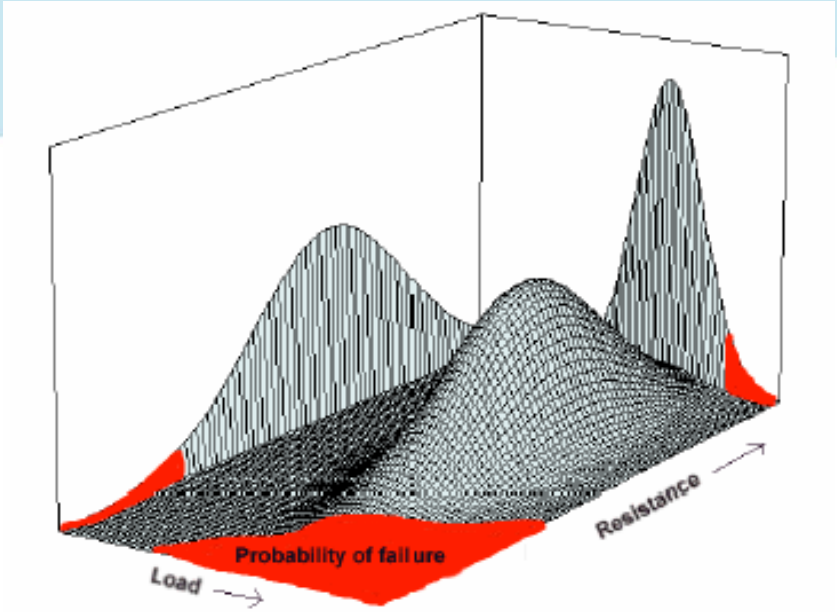
- Sound judgement: a vital part of good engineering
  - > safety assessment is arguably not engineering because nothing is being “engineered”
  - > safety assessment is arguably “engineering science”
    - “engineering science”:- the development of reliable knowledge concerning matters of engineering.
      - » safety assessment involves inferences from incomplete and uncertain data:- the domain of scientific inference
- Judging probability is notoriously difficult
  - > rigorous qualification of experts and adherence to the rules of scientific inference is the only safeguard against inadequate judgements
    - deterministic or probabilistic



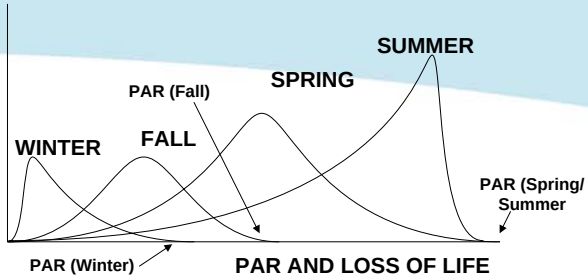
Going straight to the point: – safety assessment in terms of "risk"

