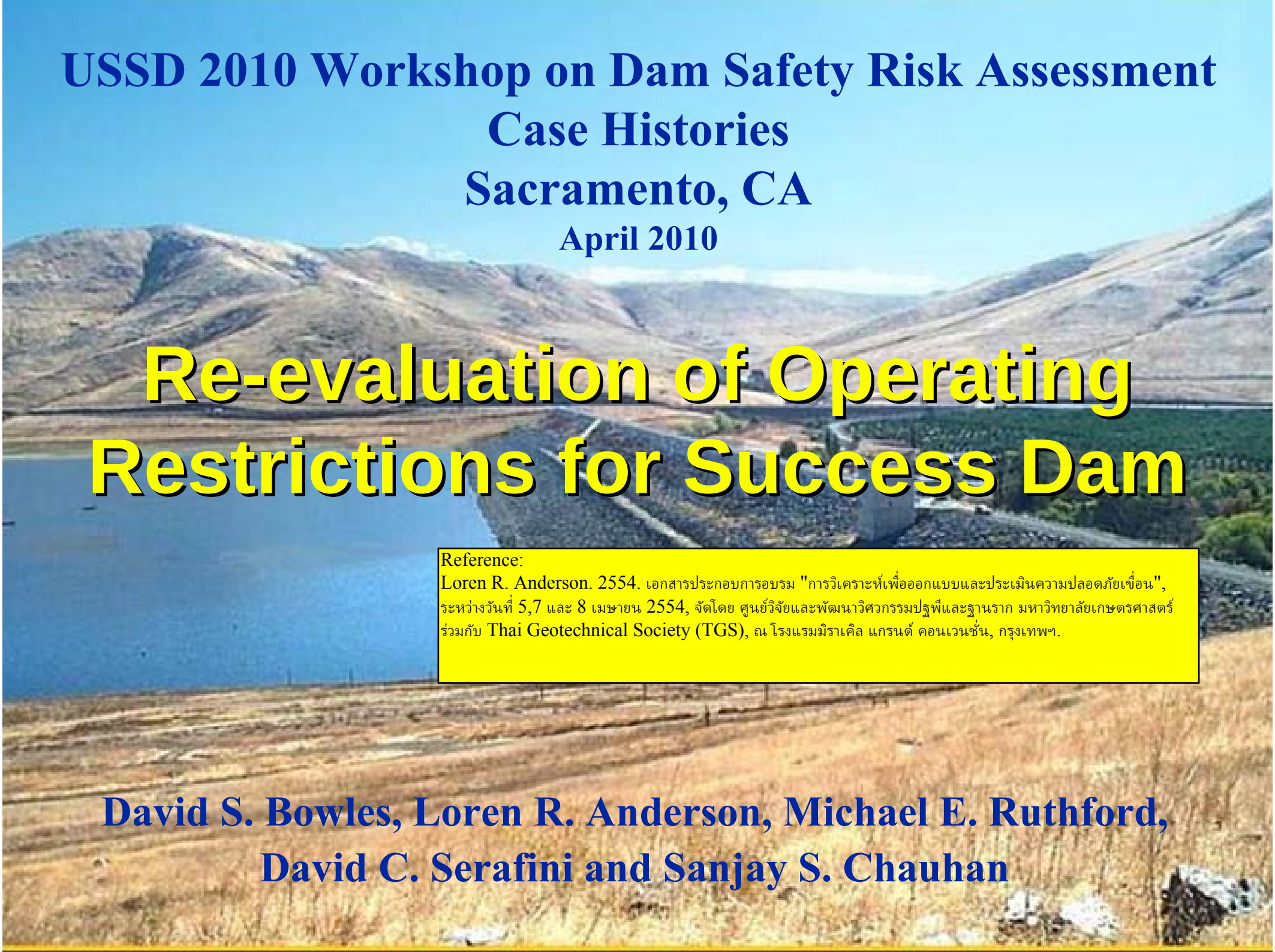


USSD 2010 Workshop on Dam Safety Risk Assessment Case Histories

Sacramento, CA

April 2010

Re-evaluation of Operating Restrictions for Success Dam

Reference:
Loren R. Anderson. 2554. เอกสารประกอบการอบรม "การวิเคราะห์เพื่อออกแบบและประเมินความปลอดภัยเขื่อน", ระหว่างวันที่ 5,7 และ 8 เมษายน 2554, จัดโดย ศูนย์วิจัยและพัฒนาวิศวกรรมปฐพีและฐานราก มหาวิทยาลัยเกษตรศาสตร์ ร่วมกับ Thai Geotechnical Society (TGS), ณ โรงแรมมิราเคิล แกรนด์ คอนเวนชั่น, กรุงเทพฯ.

David S. Bowles, Loren R. Anderson, Michael E. Ruthford, David C. Serafini and Sanjay S. Chauhan

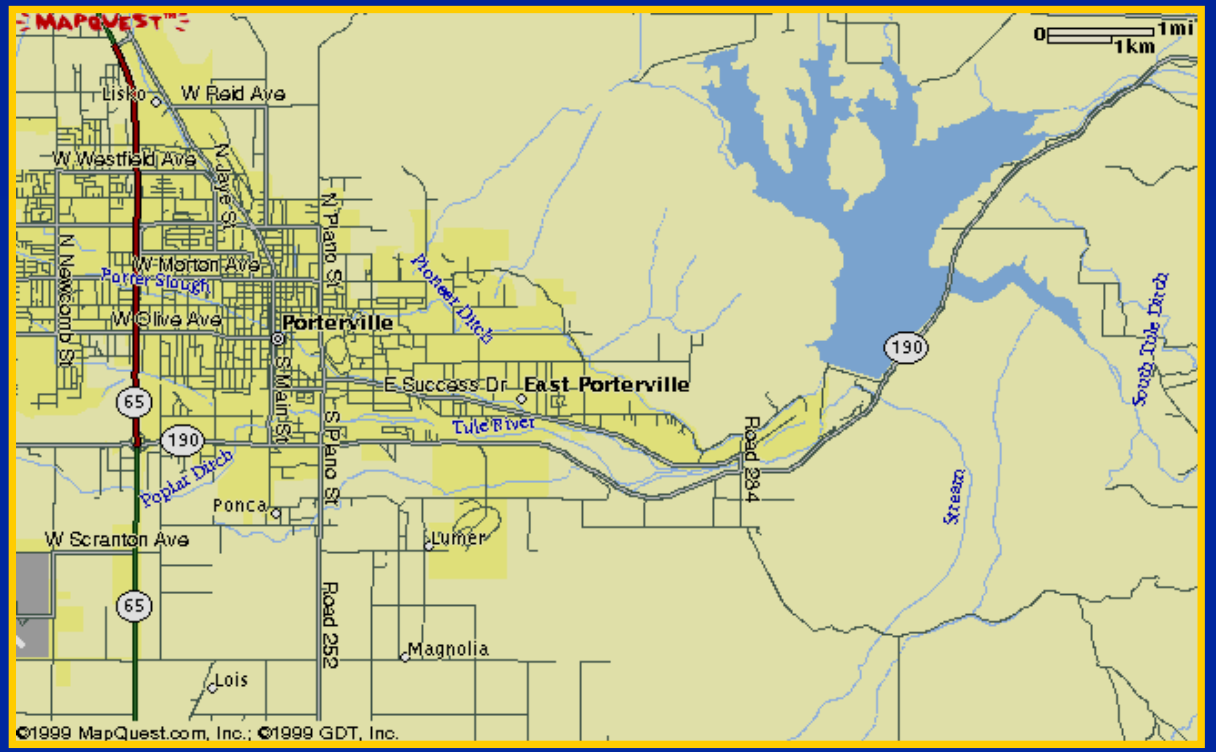
Outline

1) Purpose, Context and Scope
2) Baseline Risk Assessment
3) Risk Reduction Assessment
4) Limitations, Decisions, Risk Communication and Lessons Learned

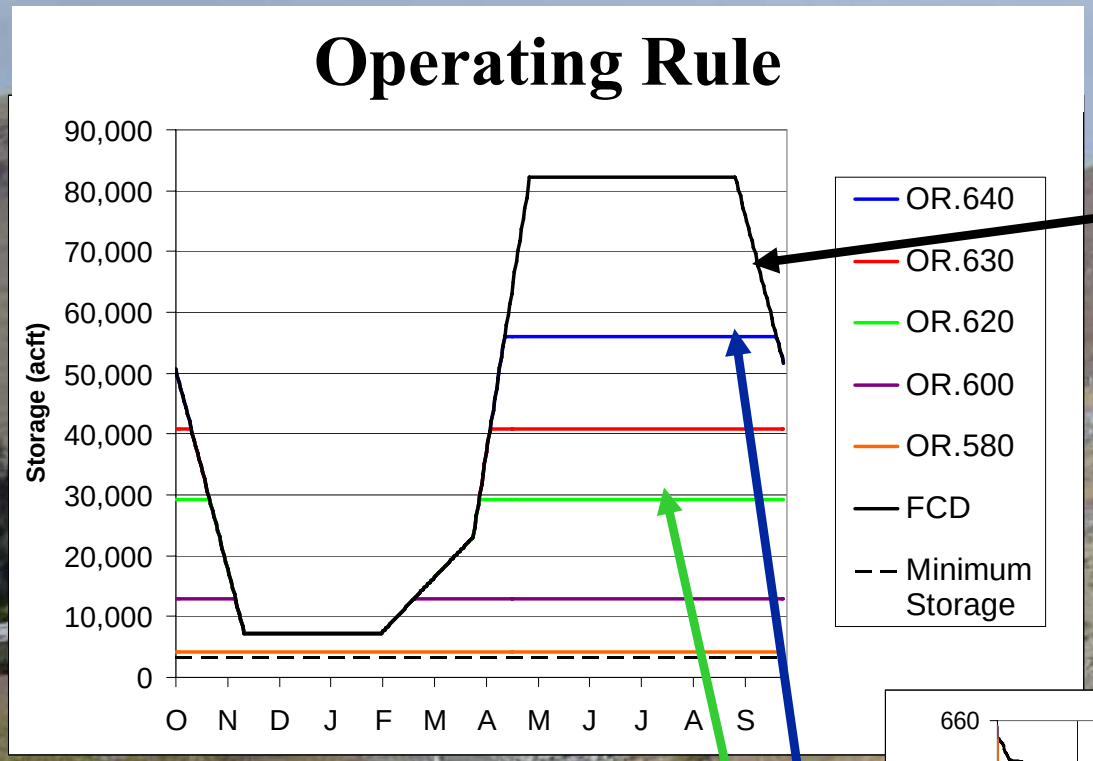
1) Purpose, Context and Scope

Purpose

1) "To Update the 2004 Risk-Based Evaluation of Operating Restrictions for Lake Success."
2) "A probable failure modes analysis (PFMA) will be conducted. Project specific significant and credible potential failure modes will be selected, described, and fully evaluated in the risk assessment."



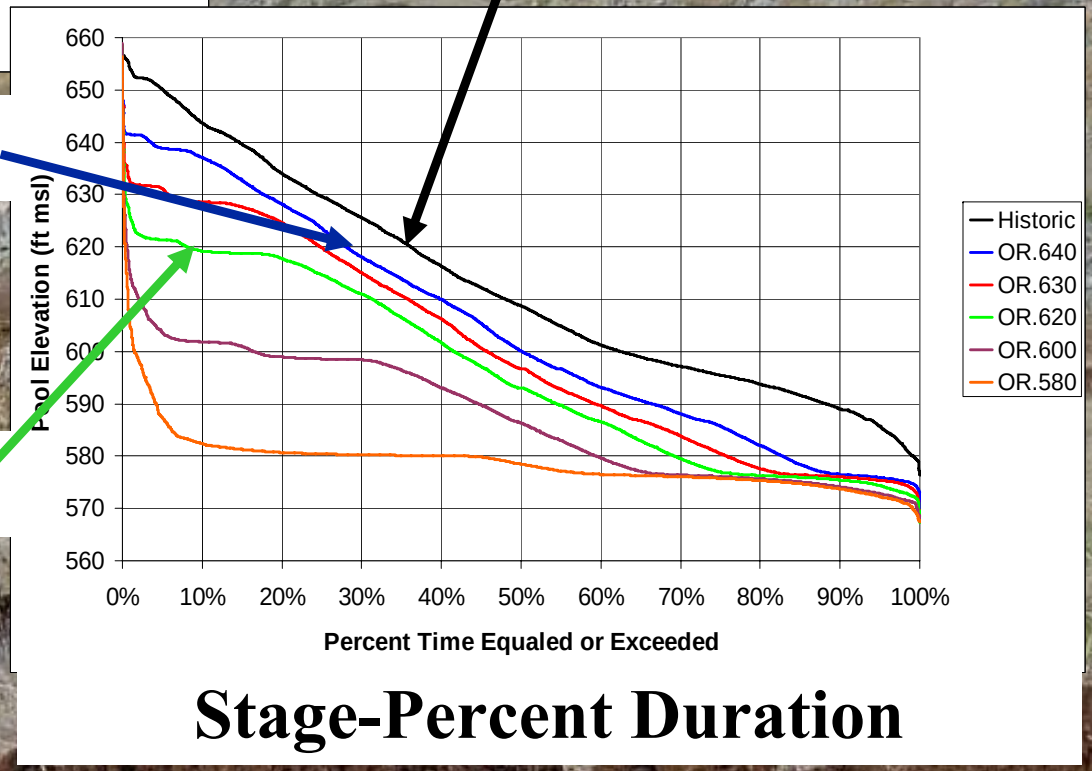
Context



Existing Rule – 652.5

Operating Restriction – 640

Operating Restriction – 620



Stage-Percent Duration

Context: Impact Cost of Operating Restrictions in 2004$

1) Agricultural losses associated with reductions in irrigation water
2) Increased flood damages in an historic terminal lake, Tulare Lake agricultural area.
3) Net recreational losses, allowing for shifts to other lakes in the region
   - $2.1 m for OR.630 and OR.640
   - $2.8 m for OR.580, OR.600 and OR.620

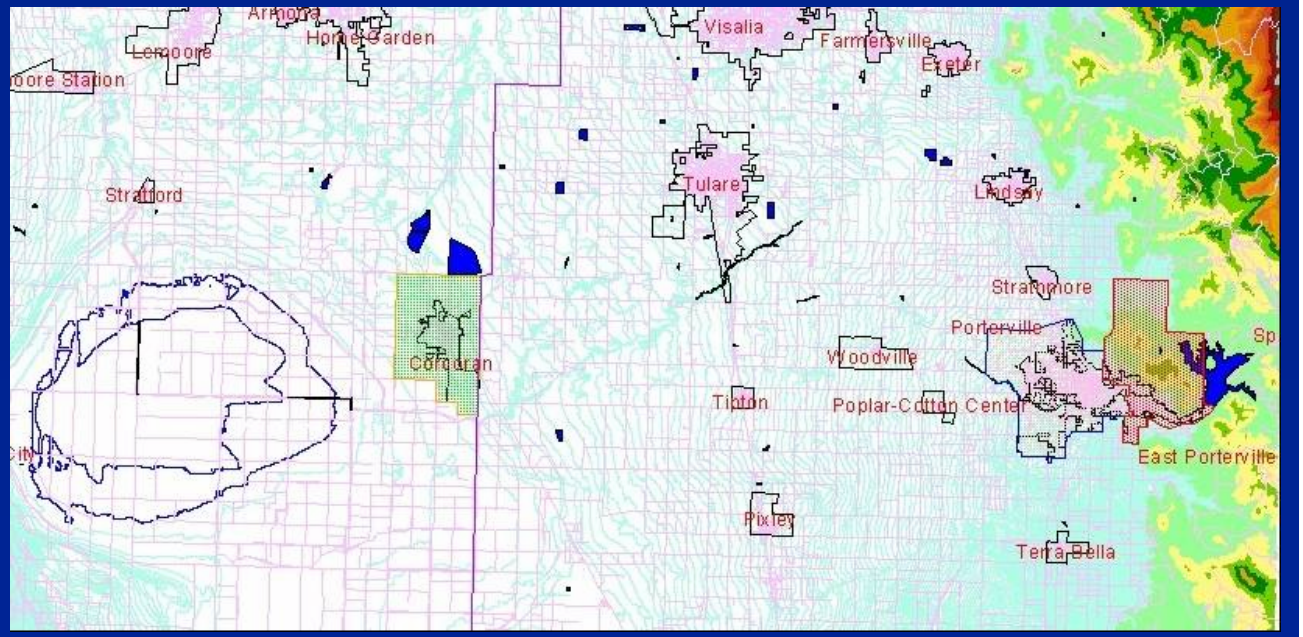


Table 1. Estimated Economic Losses to Downstream Agricultural Interests

Potential Operating Restriction	Representative Water Year					Average Annual Economic Losses ($/year)
	Very Dry	Dry	Below Average	Average	Wet	
	1976	1964	1985	1996	1980	
OR 640	$0	$0	$0	$940,660	$1,065,050	$401,142
OR 630	$0	$0	$635,810	$2,014,530	$2,152,920	$960,652
OR 620	$0	$0	$1,420,440	$2,836,050	$2,952,250	$1,441,748
OR 600	$878,220	$1,038,240	$2,590,700	$3,940,300	$3,797,220	$2,448,936

