RAC
Engineers & Economists

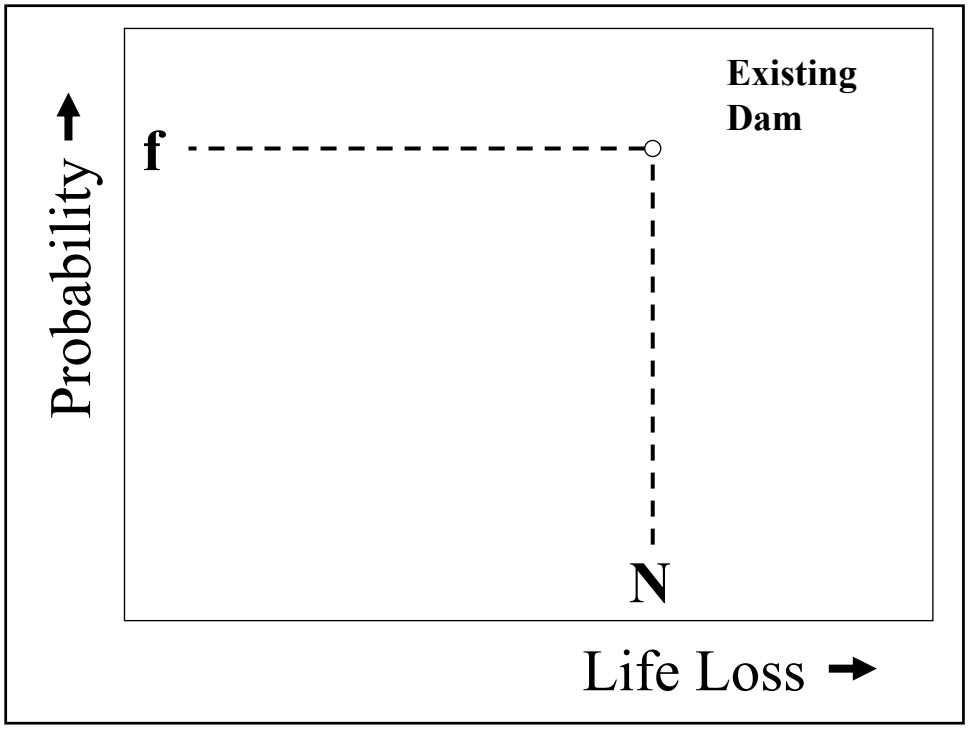
Theoretical-Practical Course
Universidad Politecnica de Valencia
Valencia, Spain
27 & 28 February 2008

