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

Complete Dam Risk Analysis & Detailed Applications:

L.6 - Hills Creek Dam Risk Assessment:

Evaluation of Flood Risk Reduction Alternatives & Uncertainty Analysis

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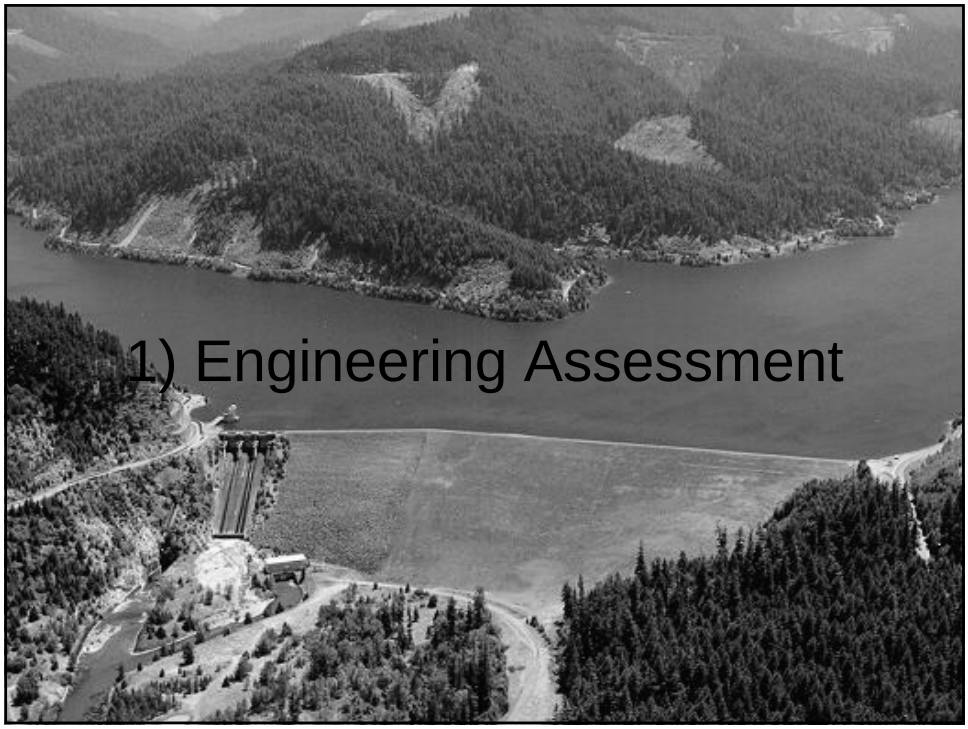
and RAC Engineers & Economists

Outline

1) Engineering Assessment
2) Event Trees & Loadings
3) Consequences Inputs and Breach-Inundation Analyses
4) RA Results - Existing Dam
5) RA Results – Risk Reduction Alternatives
6) Uncertainty Analysis
7) Conclusions & Recommendations



Engineering Assessment

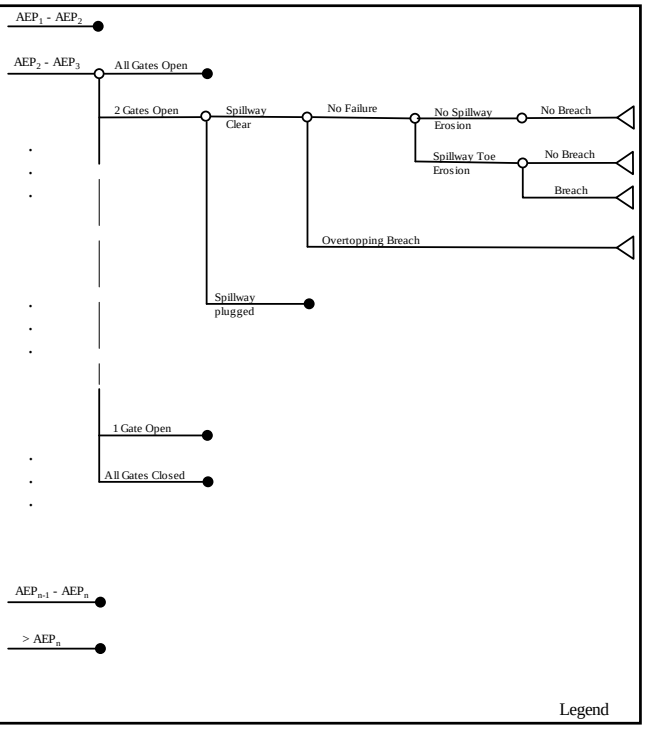
Ratings	No.	%
Number of P:	35	71%
Number of AP:	7	14%
Number of ANP:	7	14%
Number of (ANP):	0	0%
Number of NP:	0	0%
Number of (NP):	0	0%
Number of N/A:	12	
Total:	61	
Number of ANP+ NP:	7	14%
Number of (ANP) + (NP):	0	0%

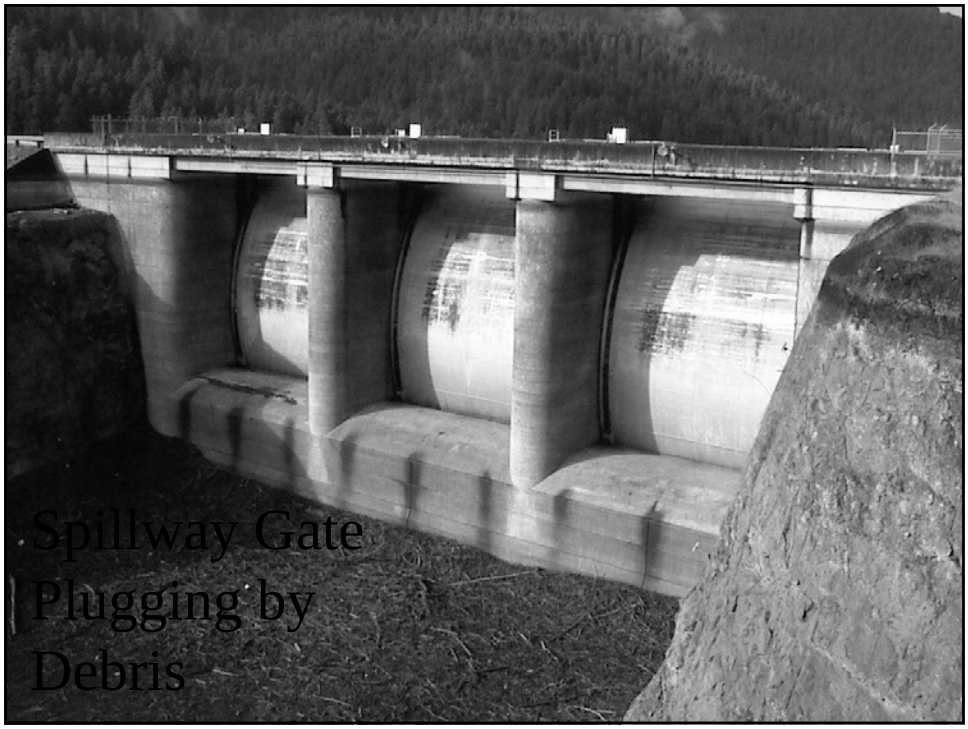
Assessment Factor	Rating
FLOOD	
Concrete Gravity Section	
External stability	N/A
Internal stability	N/A
Foundation Piping	N/A
Abutment Foundation Stability (Dam Structure)	N/A
Overall flood capacity	
PMF	ANP
Overtopping	ANP
Spillway and stilling basin system	
Structural Stability	P
Hydraulic capacity	ANP
Walls - overtopping	ANP
Gates - structural capacity	AP
Gate piers - structural capacity	P
Erodibility	ANP
Mechanical Systems	AP
Electrical Systems	P
Obstructions	
Drift and Debris	ANP
Failed Slopes	P
Sill	P
Outlet Works	
Piping	N/A
Electrical Systems	AP
Mechanical Systems	P
Stability	
Intake	P
Tunnel/Conduit	P
Obstructions	P
Embankment	
Geotech	
Piping	P
Stability	P
Toe erosion	ANP
Surface Erosion	P
Wave action	P
Abutments	P
Foundation Piping	P
Reservoir Rim	
Stability	P
Loss Of Capacity	P
Erodibility	P
Mines	N/A
Instrumentation	P

Assessment Factor	Rating
EARTHQUAKE	
Concrete Gravity Section	
External stability	N/A
Internal stability	N/A
Reservoir	
Stability	P
Loss Of Capacity	P
Mining	N/A
Spillway and stilling basin system	
Structural Stability	P
Gates - structural capacity	P
Gate piers - structural capacity	P
Appurtenances	
Outlet works	P
Embankment	
Liquefaction	AP
Stability (includes excessive deformation)	AP
Foundation	
Liquefaction	AP
Stability	AP
Fault movement	P
Instrumentation	P
NORMAL OPERATING CONDITIONS	
Concrete Gravity Section	
Foundation sliding	N/A
Foundation piping	N/A
Stresses within dam body	N/A
Reservoir	
Reservoir rim stability	P
Appurtenances	
Outlet works piping	P
Outlet works gates	P
Embankment	
Piping	P
Slope stability	P
Foundation	
Piping	P
Stability	P
Instrumentation	P
Deterioration of Materials	P

