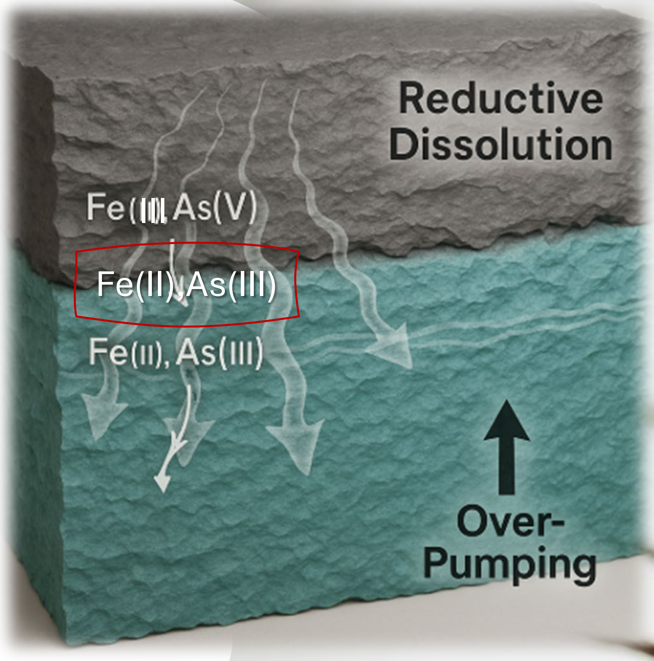
BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

The Role of Geochemistry at the Aquifer-Aquitard Boundary and its Impact on Public Supply Wells



Noah R. Heller, MS PG

BESST, Inc.

November 4th, 2025

2025 Summit

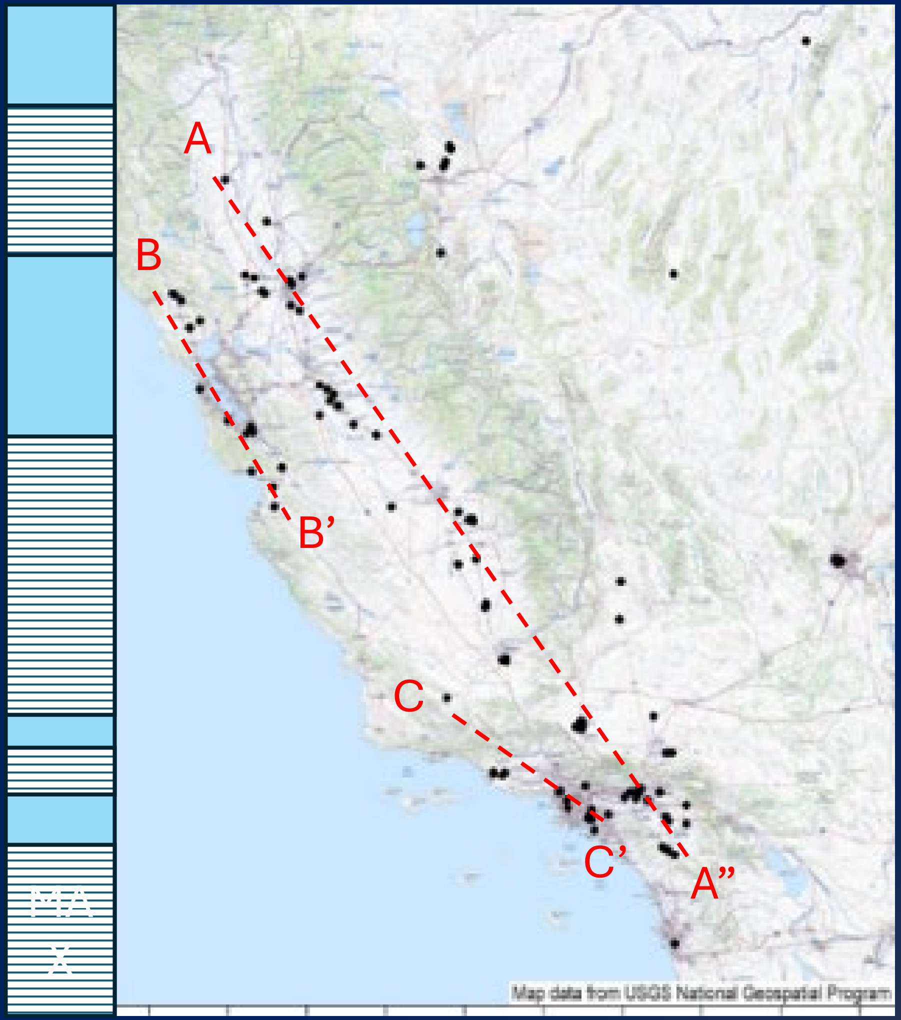
REMPLEX
CENTER FOR THE REMEDIATION OF COMPLEX SITES
@PNNL
IAEA

STUDY PARAMETERS

- 143 PUBLIC SUPPLY WELLS – HIGH CAPACITY (500 TO 2500 GPM, 500 to 1500 feet deep)
- IDENTIFIED HIGHEST MASS BALANCED CONCENTRATION ALONG WELL SCREEN PROFILE (C_{MAX})

$$C_{MAX} = \frac{(Q_1 * C_1) - (Q_2 * C_2)}{(\Delta Q_{1,2})}$$

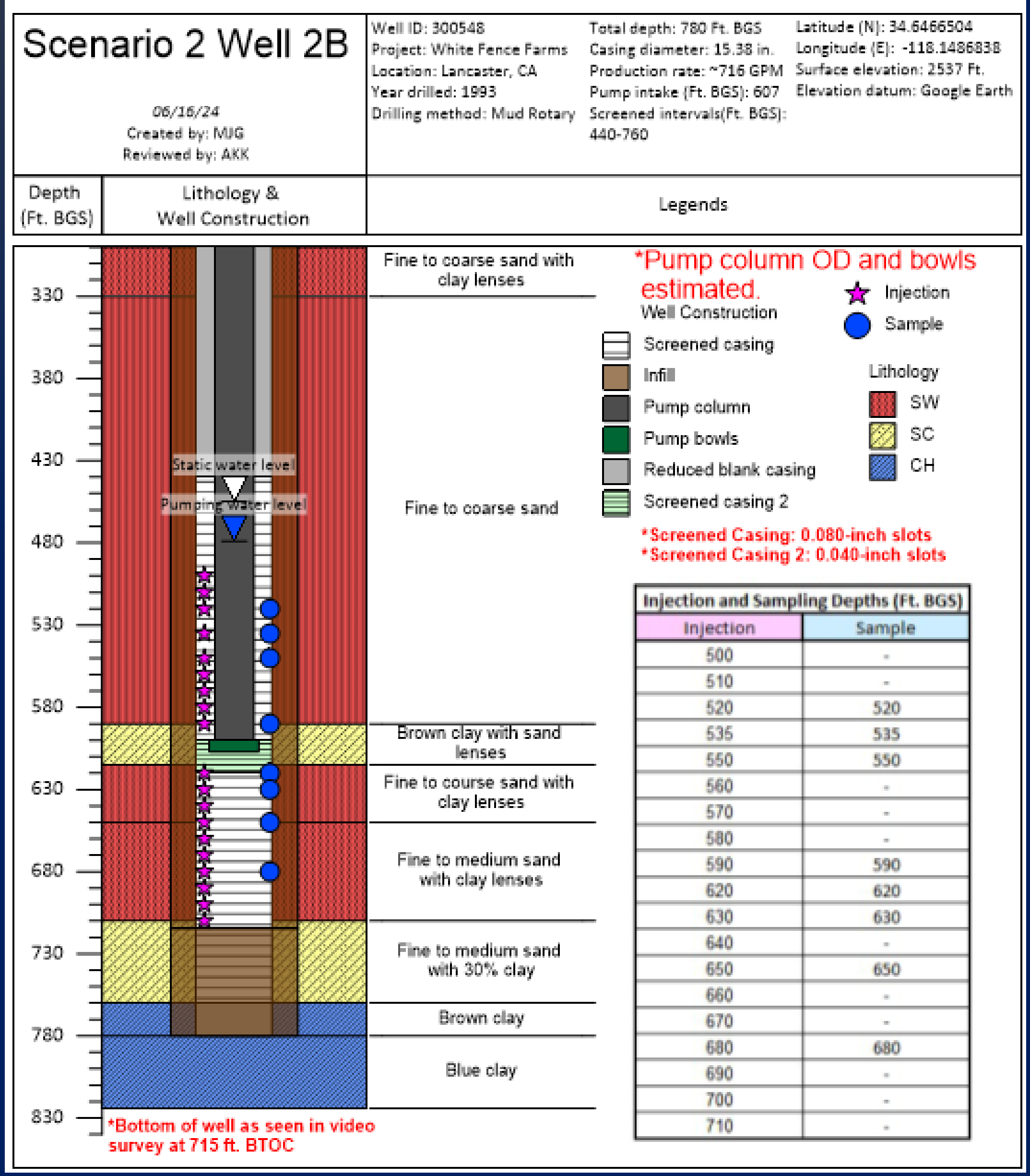
- IDENTIFIED SEDIMENT TYPE of C_{MAX} interval
- IDENTIFIED PERCENTAGE OF TOTAL FLOW of C_{MAX} interval



