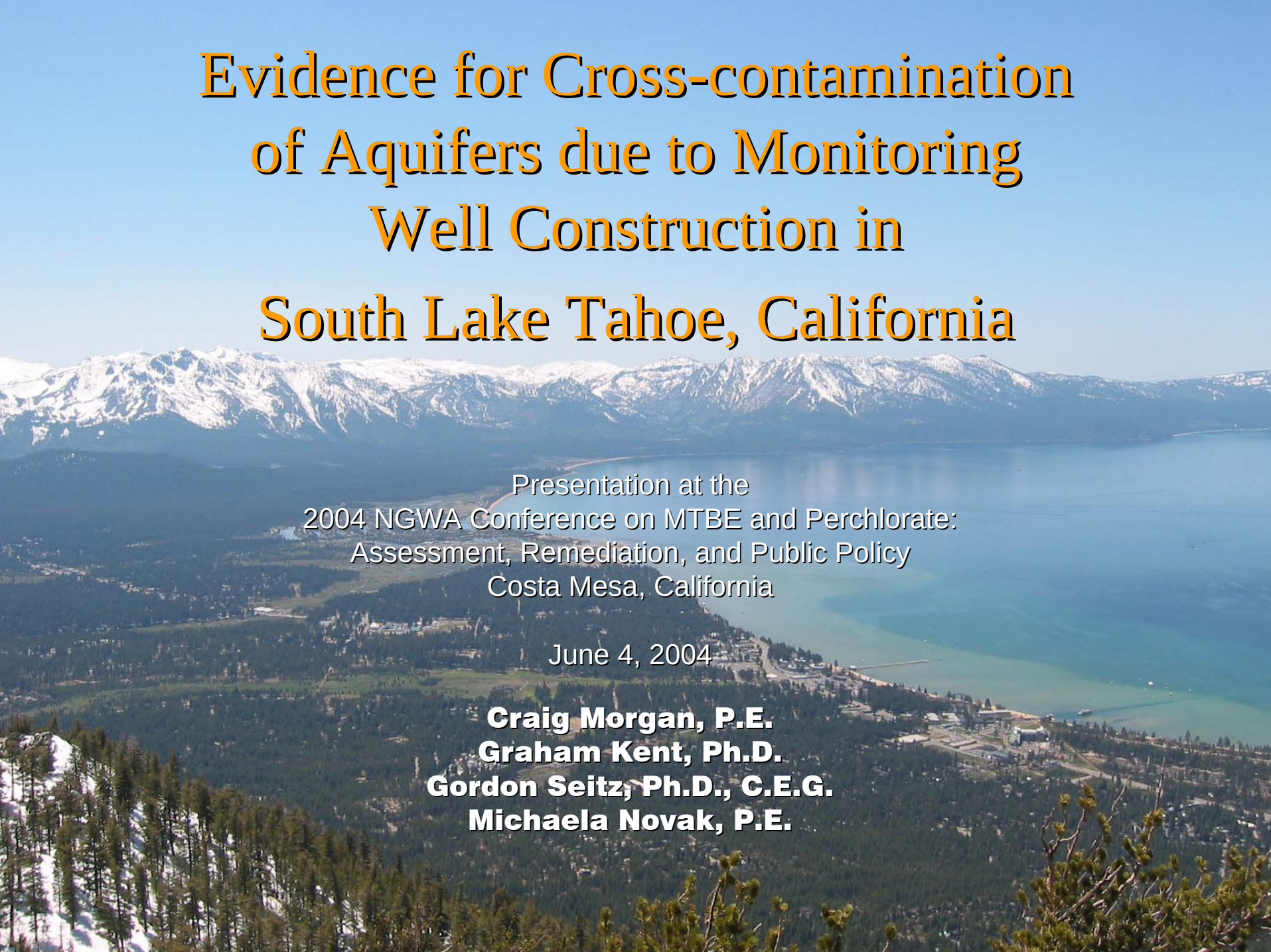
Evidence for Cross-contamination of Aquifers due to Monitoring Well Construction in South Lake Tahoe, California



Presentation at the
2004 NGWA Conference on MTBE and Perchlorate:
Assessment, Remediation, and Public Policy
Costa Mesa, California

June 4, 2004

Craig Morgan, P.E.
Graham Kent, Ph.D.
Gordon Seitz, Ph.D., C.E.G.
Michaela Novak, P.E.

Presentation Outline

- Well Bore Flow Dynamics
- Project Area Description
- Geologic Setting
- Hydrogeologic Observations
- Conclusions
- Recommendations

Well Bore Flow Dynamics

Concepts

•Natural vertical hydraulic gradients exist in groundwater bodies.

•Well and boring installations provide a “short-circuit” across these natural gradients and act as preferential conduits for groundwater flow.

•Natural groundwater flow through a well bore is often referred to as “ambient flow”.

•Flow rates are proportional to the hydraulic gradient and the diameter of the bore hole.

• Significant ambient flow can occur even under small gradients.

• Monitoring wells and improperly sealed bore holes often serve as conduits through which contaminants may migrate between aquifers.

Well Bore Flow Dynamics

Numerical Modeling of Flow Across an Aquitard

Lacombe et al., 1995 *Influence of leaky boreholes on cross-formational groundwater flow and contaminant transport*

Groundwater and Contaminant Flow Model

- *Bore hole flow across an aquitard*
- *Low hydraulic head (0.5 m difference)*
- *High hydraulic head (5 m difference)*
- *Sand filled borehole*
- *Open borehole*
- *Location of borehole*
- *Predicted borehole flow rates and contaminant transport*

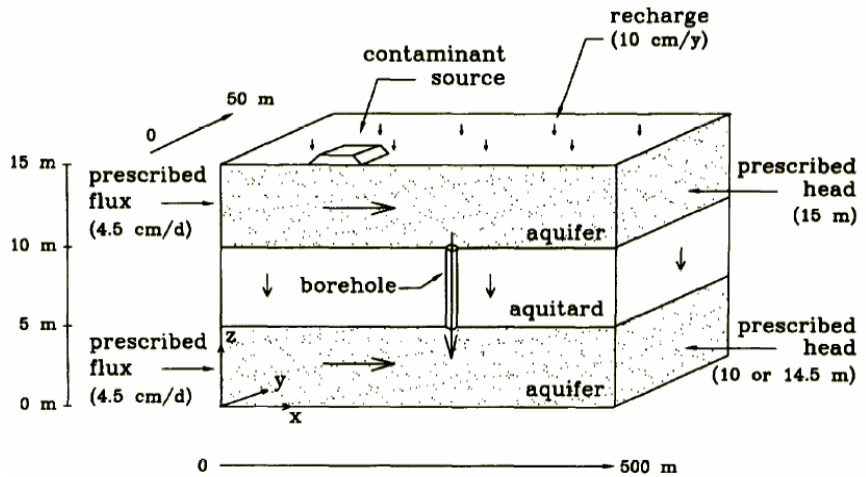
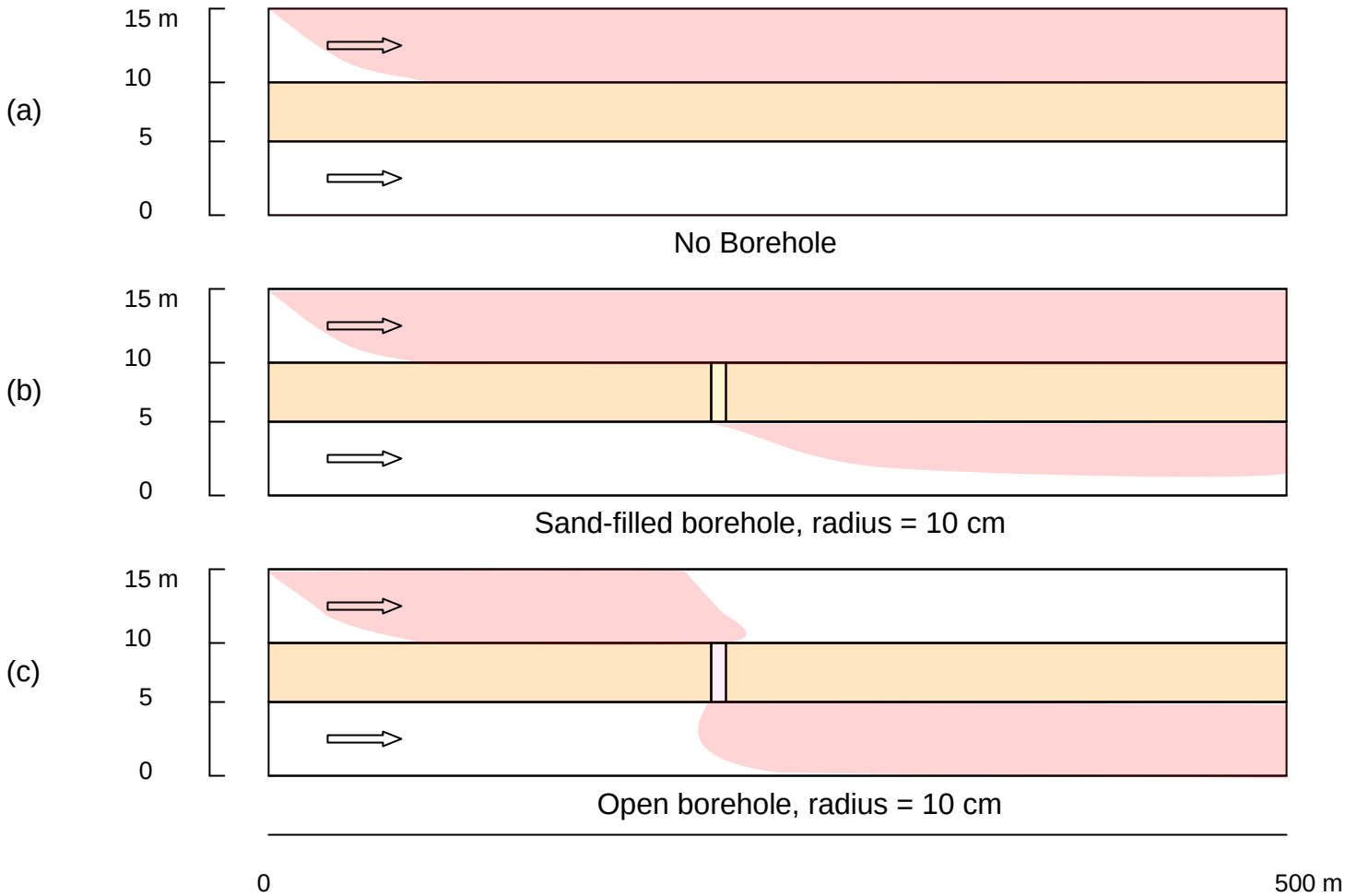