The integrated form of the policy and analytical considerations

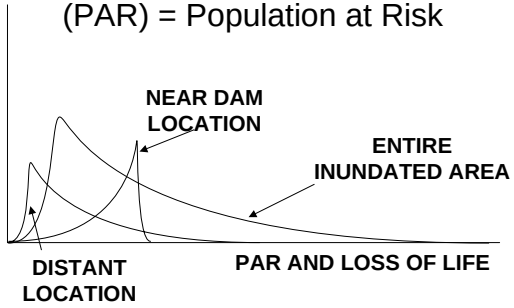
BC hydro



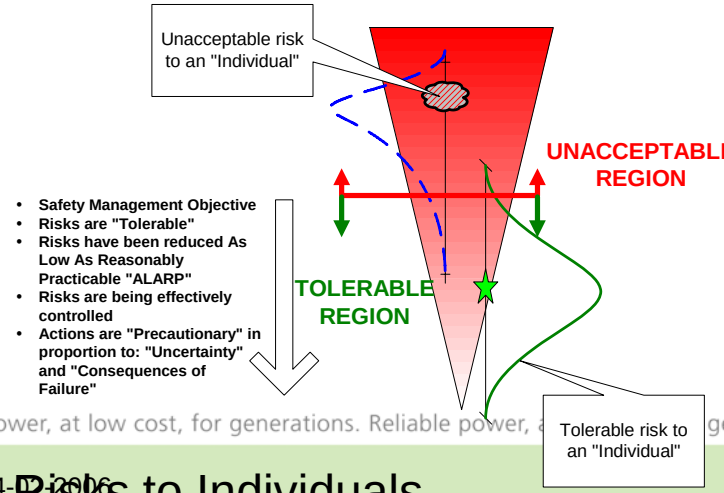
Probability of Failure



