





FERC RIDM
What's Really at Risk

Presentation by Guy S. Lund, PE URS

URS

Risk Analysis – Goals

- Understand possible failure mechanisms related to dam safety
- Overall picture of potential impacts (economic, social, life, other)
- Allocation of funds that will contribute the greatest toward risk reduction

URS

Risk Analysis – Definitions

- **Risk**
  - (probability of failure) X (consequence)
- **Failure Mode**
  - Process that leads to uncontrolled release of the reservoir
- **Probability** of Failure
  - Load probability times potential for failure
- **Consequence**
  - Estimated losses due to dam failure scenario

URS

Risk Analysis

- Levels the playing field
  - Typical loads: Usual, Unusual, Extreme
    - Usual – normal, every day load
    - Unusual – PMF can correspond to 100,000-1,000,000 year event
    - Extreme – MCE typically corresponds to 10,000 year event
  - Risk takes into account the likelihood of the event
    - Likelihood of Usual Load = 100 %, or 1.0
    - Likelihood of PMF = 1/100,000 or 10^{-5}
    - Likelihood of MCE = 1/10,000 or 10^{-4}

URS

Risk Analysis

- Levels the playing field
- Prioritization (decision-making)

URS

Risk Analysis

- Levels the playing field
- Prioritization (decision-making)
- Part of Good Engineering Practice

Risk Analysis

- Replacement to traditional dam safety
- Design criteria

URS

Risk Evaluation

$$Risk = L_p \times F \times N$$

where: L_P = Load Probability

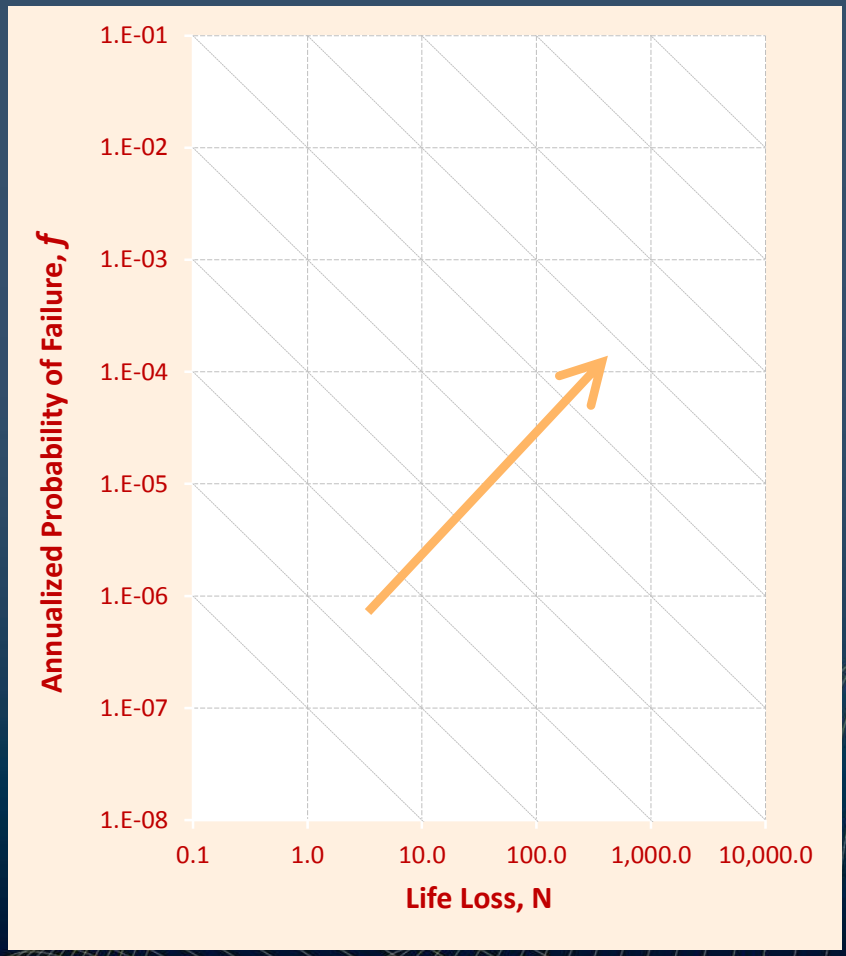
F = Probability of Failure

N = Consequences, Loss-of-Life

URS

Evaluating Risk

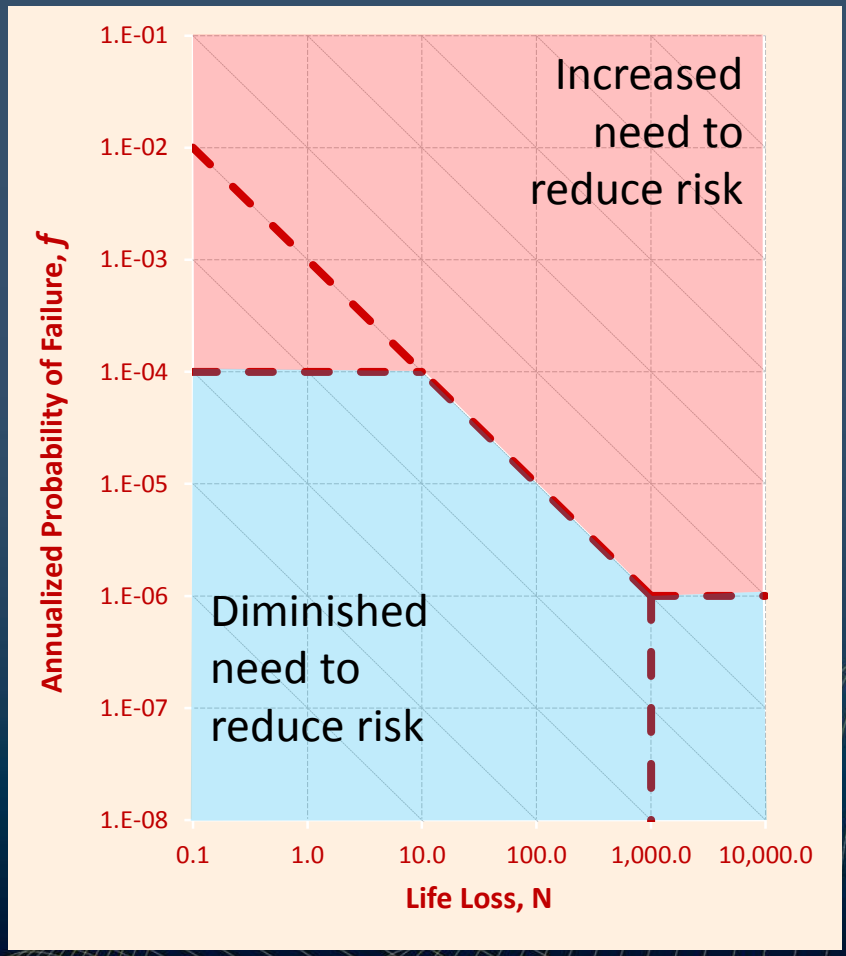
- Initially used as "decision making" tool
  - Prioritization
- Highlights topics we always knew, but didn't discuss
  - Consequences / Probability of failure cannot be eliminated
  - UNCERTAINTIES



URS

Evaluating Risk

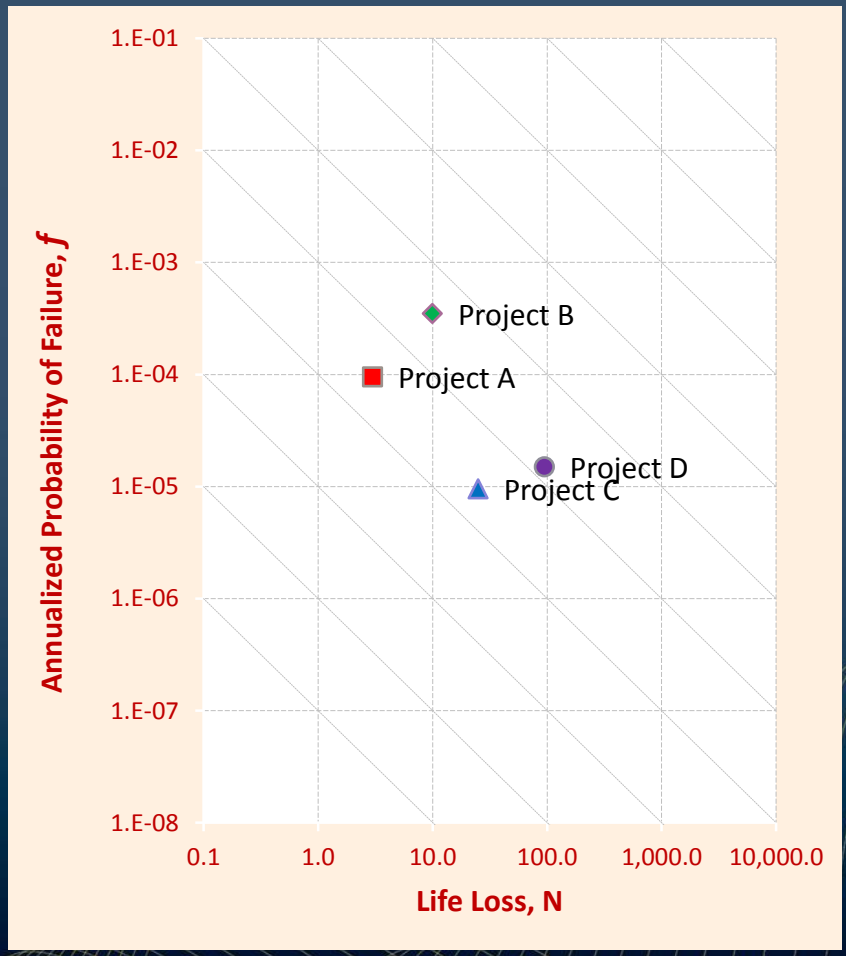
- Risk evaluation for all potential failure modes
  - Operational
  - Hydrologic
  - Earthquake