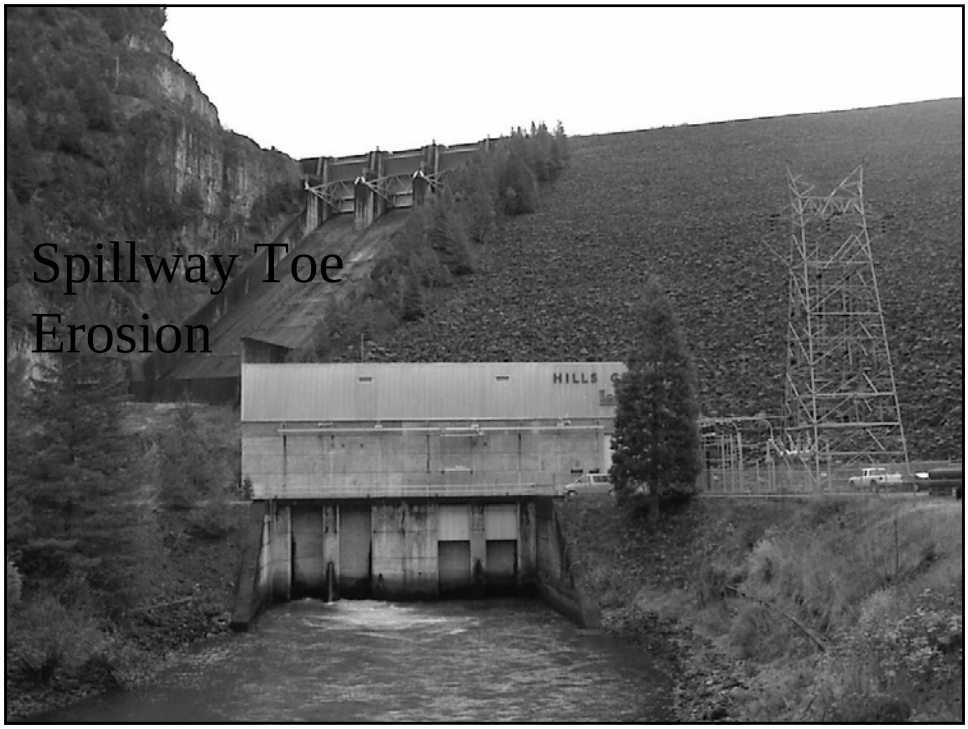
Flood Event Tree

- Embankment Failure Modes
  - Overtopping
  - Spillway toe erosion (+ loss of penstock control)
- Gate failure cases
  - Combinations of individual gates
  - Common cause failure of all gates
- Spillway plugging by debris
- Consequences
  - Life loss
  - Economic damages

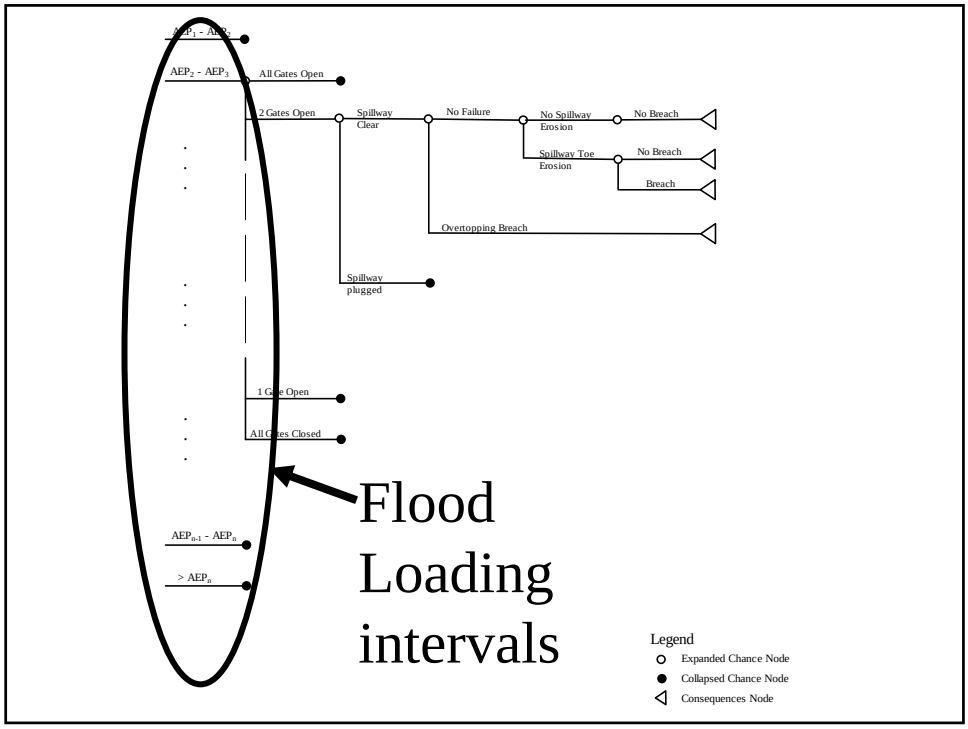




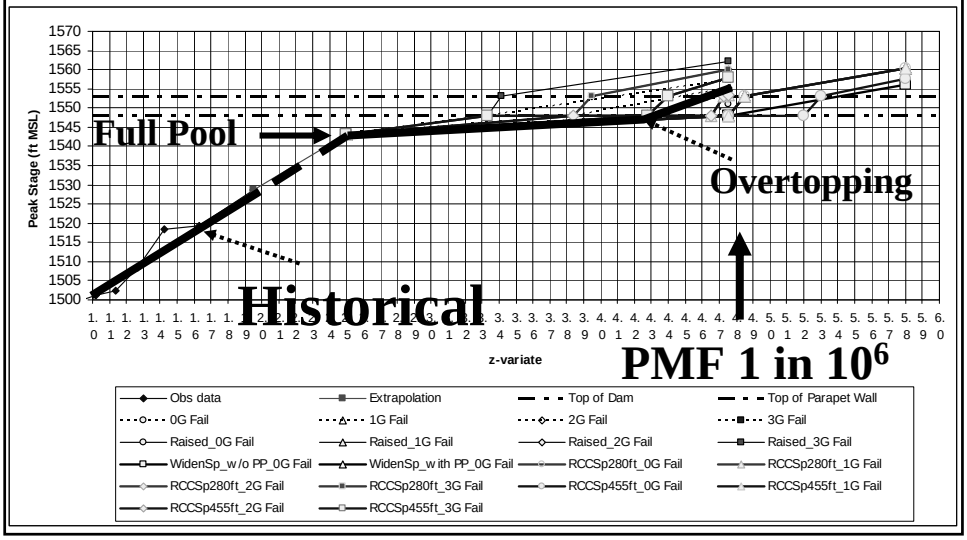
Spillway Gate Plugging by Debris

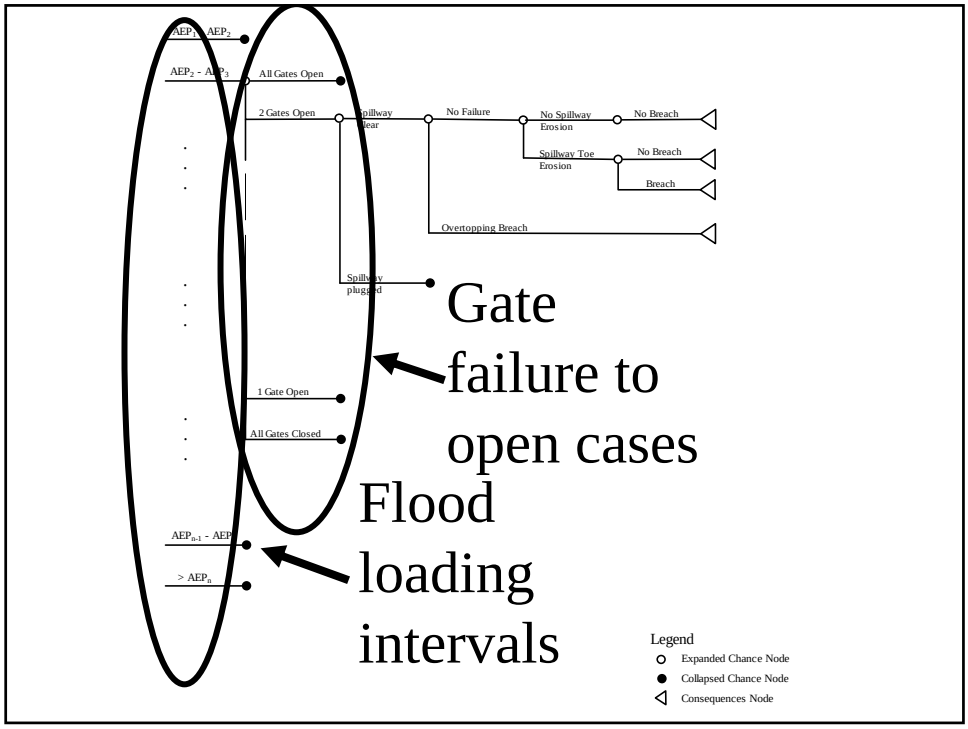


Spillway Toe Erosion



PEAK STAGE – AEP:
Existing Dam – Gates 100% reliable

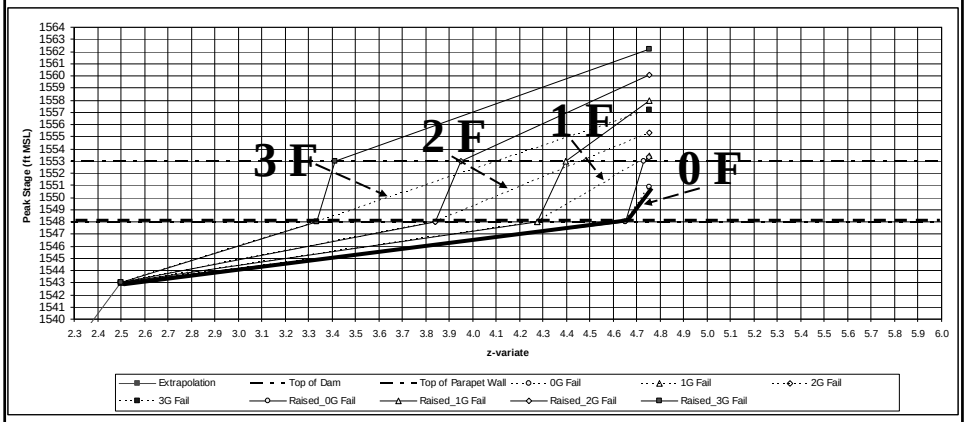




Per demand reliabilities

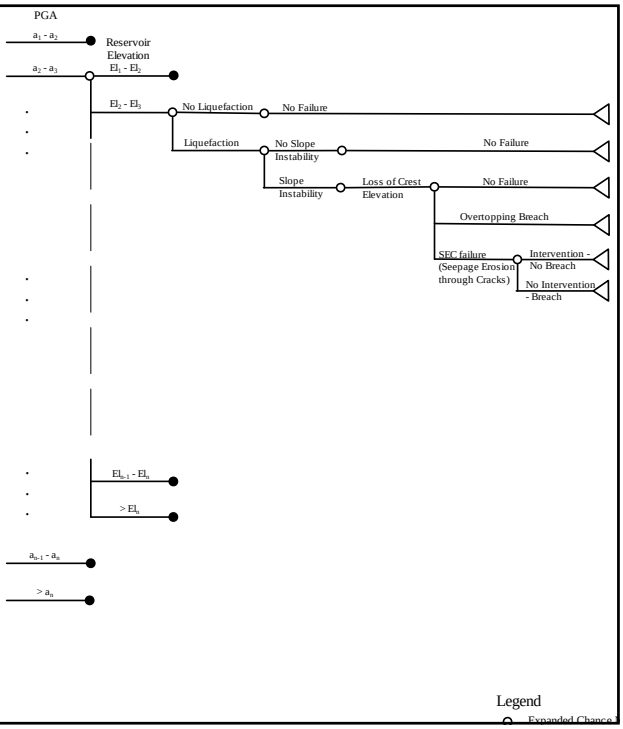
- Single gate
  - 1 in 10: Preliminary fault tree estimate
  - 1 in 50: Used to allow for repairs (1 in 100 – 1 in 10)
  - 1 in 200: After Indicative Gate Reliability Fix (1 in 1,000 – 1 in 100)
- All gates – Common Cause
  - 1 in 100: Preliminary fault tree estimate
  - 1 in 50: Used to allow for repairs (1 in 100 – 1 in 10)
  - 1 in 200: After Indicative Gate Reliability Fix (1 in 1,000 – 1 in 100)

