RAC

Engineers & Economists

2nd International Week on Risk Analysis
as Applied to Dam Safety and Dam Security
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.1 - How Safe Is Safe Enough? Acceptable and Tolerable Risk

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

1) Experience in Dam Safety Risk Assessment

- Since 1978
- Research & Development – Utah State University – Institute for Dam Safety Risk Management
- Consulting – RAC Engineers & Economists

Experience in Dam Safety Risk Assessment

- ✓ Applications to ~ 750 dams – *Partnerships with owners, consultants and regulators*
  - ✓ Portfolio Risk Assessment - *Australia, UK, Corps of Engineers, etc.*
- ✓ Organizational Change and Peer Review - *State of Victoria + Private and government owners – USBR, Corps*
- ✓ Technology Transfer & Training
  - ✓ Demonstration RAs – *State of Victoria, Corps of Engineers*
- ✓ Professional Activities & Guidelines - *ICOLD, USCOLD/USSD, ASCE, USBR, CIRIA, CEA, ANCOLD, ASDSO, NSW DSC, UK DFRA, etc.*

How Safe is Safe Enough?

Traditional Approach – established rules as to design events and loads, structural capacity, safety coefficients and defensive design measures

- Uneven across failure modes/loading types
- Not comparable with other fields

Risk-based Approach – Risk estimates alone

Risk-informed Approach – Combines traditional and risk-based approaches

Risk Evaluation

The process of examining and judging the significance of the risk

Risk Evaluation

ICOLD Bulletin 130 on "Risk Assessment in Dam Safety Management" (ICOLD 2005)

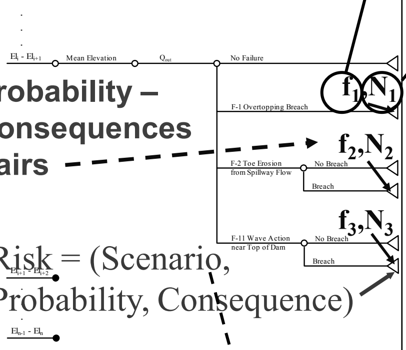
The topic of **risk evaluation** is not an easy one, especially for a technically-minded person who may be looking for straightforward and purely quantitative approaches. ...

To grapple with this topic requires that we cross the boundary from the technical world of dam safety engineering into the far more subjective world of **values and value judgments**. Yet this is the reality.

… **society** expects that it will dictate to the technological community the safety and other goals that should be met by technological systems, rather than the opposite, as has often been the case in the past.

Risk: “*Measure of the* ***probability*** *and* ***severity*** *of an adverse effect to life, health, property, or the environment.*”

ICOLD (2005)



Probability – Consequences Pairs

Risk = (Scenario, Probability, Consequence)

1) Failure Modes
2) Exposure scenarios

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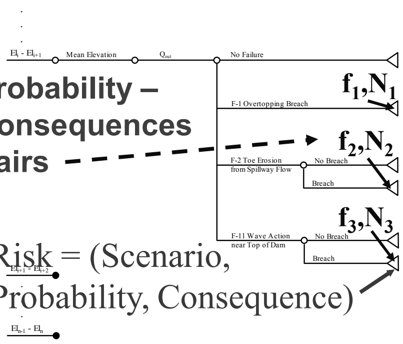

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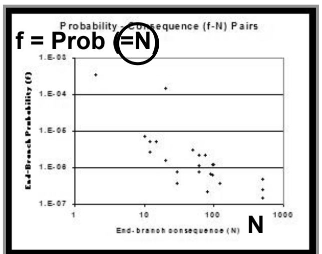
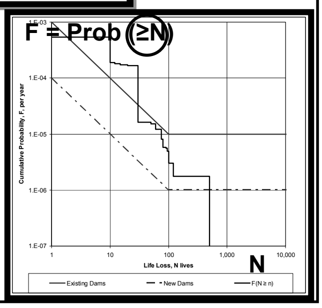