URS

Evaluating Risk

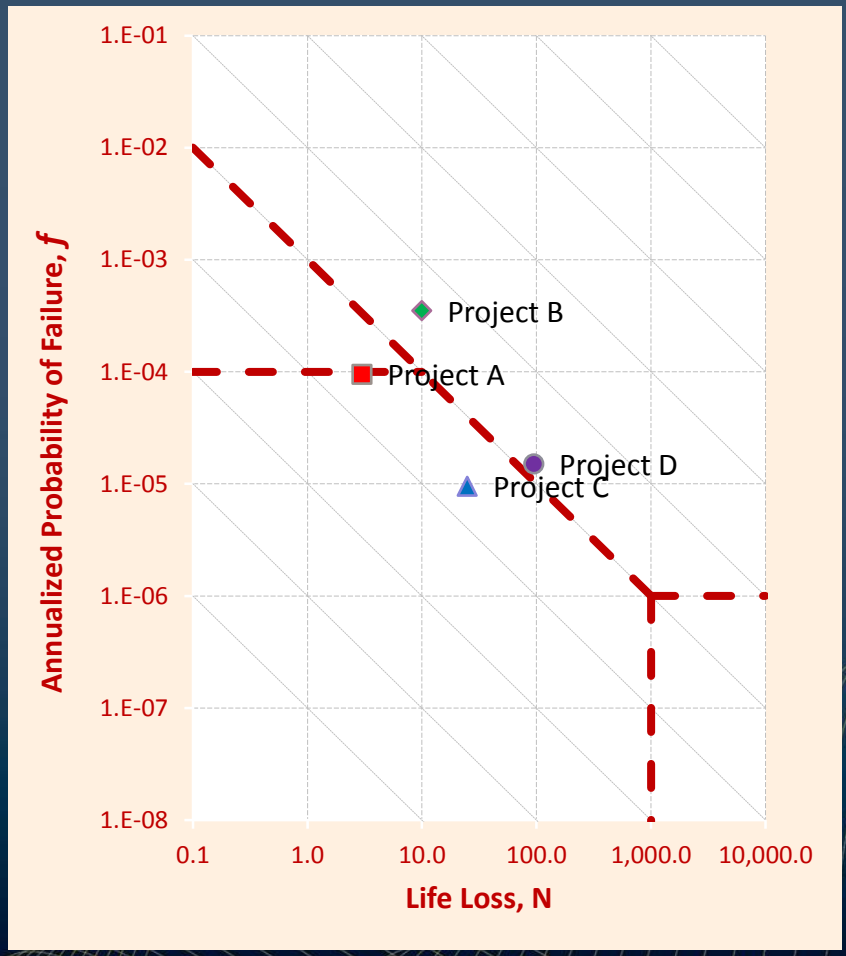
- Decision Making
  - Consider 4 projects
  - Risk profile plotted
    - Potential loss of life range from 3 to 95



URS

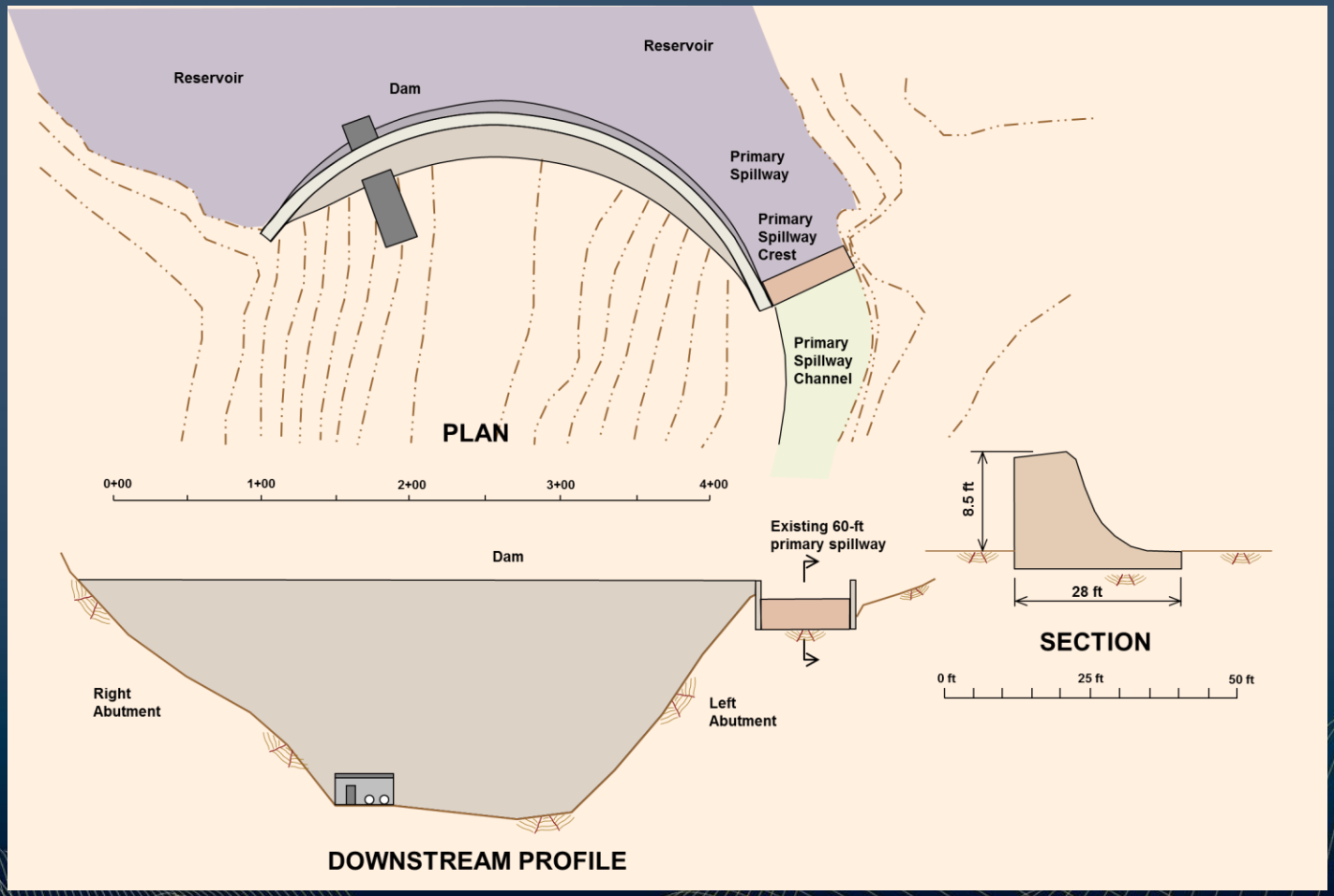
Evaluating Risk

- Decision Making
  - Consider 4 projects
  - Risk profile plotted
    - Potential loss of life range from 3 to 95
- Prioritization Highest to Lowest Risk
  - Project B
  - Project D
  - Project A
  - Project C



