RISK ASSESSMENT OF COUGAR DAM, McKENZIE RIVER, OREGON

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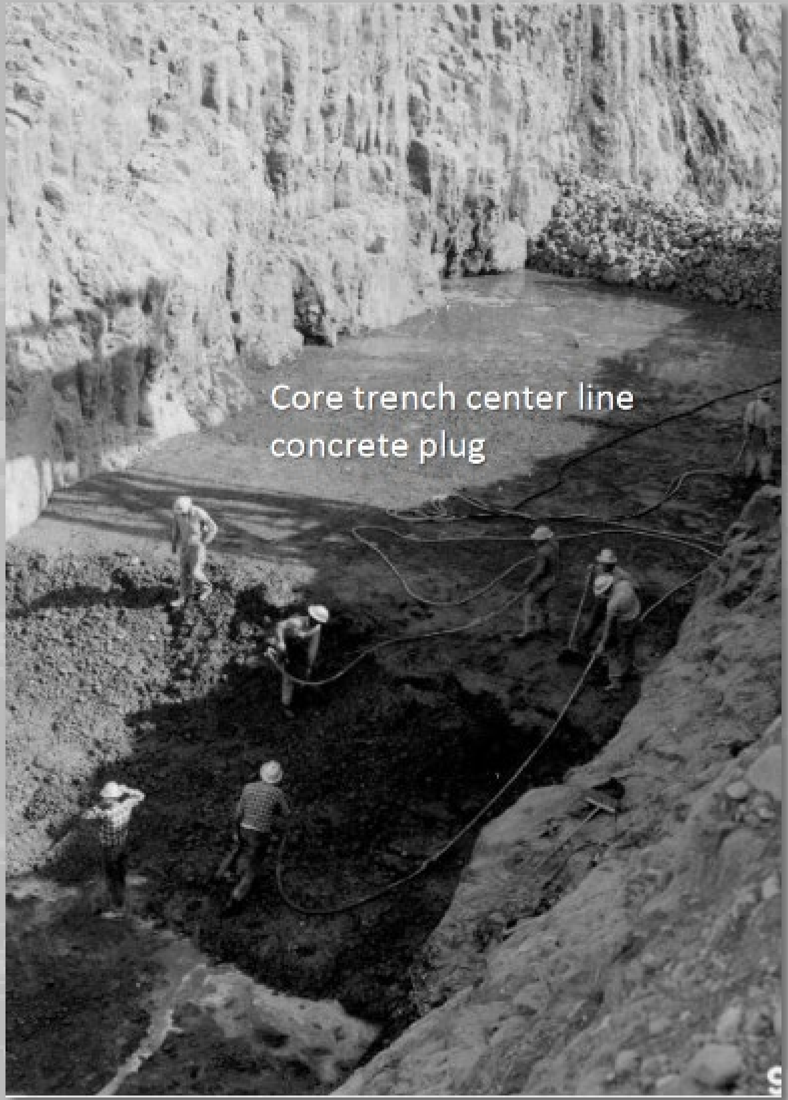
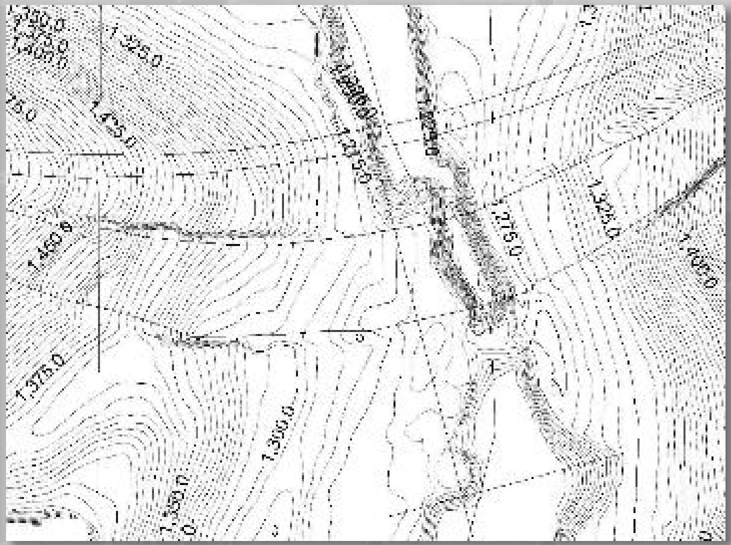
Date: 19 September 2019





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PRESENTATION OUTLINE

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- Project Background
- Risk Assessment
- Path Forward and Risk Reduction Measures

PROJECT BACKGROUND

PROJECT BACKGROUND

Located in the Willamette River Basin, NW Oregon

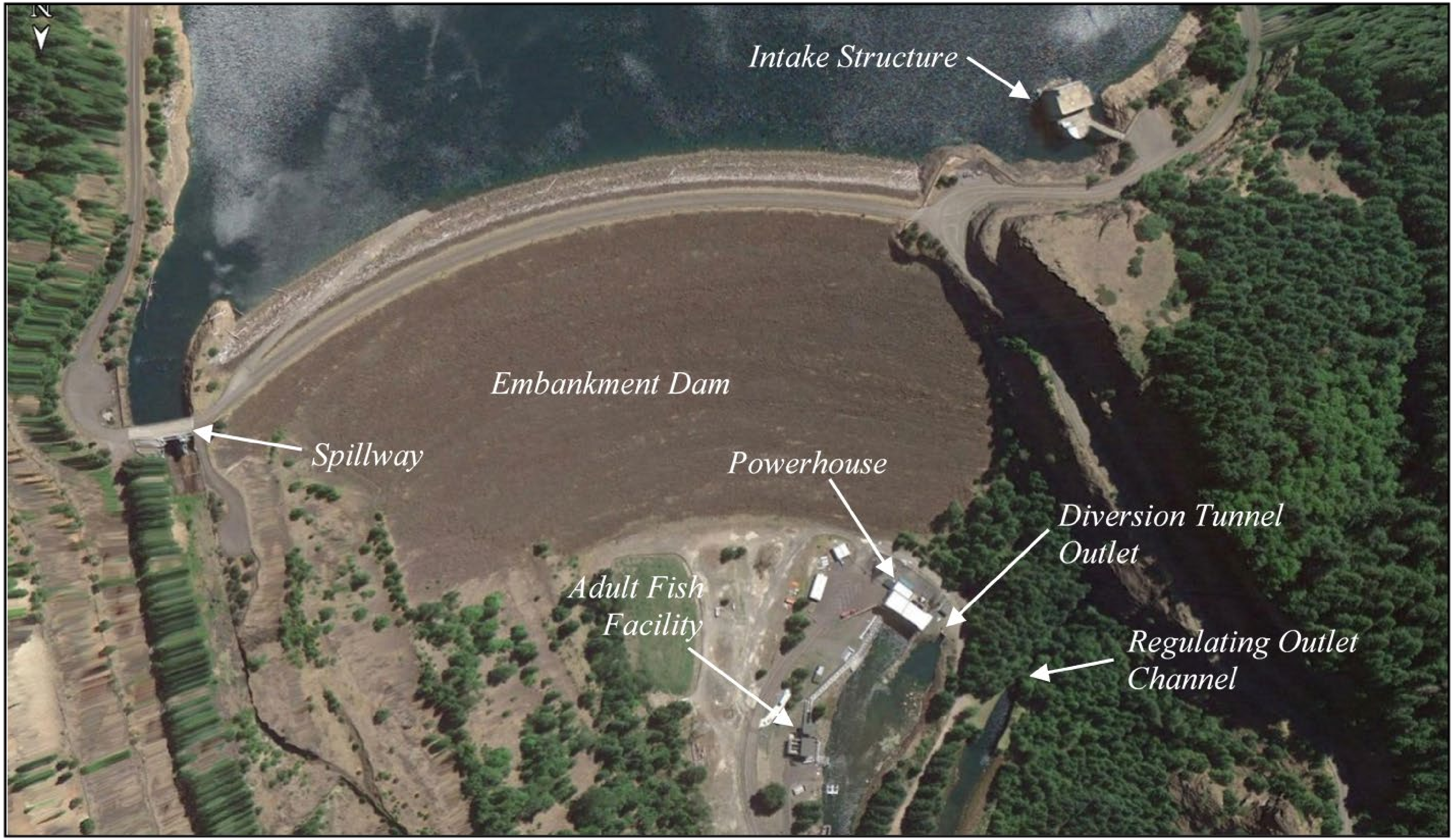
South Fork of the McKenzie River, 42 Miles East of Eugene/Springfield

Conservation Pool 189,000 acre-feet (summer) and 51,000 acre-feet (winter)