Non-compliant wells: ~55%

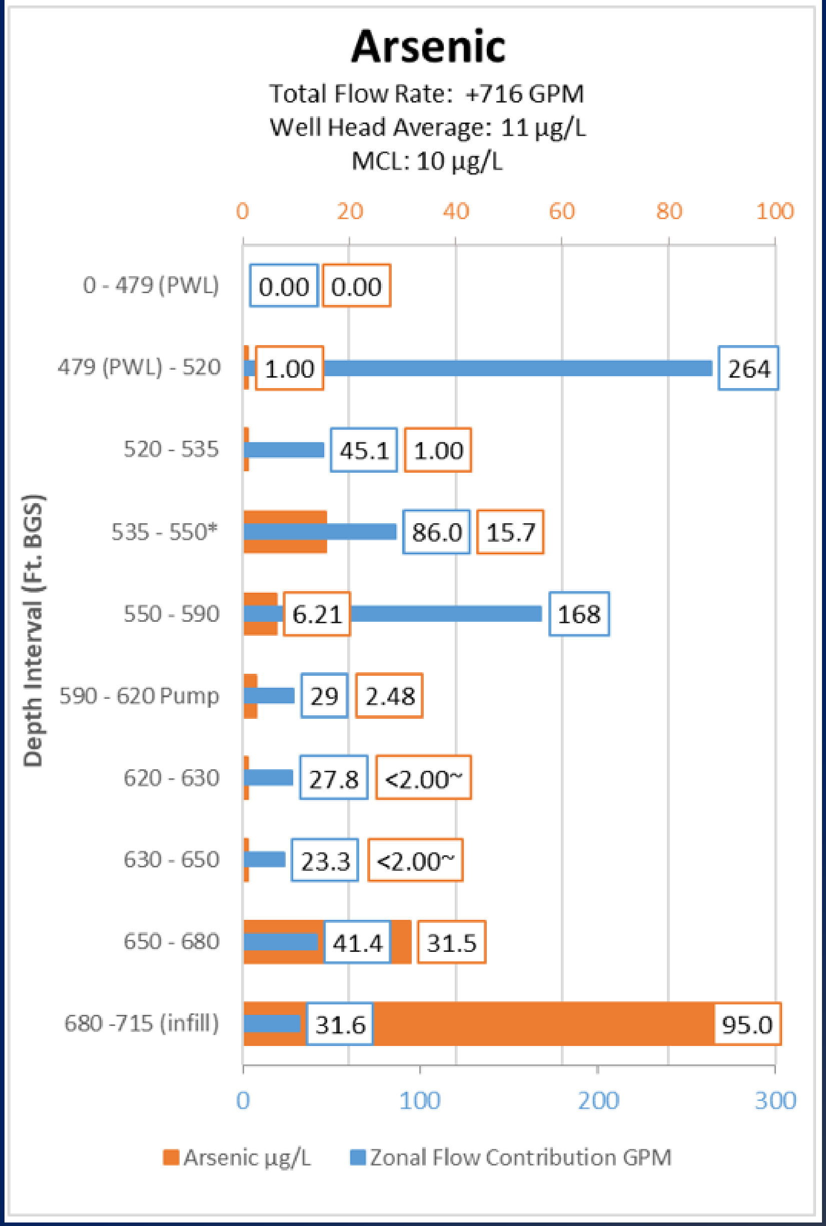
Compliant wells: ~45%

How C_{MAX}, Sediment Type and Flow Data were Collected from Each Well

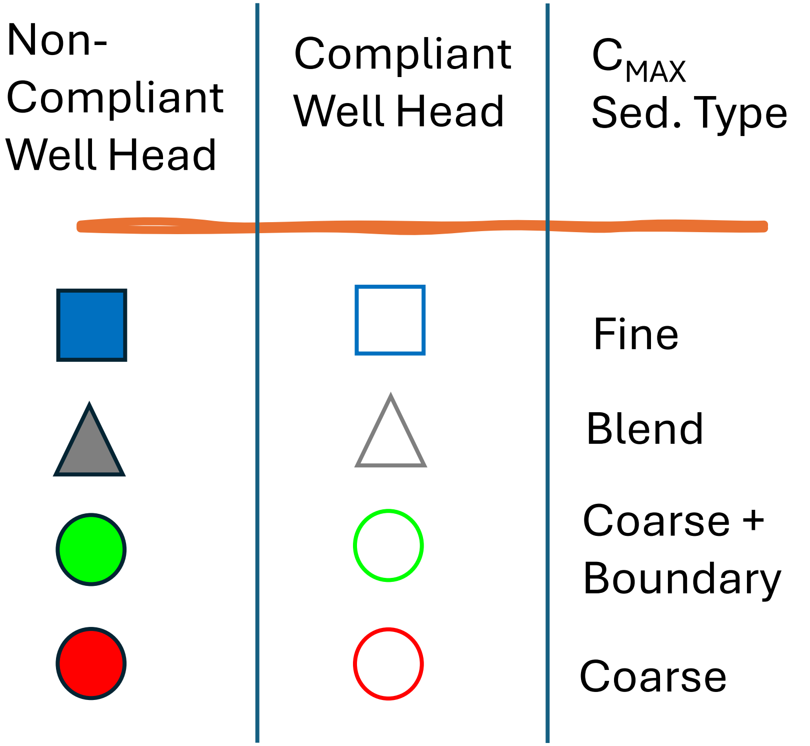


Injection and Sampling Depths (Ft. BGS)

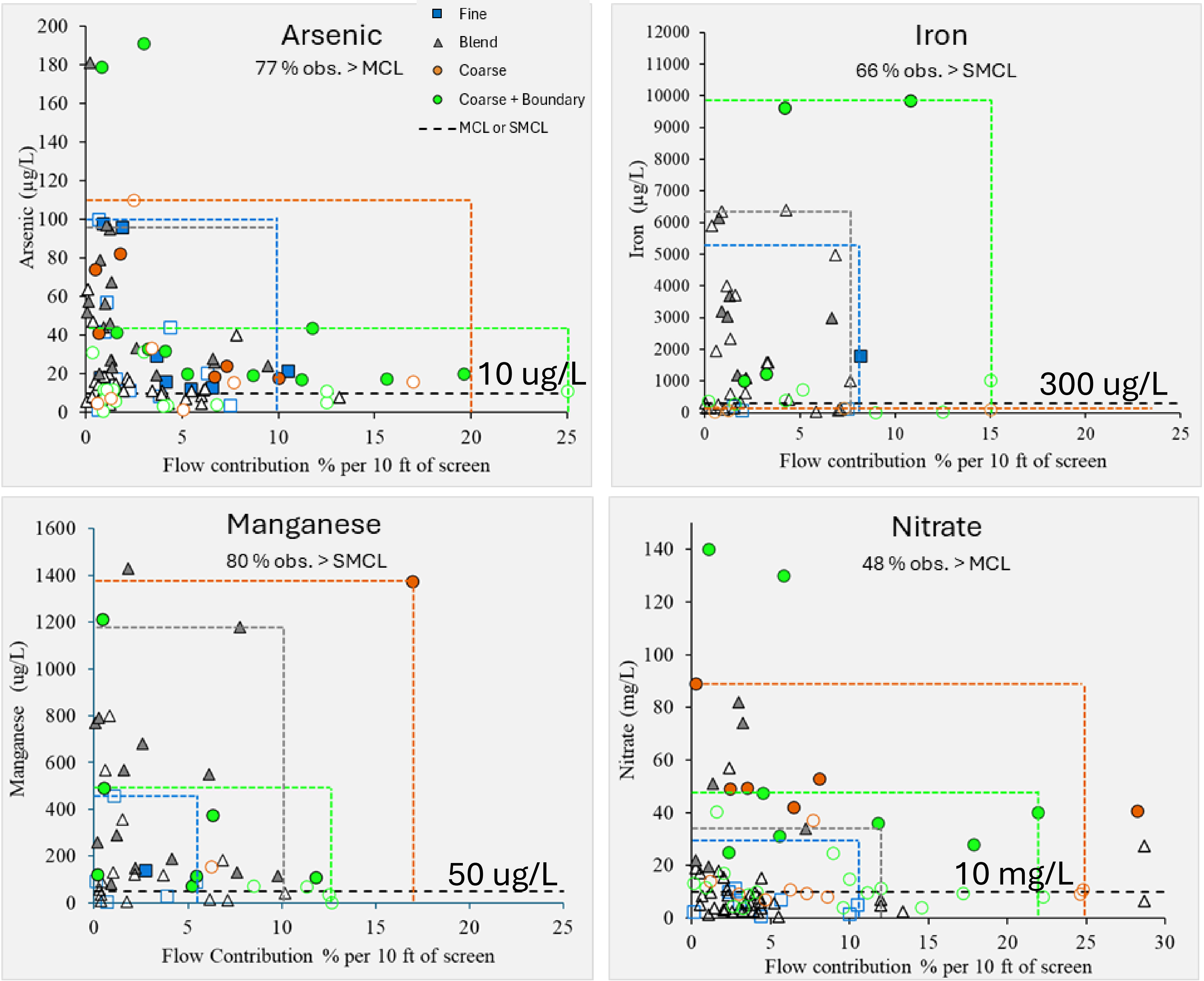
Injection	Sample
500	-
510	-
520	520
535	535
550	550
560	-
570	-
580	-
590	590
620	620
630	630
640	-
650	650
660	-
670	-
680	680
690	-
700	-
710	-



ZONAL CHEMISTRY VERSUS FLOW CONTRIBUTION AS A RETURN ON INVESTMENT (ROI)



FROM EXISTING C_{MAX} SCREEN INTERVALS



<u>Low ROI (0 to 10% Flow Fractions)</u>

Small fractional increase in production potentially leads to treatment – at a high cost.

143 PSWs and LSTWs
C_{MAX} As, Fe, Mn, NO_3 Interval
Associated Zonal Flow
Lithology Logs E-Logs ✓

Identify interval with maximum mass-balanced concentration: C_{MAX} ✓

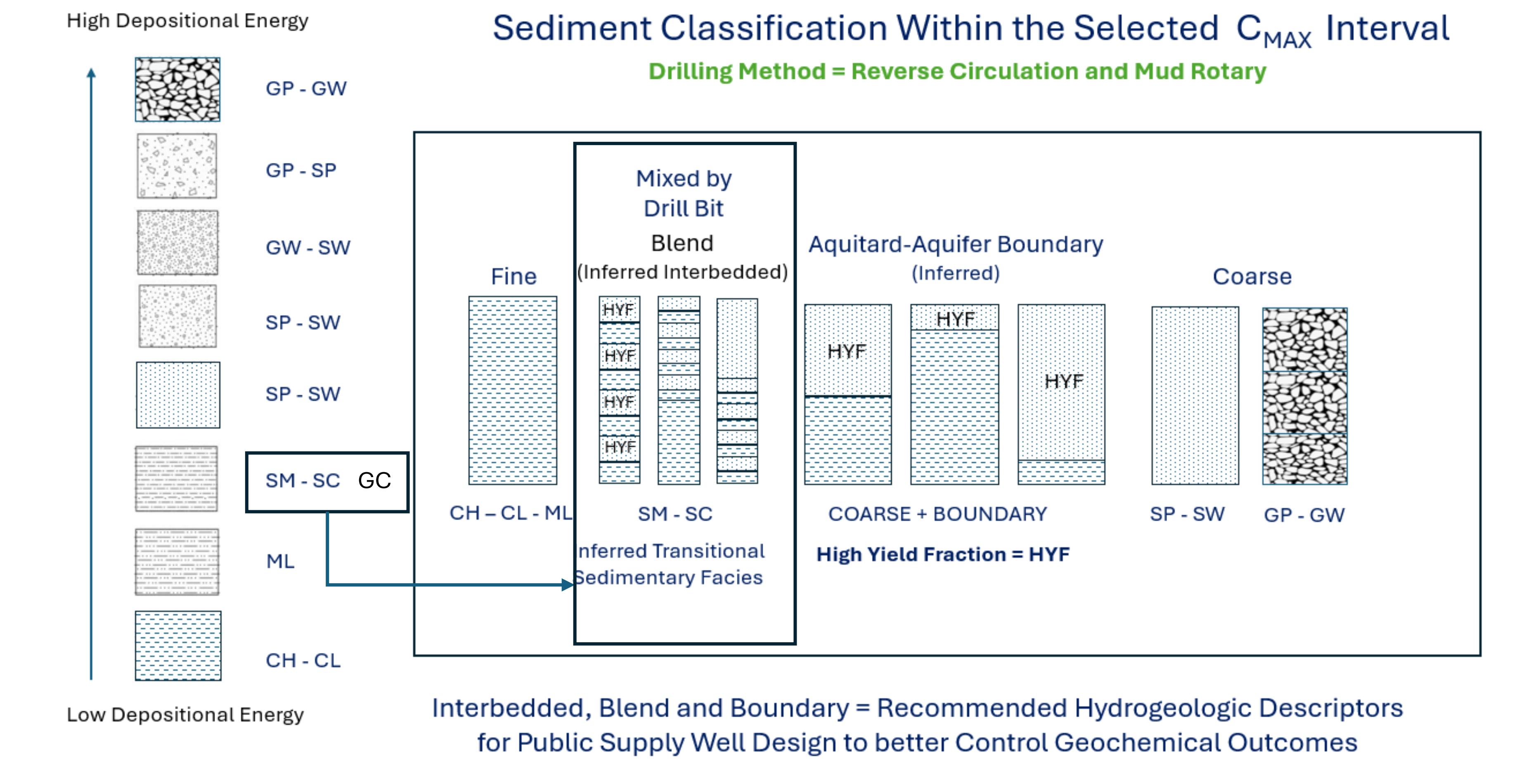
Associated Flow with maximum mass-balanced concentration: C_{MAX} ✓

Sediment type classification

Statistical Data analysis

Geotech Classification

Hydrogeological Sedimentological Classification



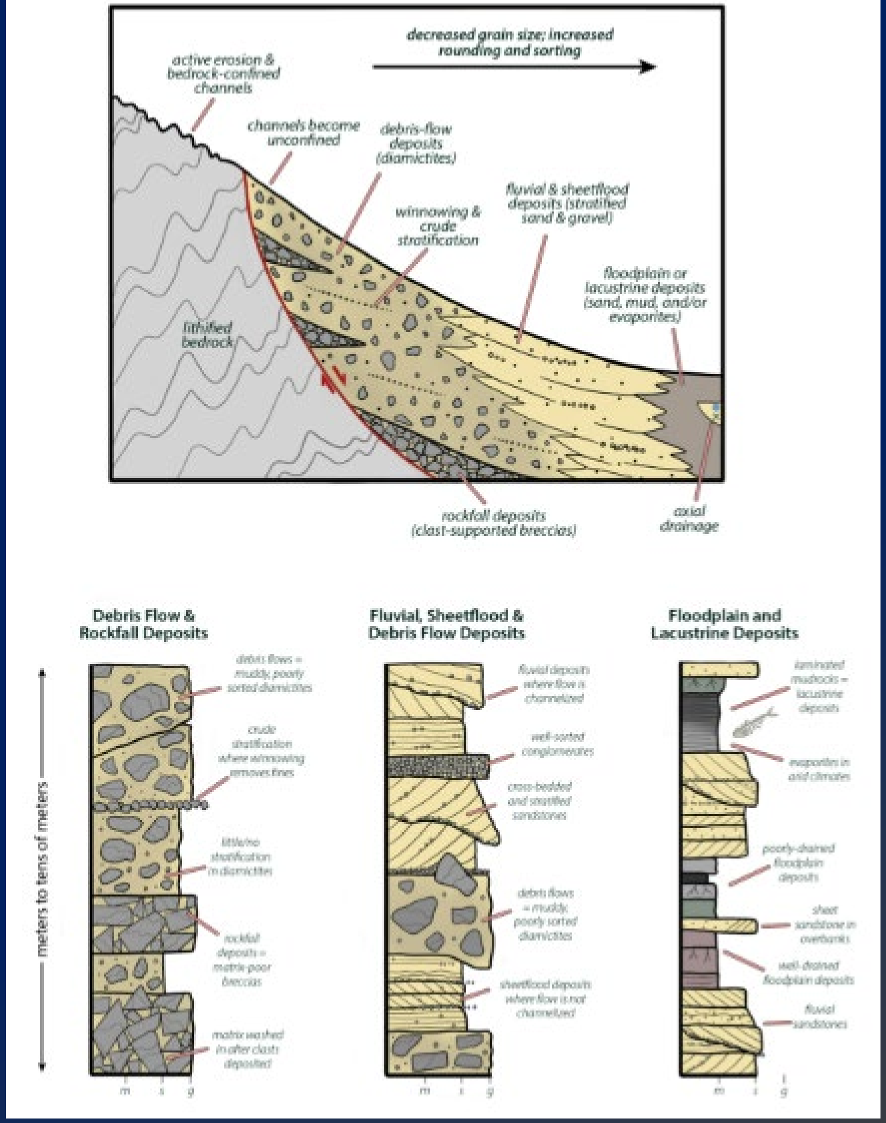
Examples of Interbedded (Blend) Deposits