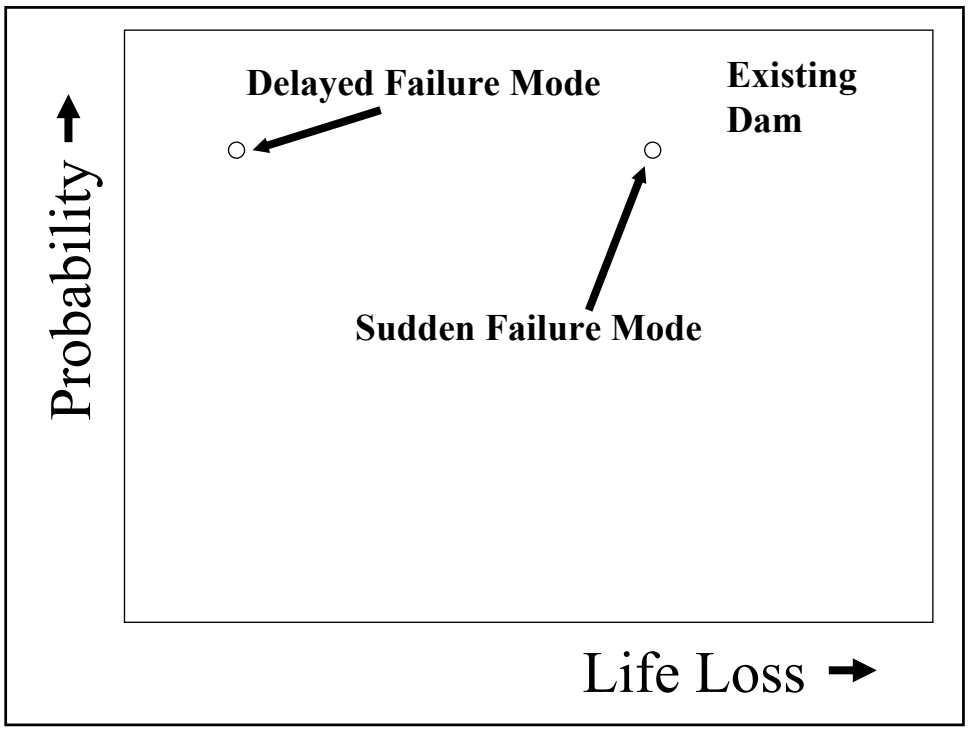
Utah State University
IDSRM

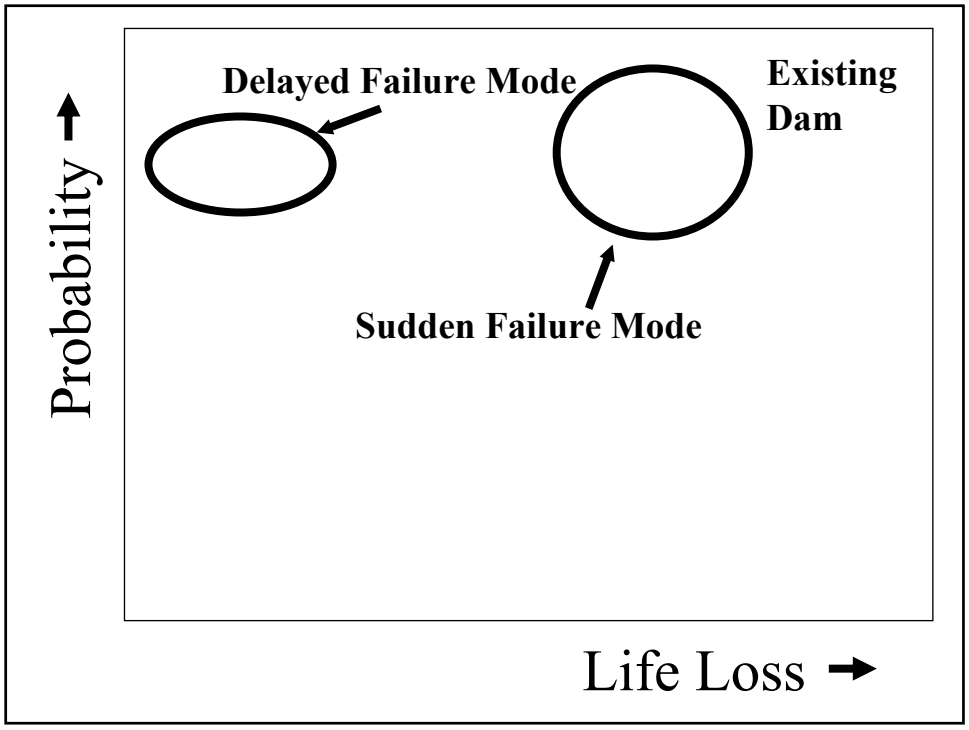
Risk Analysis as Applied to Dam Safety Fundamentals:

L.4 - Risk Model for Risk Reduction Measures

David S. Bowles
Institute for Dam Safety Risk Management - Utah State University
and RAC Engineers & Economists




Delayed Failure Mode
Existing Dam
Sudden Failure Mode
Probability
Life Loss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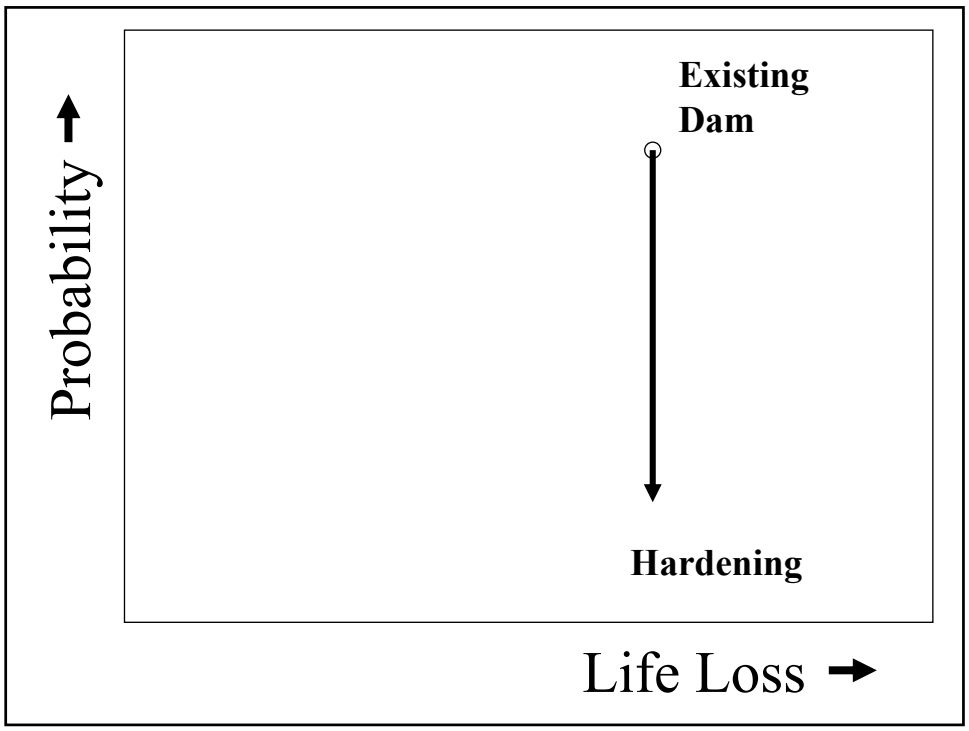
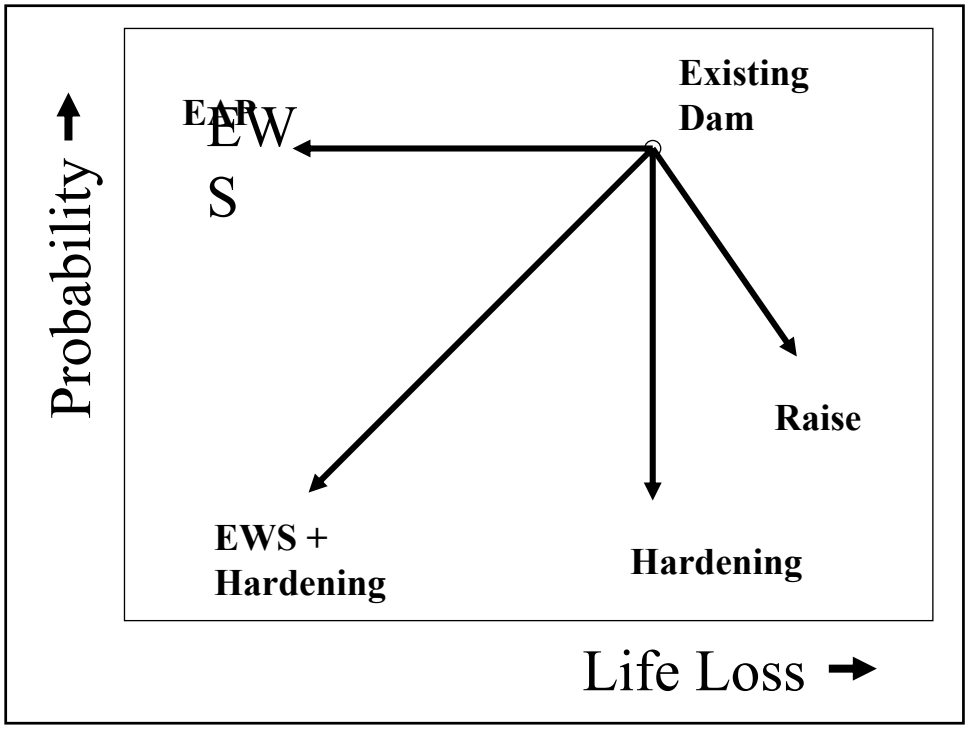