Table 1. Physiochemical Properties

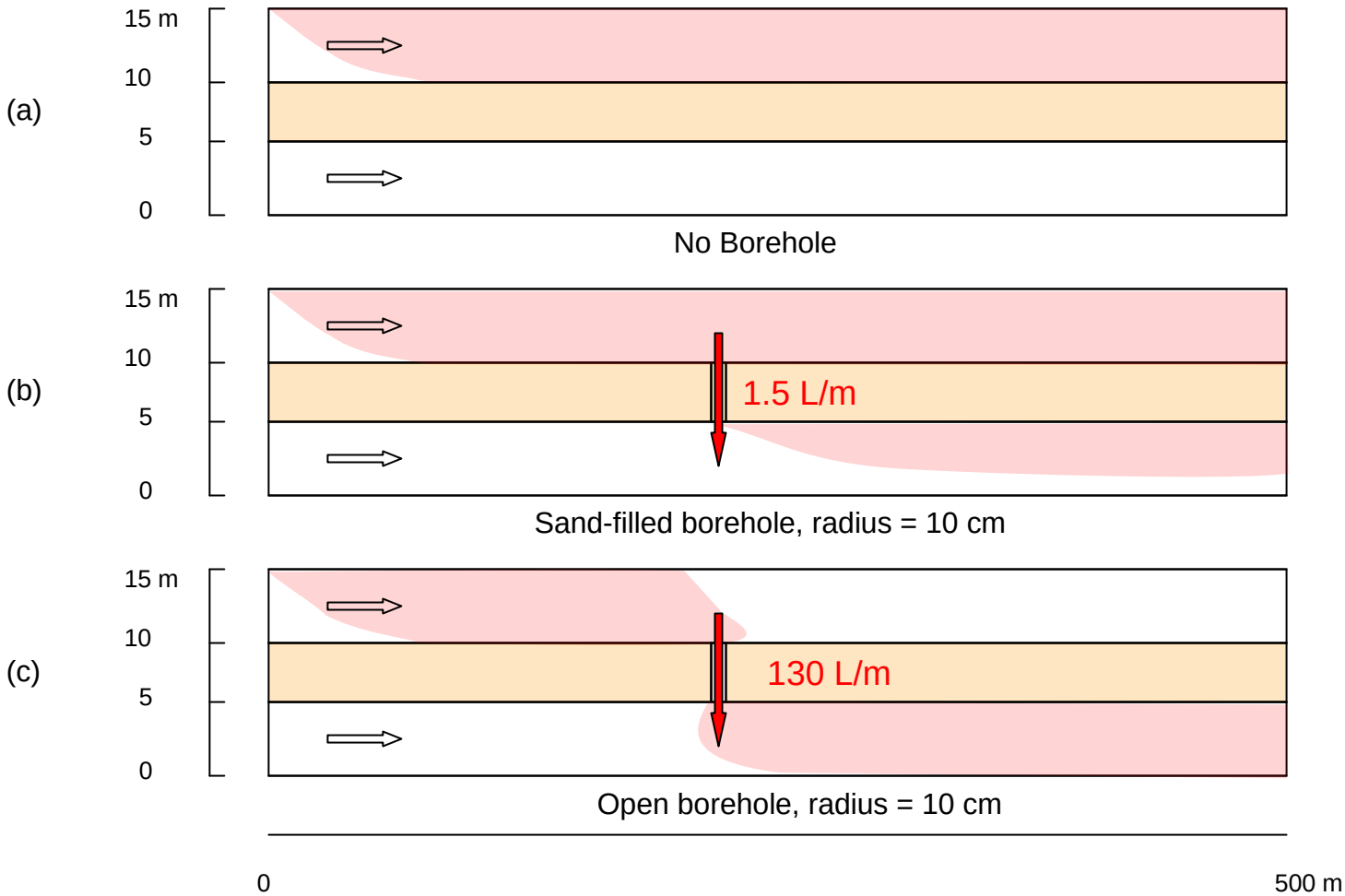
Parameter	Aquifer	Aquitard
Hydraulic conductivity (K)	2.0×10^{-4} m/s	1.0×10^{-10} m/s
Specific yield (S_y)	0.2	...
Specific storage coefficient (S_s)	1.0×10^{-4} m^{-1}	1.0×10^{-2} m^{-1}
Porosity (ϕ)	0.35	0.65
Dispersivity		
α_l	0.5 m	0.0 m
α_h	0.05 m	0.0 m
α_v	0.005 m	0.0 m
Free solution diffusion coefficient (D_0)	1.8×10^{-5} cm^2/s	1.8×10^{-5} cm^2/s
Effective diffusion coefficient (D^*)	1.2×10^{-5} cm^2/s	3.6×10^{-6} cm^2/s
Retardation factor (R)	1.0	1.0

Well Bore Flow Dynamics



Contaminant plume after 15 years with high hydraulic gradient across aquitard for (a) no borehole, (b) sand-filled borehole, and (c) open borehole. Concentration isosurface is for $c/c_o = 10^{-4}$, vertical exaggeration is ~5 times. (Reference: Lacombe, et al., 1995)

Well Bore Flow Dynamics



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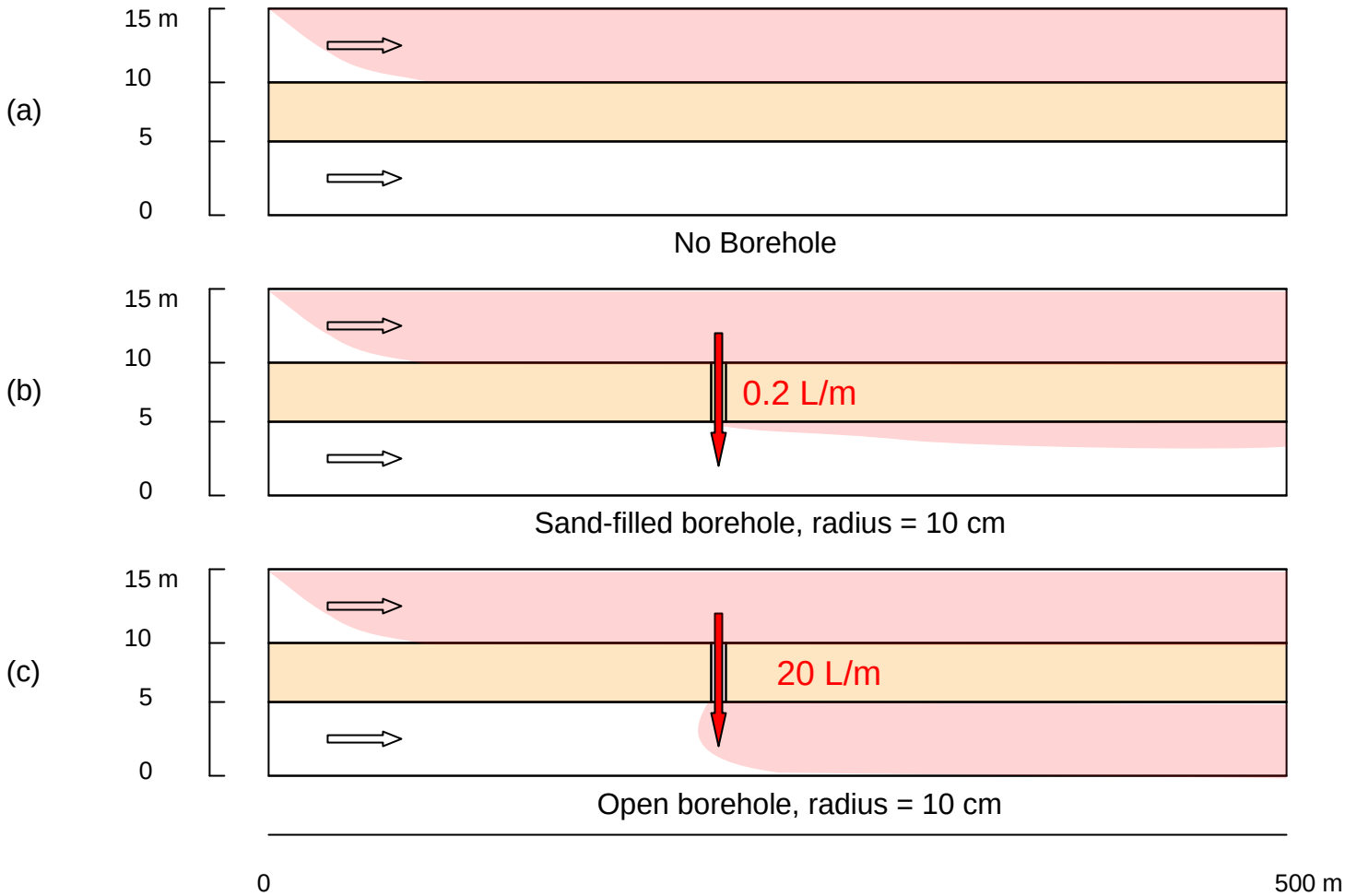
Well Bore Flow Dynamics



Contaminant plume after 15 years with low hydraulic gradient across aquitard for (a) no borehole, (b) sand-filled borehole, and (c) open borehole. Concentration isosurface is for $c/c_o = 10^{-4}$, vertical exaggeration is ~5 times. (Reference: Lacombe, et al., 1995)

Well Bore Flow Dynamics

Summary of Documented Ambient Well Bore Flow[1]				
Reference	Location and Type of Aquifer, Type of Medium	Direction of Ambient Flow	Screen Length (meters)	Maximum Ambient Flow (L/min)
Boman et al. (1997)	[2]Louisiana BAP; clay, silt and sand mixtures	Downward	6.71	0.015
	Louisiana BAP2	Downward	6.7	0.031
	Aiken, SC; confined K_{avg}=5.7 m/day	Upward	12.2	0.26
Molz et al. (1994)	Mobile, AL; confined; fluvial sediments, medium sand with silt and clay fines	Upward	21.5	3.1-3.6
	Mobile, AL (deeper well); confined	Mixed	20	1.75
Hutchins and Acree (2000)	[2]Eglin AFB, FL; unconfined, sand and gravel, K=9.1-42.7 m/day	Downward	3.1	0.30
Church and Granato (1996)	Massachusetts; unconfined, sandy, K = 1-15 m/day	Upward	18	0.48
	Massachusetts; unconfined, sandy, K = 1-50 m/day	Mixed	21	0.04
Crisman et al. (2000)	Aiken, SC; unconfined, sand and clay, K = 0.35 m/day	Upward	4.2	0.34
Waldrop (unpublished)	Coastal Virginia, confined	Downward	5.8	0.276
	Central Ohio, unconfined	Upward	12.6	6.22
	Western Texas	Downward	9.1	2.3
	Idaho, unconfined	Upward	56.6	1.03
	Central Louisiana	Mixed	21.3	0.57

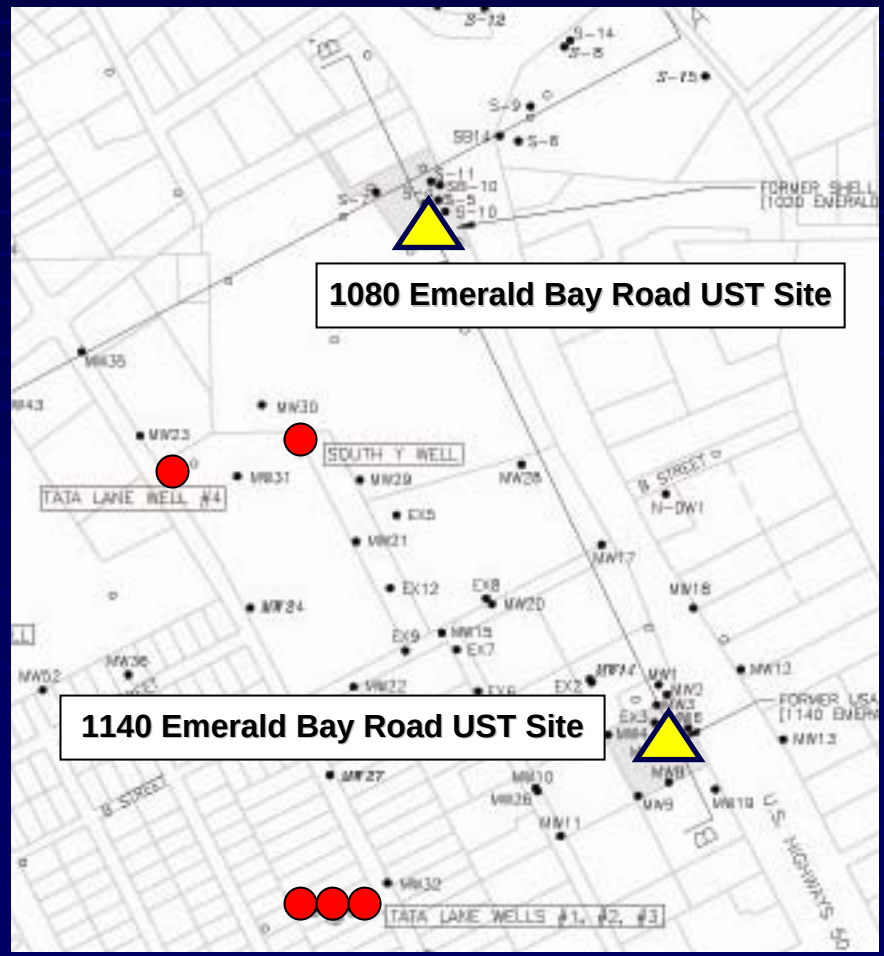
[1] For most of the wells, whether the well screen penetrated the aquifer fully was not documented. The five wells measured by Waldrop are a selected group out of 142 wells at 16 sites.