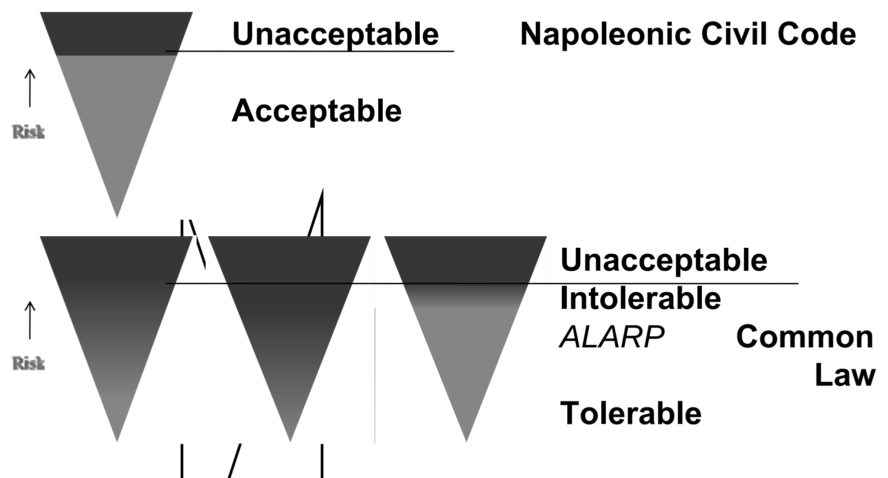
1) f-N: Non-cumulative probability of N for all failure modes and exposure scenarios



2) F-N: Cumulative probability distribution of N for all failure modes and exposure scenarios

Fundamental Principles: Equity & Efficiency

- **Equity**: The right of individuals and society to be protected, and the right that the interests of all are treated with fairness.
  - *"In practice, this often converts to fixing* ***a limit to … the maximum level of risk****"* (HSE 2001)
  - *"If the risk estimate … is above the limit and further risk control measures cannot be introduced to reduce the risk, the risk is held to be* ***unacceptable*** *whatever the benefits."* (HSE 2001)
- **Efficiency**: The need for society to distribute and use available resources so as to achieve the greatest benefit.
  - *"comparison between the incremental benefits of the measure to prevent the risk of injury … and the cost of the measure."* (HSE 2001).
  - **Benefit-cost**
  - **Cost effectiveness** (including cost per statistical life saved)



The risk criteria adopted in the United Kingdom and the Netherlands look very similar. Both countries have upper limits for 'allowable' individual risk and both countries use criteria lines in FN curves . Even their numerical values do not differ a great deal. However, the interpretation differs greatly. Whereas the criteria in the Netherlands (Napoleonic Civil Code) are the **end of the discussion**, in the United Kingdom (Common Law) they are **the starting point**. (Ale 2005)

There are no simple "bright lines" in tolerable risk evaluation in common law countries

Acceptable Risk vs. Tolerable Risk

Acceptable Risk: *"a risk, which for the purposes of life or work, everyone who might be impacted is prepared to* ***accept*** *assuming no changes in risk control mechanisms."*

HSE (1995)

Tolerable Risk: "*a risk within a range that society can* ***live with*** (1) *so as to secure certain* ***net benefits****. It is* (2) *a range of risk that we* ***do not regard as negligible or as something we might ignore****, but rather as something we need to* (3) ***keep under review*** *and* (4) ***reduce it still further if and as we can (ALARP)****.*"

ICOLD (2005) adapted from HSE (2001)

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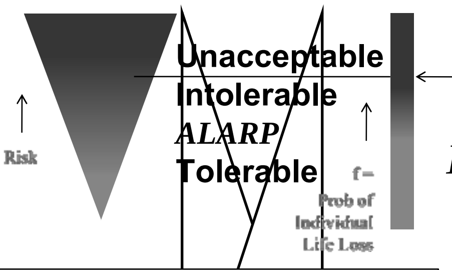
IC... ...d from HSE (2001)

Practical concept that applies to **design, construction, operation and management**

There are no simple "bright lines" in tolerable risk evaluation in common law countries

Individual Tolerable Risk

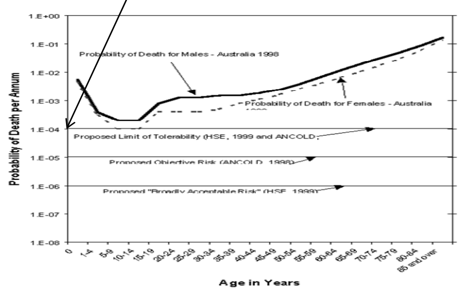
Individual concerns – "how individuals see the risk from a particular hazard affecting them and things they value personally … " (HSE 2001).