Probability
Existing
Dam
Hardening
Life Loss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S
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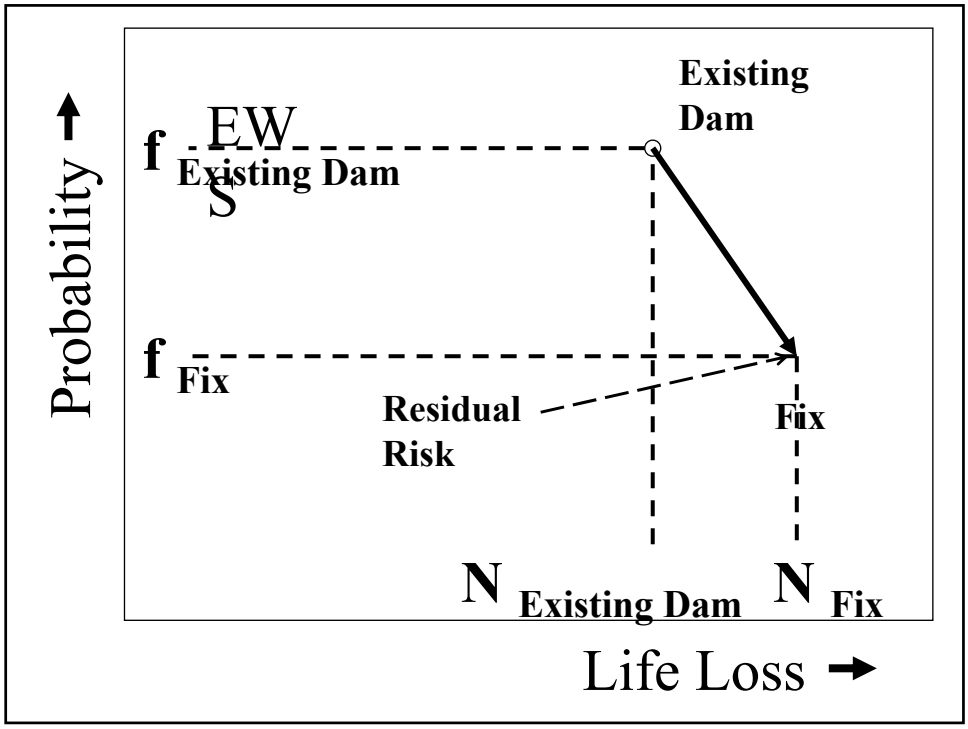
Dam
Raise
EWS +
Hardening
Hardening
Life Loss

Outline

1) Annualized Risk Reduction - Benefits
2) Economic Risk Guidelines
3) Constructing an F-N Charts
4) Calculating Cost per Statistical Life Saved (CSLS)
5) Calculating Disproportionality Ratio (Proportion Factor - HSE)

1) Annualized Risk Reduction

= Benefits of Fix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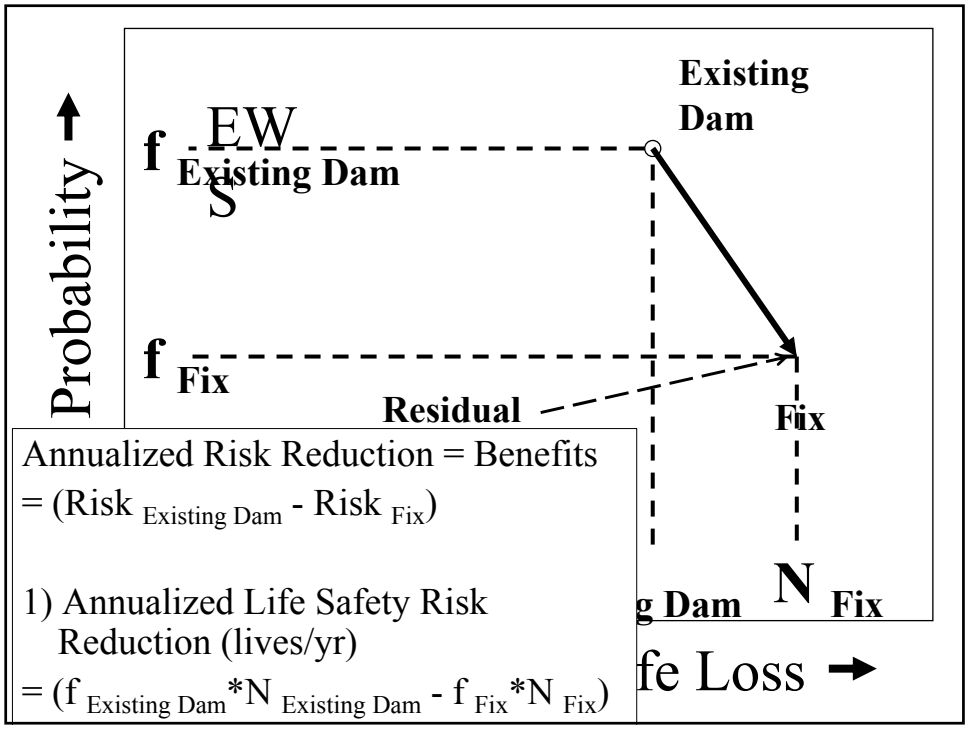
Risk
Fix
N Existing Dam
N Fix
Life Loss


Probability
Existing
Dam
f EW
Existing Dam
S
f Fix
Residual
Fix
N Fix
Annualized Risk Reduction = Benefits
= (Risk Existing Dam - Risk Fix)
1) Annualized Life Safety Risk
Reduction (lives/yr)
= (f Existing Dam*N Existing Dam - f Fix*N Fix)

Annualized Risk Reduction = *Benefits of Fix*

$$= (\text{Risk}_{\text{Existing Dam}} - \text{Risk}_{\text{Fix}})$$

1) Annualized Life Safety Risk Reduction = *Annualized Life Safety Benefits* (lives/yr)

$$= (f_{\text{Existing Dam}} * N_{\text{Existing Dam}} - f_{\text{Fix}} * N_{\text{Fix}})$$