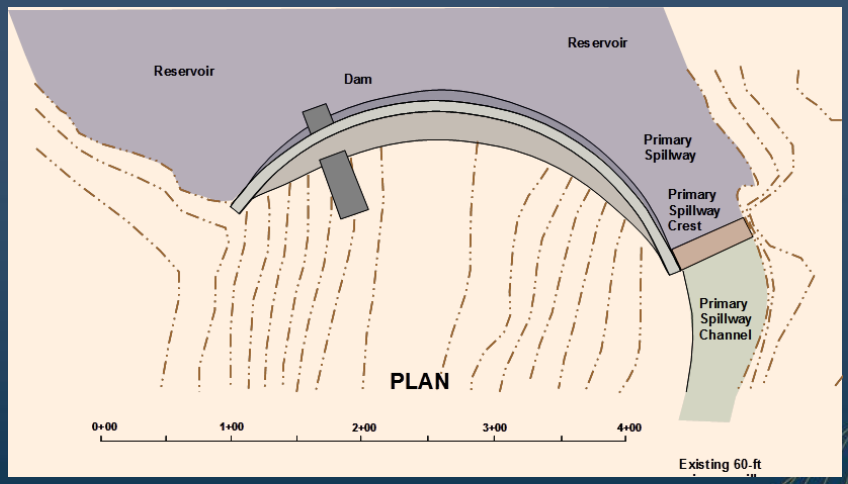
URS

Case Study – McKelvey Dam



Case Study – McKelvey Dam

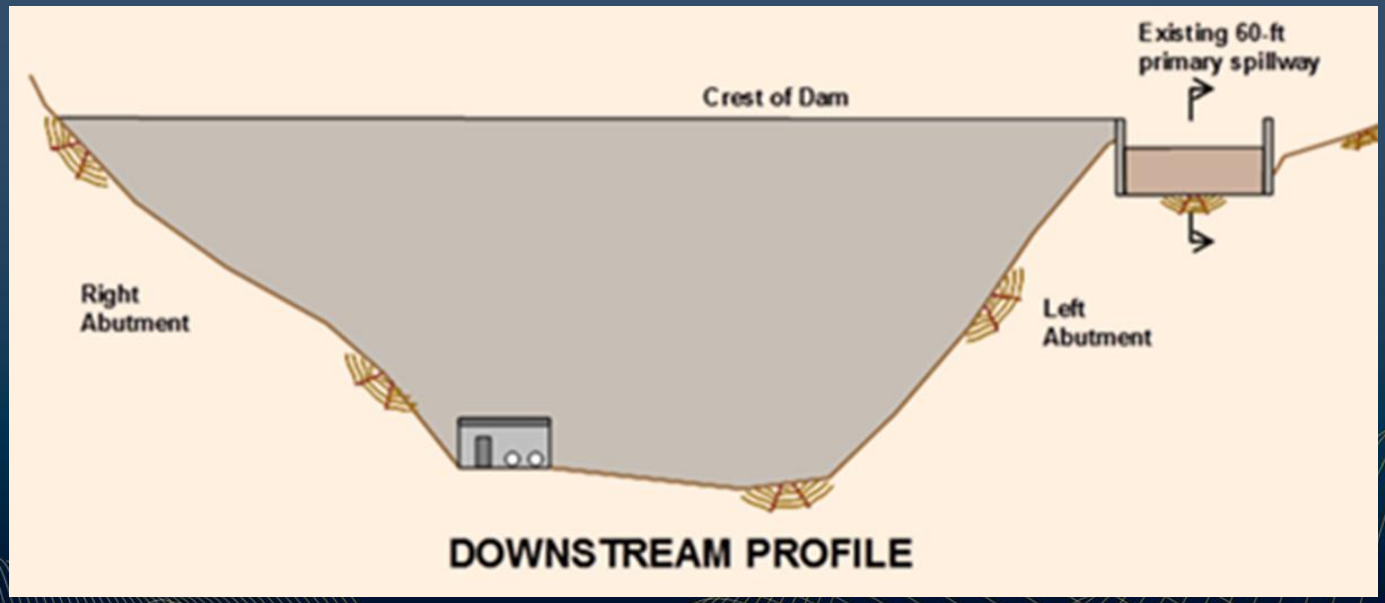
- Single curvature arch
  - Height: 75 feet
  - Crest: 450 feet
  - Uncontrolled Ogee Spillway
    - Width 60 feet
- HIGH Hazard



URS

Concrete Dam – Case Study

- Safety Evaluation
  - Spillway inadequate to safely pass probable maximum flood (PMF)
  - Dam overtops during PMF by 3.6 feet
  - Foundation rock susceptible to scour due to overtopping
  - Inadequate dam stability with erosion of foundation rock



URS

Case Study – McKelvey Dam

- Recommended Alternative
  - Spillway
    - Increase spillway capacity but widening/lowering crest
    - Construct auxiliary spillway for additional discharge capacity
  - Overtopping
    - Construct parapet along dam crest to prevent overtopping
  - Rock Scour
    - Construct concrete apron to foundation prevent scour

URS

Case Study – McKelvey Dam

- Recommended Alternative
- Estimated Cost
  - Greater than allocated funds
  - Full funding could impact ability to operate and maintain other dam projects

URS

Case Study – McKelvey Dam

- Risk Analysis
  - Compare risk for different alternatives and different phases of construction
  - Consequences
    - HIGH Hazard classification
    - Assume 1 loss of life
      - Low population at risk in inundation area
      - Warning time

URS

Case Study – McKelvey Dam

- Risk Analysis
  - Sensitivity Studies
  - Hydrologic studies
    - frequency flood events
  - Flood routing studies
    - peak reservoir levels
  - Structural studies
    - evaluate various loads and modifications
  - Define Phased Alternatives

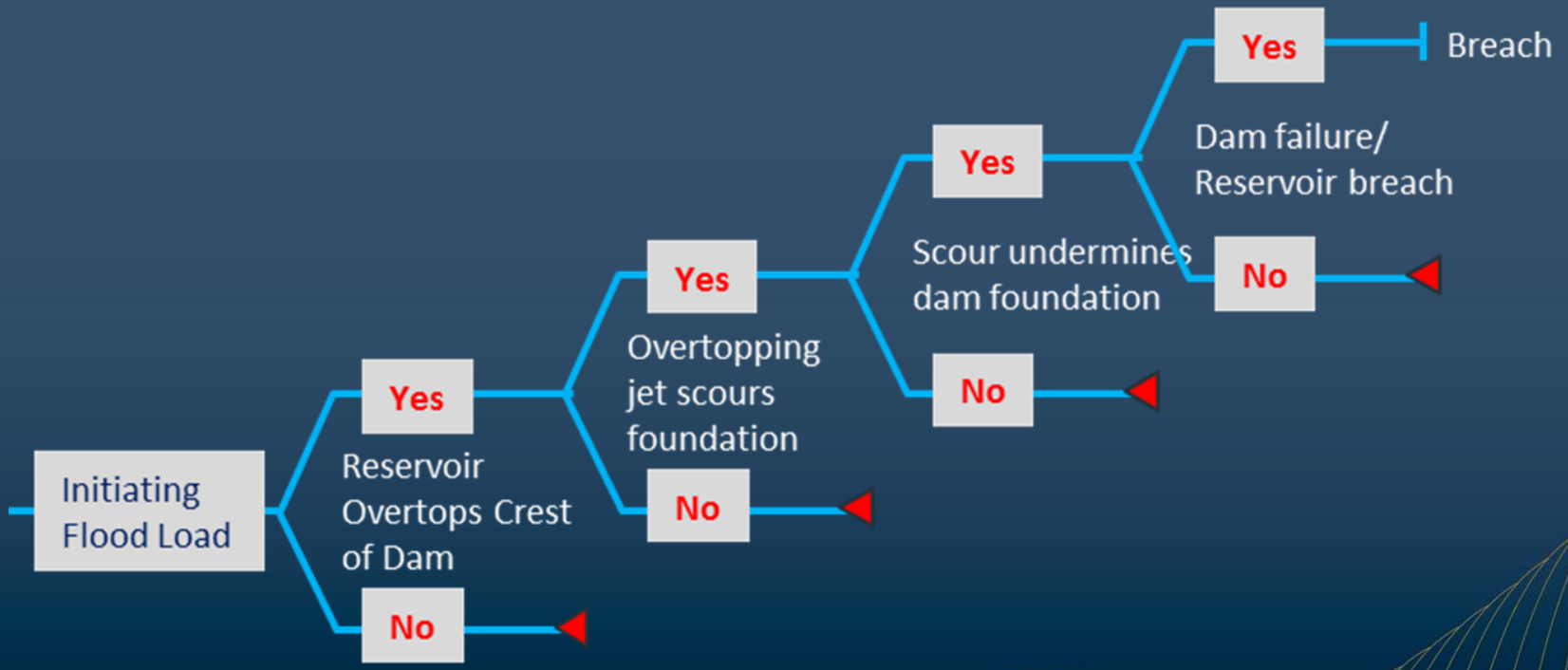
URS

Potential Failure Mode

- Hydrologic flood event
- Dam overtops
  - Inflow exceeds spillway capacity and results in overtopping of the dam crest.
- Foundation scour on abutments
  - The erosive force from the overtopping jet is greater than the erosive resistance of the rock mass, resulting in a scour hole.
- Scour undermines dam
  - The scour hole propagates underneath the dam, which reduces the structural capacity of the arch dam.
- Dam fails
  - The size of the scour hole is large, such that the dam is unable to redistribute load away from the weakened area, and the dam fails resulting in uncontrolled release of the reservoir.

URS

Failure Mode Event Tree



URS

Engineering Evaluations

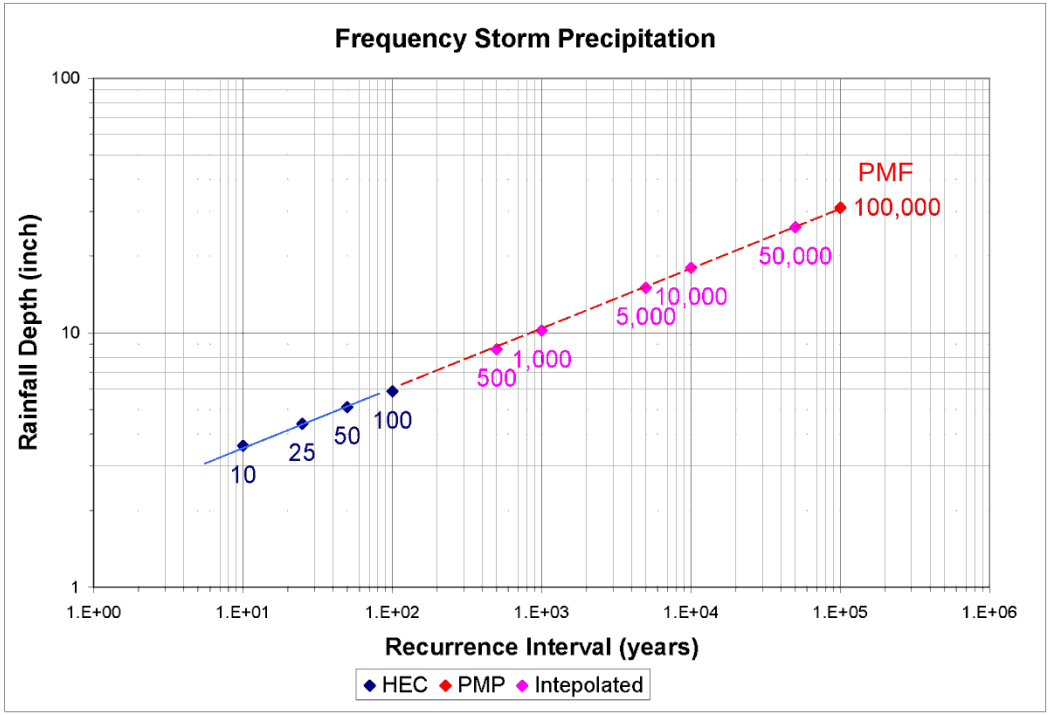
- Existing Dam
- Alternative No. 1
  - Demolish and remove spillway weir
- Alternative No. 2
  - Existing Dam
  - Phase I - Demolition and removal of the existing spillway weir
  - Phase II - Saw cut and remove notch at center of arch dam.
- Alternative No. 3
  - Cut auxiliary spillway notch
- Alternative No. 4
  - Existing Dam
  - Phase I - Demolition and removal of the existing spillway weir
  - Phase II – Widen spillway channel from 60 feet to 116 feet

URS

Alternatives

- Alternative No. 2
  - Existing Dam
  - Phase I - Demolition and removal of the existing spillway weir
  - Phase II - Saw cut and remove notch at center of arch dam.

