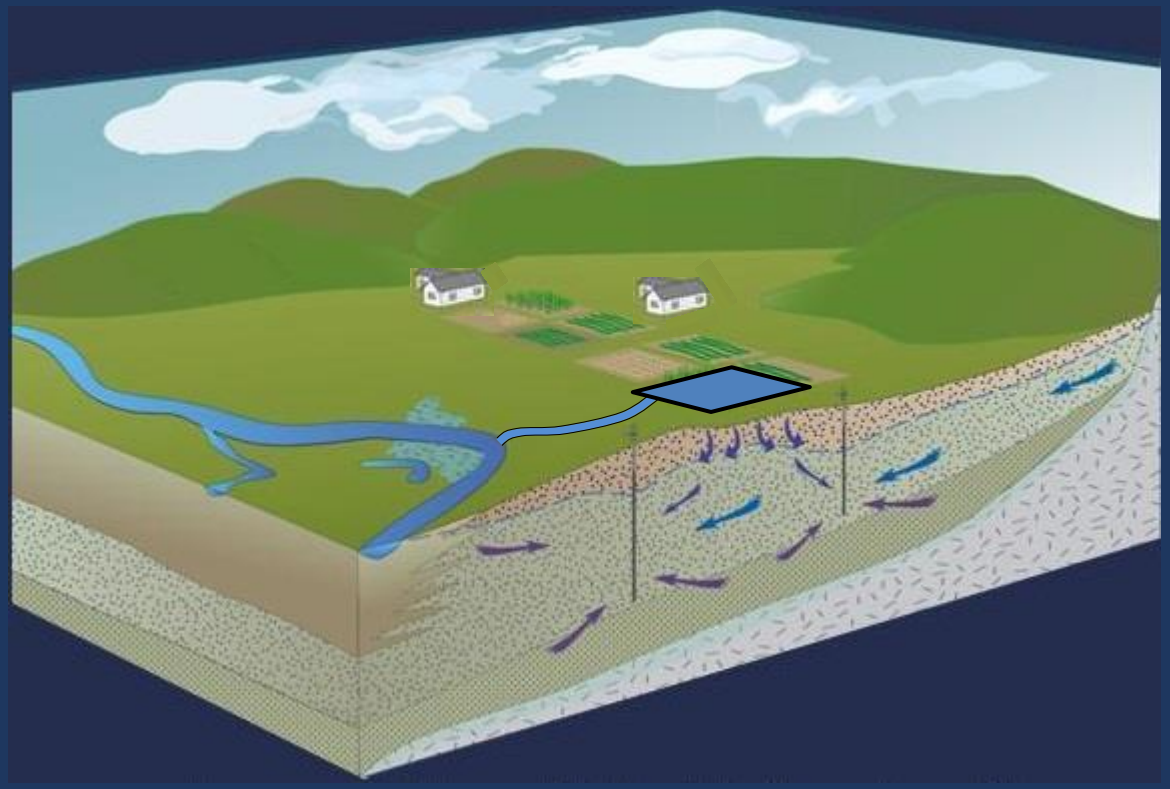
Movement of recharge water from land surface to wells



By: David O'Leary and John Izbicki

March 26, 2014

In cooperation with: The Northeastern San Joaquin Groundwater Banking Authority, Calaveras County Water District, and California Department of Water Resources

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Scope of Presentation

- Overview of recharge sites
  - Morada Lane (“*STK-2*”)
  - Stockton East (“*STK-7*”)
- Morada Lane
  - Monitoring and sample collection
  - Flow logging and depth-dependent sampling
  - Tracer test
  - Groundwater flow simulation
- Stockton East
  - Monitoring and sample collection
  - Flow logging and depth-dependent sampling
- Conclusions

