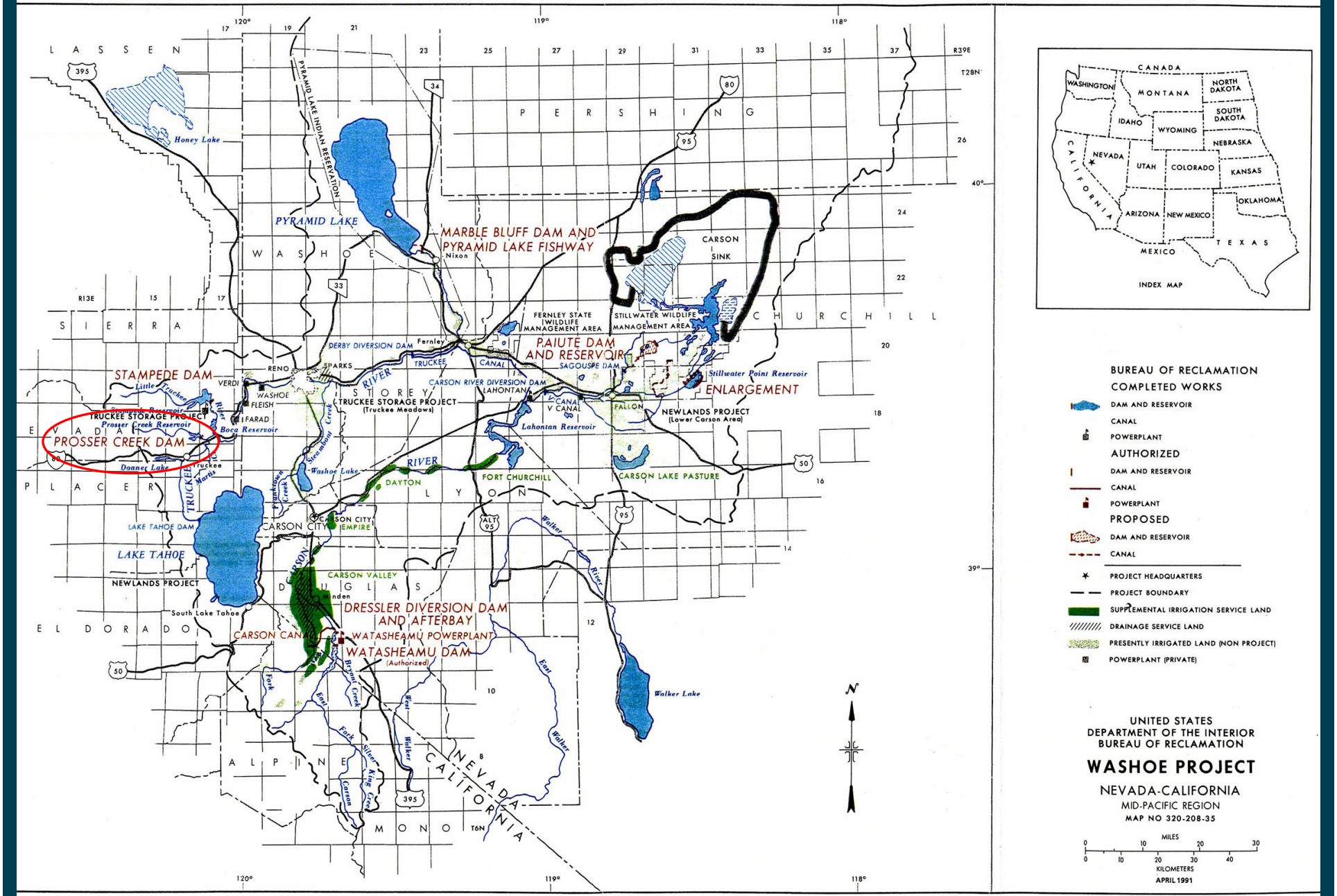
BUREAU OF RECLAMATION

Investigations for sites with liquefaction potential: Prosser Creek Dam Issue Evaluation

AEG/USSD Specialty Geotechnical Workshop for Dam and Levee Investigations

December 6, 2021



BUREAU OF RECLAMATION

COMPLETED WORKS

- DAM AND RESERVOIR
- CANAL
- POWERPLANT

AUTHORIZED

- DAM AND RESERVOIR
- CANAL
- POWERPLANT

PROPOSED

- DAM AND RESERVOIR
- CANAL

- PROJECT HEADQUARTERS
- PROJECT BOUNDARY
- SUPPLEMENTAL IRRIGATION SERVICE LAND
- DRAINAGE SERVICE LAND
- PRESENTLY IRRIGATED LAND (NON PROJECT)
- POWERPLANT (PRIVATE)