[2] Known fully penetrating monitoring wells.

Reference: Elci, et al. (2001)

Project Area Description

- In 1996, MTBE was detected in one of STPUD's wells in the "South Y Area".
- Concentrations of MTBE were later recorded in four other wells.
- Fall 1998 – Six of the wells in the "South Y Area" were shut down. Ultimately, 13 of 34 wells across the entire south shore area were shut down due to contamination or threat of contamination.
- 9 of the 34 municipal wells in 1997 were located in the "South Y Area".



Project Area Description

Former USA Station
1140 Emerald Bay Road UST Site

Petroleum release first reported in 1985.

1985 - Seven monitoring wells were installed.

1991 – Three additional monitoring wells installed.

1995 to Present – Further site investigations.

1998 – Groundwater Remediation Begins.

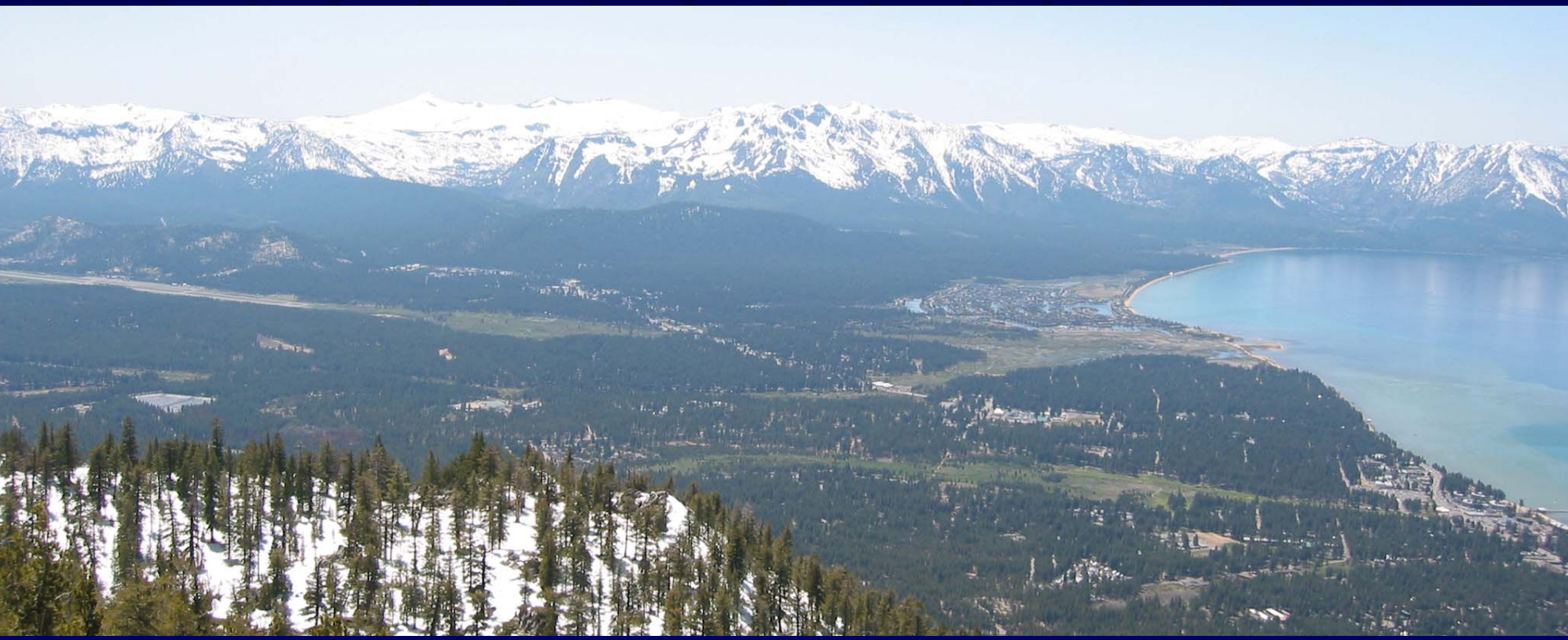
Former Shell Station
1020 Emerald Bay Road UST Site

Petroleum release reported in 1998.

1998-1999 – Fifteen monitoring wells installed

1999 - Groundwater Remediation Begins.

Geologic Setting



- The geology at the south shore of Lake Tahoe consists of alternating successions of depositional units associated with lacustrine, fluvial, and glacial processes.

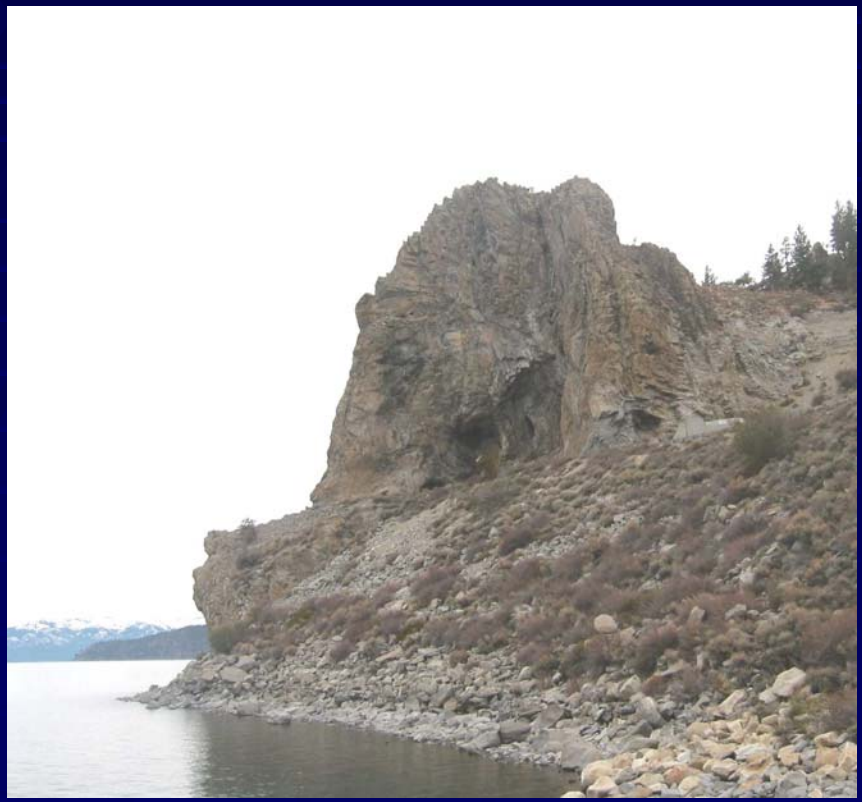
Geologic Setting

Pleistocene Glaciation

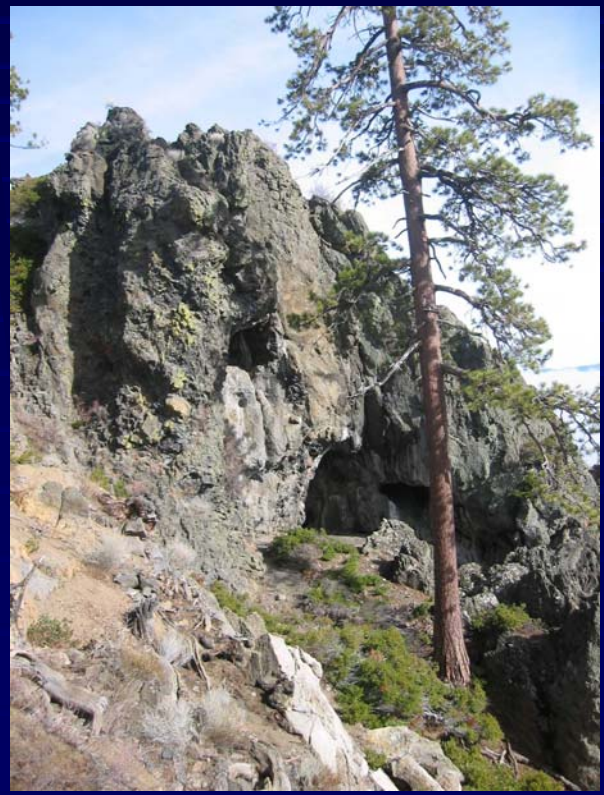
- Series of lake high stands above present elevations (1898 m MSL) resulting from glacial damming of the lake outlet during Pleistocene glaciations: Hobart, Donner, Tahoe, and Tioga glaciations. (Up to 186 m higher than present)
- Both proximal and distal glacial deposition on south shore during glaciations.
- Periods of lake high stands allow the deposition of laterally extensive less permeable silt and clay layers.

Geologic Setting

Lake High Stands



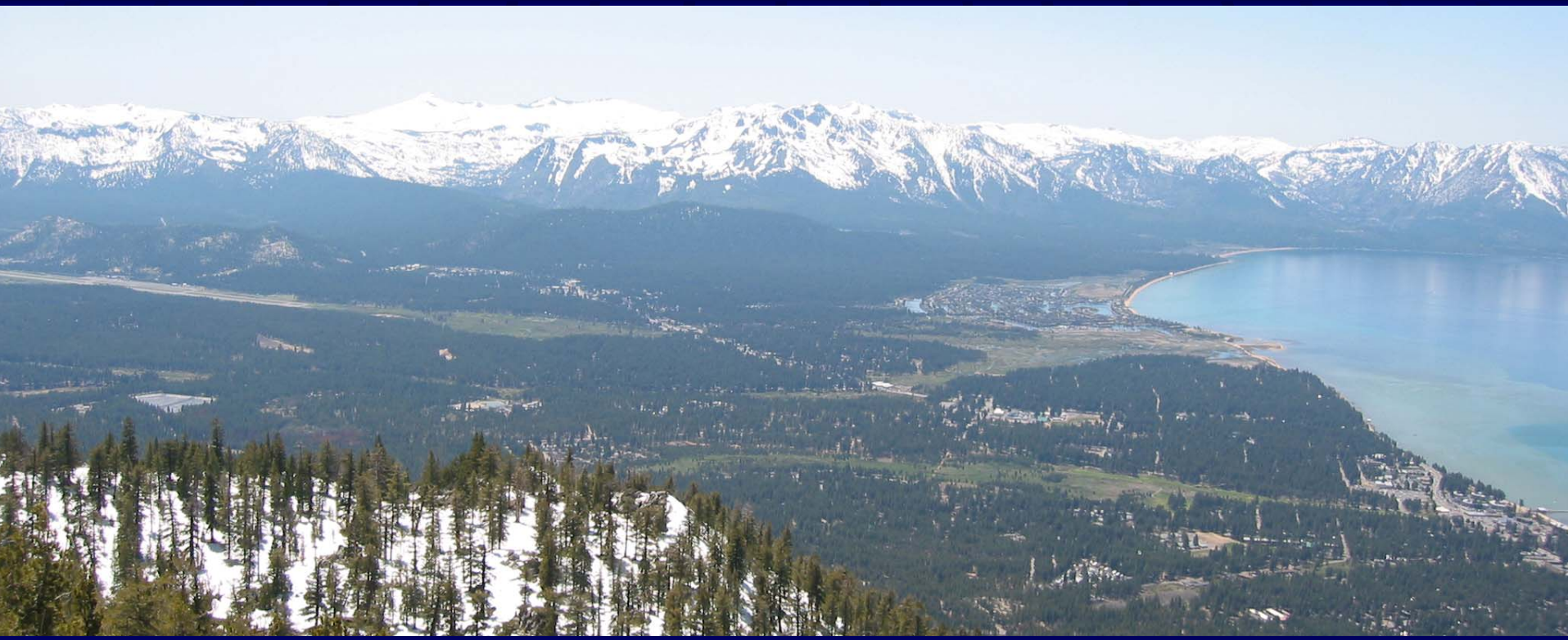
Wave cut notch elev. 1937 m
Cave Rock, east shore