HSE: 1 in 10,000/yr

ANCOLD: 1 in 10,000/yr

New Dams:1 in 100,000/yr



Function of voluntariness and benefit (Vrijling 2001)

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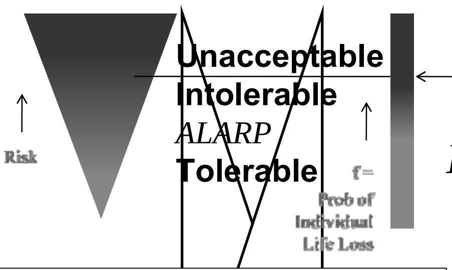

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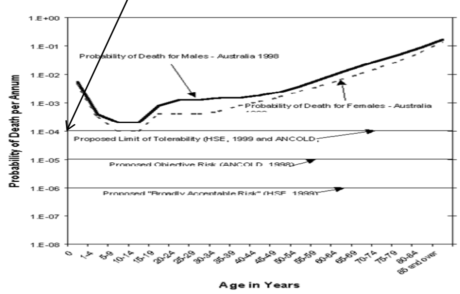


USBR: 1 in 10,000/yr

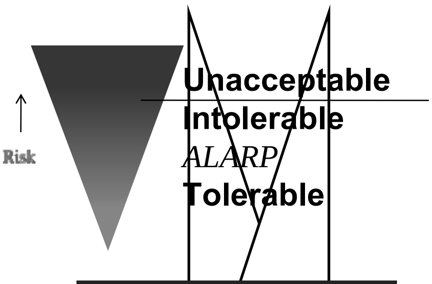
Total Probability of Failure

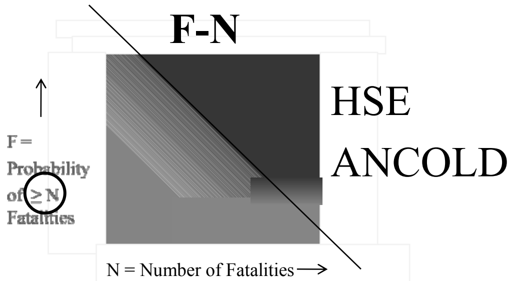
Portfolio size

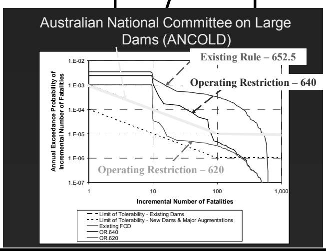
Historic failure rate

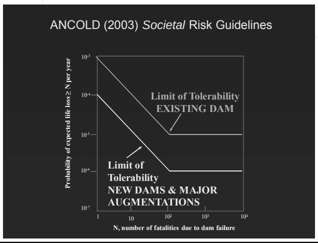
Societal Tolerable Risk

"Societal concerns – "the risks … which impact on society and … could have adverse repercussions for the institutions responsible for … protecting people … ." *including multiple fatalities ("societal risk"), exposure of especially sensitive groups, and the uneven distribution of risks and benefits.* (HSE 2001).









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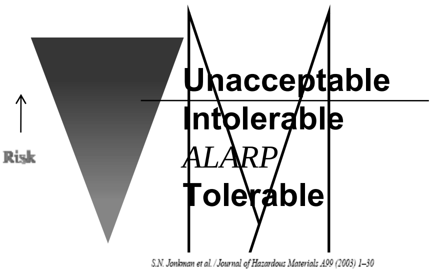
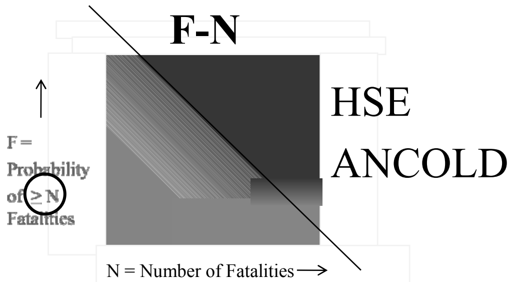