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

WASHOE PROJECT

NEVADA-CALIFORNIA

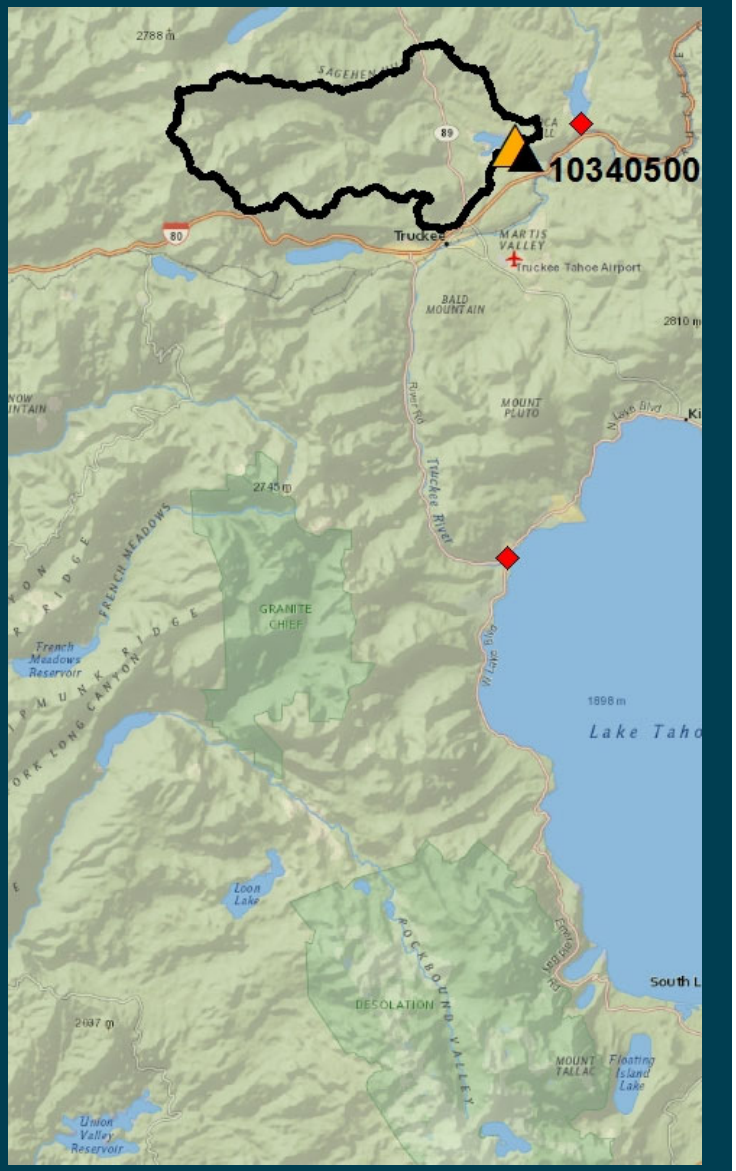
MID-PACIFIC REGION

MAP NO 320-208-35

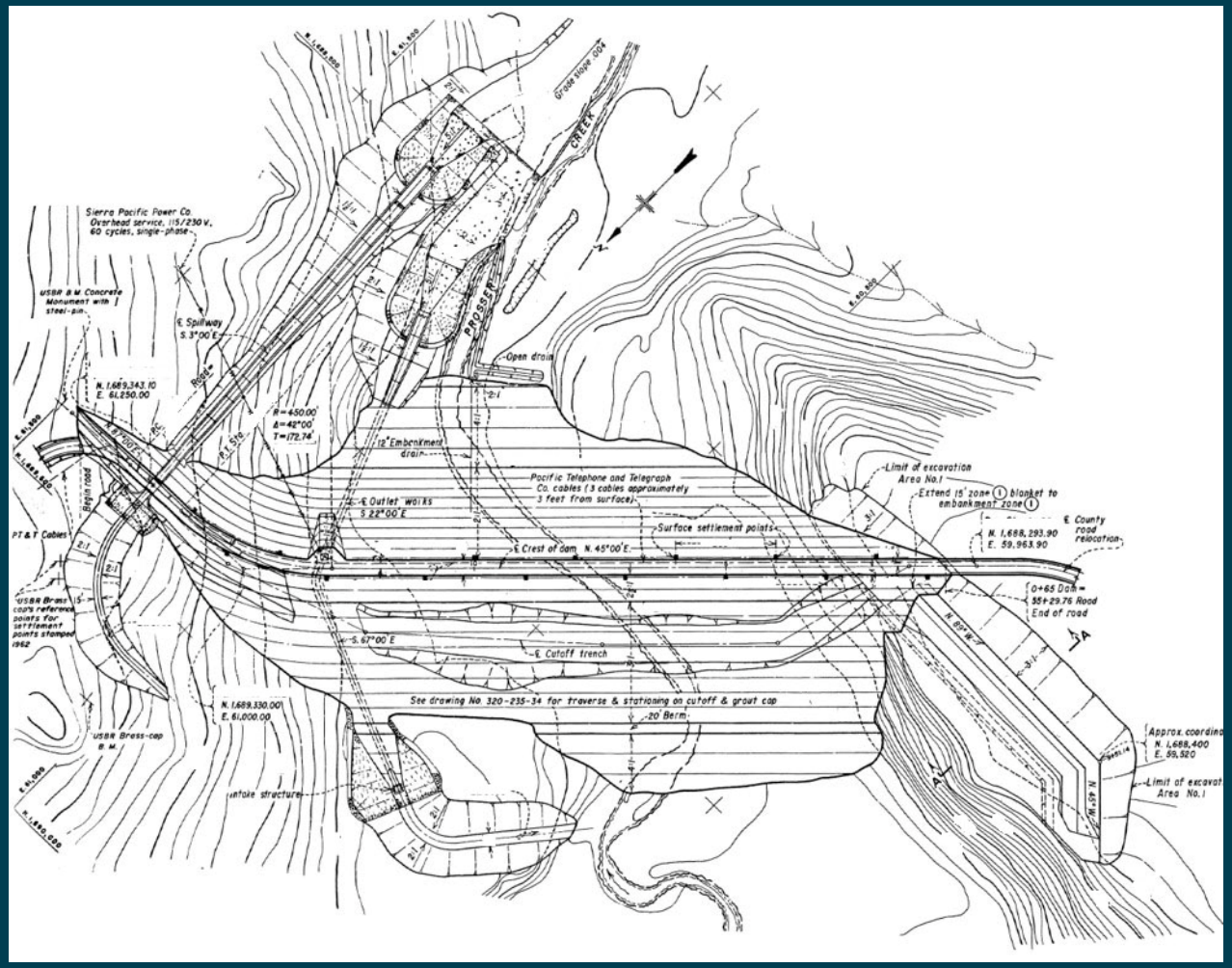
MILES 0 10 20 30

KILOMETERS 0 10 20 30 40

APRIL 1991

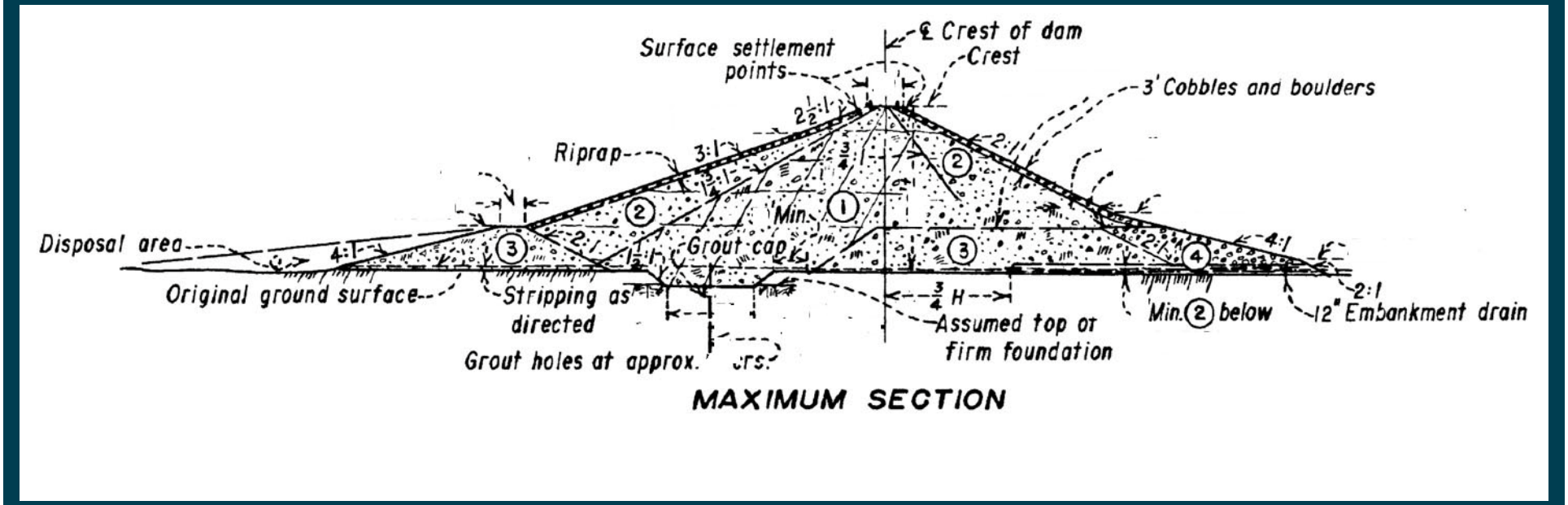

10340500
Truckee
Truckee Tahoe Airport
MARTIS VALLEY
BALD MOUNTAIN
MOUNT PLUTO
Truckee River
GRANITE CHIEF
French Meadows Reservoir
Lake Taho
Loon Lake
DESOLATION
ROCKBOUND VALLEY
MOUNT TALLAC
Floating Island Lake
Union Valley Reservoir
2788 m
2745 m
2637 m
1898 m
2810 m

Design details



- Completed in 1962
- Zoned earthfill embankment
- Moderately plastic Zone 1 (avg PI 12)

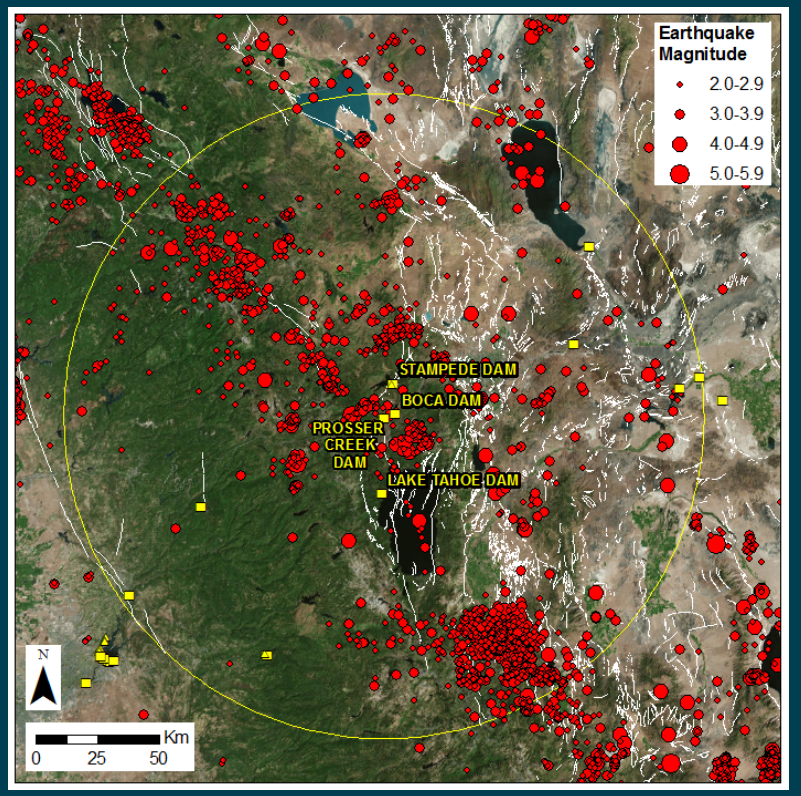
Design details



- Cutoff trench extends down to bedrock, with single line grout curtain (moderate takes)
- Overburden left in place beneath the shells
- Zone 2 drainage blanket above d/s overburden

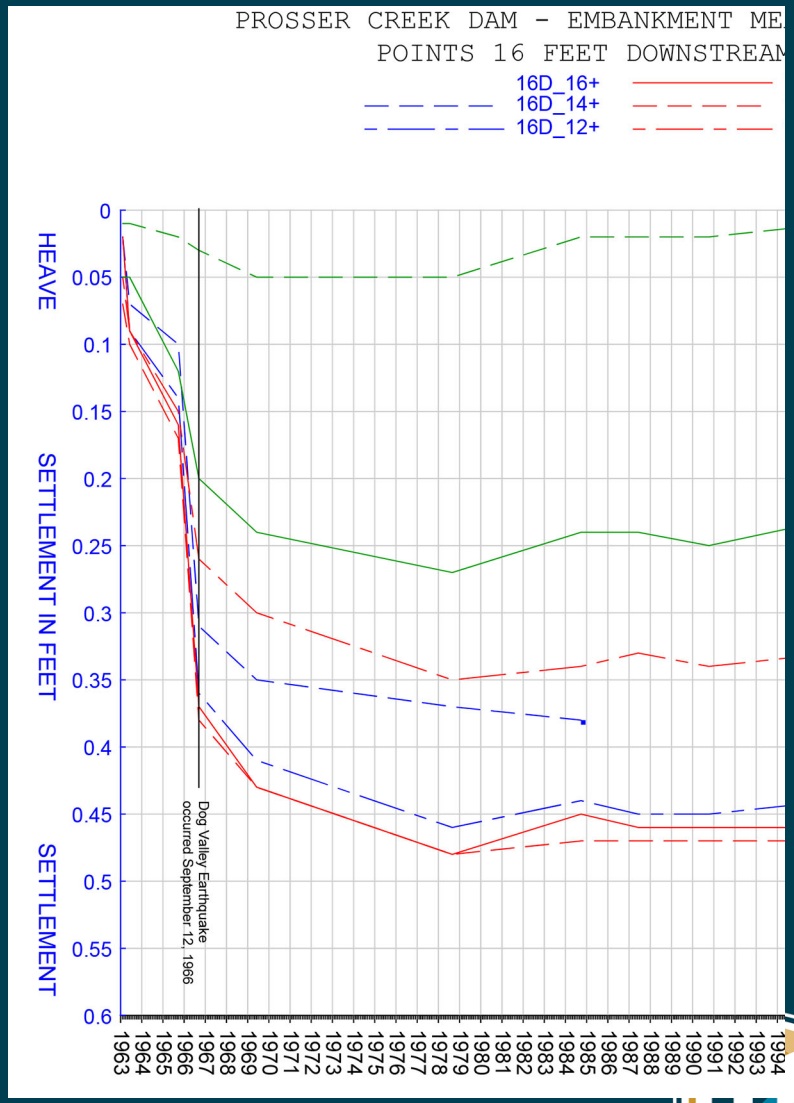
Seismic setting

- Located near the boundary of the extensional Basin and Range physiographic province and the stabler Cascades-Sierra province
- Located in a seismically active transition zone
- Est. mean PHA of 1.1g at a 10,000-year return period
- Est. mean PHA of 1.7g at a 50,000-year return period