And Alternating Depositional Energies

Fluvial Crevasse Splay

Tidal

Alluvial Fan Interfingering with Playa Lakebed



Beach Sands – Mineralogical Interlayering

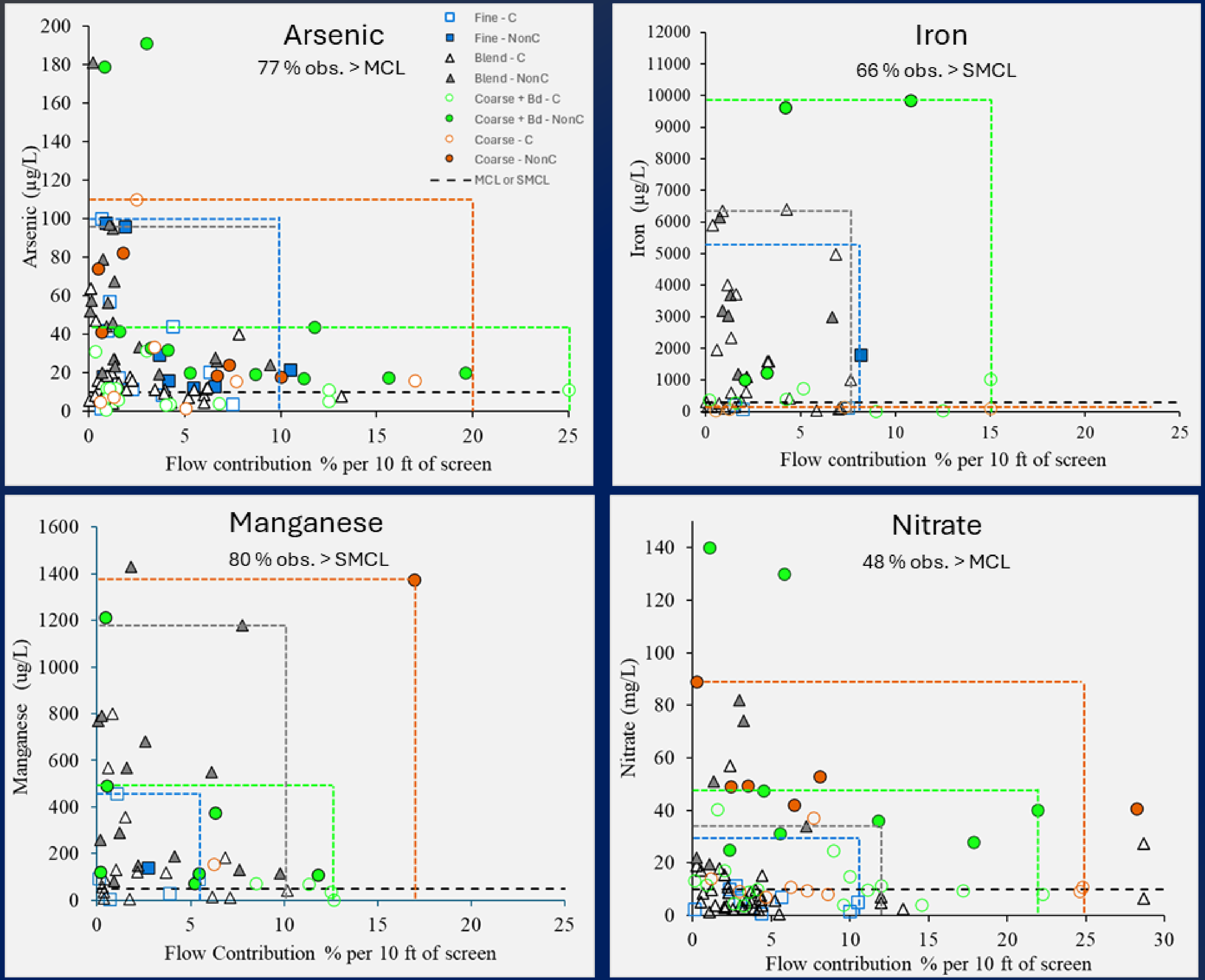
Methods and Other Results

- Data visualization: scatter plots and histograms
- Statistical Analysis
  - Magnitude of C_{MAX} (normalized to the wellhead concentration) across sediment types: Welch's ANOVA
  - C_{MAX} in depth intervals that include or do not include boundaries: Student's t test

→ In which sediment types is C_{MAX} occurring? What is the % flow contribution?

→ For which sediment types is C_{MAX} the largest?

→ Is C_{MAX} more elevated in intervals that include a boundary?

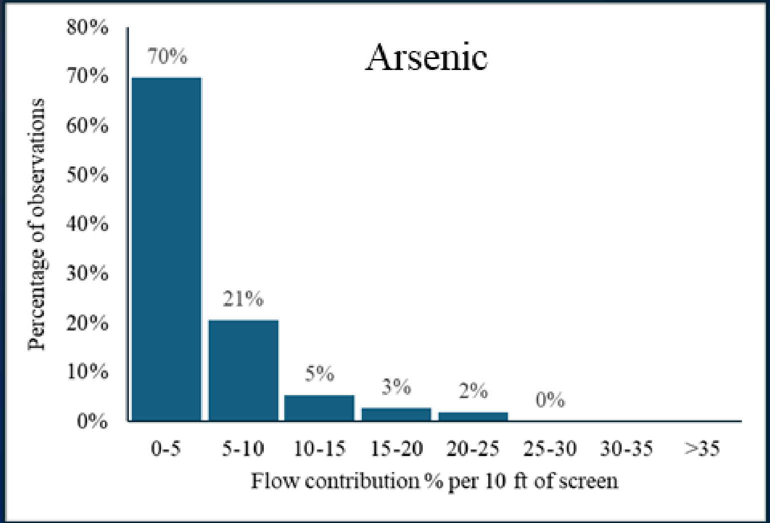


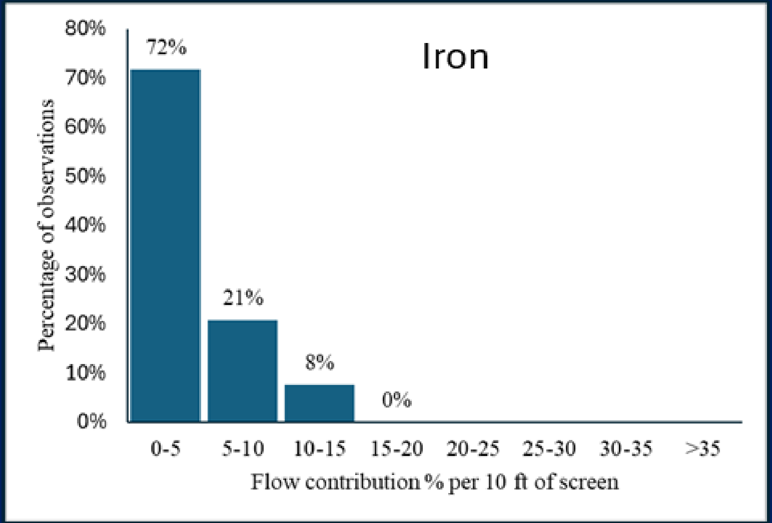
C_{MAX} values above and below the MCL/SMCL

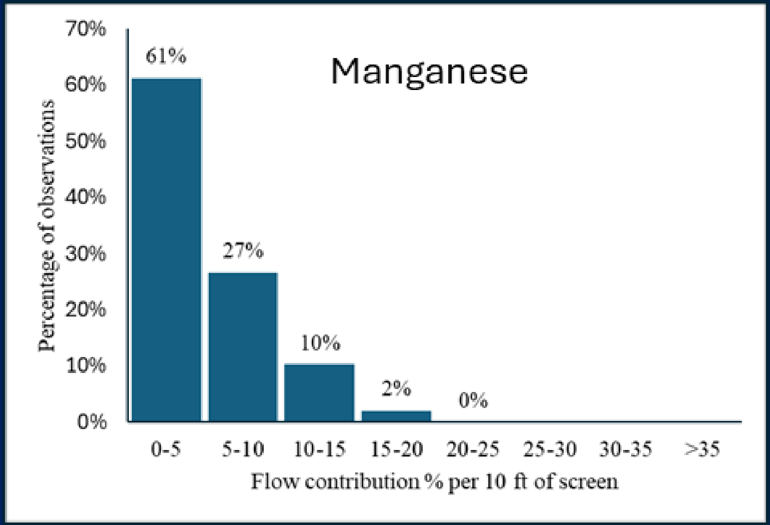
For C_{MAX} > MCL/SMCL, what is the % of non-compliant wells?

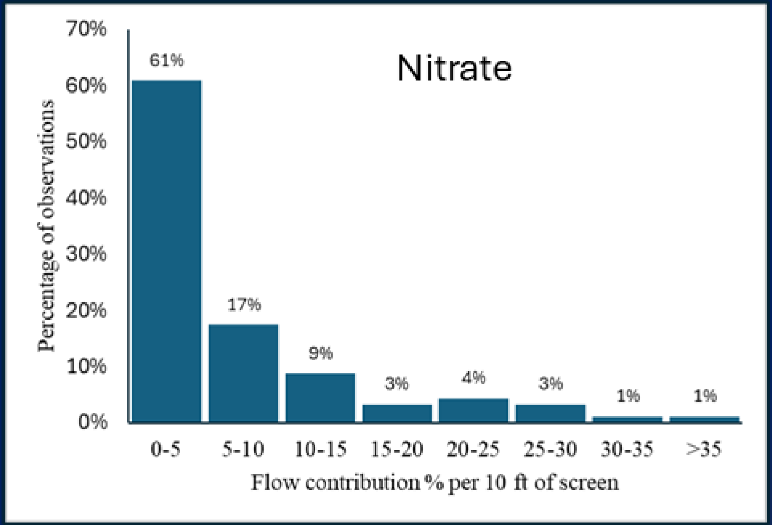
- As: 58 %
- Fe: 37 %
- Mn: 62 %
- NO_3: 50%