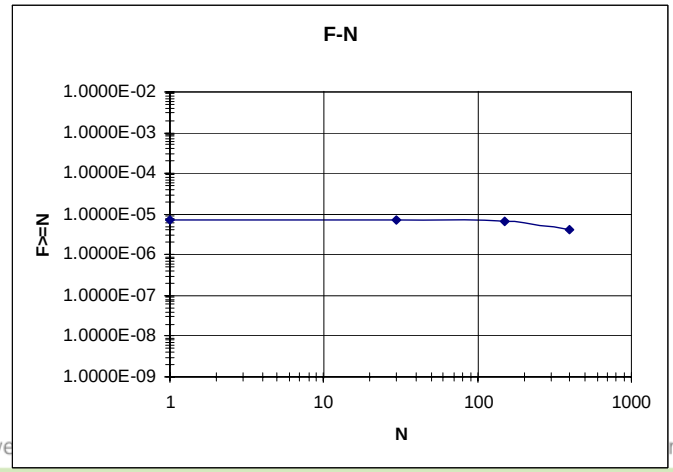
(PAR) = Population at Risk



Consequences of Failure

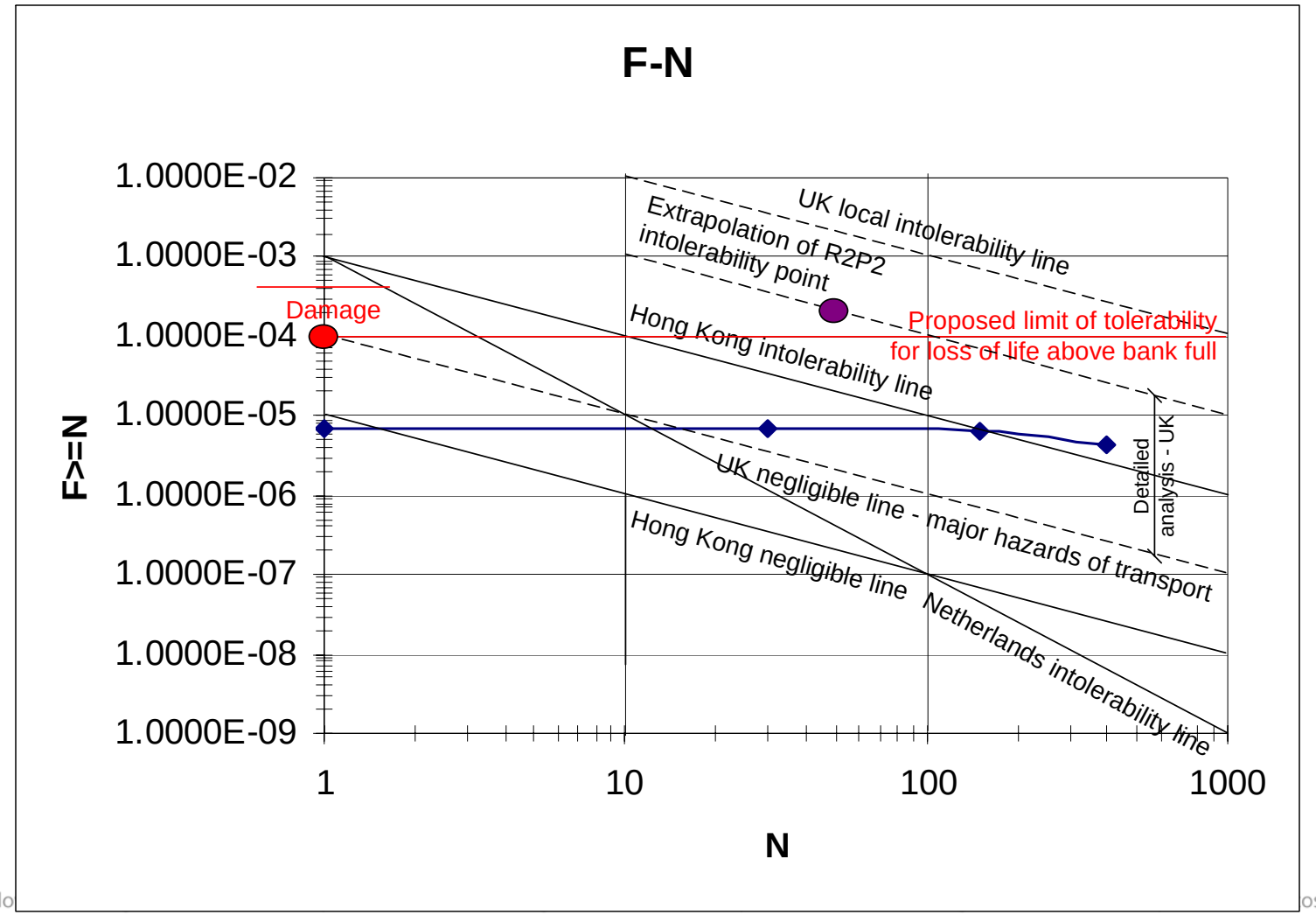


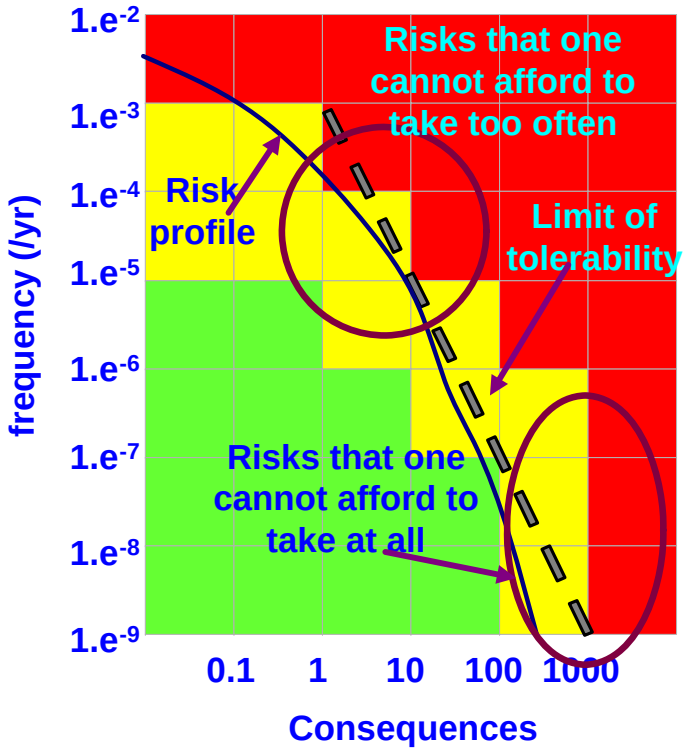