Hydrologic Studies



URS

Estimating Probability

- Load Probability

Flood Frequency	Load Probability
> 50,000 years	0.002%
10,000 – 50,000 years	0.008%
5,000 – 10,000 years	0.01%
1,000 – 5,000 years	0.08%
500 – 1,000 years	0.10%
100 – 500 years	0.80%
< 100 years	99.0%

URS

Estimating Probability

- Load Probability
- Event Probability
  - Overtopping

Flood Frequency	Overtopping Depth	Probability of Overtopping
> 50,000 years	3.6 ft	0.999
10,000 – 50,000 years	2.6 – 3.6 ft	0.999
5,000 – 10,000 years	1.8 – 2.6 ft	0.990
1,000 – 5,000 years	0.6 – 1.8 ft	0.5 - 0.9
500 – 1,000 years	0.1 – 0.6 ft	0.1 – 0.5
100 – 500 years	(-1.8) – 0.1 ft	0.01 – 0.10
< 100 years	3.6 ft	10^{-4}

URS

Estimating Probability

- Load Probability
- Event Probability
  - Overtopping
  - Rock Scour
    - Factor > 1 indicates scour will develop

Flood Frequency	Net Erodibility Factor	Probability of Scour
> 50,000 Yr	> 14.5	0.999
10,000 Yr	5.3	0.999
5,000 Yr	3.6	0.990
1,000 Yr	1.3	0.5 - 0.9
< 500 Yr	< 0.3	0.1 - 10^{-4}

URS

Estimating Probability

- Load Probability
- Event Probability
  - Overtopping
  - Rock Scour
    - Factor > 1 indicates scour will develop
- Annualized Probability of Failure

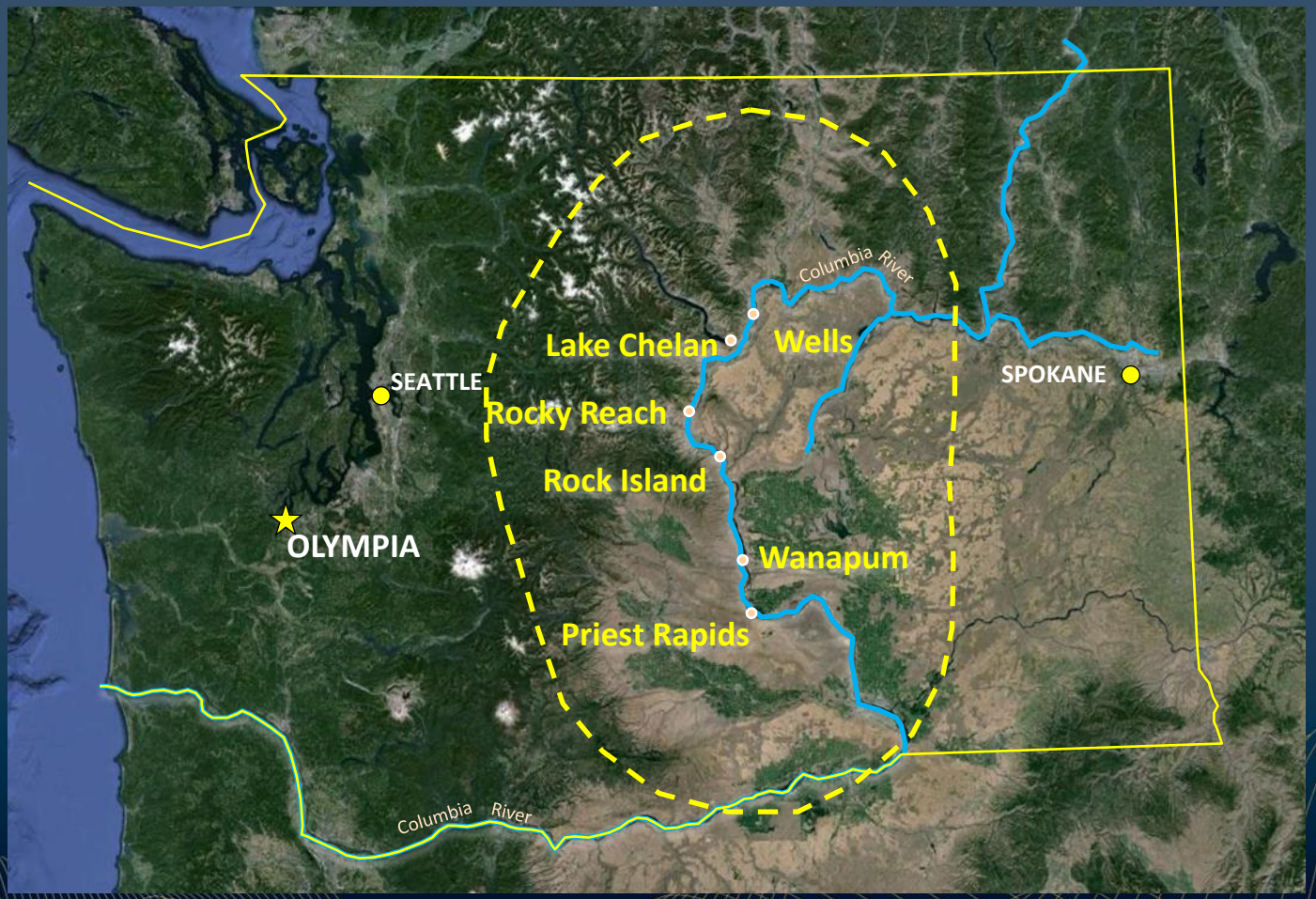
URS

Summary

- Compared the risk associated the different alternatives and different phases.
- Identified phases that were more effective at reducing risk

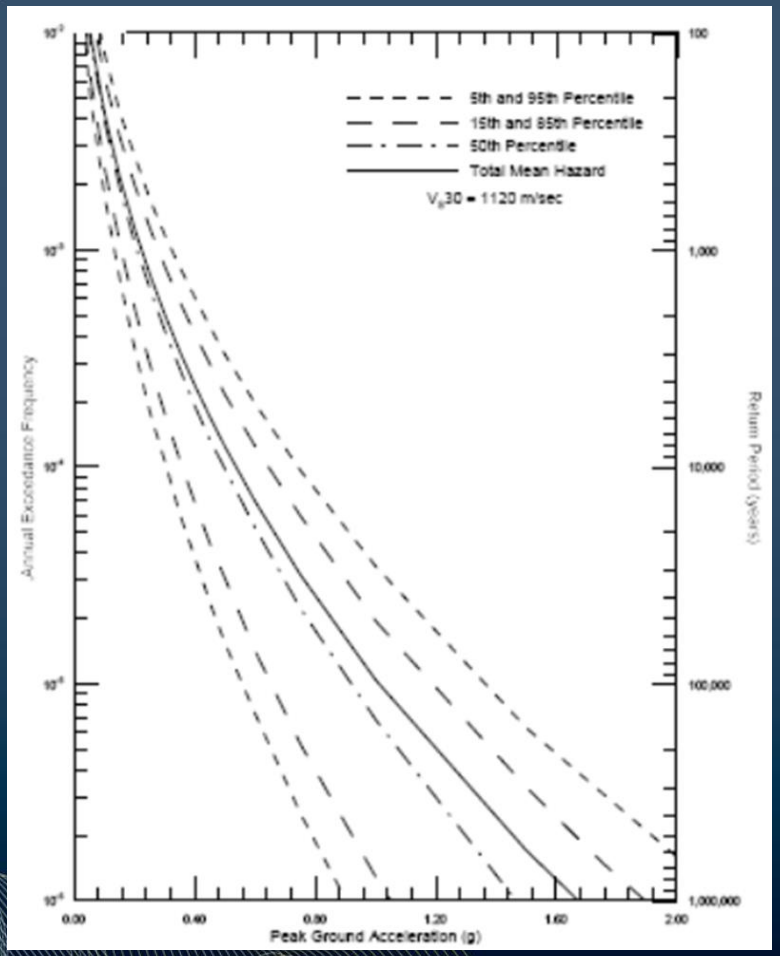
URS

Case Study – Rocky Reach Dam



URS

Probabilistic Seismic Hazard Analysis



- Likely seismic events for different return periods
  - 100-yr 0.08g
  - 1000-yr 0.23g
  - 5000-yr 0.43g
  - 10,000-yr 0.54g
  - 100,000-yr 1.02g

URS

Probabilistic Seismic Hazard Analysis

- Significant increase in the seismic hazard
  - Initial design used Pseudo static coefficients corresponding to 0.10 g
- Updated seismic hazard estimates
  - Rock Island PGA 0.32 g
  - Rocky Reach PGA 0.54 g
  - Lake Chelan PGA 0.82 g
    - Based on 10,000-year return period

URS

Risk Informed Decision Making (RIDM)

- Next Step
  - Evaluate Seismic Hazard using the PSHA
- Use risk informed decision making (RIDM)
- Evaluate the risk of principal project features
  - Establish tolerable risk criteria
  - Focus on seismic failure modes
  - Develop simplified methodology