Data Plots: Flow Contribution



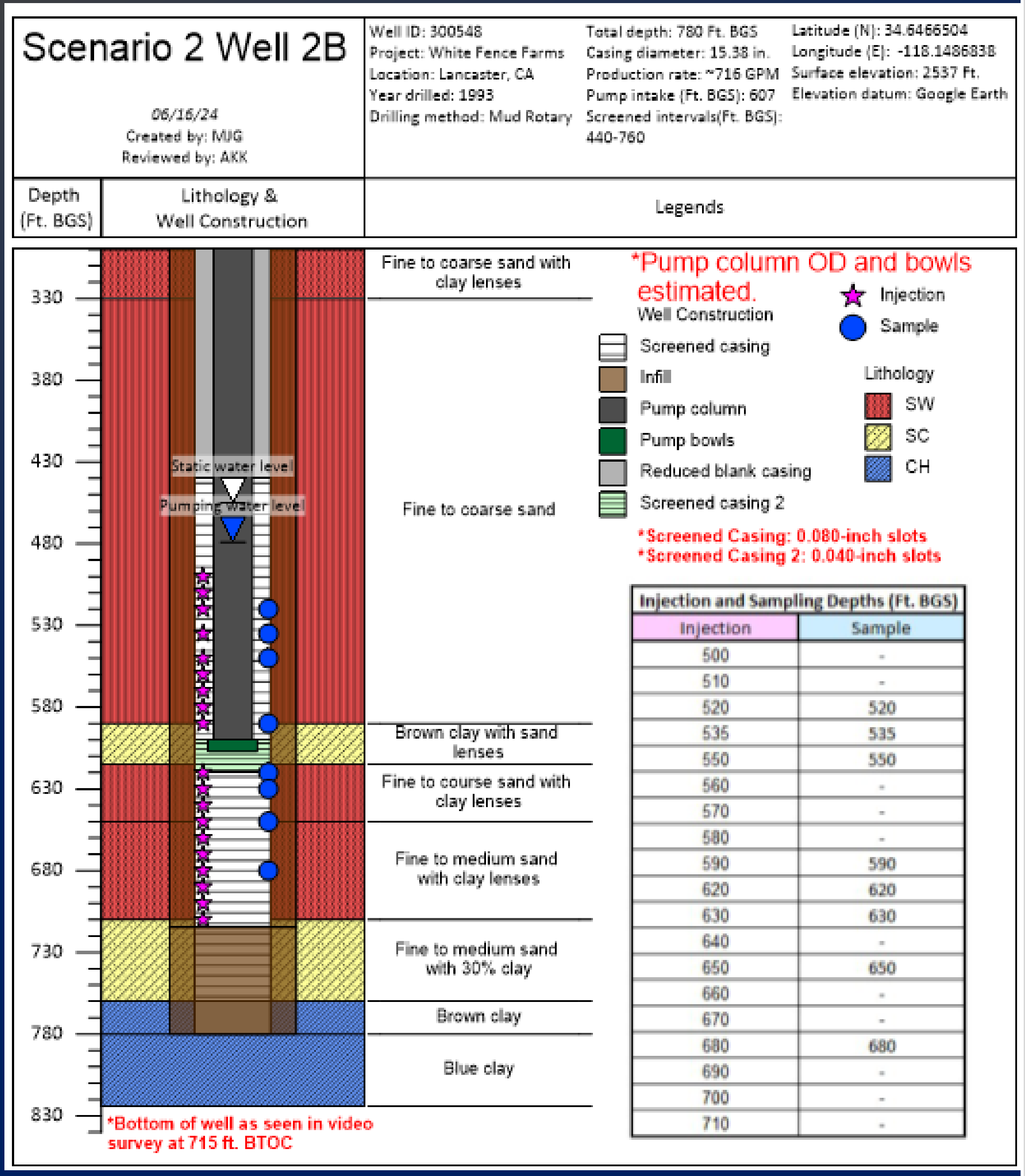






C_{MAX} intervals often associated with flow contributions ≤ 5 %

Consider potential effect on wellhead concentration – worth the risk?



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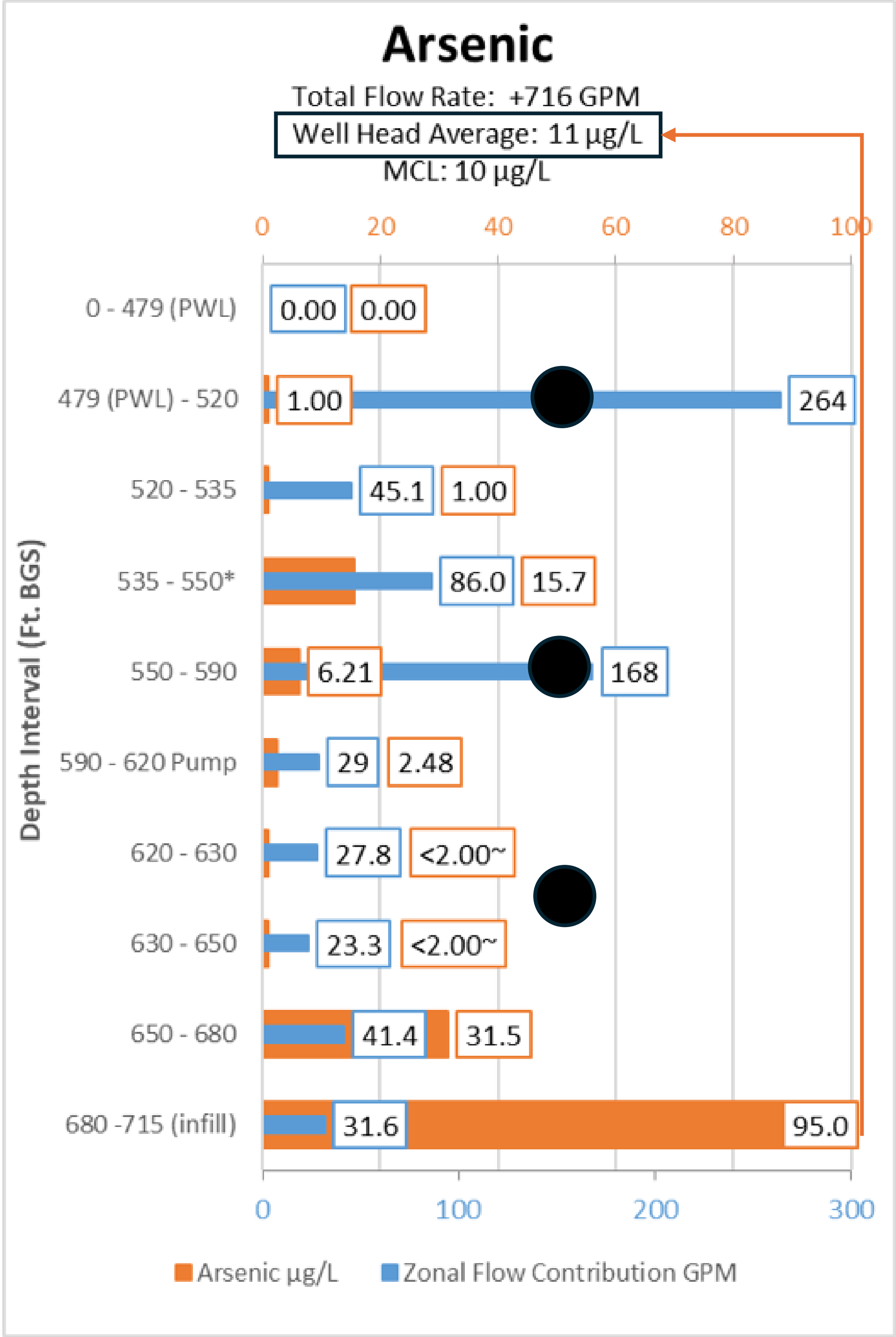
700	-
710	-