S.N. Jonkman et al. / Journal of Hazardous Materials A99 (2003) 1–30

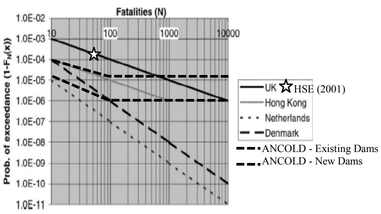
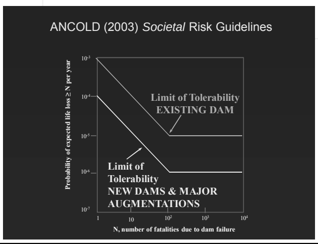


Fig. 6. Some international standards in FN format [2,8,11,21].



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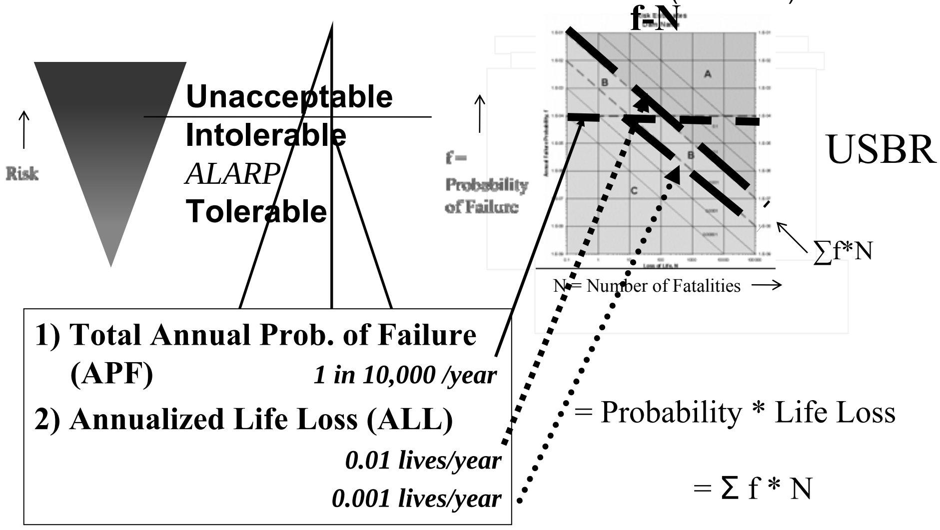


If *individual or population (societal) risk* alone is used in setting program priorities, there is no guarantee that the programs selected are reducing risk sensibly. Large individual or population risks, that are very expensive to reduce, may not be cost effective. Only by considering both the *benefits* and the *costs* of risk reduction can sensible decisions be made.

- U.S. Federal Budget, 1992

Table C-2. Risks and Cost-Effectiveness of Selected Regulations **1992 BUDGET (OMB)**

Regulation[1]	Year Issued	Health or Safety?	Agency	Baseline Mortality Risk per Million Exposed	Cost per Premature Death Averted (US$Millions 1990)
Unvented Space Heater Ban	1980	S	CPSC	1,890	0.1
Aircraft Cabin Fire Protection Standard	1985	S	FAA	5	0.1
Auto Passive Restrain/Seat Belt Standards	1984	S	NHTSA	6,370	0.1
Steering Column Protection Standard[2]	1967	S	NHTSA	385	0.1
Underground Construction Standards[3]	1989	S	OSHA-S	38,700	0.1
Trihalomethane Drinking Water Standards	1979	H	EPA	420	0.2
Aircraft Seat Cushion Flammability Standard	1984	S	FAA	11	0.4
Alcohol and Drug Control Standards[3]	1985	H	FRA	81	0.4
Auto Fuel-System Integrity Standard	1975	S	NHTSA	343	0.4
Standards for Servicing Auto Wheel Rims[3]	1984	S	OSHA-S	630	0.4
Aircraft Floor Emergency Lighting Standard	1984	S	FAA	2	0.6
Concrete & Masonry Construction Standards[3]	1988	S	OSHA-S	630	0.6
Crane Suspended Personnel Platform Standard[3]	1988	S	OSHA-S	81,000	0.7
Passive Restraints for Trucks & Buses (Proposed)	1989	S	NHTSA	6,370	0.7