2) Economic Risk Cost Reduction = *Annualized Economic Benefits* ($/yr)

$$= (f_{\text{Existing Dam}} * \$_{\text{Existing Dam}} - f_{\text{Fix}} * \$_{\text{Fix}})$$

3) Probability of Failure Reduction (/yr)

$$= (f_{\text{Existing Dam}} - f_{\text{Fix}})$$

2) Economic Risk Guidelines

One organization's criteria may not be appropriate for another organization

- Other economic criteria
  - Benefit/cost Ratio
  - Net Present Value
  - Internal Rate of Return
- Total Economic Cost

Benefit/Cost Ratio

$$= \frac{\text{Annualized Economic Benefits of Fix}}{\text{Annualized Cost of Fix}}$$

$$= \frac{\text{(Risk Cost Existing Dam - Risk Cost Fix)}}{\text{Annualized Cost of Fix}}$$

Risk Cost

RISK COST = DAMAGE PER **FAILURE** EVENT X PATHWAY PROBABILITY

UNITS

$$\frac{\$}{\text{YEAR}} = \frac{\$}{\text{EVENT}} \times \frac{\text{EVENTS}}{\text{YEAR}}$$

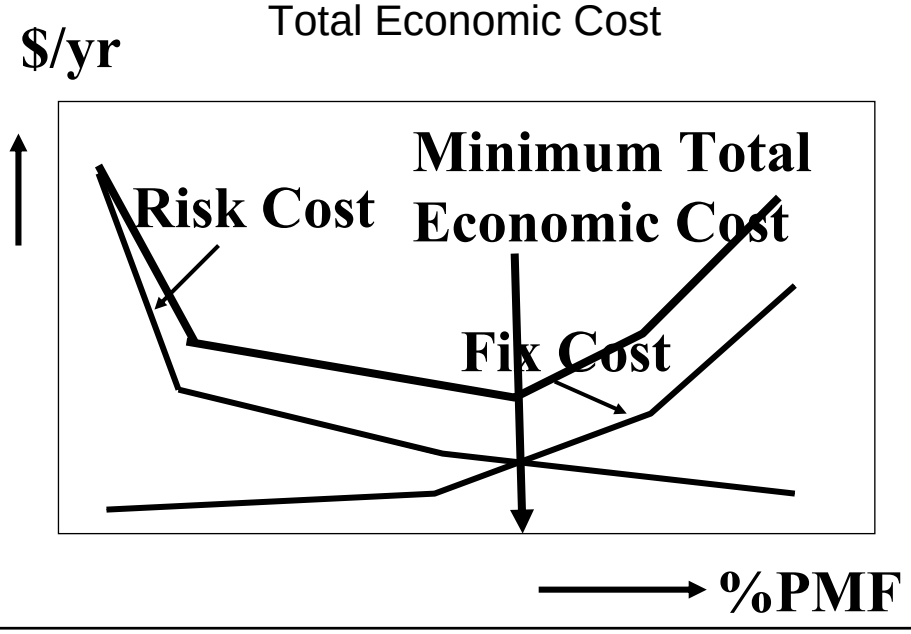
EXAMPLE

$\$1{,}000/\text{yr} = \$1{,}000{,}000 \times 10^{-3}/\text{yr}$