Zone Test

60 GPM

Zone Test

50 GPM

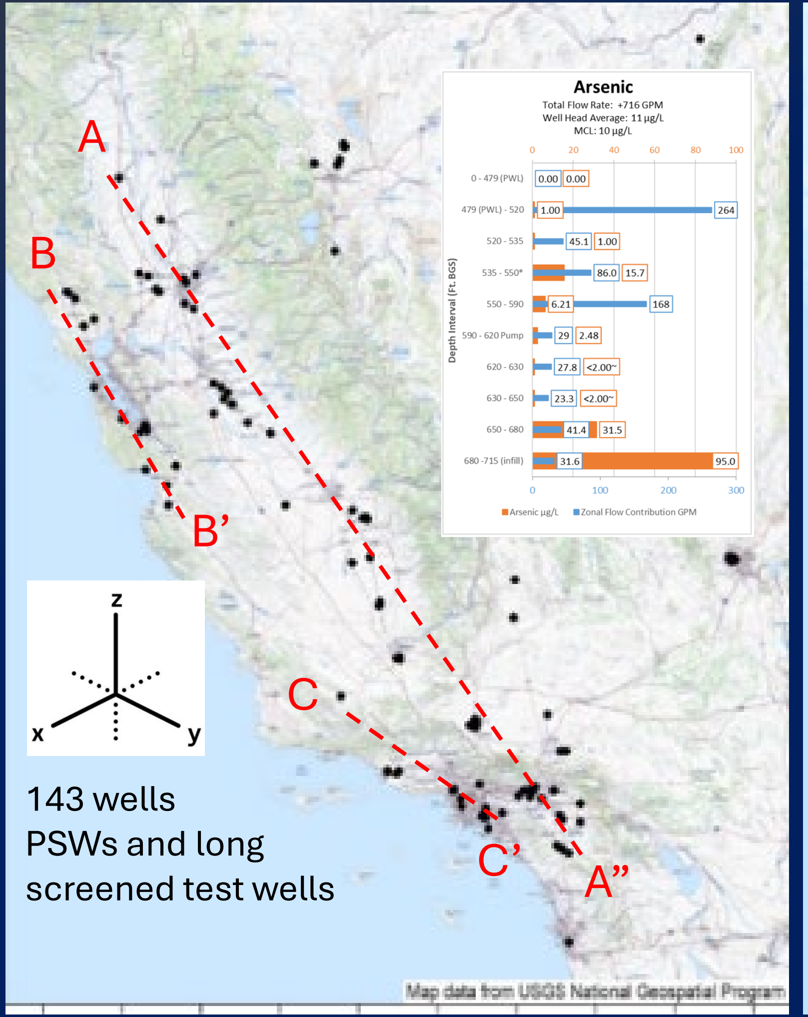
Zone Test

50 GPM

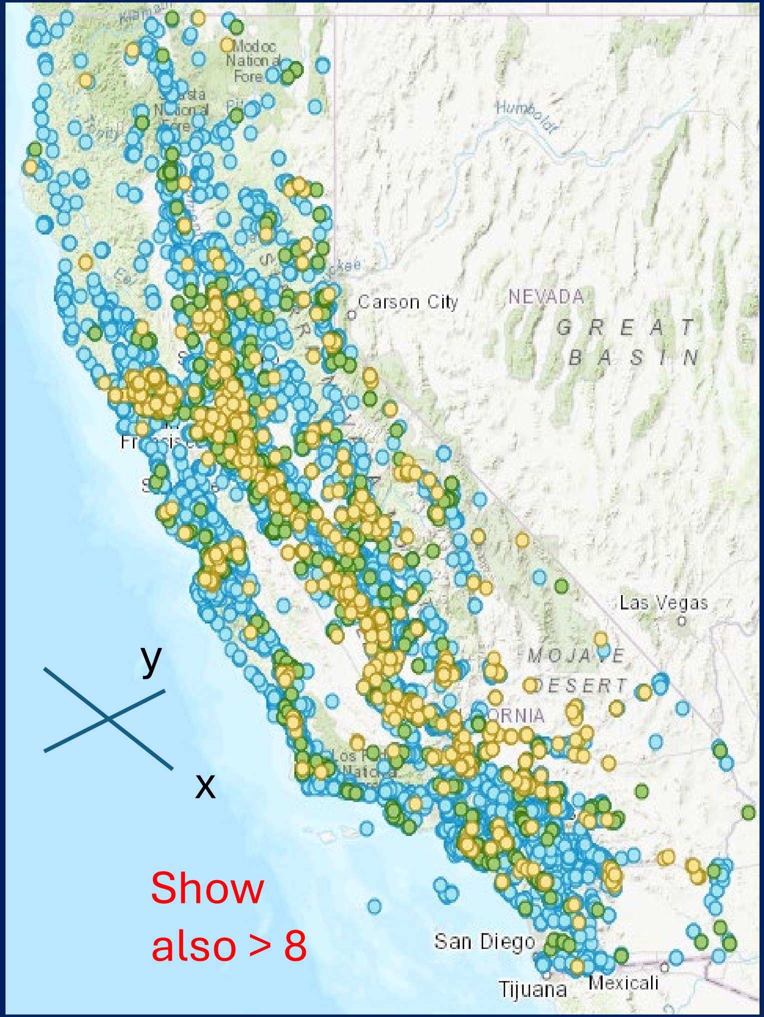
C_{MAX}

BESST dataset compared to GAMA wells

3D Chem. (X-Y-Z Coordinates) **2D Chem. (X-Y Coordinates)**



Heller et al. 2025b



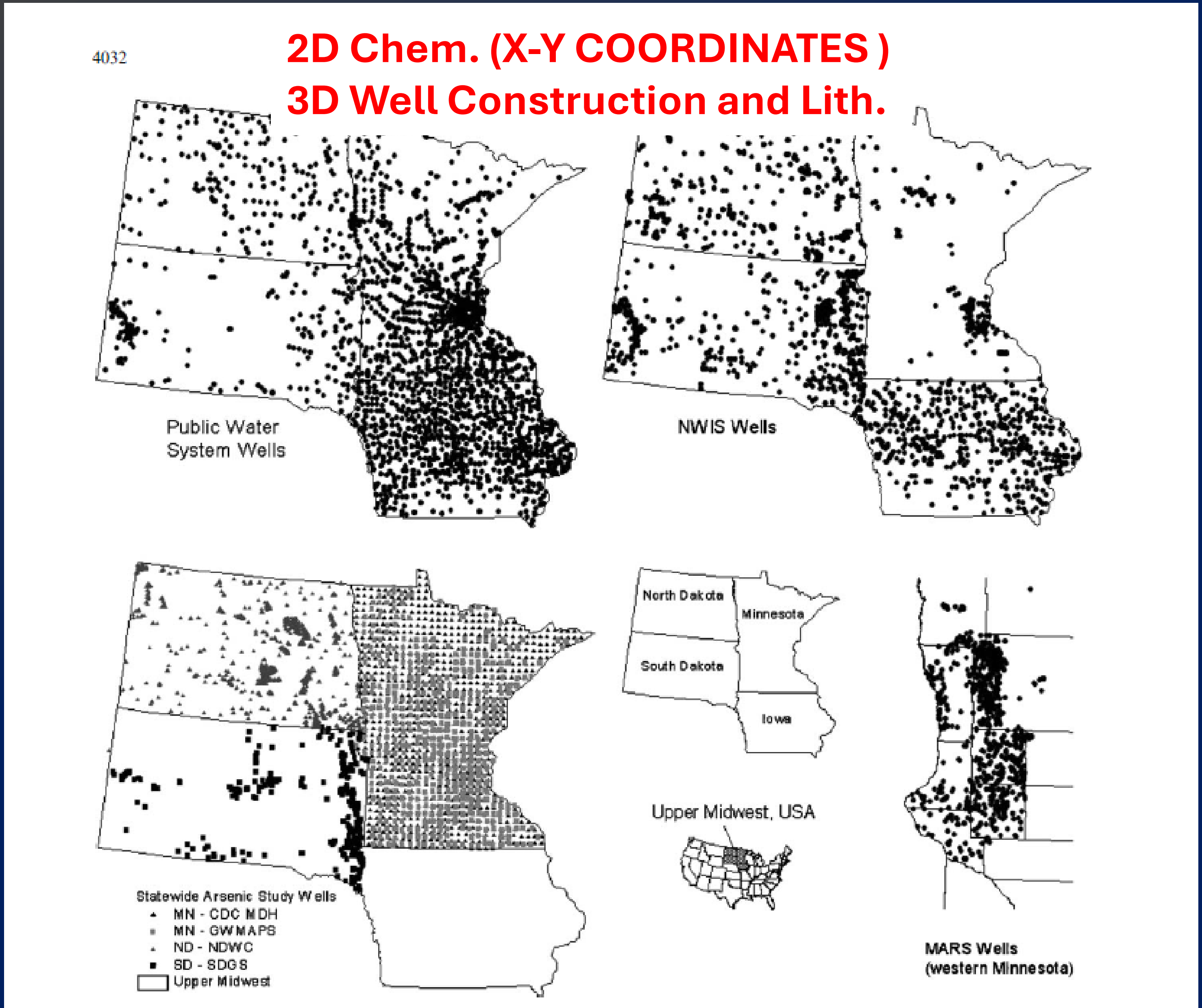
GAMA

GAMA shows wellhead concentrations - only

- Are formation concentrations uniformly elevated or only elevated in discrete intervals?

BESST study includes full zonal flow and chemistry profiles

2D Chem. (X-Y COORDINATES)
3D Well Construction and Lith.



Erickson and Barnes 2005

5,300 PSWs and domestic wells in glacial till sediments

Domestic wells with shorter screens adjacent to or < 4 ft from confining layers had more As exceedances at the wellhead than PSWs

PSW **DOMESTIC**

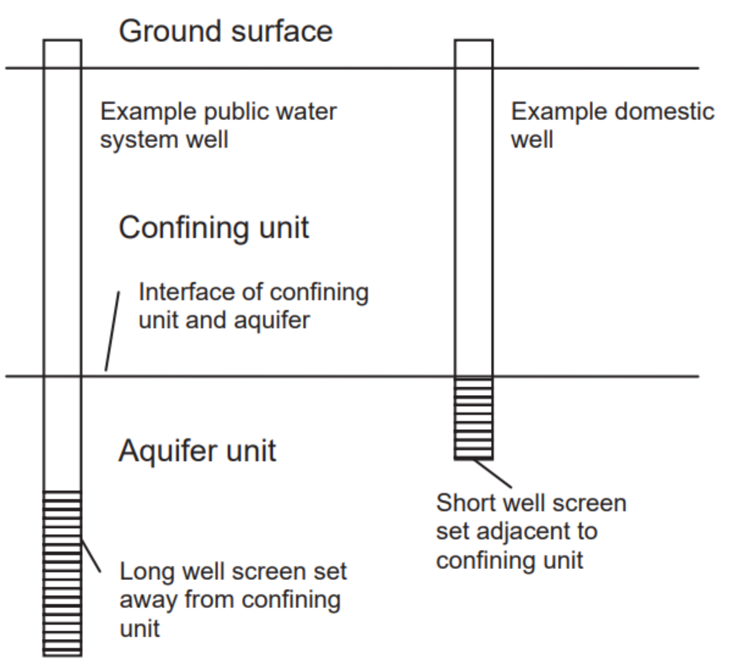
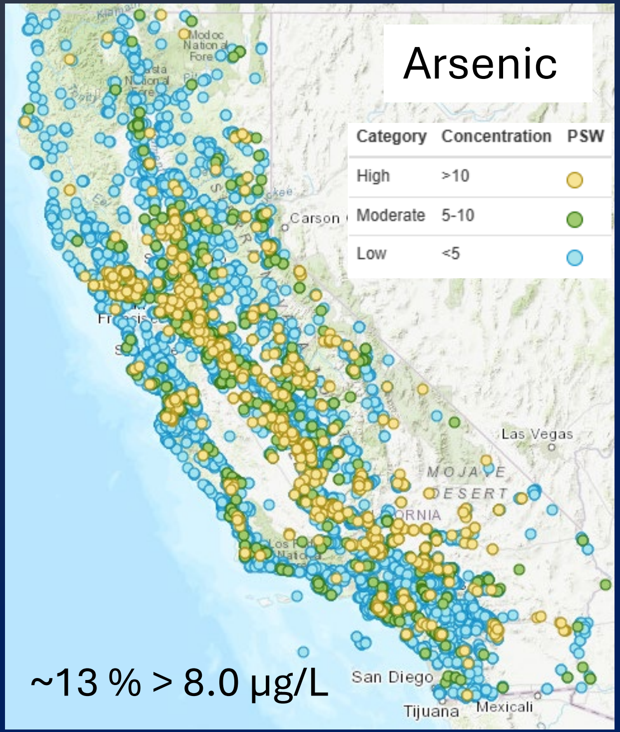
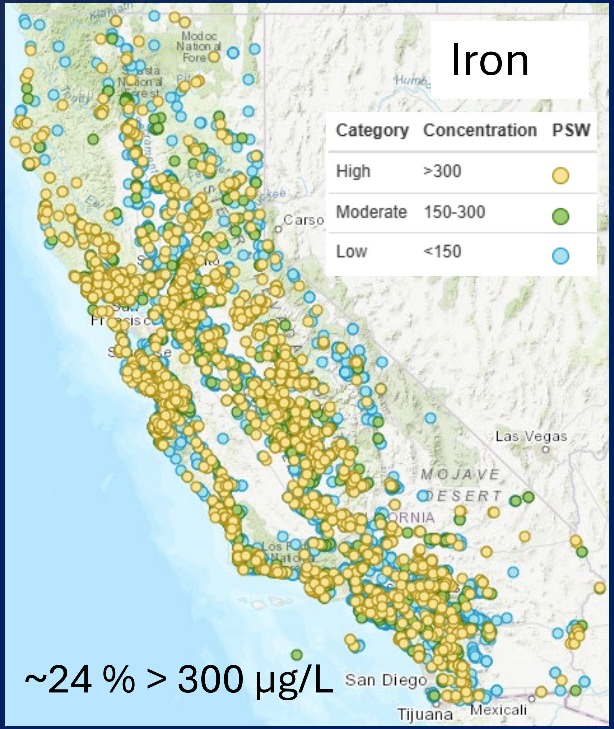
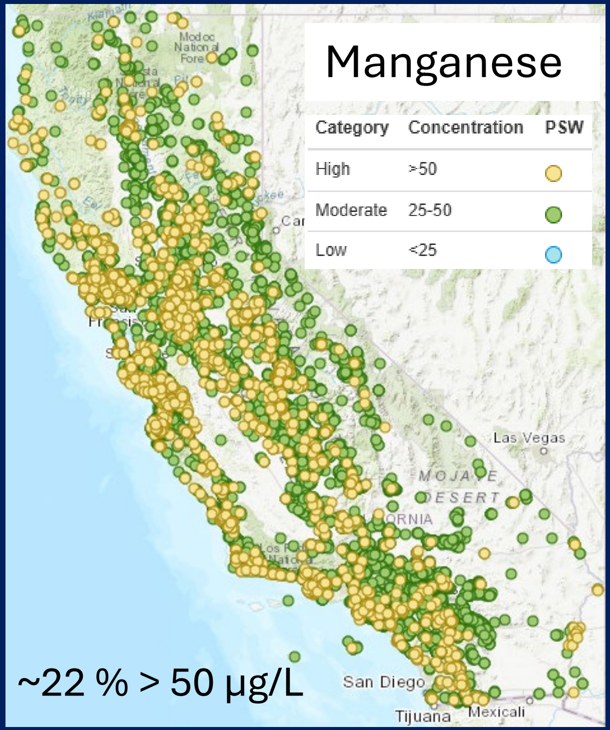


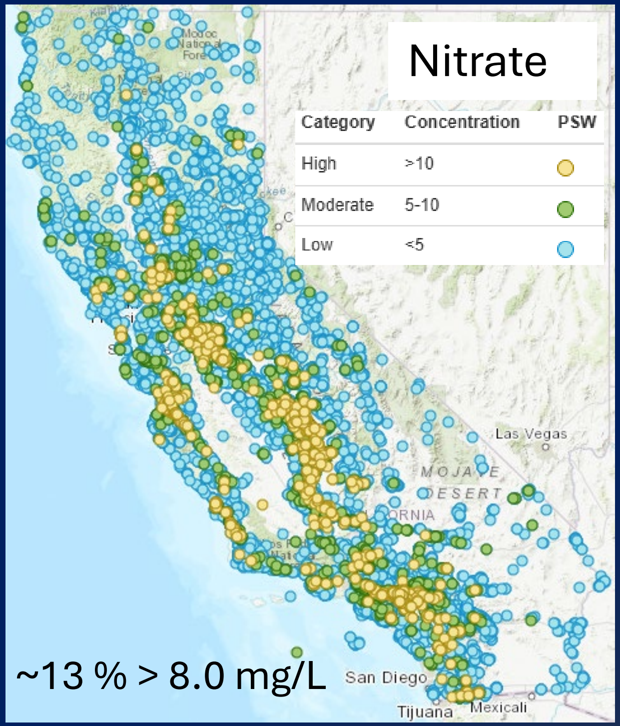
Fig. 1. Illustration of well-construction characteristics.

Groundwater quality issues are widespread in California
2025 GAMA DATA





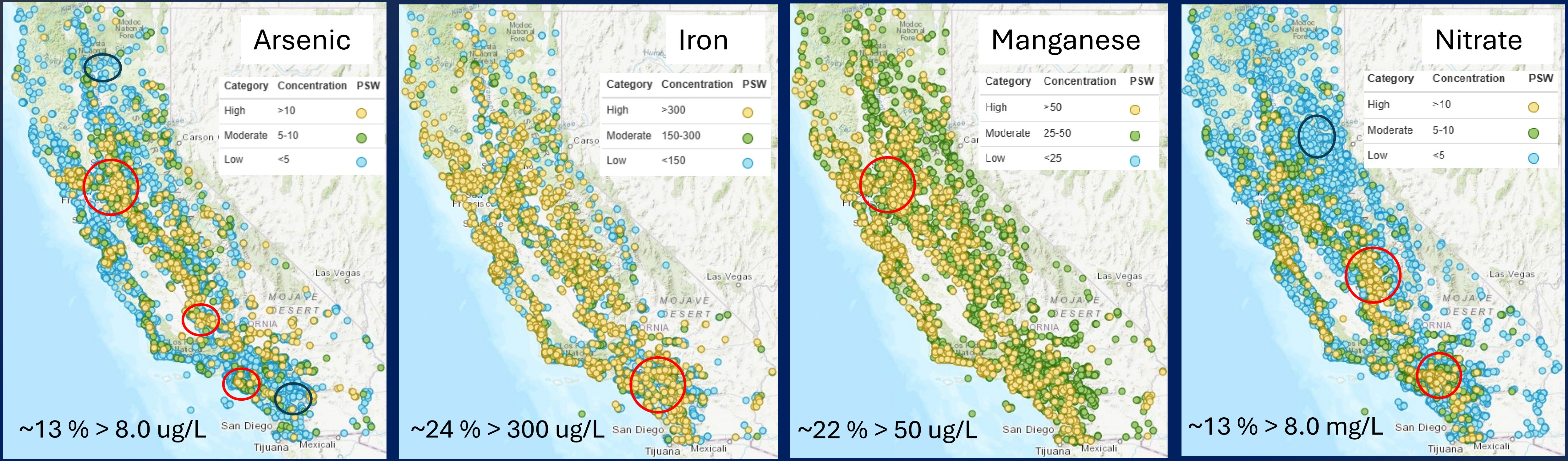




https://ca.water.usgs.gov/projects/gama/public-well-water-quality-trends/
GAMA: Groundwater Ambient Monitoring and Assessment Program
Data collected since 2015 (past 10 years).