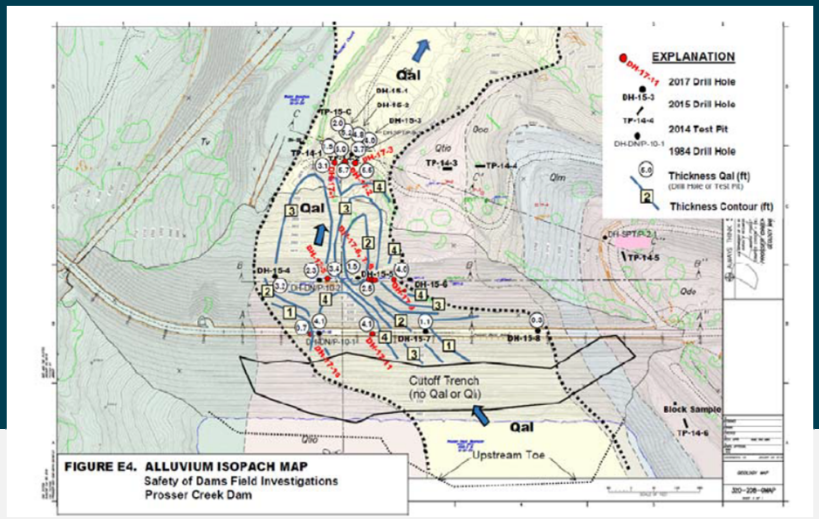


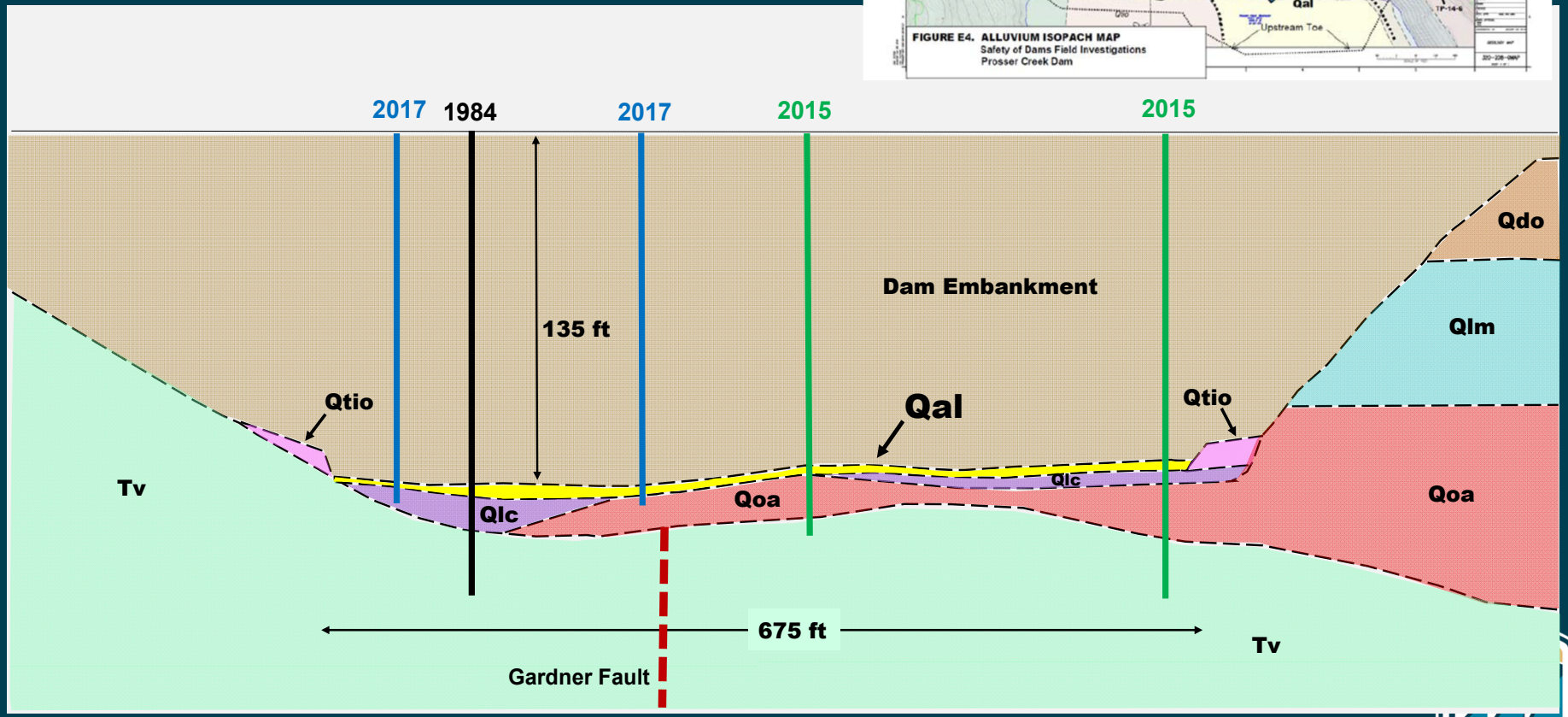
Seismic setting

- Four years after construction, dam was subjected to the M 6.6 Dog Valley earthquake
- Est. site PHA 0.25g to 0.4g
- The dam performed well, with minor settlement and shallow cracking observed along the crest
- Some “sand boils” reported downstream (most likely in fill material)