Table C-2. Risks and Cost-Effectiveness of Selected Regulations (Continued)

Regulation[1]	Year Issued	Health or Safety?	Agency	Baseline Mortality Risk per Million Exposed	Cost per Premature Death Averted (US$Millions 1990)
Side-Impact Standards for Autos (Dynamic)	1990	S	NHTSA	NA	0.8
Children's Sleepwear Flammability Ban[4]	1973	S	CPSC	29	0.8
Auto Side Door Support Standards	1970	S	NHTSA	2,520	0.8
Low-Altitude Windshear Equipment & Training Standards	1988	S	FAA	NA	1.3
Electrical Equipment Standards (Metal Mines)	1970	S	MSHA	NA	1.4
Trenching and Excavation Standards[3]	1989	S	OSHA-S	14,310	1.5
Traffic Alert and Collision Avoidance (TCAS) Systems	1988	S	FAA	NA	1.5
Hazard Communication Standard[3]	1983	S	OSHA-S	1,800	1.6
Side-Impact Stds for Trucks, Buses and MPVS (Proposed)	1989	S	NHTSA	NA	2.2
Grain Dust Explosion Prevention Standards[3]	1987	S	OSHA-S	9,450	2.8
Rear Lap/Shoulder Belts for Autos	1989	S	NHTSA	NA	3.2

Table C-2. Risks and Cost-Effectiveness of Selected Regulations (Continued)

Regulation[1]	Year Issued	Health or Safety?	Agency	Baseline Mortality Risk per Million Exposed	Cost per Premature Death Averted (US$Millions 1990)
Standards for Radionuclides in Uranium Mines[3]	1984	H	EPA	6,300	3.4
Benzene NESHAP (Original: Fugitive Emissions)	1984	H	EPA	1,470	3.4
Ethylene Dibromide Drinking Water Standard	1991	H	EPA	NA	5.7
Benzene NESHAP (Revised: Coke By-Products)[3]	1988	H	EPA	NA	6.1
Asbestos Occupational Exposure Limit[3]	1972	H	OSHA-H	3,015	8.3
Benzene Occupational Exposure Limit[3]	1987	H	OSHA-H	39,600	8.9
Electrical Equipment Standards (Coal Mines)[3]	1970	S	MSHA	NA	9.2
Arsenic Emission Standards for Glass Plants	1986	H	EPA	2,660	13.5
Ethylene Oxide Occupational Exposure Limit[3]	1984	H	OSHA-H	1,980	20.5
Arsenic/Copper NESHAP	1986	H	EPA	63,800	23.0
Haz Waste Listing for Petroleum Refining Sludge	1990	H	EPA	210	27.6
Cover/Move Uranium Mill Tailings (Inactive Sites)	1983	H	EPA	30,100	31.7
Benzene NESHAP (Revised: Transfer Operations)	1990	H	EPA	NA	32.9
Cover/Move Uranium Mill Tailings (Active Sites)	1983	H	EPA	30,100	45.0

Table C-2. Risks and Cost-Effectiveness of Selected Regulations (Continued)

Regulation[1]	Year Issued	Health or Safety?	Agency	Baseline Mortality Risk per Million Exposed	Cost per Premature Death Averted (US$Millions 1990)
Acrylonitrile Occupational Exposure Limit[3]	1978	H	OSHA-H	42,300	51.5
Coke Ovens Occupational Exposure Limit[3]	1976	H	OSHA-H	7,200	63.5
Lockout/Tagout[3]	1989	S	OSHA-S	4	70.9
Asbestos Occupational Exposure Limit[3]	1986	H	OSHA-H	3,015	74.0
Arsenic Occupational Exposure Limit[3]	1978	H	OSHA-H	14,800	106.9
Asbestos Ban	1989	H	EPA	NA	110.7
Diethylstilbestrol (DES) Cattlefeed Ban	1979	H	FDA	22	124.8
Benzene NESHAP (Revised: Waste Operations)	1990	H	EPA	NA	168.2
1,2-Dichloropropane Drinking Water Standard	1991	H	EPA	NA	653.0
Haz Waste Land Disposal Ban (1st 3rd)	1988	H	EPA	2	4,190.4
Municipal Solid Waste Landfill Standards (Proposed)	1988	H	EPA	<1	19,107.0
Formaldehyde Occupational Exposure Limit[3]	1987	H	OSHA-H	31	86,201.8