Purposes: Flood Risk Management, Hydropower, Water Quality, Water Supply

Constructed in 1963

PROJECT BACKGROUND



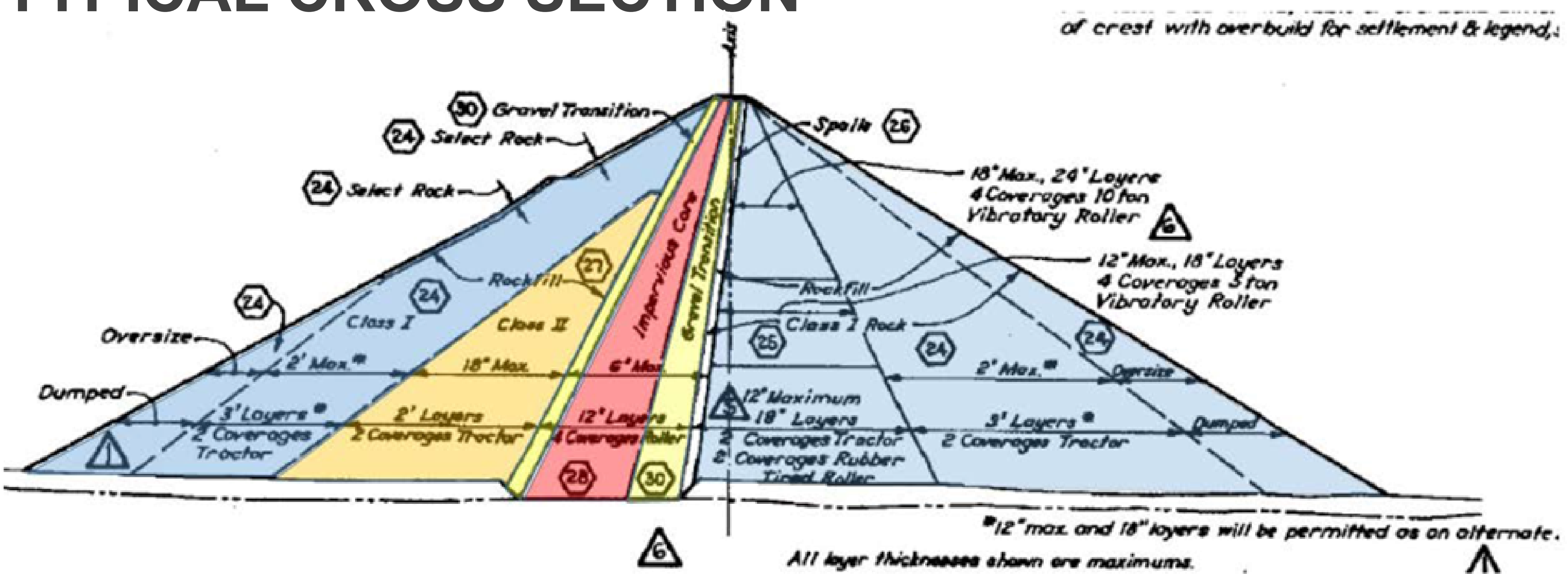
PROJECT BACKGROUND - STRUCTURES

Rockfill Embankment Dam	
Elevation Top of Dam, feet (NGVD29)	1,705 + Overbuild
Length, feet	1,600
Maximum Height, feet	519
Outlet Works (Tunnel)	
Type	13.5-ft tunnel
Size of Gates (Vertical Slide x2), feet	6.5 x 12.5
Design Discharge at Max Pool, cfs	12,050
Spillway (Gated Chute)	
Size of Gates (Tainter x2), feet	40 x 43.3
Design Discharge, ft^3/s	76,140
Gross Crest Length, feet	89
Crest Elevation, feet (NGVD29)	1,656.75
Power Plant	
Penstock (x1) Diameter, feet	10.5
Number of Generating Units	2
Rated Capacity, MW	25
Reservoir	
Minimum Power Pool, feet (NGVD29)	1,516
Minimum Flood Control Pool, feet (NGVD29)	1,532
Maximum Conservation Pool, feet (NGVD29)	1,690
Maximum Pool, feet (NGVD29)	1,699

Operations

Operated remotely from Lookout Point Dam approx. 55 miles or 1.25 hrs away

TYPICAL CROSS SECTION



Class I rockfill: unweathered basalt or andesite rock fragments with max diameter of 24” & <=15% passing the No. 4 sieve.

Class II rockfill: similar to Class I with <= 25% passing No. 4

Impervious core: rock fragments or gravel with sandy clay or sandy silt binder. Max size 6” (<=40% retained on 3” screen & >=25% passing No. 4)

Gravel transition: sandy gravel or silty sandy gravel with a max size of 6”

Spalls: max size 6 inches no more than 15% passing No. 4

Note: Many test pits in crest of dam have documented cracks through core, gravel transition, and spalls

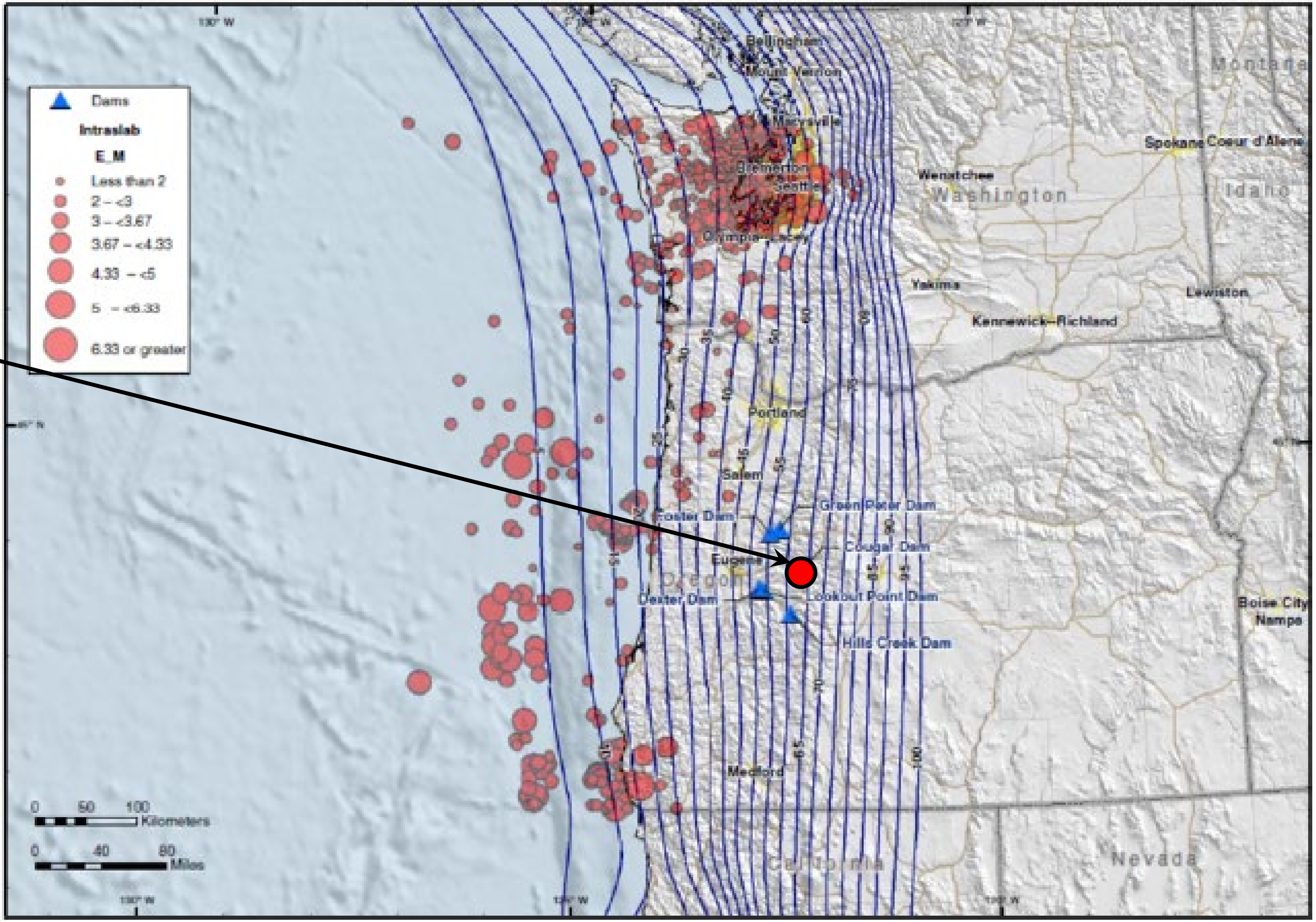
PRELIMINARY RISK ASSESSMENT: RISK DRIVING FAILURE MODES

- PFM 1: Overtopping
- PFM 4: Seismic instability of the embankment
- PFM 5: Liquefaction of the foundation
- PFM 13: CLE through settlement induced transverse cracks
- PFM 11: CLE at an abutment contact
- PFM 29: Trunnion friction Tainter gate failure
- PFM 31, 32, 38: Seismic spillway gate failure
- PFM 30: Elec/Mech Gate failure

- PFM 1: What is the probability that a peak pool will exceed the dam crest elevation, with and without debris? How much overtopping can the embankment take before failure?
- PFM 4: What ground motions might be expected, and how will the embankment respond to seismic loading?
- PFM 5: Is the as-built foundation prone to liquefaction?
- PFM 13: How continuous, deep, and wide might differential settlement cracks be within the embankment materials?
- PFM 11: Are there asperities in the foundation, how well were the abutments prepared to receive embankment materials, was the embankment well compacted at the abutments, why is there an increase in seepage when the pool exceeds a certain elevation?
- PFM 29: Were the gates designed for adequate trunnion friction?
- PFM 31, 32, 38: Are the gates stable for all seismic failure modes?
- PFM 30: Decision already was made to replace Elec/Mech Equipment

PROJECT BACKGROUND – SEISMIC LOADING

Cougar Dam



PROJECT BACKGROUND - SEISMIC LOADING

Dam	UHRS Return Period (years)	Short Period (0.2 s) CMS Scenario:				Long Period (1.0 s) CMS Scenario			
		Subduction Interface		Shallow Crustal		Subduction Interface		Shallow Crustal	
		M	Distance (km)	M	Distance (km)	M	Distance (km)	M	Distance (km)
Cougar	144	8.6	167	6.2	63	8.5	170	6.5	76
	975	8.7	148	6.3	33	8.7	150	6.7	45
	2,475	8.8	145	6.3	26	8.8	146	6.7	35
	9,950	8.8	141	6.3	19	8.8	142	6.7	25
	100,000	8.8	138	6.4	13	8.8	139	6.8	14