Wave cut notch elev. 1967 m
Eagle Rock, west shore

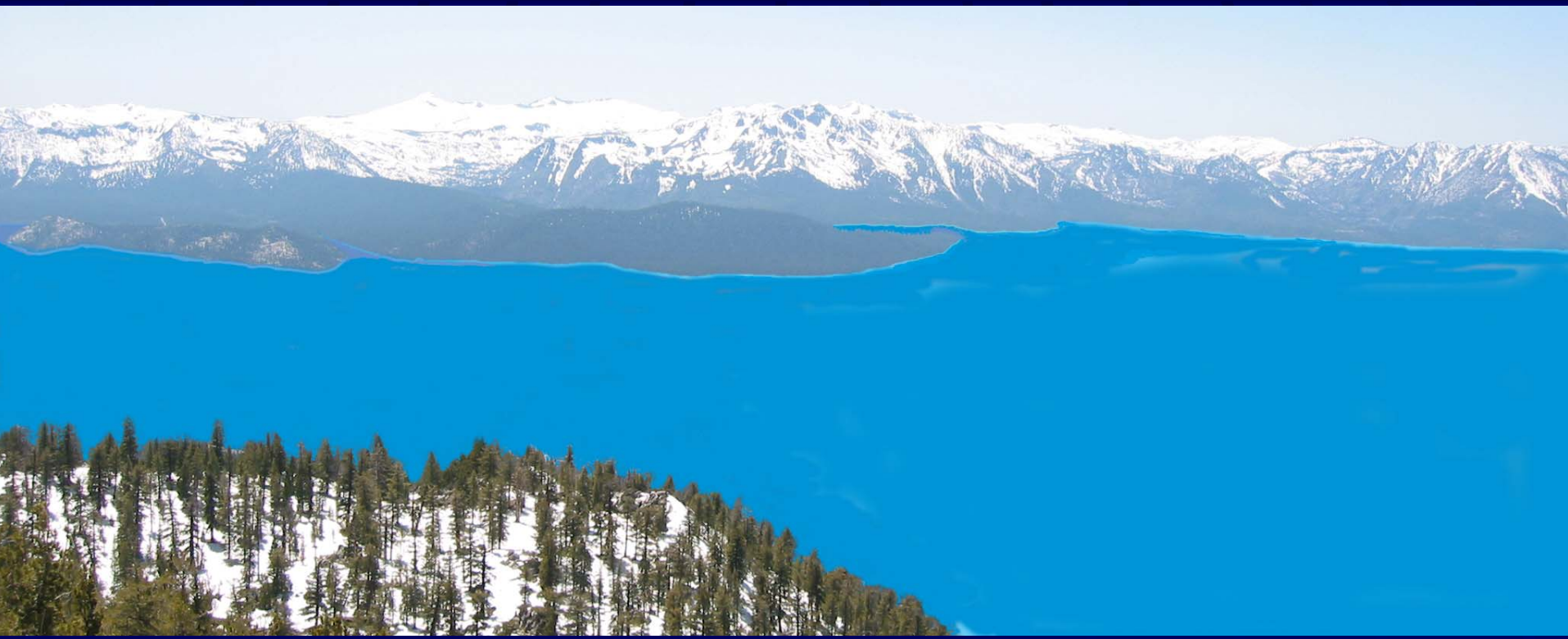
Geologic Setting

Lake High Stands



Geologic Setting

Lake High Stands



Geologic Setting

Lacustrine Silt and Clay Deposits

Borrow west of airport pit elev. 1950 m

Upper Truckee River at Hwy 50 elev. 1902 m

Borrow west of airport pit elev. 1950 m

Upper Truckee River east of Airport elev. 1905 m

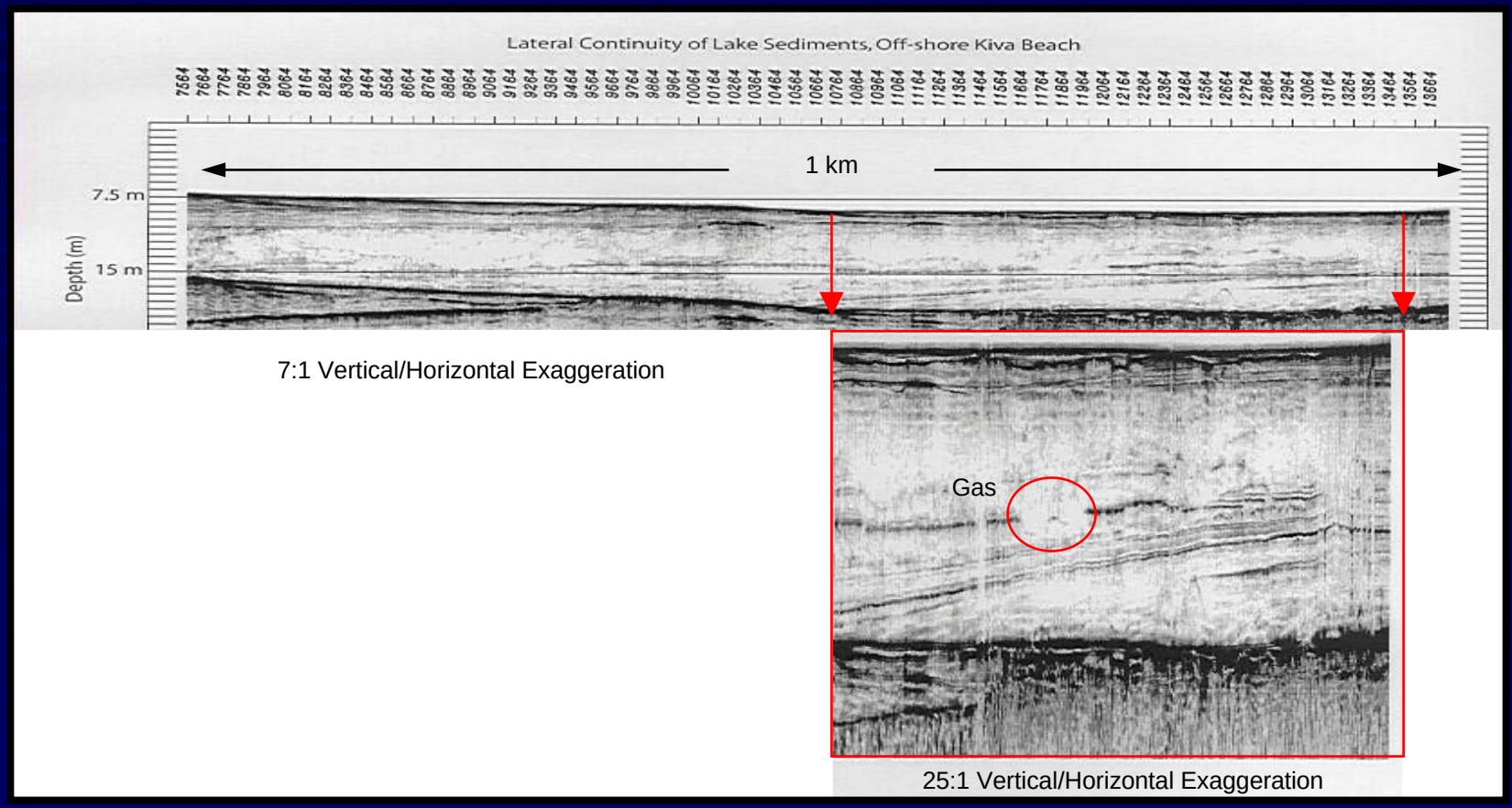
Geologic Setting

Lacustrine Silt and Clay Deposits

- How continuous are silt and clay units on the south shore?
- Based upon the depositional environment, the presumption should be that silt and clay deposits are laterally continuous.
- Most consultants and researchers, however, have presumed that they are not continuous and use a single aquifer model.

Geologic Setting

Lacustrine Silt and Clay Deposits



- Scripps/LLNL high resolution seismic CHIRP line along south shore of Lake Tahoe near Camp Richardson.
- CHIRP line shows successions of continuous depositional units.

Hydrogeologic Observations

Boring Log Information

- Boring log information has been used by some as “proof” that silt and clay deposits are not continuous.
- Estimated 300+ borings made within South Y Area. Most borings shallow less than 10 m deep and installed for UST investigations.
- Estimated 100+ borings made to depths greater than 10 m.
- Evaluations were made of 80 boring logs for our study.
  - 59 logs for borings greater than 10 m.
  - 11 logs for borings less than 10 m.

Hydrogeologic Observations

Boring Log Information

- Boring log detail and quality of information varied considerably depending upon purpose and field personnel.
- Evaluations were made using a number of criteria to determine the reliability of the boring logs.
- Each boring log was assessed for evidence of a potential aquitard between 6.5 m and 15 m depths.
- Conclusions made as to whether evidence was found in support of an aquitard at the boring location.