Table 2. Estimated Additional Flood Damages to Agricultural Lands in Tulare Lakebed

Potential Operating Restriction	Representative Water Year					Average Annual Additional Flood Damages ($/year)
	Very Dry	Dry	Below Average	Average	Wet	
	1976	1964	1985	1996	1980	
OR 640	$0	$0	$0	$0	$3,100,000	$620,000
OR 630	$0	$0	$0	$0	$3,100,000	$620,000
OR 620	$0	$0	$0	$0	$3,200,000	$640,000
OR 600	$0	$0	$0	$0	$7,500,000	$1,500,000

Scope of Risk Assessment

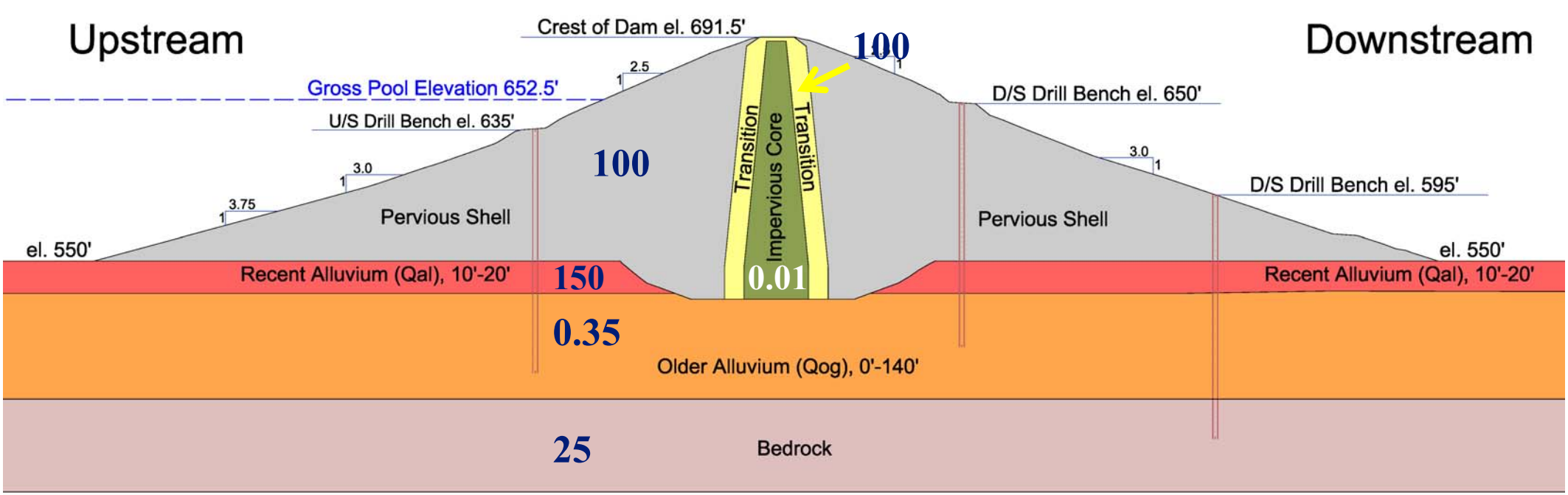
- Initiating Events
  - Earthquake
  - Flood *including Flood-internal (Piping and Instability)*
- Consequences
  - Life loss
  - Economic loss
- Risk Evaluation
  - USACE Proposed Tolerable Risk Guidelines
- Decision Alternatives
  - No Restriction & 5 Potential Operating Restrictions

2) Baseline Risk Assessment &
3) Risk Reduction Assessment

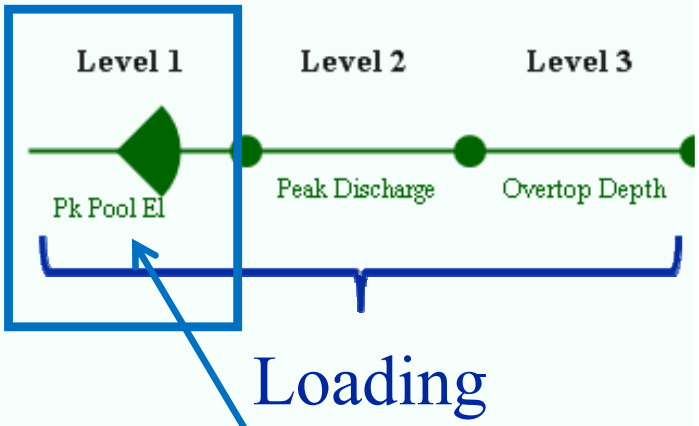
Risk Assessment Team

- Sacramento District
  - **Michael E. Ruthford**
  - **Paul V. Zianno**
  - **Dr. Vlad G. Perlea**
  - **David C. Serafini**
  - **Michael D. Ramsbotham**
  - **Jack Montgomery**
  - **Dr. Michael H. Beaty**, Consultant
- RAC and Utah State University:
  - **Dr. David S. Bowles**
  - **Dr. Loren R. Anderson**
  - **Dr. Sanjay S. Chauhan**

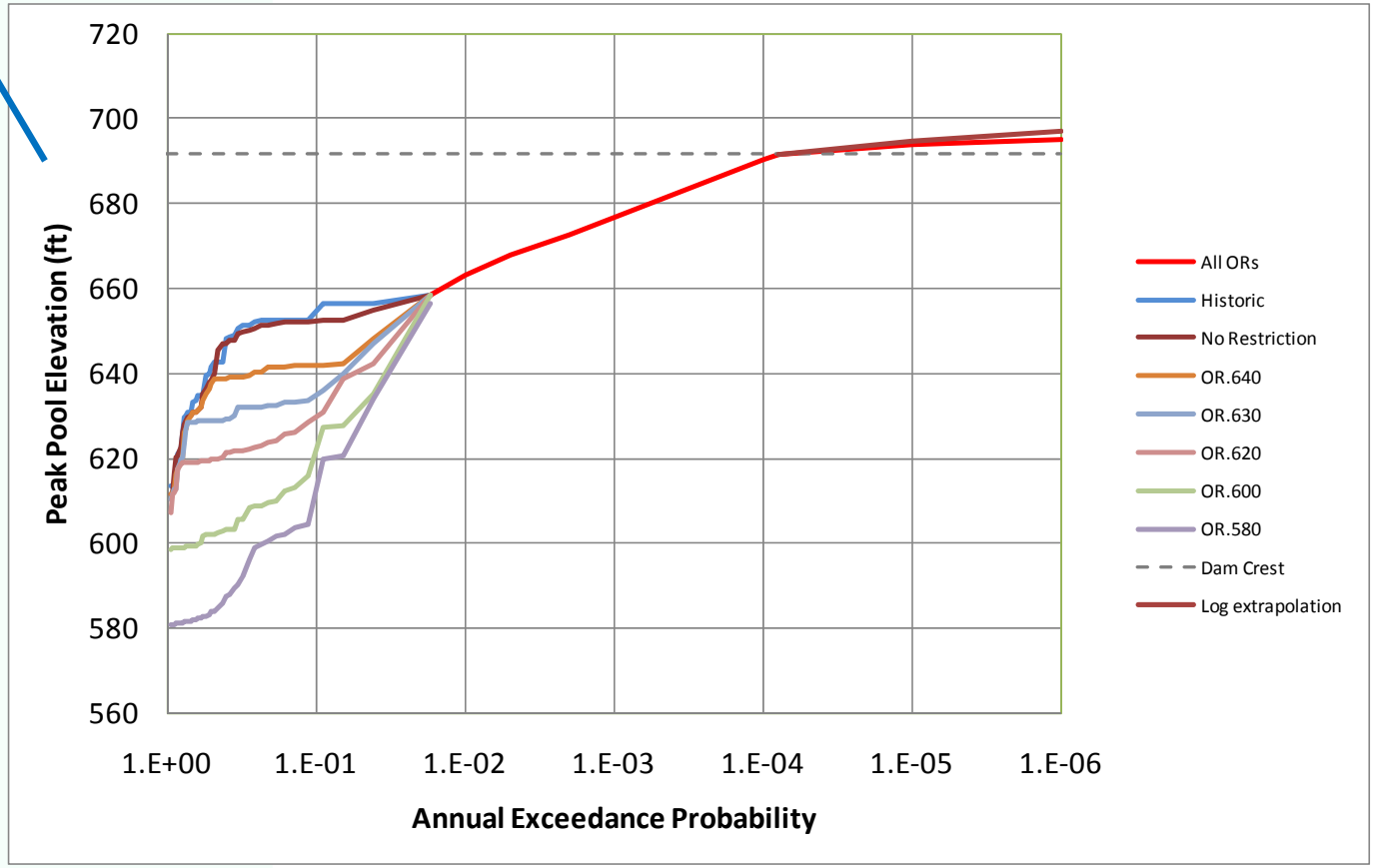
Typical Cross Section for Success Dam

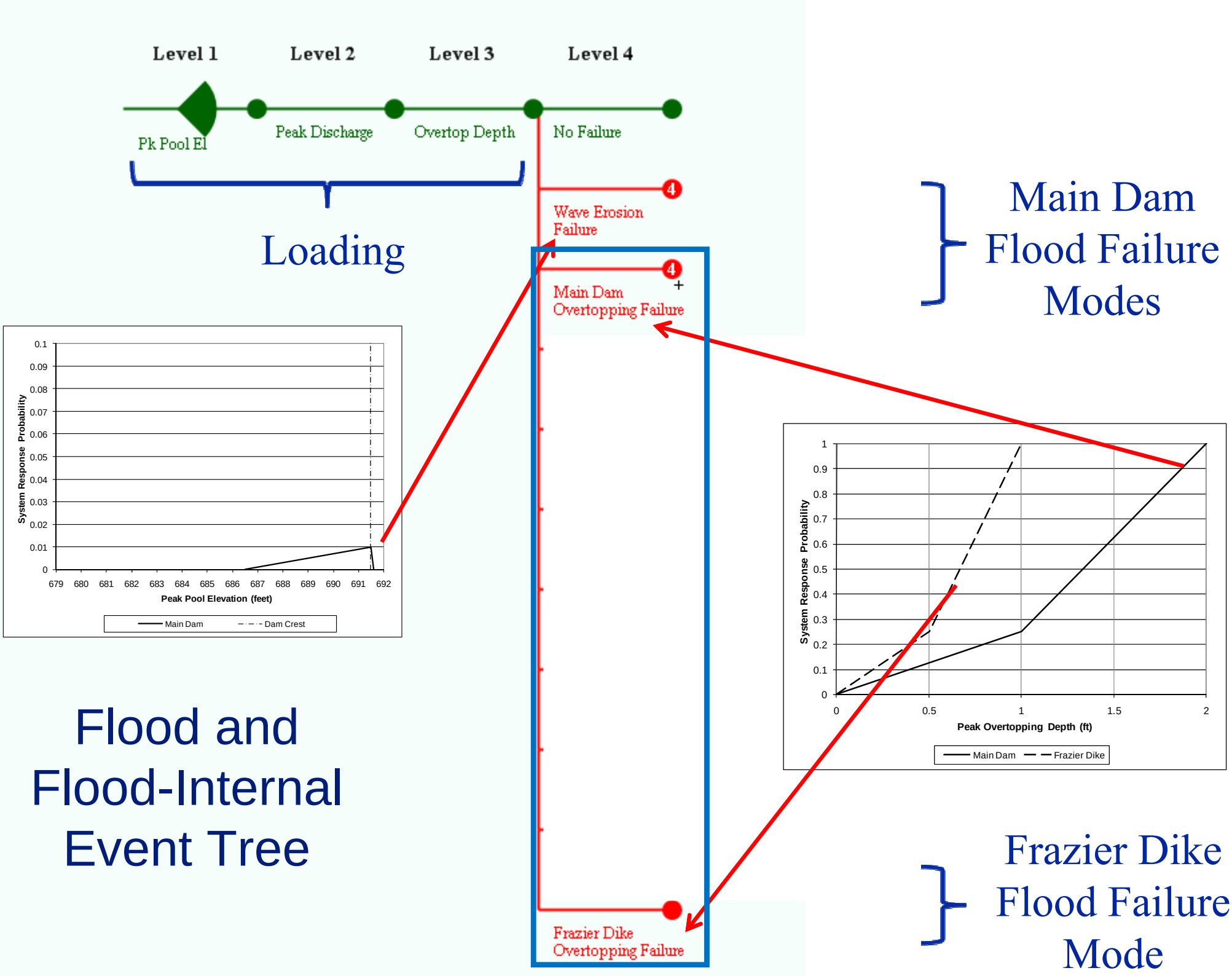


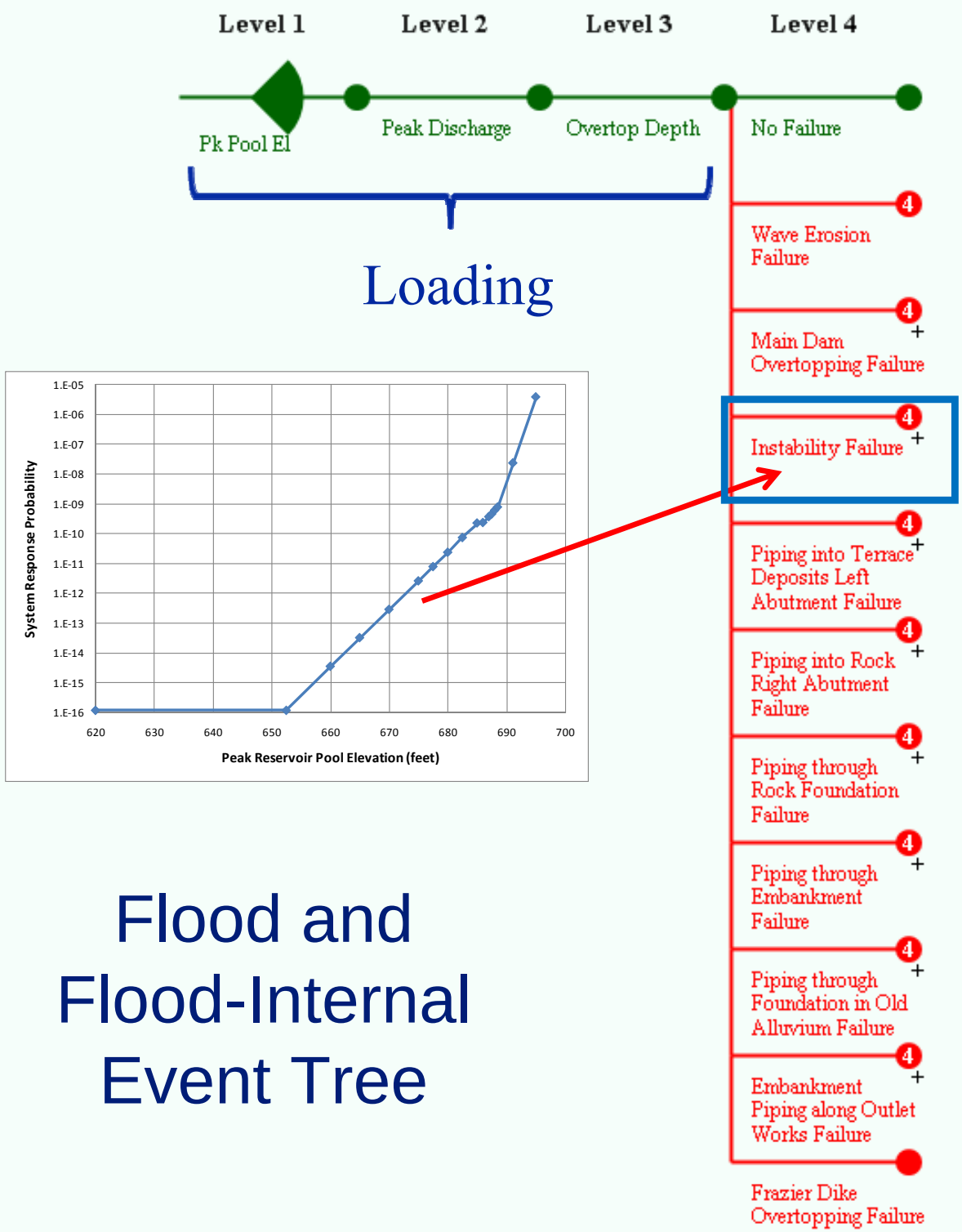
Zone	Horizontal Permeability (ft/day)
Embankment Pervious Shell	100
Embankment Transition Zone	100
Embankment Core	0.01
Recent Alluvium in Foundation	150
Older Alluvium in Foundation	0.35
Bedrock in Foundation	25