As and Nitrate ≥ 80% of MCL
Fe and Mn ≥ 100% SMCL

Groundwater quality issues are widespread in California
2025 GAMA DATA



Localized Wellhead Averages can be Higher Or Lower

Localized Spending on Treatment can be higher or lower

https://ca.water.usgs.gov/projects/gama/public-well-water-quality-trends/
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As and Nitrate ≥ 80% of MCL
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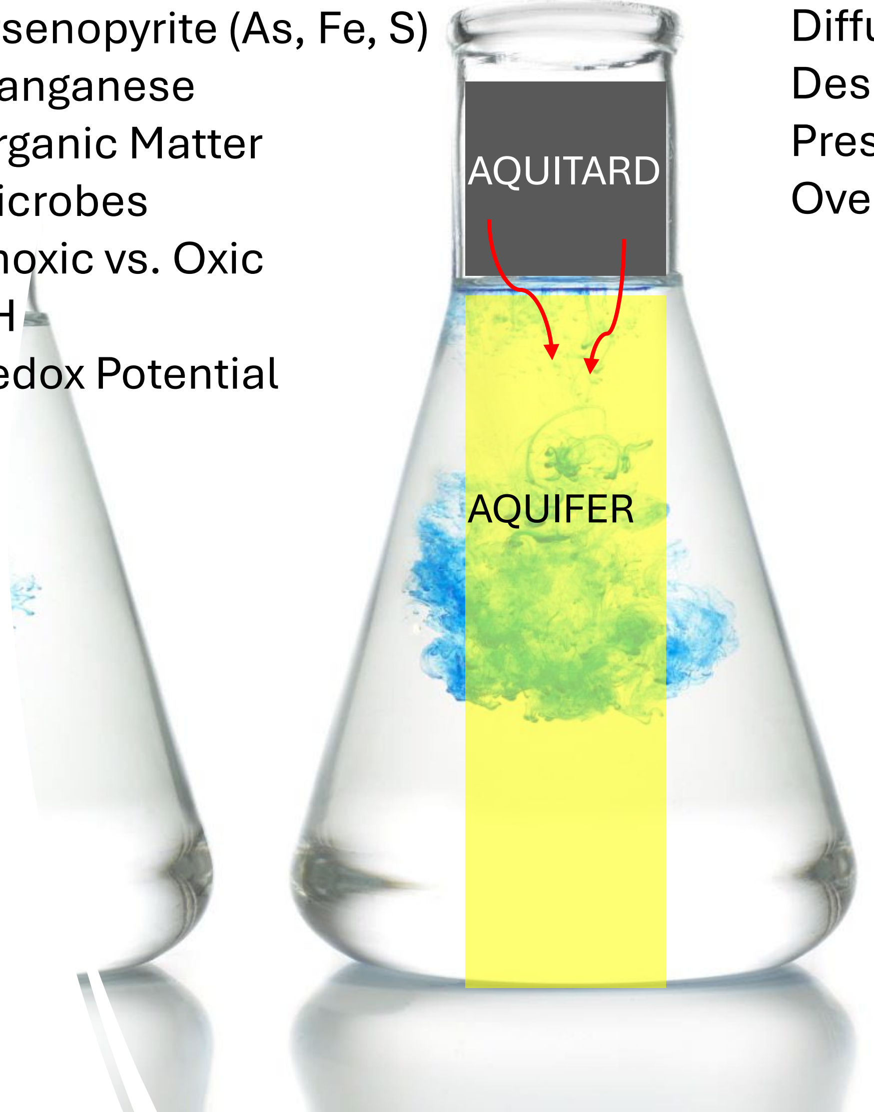
Fate and Transport Processes

Reductive Dissolution (RD)

Reductive dissolution = a mineral is dissolved due to the reduction of a specific element within its structure, such as iron.

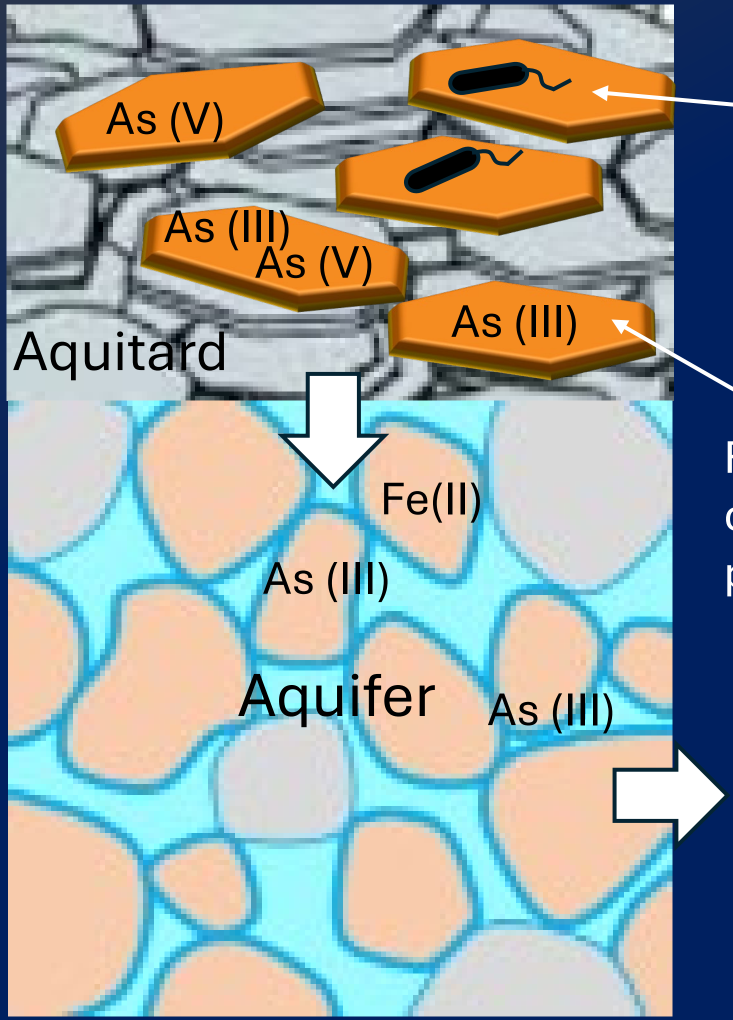
This process is often driven by biogeochemical or chemical mechanisms. In simple terms, it's the breakdown of a mineral by a reduction reaction, leading to the release of dissolved ions.

Ingredients
Pyrite (Fe, S)
Arsenopyrite (As, Fe, S)
Manganese
Organic Matter
Microbes
Anoxic vs. Oxic
pH
Redox Potential



Transport Mechanisms
Dissolution
Diffusion
Desorption
Pressure
Over Pumping

Reductive dissolution processes



Microbes
Org C
Environ. conditions

Fe (III) hydr(oxide) coatings on clay particles

Pumping Influence

Microbial-mediated reductive dissolution of Fe (hydr)oxides

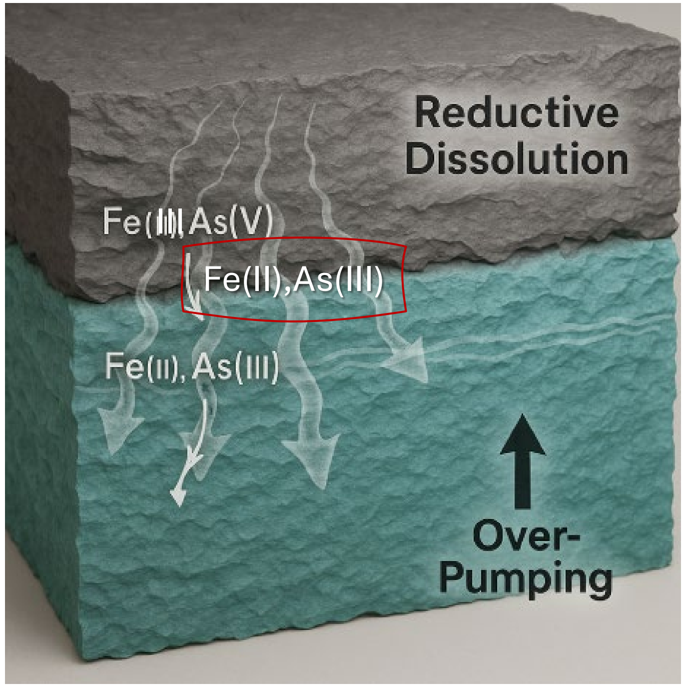
Fe (III) → Fe (II)
(precipitate) *(aqueous)*

As (V) → As (III)

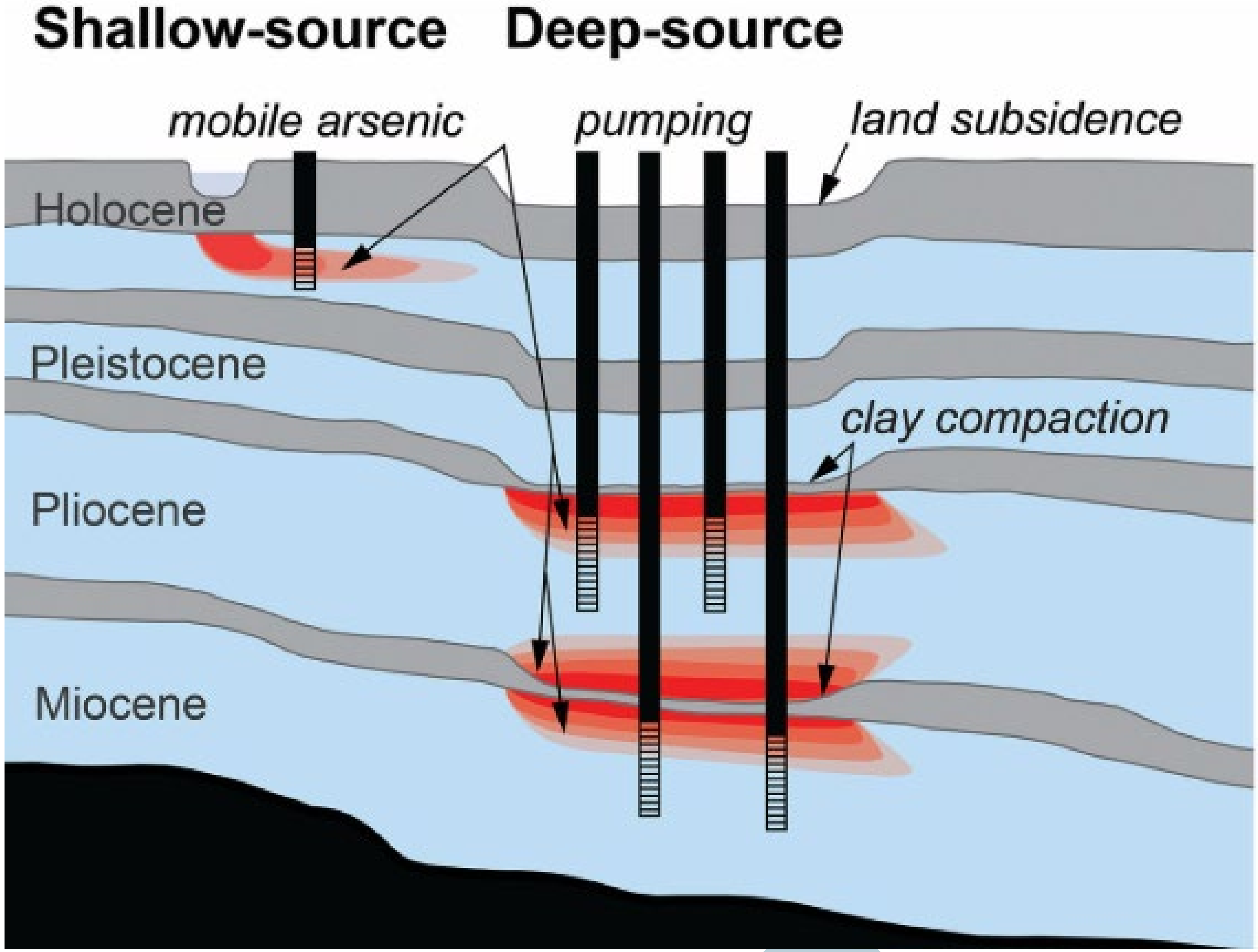
Desorption of As (III) and As (V) (and others, e.g., Mn)

Metal transport into adjacent aquifers

Overpumping



+



EXAMPLE OF IRON, MANGANESE AND ARSENIC MINERALIZATION AT CLAY BOUNDARY

"This image shows iron and manganese oxide coatings on the surfaces of mineral grains adjacent to fine-textured, reduced lacustrine deposits. The arsenic concentration in the coatings are as high as 310 mg/kg. For comparison the arsenic concentration in the bulk continental crust is 1 mg/kg and the concentration in the unaltered host material was less than 4 mg/kg. Needless to say, there are high arsenic concentrations in some wells in the area."