Table C-2. Risks and Cost-Effectiveness of Selected Regulations (Continued)

Regulation[1]	Year Issued	Health or Safety?	Agency	Baseline Mortality Risk per Million Exposed	Cost per Premature Death Averted (US$Millions 1990)
Atrazine/Alachlor Drinking Water Standard	1991	H	EPA	NA	92,069.7
Haz Waste Listing for Wood Preserving Chem.	1990	H	EPA	<1	5,700,000.0

[1]70-year lifetime exposure assumed unless otherwise specified
[2]50-year lifetime exposure
[3]45-year lifetime exposure
[4]12-year exposure period
NA=Not available
Agency Abbreviations--CPSC: Consumer Product Safety Commission; MSHA: Mine Safety and Health Administration; EPA: Environmental Protection Agency; NHTSA: National Highway Traffic Safety Administration; FAA: Federal Aviation Administration; FRA: Federal Railroad Administration; FDA: Food and Drug Administration; OSHA-H: Occupational Safety and Health Administration, Health Standards; OSHA-S: Occupational Safety and Health Administration, Safety Standards.
Source: John F. Morrll, III, "A Review of the Record." *Regulation*, Vol. 10, No. 2 (1986), p. 30. Updated by the Author, et al.

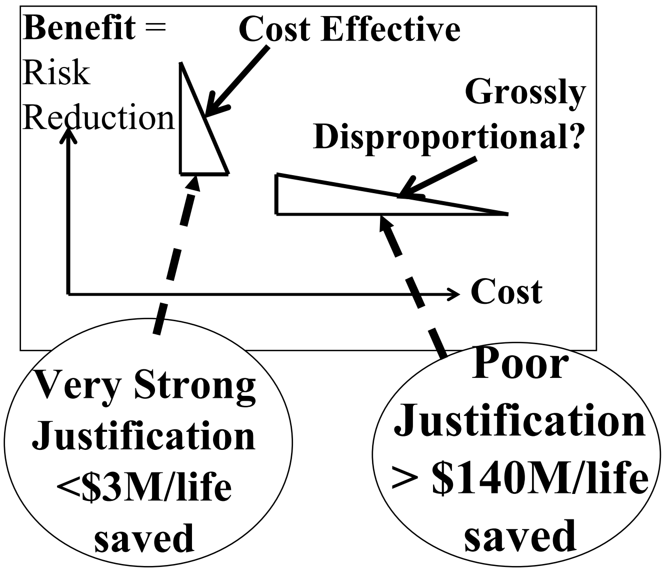
Cost per statistical life saved (CSLS) AIR BAGS - HYPOTHETICAL

- $500 per air bag
- 10 million new cars per year
- $5B COST per year
- 50,000 deaths per year
- Say 5,000 lives saved per year by air bags
- Then $5B COST per year SAVES 5,000 lives per year
- CSLS = $5B/5,000 lives
  = $1M per statistical life saved