Flood and Flood-Internal Event Tree




Level 1
Level 2
Level 3
Level 4
Pk Pool El
Peak Discharge
Overtop Depth
No Failure
Loading
Wave Erosion Failure
Main Dam Overtopping Failure
Frazier Dike Overtopping Failure
Main Dam Flood Failure Modes
Frazier Dike Flood Failure Mode
System Response Probability
Peak Pool Elevation (feet)
Main Dam
Dam Crest
Peak Overtopping Depth (ft)
Frazier Dike
Flood and Flood-Internal Event Tree

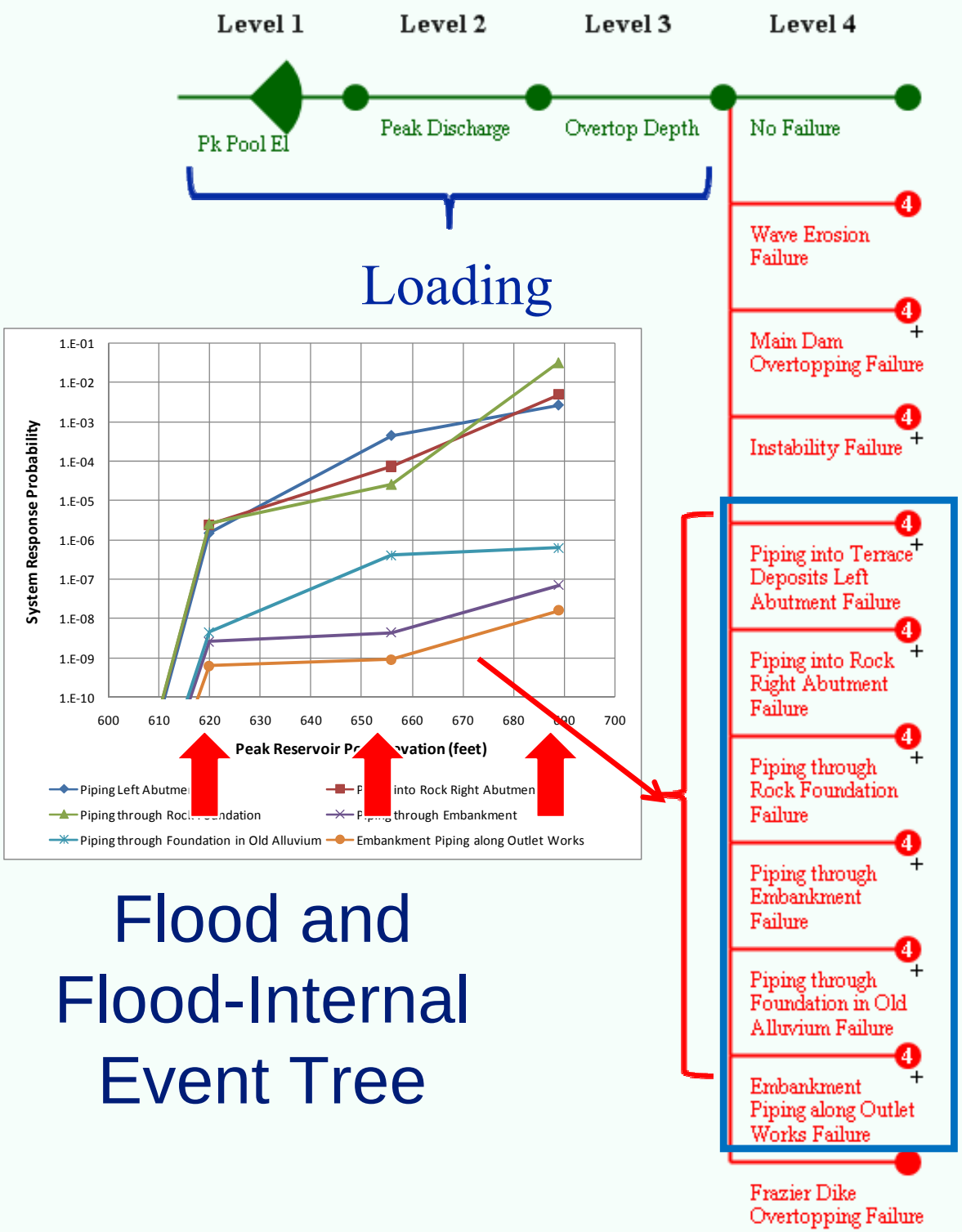


Flood and Flood-Internal Event Tree

Main Dam Flood Failure Modes

Main Dam Flood-internal Failure Modes

Frazier Dike Flood Failure Mode



Made estimates at the pool levels: 620, 656 and 689

Dam Crest = 691.5

PMF Pool = 689

Pool of Record = 658

Threshold = 590

Piping

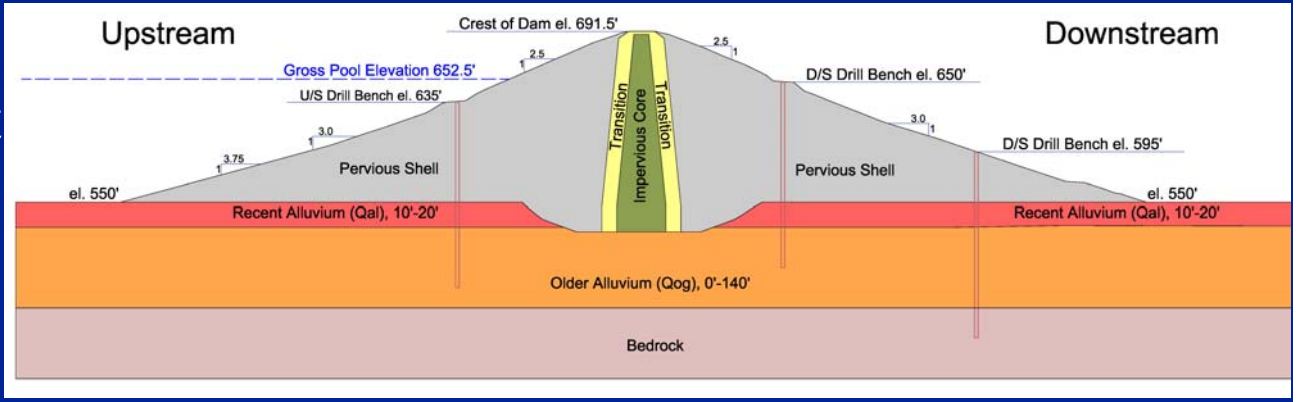
Main Dam Flood-internal Failure Modes

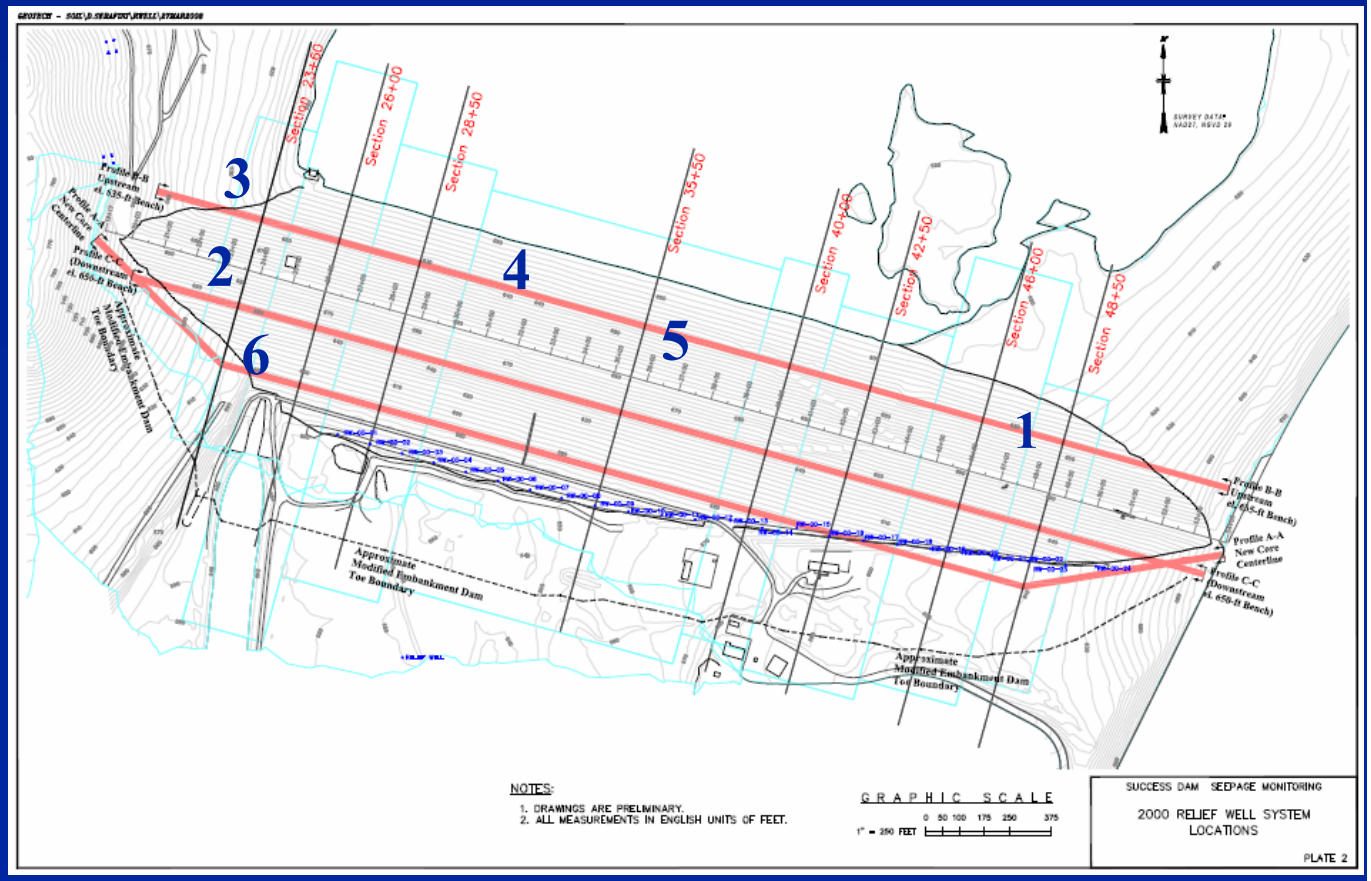
Frazier Dike Flood Failure Mode

Flood and Flood-Internal Event Tree

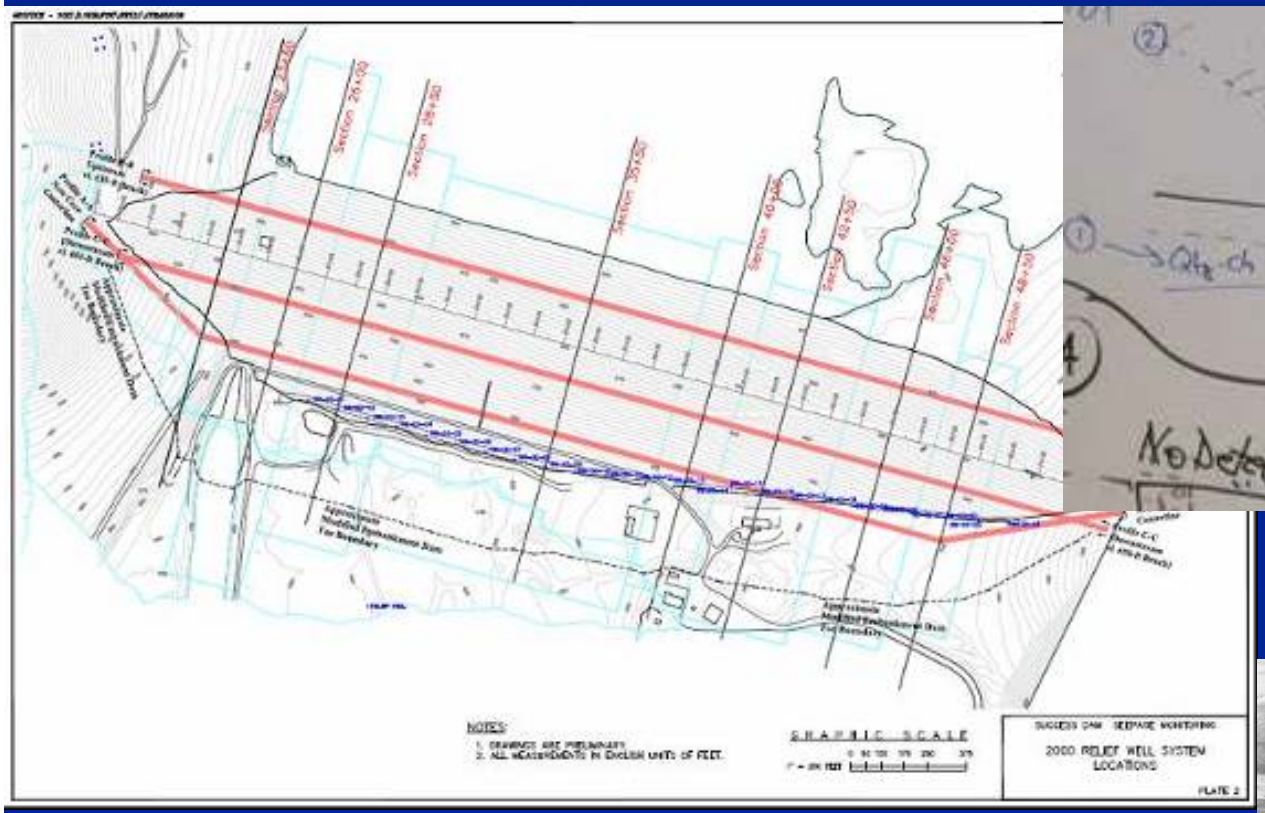
Seepage and Piping Failure Modes

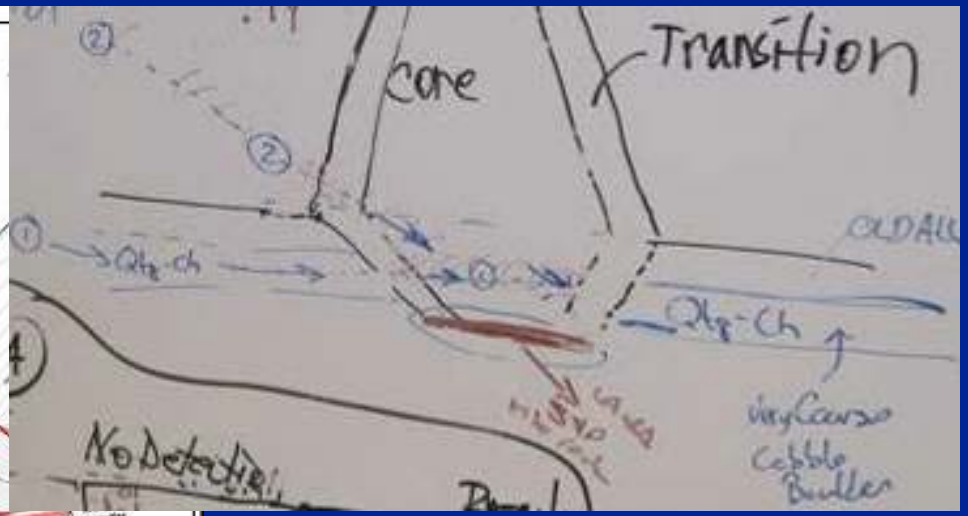
1. Piping into Terrace Deposits Left Abutment Failure
2. Piping into Rock Right Abutment Failure
3. Piping through Rock Foundation Failure
4. Piping through Embankment Failure
5. Piping through Foundation in Older Alluvium Failure
6. Embankment Piping along Outlet Works Failure