Risks to Individuals



Societal Risk

“Established” criteria



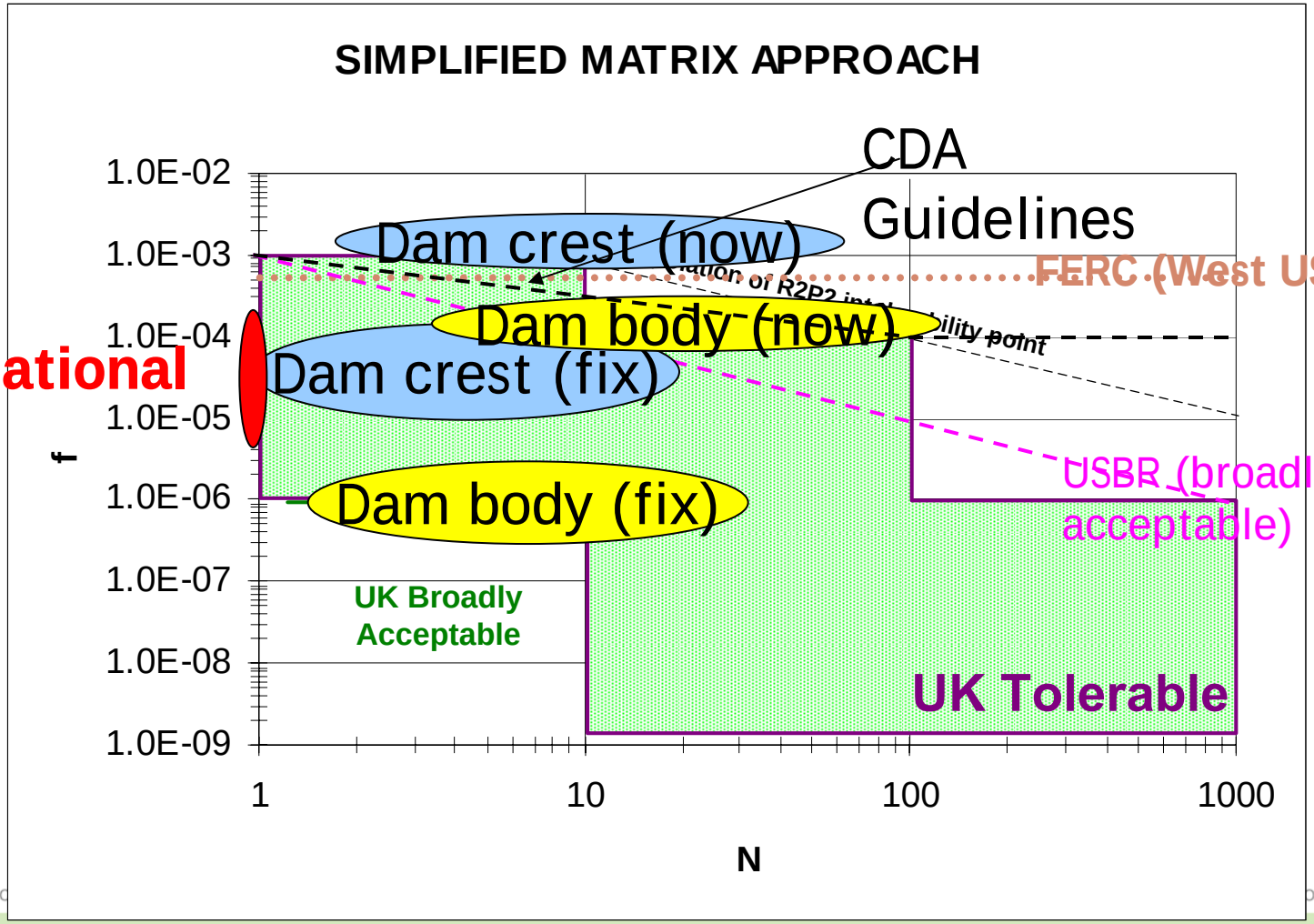


Two examples

BC hydro

Ruskin Dam