Strength of JUSTIFICATION for Risk Reduction

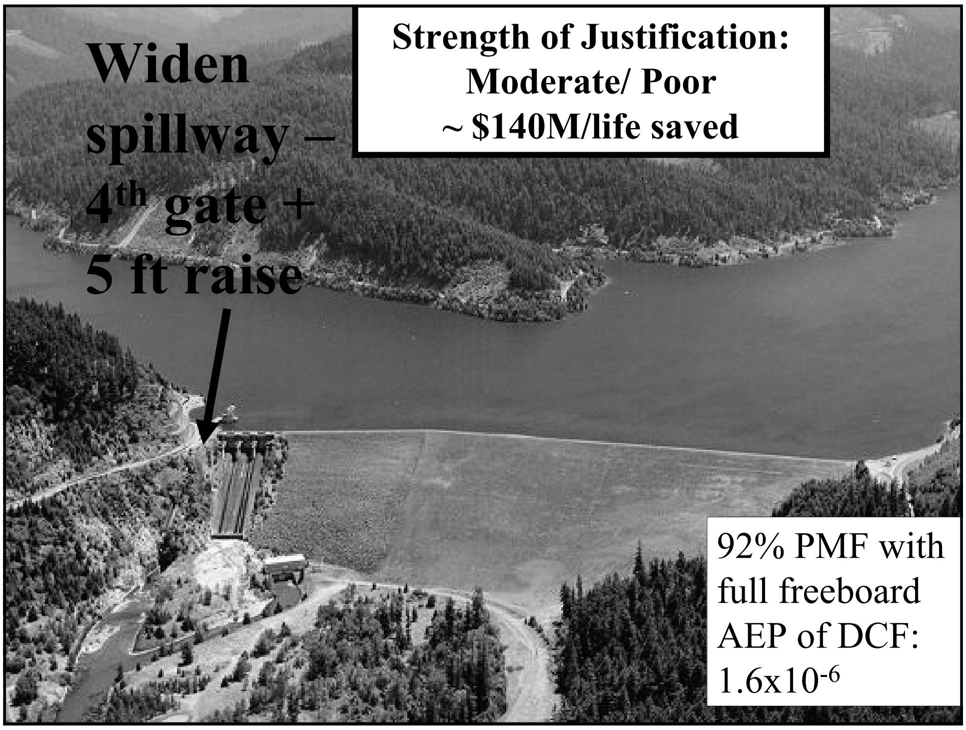
Cost per statistical life saved

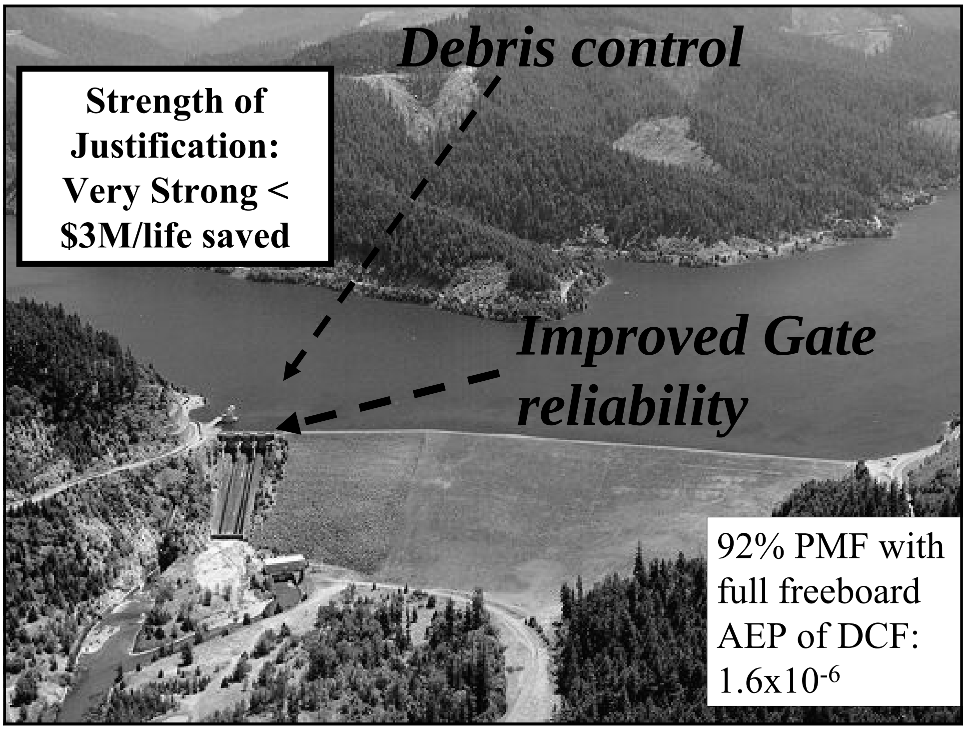
- U.S. Federal government practice (Kniesner 1997)
  - USDOT: refuses > **US$3M**
  - OMB: **US$140M**
- If entire US GDP spent on prevention of accidental death: **US$55M** (Viscusi 1998)
- Implicit accident prevention *spending* values: **US$5M ($3M - $7M)** (Viscusi 1998)
  - approximately 10x greater than accident victim *compensation* from product liability suits (Ford Pinto)
- Dams that we have assessed: **US$0 - $10^{12}**