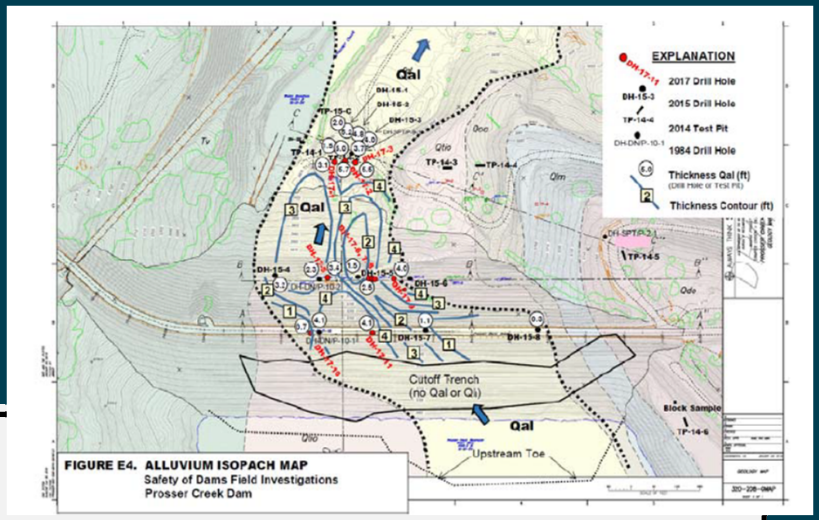


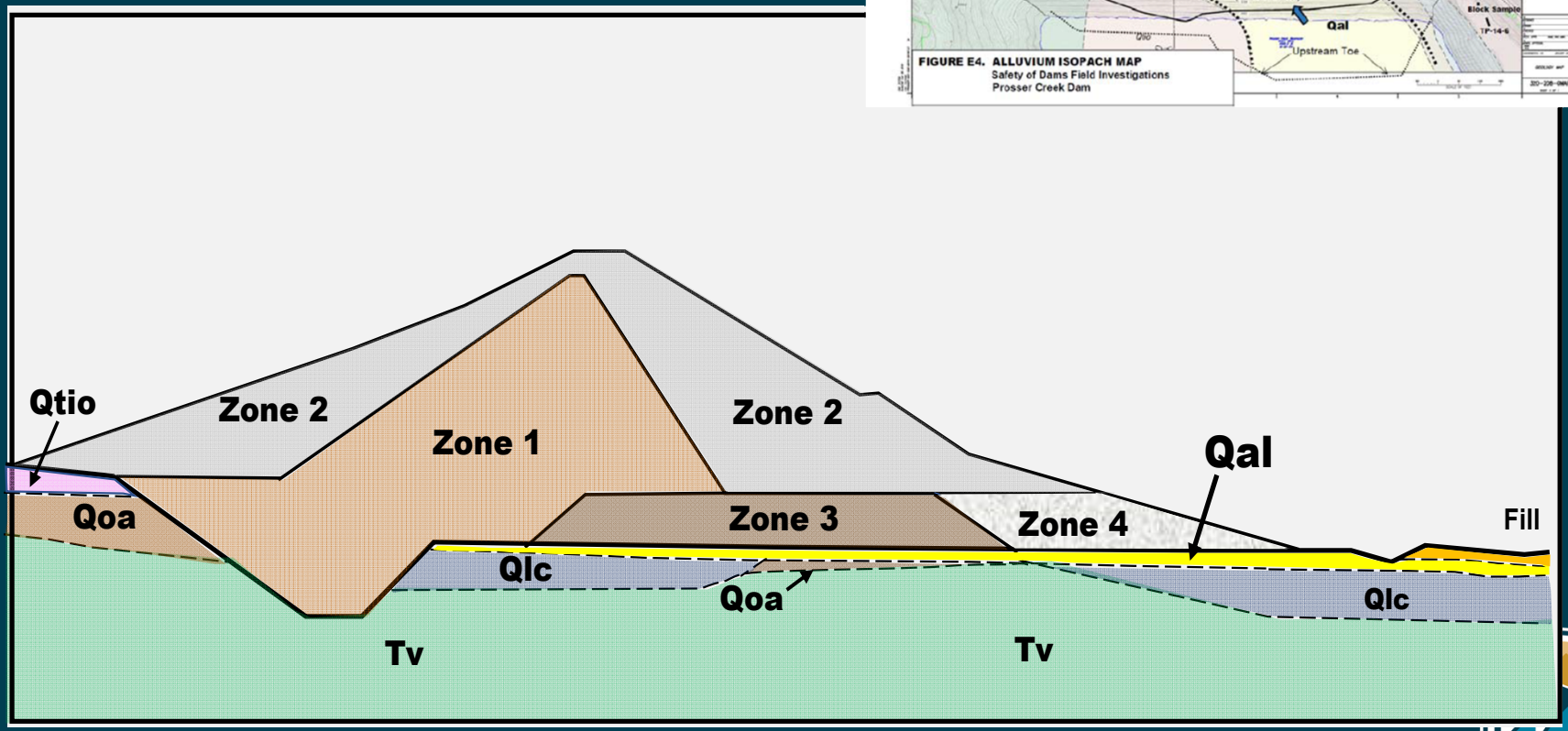
Site geology





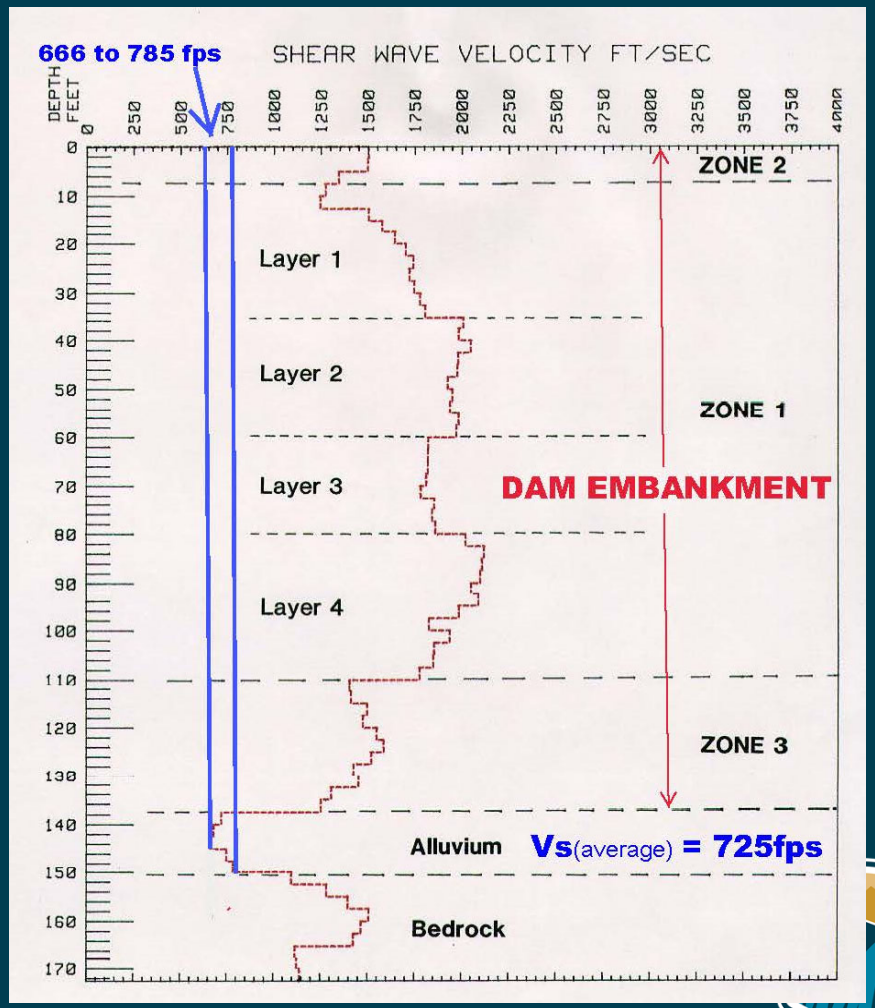
Site geology





1980s SEED investigations

- 12 Mud Rotary drill holes with SPTs
  - Generally high Qal blow counts, but gravel interference considered a possibility
- Crosshole geophysics
  - Zone of comparatively low V_s below embankment contact interpreted as Qal



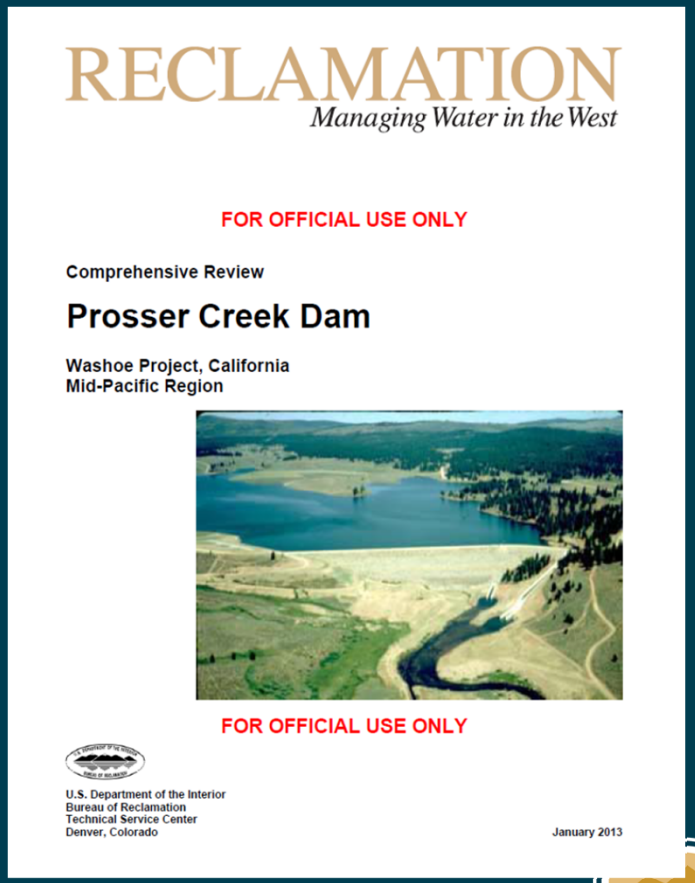
One valley to the east …

Boca Dam

- Qal layer was deposited in a similar geologic environment as the one at Prosser
- Nagging SEED study concerns
- Issue Evaluation focused on Qal layer commenced in ‘90s
- Corrective Action Study (CAS) commenced in 2008
- Final design initiated in 2014
- Modification completed in 2020 (shear key through Qal)

Prosser Creek Dam 2012 CR

- Undertaken in the midst of the Boca CAS
- Awareness of similarities in foundation conditions
- Very little site-specific data
  - 1988 geophysical investigation (drop in V_s below fnd. contact)
  - 1984 SPTs (with recognized high gravel contents)
- Increase in seismic loadings since the previous CR


RECLAMATION
Managing Water in the West

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Comprehensive Review

Prosser Creek Dam

Washoe Project, California
Mid-Pacific Region

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U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

January 2013

Prosser Creek Dam 2012 CR

- Liquefaction-induced crest loss was identified as the highest risk contributing potential failure mode
- It was recognized that uncertainty in foundation properties had the potential to impact the dam safety case (low confidence in portrayal of risk)
- Two Safety of Dams recommendations were issued on the basis of low confidence
  - 2012-SOD-A: Perform an exploration program to better define the properties of the foundation materials
  - 2012-SOD-B: Re-evaluate the risks of the seismic potential failure modes upon completion of 2012-SOD-A

Issue Evaluation initiated in 2013

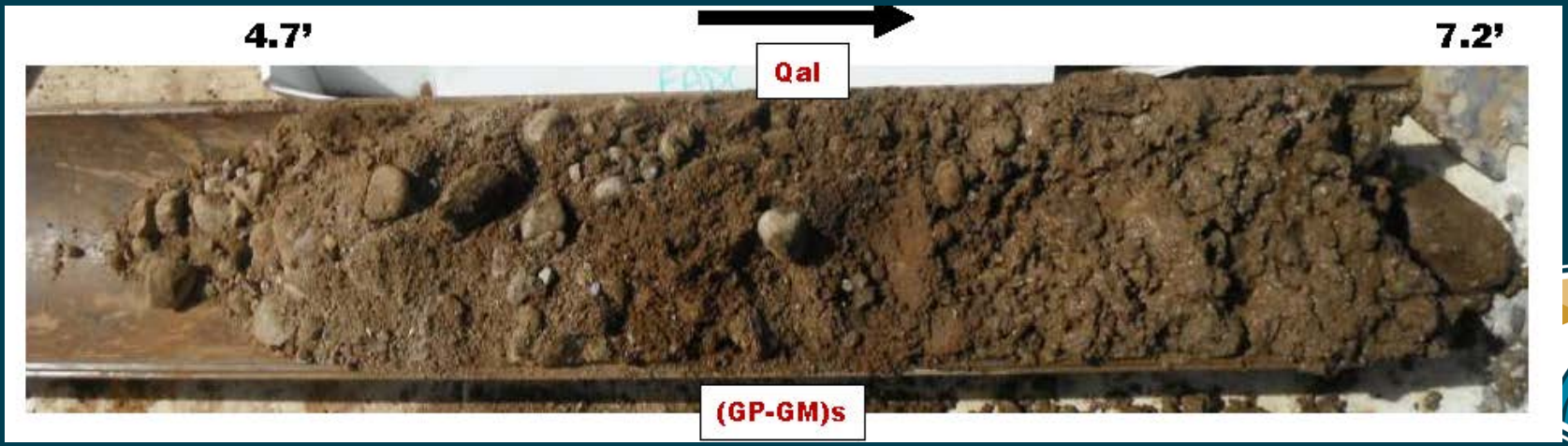
- Phased Field Exploration Request (FER) developed
- Team lead was aware of the extent of the deformation modelling (FLAC) that had been performed for Boca
- In anticipation of similar FLAC modeling at Prosser Creek, the Phase 1 FER was focused not just on the Qal layer but on other foundation units as well