John Izbicki, Ph.D. USGS, Email, November 8th, 2022

MISSING DATA ?

Sedimentary Texture and Facies

Geochemistry

SEDIMENT TEXTURE AND FACIES

Potential Issues with Downhole Sediment Sampling Using Rotary and Reverse Circulation Drilling Methods

Missed C_{MAX} Layers <10 Ft.

Key intervals may be missed!

Loss of Fine-Grained Sediments.

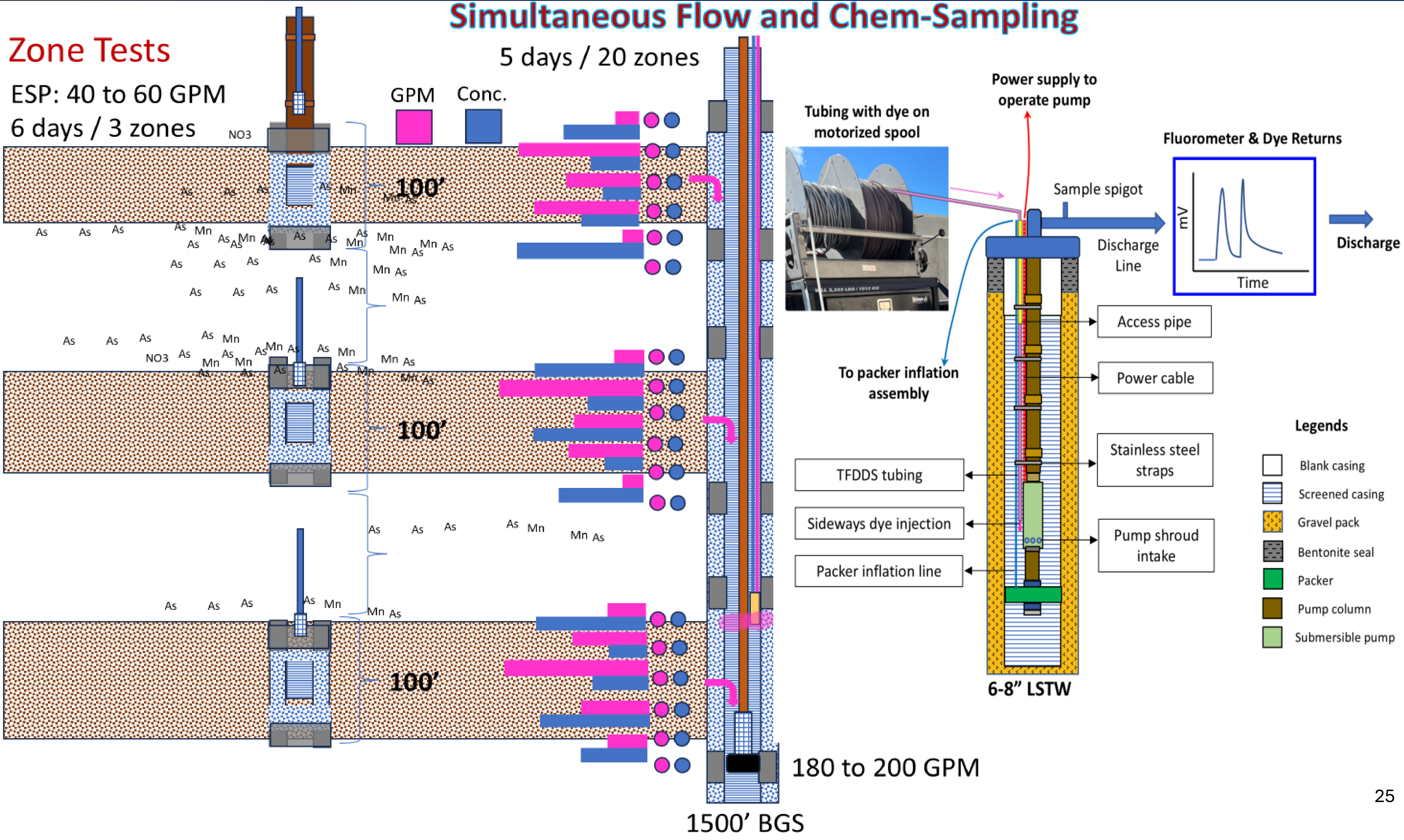
Disaggregation and loss of fines may result in an interpreted bias = Coarser Sed.

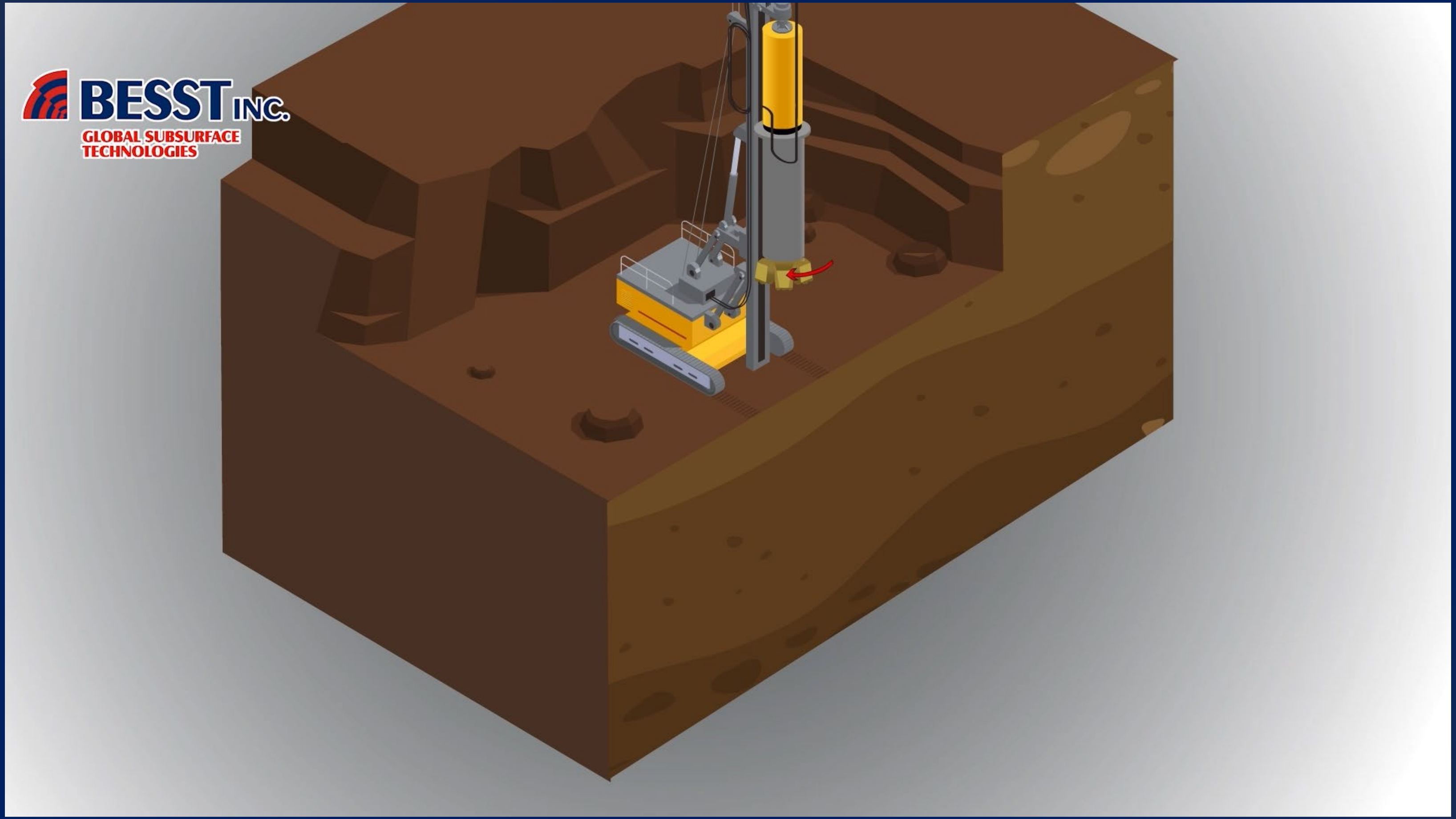
Loss of Texture and Depositional Context.

Potential mis-identification of water chemistry sampling target.

Missed Chemistry

Simultaneous Flow and Chem-Sampling

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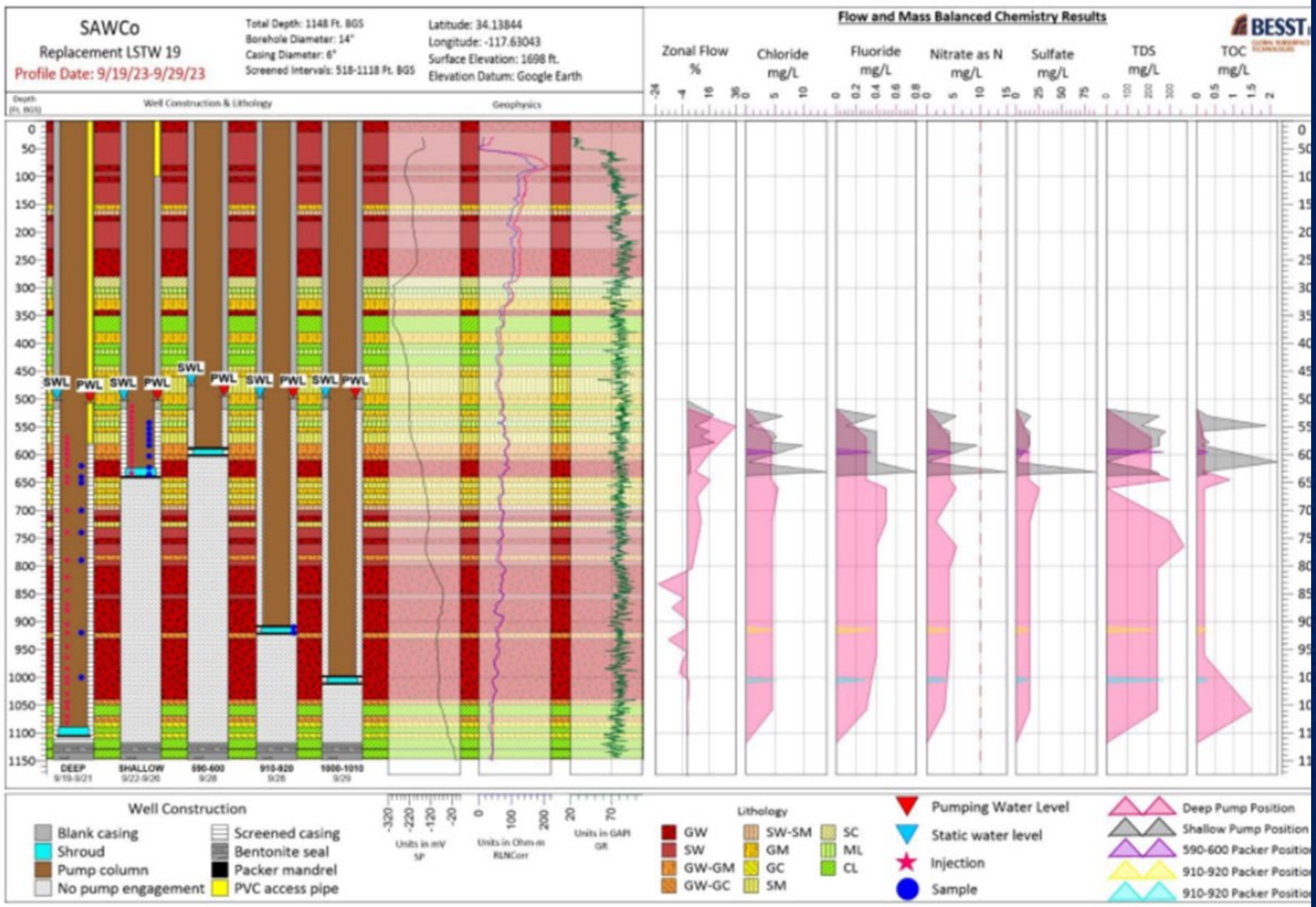
TECHNOLOGIES