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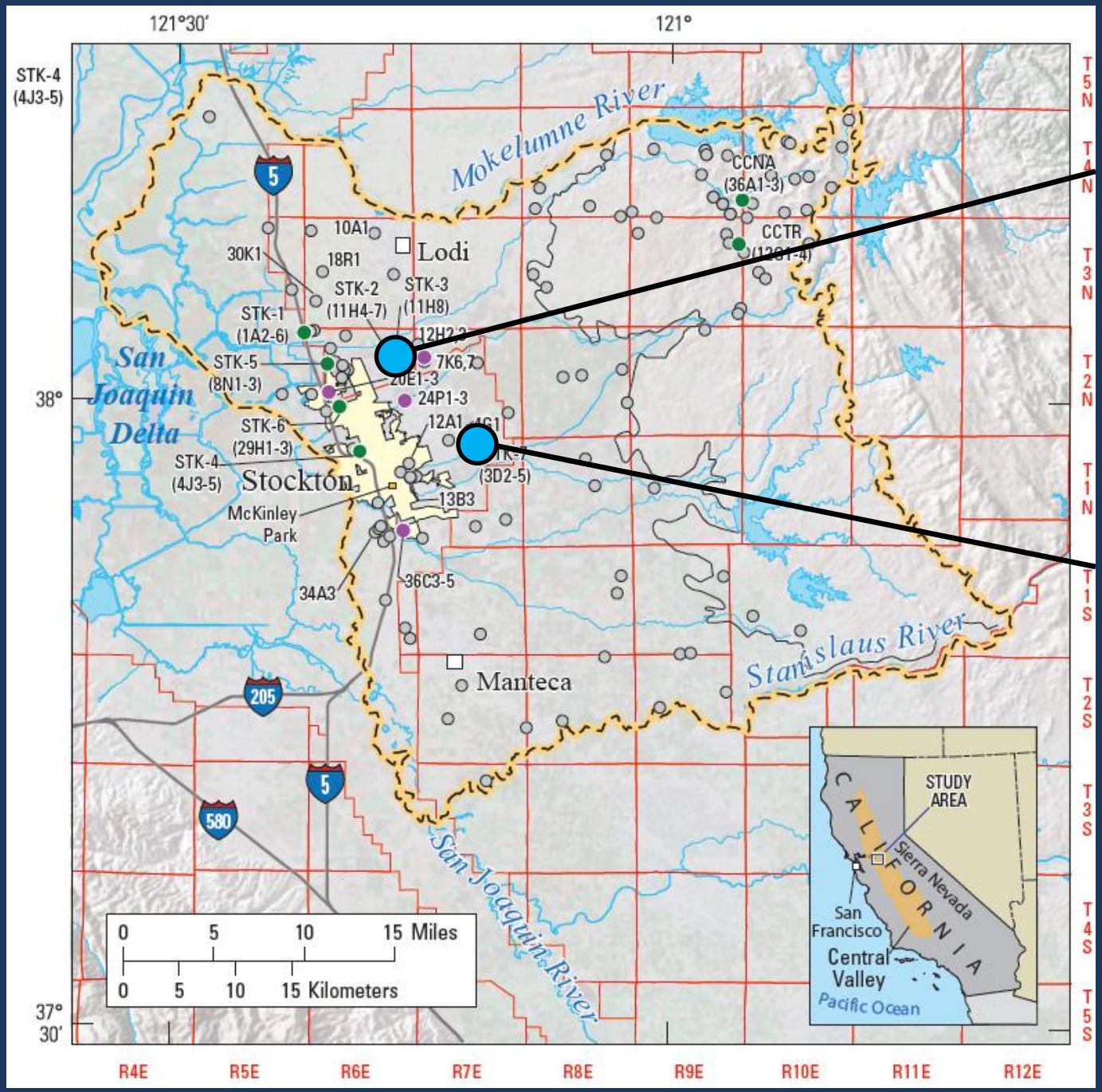

Morada Lane
"STK-2"

Stockton East
Water District
"STK-7"