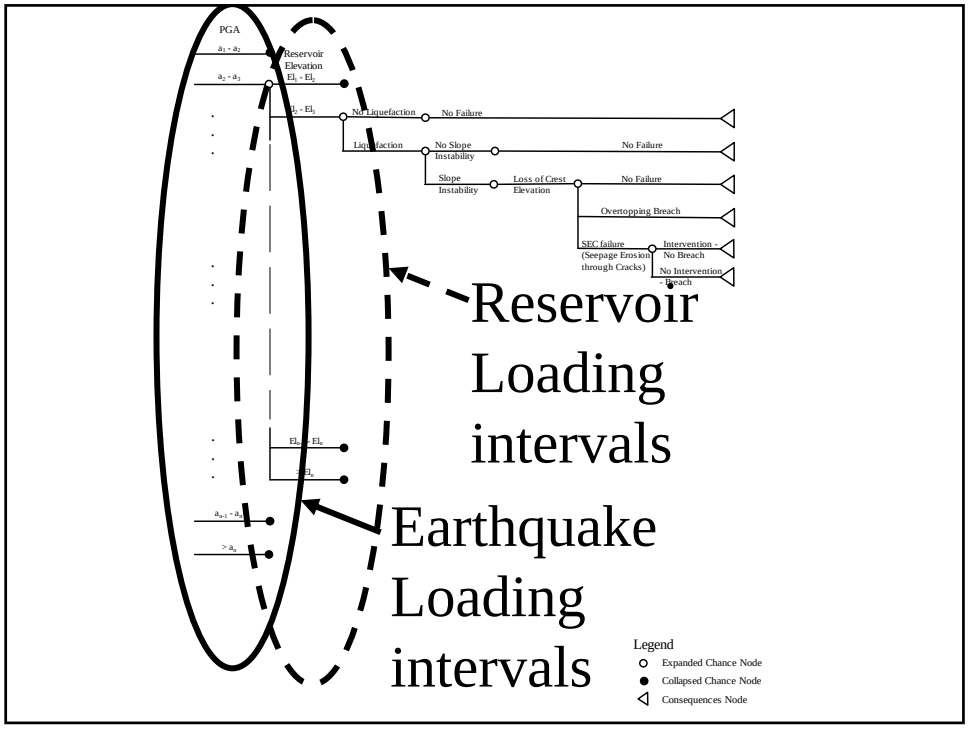
PEAK STAGE – AEP:
Existing Dam & 5 ft Raise

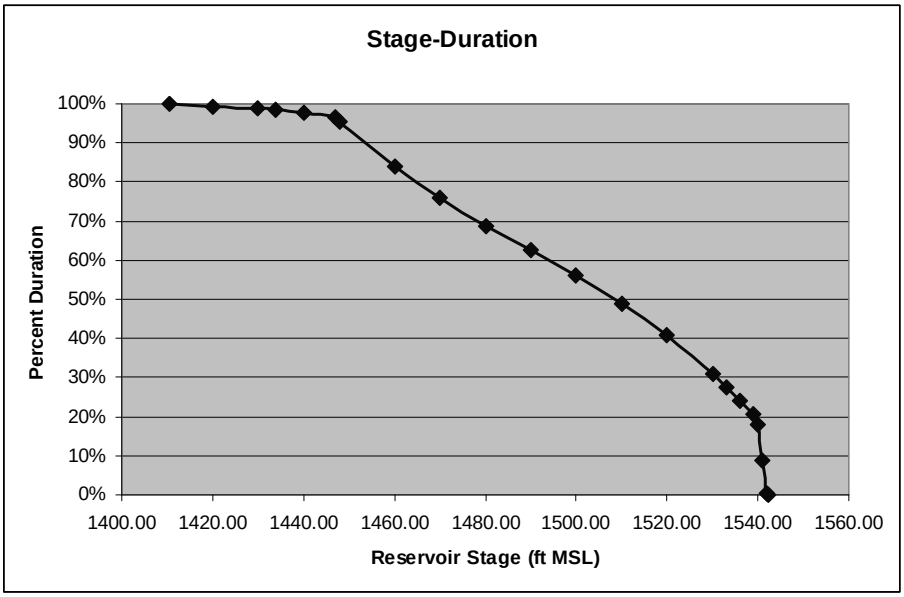


Earthquake Event Tree

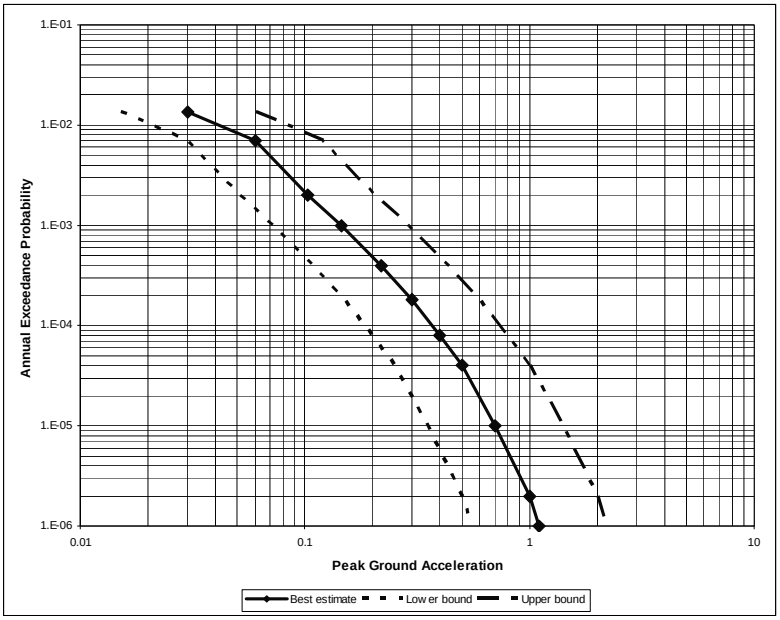
- Embankment Failure Modes
  - Liquefaction
    - Sudden Overtopping
    - Delayed Seepage Erosion Through Cracks (SEC)
      - Intervention?
- Consequences
  - Life loss
  - Economic damages

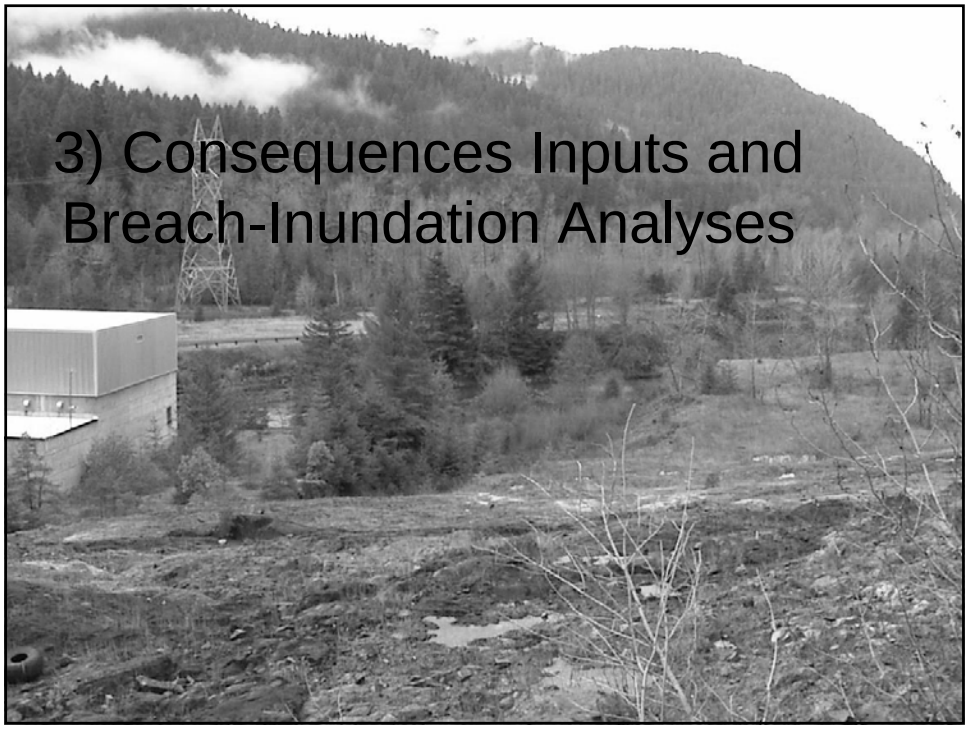



PGA
Reservoir Elevation
No Liquefaction
No Failure
Liquefaction
No Slope Instability
No Failure
Slope Instability
Loss of Crest Elevation
No Failure
Overtopping Breach
SEC failure (Seepage Erosion through Cracks)
Intervention - No Breach
No Intervention - Breach
Reservoir Loading intervals
Earthquake Loading intervals
Legend
Expanded Chance Node
Collapsed Chance Node
Consequences Node


Stage-Duration
Percent Duration
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1400.00
1420.00
1440.00
1460.00
1480.00
1500.00
1520.00
1540.00
1560.00
Reservoir Stage (ft MSL)