Total Economic Cost

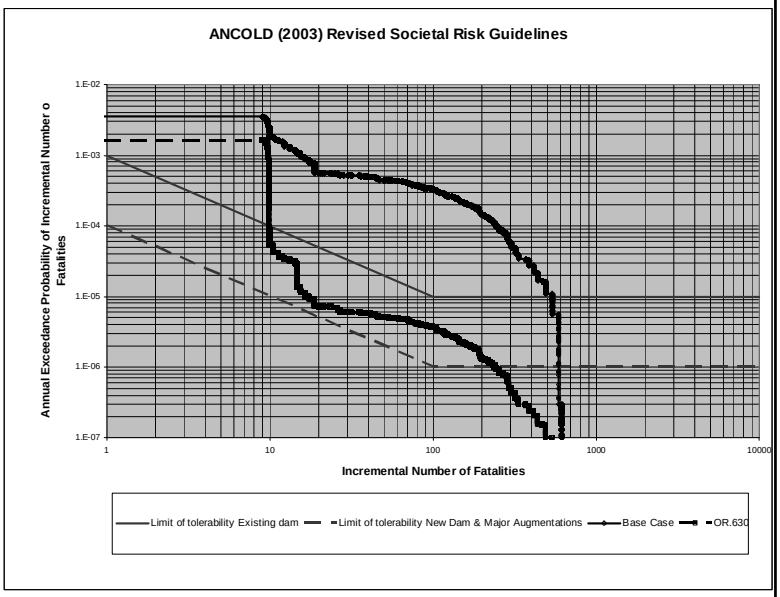
TOTAL ECONOMIC COST = RISK COST + ANNUALIZED COST OF FIX

Economic Risk Analysis
Total Economic Cost

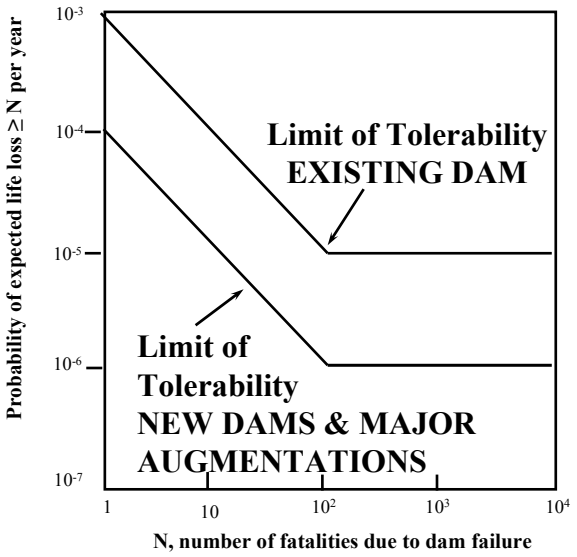


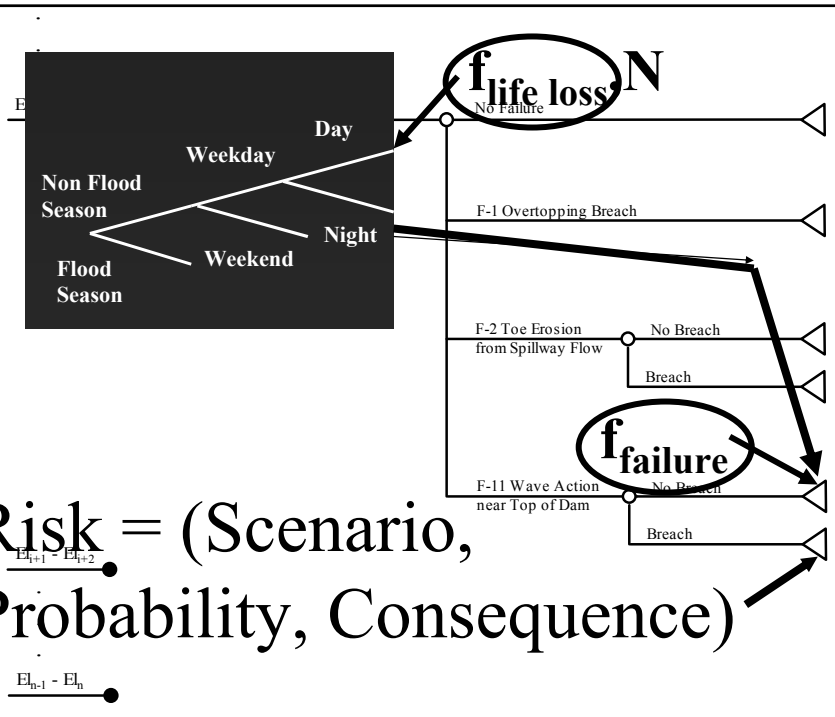
3) Constructing F-N Charts

ANCOLD (2003) Societal Risk Guidelines (F-N)



ANCOLD (2003) *Societal* Risk Guidelines





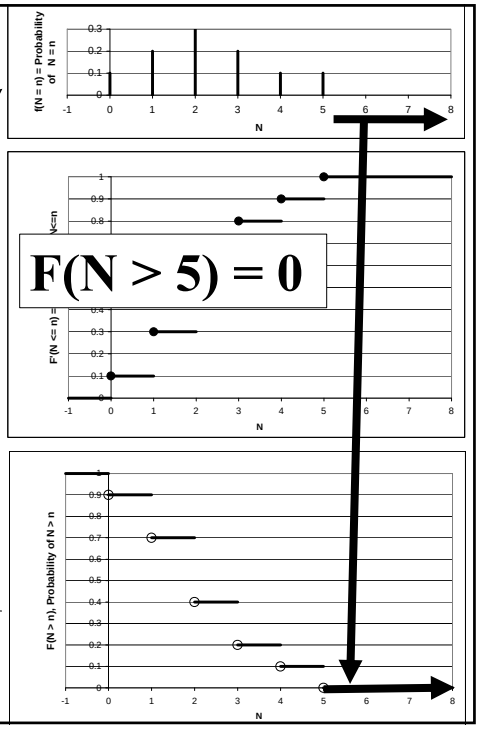
Risk = (Scenario, Probability, Consequence)

Discrete Probability Distribution

Probability Mass Function (PMF), f(n)

Cumulative Distribution Function (CDF), F'(N≤n)

Complementary Cumulative Distribution Function (CDF), F(N > n)

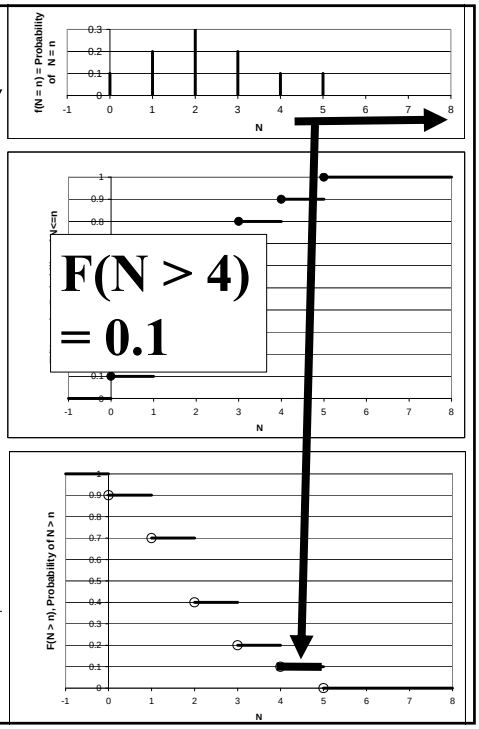


Discrete Probability Distribution

Probability Mass Function (PMF), f(n)

Cumulative Distribution Function (CDF), F '(N≤n)

Complementary Cumulative Distribution Function (CDF), F(N > n)



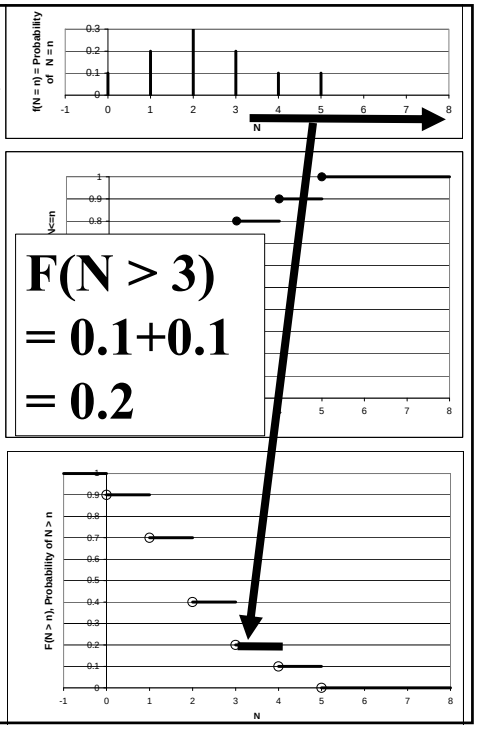
Discrete Probability Distribution

Probability Mass Function (PMF), f(n)