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Morada Lane

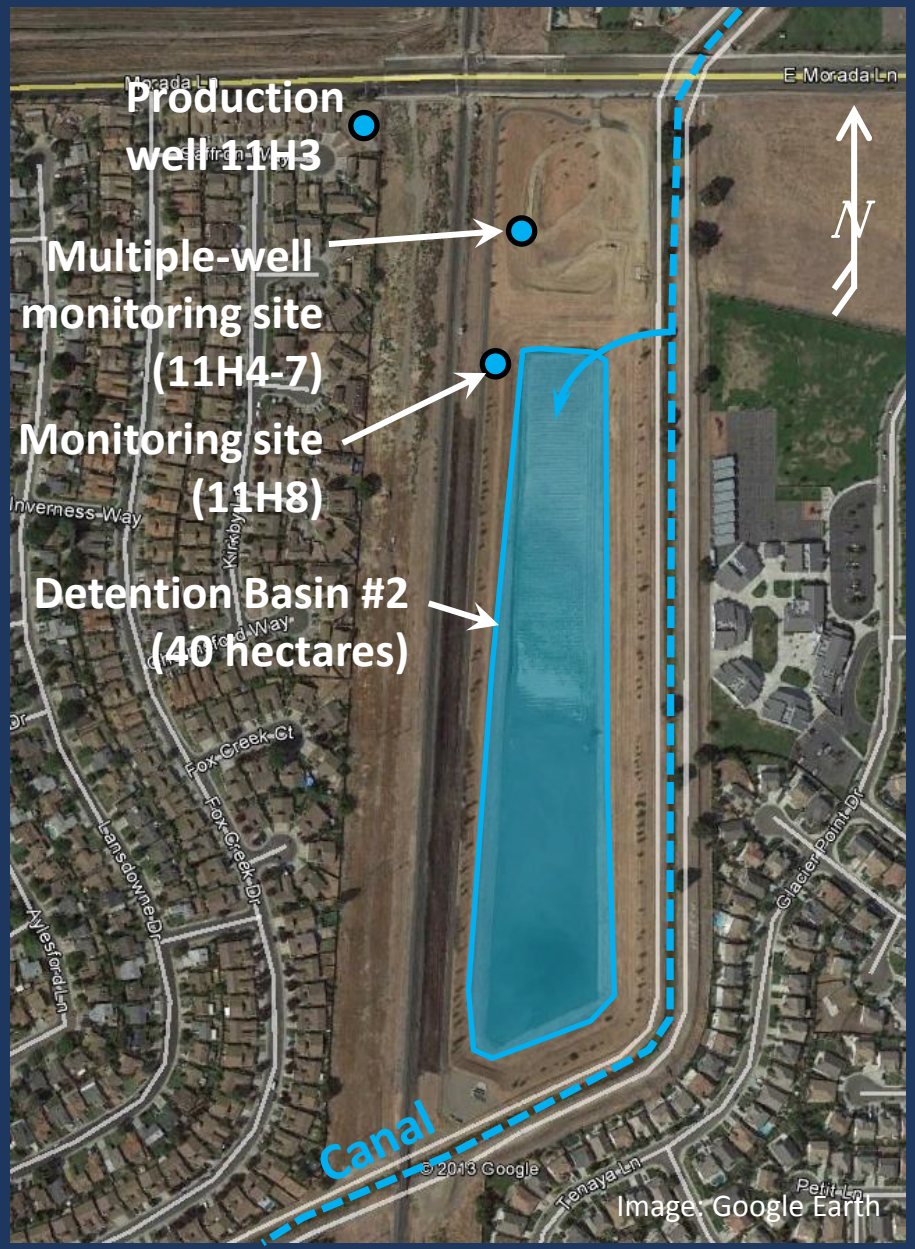

Image: Google Earth

- Depth to water = 50-65 ft
- Infiltrated water from Mokelumne River plus storm-flow
- 2,675 ac-ft recharge infiltrated between 2003 - 2007
- Monitoring of wells 11H4-7, 8
- Flow logging and depth-dependent sampling of 11H3
- SF_6 tracer test
- 2-dimensional radial flow simulation

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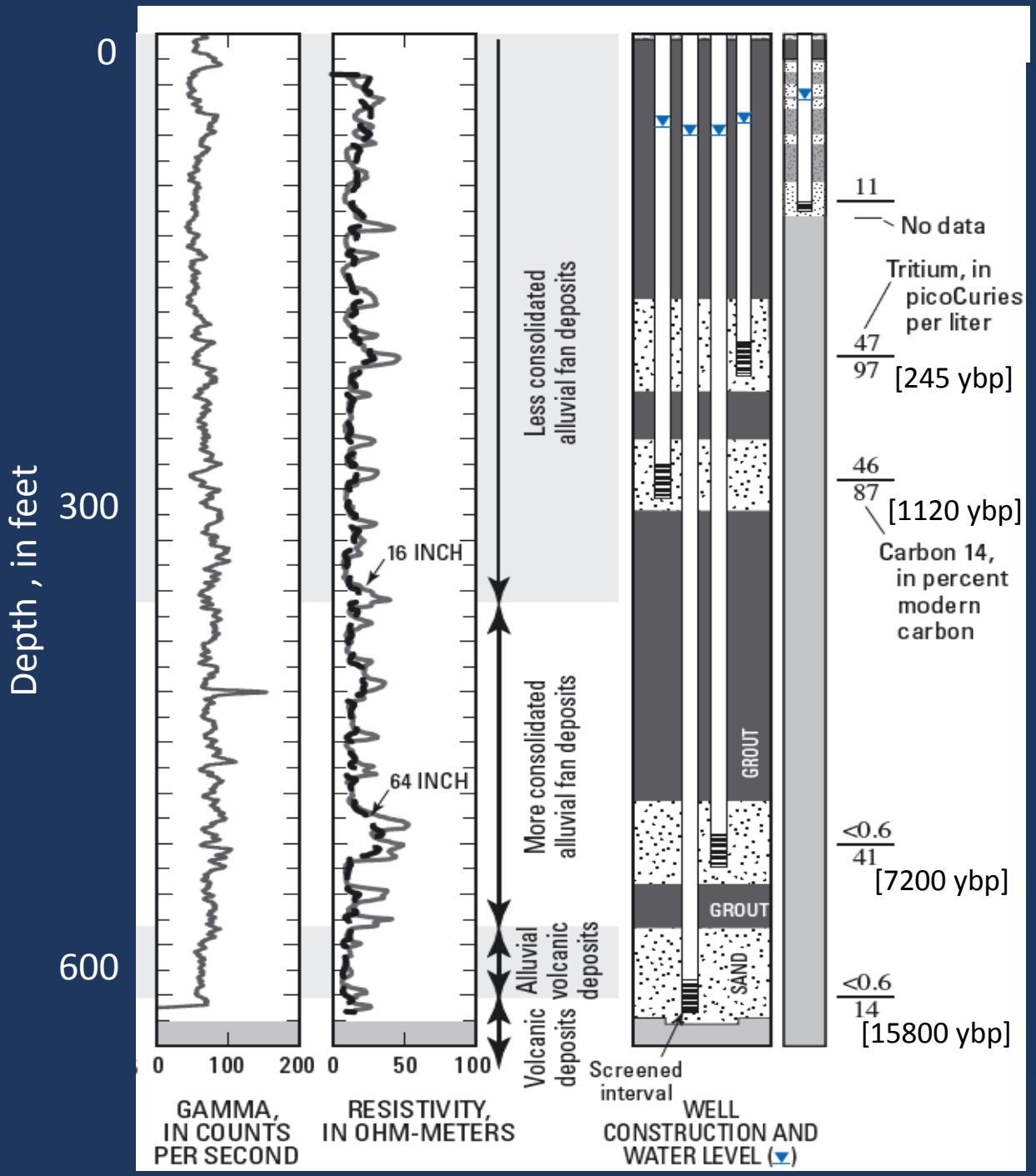