Geochemical Failures in Municipal Supply Wells

6” FIBERGLASS LONG-SCREENED TEST WELL – UPLAND, CA

Geologic Application of Long Screened Test Wells

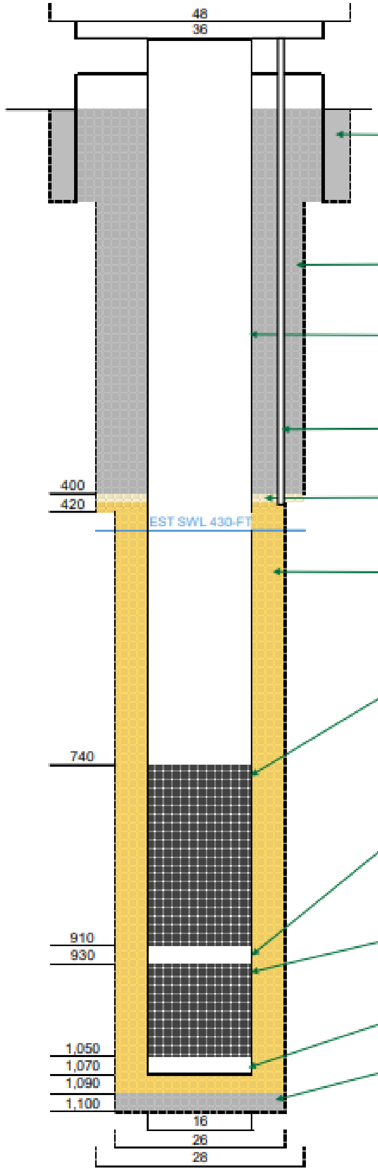


6” FIBERGLASS LONG SCREENED TEST WELL – UPLAND, CA

Groundwater Resources Association of California
grac.org

Reaming Fiberglass Test Well to Construct Municipal Supply Well

SAWCO-19R PRODUCTION WELL 10/25/2023
FINAL DESIGN



<-- CONDUCTOR BOREHOLE DIAMETER (INCHES)
<-- CONDUCTOR CASING DIAMETER (INCHES)

		FROM	TO		
WELL CASING (TOP)				2	FEET
CONDUCTOR CASING (TOP)				-1	FEET
GROUND LEVEL				0	FEET
CONDUCTOR CASING & SEAL	36-in x 0.375-in wall A53 Casing & 10.3-sk sand cement grout	0	50	50	FEET
SANITARY SEAL	11.22-SK SAND CEMENT GROUT; 54-CY	0	400	400	FEET
BLANK CASING	16.625" OD x .312" wall ASTM A606 Type 4 HSLA Blank Casing with welding Collars attached, 40 ft lengths NSF61 Certified; INCLUDES 10-FT OF TEMPORARY STICK UP	+2	740	750	FEET
GRAVEL FEED TUBE	3" PS x Sch 40 Mild Steel Tubing with beveled ends, 40 ft lengths; INCLUDES 25-FT OF TEMPORARY STICK UP	+2	415	440	FEET
FINE SAND TRANSITION	#30 PLAY SAND; 20-EA 50# BAGS	400	405	5	FEET
FILTER PACK	TACNA C. 1/4X16 NSF61 Certified; 56-EA 3,000# SUPER SACKS	405	1,090	685	FEET
SCREEN	16.625" OD x .312" wall ASTM A606 Type 4 HSLA 0.080-IN SLOT Ful Flo Louvered Screen with Welding Collars attached, 40 ft lengths NSF61 Certified	740	910	170	FEET
BLANK CASING	16.625" OD x .312" wall ASTM A606 Type 4 HSLA Blank Casing with welding Collars attached, 40 ft lengths NSF61 Certified	910	930	20	FEET
SCREEN	16.625" OD x .312" wall ASTM A606 Type 4 HSLA 0.080-IN SLOT Ful Flo Louvered Screen with Welding Collars attached, 40 ft lengths NSF61 Certified	930	1,050	120	FEET
BLANK SUMP	16.625" OD x .312" wall ASTM A606 Type 4 HSLA Blank Casing with	1,050	1,070	20	FEET
	16.625" HSLA Bottom Plate with SE Head attached		1,070		
BENTONITE SEAL	#3/8" CHIPS; 38-EA 50# BAGS	1,090	1,100	10	FEET
BOTTOM OF 26-IN REAM (INCHES)				1,100	FEET

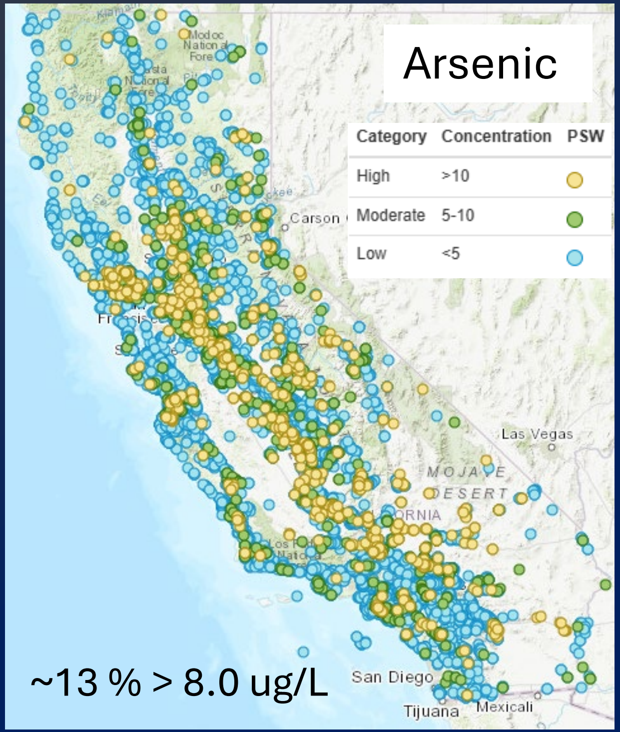
<-- CASING DIAMETER NOM (INCHES)
<-- DIAMETER OF BOREHOLE (INCHES)
<-- DIAMETER OF BOREHOLE (INCHES)

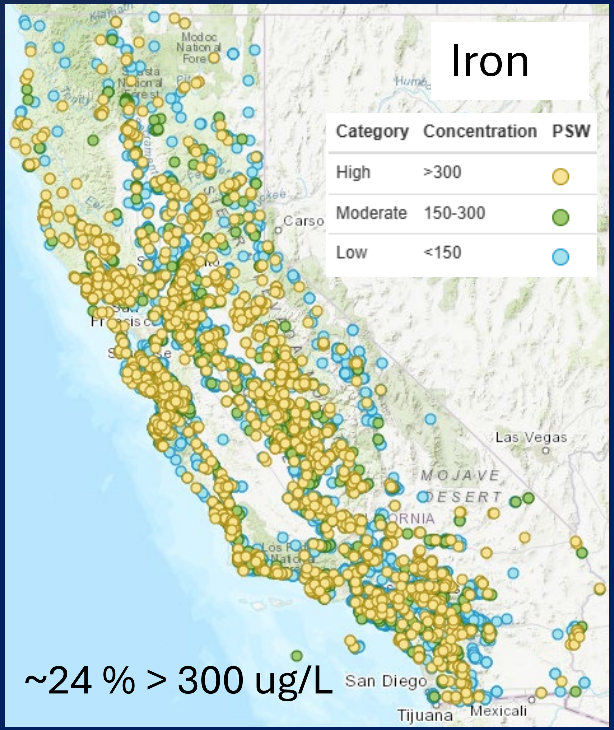
NOTES: 1 NOT TO SCALE

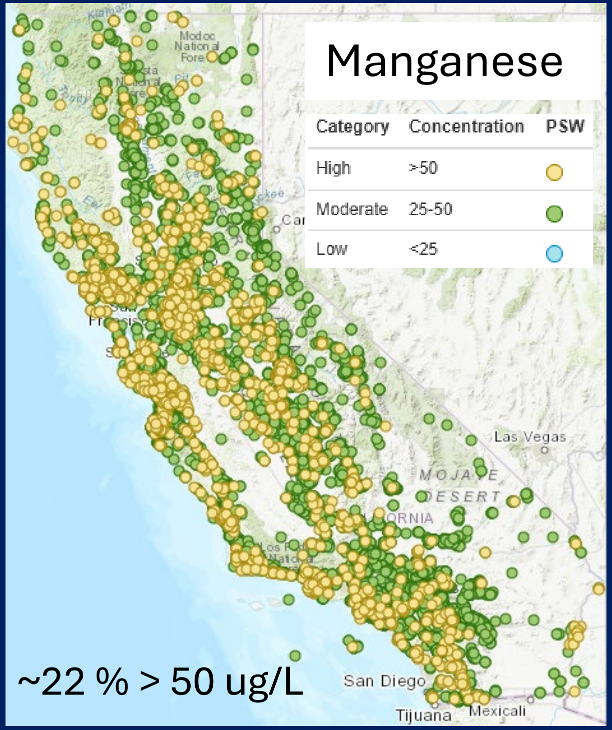
Main Takeaways – Reaching New PSW Water Quality Compliance

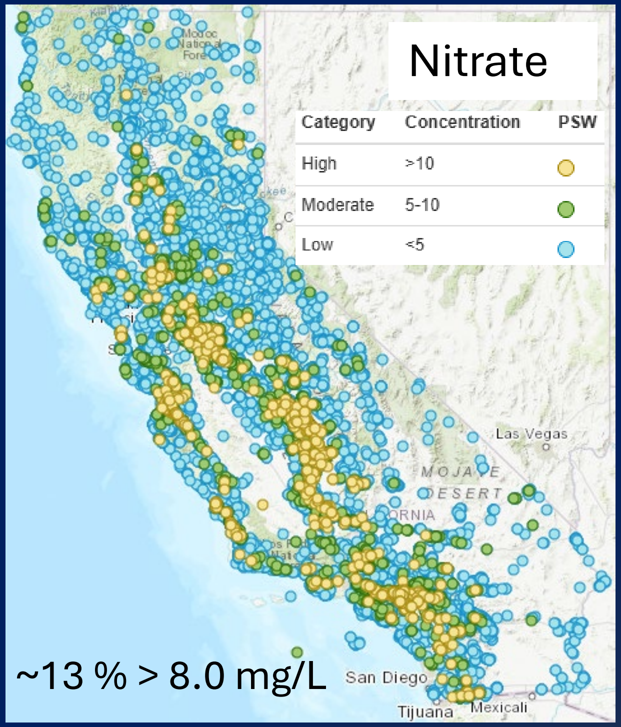
- Screen placement matters.
- Not all sediment types produce geochemically equal groundwater (i.e., Clay vs. Sand.
- Sedimentary context is important.
  - Fine
  - Interbedded
  - Coarse-Boundary (Aquifer-Aquitard)
  - Coarse
- C_{MAX} Intervals **may or may not** be diluted sufficiently to construct a compliant well.

How many of these wells could have been compliant?









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CONSIDERATIONS

WATER QUALITY OPTIMIZATION:

Balance maximizing production with the potential treatment cost.

ROI:

Marginal increase in groundwater yield may be a risky investment if water treatment is needed for compliance.

LOCATION

Localized Risks may be much higher than State Averages

Future Directions

- Treatment Avoidance or Reduction in Non-Compliant Wells
  - Using Granular Well Profiling and Customized Well Modification (packers, sleeves, engineered suctions, etc.)

- Treatment Optimization or Increased Capture
  - Using Granular Well Profiling and Customized Well Modification (packers, sleeves, engineered suctions, etc.)

- Cross-Sectional Mapping and Modeling of Zonal Flow and Chemistry Profiling Data from PSWs and Monitoring Wells.

- We see the potential intersection of Environmental Sequence Straigraphy and Geochemical Sequence Stratigraphy – Particularly as it applies to SGMA.

Any Questions

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Christian Leach, BESST, Inc.

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Compliance in Study Wells

45 % Compliant Wells
55% Non-Compliant