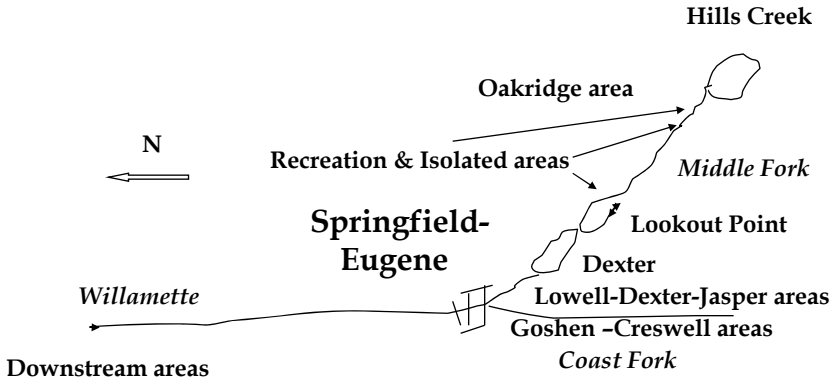
Earthquake Loading





3) Consequences Inputs and Breach-Inundation Analyses

Consequence Areas



Summary of Economic Damages
- Flood Overtopping Failure & No Failure

Failure/No Failure – Reservoir Level (No. gates failed)	Higher Projection ($M)	Lower Projection ($M)
DCF(0) - 1548	61,615	47,649
DCF(0)nf	59,796	46,359
DCF(1) - 1548	90,063	69,087
DCF(1)nf	56,810	44,065
DCF(2) - 1548	84,547	64,889
DCF(2)nf	4,501	4,500
DCF(3) - 1548	75,186	57,693
DCF(3)nf	3,034	3,033

Summary of Economic Damages

- Flood, Normal Operating & Earthquake Failure Modes

Failure Mode – Reservoir level	Higher Projection ($M)	Lower Projection ($M)
Toe Erosion - 1543	76,368	58,598
Piping - 1543	72,890	55,876
Slope Stability - 1543	74,447	57,029
EQ(1) - 1541	72,704	55,725
EQ(2) - 1500	47,401	36,710
EQ(3) - 1450	35	28
EQ(4) - 1425	27	21

Warning time

- Warning time = Travel time +/– Warning Time Adjustment
- Adjustment Time depends on failure timing-detection-decision-notification-warning conditions - estimated by Engineering Team

Hills Creek Warning Time Adjustments		
Event case	Day Exposure	Night Exposure
Dam Crest Flood	> 200 minutes	> 200 minutes
Earthquake	-30 to -120 minutes	-30 to -120 minutes
Normal Operating Condition	0 to 120 minutes	-30 to -120 minutes

Life Loss Estimates – Graham Method

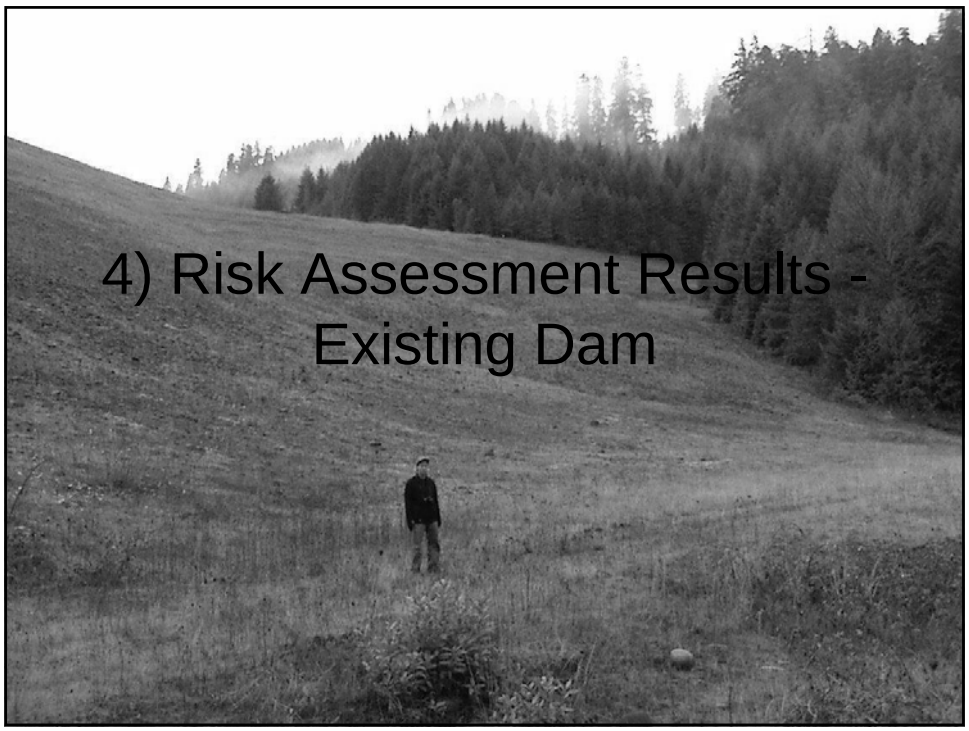
Flood Overtopping Failure & No Failure

Failure/No Failure Event	Best Estimate	Lower Estimate	Higher Estimate
DCF(0)	2,229	370	4,457
DCF(0)nf	2,188	363	4,376
DCF(1)	3,100	516	6,201
DCF(1)nf	2,115	351	4,230
DCF(2)	3,039	506	6,077
DCF(2)nf	215	35	430
DCF(3)	2,667	444	5,334
DCF(3)nf	186	31	372

Life Loss Estimates – Graham Method

Piping, Slope Stability and Earthquake Failures

Event (WT Adjustment)	Best Estimate	Event Case (WT Adjustment)	Best Estimate
TOE EROSION	2,843	SLOPE ST.: -120 NIGHT	2,954
PIPING: 0 DAY	2,577	EQ(1): -30 DAY OR NIGHT	2,595
PIPING:120 DAY	2,576	EQ(1): -120 DAY OR NIGHT	2,886
PIPING: -30 NIGHT	2,605	EQ(2): -30 DAY OR NIGHT	1,806
PIPING: -120 NIGHT	2,907	EQ(2): -120 DAY OR NIGHT	2,047
SLOPE ST.: 0 DAY	2,624	EQ(3): -30 DAY OR NIGHT	247
SLOPE ST.: 120 DAY	2,623	EQ(3): -120 DAY OR NIGHT	492
SLOPE ST.: -30 NIGHT	2,650	PIPING: -120-NIGHT REC. SEASON	2,939



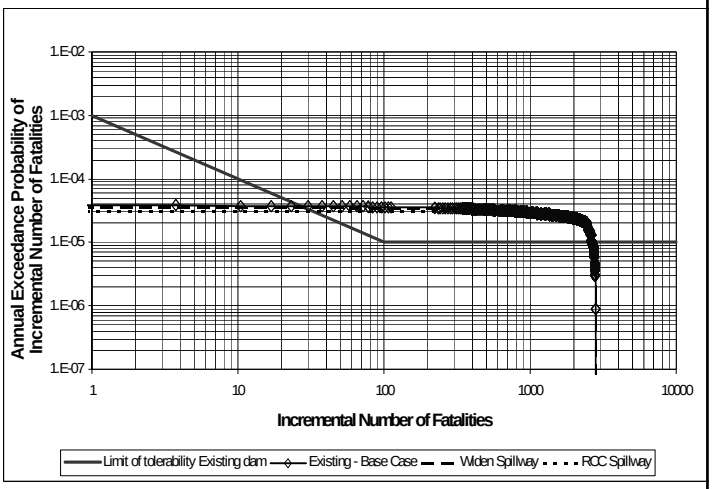
Existing Dam Results

USBR APF **USBR ALL**

	(a) Probability of failure		(b) Incremental risk cost		(c) Risk Reduction benefit	(d) Risk Reduction cost	(e) Total economic cost	(f) Benefit: Cost	(g) Annualized Incremental life loss	
	(/yr)	%	($/yr)	%	($/yr)	($/yr)	($/yr)	(-)	(lives/yr)	%
E-B: Existing - Base Case										
Flood	9.4E-06	27%	$ 317,612	20%			$ 317,612		0.012	18%
Earthquake	1.6E-05	47%	$ 646,653	41%			$ 646,653		0.030	45%
Normal Operating	9.3E-06	26%	$ 605,469	39%			$ 605,469		0.025	37%
Total	3.5E-05	100%	$ 1,569,733	100%			$ 1,569,733		0.067	100%

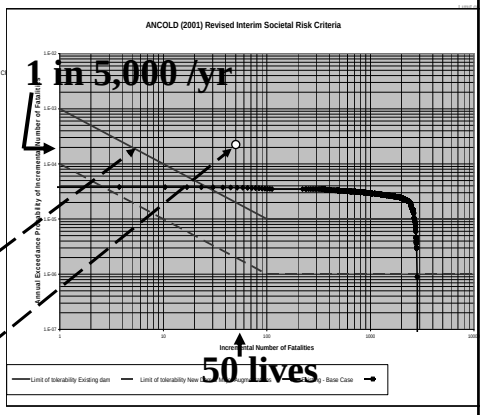
(j) Incremental Damages		(l) Incremental Life Loss		(n)	(o)	(p)	(q)
Minimum	Maximum	Minimum	Maximum	No Failure Flood Ann. Damages	Reduction in Flood Benefits	No Failure Flood Ann. Life Loss	Reduction in Flood Benefits
($M)	($M)	(lives)	(lives)	($/yr)	($/yr)	(lives/yr)	(lives/yr)
222	75,476	4	2,893	$ 3,897,565		0.210	
24	64,755	345	2,789				
64,383	65,738	2,577	2,829				
				$ 3,897,565		0.210	

Existing Dam Hills Creek Dam ANCOLD (2003) Societal Risk Guideline (F-N)



Existing Dam – Risk Evaluation

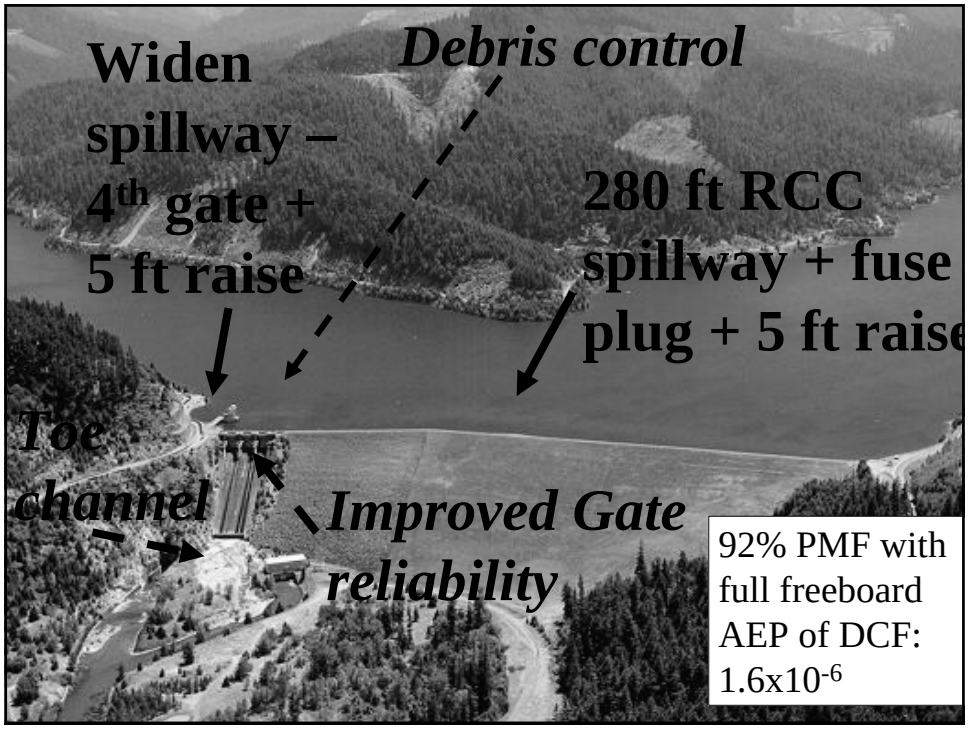
- **USBR ALL**
  - **Flood** > *0.01 lives/yr*
  - **EQ** > *0.01 lives/yr*
  - **NOC** > *0.01 lives/yr*
- **USBR APF/ HSE & ANCOLD Individual** *< 1 in 10,000 /yr*
- **ANCOLD Societal** *above F-N limit line*
- **HSE Societal** *< 1 in 5,000 for > 50 lives*