D.O	DOC	Arsenic µg/L
Reducing		6
↓		3
Oxic		3
↓	Decreasing ↓	10
Reducing		30

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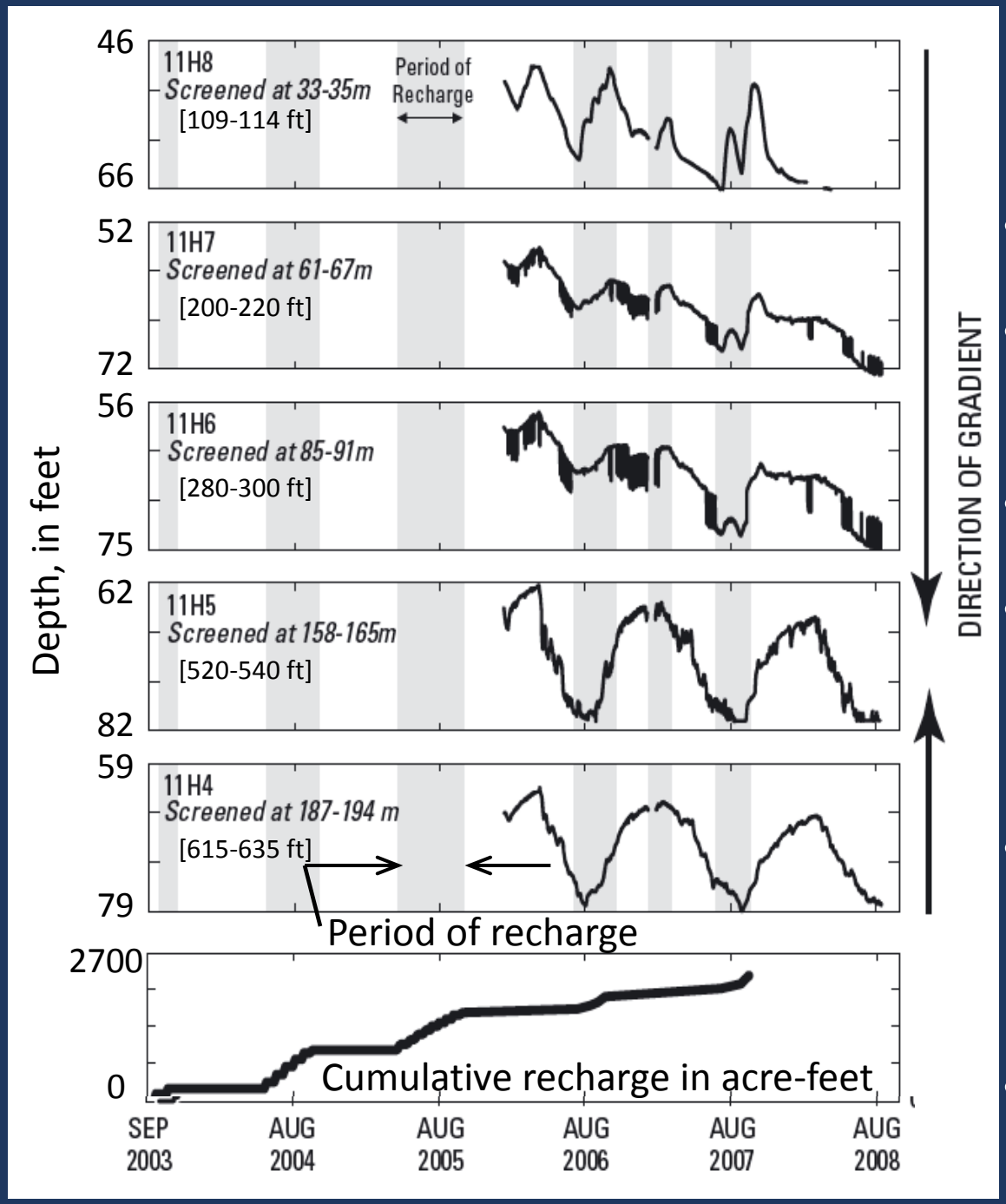

Monitoring Site 11H4-8

- Water level hydrographs
- Downward gradient in general
- Upward gradient at depth
- Pressure responses to pumping and infiltration throughout aquifer(s)
- Dampened/delayed response at depth (>400 feet)
- Arsenic changes