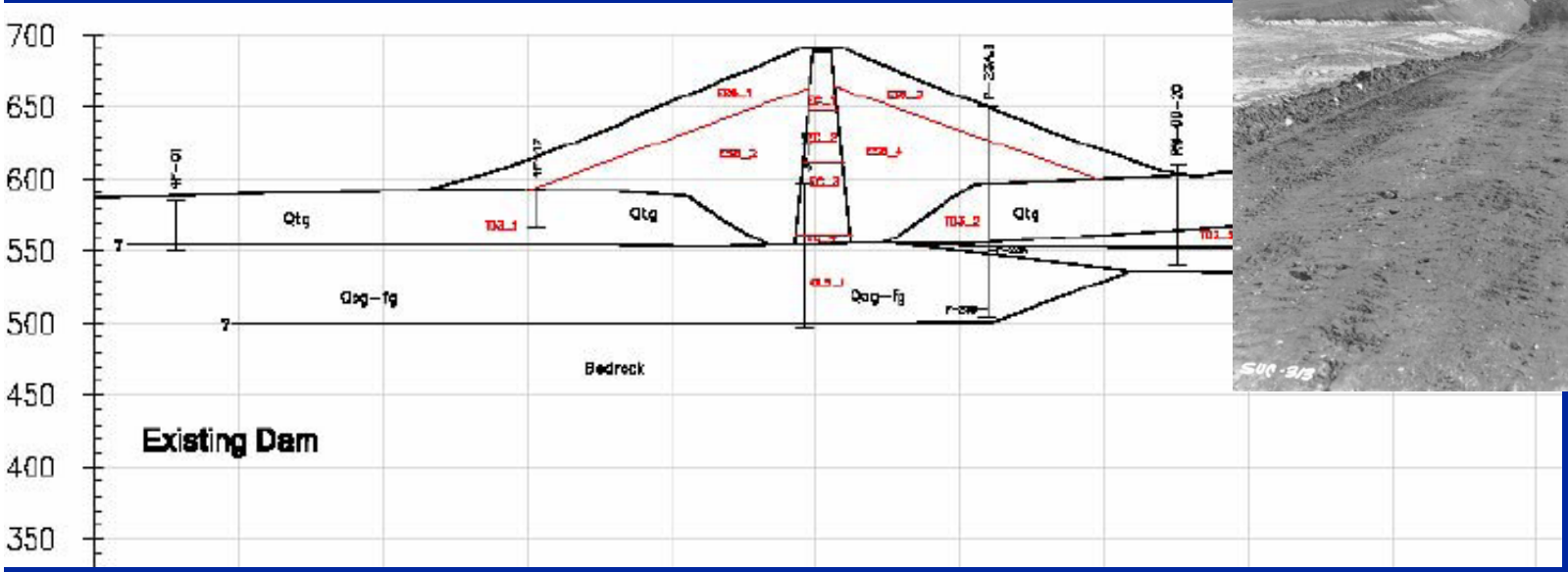




1. Piping in the Left Abutment

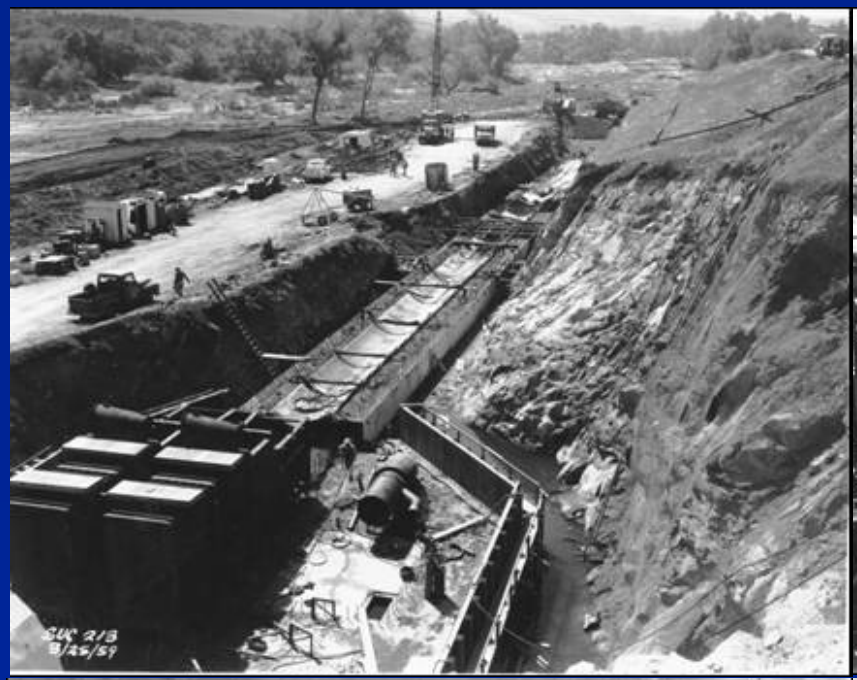






4. Embankment Piping Flaw in Core

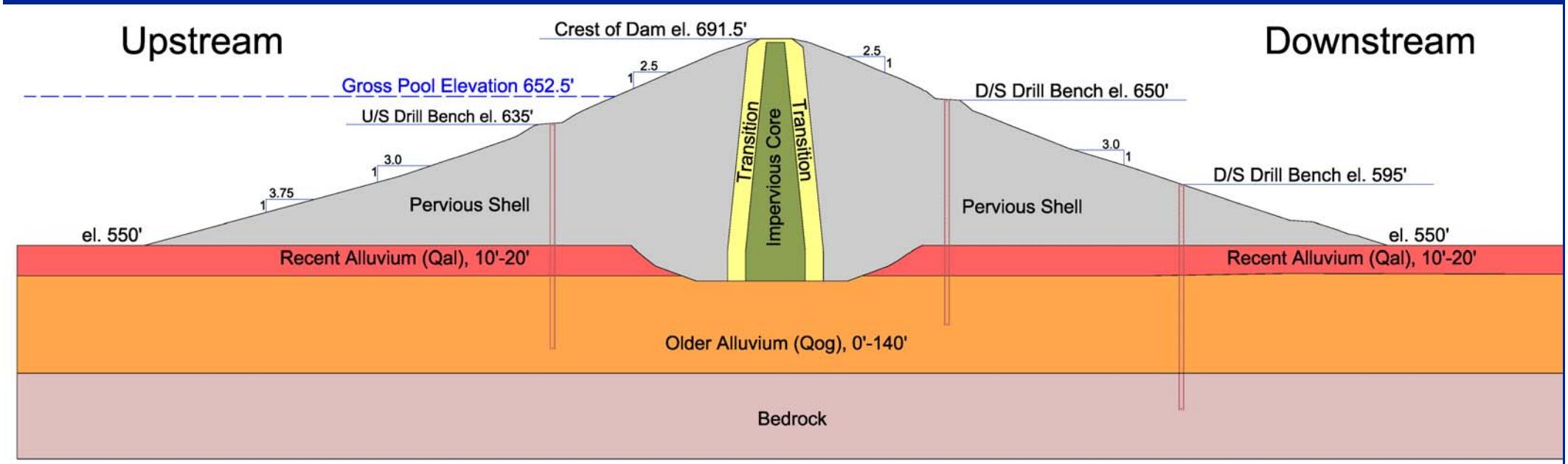
2., 3., & 6: Construction Photos of Foundation Conditions in Right Abutment



Process to Estimate Piping SRPs

- Potential Failure Modes Analysis
  - Standard PFMA method
  - Used USACE Toolbox for guidance
- Used event tree model
- Piping and seepage toolbox – two versions
- All estimates made by Engineering Team

Earthquake Failure Modes
- Liquefaction in Recent Alluvium and Upstream Shell



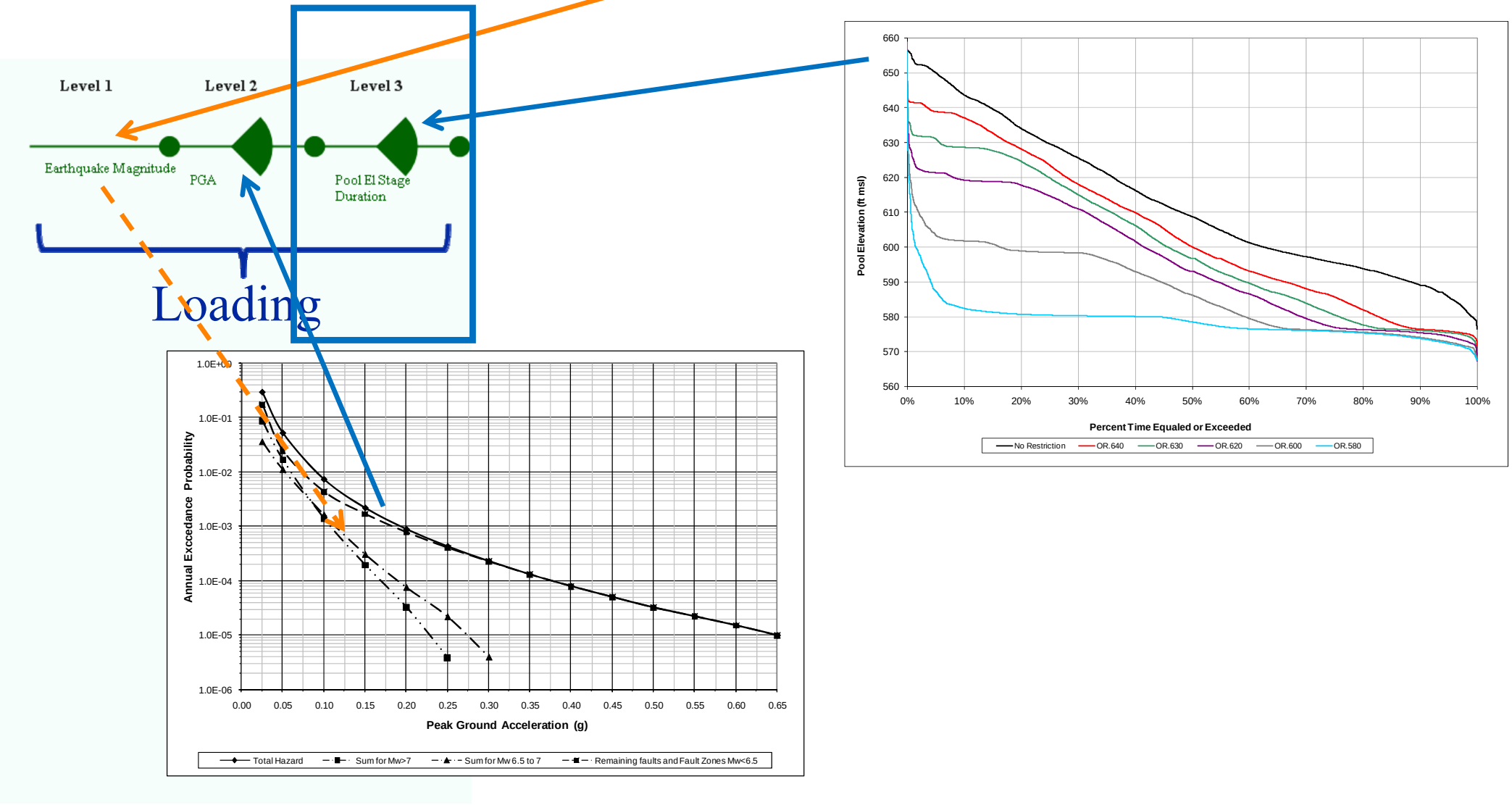
Earthquake Failure Modes

1) Liquefaction leading to vertical crest deformation and failure by Above-Core Erosion (ACE) of the dam.
2) Liquefaction leading to embankment deformation and failure by Seepage Erosion through Cracks (SEC).
3) Liquefaction leading to embankment and tower deformation resulting in failure by piping into a rupture in the control tower - outlet works system, referred to as a Tower-induced Piping (TIP) failure.