Cumulative Distribution Function (CDF), F'(N≤n)

Complementary Cumulative Distribution Function (CDF), F(N > n)

F(N > 3) = 0.1+0.1 = 0.2



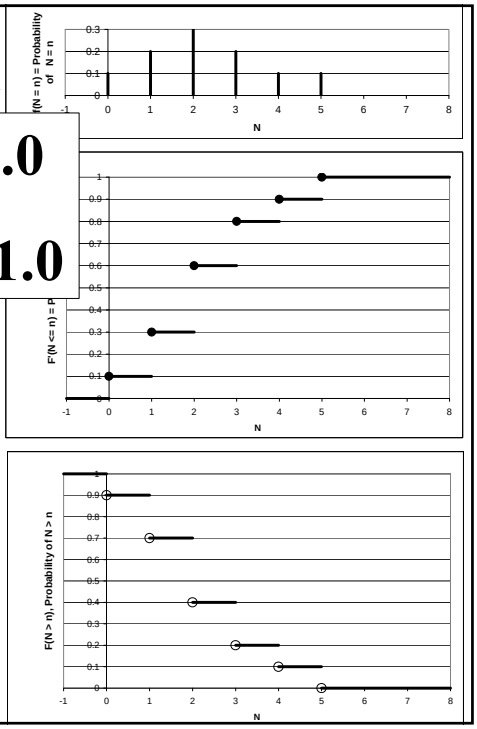
Discrete

CDF + CCDF = 1.0

F'(N≤n)+F(N>n)=1.0

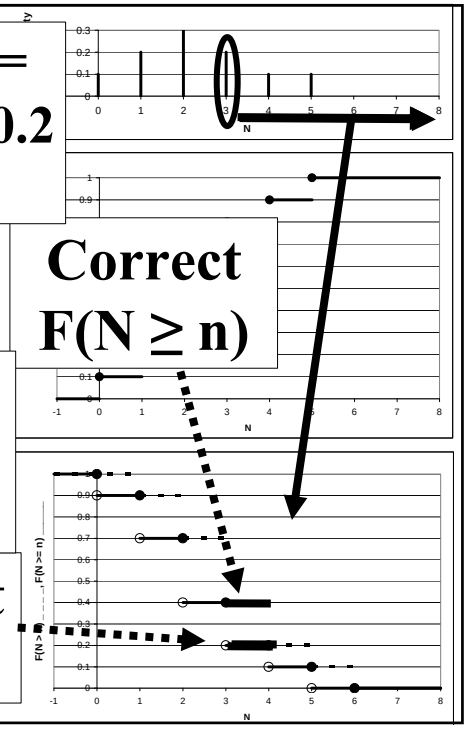
Cumulative Distribution Function (CDF), F'(N≤n)

Complementary Cumulative Distribution Function (CDF), F(N > n)



Correctly calculating F-N Curve - NOT SAME AS CCDF

$F(N \geq 3) = 0.1+0.1+0.2 = 0.4$



Correct $F(N \geq n)$

$F(N > 3) = 0.1+0.1 = 0.2$

Incorrect $F(N > n)$

HAND EXAMPLE

Summary – F-N Charts & Other RA Calculations

1) Calculate F-N as **F(N ≥ n)** ***NOT F(N > n) as for CCDF***
2) Select level of detail in Risk Analysis that is:
   - "Fit for purpose"
     - *Initial PRA, progressive improvement, final sign off, etc*
   - To obtain a **representative** estimated F-N relationship
     - *Failure modes, exposure conditions, response cases etc.*
   - "Art of risk analysis"
3) Control numerical precision errors through small initiating event increments
4) Consider & Communicate the uncertainties in the Societal Risk evaluation
   - Even if not performing an Uncertainty Analysis

4) Calculating Cost per statistical life saved (CSLS)

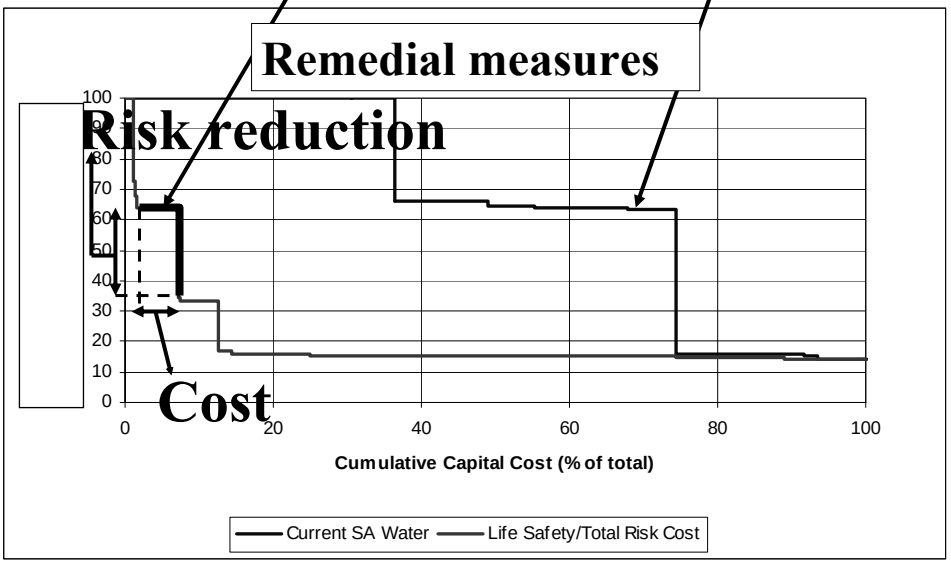
Unadjusted Cost Per Statistical Life Saved

$$\frac{\text{Cost of Fix}}{\text{Life Loss}_{\text{existing}} - \text{Life Loss}_{\text{fix}}}$$

$$\frac{\$/\text{Year}}{\text{Lives/Year}} = \frac{\$}{\text{Lives}}$$

ALARP Implications for Prioritization?