2015 Test Pits

2015 FADC boreholes (w/SPTs)

Issue Evaluation Continued

- In early 2015, the Issue Evaluation was reassigned
- The new team lead also had some background on Boca, but more extensive RIDM experience
- New TL participated in a site visit and observed that the Qal materials in the FADC boreholes did not appear “classically” liquefiable



Issue Evaluation Continued

- With the Phase 1 investigations winding down, the next step would be to develop the Phase 2 FER
- However, the TL was starting to believe that there was already enough information to re-evaluate the risk estimates reported in the 2012 CR
- TL believed that even without any analysis results, the key risk estimates would be reduced to the extent that the 2012 SODs could be completed
- Peer reviewer disagreed, believing that the investigations performed to date had not reduced the uncertainty enough

Arguments against any additional field investigations (TL viewpoint)

- The observation that the Qal is only partially saturated suggests that excess pore pressures could be effectively dissipated into the unsaturated Qal
- The Qal materials extracted from the FADC boreholes and from the test pits are likely too coarse to experience flow-slide instability
- Compared to structural height, there is significant freeboard at this facility, ranging from [lots] at the 50% pool to [slightly less] at the 10% pool
- The 3D geometry of the dam and Qal unit make large deformations unlikely

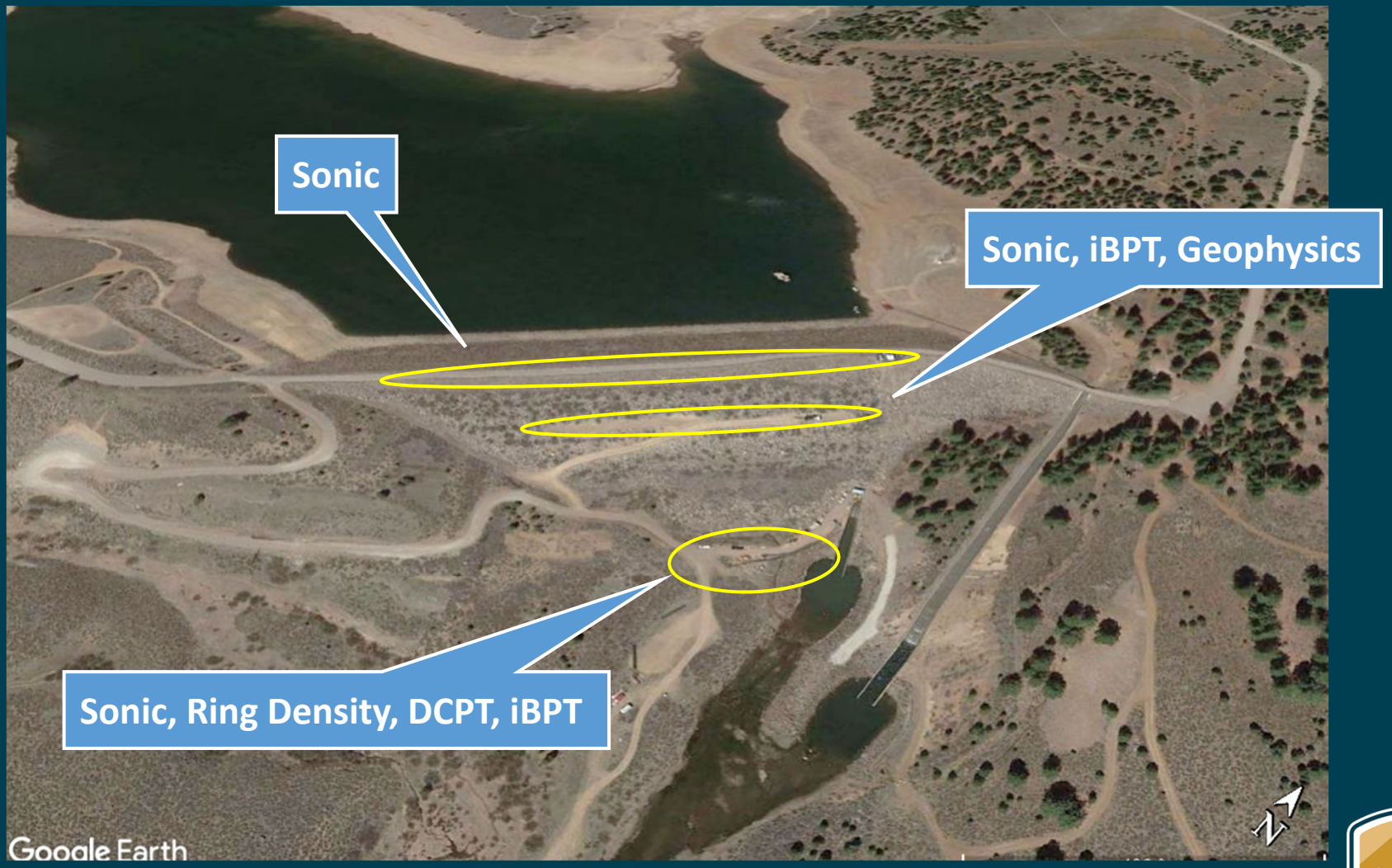
Arguments for additional field investigations (PR viewpoint)

- Decently sized dam/reservoir located upstream of a major population center
- If large deformations were possible, an infrequent pool could still control the risk
- There will continue to be significant uncertainty unless enough information is collected to do a formal liquefaction triggering analysis
- Boca Dam was in the process of being modified for a similar issue; without additional data, could Reclamation reasonably explain why Prosser Creek Dam was being treated differently?

Decision to continue with seismic evaluation

- As a compromise, TL proposed some limited additional field exploration targeting the Qal
- The question of whether to go beyond that was put directly to Reclamation's EQ engineering expert
- Advice was to continue with a more robust suite of investigations, including iBPT, which had just been incorporated into design standard DS-13-13
- Phase 2 FER ended up including a number of investigations focused on the liquefaction potential of the Qal, but also reflected the TL's view that a deformation analysis would not be required

Phase 2 Investigations (2017)

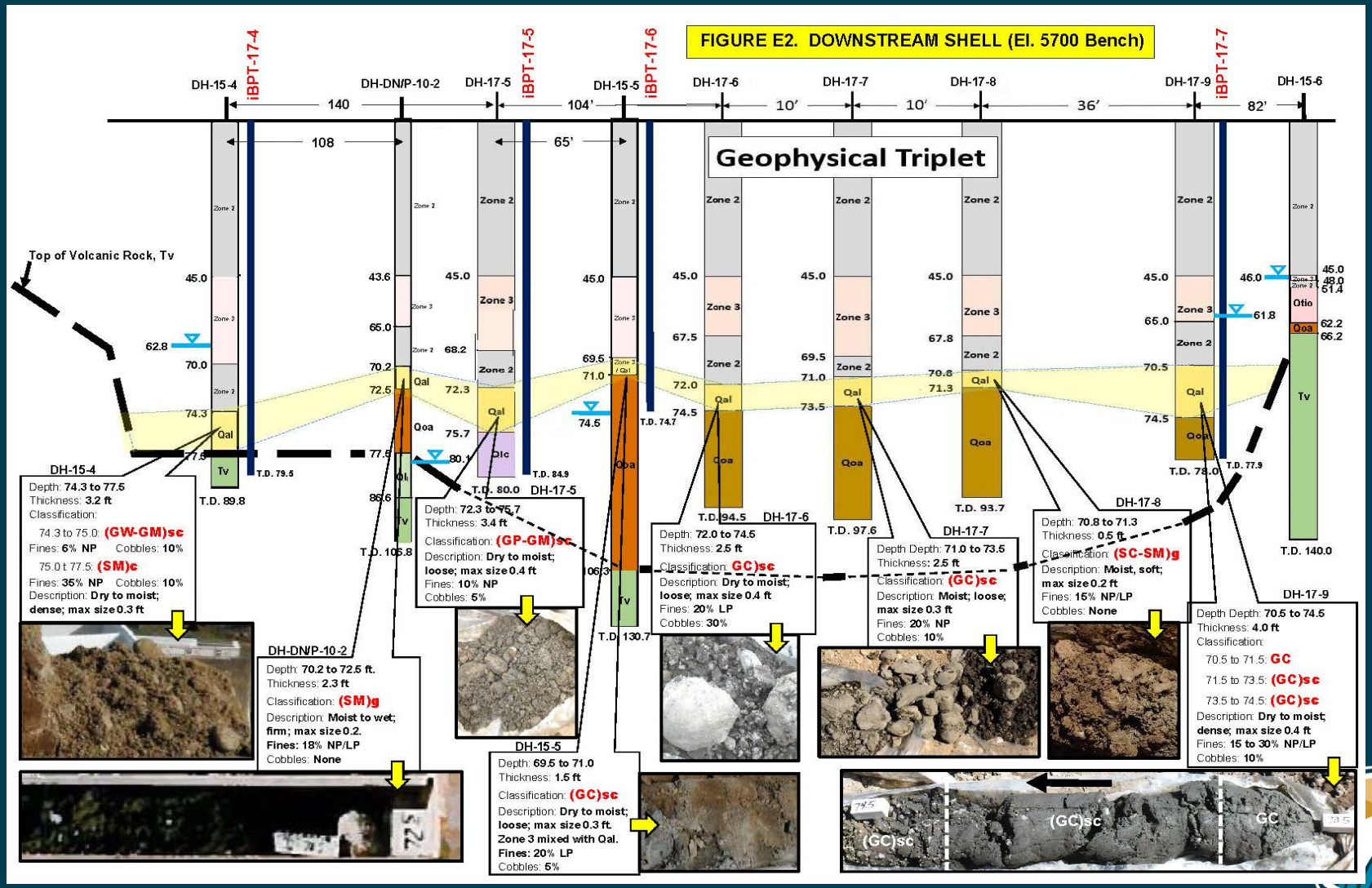


Sonic drill holes

- Basic purpose: Evaluate the continuity of the Qal in areas where there were no or limited prior mud-rotary or FADC holes
- Allowed for logging adjacent to iBPT holes
- Added benefit: visual observations and gradations from bag samples of the Qal