Delayed failure from loss of outlet works

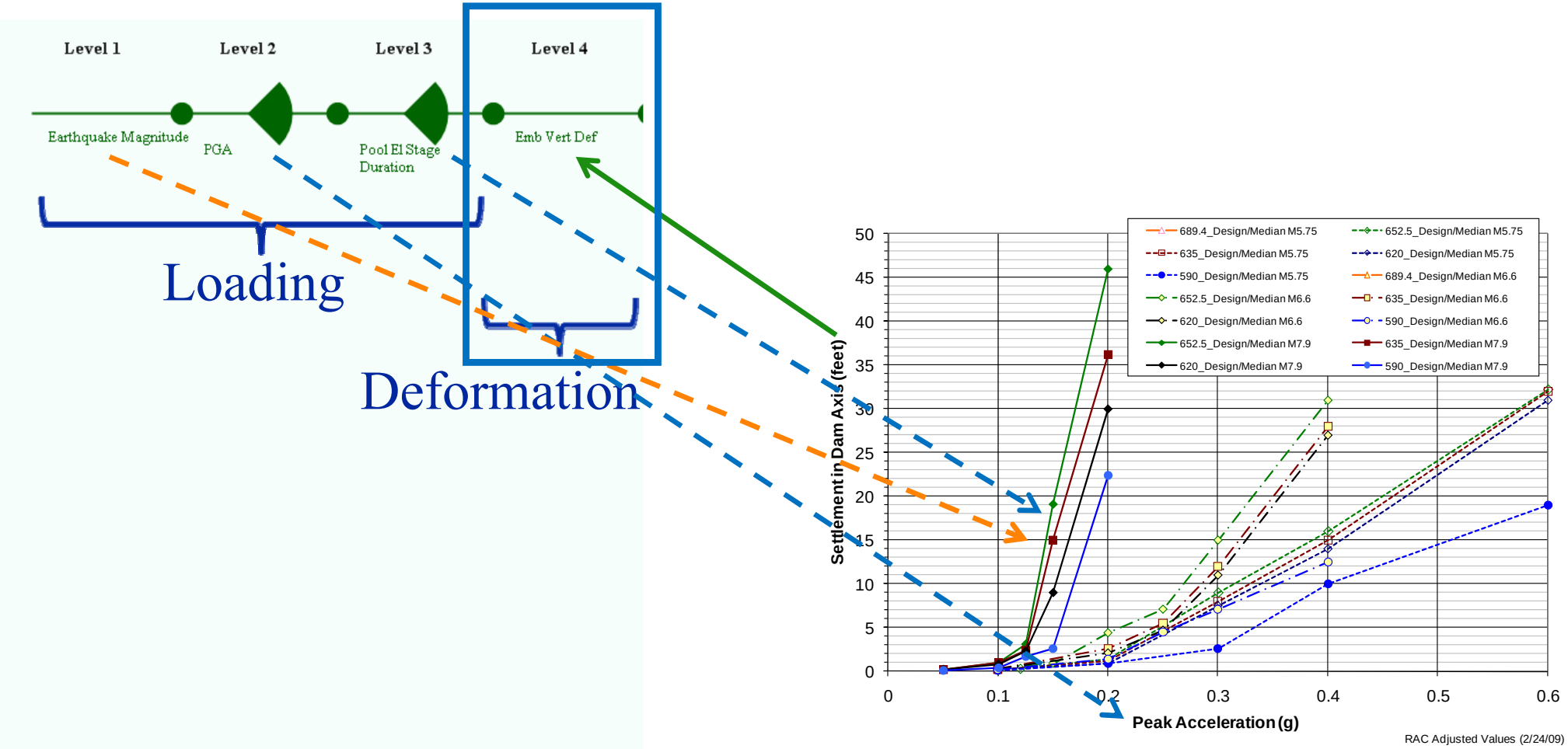
Earthquake Event Tree

For < M6.5, M6.5 – 7 & > M7

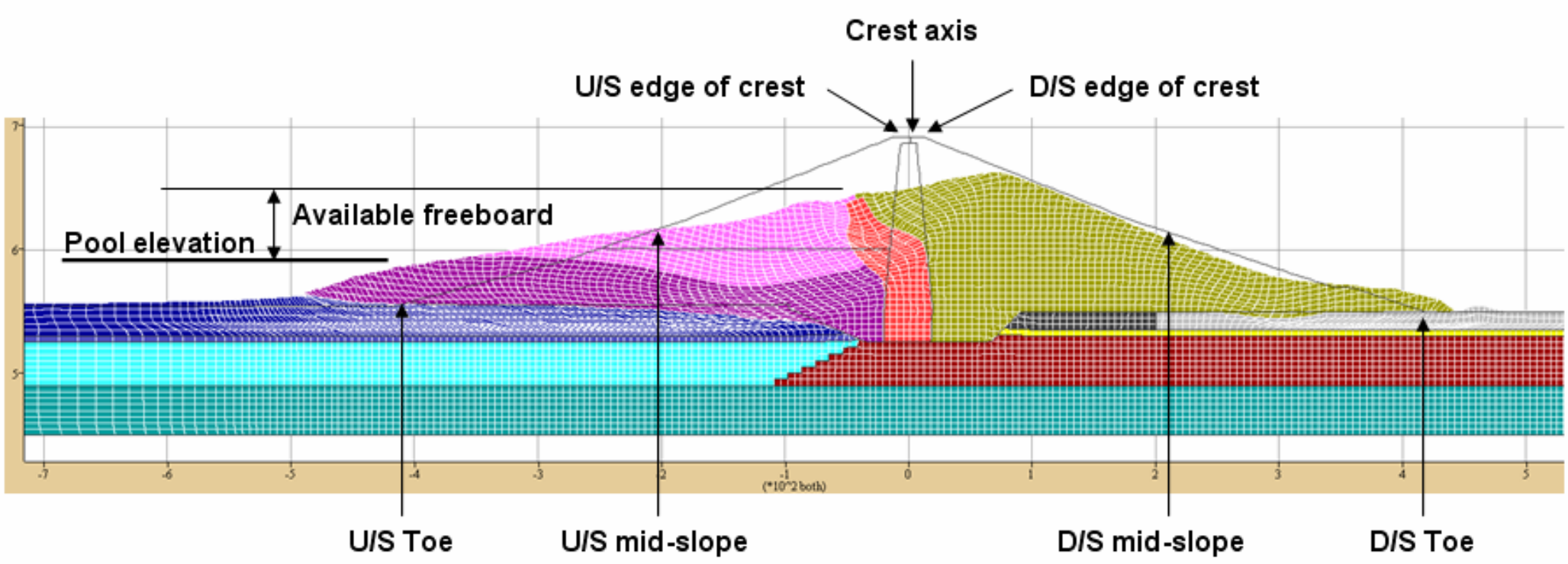


Earthquake Event Tree

For < M6.5, M6.5 – 7 & > M7

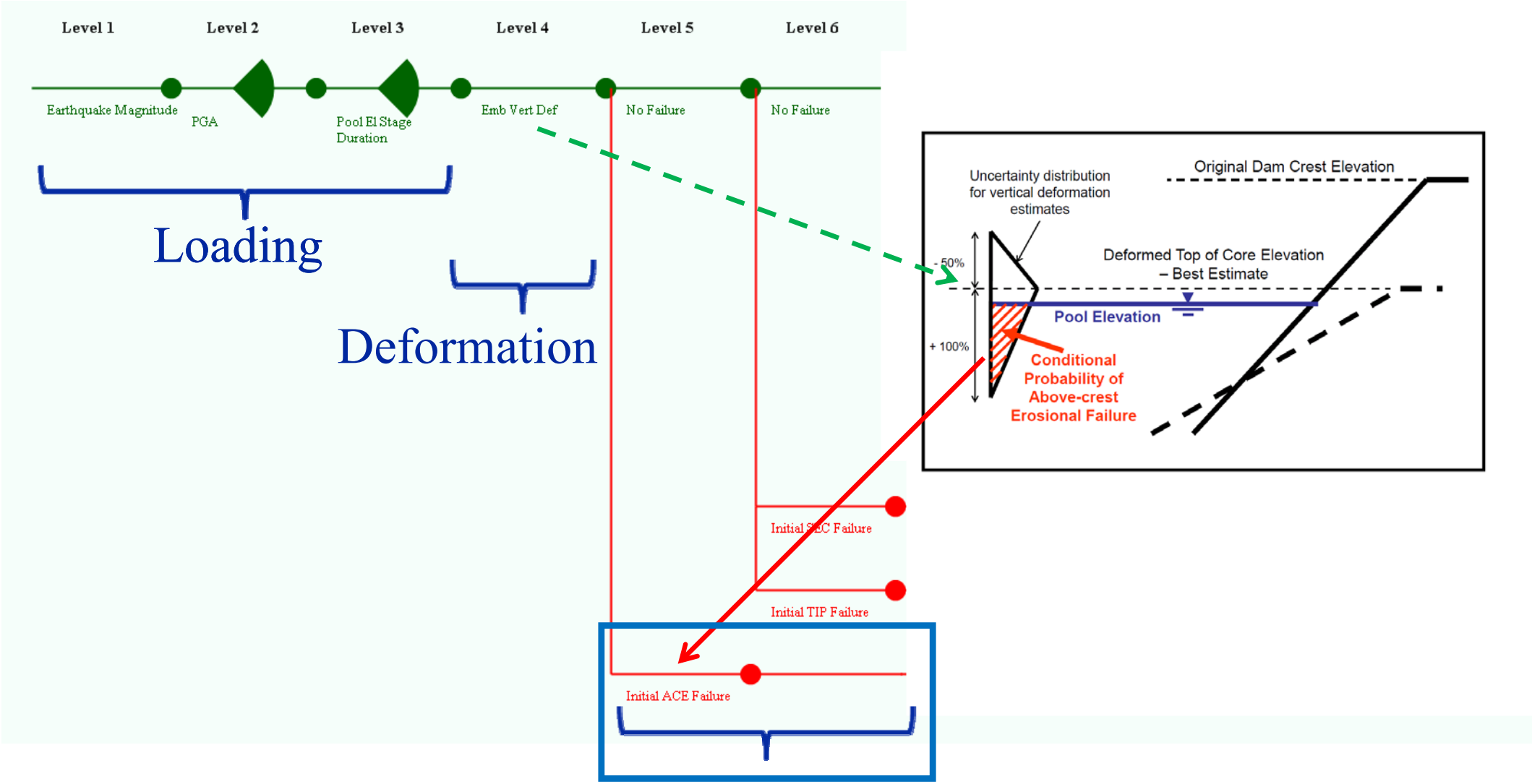


Above-Core Erosion (ACE) Failure Mode

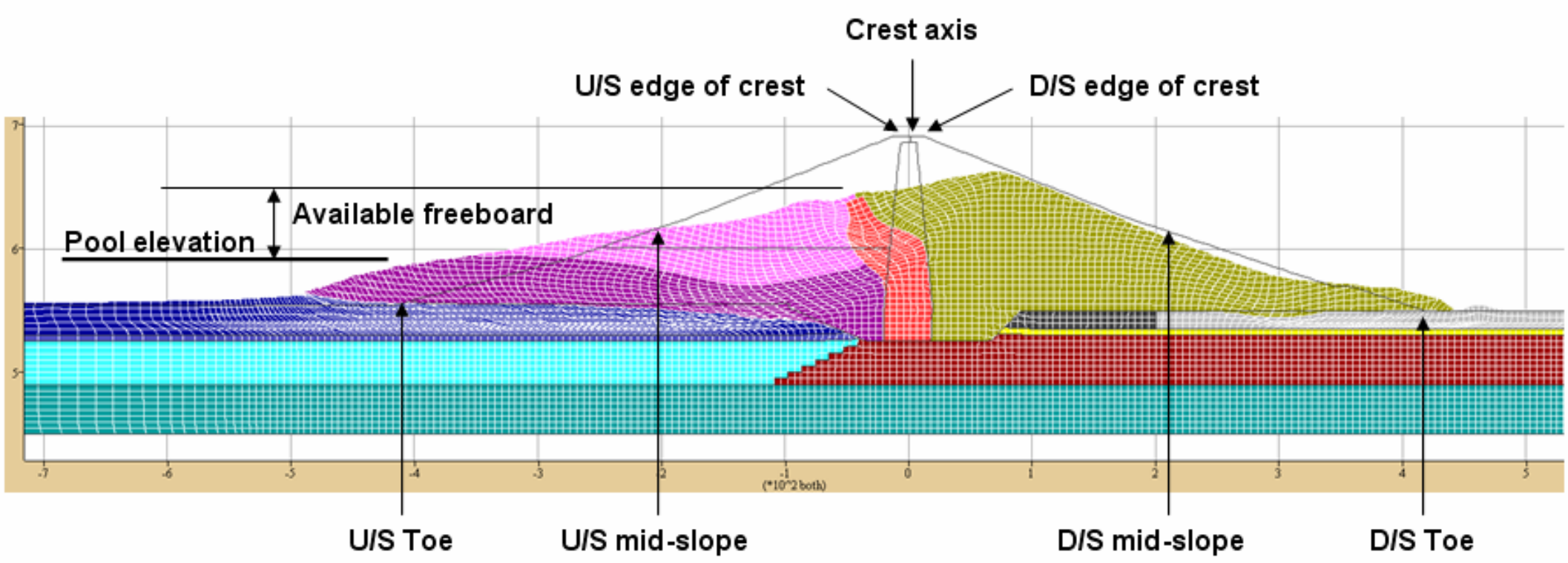


Earthquake Event Tree

For < M6.5, M6.5 – 7 & > M7



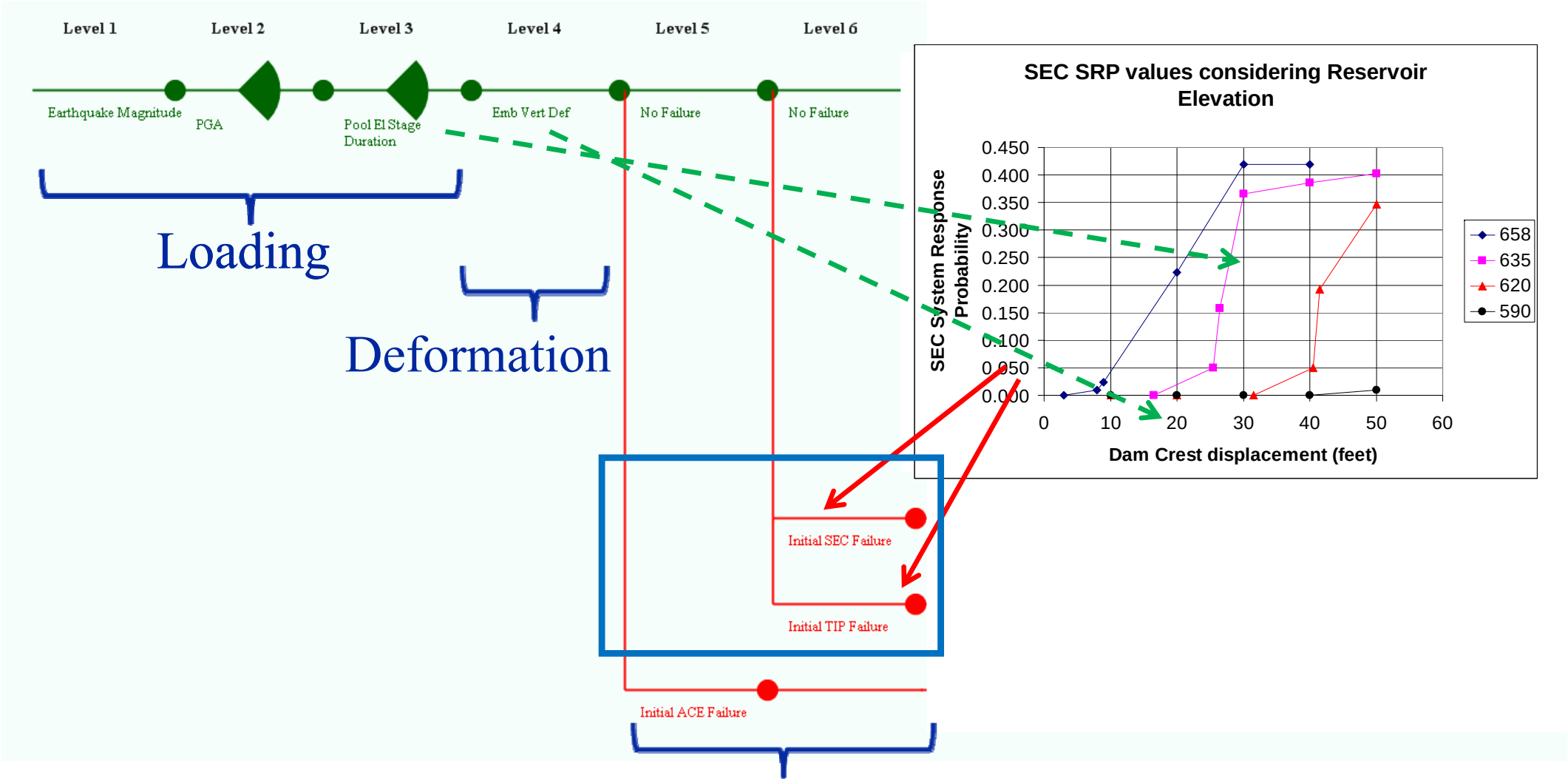
Seepage Erosion through Cracks (SEC) and Tower-induced Piping (TIP) Failure Modes



- Used Event Tree Method Guided by the USACE Piping and Seepage Toolbox
- All estimates made by Engineering Team
- Loss of Outlet control