Life Loss Risk Reduction



Adjusted Cost Per Statistical Life Saved

$$\frac{\text{Cost of Fix} - \text{Economic Benefits}}{\text{Life Loss}_{\text{existing}} - \text{Life Loss}_{\text{fix}}}$$

$$\frac{\$/\text{Year}}{\text{Lives/Year}} = \frac{\$}{\text{Lives}}$$

ALARP Strength of Justification Ratings (Example)

To inform and not to prescribe the ALARP test outcome

Based on U.S. Federal government practice (USDOT has refused > $3M - OMB max. used: $140M)

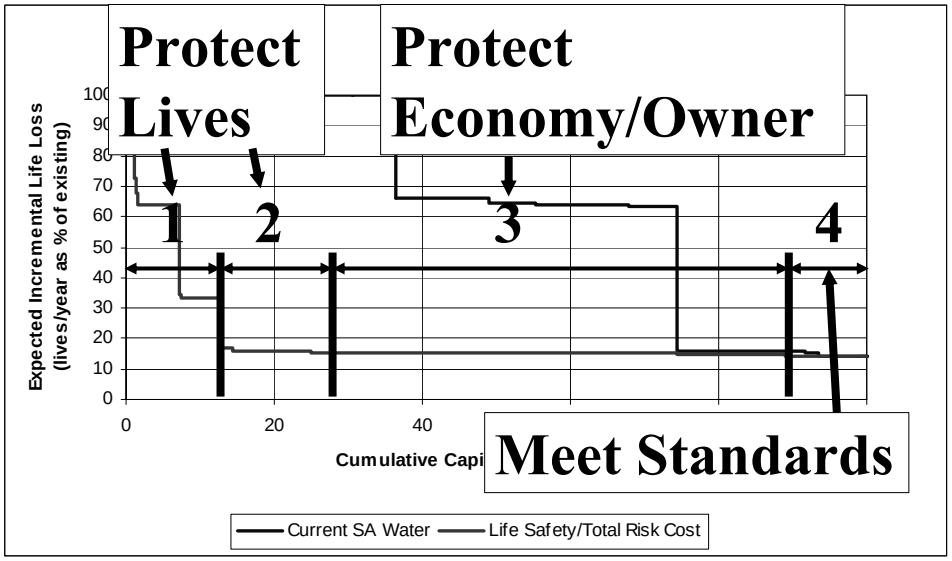
Include in Decision Justification Matrix

ALARP Evaluation – Existing Good Practice

- HSE (2001) state that a comparison against "existing good practice" could be used as an ALARP test *if such practice is known to be ALARP*
- Not clearly established what aspects of existing good dam safety practice would be ALARP, and which might fall short or go beyond satisfying ALARP

Diminishing Returns

Life Loss Risk Reduction



5) Calculating Disproportionality Ratio (R)

Proportion Factor (HSE)

ALARP - Legal Significance
As Low As Reasonably Practicable

"established that a computation must be made in which the **quantum of risk** is placed on one scale and the **sacrifice**, whether in money, time or trouble, involved in the measures necessary to avert the risk is placed in the other; and that, if it be shown that there is a **gross disproportion** between them, the risk being significant in relation to the sacrifice, the person upon whom the duty (of care) is laid discharges the burden by proving that compliance was not reasonably practicable"

- Edwards v. The National Coal Board (1949 1 All ER 743)

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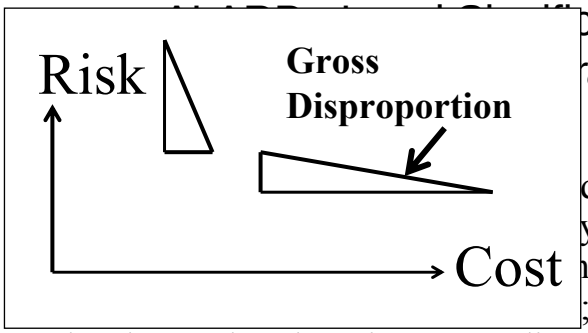

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Disproportionality Ratio, R
HSE "Proportion Factor"

R = ACSLS/VPF

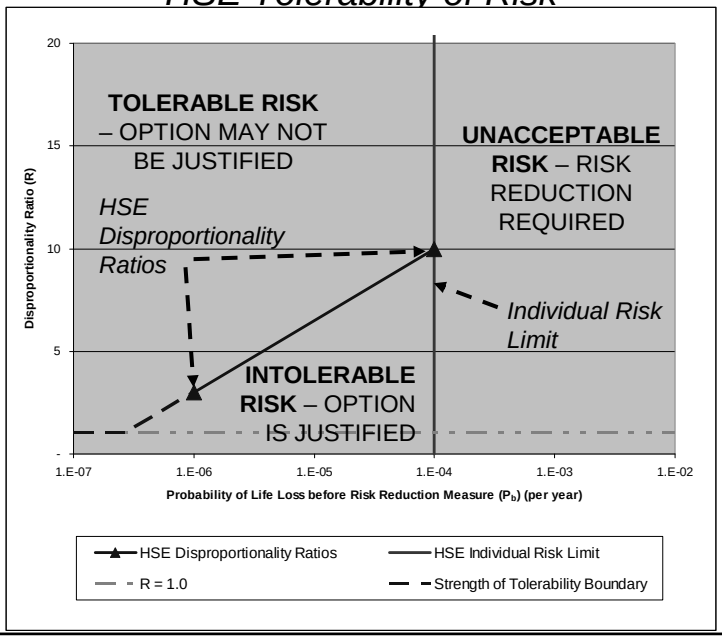
VPF = Value of preventing a fatality based on a willingness to pay for risk reduction

[UKHSE: £1M per fatality (2001 prices);

US Federal Agency average VPF: $6M per fatality (2004 $)]

= A means of valuing the safety benefit

Evaluation of Disproportionality Ratio
HSE Tolerability of Risk



CSLS – Two Stage Dam Safety Fix

Existing dam: *Consequences: 1 in 100 /yr, 30 lives*

Stage 1 Fix: *Cost = \$3.2 M/yr, Benefits = \$0.3 M/yr*
Consequences: 1 in 10,000 /yr, 100 lives

$$\text{ACSLS} = \frac{\text{Fix Cost - Fix Benefit}}{\text{Prob*Lives}_{exist} - \text{Prob*Lives}_{fix}}$$

$$= \frac{\$3.2 - 0.3}{1/100 \times 30 - 1/10{,}000 \times 100} = \frac{2.9}{0.29}$$