OURCE CONTRIBUTIONS TO SITE HAZARD

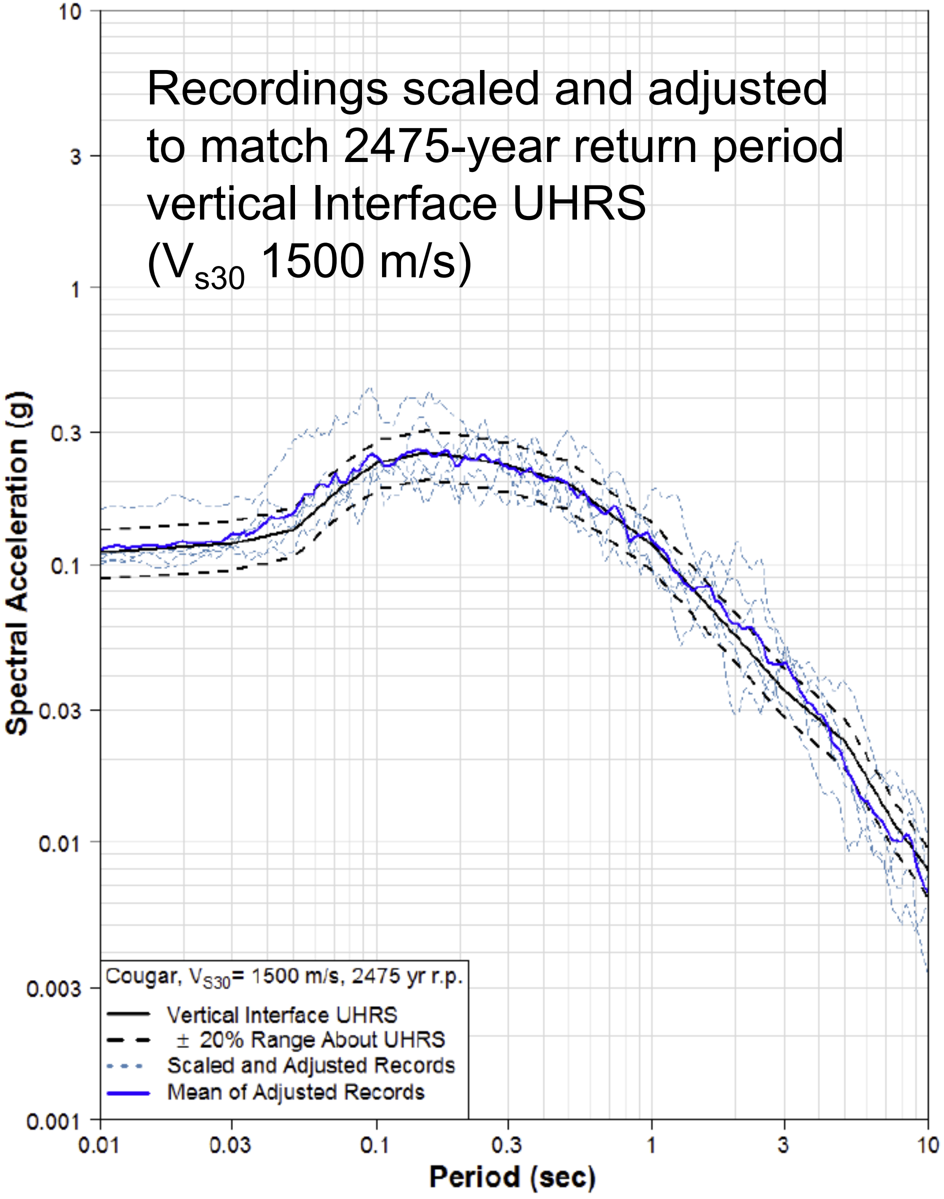
Dam	Return Period (years)	Percent Contribution to Mean Hazard for Spectral Period:					
		0.2 seconds			1.0 seconds		
		Crustal	Intraslab	Interface	Crustal	Intraslab	Interface
Lookout Point	2,475	7.0%	2.5%	90.5%	1.7%	0.5%	97.8%
	9,950	7.8%	2.1%	90.1%	1.6%	0.3%	98.1%
	100,000	11.0%	2.5%	86.5%	1.9%	0.2%	97.9%
Hills Creek	2,475	8.1%	2.1%	89.8%	3.2%	0.5%	96.3%
	9,950	9.7%	1.8%	88.5%	3.0%	0.3%	96.7%
	100,000	17.6%	1.9%	80.5%	3.8%	0.3%	95.9%
Green Peter	2,475	11.8%	4.8%	83.6%	3.2%	1.0%	95.8%
	9,950	13.1%	4.4%	82.5%	2.9%	0.7%	96.4%
	100,000	18.9%	5.2%	75.9%	3.5%	0.5%	96.0%
Cougar	2,475	15.2%	3.3%	81.5%	4.9%	0.9%	94.2%
	9,950	17.1%	3.0%	79.9%	4.0%	0.6%	95.4%
	100,000	25.5%	3.5%	71.0%	4.7%	0.5%	94.8%

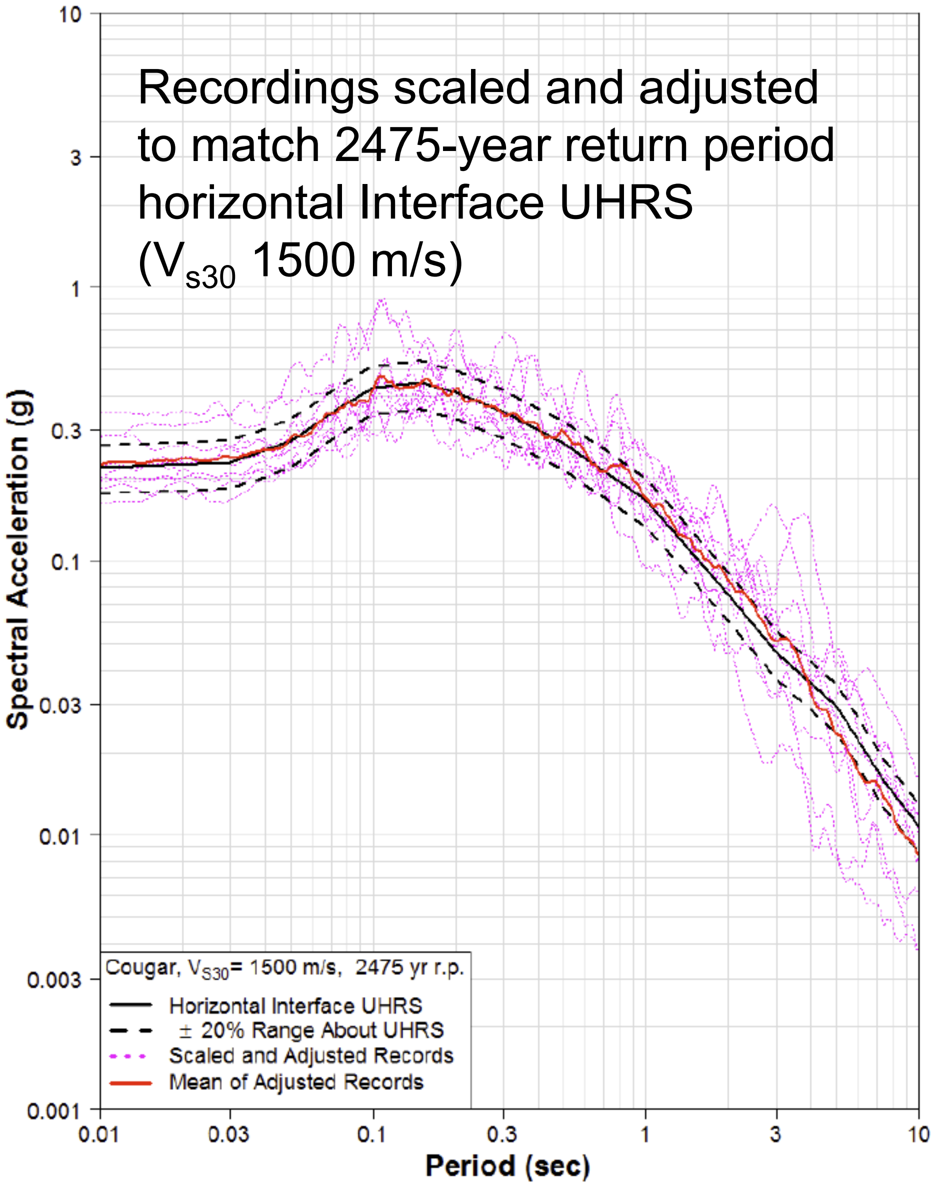
PROJECT BACKGROUND - SEISMIC LOADING

PARAMETERS OF SCALED AND ADJUSTED TIME HISTORIES

Dam	Target Spectrum	Record	Component	PGA (g)	PGV (cm/s)	PGD (cm)	Arias Intensity (m/s)	5%-75% Duration (s)
Cougar	100,000-yr Long Period Interface CMS	Tohoku IWTH24	EW	2.859E-01	3.451E+01	2.215E+01	6.684E+00	56.53
			NS	3.145E-01	4.159E+01	2.118E+01	6.204E+00	61.65
			UD	1.618E-01	3.129E+01	1.397E+01	3.538E+00	66.87
		Tohoku IWTH28	EW	7.043E-01	5.569E+01	2.686E+01	3.988E+01	60.70
			NS	7.606E-01	5.373E+01	2.287E+01	4.460E+01	60.97
			UD	3.388E-01	2.994E+01	1.565E+01	1.501E+01	64.65
		Tohoku YMTH01	EW	3.788E-01	4.599E+01	2.007E+01	1.186E+01	78.58
			NS	4.234E-01	4.735E+01	2.333E+01	1.228E+01	67.21
			UD	1.528E-01	3.152E+01	1.661E+01	2.698E+00	69.14
		Maule 20128	EW	4.241E-01	3.914E+01	2.421E+01	1.193E+01	37.50
			NS	4.092E-01	4.592E+01	2.509E+01	8.786E+00	29.97
			UD	2.985E-01	2.535E+01	1.733E+01	4.198E+00	38.77
		Maule 20130	EW	4.141E-01	5.014E+01	2.809E+01	7.770E+00	33.75
			NS	4.180E-01	5.371E+01	2.366E+01	7.896E+00	24.29
			UD	1.566E-01	2.888E+01	1.826E+01	2.116E+00	35.90