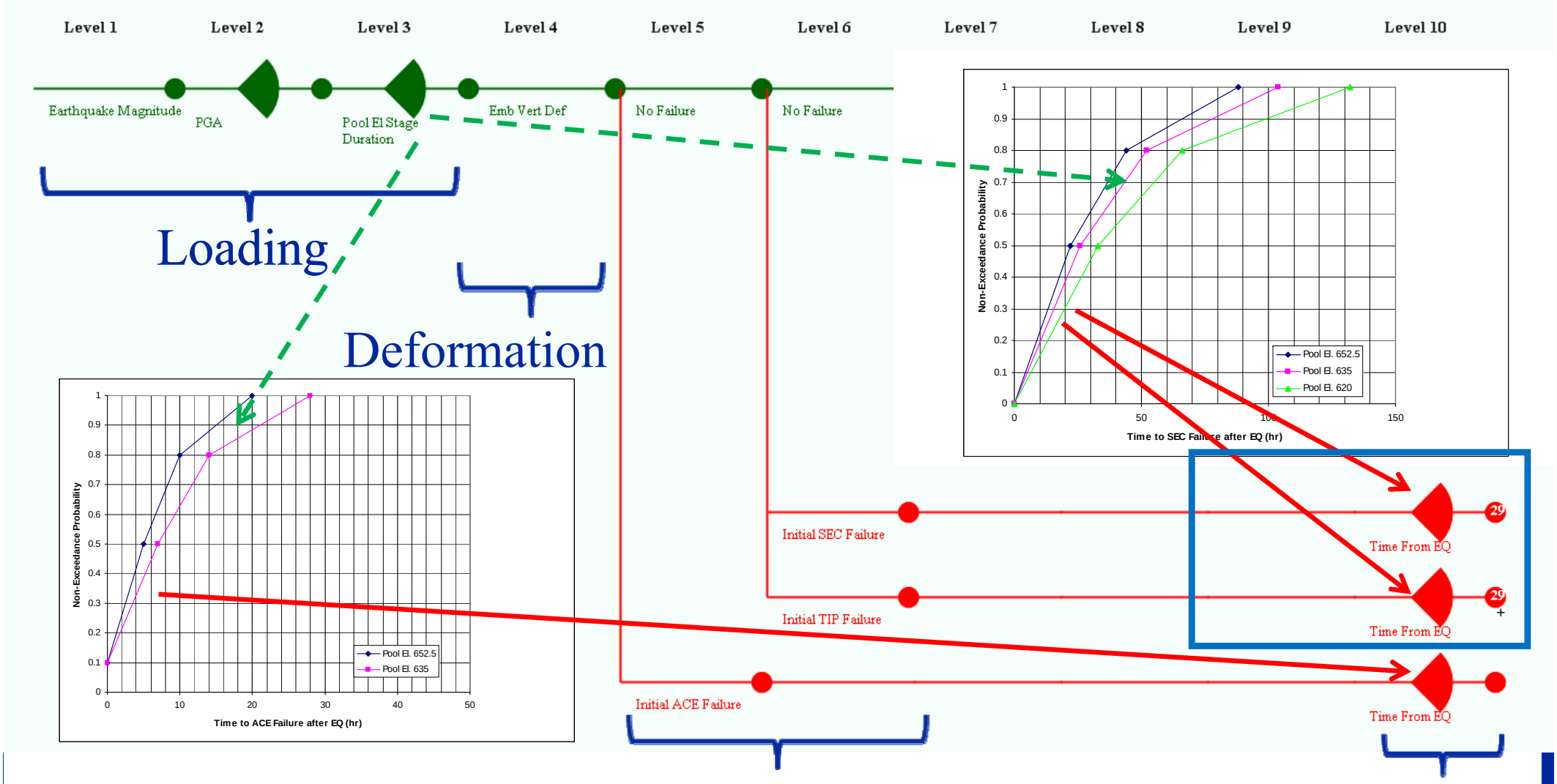
Earthquake Event Tree

For < M6.5, M6.5 – 7 & > M7



Earthquake Event Tree

For < M6.5, M6.5 – 7 & > M7

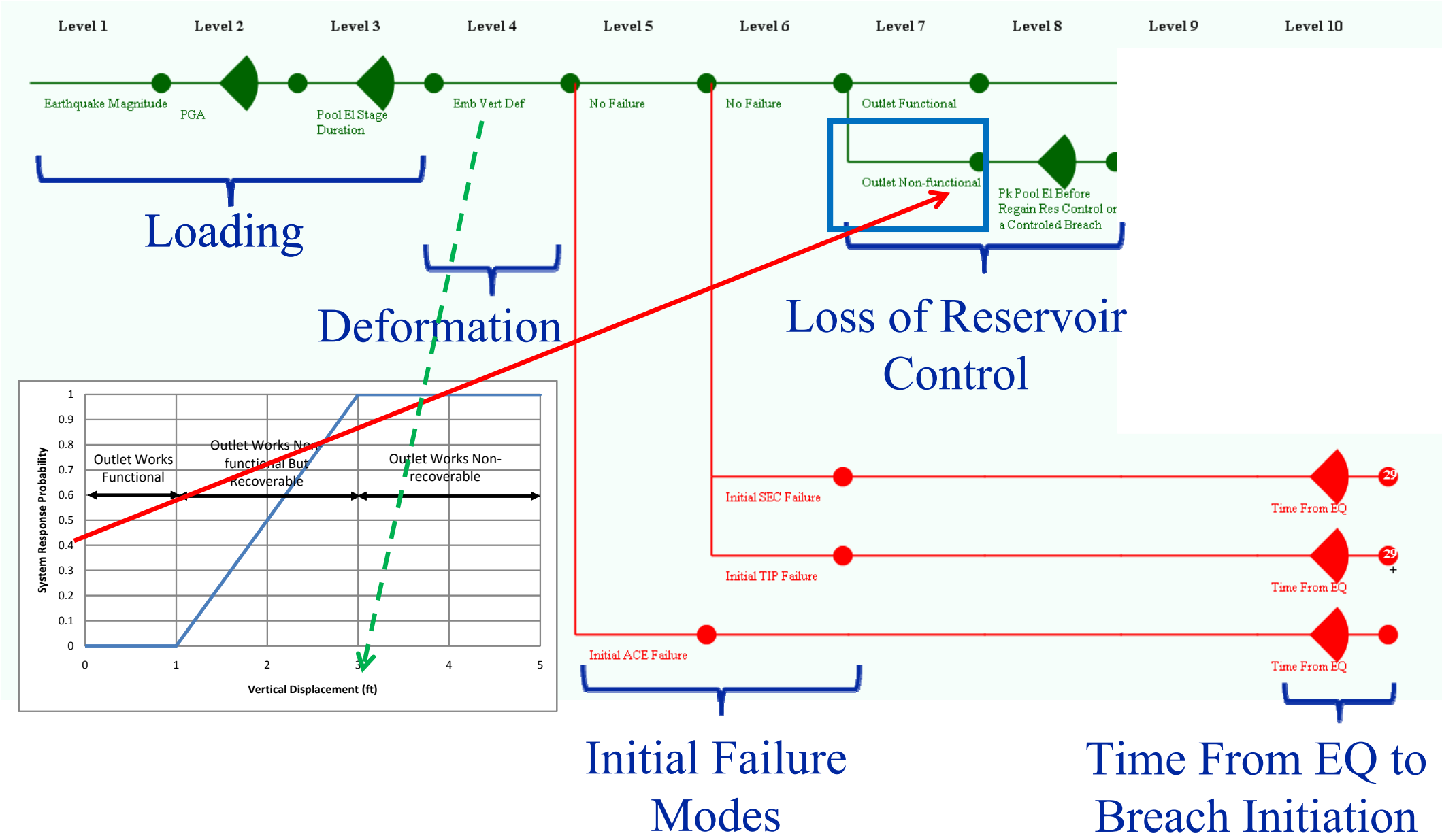


Initial Failure Modes

Time From EQ to Breach Initiation

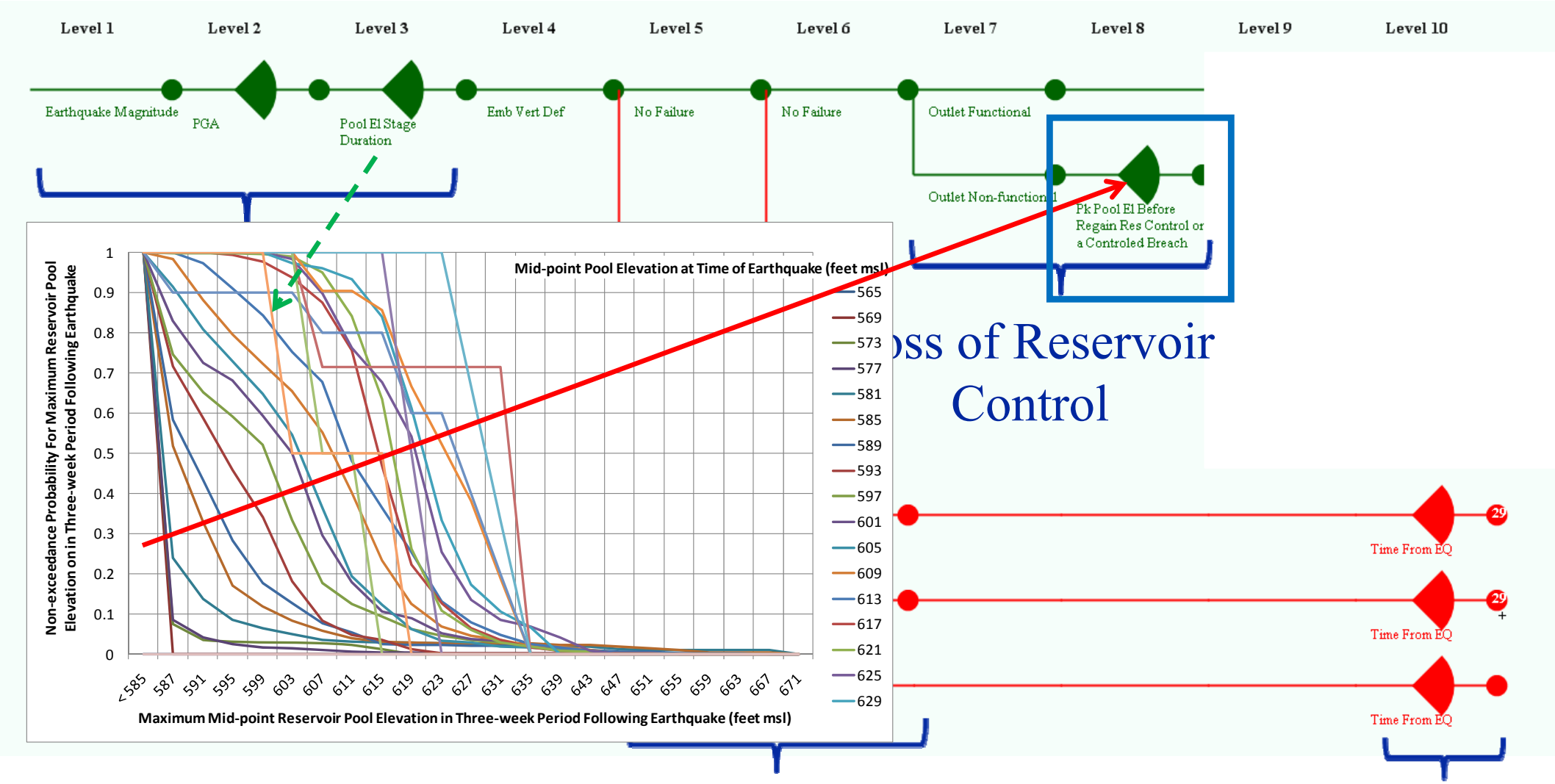
Earthquake Event Tree

For < M6.5, M6.5 – 7 & > M7



Earthquake Event Tree

For < M6.5, M6.5 – 7 & > M7



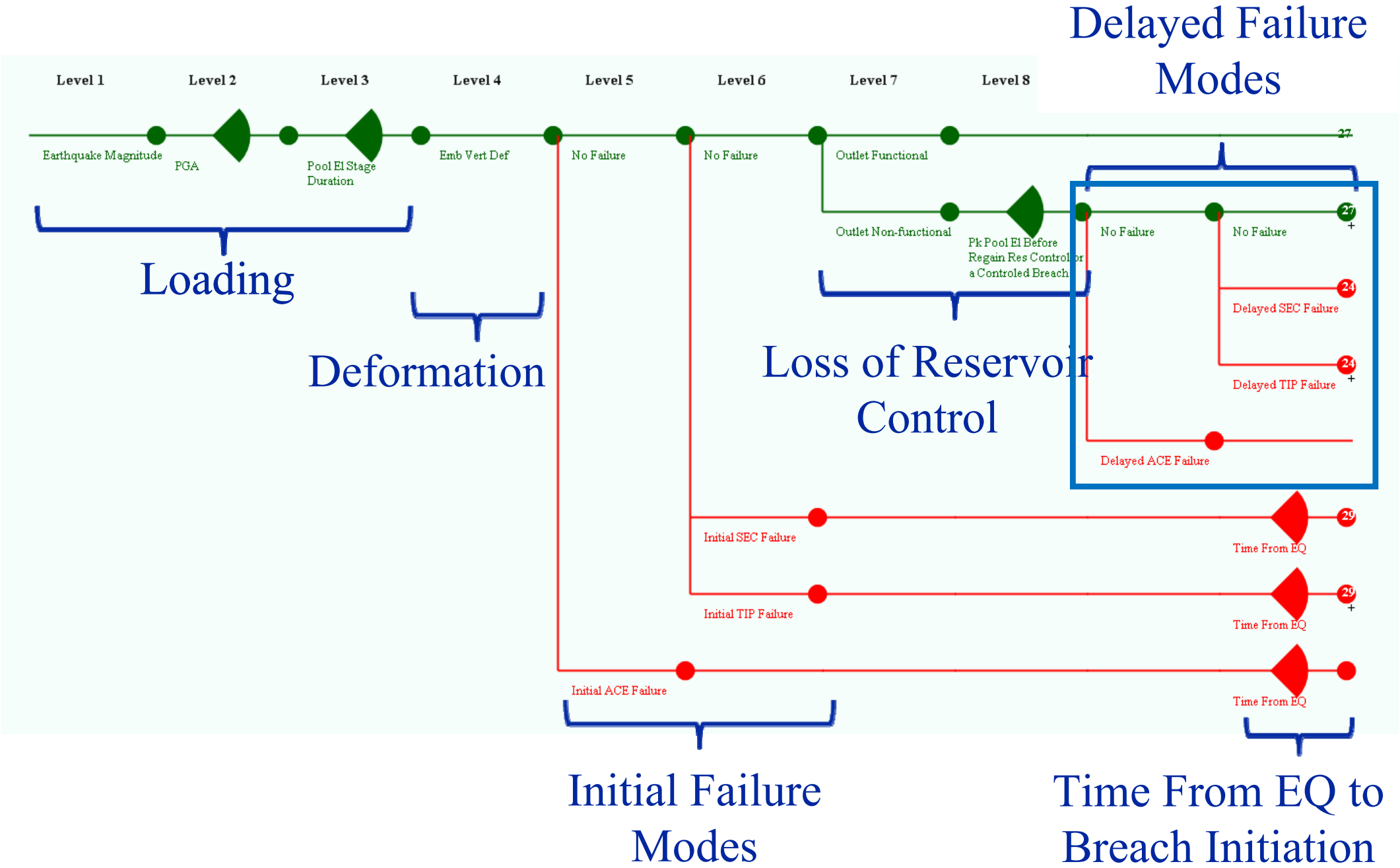
Loss of Reservoir Control

Initial Failure Modes

Time From EQ to Breach Initiation

Earthquake Event Tree

For < M6.5, M6.5 – 7 & > M7



Estimated Life Loss

Earthquake Failure Modes

Breach-Inundation Case	Failure Modes	Exposure Case	Warning Time Adjustment (ΔWT) (mins)	Total (1 + 4 + 6)		Average Fatality Rate
				PAR	Life Loss	
E.590	SEC, TIP and ACE	Day	> 200	48,508	9.4	0.0002
		Night	> 200		9.4	0.0002
E.630	SEC, TIP and ACE	Day	> 200	49,485	9.9	0.0002
		Night	> 200		9.9	0.0002
E.FP	SEC, TIP and ACE	Day	-30	61,821	310.4	0.0050
		Night	-60		599.4	0.0097
	SEC, TIP and ACE	Day	90	61,821	195.7	0.0032
		Night	60		203.9	0.0033
	SEC, TIP and ACE	Day	> 200	61,821	18.7	0.0003
		Night	> 200		18.7	0.0003
	ACE	Day	-45	61,821	451.4	0.0073
		Night	-60		599.4	0.0097

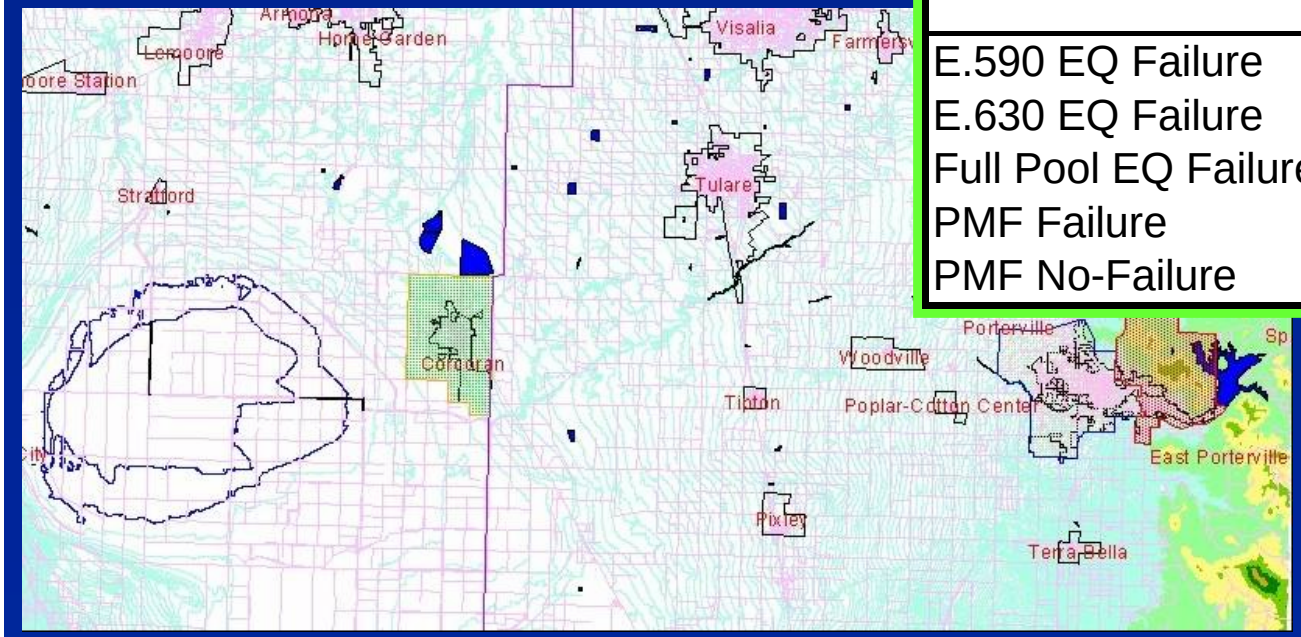
Flood and Flood-internal Failure Modes and Flood No Failure