= **\$10 M/life saved**

Disproportionality Ratio = ACSLS/VPF = \$10M/\$2M = **5**

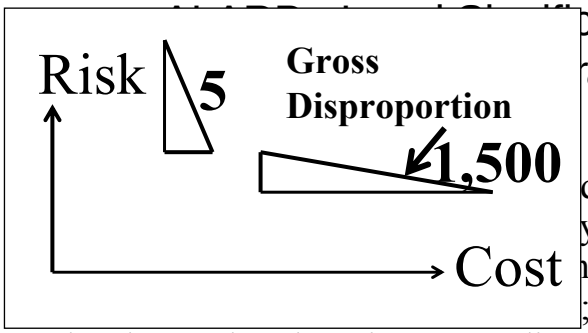
Stage 2 Fix: *Cost: \$3.0 M/yr, Benefits: \$0.03 M/yr*
Consequences: 1 in 1,000,000 /yr, 100 lives

$$\text{ACSLS} = \frac{\$3.0 - 0.03}{1/10{,}000 \times 100 - 1/1{,}000{,}000 \times 100} = \frac{2.97}{0.0099}$$

= **\$3 B/life saved**

Disproportionality Ratio = \$3B/\$2M = **1,500**

CSLS & VPF DO NOT INVOLVE PLACING A VALUE ON HUMAN LIFE



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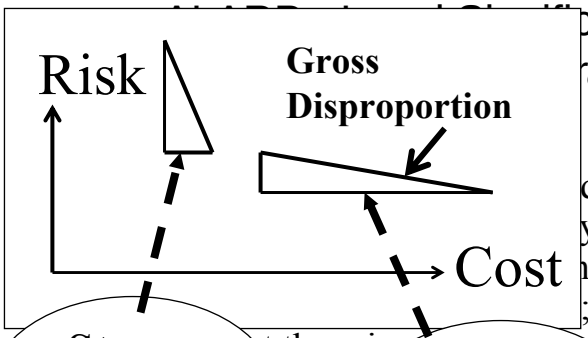

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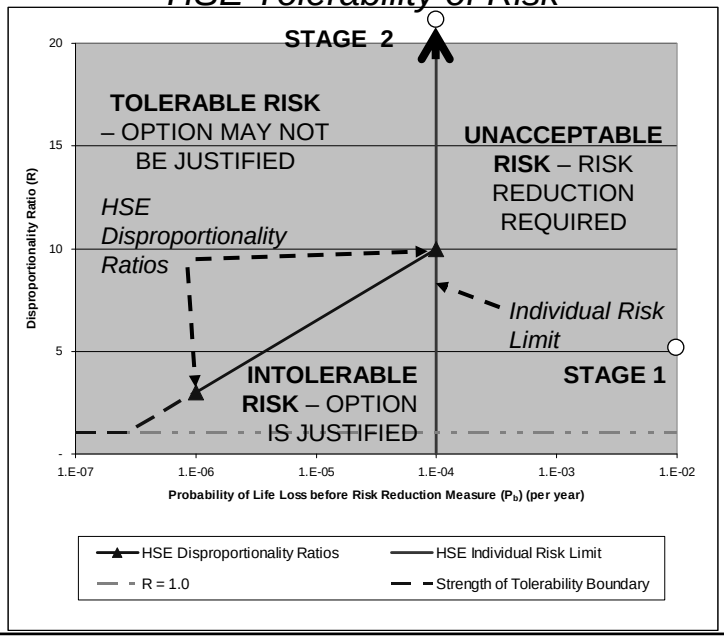
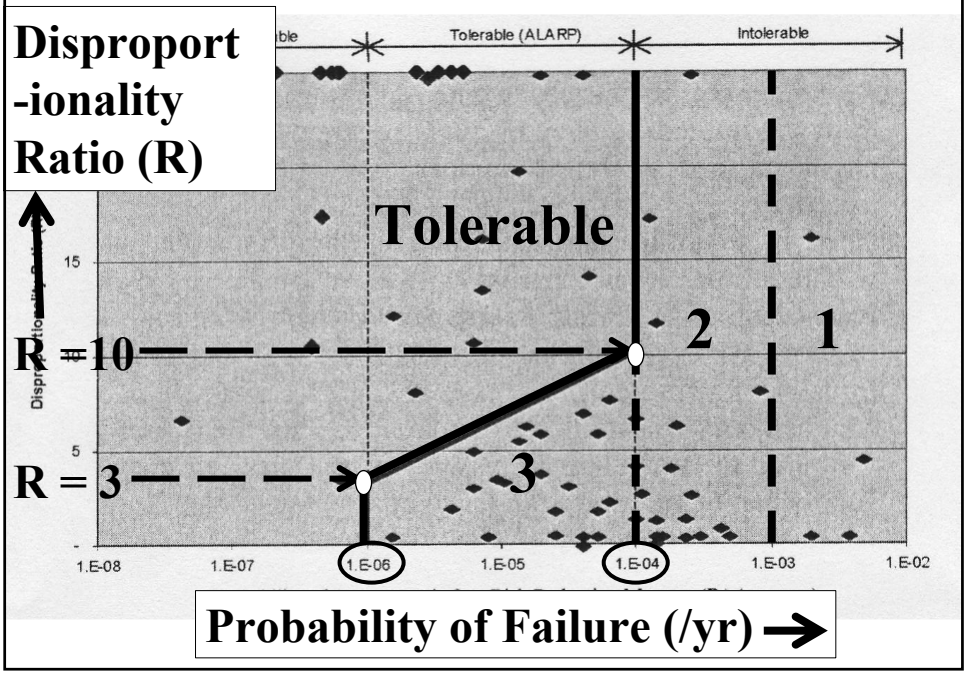
- Edwards vs. the National Coal Board in HSE 1999

Evaluation of Disproportionality Ratio

HSE Tolerability of Risk





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