PROJECT BACKGROUND - SEISMIC LOADING





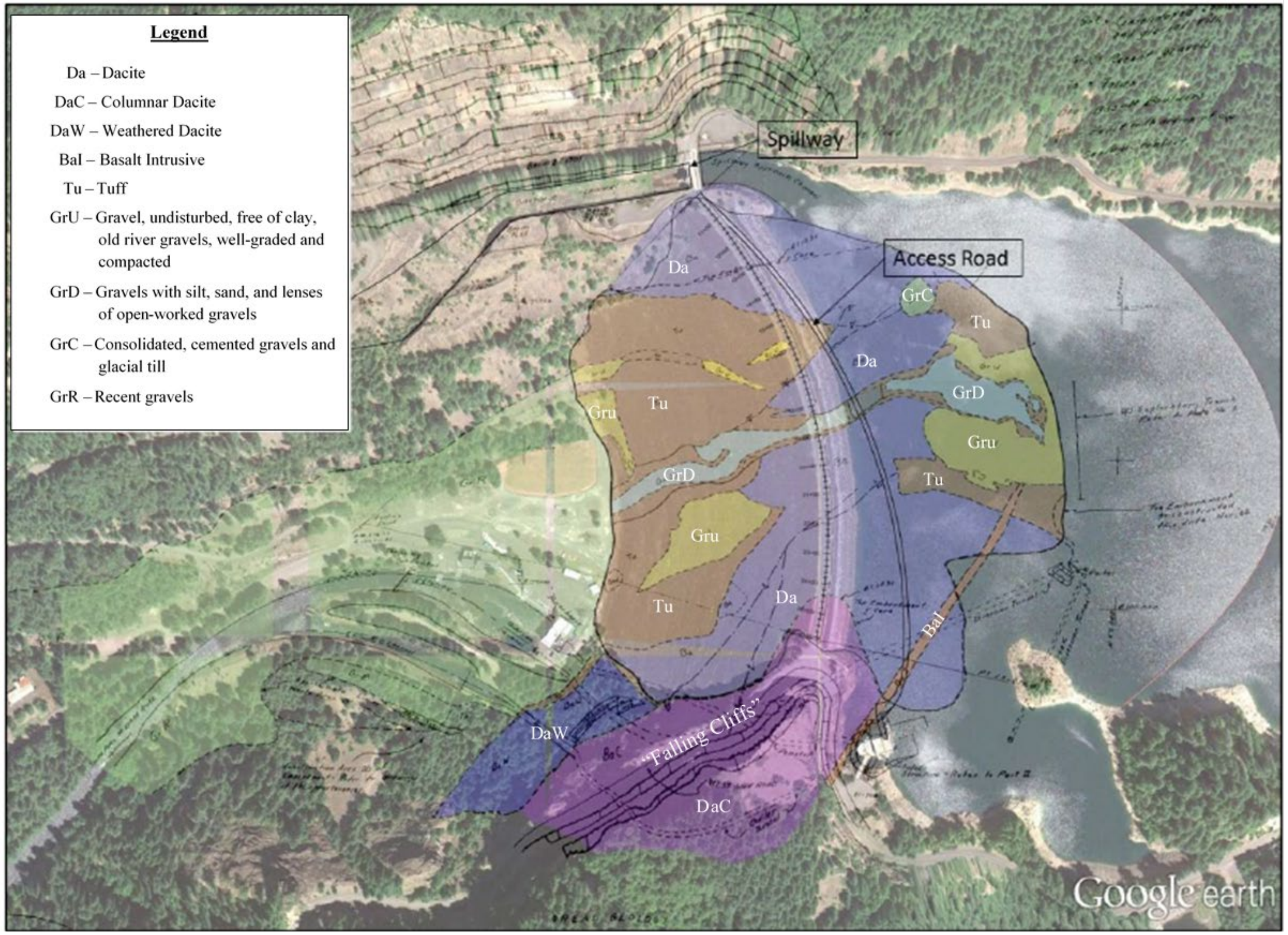
PROJECT BACKGROUND - SEISMIC LOADING

Foundation Liquefaction?

- GrD- Gravels with silt, sand, and lenses of open work gravels
- GrU- Gravel, undisturbed, free of clay, old river gravels, well-graded and compacted

Liquefaction not credible

- Loose GrD materials were removed from bedrock gorge, dense gravels remain in places
- Not all GrU was removed under shells
- Gru is discontinuous and impacts only small area of the footprint
- Based on interview with project engineer, all loose material was ripped and removed with heavy equipment down to dense material



Embankment Deformation?

- Evaluate as a potential risk driver

PROJECT BACKGROUND – SEISMIC LOADING - EMBANKMENT

Seismic Deformation of the Embankment (15-ft of freeboard)

Preliminary FLAC analyses had similar results

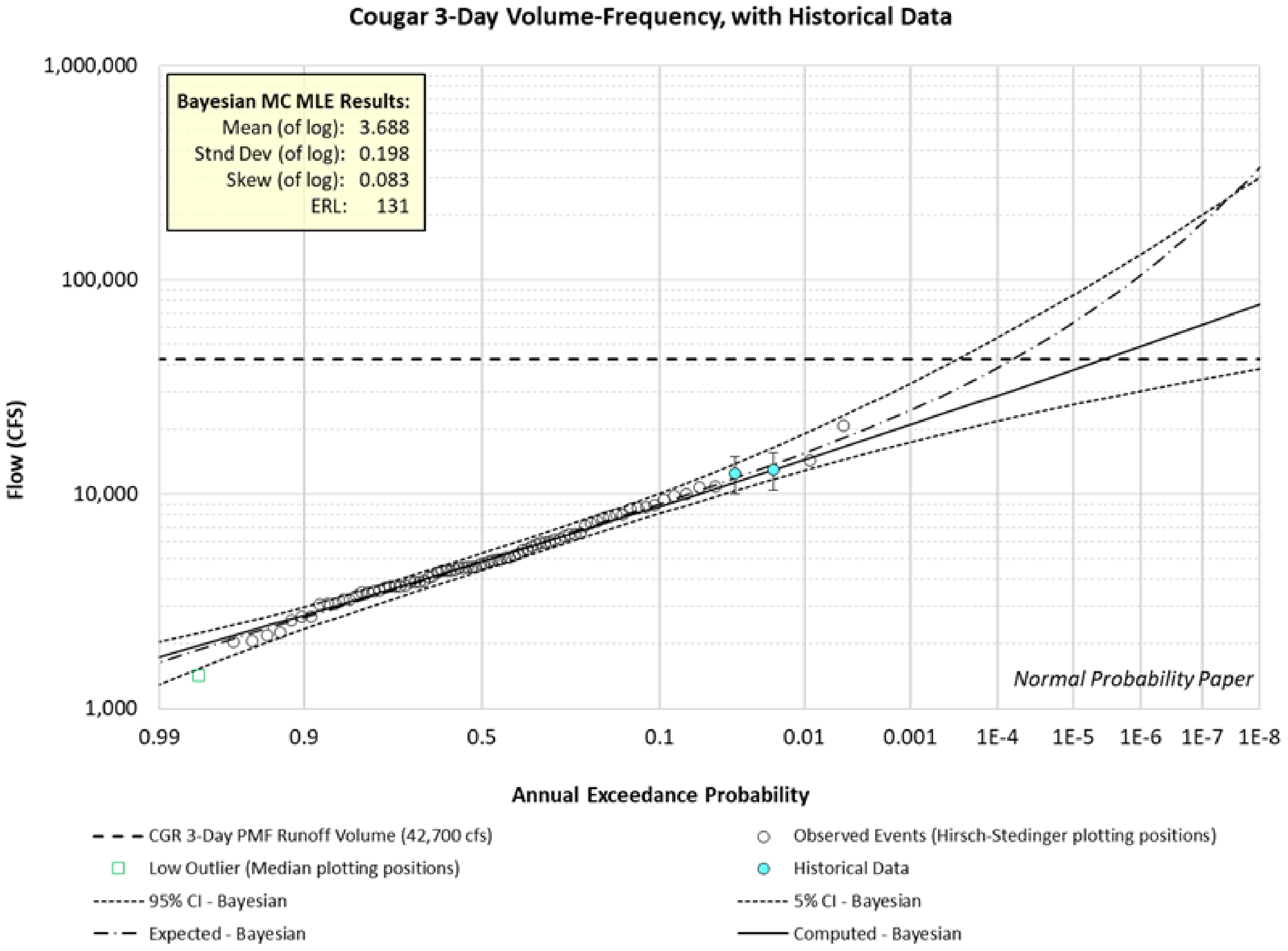
Newmark Analysis Results (feet of vertical deformation)

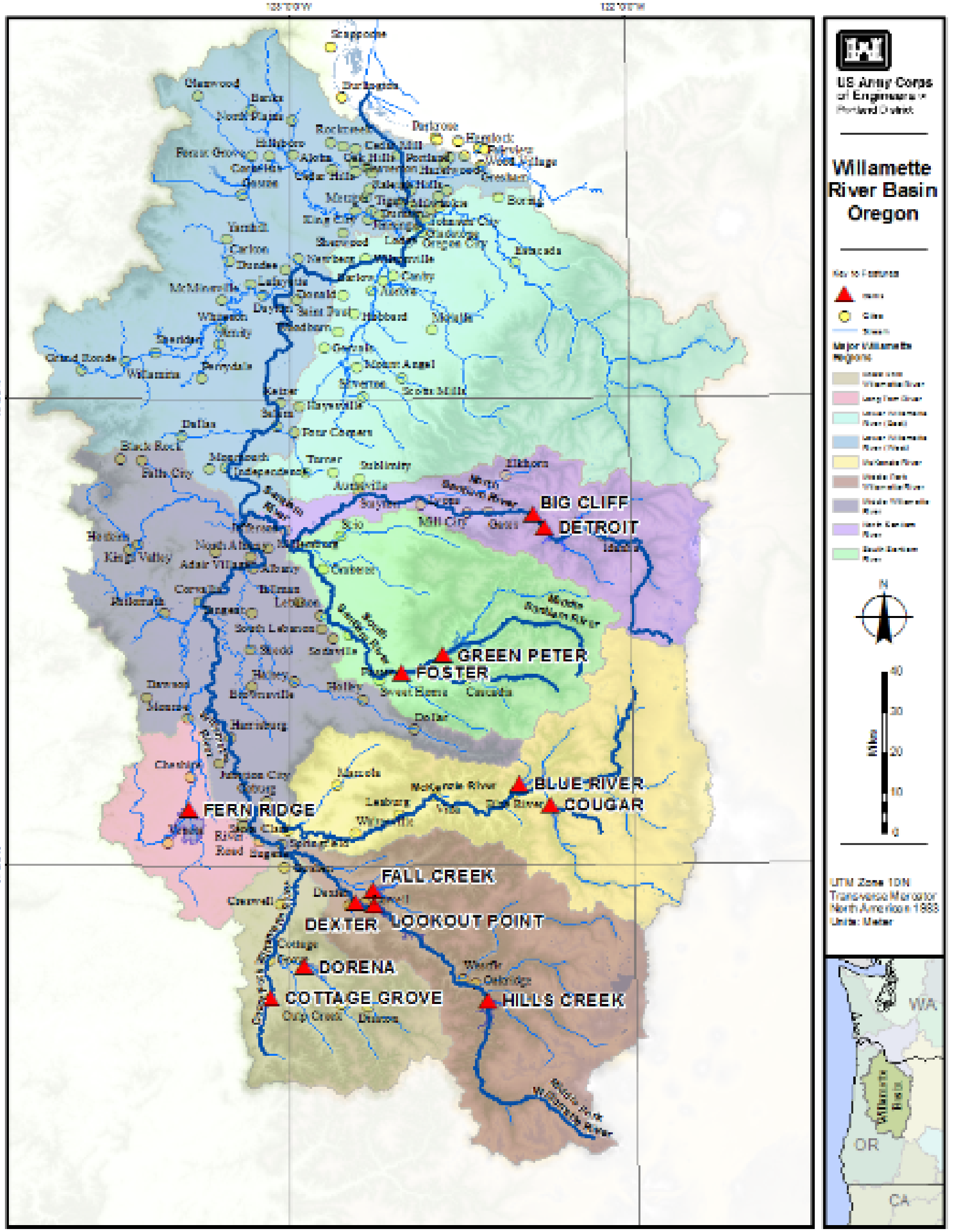
Analysis Station	Slip Surface Location		k_y	Return Period (Years)		
				2,475	9,950	100,000
19+00	D/S	Deep	0.19	0	0.03	0.50
		Intermediate	0.23	0.33	1.13	4.43
		Shallow	0.38	0.38	1.59	7.82
	U/S	Deep	0.12	0.33	1.43	6.32
		Intermediate	0.15	1.61	4.96	18.56
		Shallow	0.22	2.19	7.13	27.14
24+00	D/S	Deep	0.18	0.05	0.27	2.79
		Shallow	0.37	0.07	0.41	2.76
	U/S	Deep	0.06	2.01	5.10	20.41
		Shallow	0.14	1.03	2.25	12.05