Observations on Existing Dam

- Does not meet Corps flood requirements (Engineering Assessment - ANPs)
- "Apparently" meets all other Corps Earthquake and Normal Operating requirements for dam safety
  - Investigations needed (ANP, AP ratings)
- Probability of failure not high, but not low
  - Needs to be considered in context of consequences
- Potential life loss is large
  - Non-structural opportunities for risk reduction?
- Potential economic consequences are large
- "Apparently" meets
  - USBR APF/ANCOLD Individual Risk/HSE Individual Risk Guidelines: *Combination of all initiating events*
  - HSE Societal Risk Guideline: *Combination of all initiating events*
- "Apparently" does not meet
  - USBR ALL Guideline: Flood, Earthquake & Normal Operating
  - ANCOLD Societal Risk Guidelines: *Combination of all initiating events*
- Before Existing Dam RA is used for "sign off" decision making investigations needed to:
  - test failure modes, improve strength parameter estimates, conduct in-depth analyses, etc.

5) Risk Assessment Results – Risk Reduction Alternatives



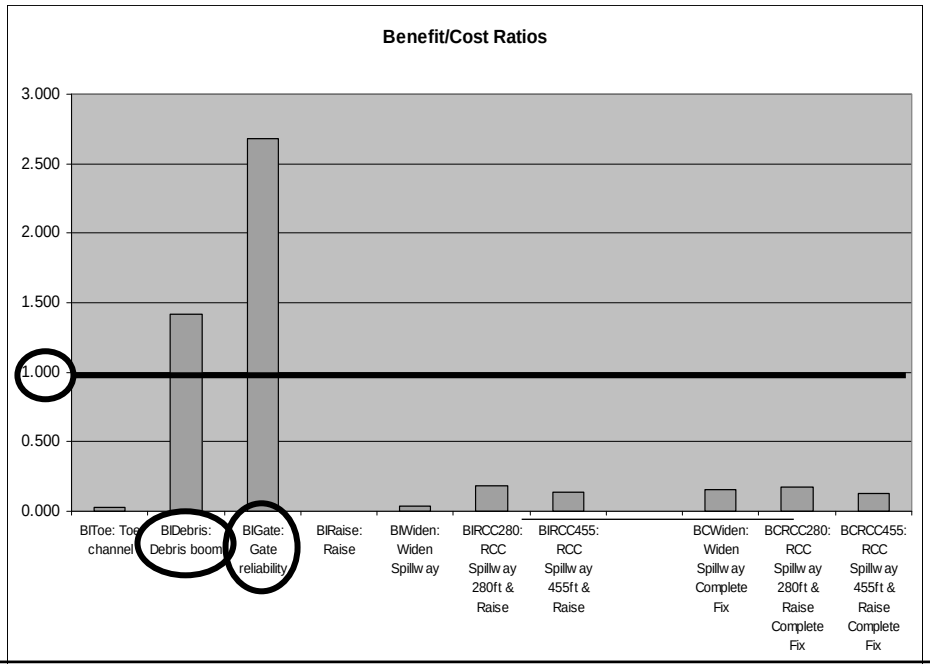
Summary of Results & Evaluations

Divide R by 3

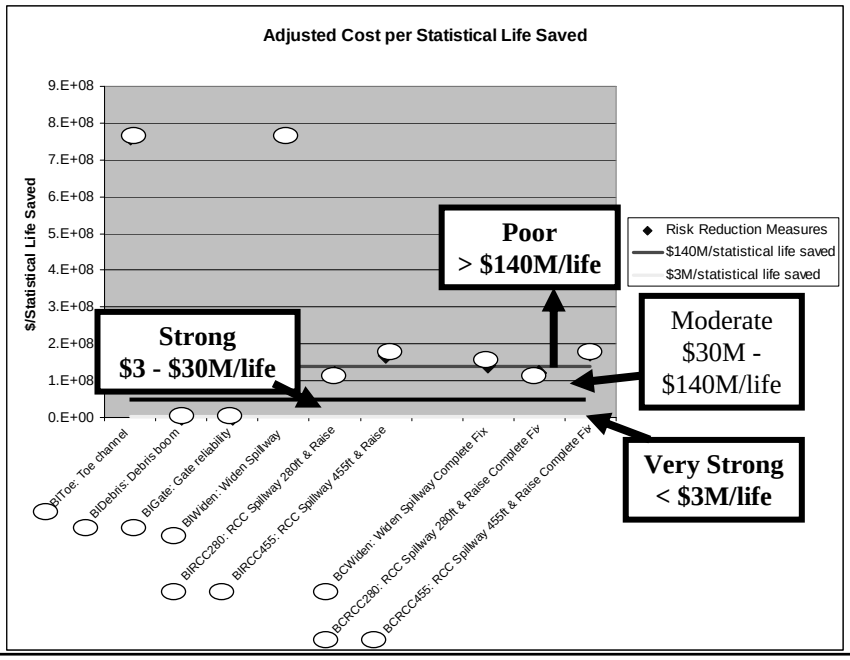
Fix Description	Probability of failure				Annualized Incremental life loss				Incremental risk cost				Risk Reduction benefit	Risk Reduction cost	Benefit/ Cost Ratio	(ACSLS)	Disproportionality Ratio	ANCOLD Societal	HSE Societal
	Flood	Earthquake	Normal Operating	Total	Flood USBR Tier 1	Earthquake USBR Tier 1	Normal Operating USBR Tier 1	Total	Flood	Earthquake	Normal Operating	Total							
E-B: Existing - Base Case	9.4E-06	1.6E-05	9.3E-06	3.5E-05	0.012	0.030	0.025	0.067	$ 317,612	$ 646,653	$ 605,469	$1,569,733	$ -	$ -				N	Y-ALARP?
E-SAEPLimit: Existing - Sensitivity	9.4E-06	2.0E-05	9.3E-06	3.9E-05	0.012	0.036	0.025	0.074	317,612	$ 781,607	$ 605,469	$1,704,688	$ (134,955)	$ -				N	Y-ALARP?
BIToe: Toe channel	9.3E-06	1.6E-05	9.3E-06	3.5E-05	0.012	0.030	0.025	0.067	312,876	$ 646,653	$ 605,469	$1,564,997	$ 4,736	$ 157,148	0.030	7.62E+08	381	N	Y-ALARP?
BIDebris: Debris boom	7.3E-06	1.6E-05	9.3E-06	3.3E-05	0.012	0.030	0.025	0.067	310,091	$ 646,653	$ 605,469	$1,562,212	$ 7,521	$ 5,301	1.418			N	Y-ALARP?
BIGate: Gate reliability	5.5E-06	1.6E-05	9.3E-06	3.1E-05	0.004	0.030	0.025	0.059	93,743	$ 646,653	$ 605,469	$1,345,864	$ 223,869	$ 83,435	2.683			N	Y-ALARP?
BIRaise: Raise	1.1E-05	1.6E-05	9.3E-06	3.6E-05	0.017	0.030	0.025	0.072	431,572	$ 646,653	$ 605,469	$1,683,693	$ (113,960)	$ 72,635				N	Y-ALARP?
BIWiden: Widen Spillway	7.2E-06	1.6E-05	9.3E-06	3.4E-05	0.011	0.030	0.025	0.066	280,470	$ 646,653	$ 605,469	$1,532,592	$ 37,142	$1,038,079	0.036	7.67E+08	383	N	Y-ALARP?
BIRCC280: RCC Spillway 280ft & Raise	2.2E-06	1.6E-05	9.3E-06	2.8E-05	0.002	0.030	0.025	0.057	44,716	$ 646,653	$ 605,469	$1,296,837	$ 272,896	$1,497,623	0.182	1.17E+08	58	N	Y-ALARP?
BIRCC455: RCC Spillway 455ft & Raise	8.7E-07	1.6E-05	9.3E-06	2.6E-05	0.000	0.030	0.025	0.055	12,381	$ 646,653	$ 605,469	$1,264,502	$ 305,231	$2,274,296	0.134	1.67E+08	84	N	Y-ALARP?
BCWiden: Widen Spillway Complete Fix	2.7E-06	1.6E-05	9.3E-06	2.8E-05	0.004	0.030	0.025	0.059	$ 108,254	$ 646,653	$ 605,469	$1,360,375	$ 209,358	$1,356,598	0.154	1.43E+08	71	N	Y-ALARP?
BCRCC280: RCC Spillway 280ft & Raise Complete Fix	9.3E-07	1.6E-05	9.3E-06	2.7E-05	0.000	0.030	0.025	0.055	$ 9,001	$ 646,653	$ 605,469	$1,261,123	$ 308,611	$1,743,507	0.177	1.20E+08	60	N	Y-ALARP?
BCRCC455: RCC Spillway 455ft & Raise Complete Fix	2.2E-07	1.6E-05	9.3E-06	2.6E-05	0.000	0.030	0.025	0.055	$ 3,151	$ 646,653	$ 605,469	$1,255,272	$ 314,461	$2,436,745	0.129	1.74E+08	87	N	Y-ALARP?