Typical bag sample

Sample data presentation



Ring density tests

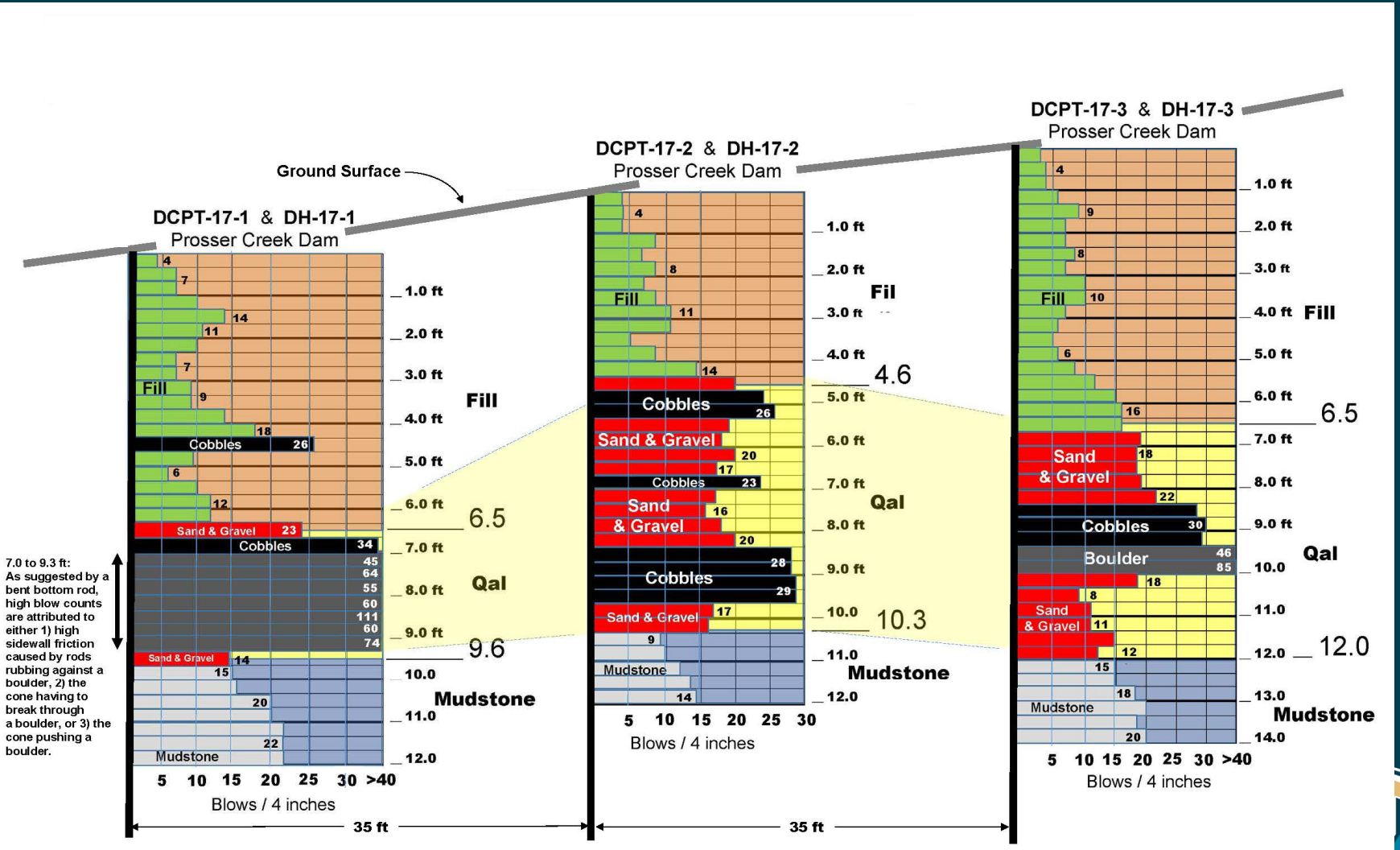
- Basic purpose: establish in-place densities for the more easily accessible Qal near the toe of the dam
- (Material is too coarse for sand cones or <6’ RDTs)
- Added benefit: visual observations and a greater appreciation for how dense the Qal materials are in situ

Ring density tests

DCPT ("Chinese Cone")

- Basic purpose: Satisfy curiosity
  - Often described as an inexpensive and simple way to gauge in place density
  - Reference: Cao, Youd, and Yuan (2013)
- A Reclamation employee in Provo, UT, was doing research on the DCPT platform and the Provo drill crew was familiar with the equipment
- This was the first Reclamation project where the DCPT was used as part of a dam safety investigation