Reassess Embankment Seismic Deformations (SME Elicitation Team)

PROJECT BACKGROUND - HYDROLOGIC LOADING

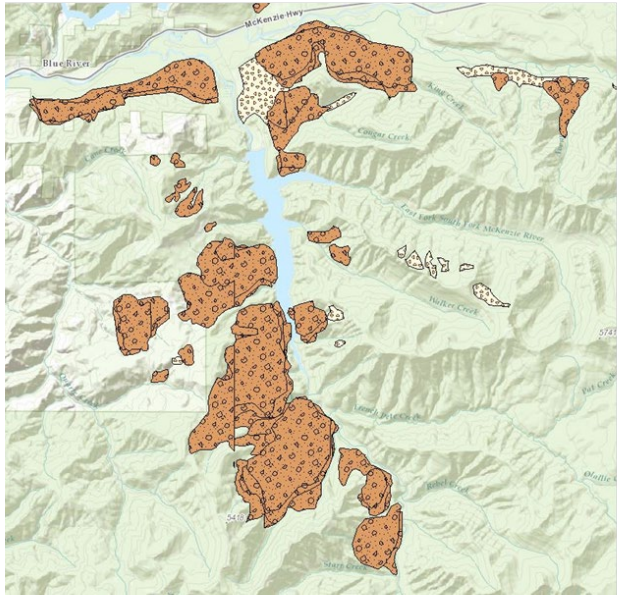
Update hydrology, runoff, and hydrologic loading conditions



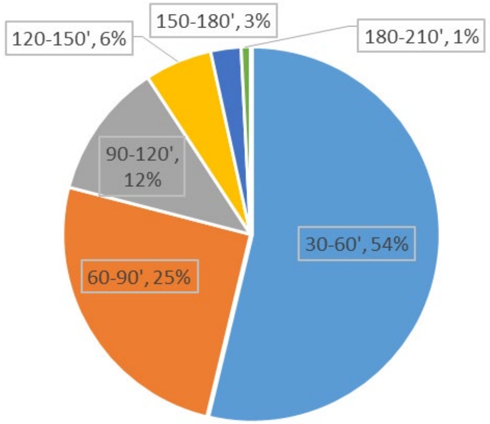


PROJECT BACKGROUND - DEBRIS BLOCKAGE

Researched debris and spillway blockage studies, debris booms, and watershed characteristics



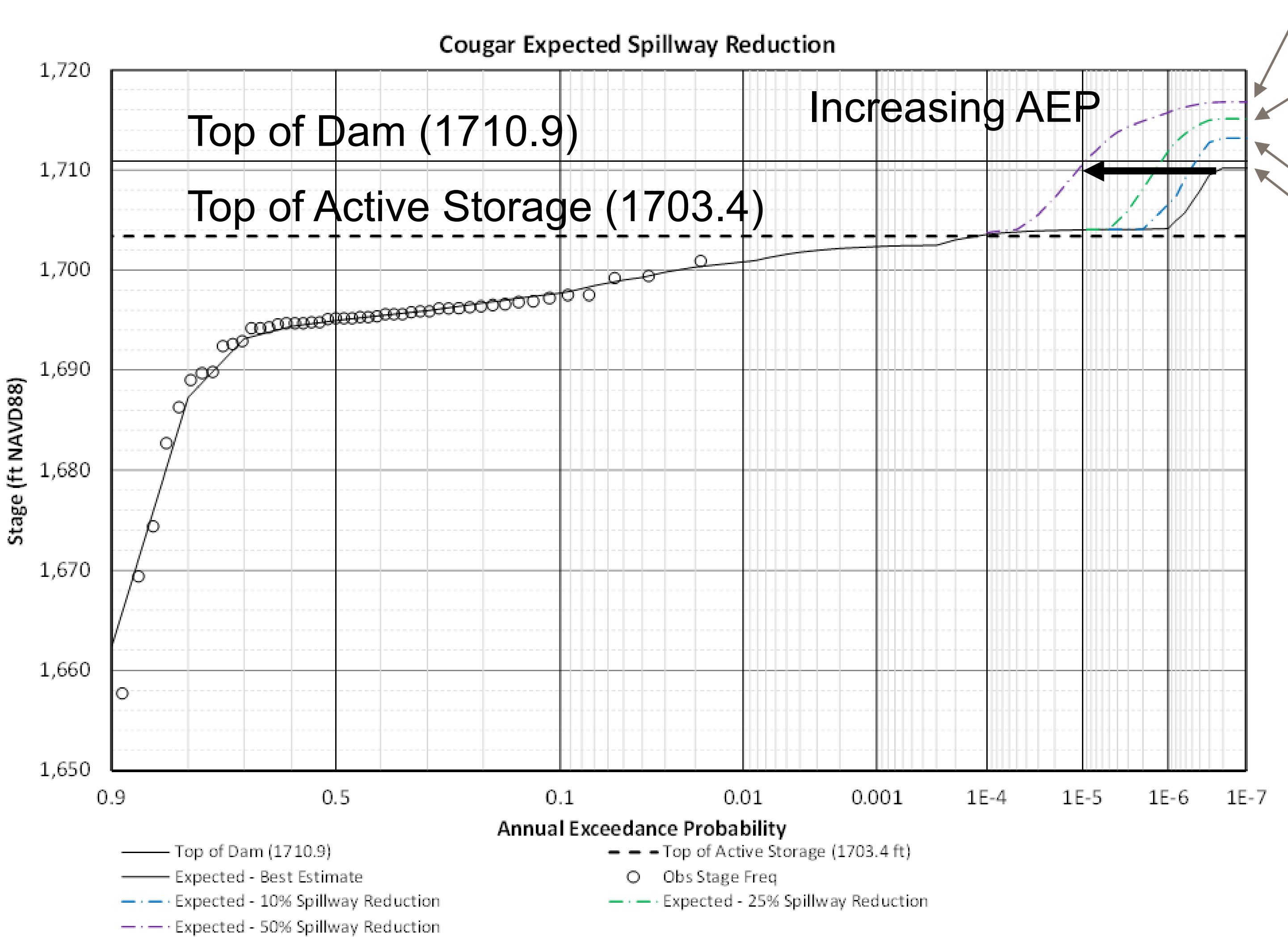
Historically active landslides in heavily forested area



Distribution of tree heights

Log jam above Wiley Creek Bridge (1964)

PROJECT BACKGROUND - HYDROLOGIC LOADING (WITH AND WITHOUT DEBRIS BLOCKAGE)



Spillway gates activate when pool approaches top of active storage (1703.4).

Spillway has never been activated.

AEP very sensitive to debris blockage! (1.5 Orders of Magnitude)

PROJECT BACKGROUND - HYDROLOGIC LOADING

Two Hydrologic Failure Modes of Primary Concern:

- Overtopping during an Extreme Event (Not credible)
- Overtopping due to debris blocking spillway gates (Credible)

Sensitivity Analysis to Determine “High” Probable Maximum Flood:

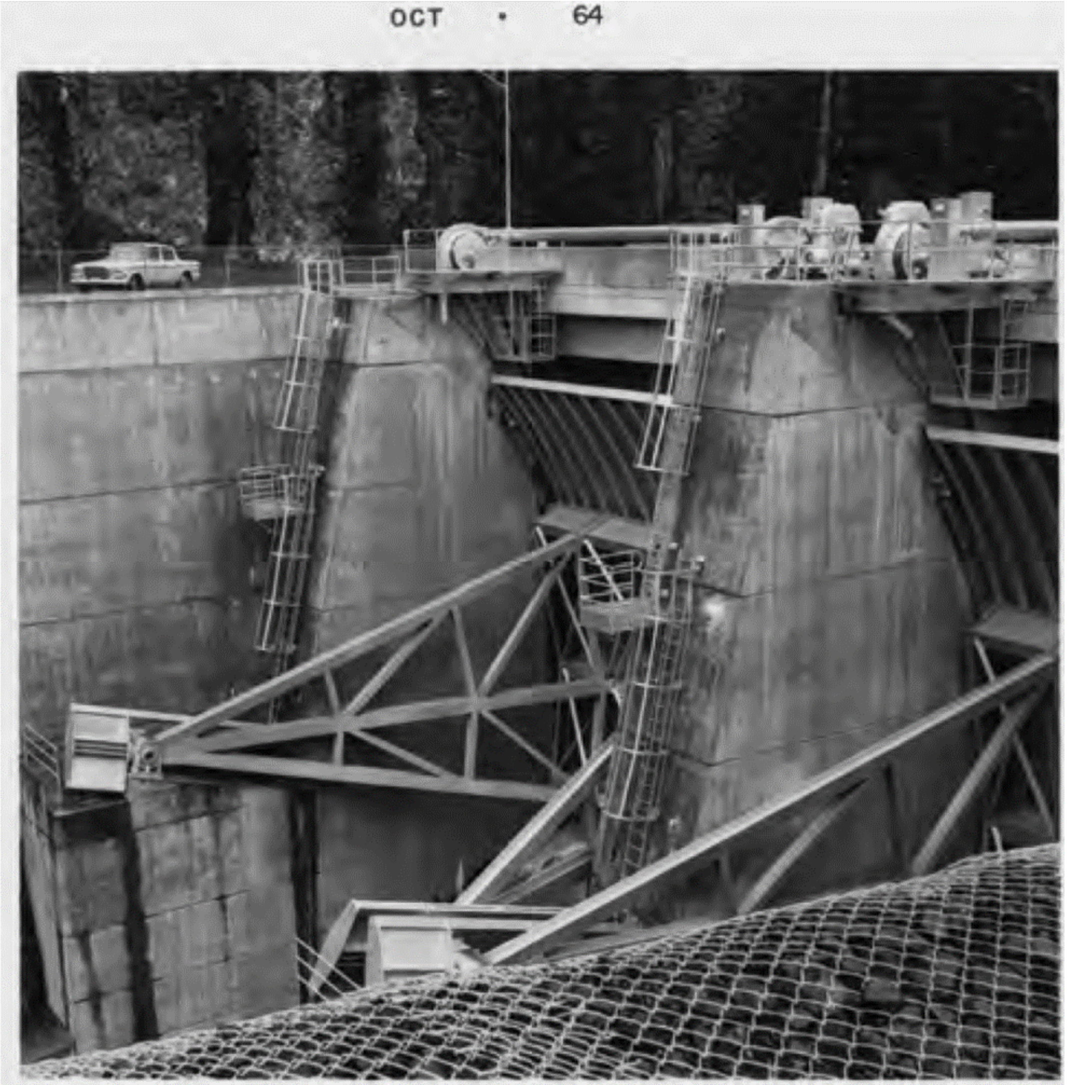
- Peak Pool = 1710.2 (NAVD88)
- Surveyed Low Point on Dam Crest = 1710.9 (NAVD88)
- Wind Orientation and Magnitudes/Frequency indicate low probability of wave overwash coincident with a High-PMF peak pool
- 0.7 feet of freeboard at a High-PMF acceptable in terms of Tolerable Risk