Fix Description	Incremental Damages						Incremental Life loss						No Failure Flood Ann.	Reduction in Flood	No Failure Flood Ann.	Reduction in Flood
	Flood		Earthquake		Normal Operating		Flood		Earthquake		Normal Operating					
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Damages	Benefits	Life Loss	Benefits
E-B: Existing - Base Case	$ 222	$ 75,476	$ 24	$ 64,755	$ 64,383	$ 65,738	4	2,893	345	2,789	2,577	2,829	$ 3,897,565	$ -	0.210	0.000
E-SAEPLimit: Existing - Sensitivity	$ 222	$ 75,476	$ 24	$ 64,755	$ 64,383	$ 65,738	4	2,893	345	2,789	2,577	2,829	$ 3,897,565	$ -	0.210	0.000
BIToe: Toe channel	$ 222	$ 75,476	$ 24	$ 64,755	$ 64,383	$ 65,738	4	2,893	345	2,789	2,577	2,829	$ 3,903,103	$ (5,538)	0.211	0.000
BIDebris: Debris boom	$ 222	$ 76,532	$ 24	$ 64,755	$ 64,383	$ 65,738	4	2,914	345	2,789	2,577	2,829	$ 4,014,464	$ (116,899)	0.215	-0.005
BIGate: Gate reliability	$ 222	$ 75,476	$ 24	$ 64,755	$ 64,383	$ 65,738	4	2,893	345	2,789	2,577	2,829	$ 3,941,389	$ (43,824)	0.212	-0.002
BIRaise: Raise	$ 222	$ 70,409	$ 24	$ 64,755	$ 64,383	$ 65,738	4	2,828	345	2,789	2,577	2,829	$ 3,917,236	$ (19,672)	0.211	-0.001
BIWiden: Widen Spillway	$ 222	$ 75,476	$ 24	$ 64,755	$ 64,383	$ 65,738	4	2,893	345	2,789	2,577	2,829	$ 4,001,132	$ (103,568)	0.215	-0.004
BIRCC280: RCC Spillway 280ft & Raise	$ 222	$ 64,354	$ 24	$ 64,755	$ 64,383	$ 65,738	4	2,629	345	2,789	2,577	2,829	$ 4,074,236	$ (176,671)	0.218	-0.008
BIRCC455: RCC Spillway 455ft & Raise	$ 222	$ 63,065	$ 24	$ 64,755	$ 64,383	$ 65,738	4	2,629	345	2,789	2,577	2,829	$ 4,129,787	$ (232,222)	0.220	-0.010
BCWiden: Widen Spillway Complete Fix	$ 222	$ 76,131	$ 24	$ 64,755	$ 64,383	$ 65,738	4	2,906	345	2,789	2,577	2,829	$ 4,110,808	$ (213,243)	0.219	-0.009
BCRCC280: RCC Spillway 280ft & Raise Complete Fix	$ 222	$ 69,211	$ 24	$ 64,755	$ 64,383	$ 65,738	4	2,643	345	2,789	2,577	2,829	$ 4,125,490	$ (227,925)	0.220	-0.010
BCRCC455: RCC Spillway 455ft & Raise Complete Fix	$ 222	$ 28,888	$ 24	$ 64,755	$ 64,383	$ 65,738	4	979	345	2,789	2,577	2,829	$ 4,159,568	$ (262,003)	0.221	-0.011

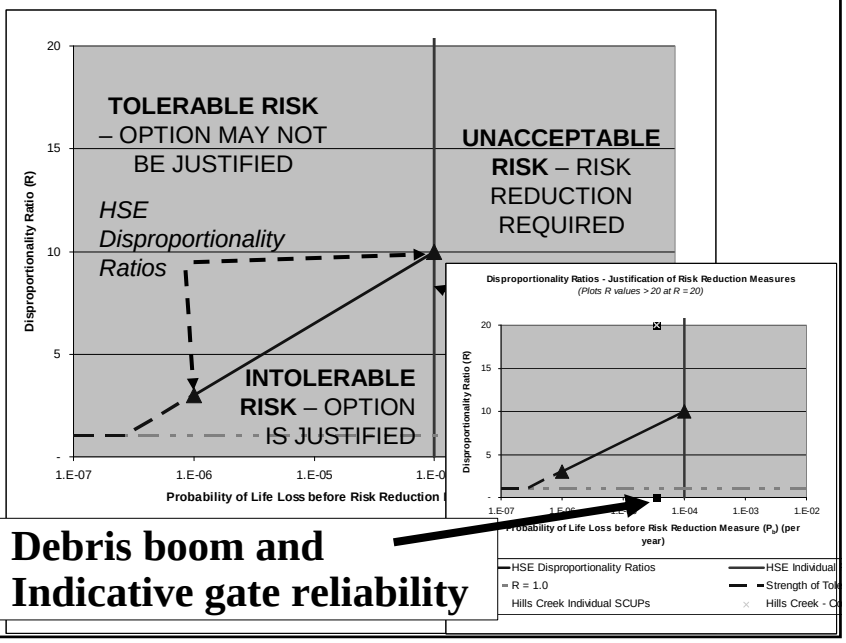
Benefit/Cost Ratios



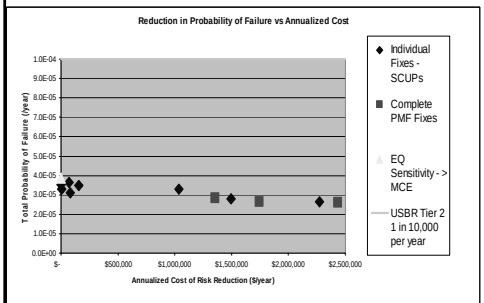
ALARP Strength of Justification Ratings for Fixes



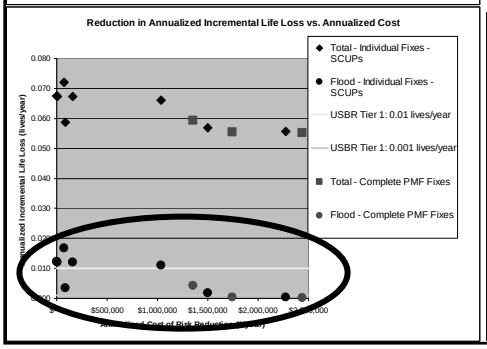
HSE Tolerability of Risk

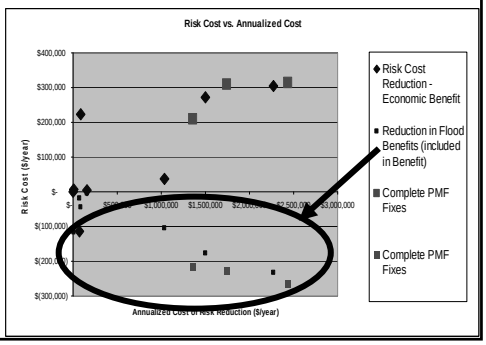


Risk Reduction vs. Annualized Cost



Fix Description	Annualized Cost of Risk Reduction
INDIVIDUAL FIXES- SCUPs	
E-B: Existing - Base Case	$ -
BIToe: Toe channel	$ 157,148
BIDebris: Debris boom	$ 5,301
BIGate: Gate reliability	$ 83,435
BIRaise: Raise	$ 72,635
BIWiden: Widen Spillway	$ 1,038,079
BIRCC280: RCC Spillway 280ft & Raise	$ 1,497,623
BIRCC455: RCC Spillway 455ft & Raise	$ 2,274,296
COMPLETE PMF FIXES:	
BCWiden: Widen Spillway Complete Fix	$ 1,356,598
BCRCC280: RCC Spillway 280ft & Raise Complete Fix	$ 1,743,507
BCRCC455: RCC Spillway 455ft & Raise Complete Fix	$ 2,436,745





6) Uncertainty Analysis

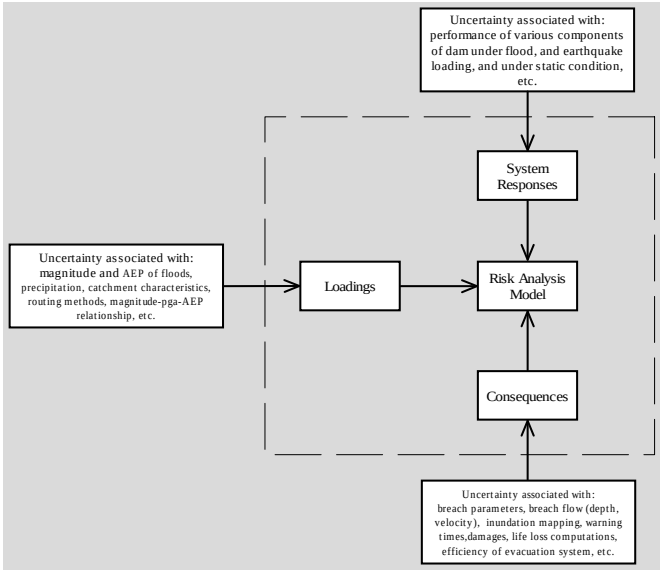
- Intrinsic to RA and TA (SBA)
- In RA “best estimates” plus sensitivity analysis
- Limited examples of uncertainty analysis
  - USBR uses for more detailed RAs
  - Corps draft Tolerable Risk guidelines depend on Uncertainty Analysis

Uncertainty

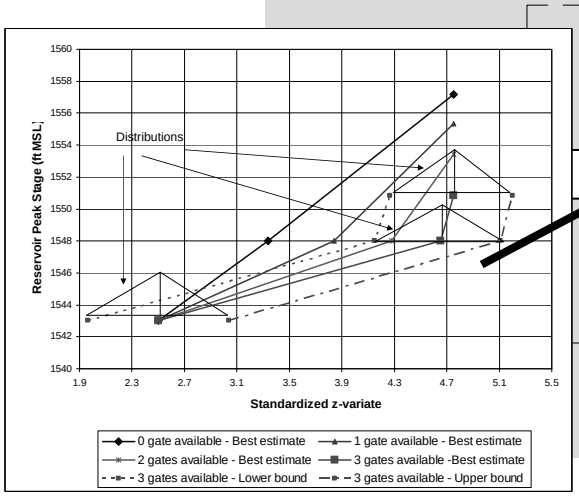
- Intrinsic to RA and TA (SBA)
- In RA “best estimates” plus sensitivity analysis
- Limited exa
  - USBR uses
  - Corps draft Uncertainty