ALARP – Cost Effectiveness

As Low As Reasonably Practicable


Widen spillway – 4th gate + 5 ft raise
Strength of Justification: Moderate/ Poor ~ $140M/life saved
92% PMF with full freeboard AEP of DCF: 1.6x10-6


Debris control
Strength of Justification: Very Strong < $3M/life saved
Improved Gate reliability
92% PMF with full freeboard AEP of DCF: 1.6x10-6

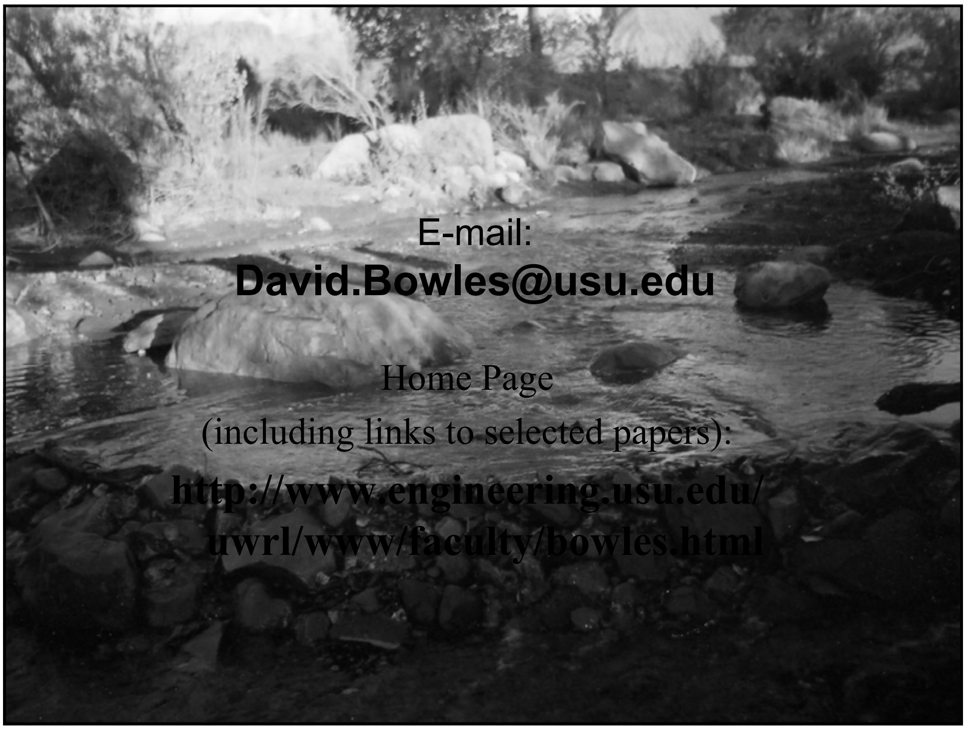
ALARP Evaluation – Optioneering

- Fundamental to ALARP evaluation is the identification of potential risk reduction measures to examine cost effectiveness and disproportionality
- Fischhoff et al. (1981) state,

  "*One accepts options, not risks*."
- Potential Failure Modes Analysis
  - for the existing dam
  - & proposed risk reduction options

Closing

- Shift in **focus**
  - From "dam" safety to **"public" safety**
  - From acceptable risk to **tolerable risk**
  - From technically-based safety justification to **risk-informed** justifications
- **Risk evaluation** provides the opportunity to:
  - **Level the playing field** for different failure modes/loading types
  - **Compare with other types of risk** to the public
  - Can strengthen the **justification for funding** dam safety
- What **tolerable risk guidelines** should be used for dams (and levees) in the US?
  - Not just a matter of meeting a quantitative criterion
    - **No simple "bright lines"** in tolerable risk evaluation in common law
    - **Dam Safety Management and human factors** – ICOLD Bulletin 59 Revision
  - What role should **ALARP** play in the US?
  - What role should the **owner's liability protection** play in reducing risks?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