Re-assess Debris Blockage Risk:

- Debris Blockage Loading Curves and
- Final Elicitation of Debris Blockage Probabilities

PROJECT BACKGROUND – SPILLWAY AND GATES

2 Tainter gates, 40-ft wide by 43.33-ft tall



PROJECT BACKGROUND – SPILLWAY AND GATES

PFM-30: Mechanical/Electrical Failure of Gates

PFM-31: Earthquake loading causes Tainter gate to collapse

PMF-32: Earthquake loading causes failure of (A) trunnion, (B) trunnion girder, or (C) anchorage girder

PFM-33: Earthquake causes failure of Tainter gate embedded anchorage

With completion of ongoing gate modifications- all gate failure modes screen out as result of structural analyses

PROJECT BACKGROUND – SPILLWAY PIERS

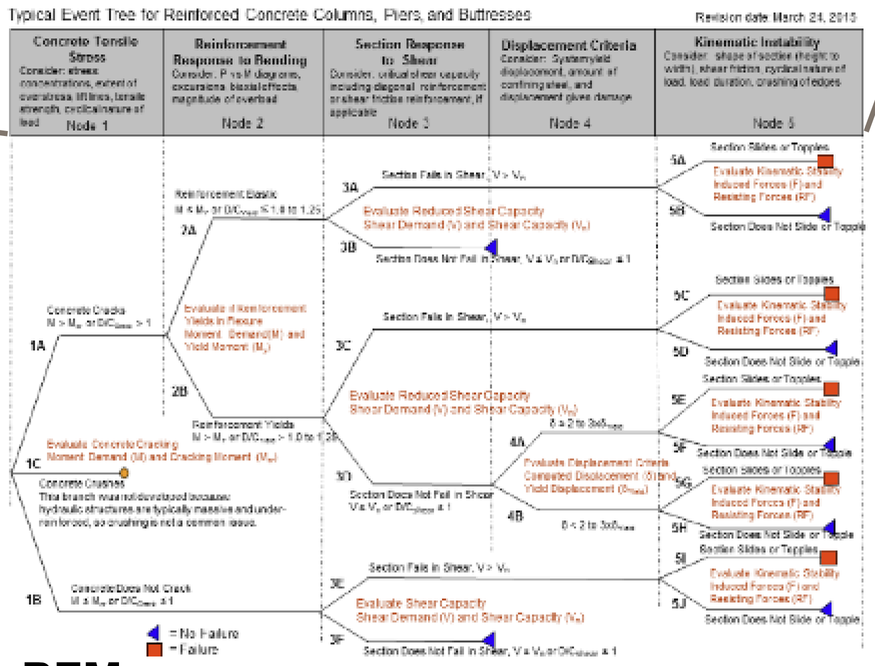
PFM 38: Seismic loading causes damage to pier, leading to gate failure

Concrete Tensile Stress	Reinforcement Response to Bending	Section Response to Shear	Displacement Criteria	Kinematic Instability
Consider: stress concentrations, extent of overstress, lift lines, tensile strength, cyclical nature of load	Consider: P vs M diagrams, excursions, biaxial effects, magnitude of overload	Consider: critical shear capacity including diagonal reinforcement or shear friction reinforcement, if applicable	Consider: System yield displacement, amount of confining steel, and displacement given damage	Consider: shape of section (height to width), shear friction, cyclical nature of load, load duration, crushing of edges
Node 1	Node 2	Node 3	Node 4	Node 5

Structural Analysis for Pier Failure Focuses on Reinforcement and Concrete Responses to Loading

Screening-Level Assessment Defines Failure as Cracking (tensile condition)

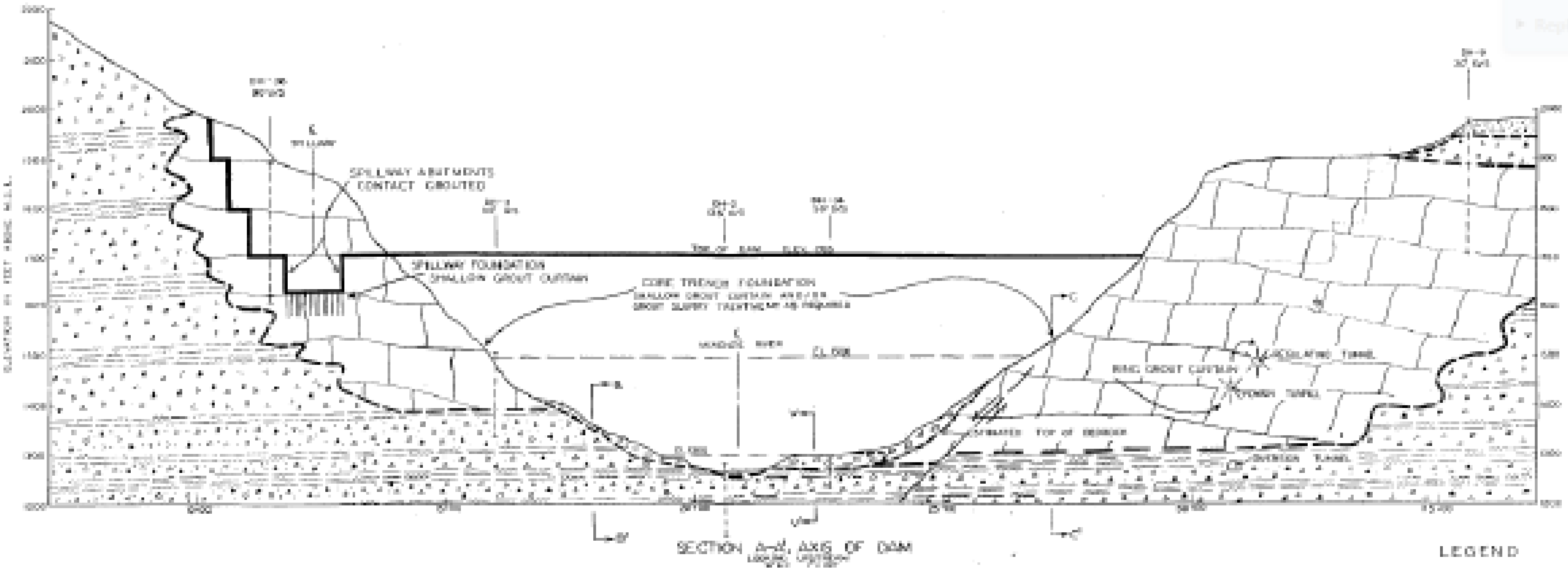
Advanced (FEM) Analysis Uses Event Tree to Define Failure