Hydrogeologic Observations

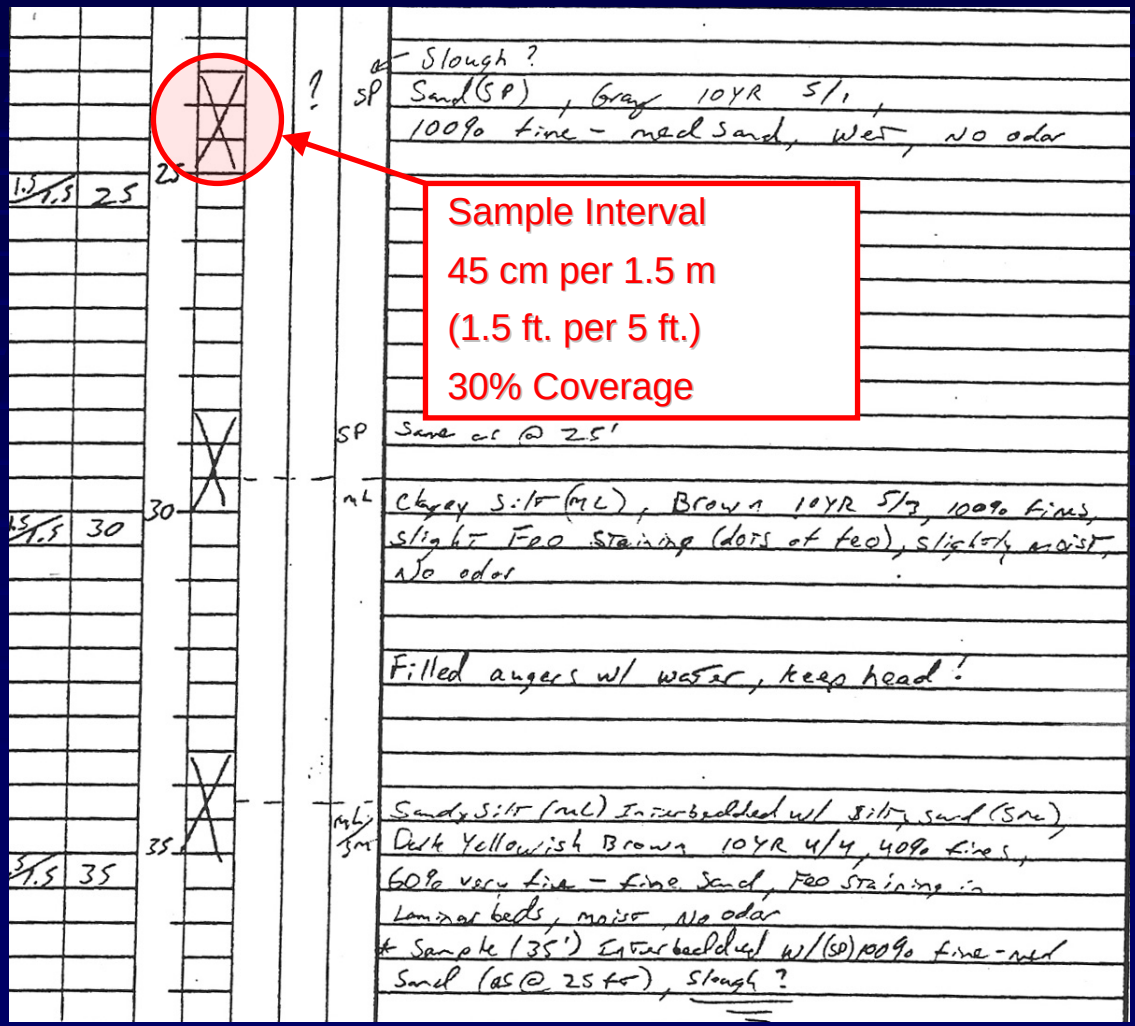
Boring Log Information

Criteria for Evaluation

- Drilling technique – HSA, Rotary, Cable Tool.
- Sample collection frequency, e.g. continuous or 1.5 m (5 feet) intervals.
- Observations of field personnel.
- Boring log detail.
- The absence of a geologic unit in a log may reflect limitations in the data collection technique.