URS

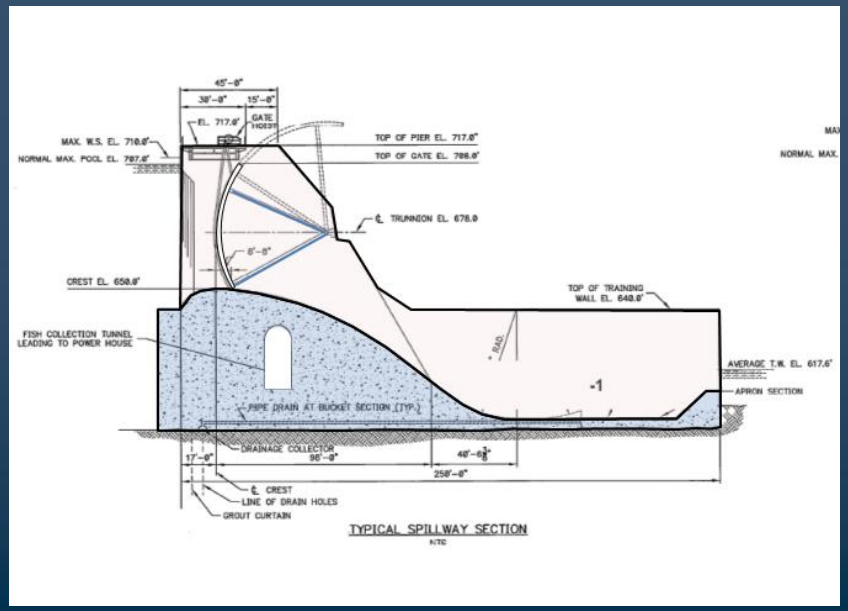
Rocky Reach Dam
Chelan Public Utility District

URS

Rocky Reach Dam
Chelan Public Utility District

URS

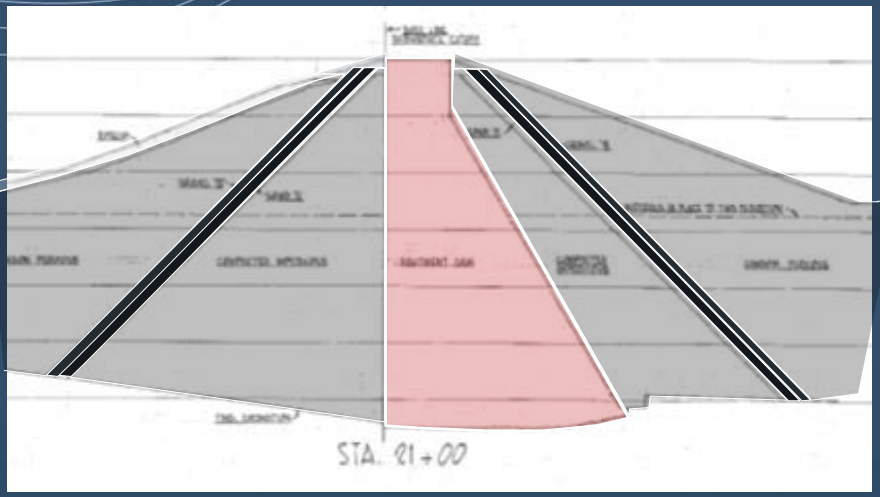
Spillway

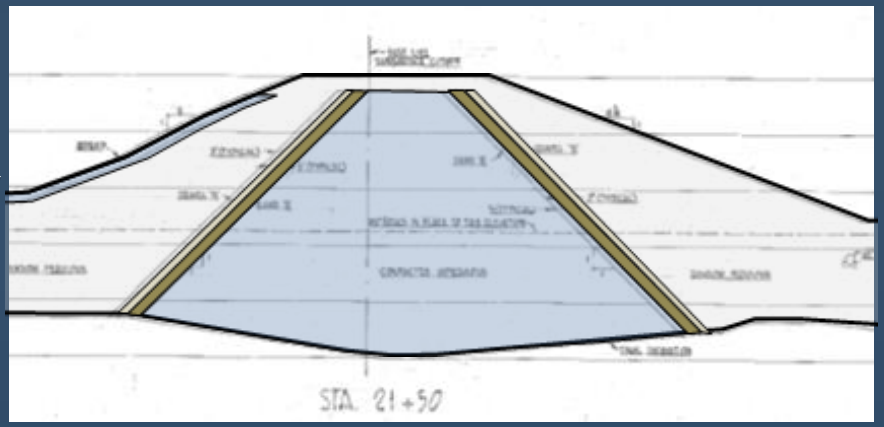


- Structural Parameters
  - Hydraulic height 127 feet
  - Crest El. 650
- Twelve Tainter Gates
  - 50-ft x 58-ft Radial gates
    - Gate 1 closest to powerhouse
    - Gate 12 closest to east abutment
- Gate Operation
  - Local and Remote control
  - Power from grid & powerhouse
  - Emergency generator backup

URS

East Abutment
Retaining Wall and Embankment Cutoff





- East Abutment wall
  - Non-overflow gravity dam
- Seepage Cutoff
  - Length approx. 2,000 feet
  - Reduce flow gradient through terrace deposits east of present river channel
  - Maximum depth approximately 200 feet

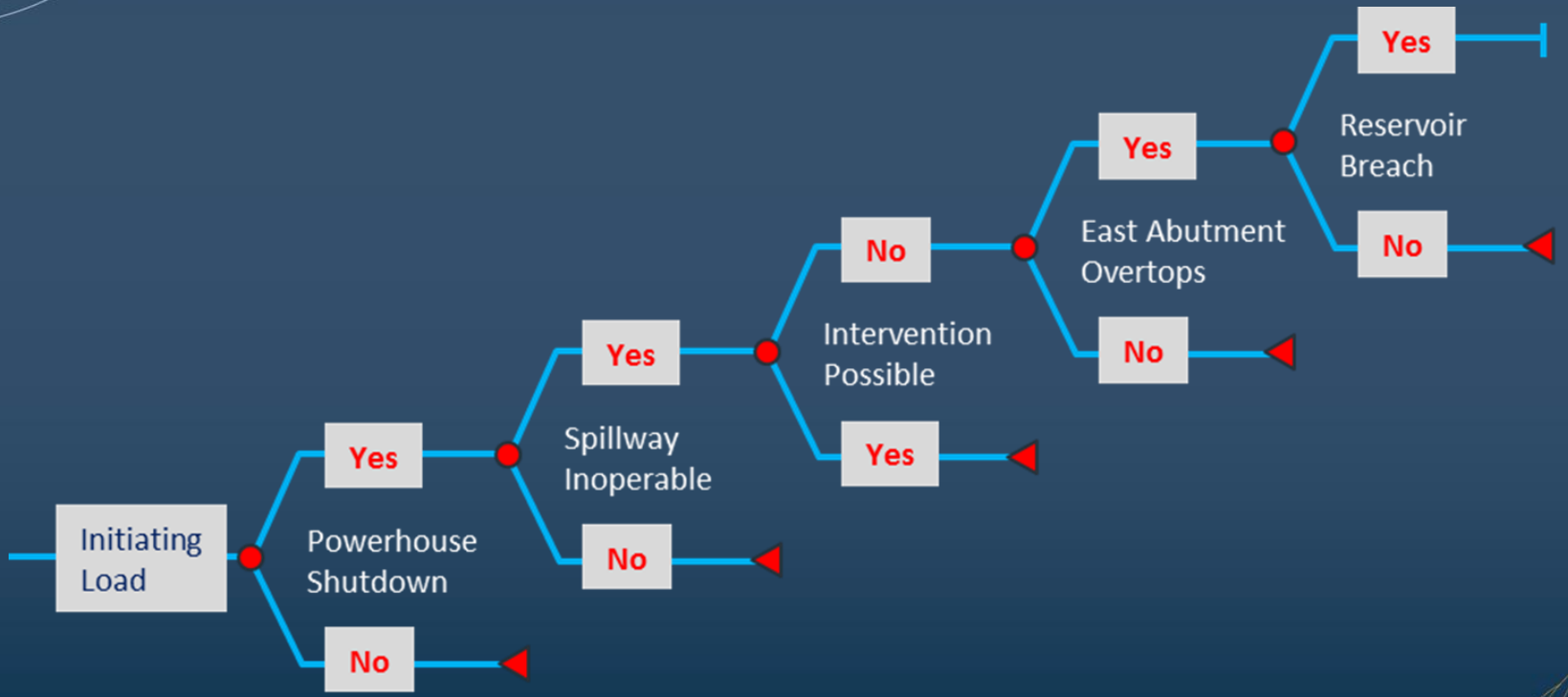
URS

Considered Seismic Failure Mode

- PFM No. 16, Spillway Gate Failure (Seismic)
  - Seismic Event occurs
  - Loss of grid
  - Powerhouse shuts down
  - Gates damaged and inoperable (closed)
  - Reservoir level increases
  - Dam overtops
  - East embankment breaches