PFM 38- Failed Screening Level Assessment

PFM 38- Passed More Advanced FEM Assessment – Non-Credible PFM

PROJECT BACKGROUND – SPILLWAY CHUTE



PROJECT BACKGROUND – SPILLWAY AND GATES

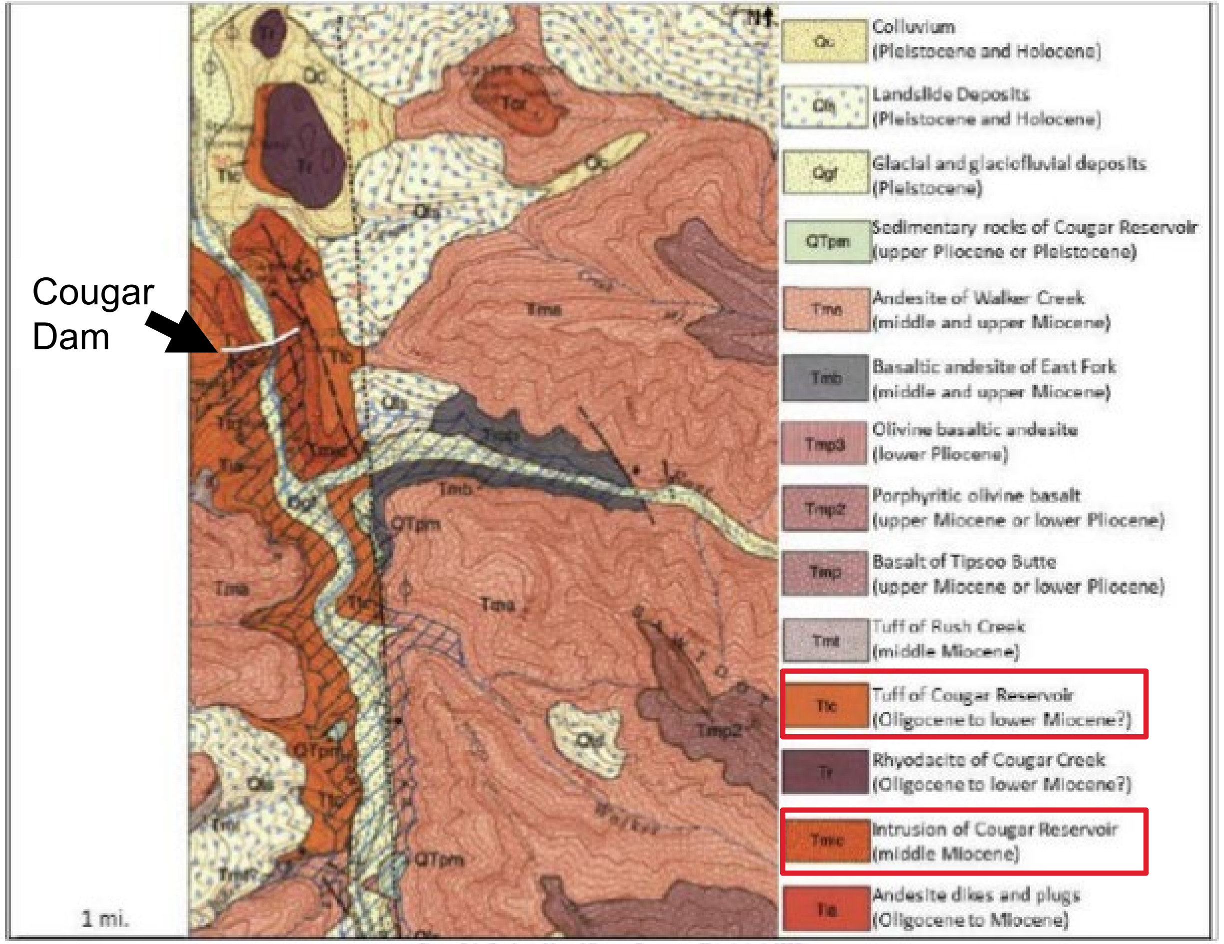


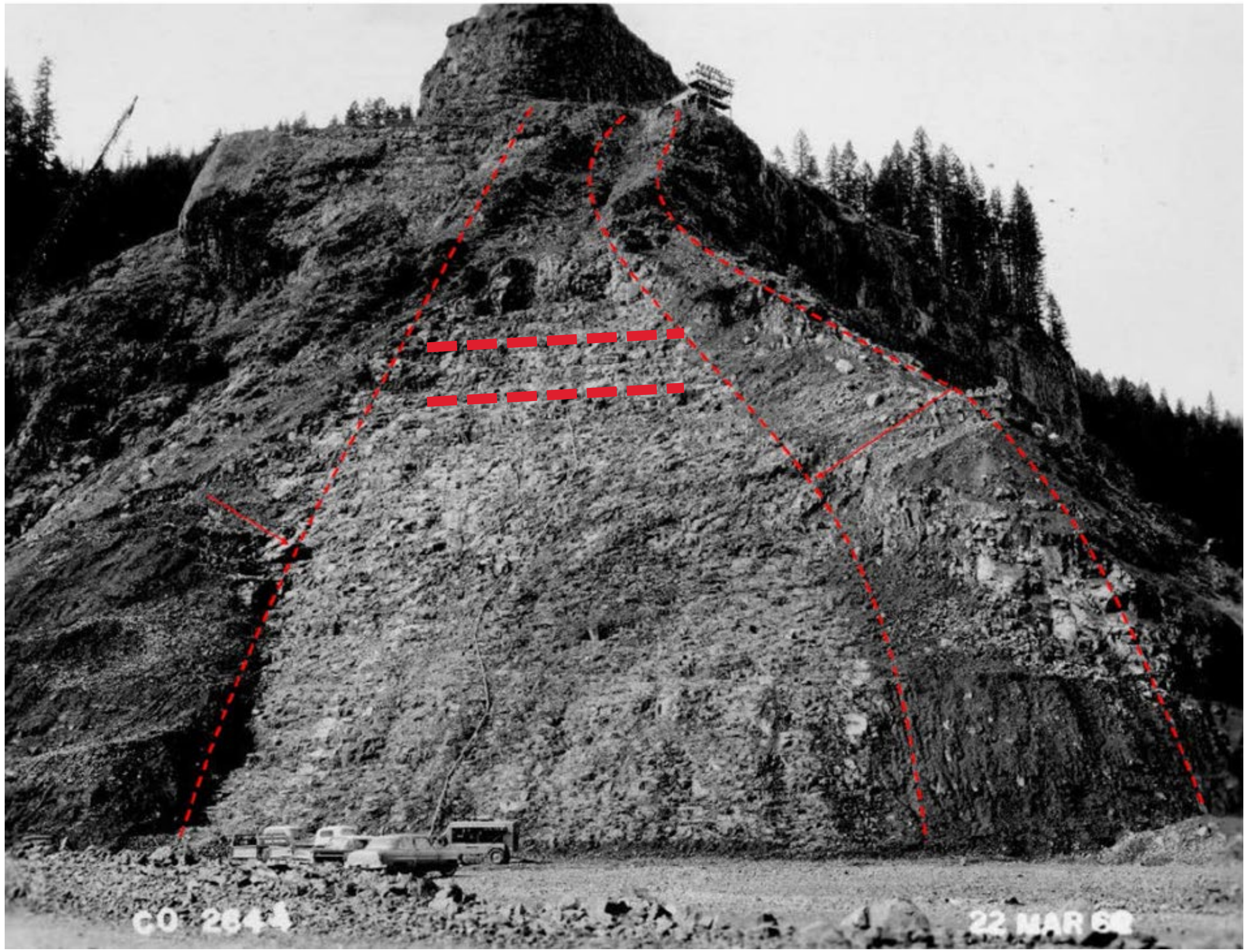
Figure 2-1. Geologic Map of Cougar Dam area (Priest et al. 1988)

Steep contact on the right of chute (Tuff under dark grey Dacite intrusion)

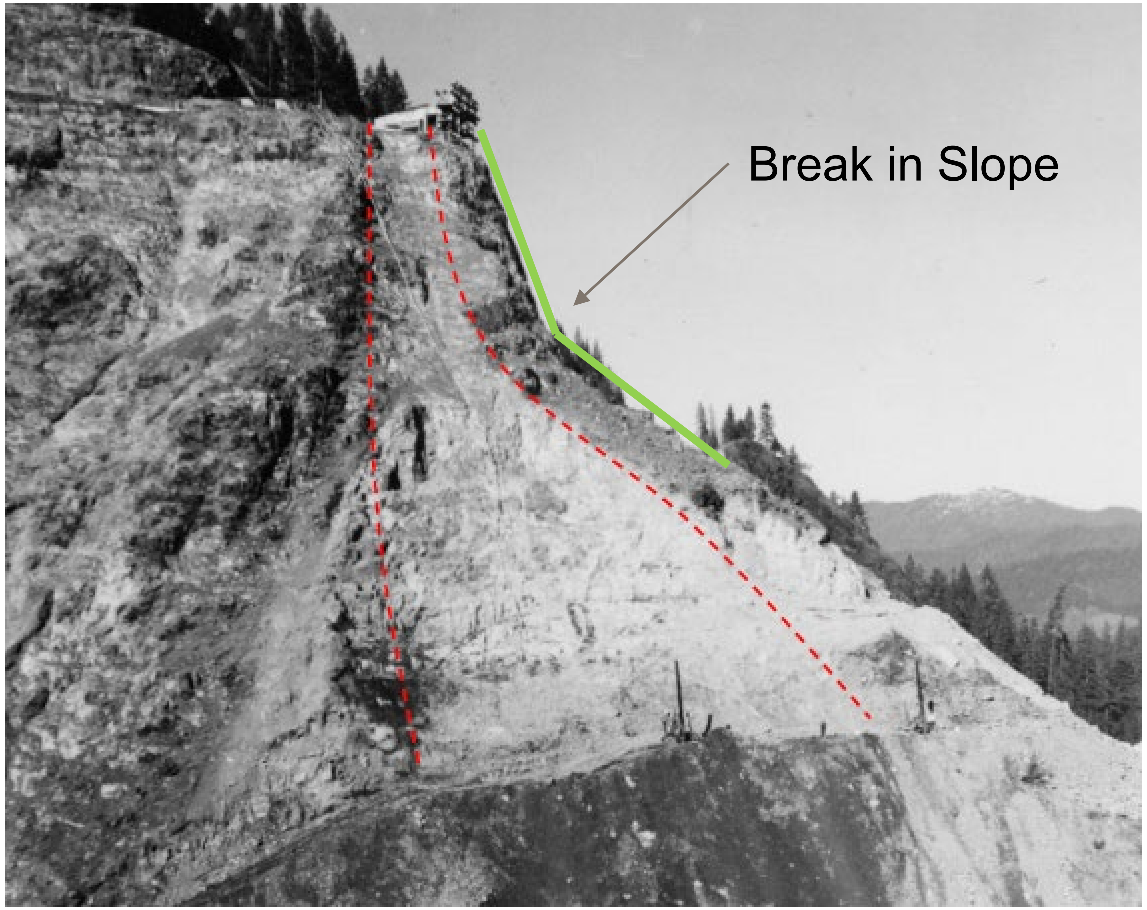
Discontinuity Set Number	Discontinuity Type	Dip (Degrees 0-90)	Dip Direction (Degrees 0-360)
1	Joint	80	240
2	Joint	75	055
3	Joint	35	300
4	Joint	60	140
5	Joint	90	320
6	Joint	85	190

Tlc	Tuff of Cougar Reservoir (volcanoclastics, debris flow, ash flow)
Tmc	Dark Grey, Glassy, Porphyritic Dacite Intrusion