Hydrogeologic Observations

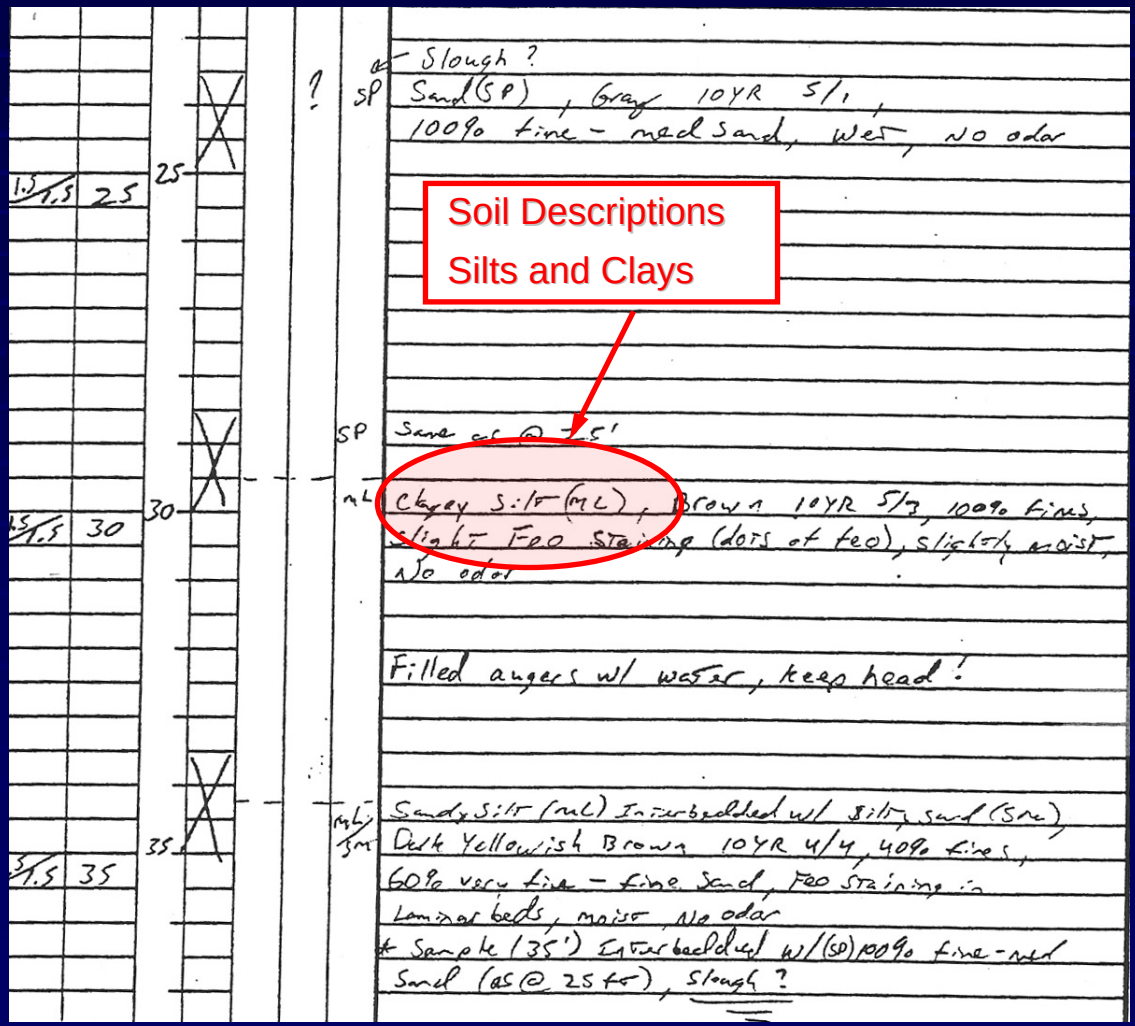
Boring Log Information



Source: LRWQCB UST Files - 1140 Emerald Bay Road

Hydrogeologic Observations

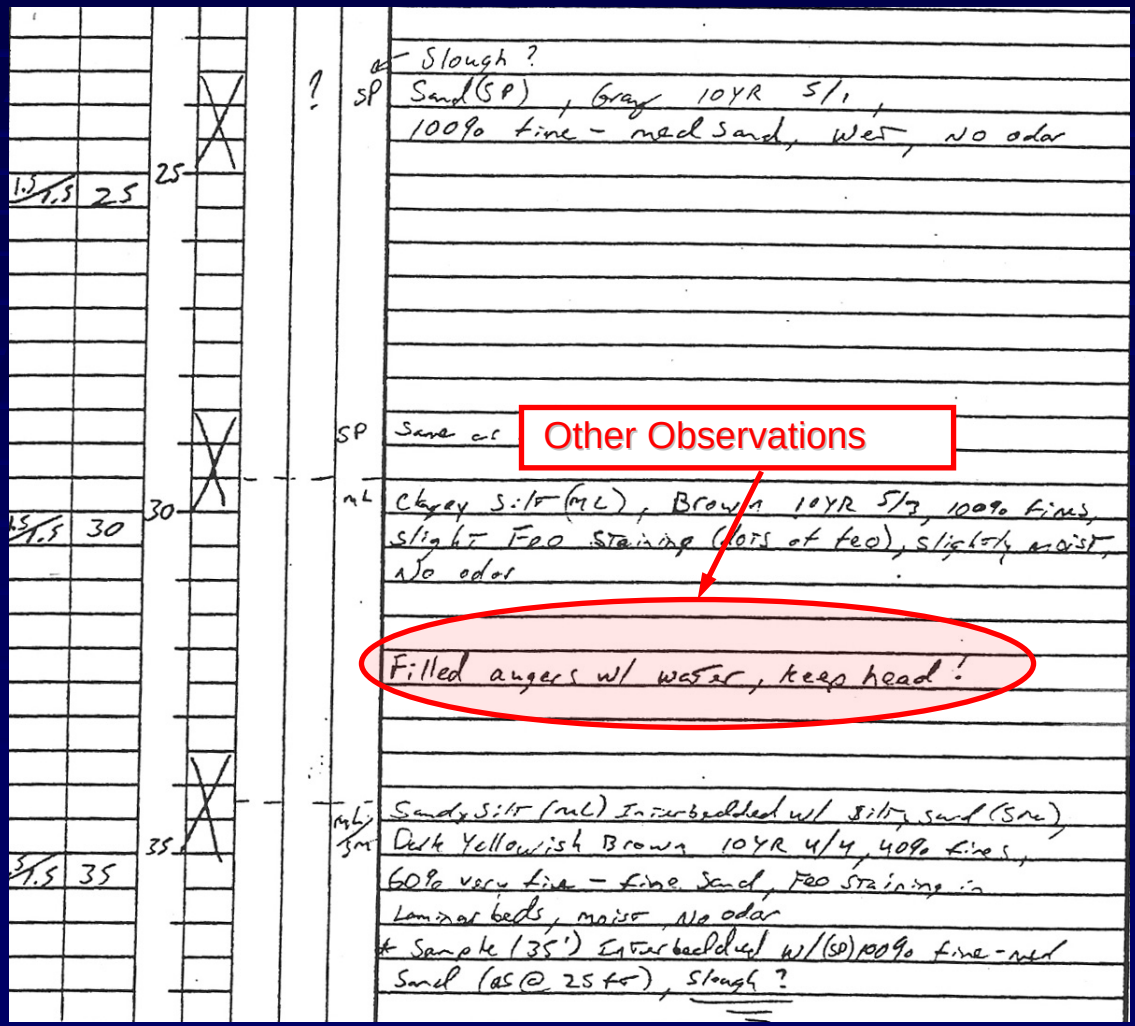
Boring Log Information



Source: LRWQCB UST Files - 1140 Emerald Bay Road

Hydrogeologic Observations

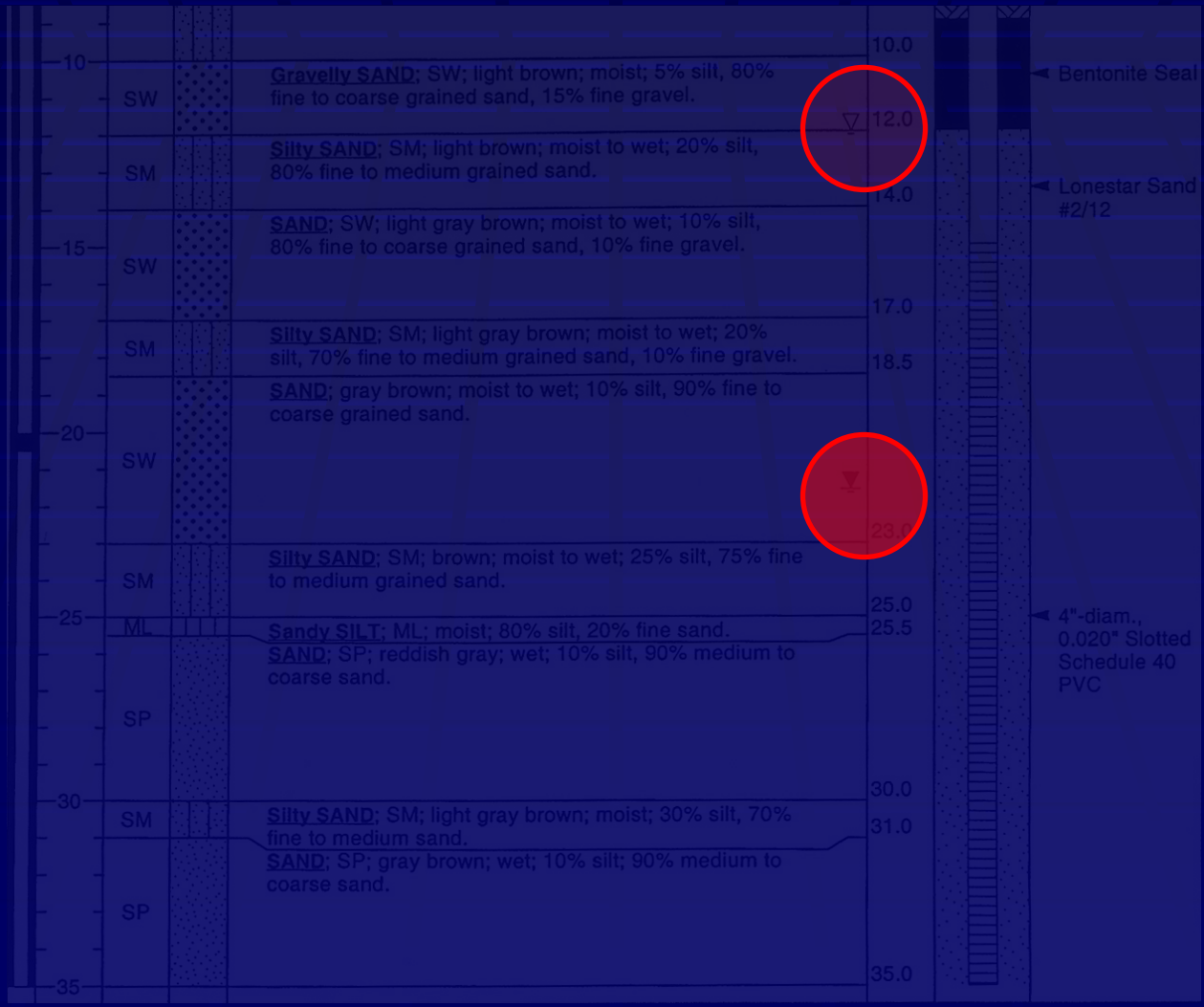
Boring Log Information



Source: LRWQCB UST Files - 1140 Emerald Bay Road

Hydrogeologic Observations

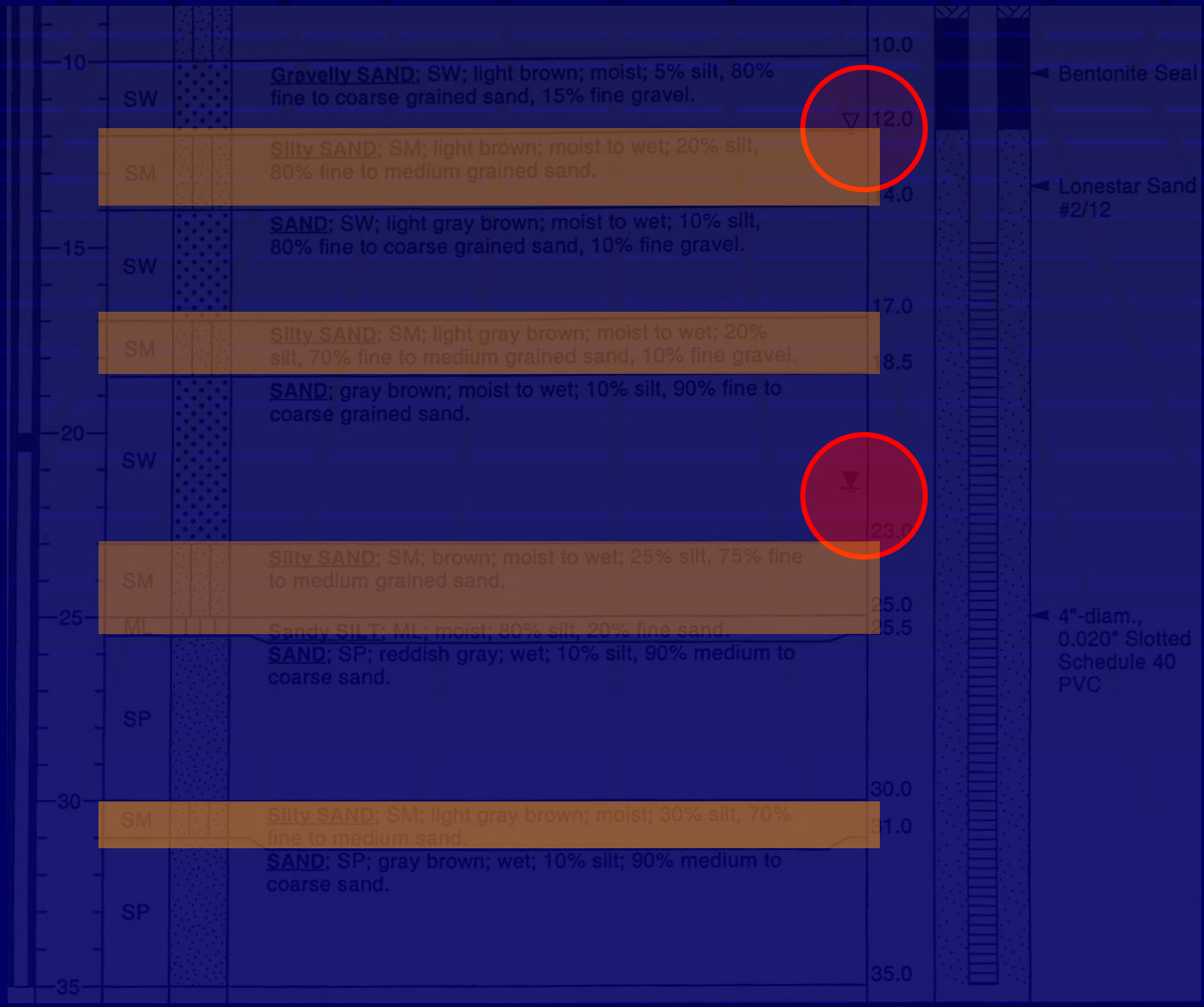
Boring Log Information



Source: LRWQCB UST Files - 1140 Emerald Bay Road

Hydrogeologic Observations

Boring Log Information



Source: LRWQCB UST Files - 1140 Emerald Bay Road

Hydrogeologic Observations

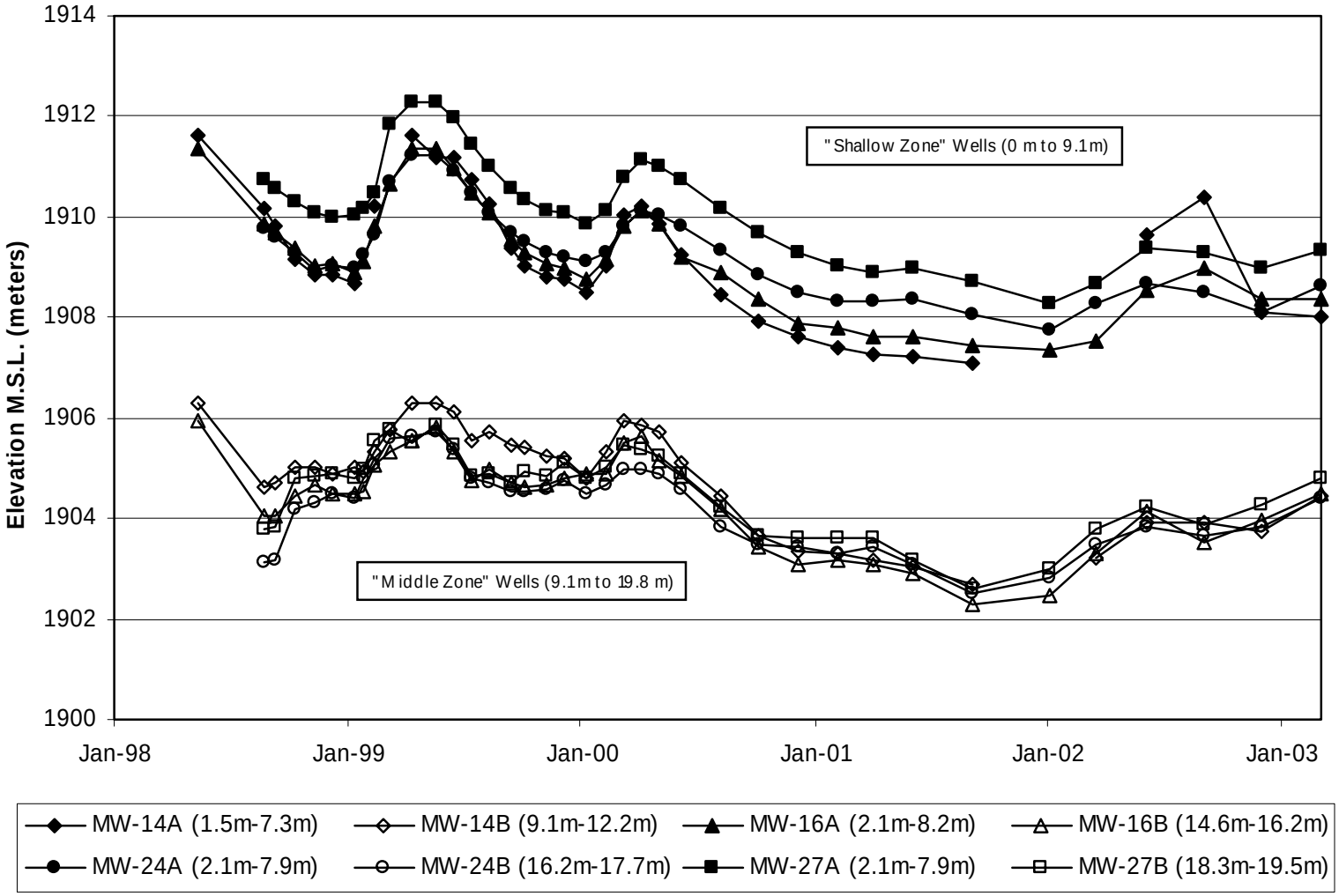
Boring Log Information

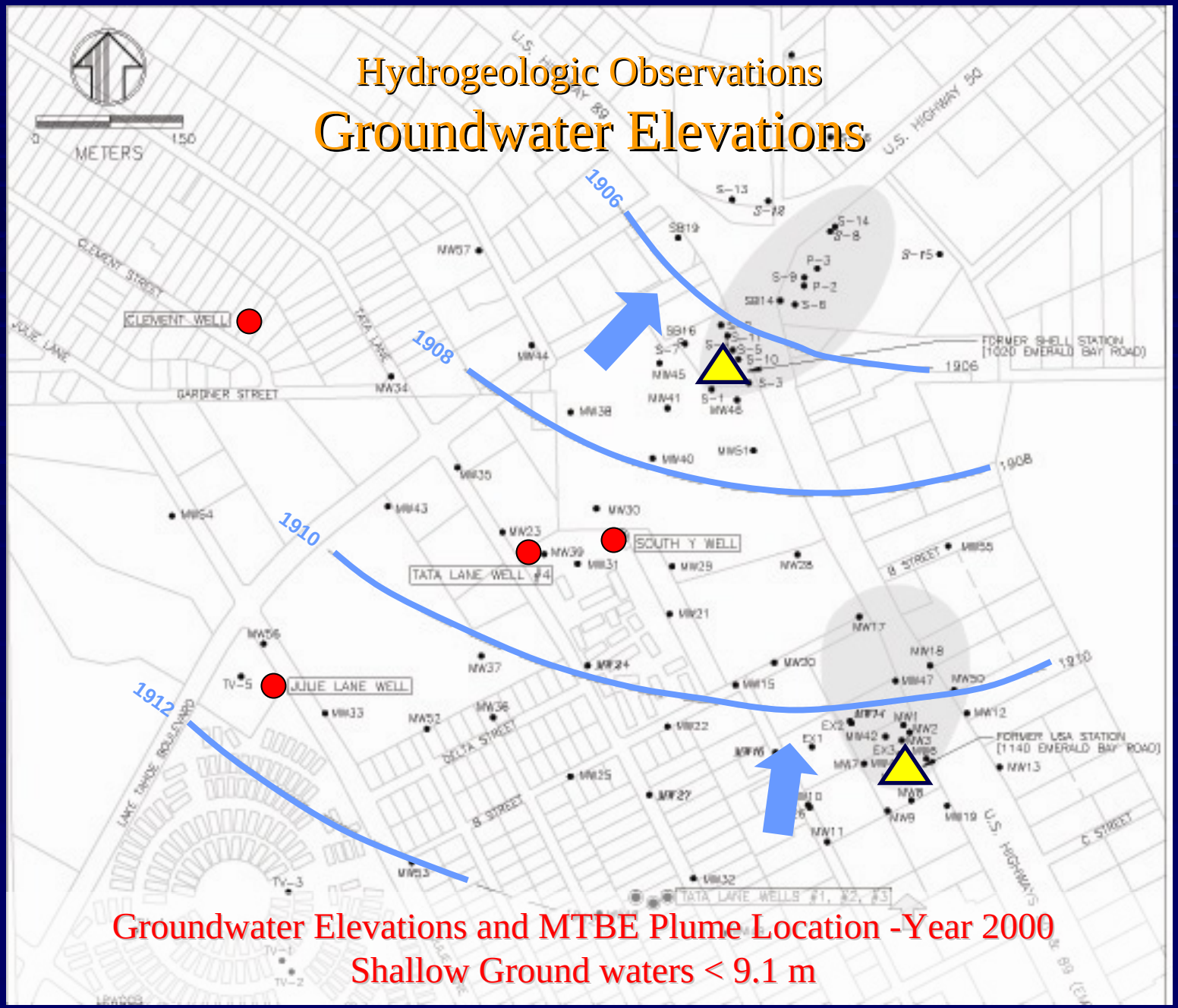
Summary of Observations

- 55 of the 80 Logs (69%) supported the existence of an aquitard at the boring location.
- 25 logs (31%) were judged inconclusive as to the existence of an aquitard. Of these logs, 8 were for borings less than 10 m deep.
- None of the boring logs supported the non-existence of an aquitard.
- No channel deposits were observed within any of the boring logs between the 6 m and 20 m depth interval.

Hydrogeologic Observations