URS

Seismic Failure Mode Event Tree



URS

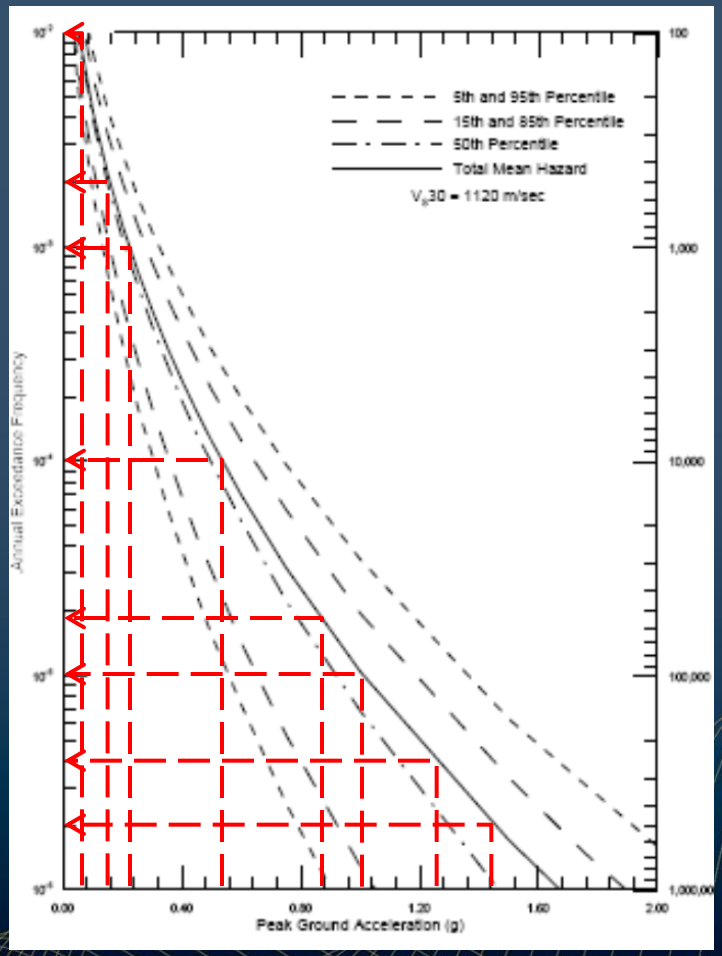
Spillway Gate Failure

- Failure in the open position
  - Simulate run-of-river operation
- Failure in closed position
  - Reduced spillway capacity could results in increased reservoir level.
  - Overtopping of spillway gates
  - Overtopping of East Embankment Cutoff
  - Breach of cutoff

URS

Probabilistic Seismic Hazard

Seismic Return Period	Peak Ground Acceleration
100	0.08
500	0.16
1000	0.23
2500	0.34
5000	0.43
10,000	0.54
100,000	1.02
1,000,000	1.68



URS

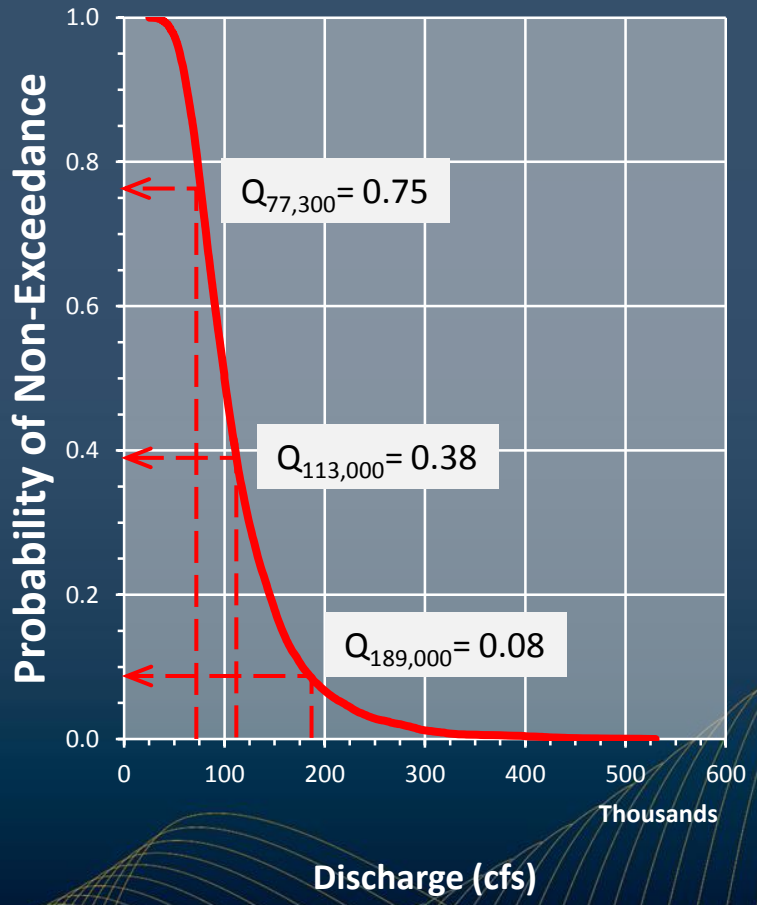
Evaluations

- Evaluations completed for workshop
  - River inflow exceedance curve
  - Spillway pier capacity
  - Radial gate capacity
  - Discharge rating curves
    - Spillway
    - Overtopping
  - HEC-RAS Analysis
    - Breach of East Abutment Cutoff
    - Upstream inundation
    - Downstream inundation

URS

Columbia River Inflow

- Probability Columbia River Inflow
  - 40 years River flow data
- Assumed inflow rates
  - 77,300 cfs 75 %
  - 113,000 cfs 38 %
  - 189,000 cfs 8 %



URS

Estimate Time for Intervention

- Estimated active storage volume
  - Normal Pool, El. 707 — 38,570 ac-ft
  - Top of Gate, El. 708 — 47,700 ac-ft
  - West Abutment, El. 717 — 130,000 ac-ft
  - Crest of Dam, El. 720.0 — 157,400 ac-ft
- El. 708 (gate overtopping)
  - 77,300 cfs — 1.4 hrs
  - 113,000 cfs — 1.0 hrs
  - 189,000 cfs — 0.6 hrs
- El. 717 (crest overtopping)
  - 77,300 cfs — 20.3 hrs
  - 113,000 cfs — 13.9 hrs
  - 189,000 cfs — 8.3 hrs

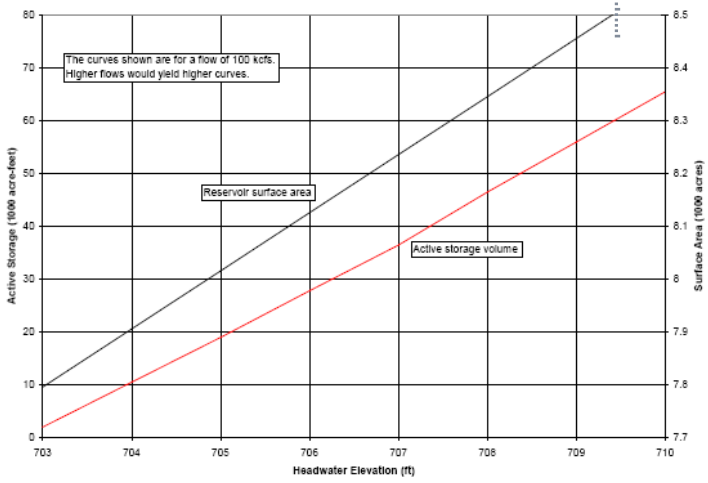


Figure A-1: Rocky Reach Hydroelectric Project Reservoir Area-Capacity Curve

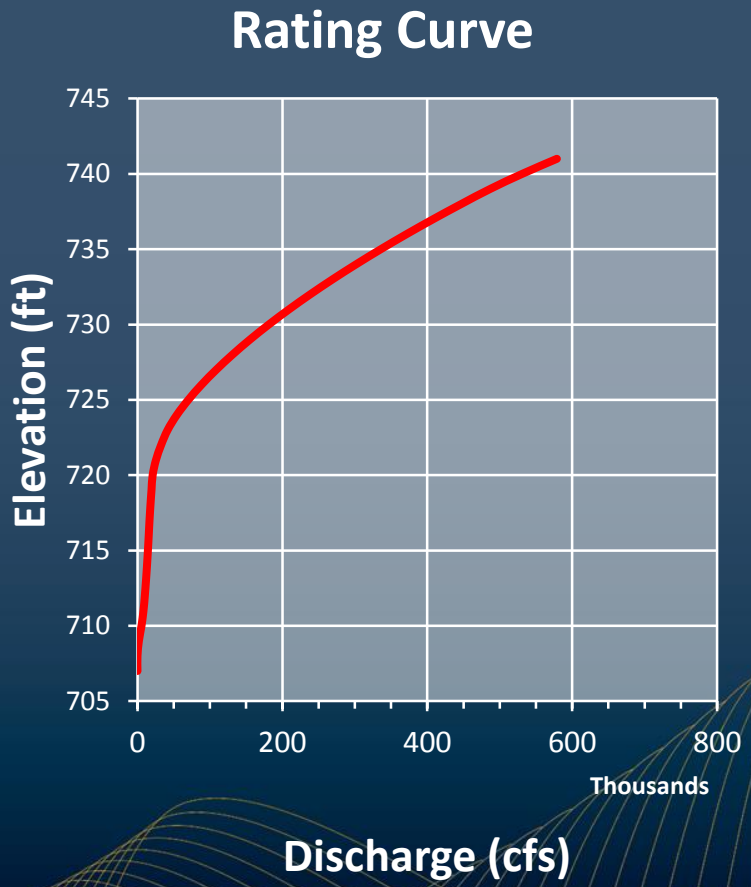
Table A-8: Reservoir Features

Feature	Description
RESERVOIR	
Normal Maximum Headwater Level	707 ft
Drainage Area	87,800 sq. mi.
Length	43 miles, River Mile 473.7 to 516.5
Area @ 707' HW (headwater)	8,235 acres @ 100,000 cfs
Average Width	0.3 mi.
Maximum Depth	Approx. 130 ft
Average Flow, 1973 – 2001	113,200 cfs
Minimum Flow, 1973 – 2001	25,100 cfs
Maximum Flow, 1973 – 2001	358,000 cfs
Useable Storage (707' HW to 703' HW)	36,400 acre-ft @ 100,000 cfs
Gross Storage Capacity	387,500 acre-ft