PROJECT BACKGROUND – INTERNAL EROSION

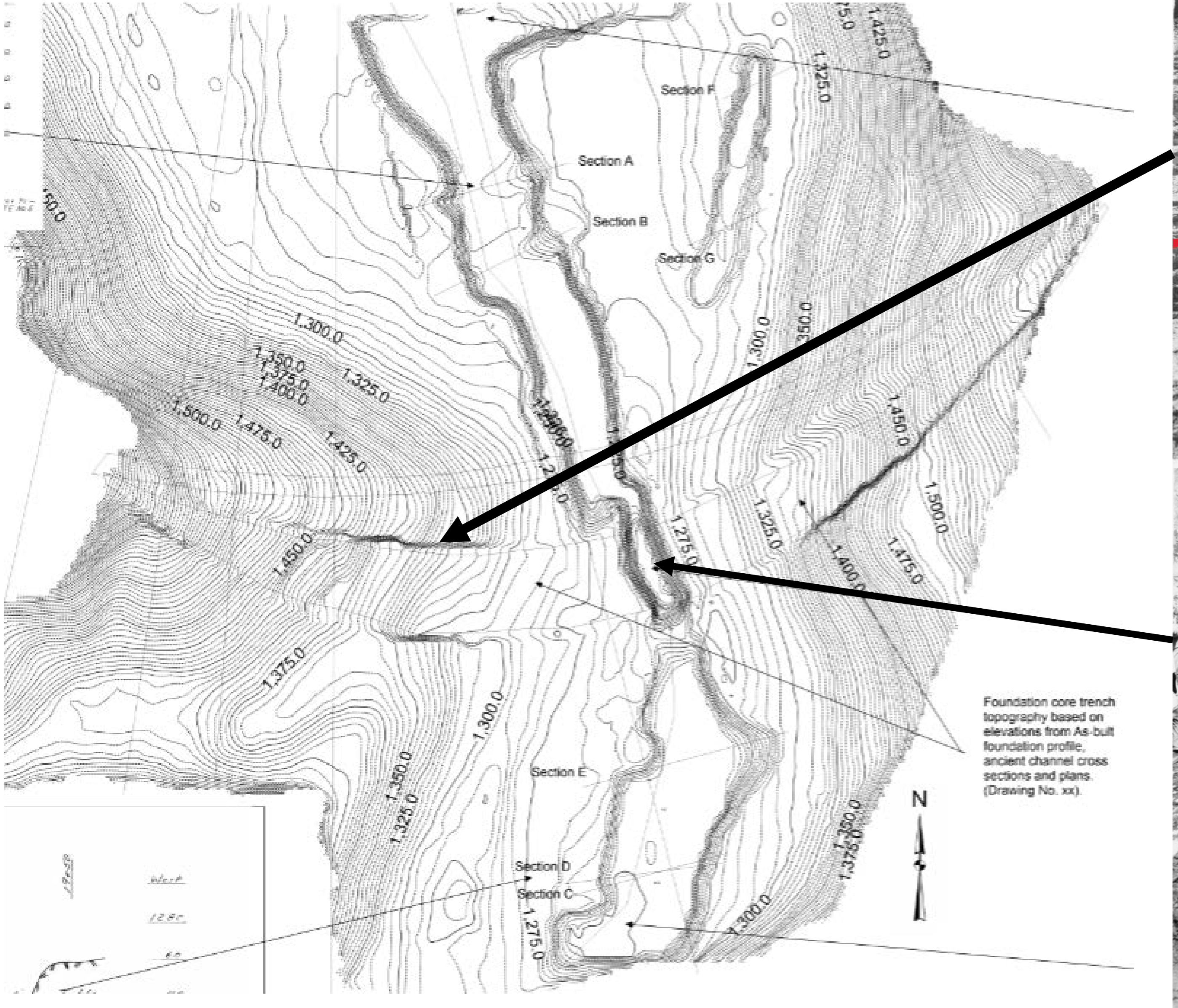


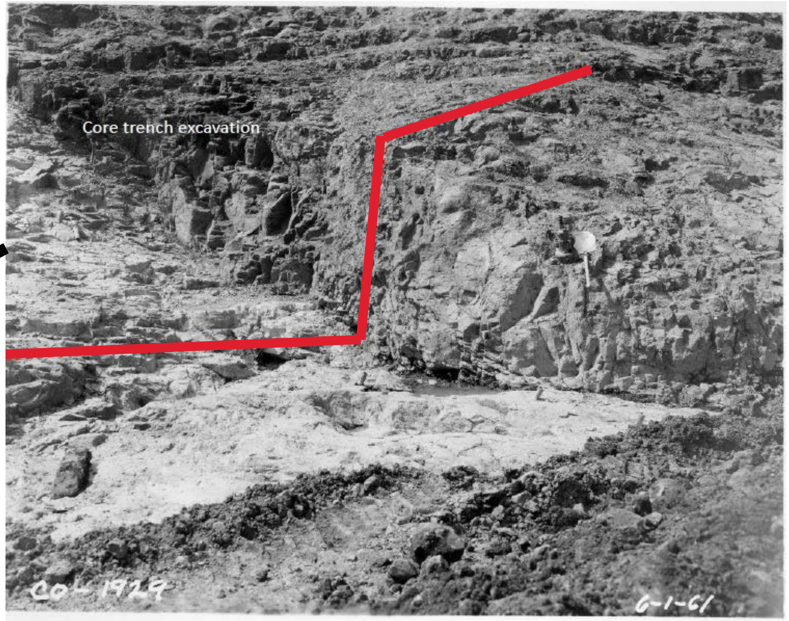
Linear asperities/benching (up to 5-ft high) through core zone (develop a flaw through dam core?)



Break in slope on left abutment surface lead to development of a flaw through dam core?

PROJECT BACKGROUND – INTERNAL EROSION

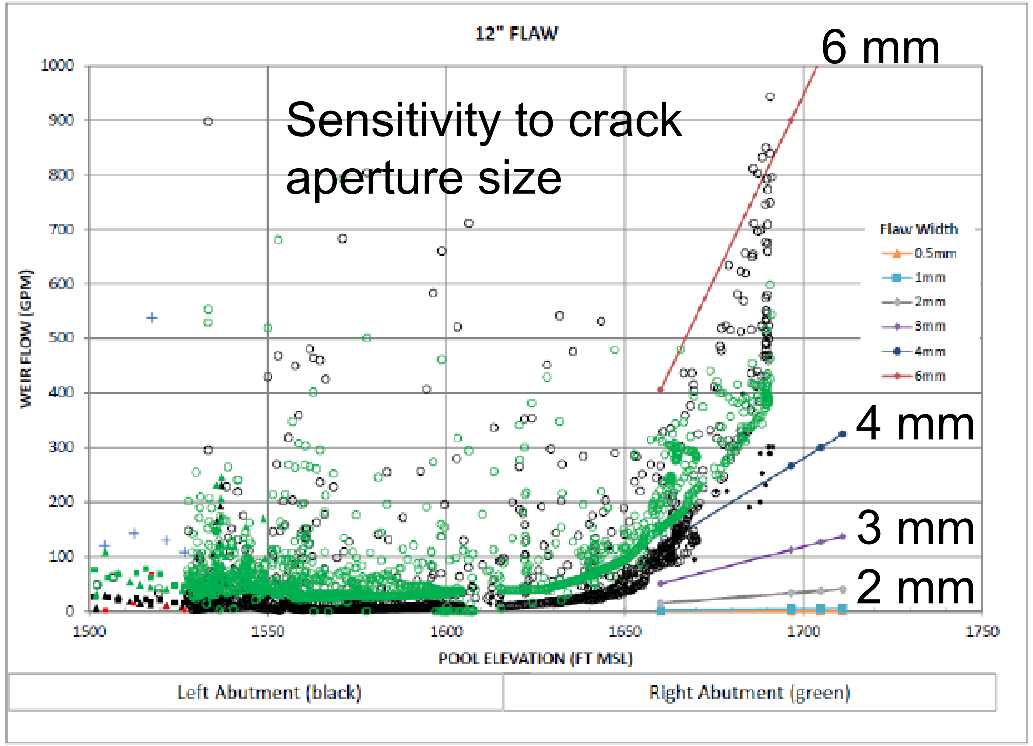




PROJECT BACKGROUND – INTERNAL EROSION

Two Internal Erosion Failure Modes of Primary Concern

- Concentrated Leak Erosion Through the Embankment
  - History of Ongoing Differential Settlement and Cracking of the Embankment
- Concentrated Leak Along Embankment/Abutment Contact
  - Unexplained increase in weir flow when pool exceeds ~1635



Critical shear stress of 4 psf required to initiate erosion in the core

- HET ranged from 0.1 [outlier] to 7.5

Core, transition zone, and spalls very likely to hold a crack

- Open cracks observed in test pits through the spalls
- Two samples available for spalls zone indicate high fines content

PROJECT BACKGROUND – INTERNAL EROSION

PFM 13: Concentrated Leak Due to Differential Settlement (static or dynamic loading)

- Static load case controls
- Vertical cracks, uppermost 10 meters
- Loaded during summer pools and above
- Shorter seepage path (across top of dam)

PFM 11: Concentrated Leak Along Abutment Contact

- Deeper seated cracking along asperities and break in slope
- Less likely to be continuous
- Longer seepage path
- Potentially higher hydraulic stresses
- Loaded during pools above ~1635 (NAVD88)
- Hydraulic shear stress may exceed critical shear stress, if outlier HET result is considered

INTERIM RISK ASSESSMENT

INTERIM RISK ASSESSMENT

Total incremental life safety risk:
- AALL of 1.55E-02
- APF of 3.42E-04
- N of 45

Risk-drivers:
- PFM 4: Seismic Instability
- PFM 11: CLE at Abutment Contact
- PFM 13: CLE due to Differential Settlement
- PFM 20: Debris Blockage leads to Overtopping
- PFM 29: Trunnion Friction Tainter Gate Failure
- PFM 30: Mech./Elect. Failure of Gates
- PFM 31: Seismic Failure of Tainter Gates

Incremental risk is above APF and societal risk guidelines

Recommend maintaining DSAC 2
- Repair second Tainter gate as planned.
- Collect data from the newly installed instruments through the next planned deep drawdown in 2021 and continue under a IES Phase 2.

PATH FORWARD AND RISK REDUCTION MEASURES

PATH FORWARD AND RISK REDUCTION MEASURES

1. Further evaluate the estimated seismic deformations and associated system response probabilities for PFM 4 (Seismic instability of the embankment). Effort will be performed by an ad-hoc cadre of experts in seismic deformation risk analysis designated by the RMC Director.
2. Perform additional field investigation to obtain samples of the downstream materials in order to further evaluate filter compatibility and the associated system response probabilities (SRP) for PFM 13 (Concentrated Leak due to differential settlement).
3. Further evaluate the overtopping SRP and quantify risk associated with PFM 20 (debris blockage leading to overtopping) and refine the consequence analysis for the overtopping scenario.
4. Develop and initiate consequence management efforts, through risk communication with downstream communities and improve evacuation effectiveness.
5. Confirm that OM funding is established for the gate modification (one gate already completed, need to complete the remaining gate).
6. In addition to the above, the study report is being finalized to address technical review comments (QCC, ATR, DQC reviews) and to incorporate new H&H and geotechnical information.

ACKNOWLEDGMENTS

The work presented here was a large team effort. The following groups all contributed to completion of this work;

1. U.S. Army Corps of Engineers Portland District- Cougar Dam Risk Assessment Product Development Team
2. U.S. Army Corps of Engineers St. Louis District- Risk Cadre
3. U.S. Army Corps of Engineers Risk Management Center- HH Team
4. U.S. Army Corps of Engineers Risk Management Center- Geotech/Geology/Seismicity Team
5. U.S. Army Corps of Engineers Risk Management Center- Cougar Dam Issue Evaluation Study Advisors
6. U.S. Army Corps of Engineers Savannah District Explorations Unit- Sonic Drill Crew
7. U.S. Army Corps of Engineers Modeling, Mapping and Consequence Center
8. AMEC Foster Wheeler
9. U.S. Bureau of Reclamation- Geophysics Team