Groundwater Elevations



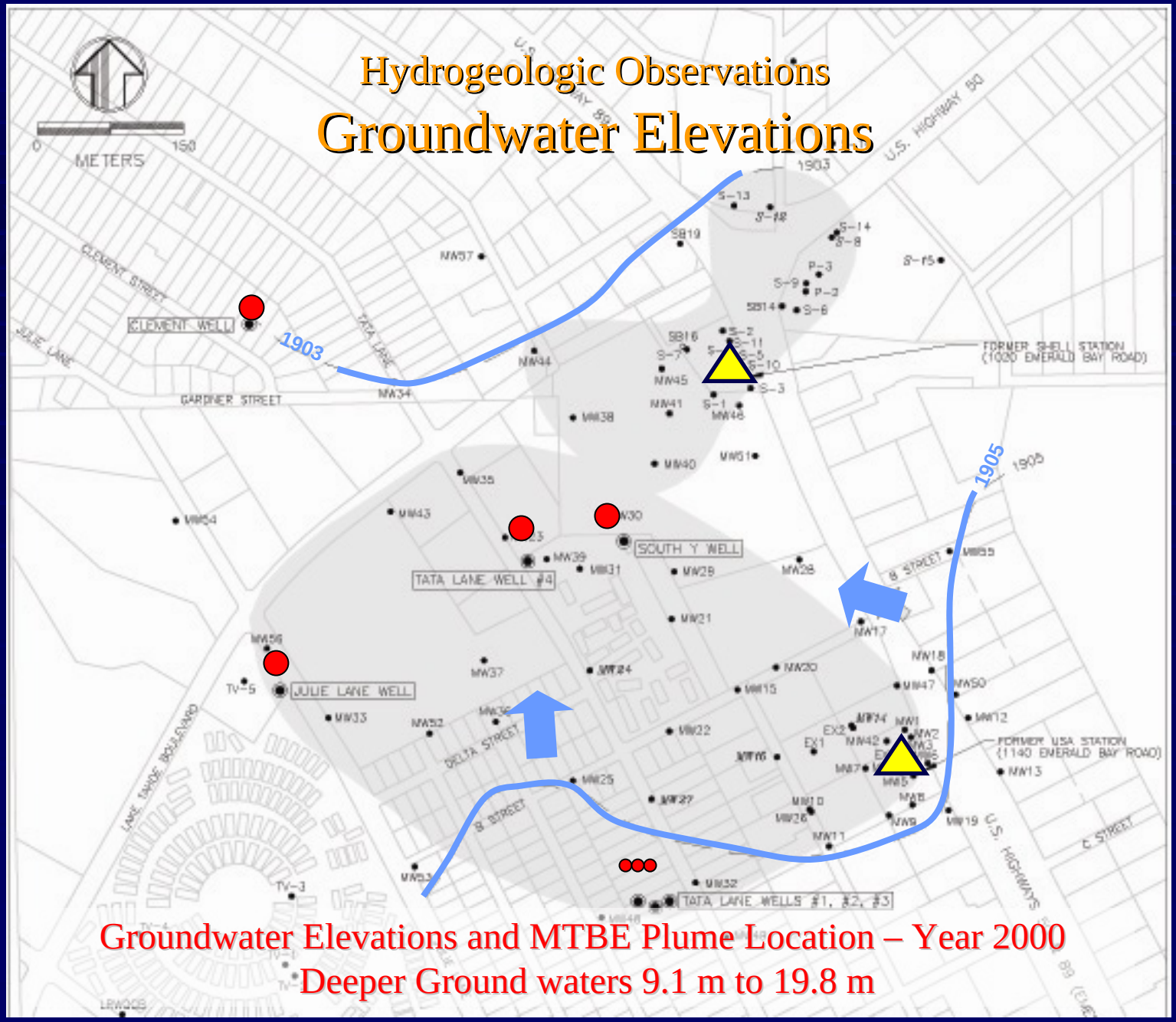


Groundwater Elevations and MTBE Plume Location -Year 2000

Shallow Ground waters < 9.1 m

Hydrogeologic Observations

Groundwater Elevations



Groundwater Elevations and MTBE Plume Location – Year 2000

Deeper Ground waters 9.1 m to 19.8 m

Hydrogeologic Observations

Pump Test Data

- Storage Coefficient of 0.0052 reported for the STPUD Tata Lane Well near the South Y Area is within the range commonly found for confined or semi-confined aquifers.

Ref. Scott et.al. (1978) and Blum (1979)

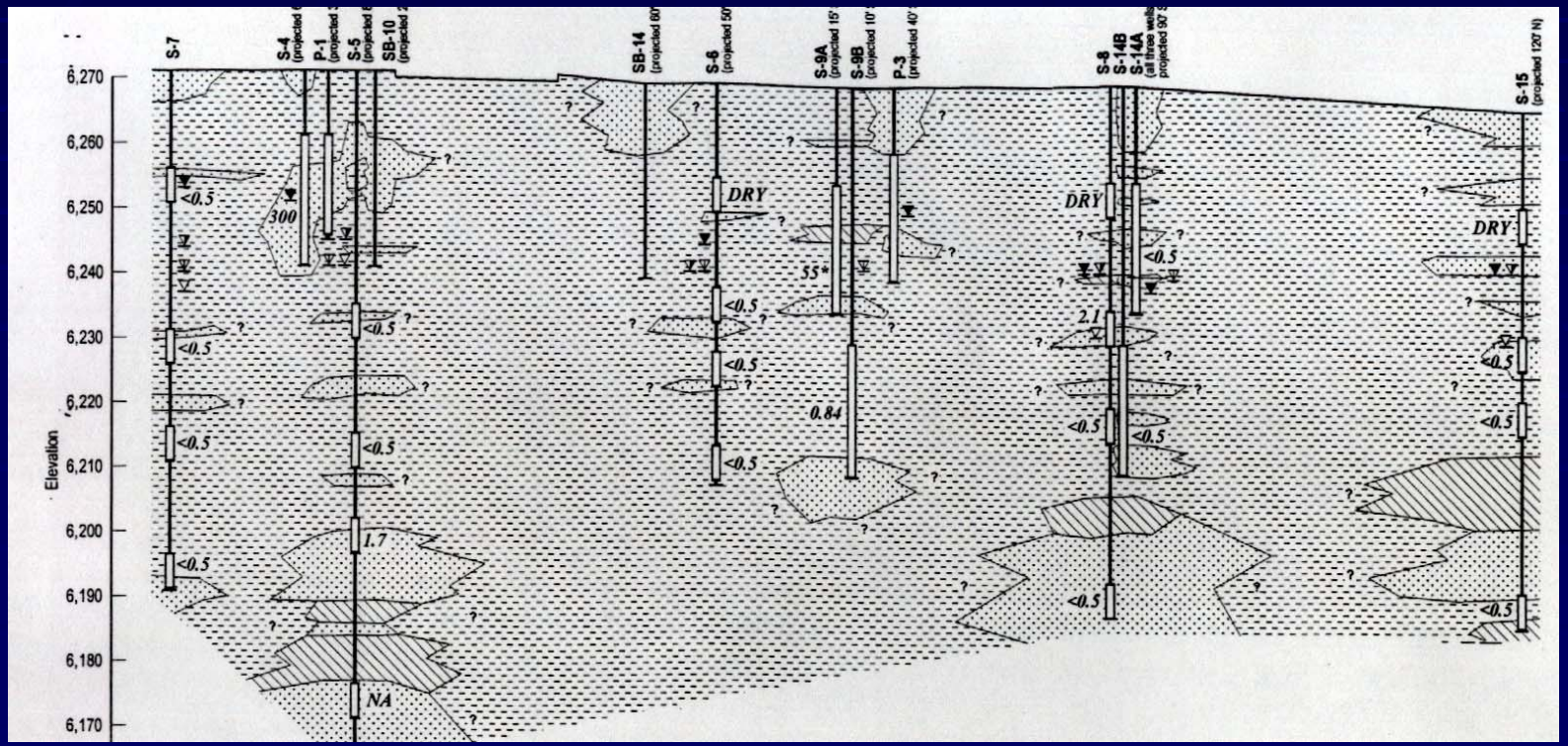
Hydrogeologic Observations

Summary of Key Observations

- Evidence of lacustrine depositional environment.
- Boring logs support the presence of an aquitard beneath the South Y Area and do not provide evidence of erosion.
- Geophysical data demonstrates continuity of sedimentary units.
- Significant head differences between shallow and deeper ground waters consistent across the South Y Area.
- Contamination plumes migrated in separate directions from UST sites depending upon groundwater depth.
- Pump test data supports confined and semi-confined aquifer conditions.
- MTBE detected in STPUD wells in South Y area after cross-screened monitoring wells installed at LUST site.