URS

Overtopping Rating Curve

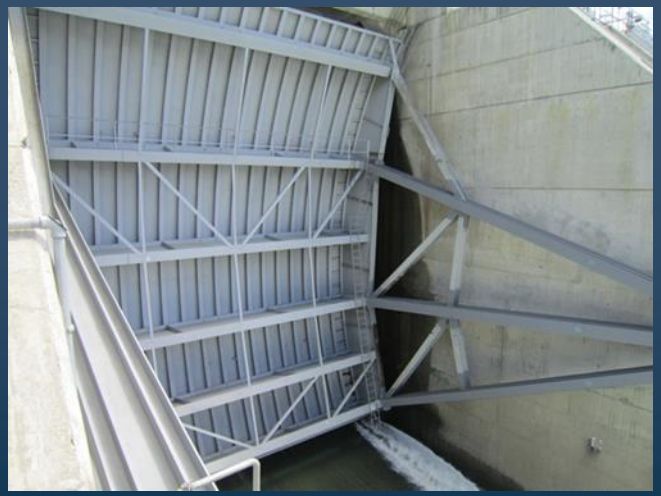
- Discharge Rating Curve
  - West Abutment
    - Open channel flow, C = 2.5
  - Forebay Wall
    - Weir flow, C = 2.9
  - Center Dam
    - Weir flow, C= 2.9
  - Spillway
    - Sharp crest flow, C = 3.30
    - Orifice flow > 709, C = 0.61
    - Weir flow > 724, C = 2.9
  - East Abutment Gravity Wall
    - Weir flow, C = 3.1
  - East Abutment Cutoff
    - Weir flow, C = 2.7



URS

Spillway Gate Evaluation

$$\xi = \frac{P_r}{P_c} + \left(\frac{8}{9}\right) \cdot \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0$$

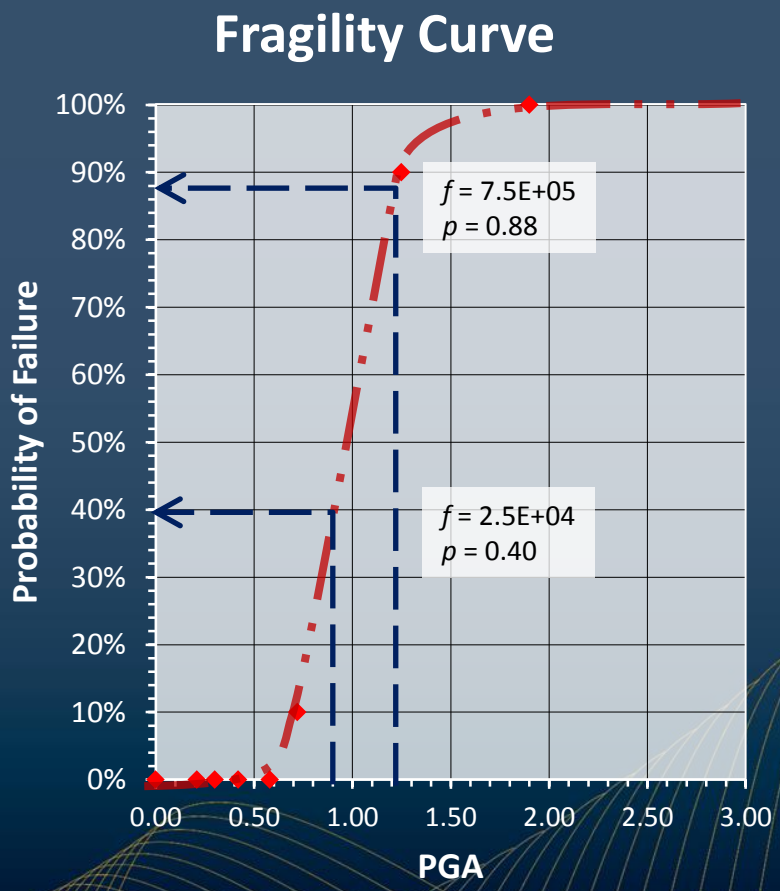


Seismic Frequency	PGA	Axial/Bending Coefficient		
(yrs)	(g)	Lower	Middle	Upper
Static	- -	0.26	0.33	0.38
500	0.21	0.28	0.35	0.41
1000	0.30	0.28	0.35	0.43
2500	0.42	0.29	0.37	0.44
5000	0.58	0.31	0.38	0.46
10,000	0.72	0.32	0.39	0.47

URS

Pier Evaluation

Seismic Frequency	PGA	Maximum Moment	Maximum Shear
(yrs)	(g)	(k-ft)	(k)
500	0.21	252.5	134.5
1000	0.30	519.5	145.8
2500	0.42	773.5	162.8
5000	0.58	1,013	179.8
10,000	0.72	1,274	196.3
100,000	1.25	2,198	258.2
1,000,000	1.90	3331	334.1
Capacity		2,997.2	250.6



URS

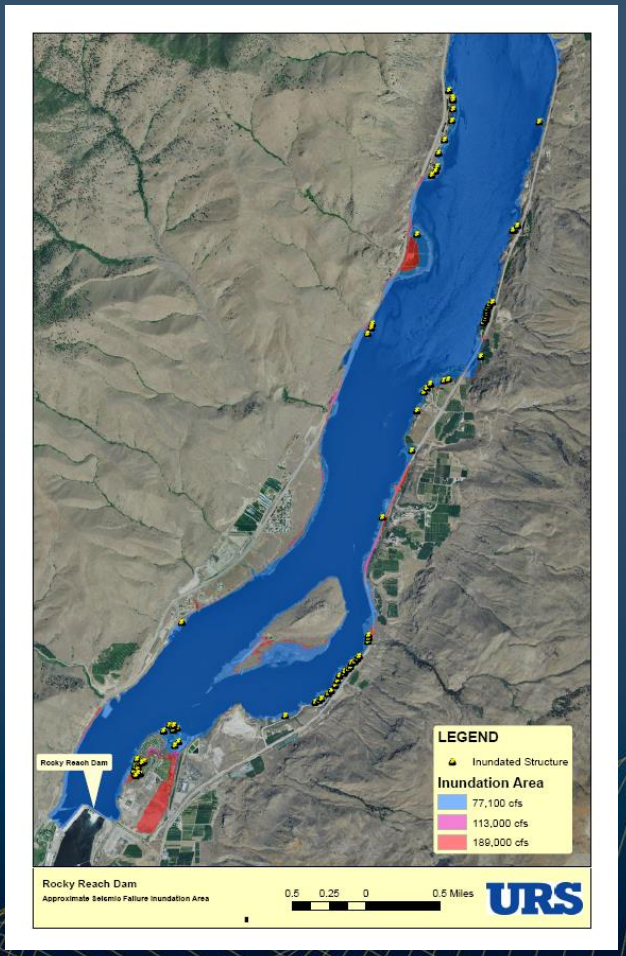
HEC-RAS Studies

- USACE HEC-RAS Model
- Evaluated three selected inflow rates
  - 77,300 cfs
  - 113,000 cfs
  - 189,000 cfs
  - Assumptions
    - Powerhouse offline, no discharge capability
    - Spillway gate failure, closed position no discharge capability
    - East Abutment Cuttoff Breach Scenarios
      - Breach at overtopping depth of 2 feet
      - Breach at maximum overtopping depth
  - Estimate number of structures within inundation area

URS

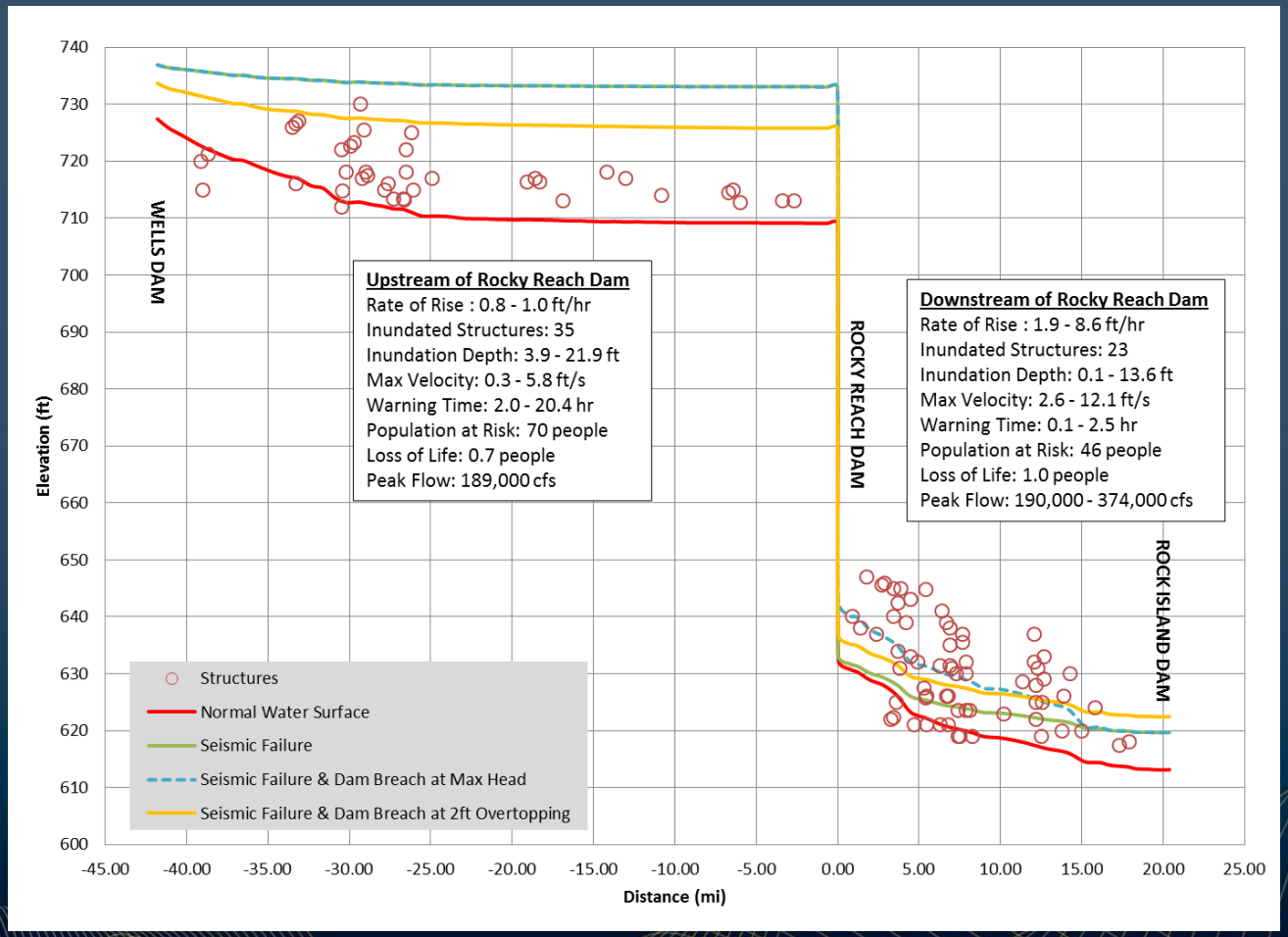
Reservoir Routings

- Inundation results relatively insensitive
  - Inflow
  - Breach scenario
- Upstream Inundation affects greater population