Tolerability of Risk Framework

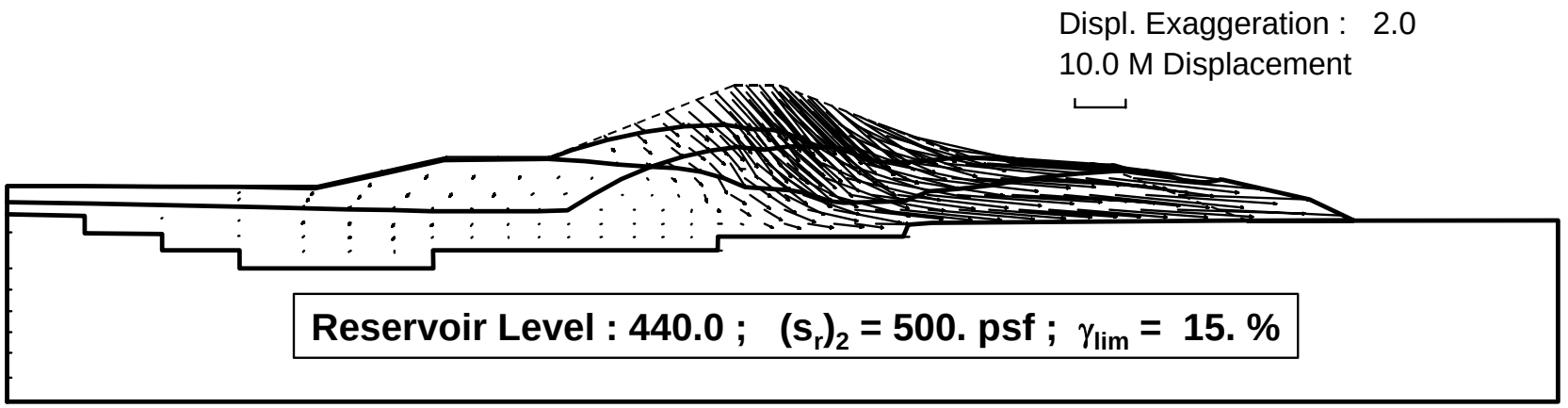


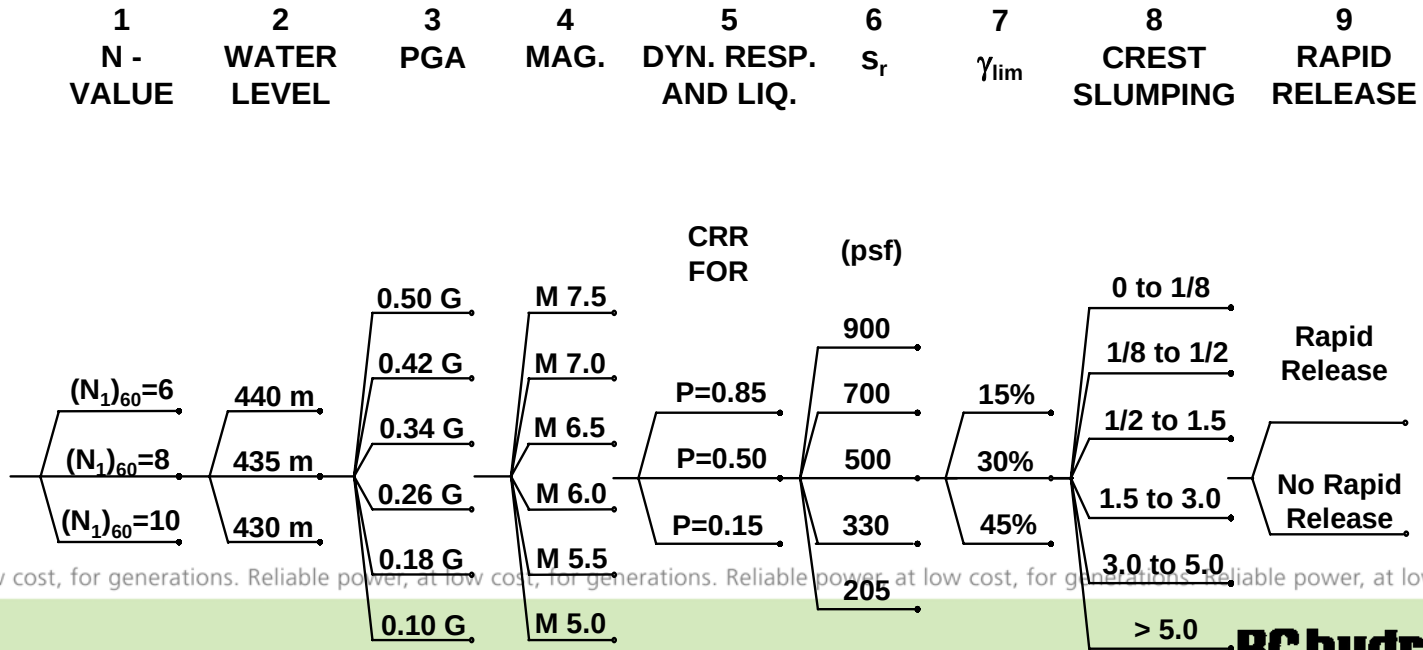
Recreational Risk

Reliable power, at low co ost, for generations.