Best Estimate Inputs do not in general lead to Best Estimate Outputs

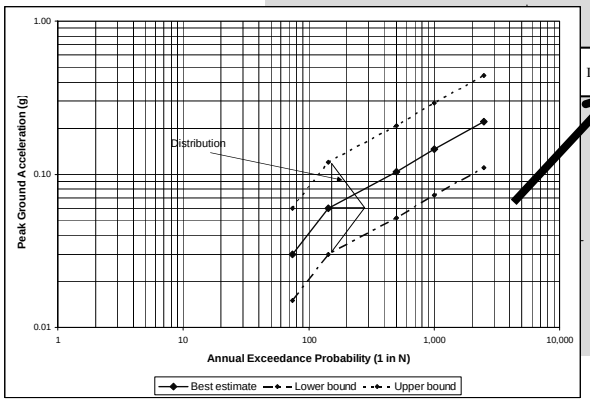
RA Inputs

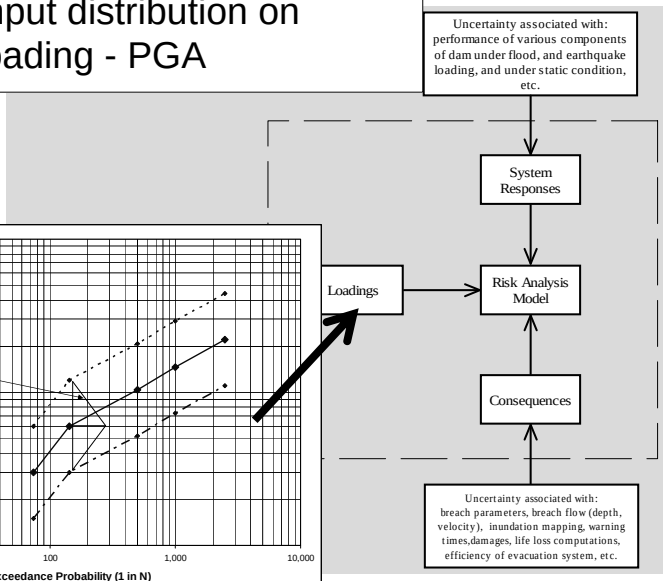


Uncertainty input distribution on flood loading - peak reservoir stage

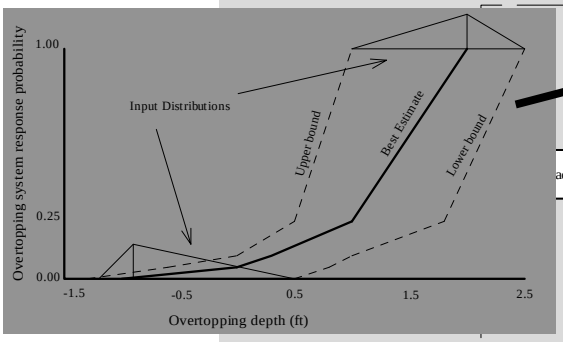


Uncertainty input distribution on earthquake loading - PGA

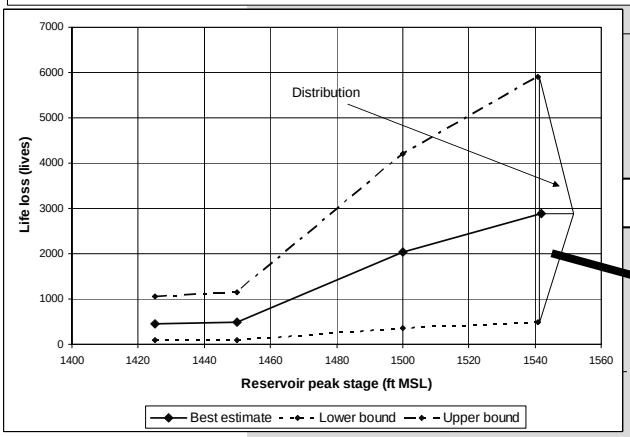




Uncertainty input distribution on flood overtopping failure SRP



RA Inputs - Uncertainty input distribution on dam failure life loss



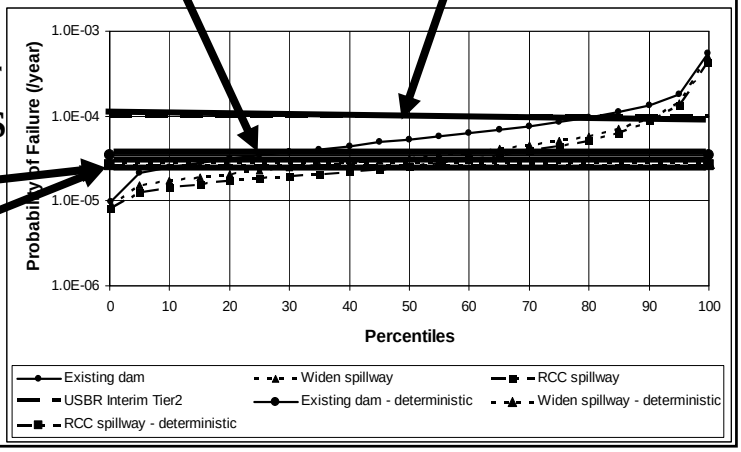
EXISTING DAM

- Deterministic (Best Est Inputs) 3.5×10^{-5} /yr
- 25^{th} percentile
- Mean 7×10^{-5} /yr

S/W FIXES

- Widen
- RCC

USBR APF (Tier 2)
- Tot. Prob. Fail. 1×10^{-4} /yr



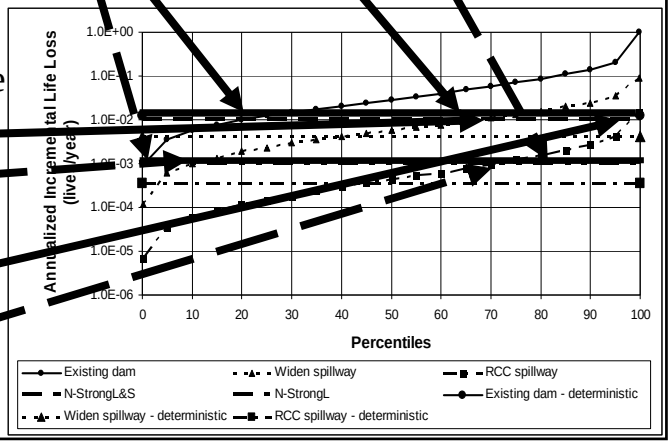
EXISTING DAM

- Deterministic (Best Est Inputs) $1.2x10^{-2}$ /yr
- 20% confid. $1x10^{-2}$
- <1% confid. $1x10^{-3}$

S/W FIXES

- Widen: 4th gate
- 70% & 10% confid
- RCC
- 97% & 70% confid

USBR ALL (Tier 1) - Flood
- Inc. Ann Life Loss
$1x10^{-2}$ & $1x10^{-3}$ lives/yr



DETERMINISTIC

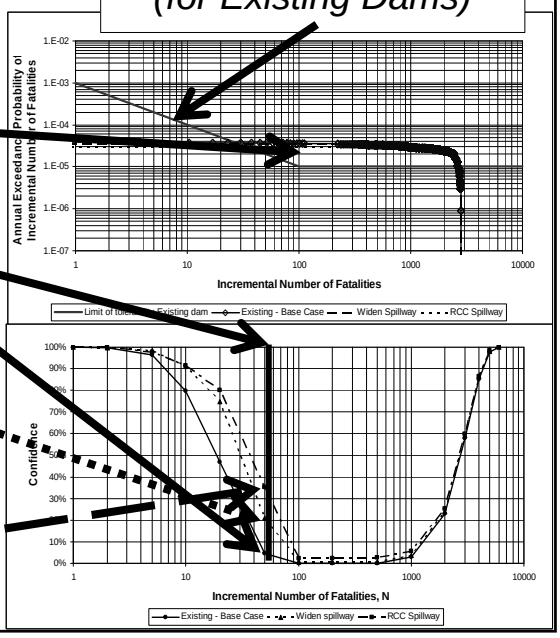
- Existing Dam & S/W Fixes
  Do not meet

UNCERTAINTY

E.g. 50 lives

- Existing:
  5% confid meets
- Widen S/W (4th gate):
  20% confid meets
- RCC S/W:
  35% confid meets

ANCOLD Societal Risk
(for Existing Dams)



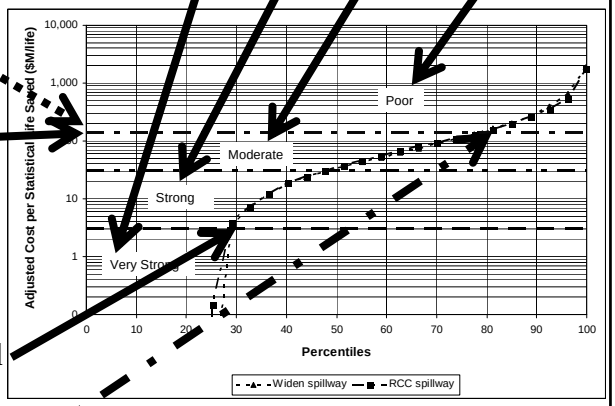
DETERMINISTIC

- Widen S/W (4th gate):
  - US$143M
  - Moderate/Poor
  - 80th percentile
- RCC S/W:
  - US$120M
  - Moderate
  - 75th percentile

UNCERTAINTY

- Widen & RCC S/W:
- V. Strong: 30% confid
- Strong: 20% confid
- Moderate: 30% confid
- Poor: 20% confid

ALARP Justification - Adjusted CSLS



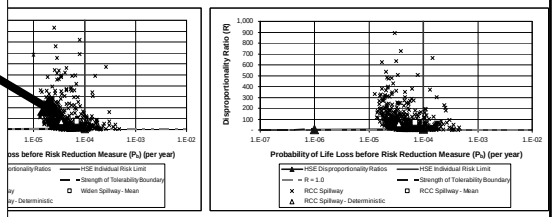
DETERMINISTIC

- Widen S/W (4th gate):
  - R = 24
- RCC S/W:
  - R = 20
- HSE guidelines would not justify risk reduction

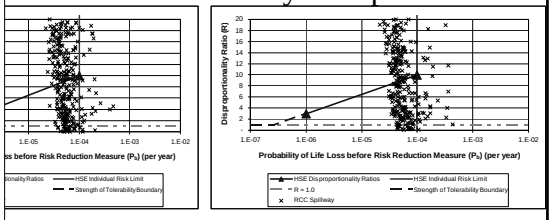
UNCERTAINTY

- Widen & RCC S/W
  - 30% confid. that HSE guidelines would justify risk reduction
- Mean R:
  - Widen S/W (4th gate):
  - R = 25
  - RCC S/W:
  - R = 23