URS

Seismic PFM Profile - 189,000 cfs

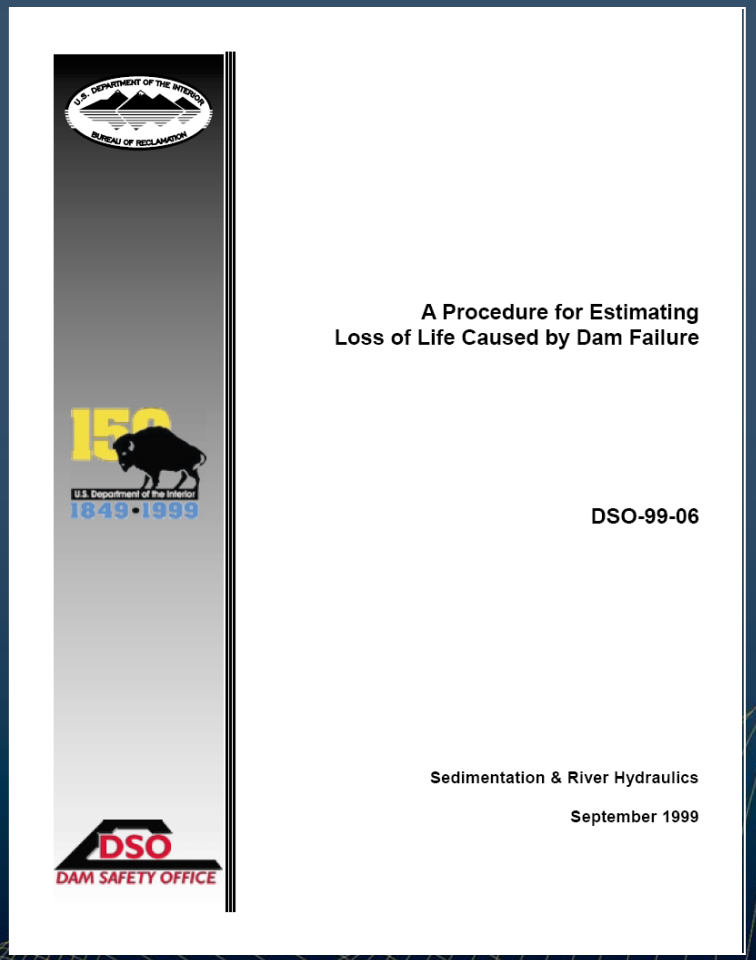


URS

PAR/Potential Life Loss (LL)

- Upstream Inundation
  - No. of Structures — Mid 30s
  - Population at Risk — 65-70
  - Potential Life Loss — <1
- Downstream Inundation
  - No. of Structures — 10-20
  - Population at Risk — 15 - 35
  - Potential Life Loss — <1

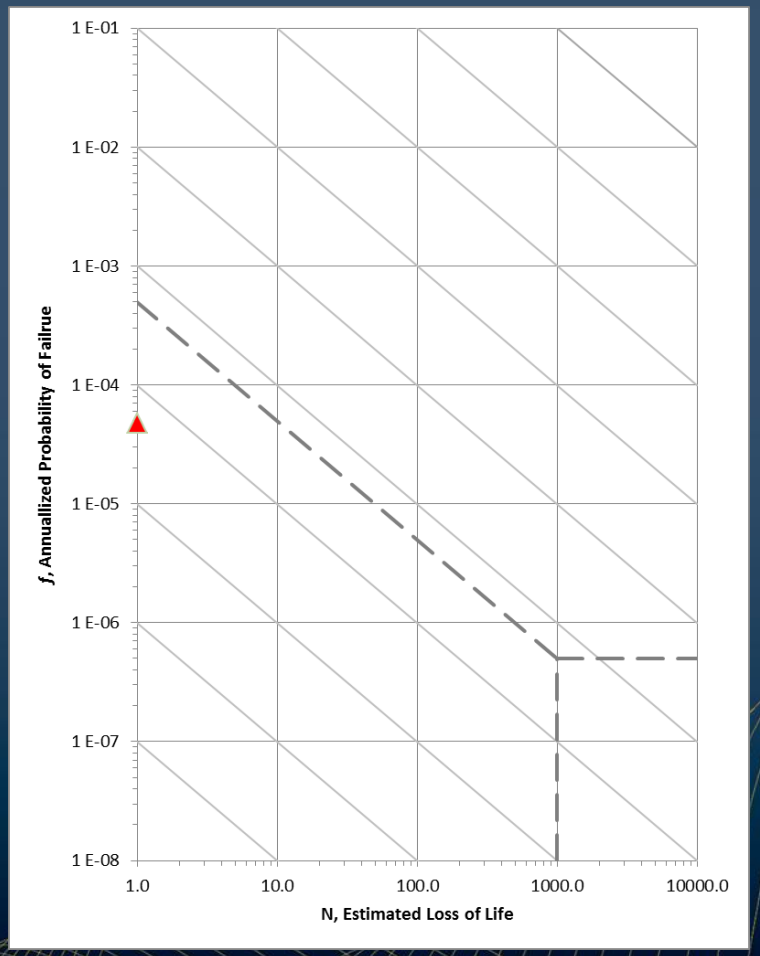
- Potential Life Loss <1



URS

Tolerable Risk

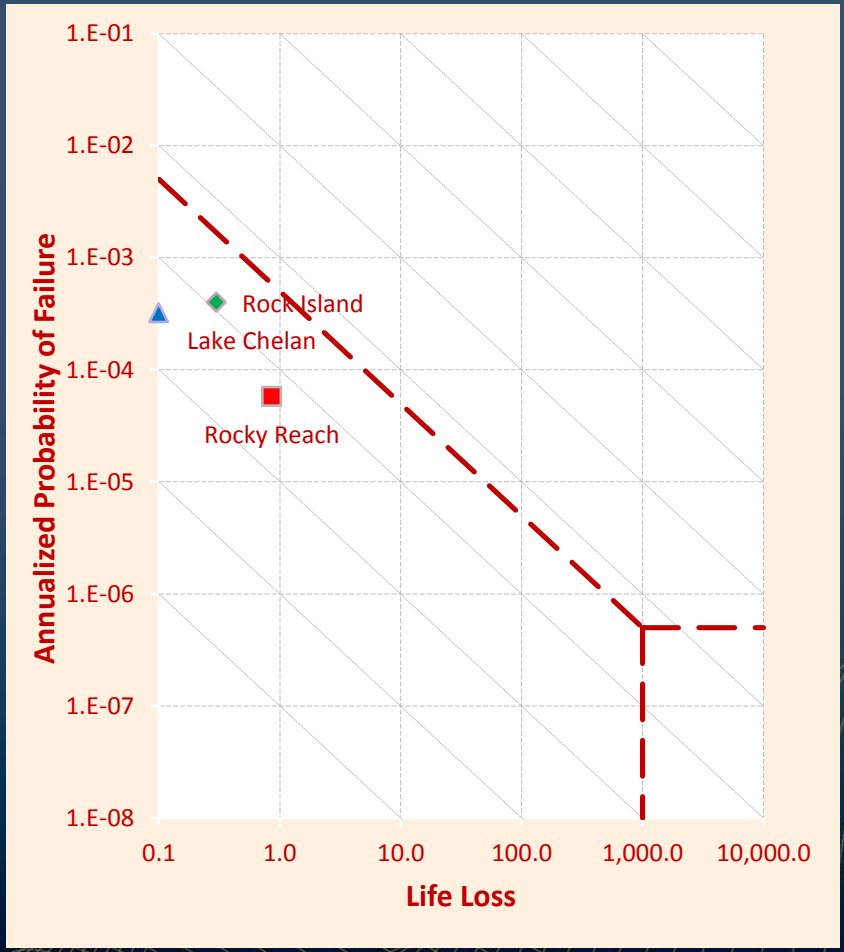
- Estimated risk
  - 4.8 E-05
- Assume seismic risk is 50 percent of total risk
  - Total Risk 9.6 E-05
  - This scenario is less than the Tolerable Risk Criteria of 1.0 E-04



URS

Estimating Probability

- Estimated risk
- Assume seismic risk is 50 percent of total risk
  - These scenarios are less than Tolerable Risk Criteria of 5.0 E-04



URS

Summary

- Pilot program used risk informed decision making methods to evaluate the seismic risk
- Estimated risk is below tolerable risk level
- Next phase will be to evaluate the additional failure modes

URS







QUESTIONS

URS