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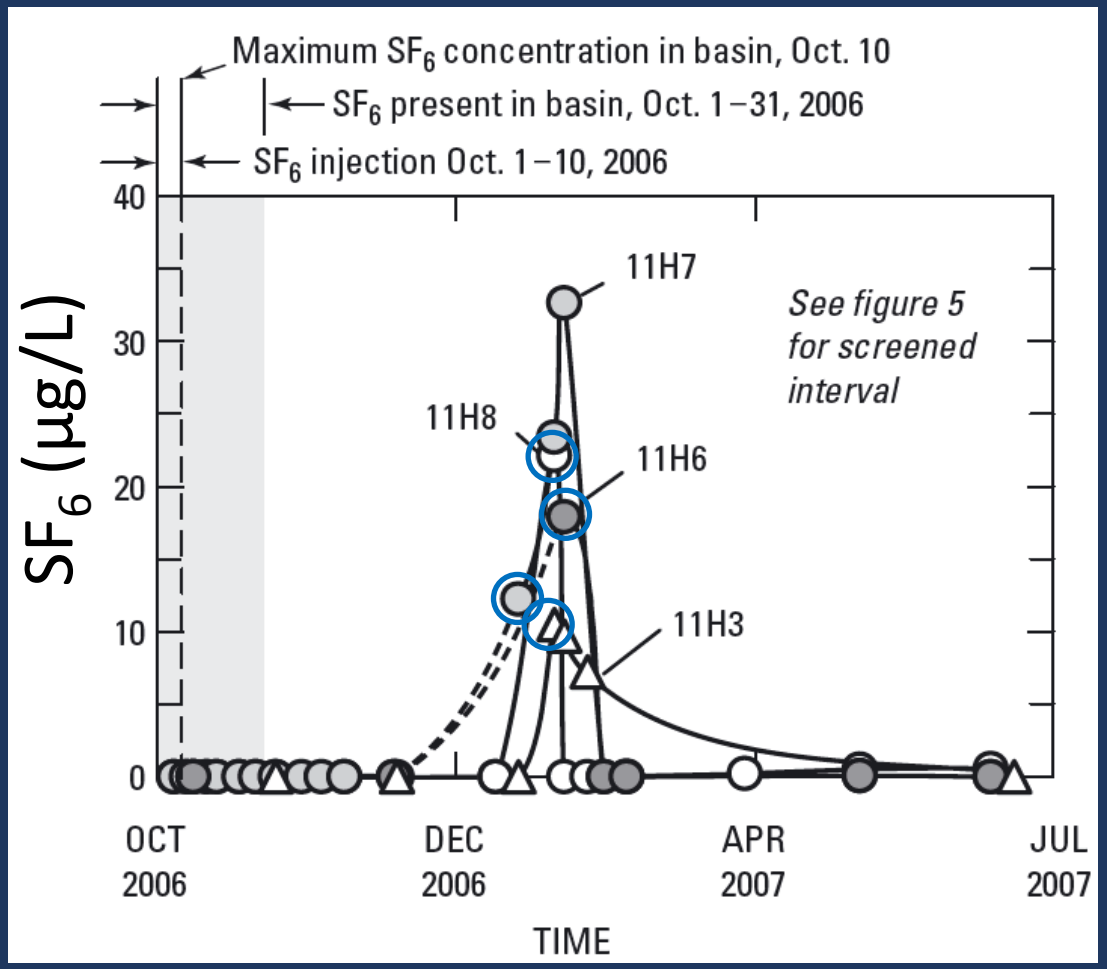
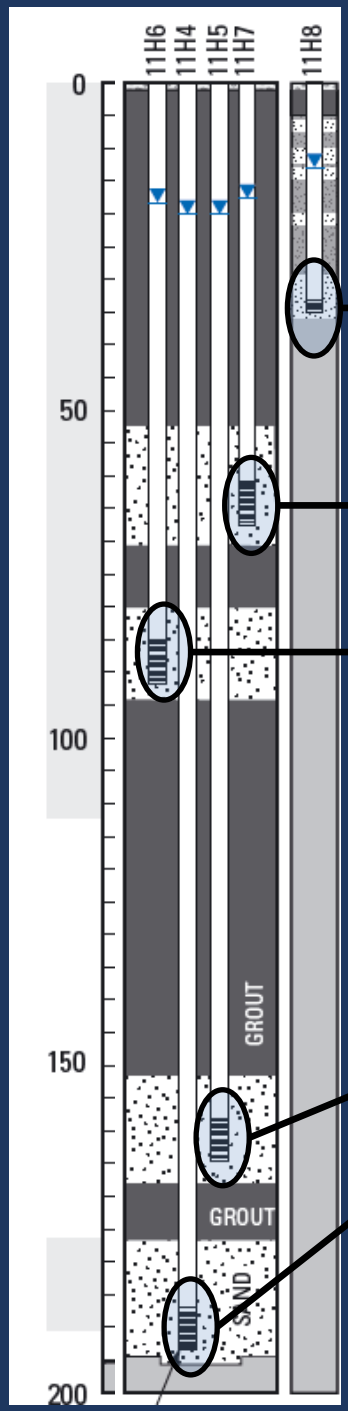
SF_6 Tracer Test

- Non-reactive tracer
- Applied to detention basin
- Monitored 1st arrival times in wells





SF_6 Arrival times

119 days (2nd) [11H8]
Also arrived at 11H3 (prod. well)

108 days (1st) [11H7]

122 days (3rd) [11H6]

175 days (4th) [11H5] (very low conc.)

ND (upward gradient at depth) [11H4]