Sample data presentation



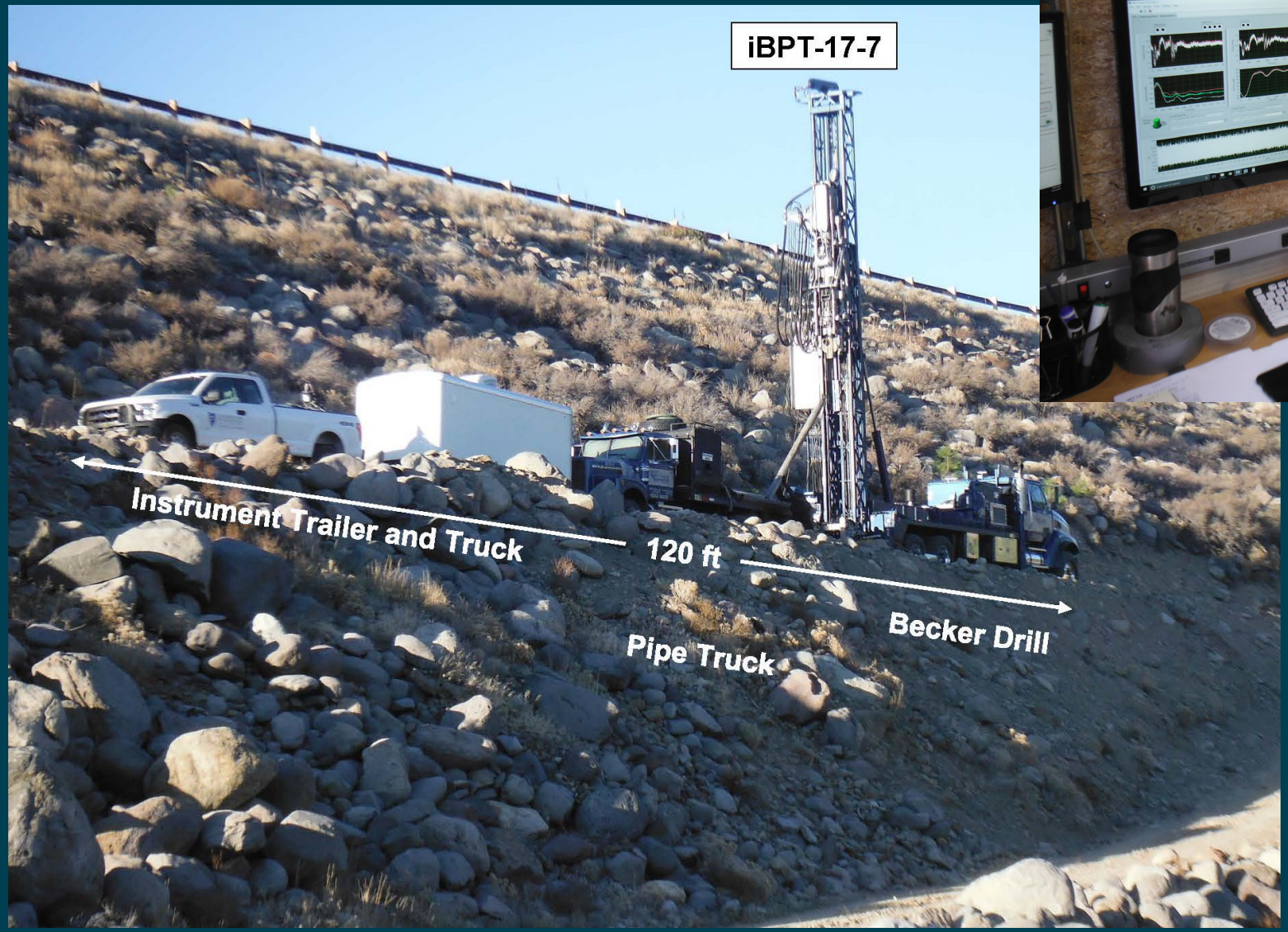
iBPT: Rationale for using

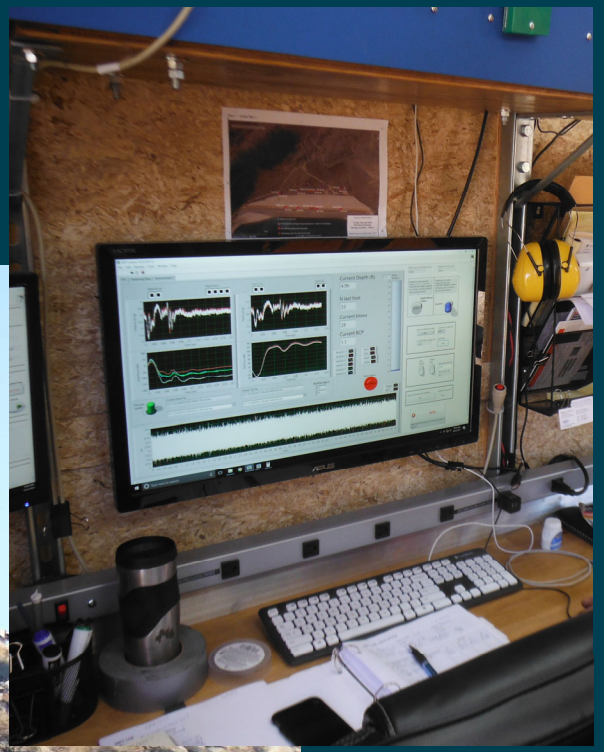
- SPTs performed in gravelly soils can be unreliable because the plugging of the sampler can lead to inflated blow counts
- Historically, the solution has been to perform Becker Penetration Testing (BPTs) in such soils and then convert the results to equivalent SPTs
- The BPT drill string does not have an open bit and so cannot be plugged by gravel. However, the friction along the drill string increases with depth
- Different BPT-SPT correlations use different approaches to account for the shaft friction

iBPT: Rationale for using

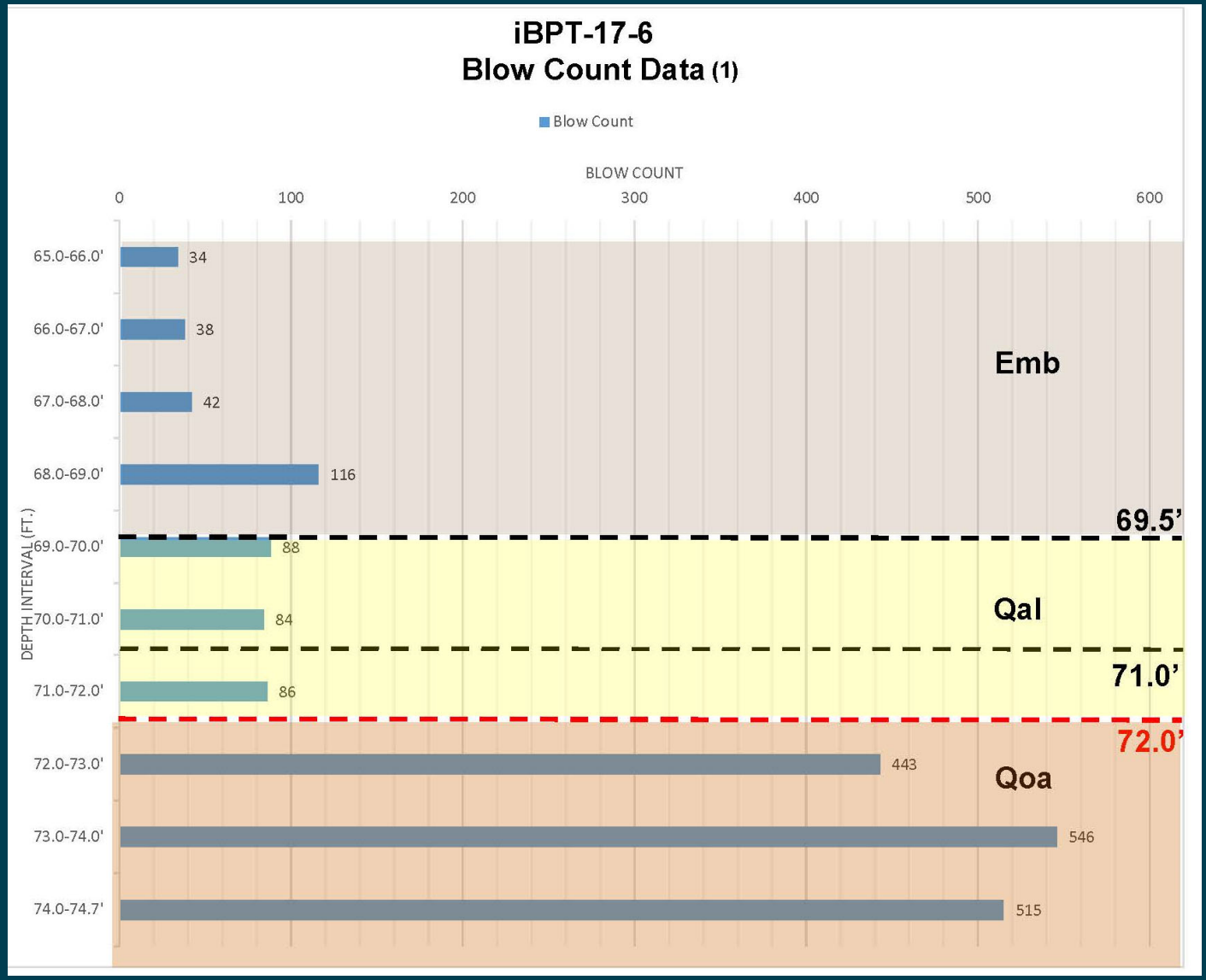
- The iBPT platform addresses shaft friction by measuring energy at both the top and bottom
- Embedded sensors transmit the information to the equipment operator in real time
- The system was originally developed by researchers at the University of California, Davis
- Verification testing using SPTs allowed them to develop a linear correlation : SPT $N_{60} = 1.8N_{B30}$
- References:
  - Ghafghazi et al (2017), ASCE Geotechnical J, 143(9)
  - DeJong et al (2017), ASCE Geotechnical J, 143(9)

iBPTs


iBPT-17-7
Instrument Trailer and Truck
120 ft
Becker Drill
Pipe Truck



Sample data presentation

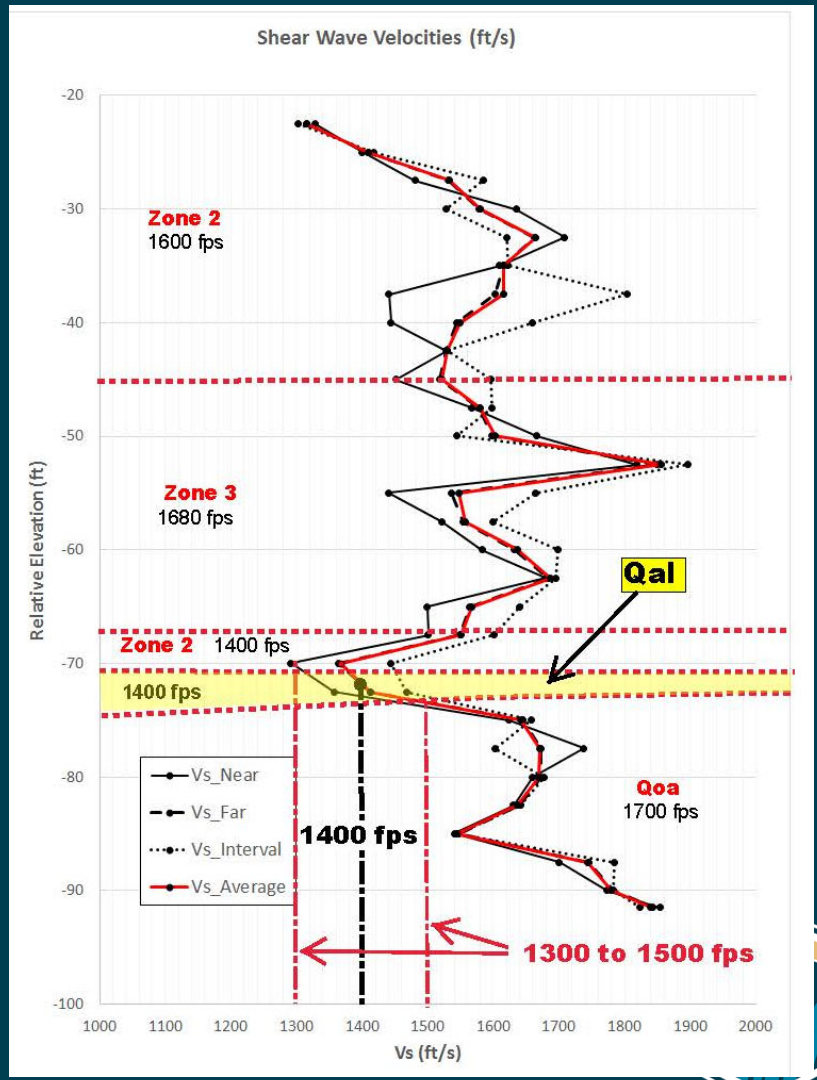


iBPT data analysis

- Corrected (converted) blow counts were used in a liquefaction triggering analysis (Seed simplified)
- None of the Qal materials encountered were found to be susceptible to liquefaction
- Although a dynamic response analysis was not performed in calculating the CSR (r_d only), the corrected blow counts are high enough (>34) for the results to not be sensitive to the CSR
- Although some potential for triggering was indicated in the Qls (located below the Qal), mudstone is not susceptible to liquefaction