Breach-Inundation Case	Failure Modes	Exposure Case	Warning Time Adjustment (ΔWT) (mins)	Total		Average Fatality Rate
				PAR	Life Loss	
F.PMF	All Flood & Flood-internal	Day	> 200	115,176	27.5	0.0002
		Night	> 200		27.5	0.0002
F.FP		Day	> 200	61,821	12.4	0.0002
		Night	> 200		12.4	0.0002
F.630		Day	> 200	49,485	9.9	0.0002
		Night	> 200		9.9	0.0002
F.590		Day	> 200	48,508	9.4	0.0002
		Night	> 200		9.4	0.0002
F.PMF NF	No Failure	Day	> 200	56,793	12.8	0.0002
		Night	> 200		12.8	0.0002
F.FP NF		Day	> 200	Not available	0.0	0.0000
		Night	> 200		0.0	0.0000
F.630 NF		Day	> 200	Not available	0.0	0.0000
		Night	> 200		0.0	0.0000
F.590 NF		Day	> 200	Not available	0.0	0.0000
		Night	> 200		0.0	0.0000

Economic Consequences of Dam Failure

Estimated flood damages to agricultural lands in Tulare Lakebed

Breach Case	Breach Run	Flood Damages ($M)
E.590 EQ Failure	E.590	7
E.630 EQ Failure	E.630	14
Full Pool EQ Failure	E.FP	31
PMF Failure	F.PMF	56
PMF No-Failure	F.PMF NF	45



Estimated economic damages ($M) to agriculture and structures

Breach Case	Consequence Center				
	2) Eastern Porterville Area	3) Western Porterville Area	4) Tulare County	5) Corcoran	6) Kings County
E.590	187	59	264	0.6	7.6
E.630	560	91	669	0.7	15
E.FP	625	74	725	1.0	33
F.PMF	895	125	1,051	3.0	3.2
F.PMF NF	421	91	529	0.8	0.9

USACE Tolerable Risk Guidelines

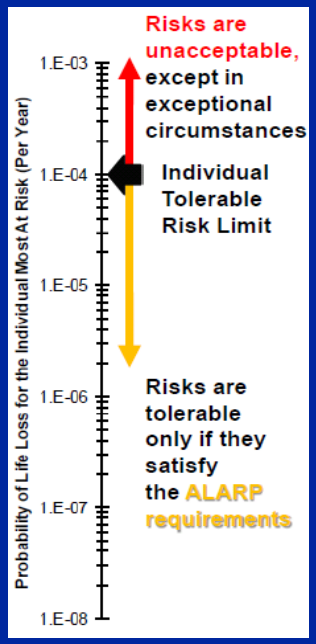
- Existing Dams

A) LIMIT GUIDELINES that should not be exceeded regardless of cost except in exceptional circumstances:

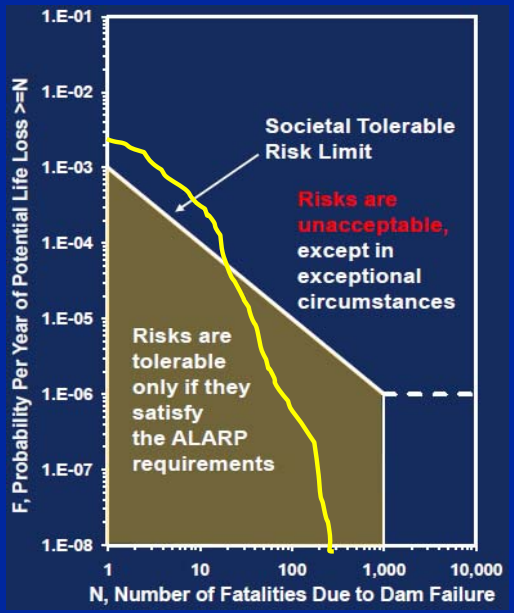
1) Annual Probability of Failure (APF) < 1 in 10,000 per yr

2) Individual Risk (IR) - Probability of life loss for the most exposed individual

= APF if assume 24x7 presence below dam



3) Societal Risk (SR) - A probability distribution (F-N chart) of the number of fatalities from entire PAR



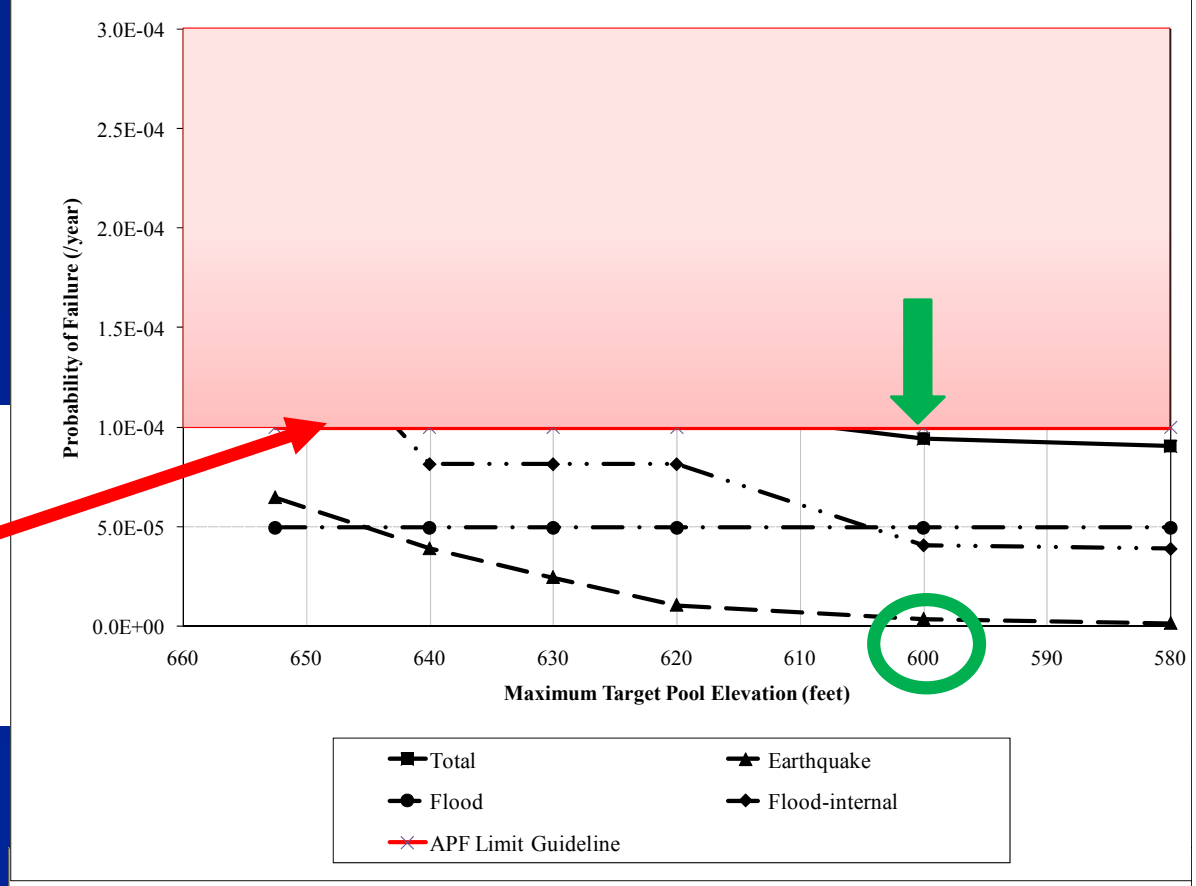
4) Annualized Life Loss (ALL) – Av. annual life loss < 0.001 lives/yr

B) ALARP (As Low As Reasonably Practicable) considerations:

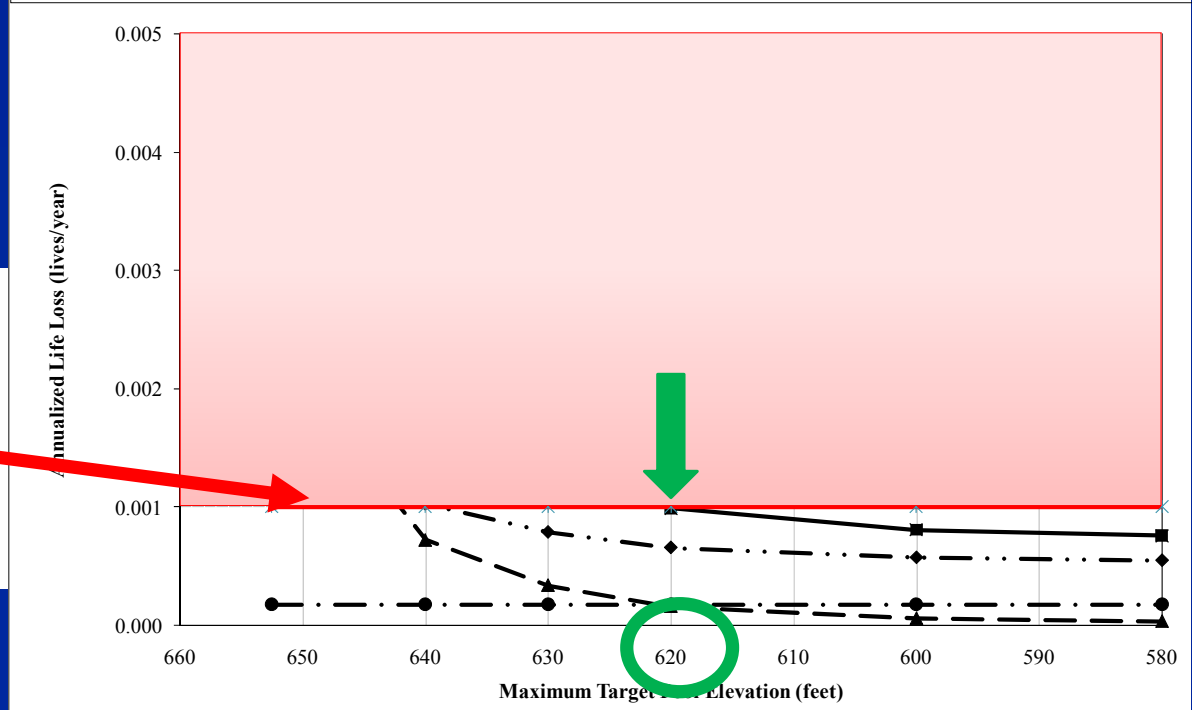
1) Level of risk compared with Limit Guidelines; 2&3) Cost effectiveness of further risk reduction below the Limit Guidelines (BCR, CSSL, Disproportionality); 4) Essential USACE guidelines; and 5) Consultation.

USACE 1) APF & 2) ALL Tolerable Risk Limit Guidelines

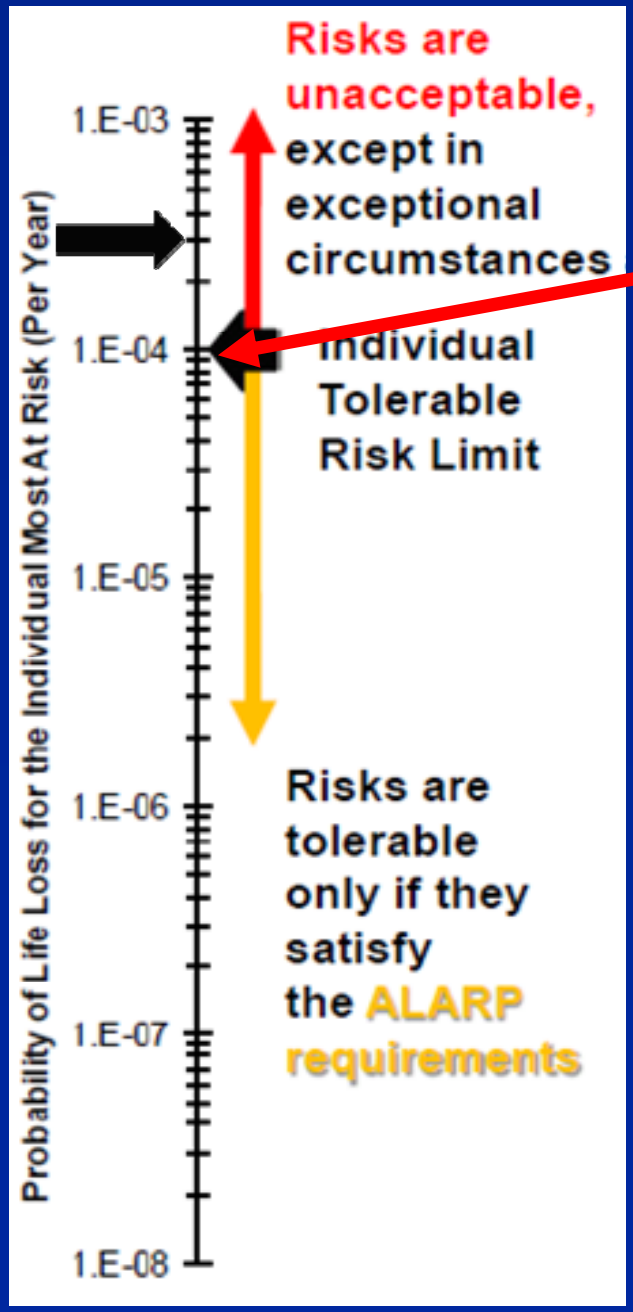
APF Limit: 1 in 10,000/year



ALL Limit: 0.001 lives/year



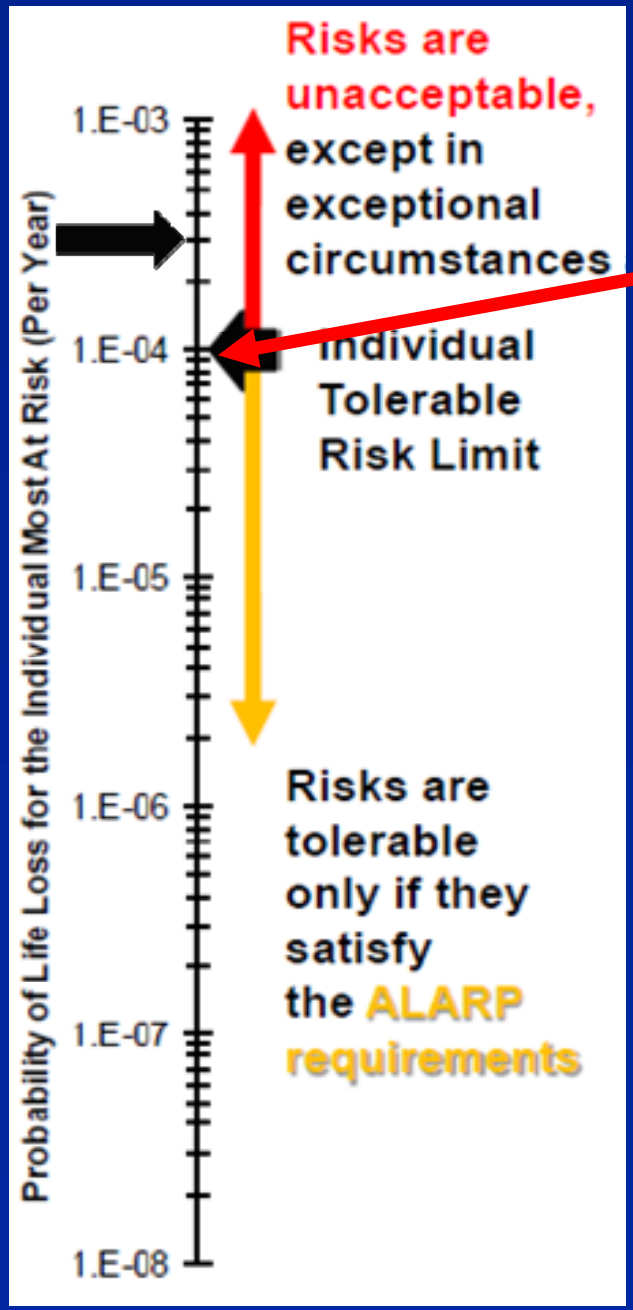
USACE 3) Individual Tolerable Risk Limit Guideline for Existing Dams