Disproportionality Ratio Justification *(UK HSE)*



Divide R by 3 on plots



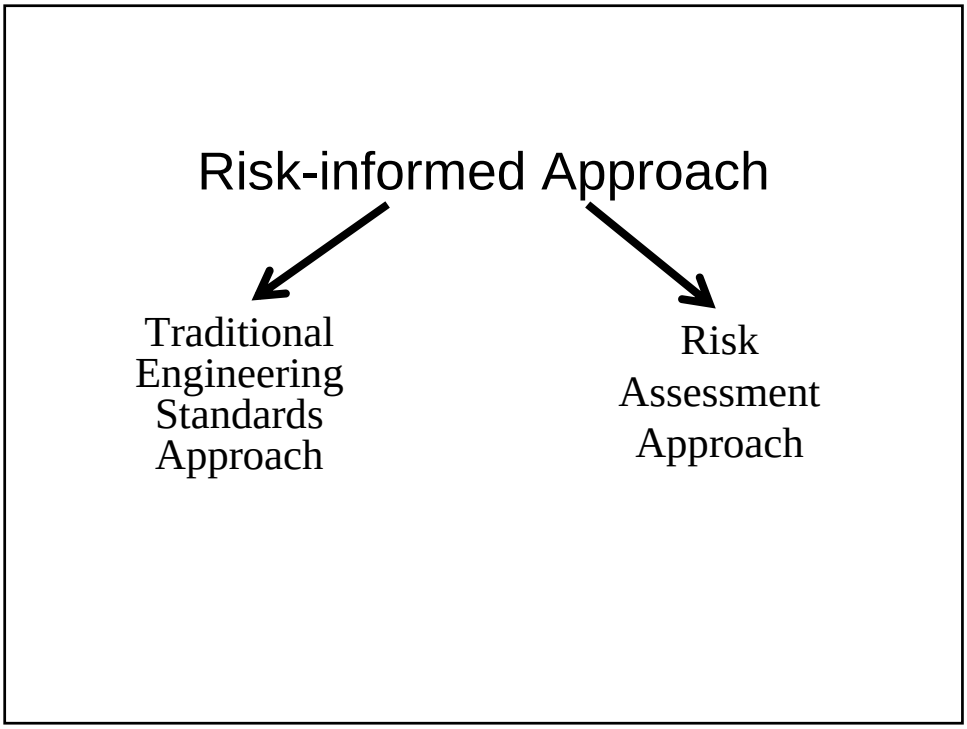
Widen S/W RCC S/W

Some thoughts on Uncertainty Analysis

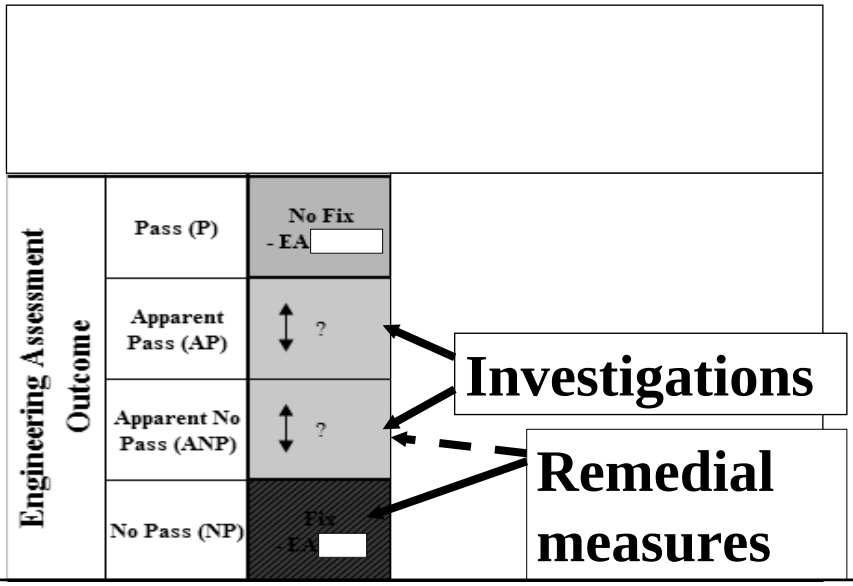
- Best Estimate Inputs do not in general lead to Best Estimate Outputs
- Confidence in meeting Tolerable Risk Guidelines
  - Valuable insights into reality of uncertainty
  - Adds to challenge of interpretation and understanding
  - Corps of Engineers draft Tolerable Risk guidelines based on confidence
- Guidelines for consistent uncertainty analysis
- USBR using in detailed RAs

Observations on Risk Reduction Alternatives

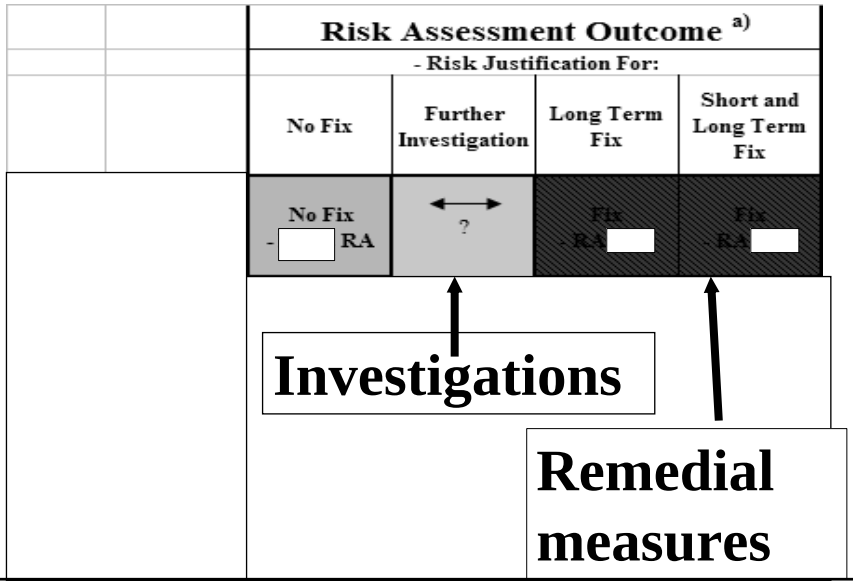
- Flood alternatives:
  - Potential for risk increases
    - Flood "disbenefits"
    - Raise leads to increase in toe erosion probability
  - Strength of risk-based justification:
    - ALARP strength of justification: very high – poor for individual SCUPs
    - B/C > 1.0: Debris boom (1.4) and Indicative gate reliability (2.7)
    - *HSE Disproportionality justifies Debris boom and Indicative gate reliability*
- Residual Risk Evaluation
  - Only RCC spillway "appears" to meet USBR ALL Guideline
  - Earthquake and Normal Operating "appear" not to meet USBR ALL
- Where to go from here?
  1) Investigations (ANP, AP ratings)
  2) What structural OPTIONS to consider in ALARP evaluation for Flood, EQ & NOC?
  3) What non-structural OPTIONS to consider in ALARP evaluation for Flood, EQ & NOC?



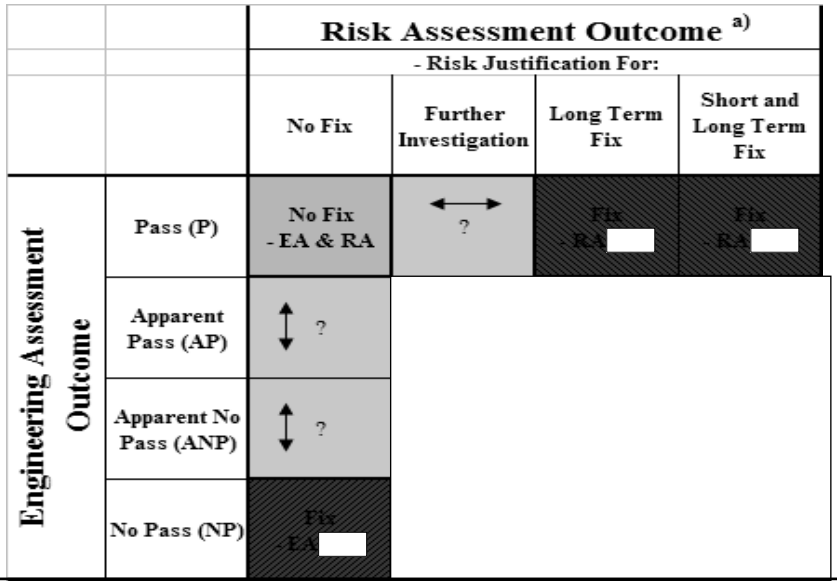
Engineering Assessment – EA
(TA – Traditional Approach to Reservoir Safety)



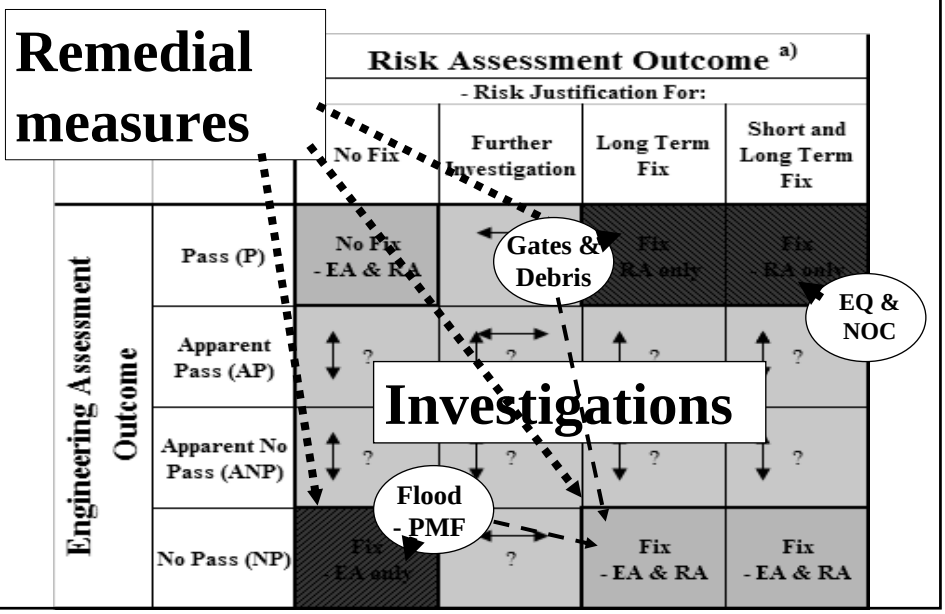
Risk Assessment – RA
(Tolerable Risk Guidelines - Indicative)



Engineering & Risk Assessments – EA (TA) & RA



Engineering & Risk Assessment – EA (TA) & RA



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