Conclusions

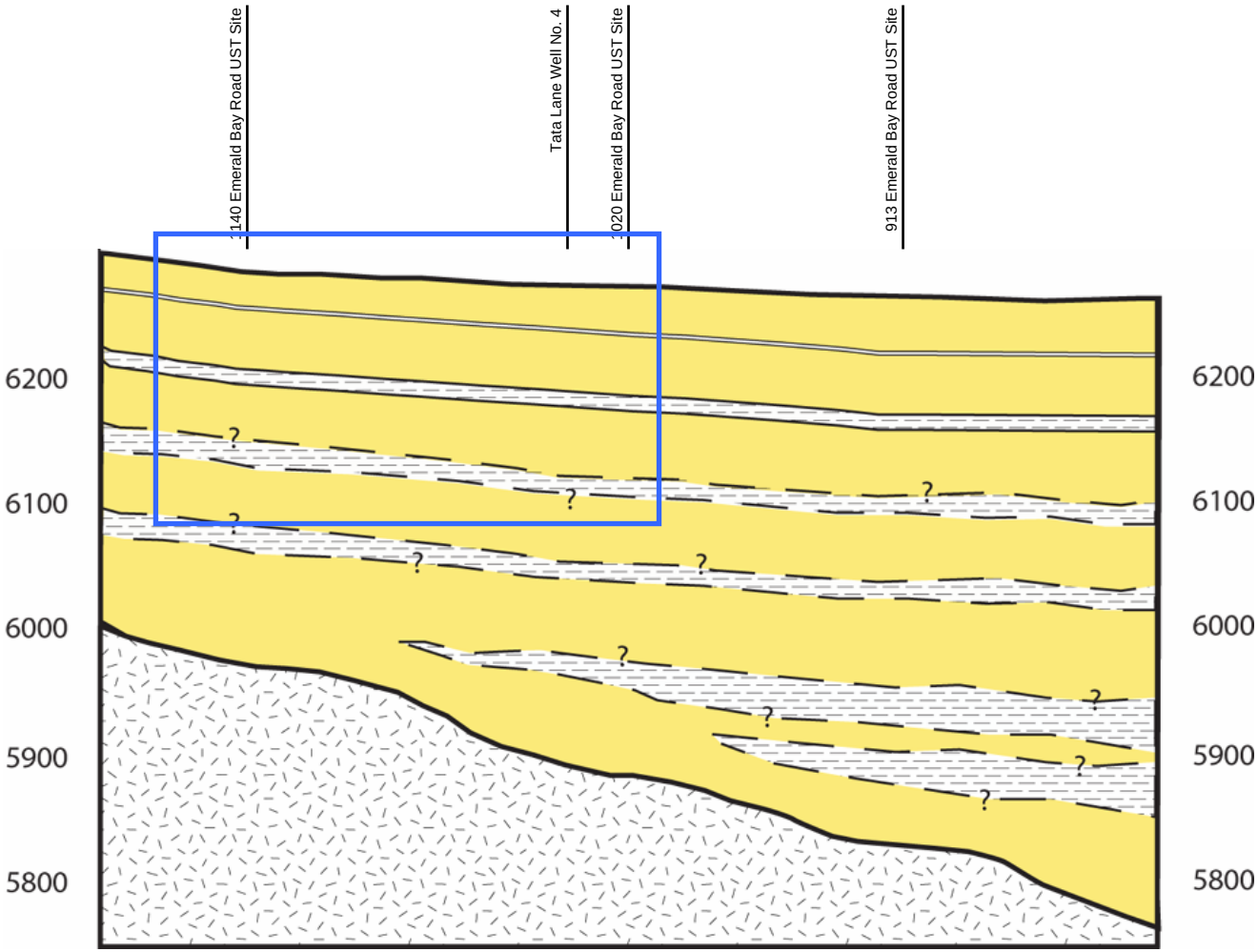
- Prevailing single aquifer ground water model does not explain key observations.



Source: 1020 Emerald Bay Road UST File, LRWQCB

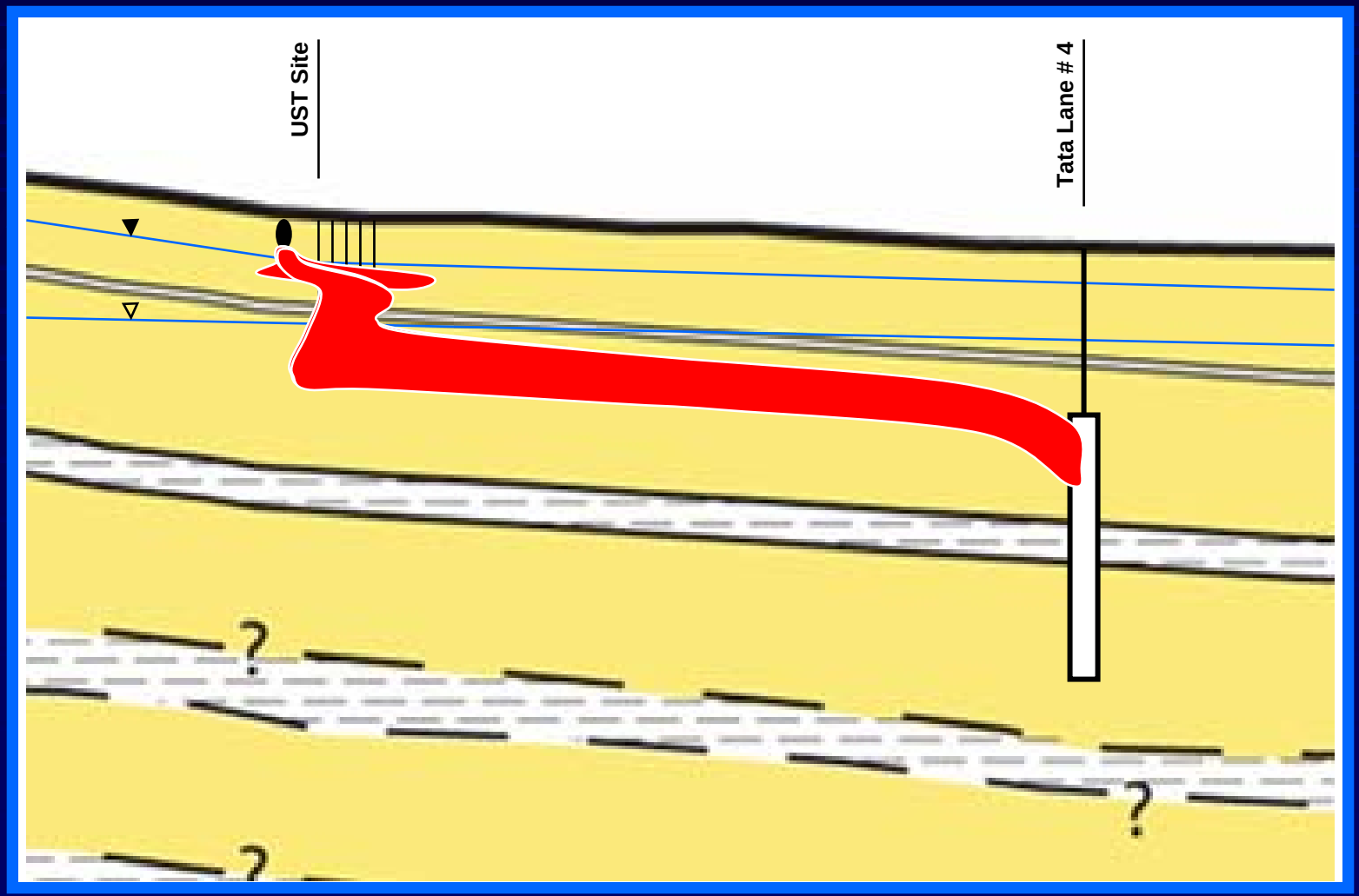
Conclusions

Conceptual Model



Conclusions

Conceptual Model



Conclusions

- A multiple aquifer model explains the 1.5 m to 7.6 m head difference between the shallow and deeper ground waters in the South Y Area and is consistent with the depositional environment.
- Cross-screened monitoring wells have resulted in the vertical migration of contamination from shallow ground waters to deeper ground waters.
- STPUD's water supply wells near the South Y area were adversely impacted as a result of this cross-contamination.
- This mechanism of contaminant migration has not been fully recognized.

Recommendations

- Recognition of multiple aquifer conditions by agencies responsible for water resources management and protection to prevent further cross-screening of wells.
- Further characterization of hydrogeologic conditions in the Tahoe Basin using modern imaging techniques is needed to protect groundwater resources.
- Continuous core sampling of all soil boring and monitoring well installations at UST sites.
- Cross-contaminating monitoring wells should be destroyed by removing the well casing and filter pack and properly sealing the boring in accordance with California Department of Water Resources Bulletin 74-81 and Bulletin 74-90.

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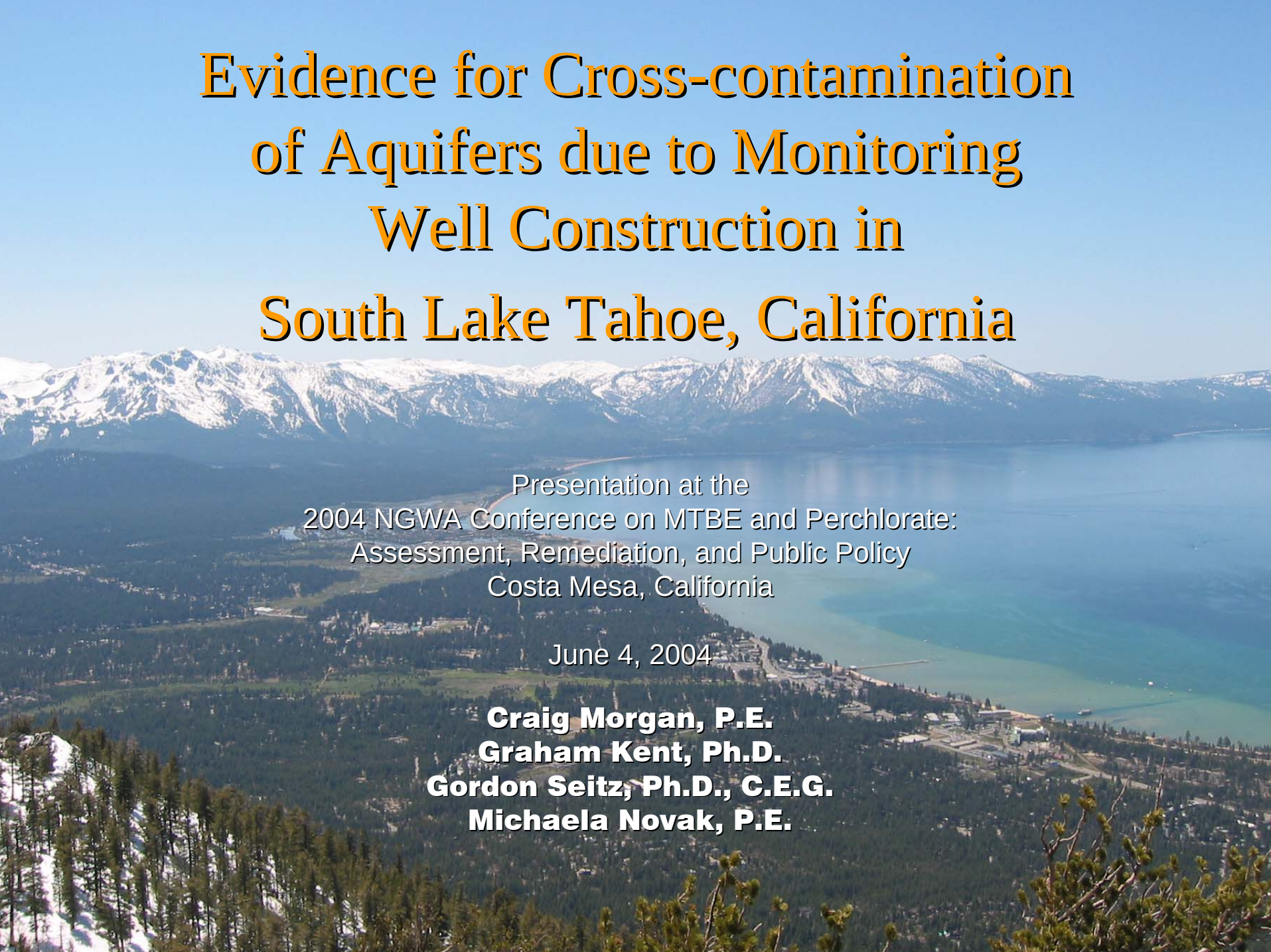

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