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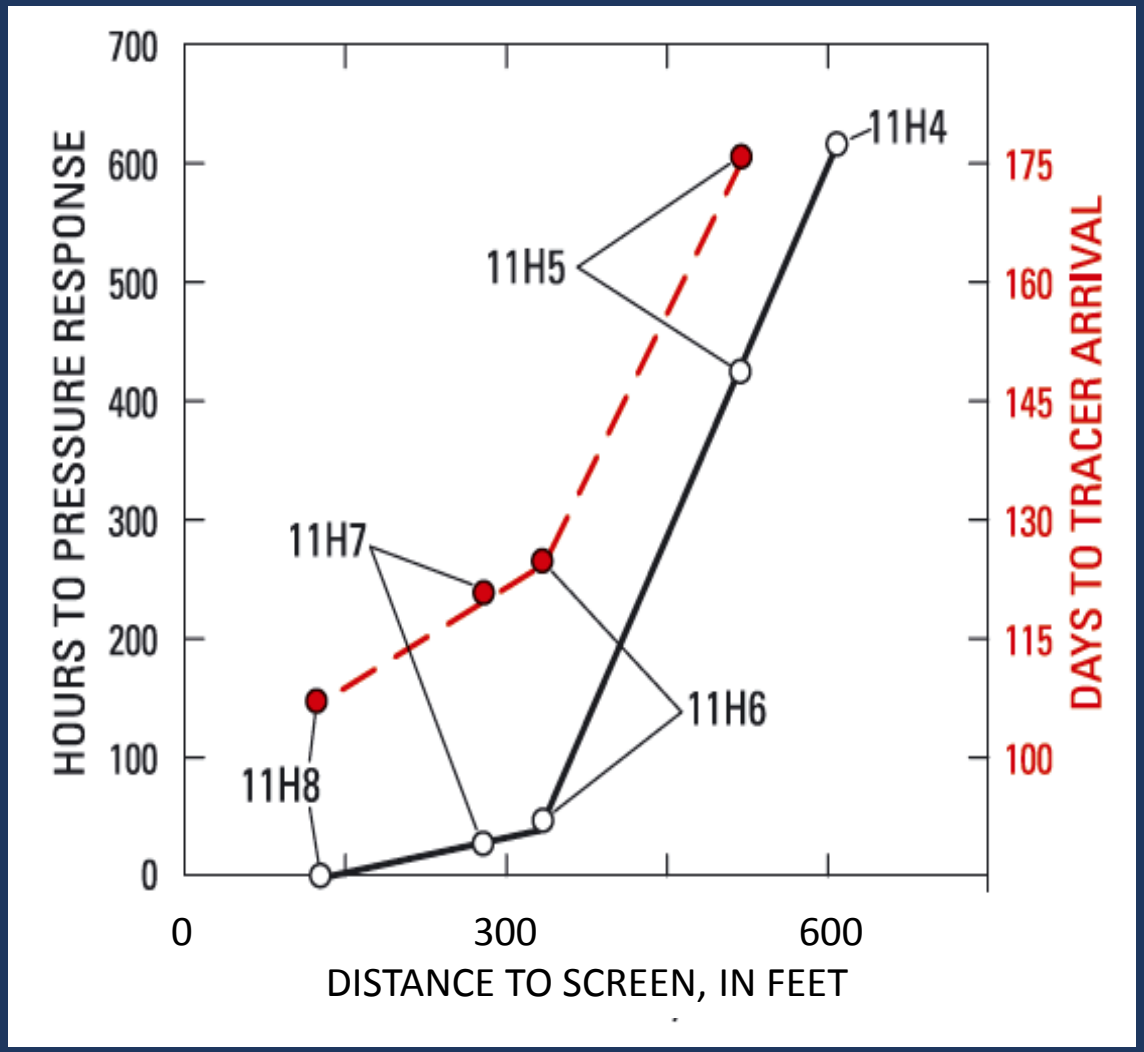
Pressure propagation vs. physical movement of water



- Pressure responses to recharge seen up to 635 ft (11H4)
- Pressure responses and tracer travel times show relative isolation of deposits >300 ft (>11H6)

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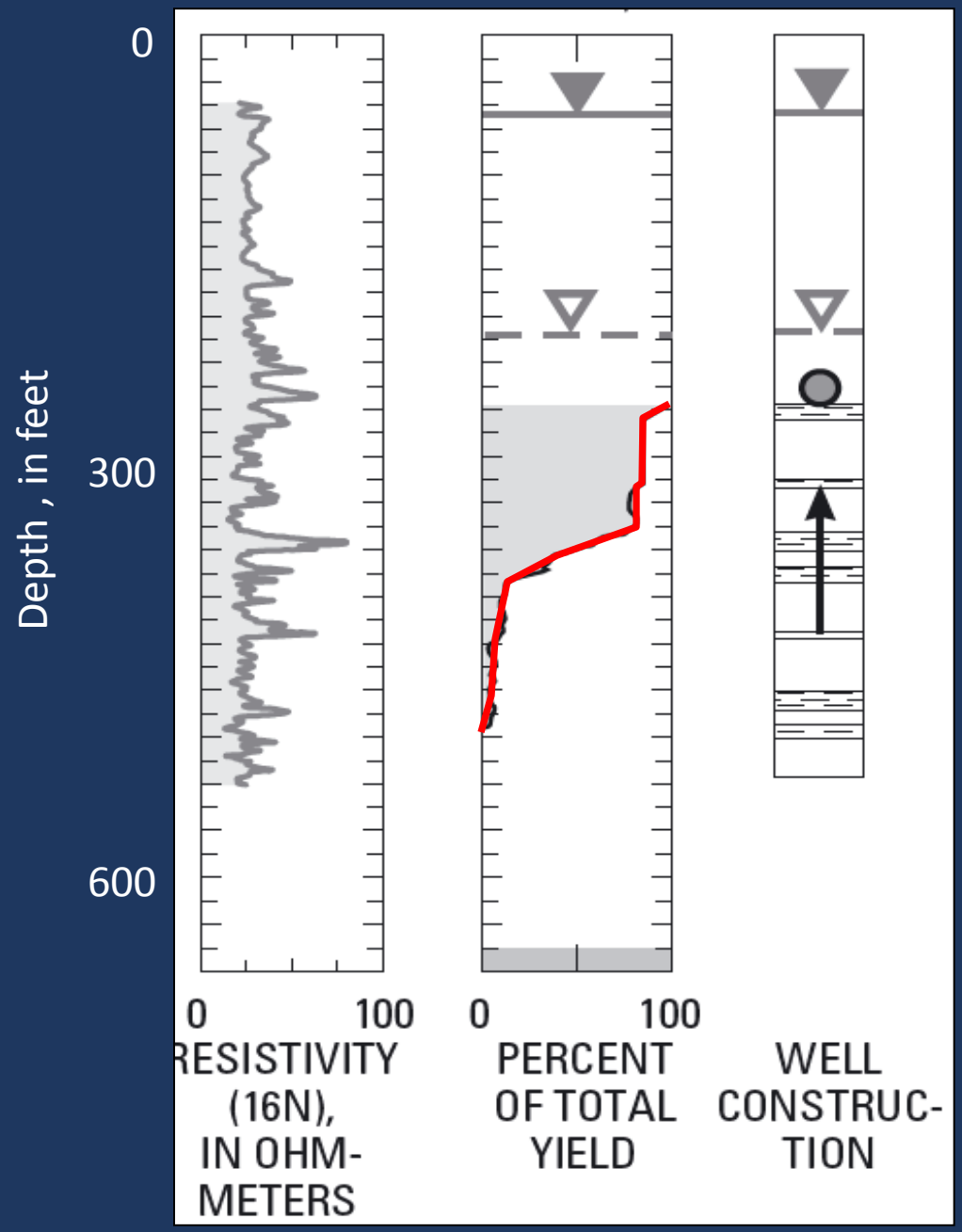
Flow Logging (Production Well 11H3)