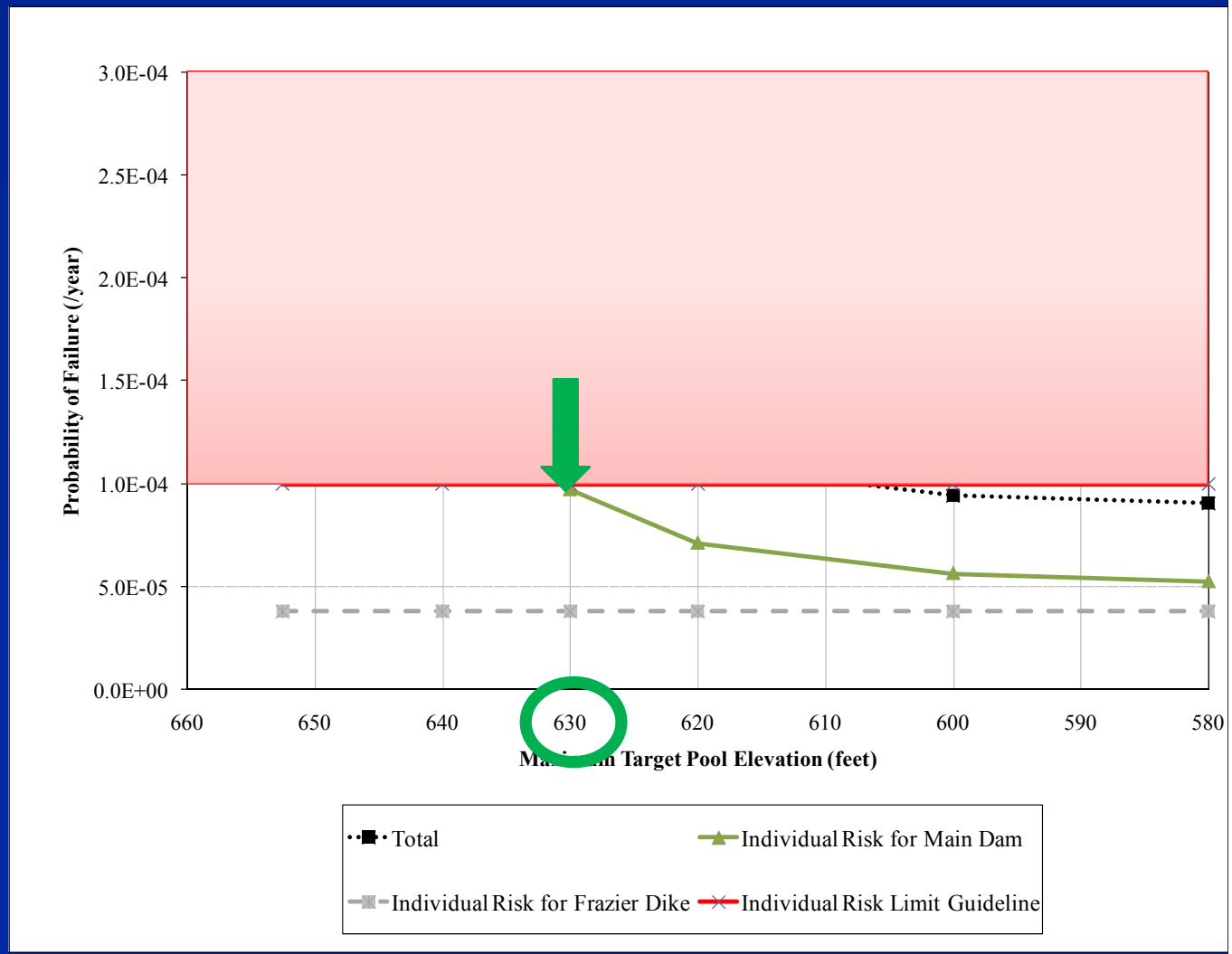
Individual Risk Limit:
1 in 10,000/year

Probability of life loss for the most exposed individual

USACE 3) Individual Tolerable Risk Limit Guideline for Existing Dams



Individual Risk Limit: 1 in 10,000/year



USACE APF & ALL Tolerable Risk Limit Guidelines

APF Limit: 1 in 10,000/year

ALL Limit: 0.001 lives/year

USACE 4) Societal Risk Limit Guideline for Existing Dams – No Restriction

A probability distribution (F-N chart) of the number of fatalities from entire PAR

USACE 4) Societal Risk Limit Guideline for Existing Dams – All ORs

A probability distribution (F-N chart) of the number of fatalities from entire PAR

Decision Options Matrix

(1)	(2)	(3.1)	(3.2)	(3.3)	(4.1)	(4.2)	(4.3)	(4.4)	(5.1)	(5.2)	(5.3)	(5.4)
DECISION OPTION: OPERATING RESTRICTION ALTERNATIVE (Reservoir Volume at Maximum Target Reservoir Pool Elevation as Percent of Normal Capacity)	**CHARACTERIZATION OF DECISION OPTION**	**ESTIMATED RESIDUAL DAM FAILURE RISK AS PERCENT OF NO RESTRICTION RISK**			**EVALUATION AGAINST PROPOSED USACE TOLERABLE RISK GUIDELINES**				**ANNUAL AVERAGE ESTIMATED IMPACT COSTS** (Range of Estimated Annual Impact Costs)			
		TOTAL Annual Probability of Failure (APF)	**TOTAL Annualized Life Loss (ALL)**	**TOTAL Risk Cost (RC)**	**TOTAL Annual Probability of Failure (APF)**	**TOTAL Individual Risk (IR)**	**TOTAL Societal Risk (SR)**	**TOTAL Annualized Life Loss (ALL)**	**Impact on Agricultural Water Users**	**Flood Damages in Tulare Lakebed**	**Impact on Recreation**	**Total**
		(/year)	Life Loss x Probability (lives/year)	Dam Failure Damages x Probability ($M/year)	Total Probability of Failure for all Failure Modes < 1 in 10,000 /year	Probability of Life Loss for the Identifiable Person(s) Most At Risk for all Failure Modes < 1 in 10,000 /year	Probability of Exceeding Various Magnitudes of Random Life Loss < A Limit of Tolerability in Figure 2.4-3b	Total Annualized Life Loss for all Failure Modes < 0.001 lives/year	($M/year)	($M/year)	($M/year)	($M/year)
No Restriction (100% Normal Capacity)	**a) Estimated not to meet any of the proposed USACE Tolerable Risk Limit Guidelines. b) Disregards the justification for operating restrictions. c) Poor defensibility. d) Likely would not be well received by the public who are at risk from failure of Success Dam.**	100% (1 in 3,600 /year)	100% (0.0046 lives/year)	100% ($0.17 M/year)	**UNACCEPTABLE except in exceptional circumstances**	**UNACCEPTABLE except in exceptional circumstances**	**UNACCEPTABLE except in exceptional circumstances**	**UNACCEPTABLE except in exceptional circumstances**				
OR.640 (68% Normal Capacity)		61% (1 in 5,900 /year)	41% (0.0019 lives/year)	52% ($0.087 M/year)	**UNACCEPTABLE except in exceptional circumstances**	**UNACCEPTABLE except in exceptional circumstances**	**UNACCEPTABLE except in exceptional circumstances**	**UNACCEPTABLE except in exceptional circumstances**	$0.4M ($0 - $3.0M)	$0.6M ($0 - $3.1M)	$2.1M	$3.1M
OR.630 (50% Normal Capacity)	**a) Estimated to meet the proposed USACE Societal Risk and Individual Risk Limit Guidelines without full consideration of Frazier Dike. b) Estimated to achieve about a 70% reduction in annualized life loss. c) Estimated to achieve about a 50% reduction in the probability of failure.**	48% (1 in 7,400 /year)	28% (0.0013 lives/year)	37% ($0.062 M/year)	**UNACCEPTABLE except in exceptional circumstances**	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	**UNACCEPTABLE except in exceptional circumstances**	$1.0M ($0 - $2.2M)	$0.6M ($0 - $3.1M)	$2.1M	$3.7M
OR.620 (35% Normal Capacity)	**a) Estimated to meet the proposed USACE Societal Risk, Individual Risk, and Annualized Life Loss Limit Guidelines without full consideration of Frazier Dike. b) Estimated to achieve about an 80% reduction in annualized life loss. c) Estimated to achieve about a 60% reduction in the probability of failure.**	39% (1 in 9,100 /year)	21% (0.0010 lives/year)	26% ($0.044 M/year)	**UNACCEPTABLE except in exceptional circumstances**	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	$1.4M ($0 - $3.0M)	$0.6M ($0 - $3.2M)	$2.8M	$4.9M
OR.600 (16% Normal Capacity)	**a) Least restrictive operating restriction alternative that is estimated to meet all proposed USACE Tolerable Risk Limit Guidelines without full consideration of Frazier Dike. b) Estimated to achieve more than an 80% reduction in annualized life loss. c) Estimated to achieve about a 65% reduction in the probability of failure.**	34% (1 in 10,600 /year)	17% (0.0008 lives/year)	21% ($0.035 M/year)	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	$2.4M ($0.9M - $3.8M)	$1.5M ($0 - $7.5M)	$2.8M	$6.7M
OR.580 (5% Normal Capacity)	**a) Meets all proposed USACE Tolerable Risk Limit Guidelines without full consideration of Frazier Dike. b) Poor justification to further reduce the risk from OR.600 to OR.580 based on an extremely large incremental Disproportionality Ratio and very small incremental Benefit/Cost Ratio. c) Estimated to achieve more than an 80% reduction in annualized life loss. d) Estimated to achieve about a 65% reduction in the probability of failure.**	32% (1 in 11,000 /year)	16% (0.0008 lives/year)	19% ($0.032 M/year)	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	**TOLERABLE providing all ALARP considerations are met on an on-going basis**	$3.1M ($1.1M - $4.8M)	$1.9M ($0 - $9.4M)	$2.8M	$7.7M

USACE ALARP Considerations

Determining that ALARP is satisfied is ultimately a matter of judgment considering:

1) The level of risk in relation to the tolerable risk limit;
2) The disproportion between the sacrifice (money, time, trouble and effort) in implementing the risk reduction measures and the subsequent risk reduction achieved;
3) The cost-effectiveness of the risk reduction measures;
4) Compliance with essential USACE guidelines; and
5) Societal concerns as revealed by consultation with the community and other stakeholders.

Disproportionality Ratio, R

HSE "Proportion Factor"

R = CSSL/WTP

CSSL = Cost per Statistical Life Saved ($/life saved)

= The **COST** (economic impact cost of an OR) of saving a statistical life based on the reduction in annualized life loss estimated for an OR

WTF = Willingness To Pay for reducing annualized life loss *(VSL = Value of saving a life)* ($/life saved)

= A means of valuing the safety **BENEFIT**

- USDOT VSL: US$6.0M ($3.4M - $8.6M) (2009$)
  - Standard deviation of $2.4M
  - OMB VSL: $5M – $6.5M (2008$)

Justification for implementing the next more stringent OR – Only applies to ORs that meet all Limit Guidelines

USACE ALARP Justification for Risks just below the Tolerable Risk Limit

ALARP Justification Rating	Range of Disproportionality Ratios	
	Greater than or equal to	Less than
Very Strong	Zero	1
Strong	1	4
Moderate	4	20
Poor	20	

Incremental Risk Reduction	Incremental Total Impact Cost	Incremental Cost per Statistical Life Saved (CSSL)	Incremental Benefit/Cost Ratio	Incremental Disproportionality Ratios (R = CSSL/WTP)		
				Lower WTP	Best WTP	Upper WTP
				$3.4M/life saved	$6.0M/life saved	$8.6M/life saved
From NR to OR.640	*$3,128,000*	*$1,120,320,215*	*0.026*	*330*	*187*	*130*
From OR.640 to OR.630	*$550,000*	*$844,565,359*	*0.045*	*248*	*141*	*98*
From OR.630 to OR.620	*$1,204,000*	*$3,845,111,105*	*0.015*	*1,131*	*641*	*447*
From OR.620 to OR.600	*$1,861,600*	*$9,974,439,646*	*0.005*	*2,934*	*1,662*	*1,160*
From OR.600 to OR.580	**$990,315**	**$20,208,132,439**	**0.002**	**5,944**	**3,368**	**2,350**

USDOT (2009) WTP: US$6.0M ($3.4M - $8.6M) (2009$)

Comparison with 2004 Study Results – No Restriction

- **Decrease in Earthquake (and Total) probabilities of failure** – net effect of:
  - **Lower deformation** estimates for OBE analysis.
  - **Higher estimates of ACE SRP** for MCE and wider uncertainty range for FLAC predictions of vertical deformations that lead to a probability of lower elevations for the deformed dam crest.
  - **Lower estimates of SEC SRPs** based on advisory panel input on crack depth and new USACE Piping and Seepage Toolbox.
  - **Addition of TIP failure mode** for piping into rupture in the control tower - outlet works system.
  - **Addition of delayed ACE, TIP and SEC Earthquake-induced failure modes** to account for increase in reservoir pool as a result of the loss of reservoir control.

Comparison with 2004 Study Results – No Restriction (cont'd)

- **Increases in Flood and Flood-internal probabilities of failure**:
  - **Increase in AEP assigned to PMF** from 10^{-5} /yr to 10^{-4} /yr based on USACE guidance.
  - **Increase of about one-foot in the PMF peak reservoir pool elevation**.
  - **Exclusion of most Frazier Dike failure modes** - omitting piping failure modes reduces the total estimated probability of failure for the Success Project, but increases the Flood-internal probability of failure for the Main Dam.
  - **Increase in some piping SRPs** due to lower threshold pool elevation, new information about the conditions in the left and right abutment areas and in the foundation, and using the USACE Piping and Seepage Toolbox.

Comparison with 2004 Study Results – No Restriction (cont'd)

- **Decrease** in life loss and annualized life loss:
  - Decreases in estimated life loss due to **longer estimates of times from the occurrence of earthquake to initiation of an ACE, SEC or TIP breach**.
  - Reductions in the estimated probability of failure.

4) Limitations, Decisions, Risk Communication and Lessons Learned

Limitations

- Identified failure modes and SRP estimates based on team's knowledge, experience and interpretations of available information and analyses – no other options.
- RA scope based on the RA purpose and the significance for the decisions on operating restrictions – expanded following ATR but no significant effect:
  - Add all credible and significant failure modes and associated consequences for the Frazier Dike in Issue Evaluation Study (IES) and Dam Safety Modification Study (DSMS) RAs.
- Approximate extrapolation of peak reservoir pool elevation - AEP relationship:
  - Refine using the USACE HH&C CoP recommended procedure "based on the volume duration frequency relationship with balanced hydrographs for the extrapolated volumes routed through the dam with due consideration for overtopping discharge."

Limitations (cont'd)

- Consequences:
  - Two-dimensional inundation modeling should provide an improved basis for consequences estimation.
  - Modified-Graham life-loss estimates – will be improved using LIFESim model or its simplified version in HEC-FIA, as appropriate for the conditions below the Main Dam and Frazier Dike.
  - Estimates of economic consequences will be updated from 2004$.
- Permanent loss of project benefits associated with non-repairable damage to control tower not estimated for non-failure cases:
  - Should be estimated for non-dam failure cases and for controlled breach.
- Seasonal variation in OR not considered although likelihood of a flood changes seasonally.
- Sensitivity to successful intervention not considered.
- Uncertainties in some sensitive variables considered (deformation estimates and time to earthquake-induced failures)
  - Could expanded to include flood and earthquake loading and SRPs.

THE CORPS' DECISION

A temporary relaxation from OR.620 to OR.630 is likely with additional measures in place

- Least restrictive OR that meets all limit guidelines: ~ **OR.605**.
- However, **OR.630** is estimated to meet the Societal and Individual Risk limits, which are the most widely-used internationally, although not APF and ALL limits.
- More restrictive ORs not justified because increased impact costs are extremely disproportionate compared with their additional life-safety benefits.
- Additional measures (ALARP) are in process (e.g. community consultation, land acquisition, reverse-911 and improved warning and evacuation).

Risk Communication

- Decision makers briefed throughout
- Stakeholders (loss of benefits) briefed throughout the RA and subsequent OR decision process
- Stakeholders estimated their own impacts of ORs in 2004 Study
- Emergency Managers briefed

Lessons Learned

- Importance of holding life safety paramount in decision making
- Importance of team to identify PFMs and to estimates SRPs
- Importance of decision maker and stakeholder involvement throughout the RA process
- Importance of tailoring RA scope to RA purpose and not using a "canned approach"
  - E.g. importance of considering the variability in time to earthquake-induced breach failure
- Importance of updating RA and decision informed by RA when new information becomes available

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