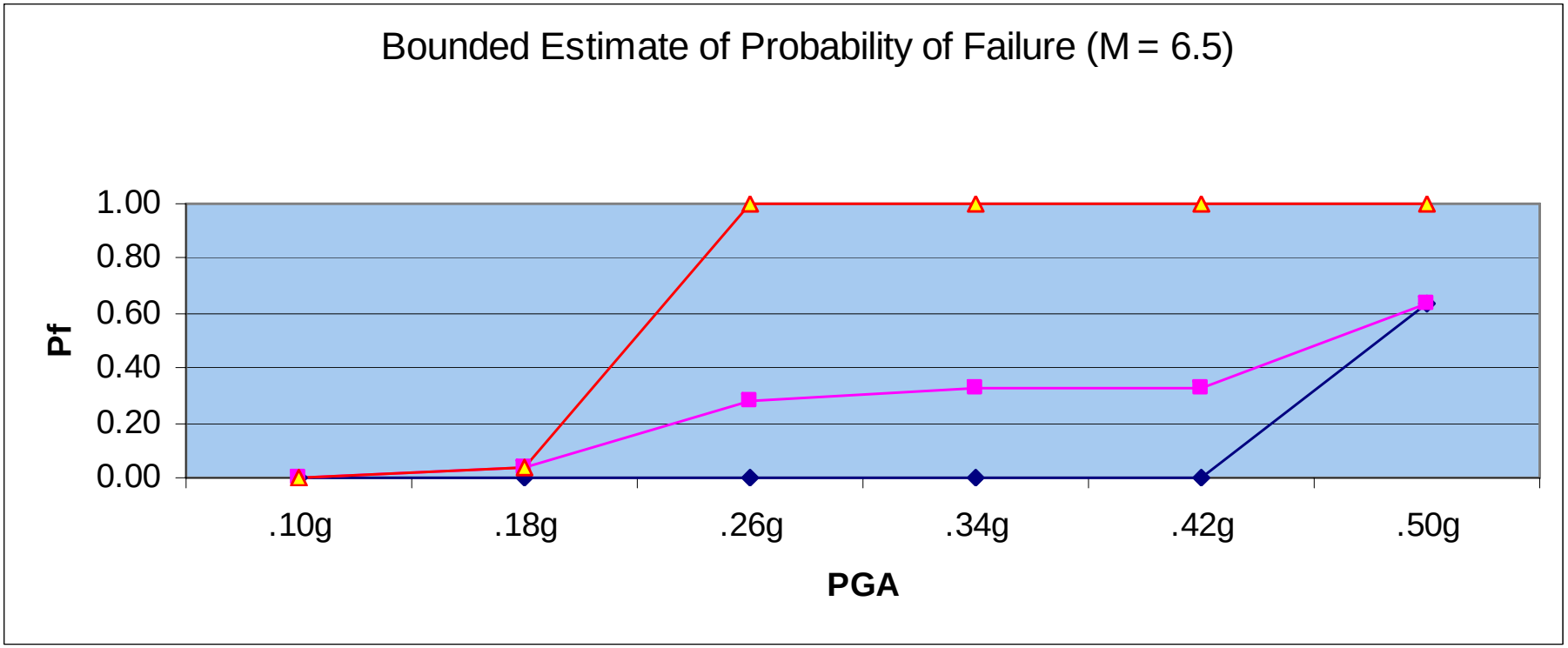
Hugh Keenleyside Dam

Detailed quantitative risk analysis

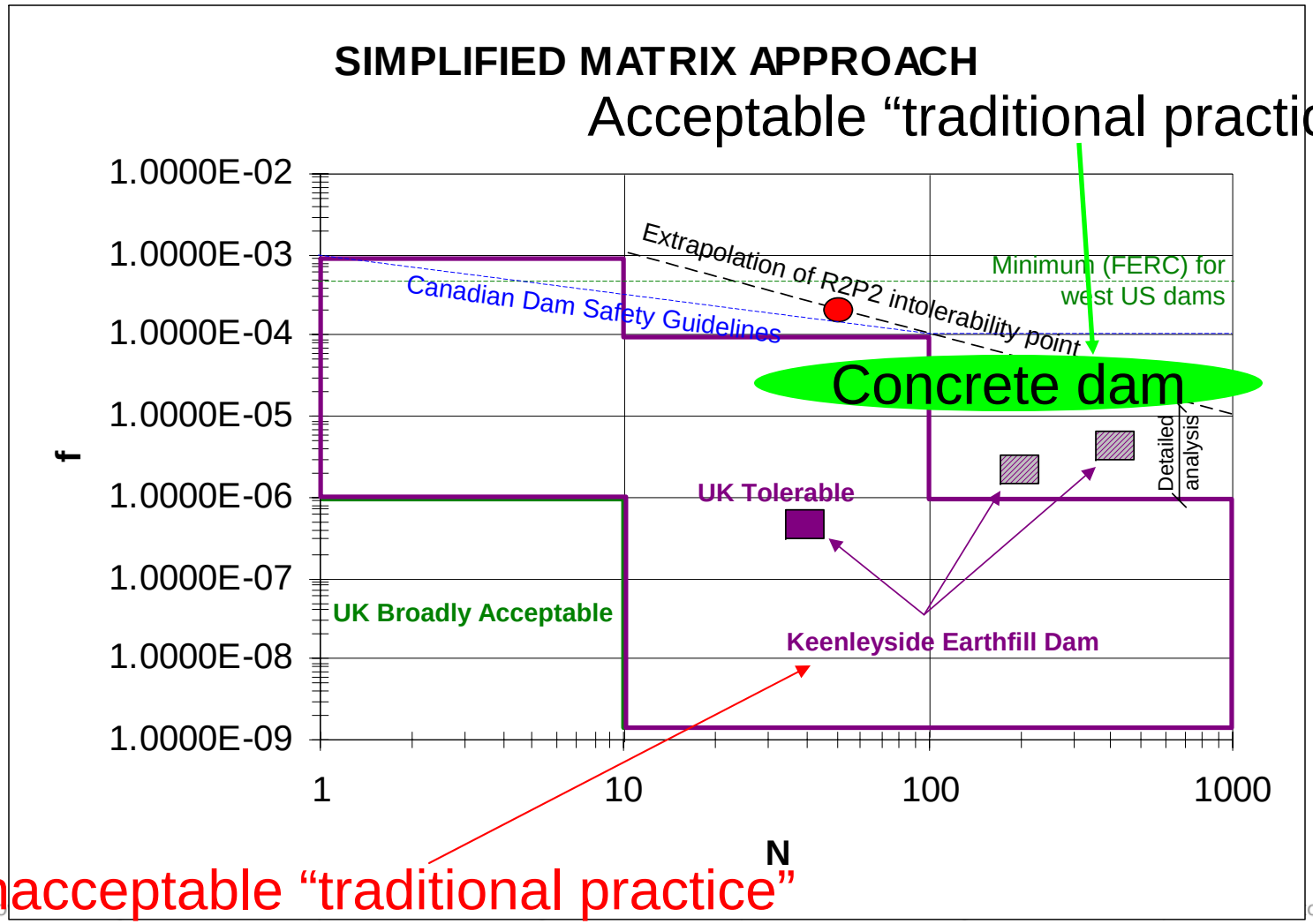




Probabilities of earth dam failure M=6.5, all PGA's



Loss of life scenarios



Some comments on “ALARP”

- It is not sufficient for the estimated probability of failure meet one or several numerical Risk Tolerability criteria
  - > Nor is it sufficient to meet numerical risk tolerability criteria and some Cost:Benefit criterion
    - These considerations are only the starting point.
- The remainder of the ALARP demonstration involves explaining:
  - > what level of safety is physically achievable i.e. what is practicable
  - > why the safest of the physically achievable options was not selected
    - why other options that provide more safety than the option that was selected were not chosen
  - > justifying the selection to the regulator and the affected public
    - Demonstrating reasonableness – a “societal value” judgement, not an “engineering judgement”

Some conclusions

- Dam safety assessment is not an “exact science”
  - > Dam safety assessment can be a “rigorous science”
    - if dam owners, dam safety regulators and the engineering profession want it to be!
      - – Given the consequences of dam failure, why is rigorous engineering science not a requirement of dam safety assessment?
        - » why are dam owners and regulators not demanding it?
- Risk analysis provides the framework for scientific rigour and transparency in dam safety assessment
  - > risk assessment provides a means of compensating for the weaknesses in traditional practice
    - why not use it?

References

Risk and Uncertainty in Dam Safety

By D.N.D. Hartford and G.B. Baecher on behalf of:

BC Hydro, Bureau of Reclamation, Corps of Engineers, Hydro Quebec, Manitoba Hydro, Ontario Power Generation, Scottish & Southern Energy and Vattenfall

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