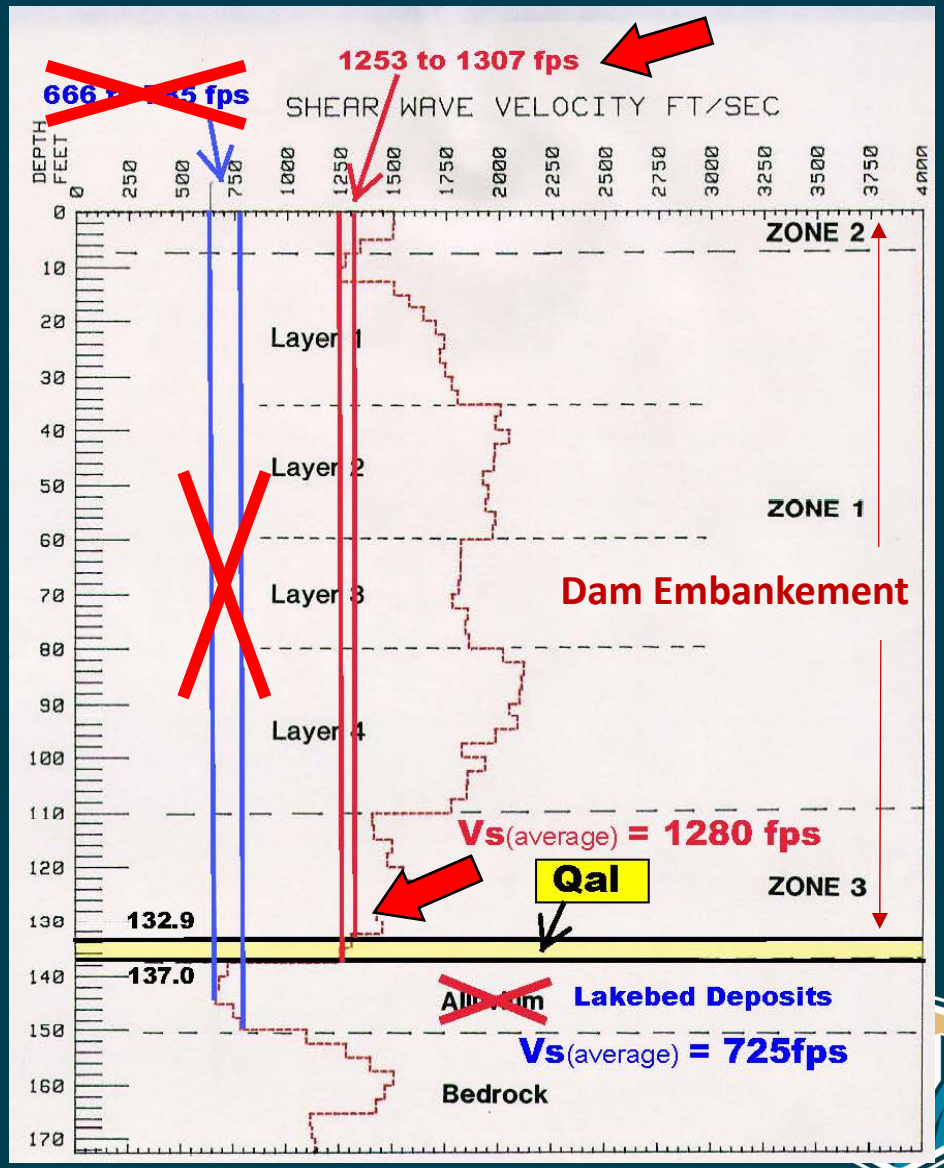
Crosshole geophysics (2017)

- Basic purpose: Verify the low Qal shear wave velocities from 1988
- Correlate shear wave velocities with the updated stratigraphy
- Measured 2017 Qal V_s was about twice as high as reported in 1988, a few hundred feet to the east (where there were now additional sonic holes)



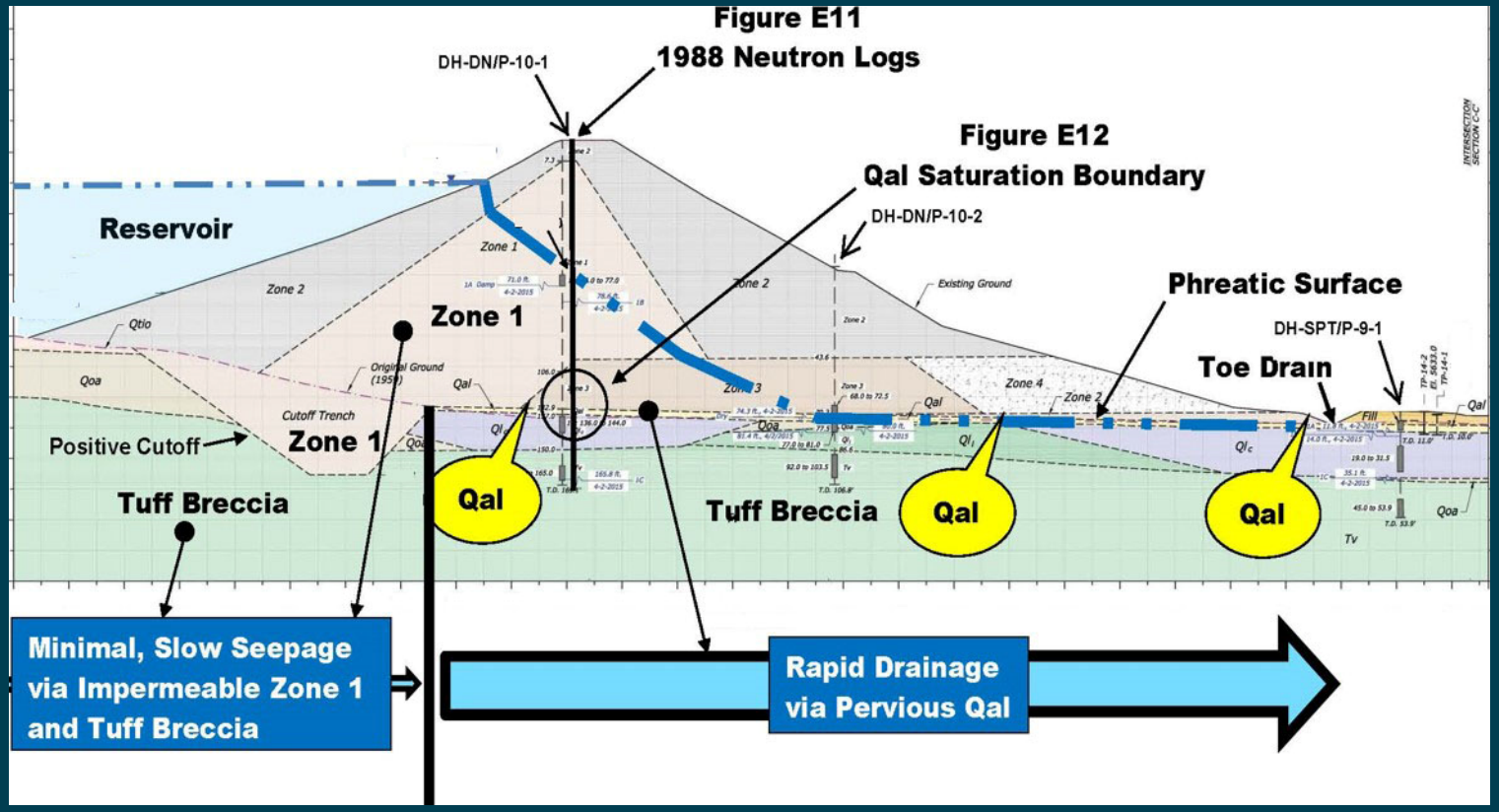
1988 crossholes revisited

- Updated stratigraphy called into question whether the 1988 low velocity zone was truly within the Qal
- 2017 reinterpretation suggested it was actually within the Qlc unit, which consists of the soft (but fully indurated) mudstone



Groundwater interpretation

- Qal samples from drill holes logged as dry to moist
- Upper three feet of Qal dry to moist in test pits
- Qal did not appear to be fully saturated anywhere



Dam safety case for closing out the Issue Evaluation (2018)

- Based on the results of the iBPT investigations and consistent with those of the other investigations, Qal materials below the downstream shell are likely not susceptible to liquefaction and strength loss.
- Enough data has been collected on the downstream Qal unit for the conclusions of the investigations to be considered representative of that area.
- Even if the iBPT results are not representative of the *upstream* Qal, the upstream-cheated cutoff trench provides a shear key in that direction and upstream slope instability is considered unlikely.

Dam Safety Case

- The freeboard at the dam is significant, ranging from [some] at the 10% pool to [lots] at the 50%. Even with some liquefaction, deformations would likely not be sufficient to exceed freeboard.
- The 3D geometry of the dam (located at a bend in the creek, buttressed by a ridge on the right side) and the downstream slope configuration (4:1 berm section below 2:1 slope) are conducive to stability.
- *Absent* liquefaction, it would be implausible for enough deformation or settlement to occur to result in the overtopping of the dam.

Dam Safety Case

- Prior to the Issue Evaluation, the most compelling adverse information on the Qal was that the shear wave velocity could be comparatively low.
- Based on detailed borehole logging performed as part of the 2017 Issue Evaluation, it appears likely that the "low" 1988 shear wave velocity is actually associated with the underlying Qlc mudstone.
- It is not known why the Qal at Boca was less dense, despite being deposited in a similar environment. However, the investigations have shown that the Qal materials at Prosser are relatively dense.

Conclusions on site investigations

- Data obtained from geophysics and penetration testing is most meaningful when it can be placed within (and shown to be consistent with) the broader geologic context.
  - The numbers alone can be misleading if they are not associated with the right stratigraphic unit.
  - When the field testing does not yield samples, twinned FADC or Sonic boreholes can provide a good means of establishing site stratigraphy & foundation unit continuity
- When investigating shallow subsurface conditions (surface to 20 feet), test pits can be a good option.
- The cost of a comprehensive site evaluation can be small compared to the cost of modifying a dam.

Questions