- Flow contribution to well is heterogeneous
- ~70% of flow at:
  350-365 ft
  375-385 ft
- ~10% from deeper screens
- Low arsenic concentrations
- Wellbore flow, ground-water flow, and particle-tracking simulated using 2D radial flow model (*AnalyzeHOLE*)

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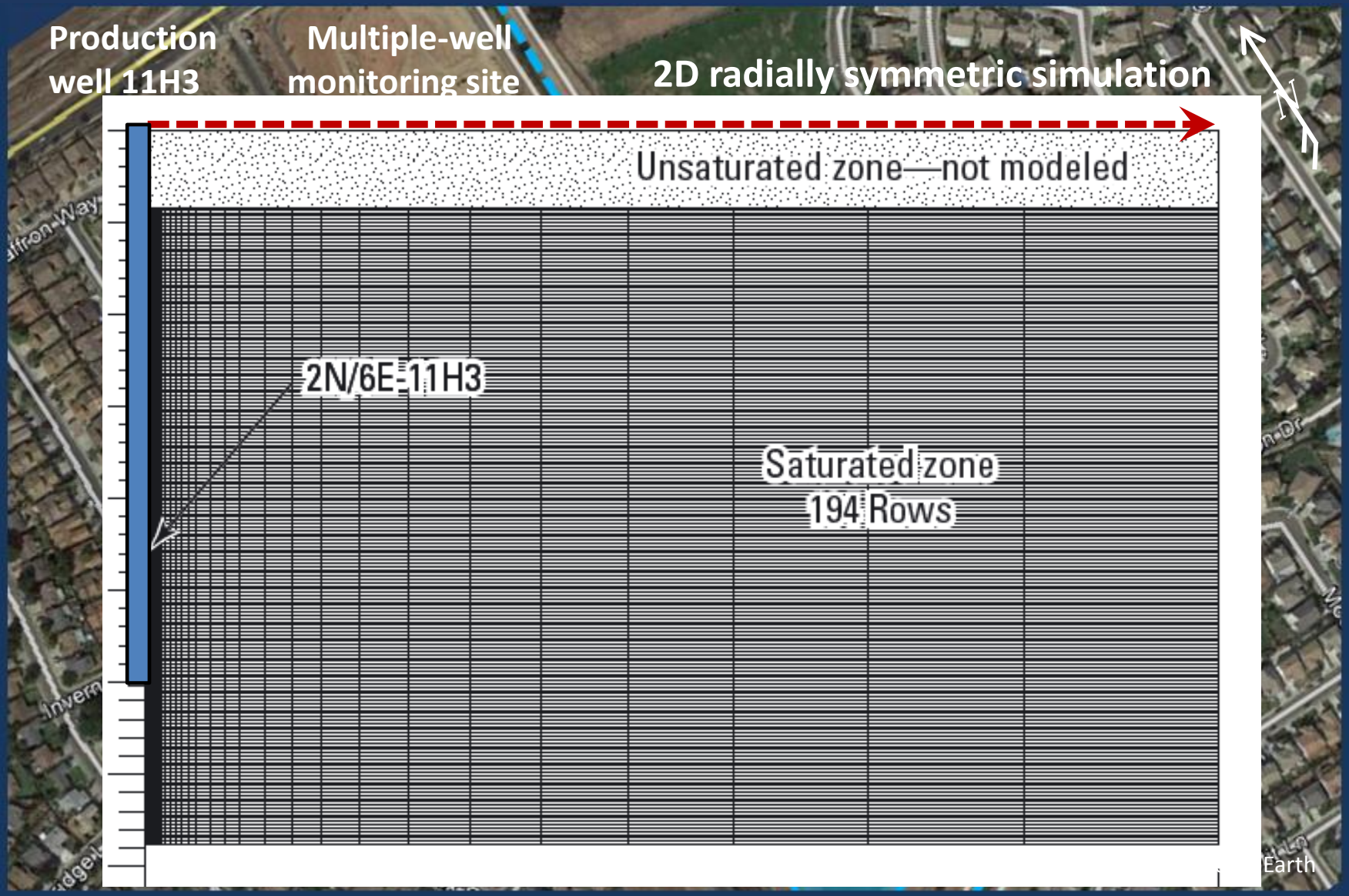
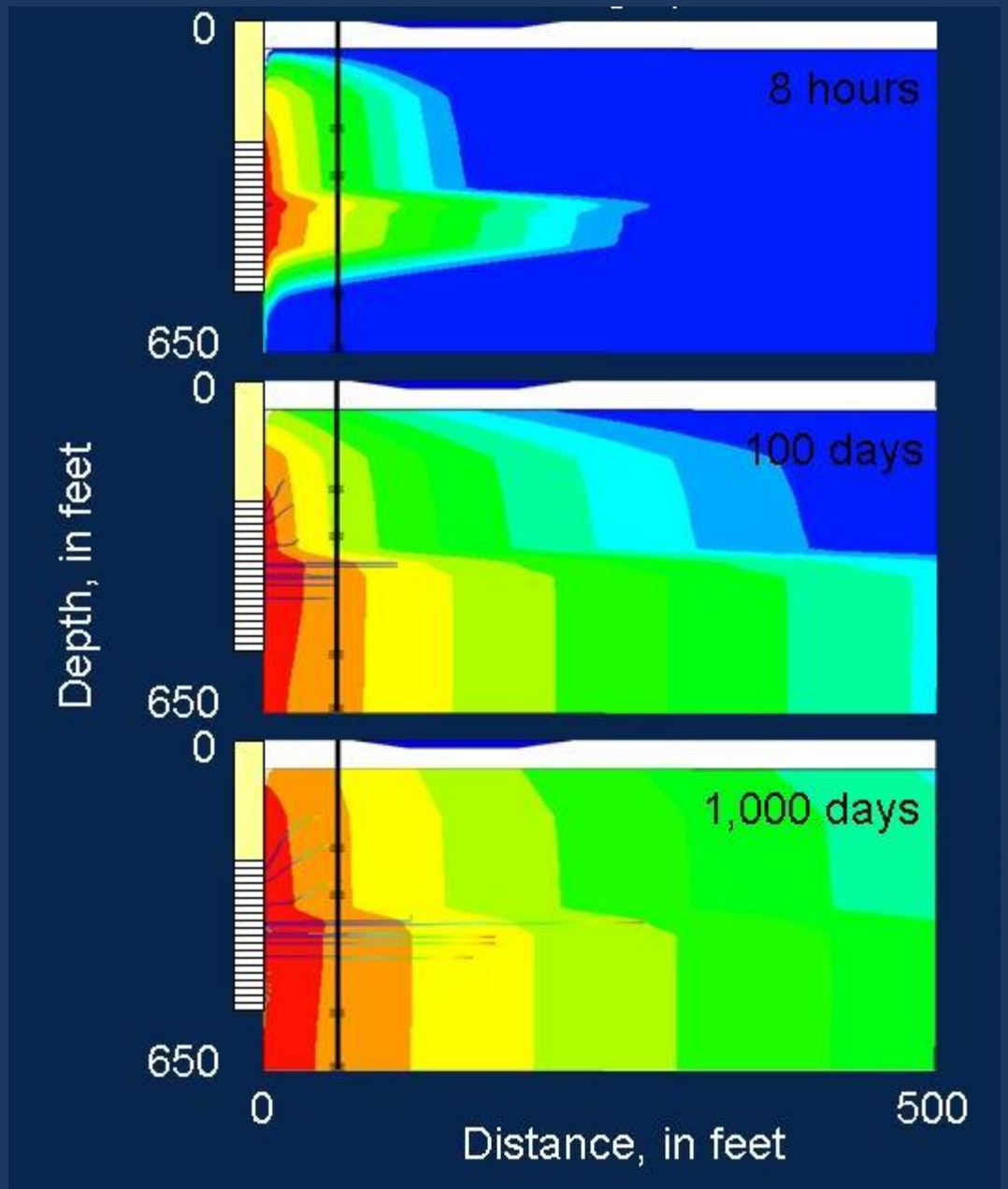
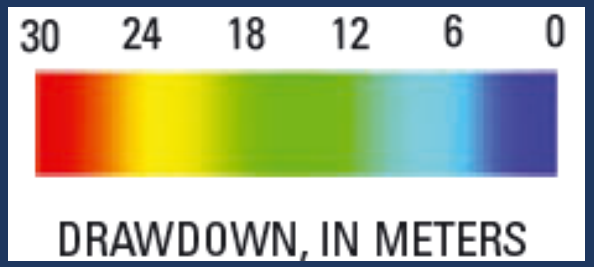
Radial Flow Model



Simulated response to pumping in well 11H3



- Calibrated by adjusting K's to match wellbore flow and observed drawdowns
- Simulated particle velocity = 6.2 ft/d
- SF_6 Tracer particle velocity = 5.5 ft/d
- Propagation of pressure head vs. physical movement of water



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Stockton East Water District

Image: Google Earth

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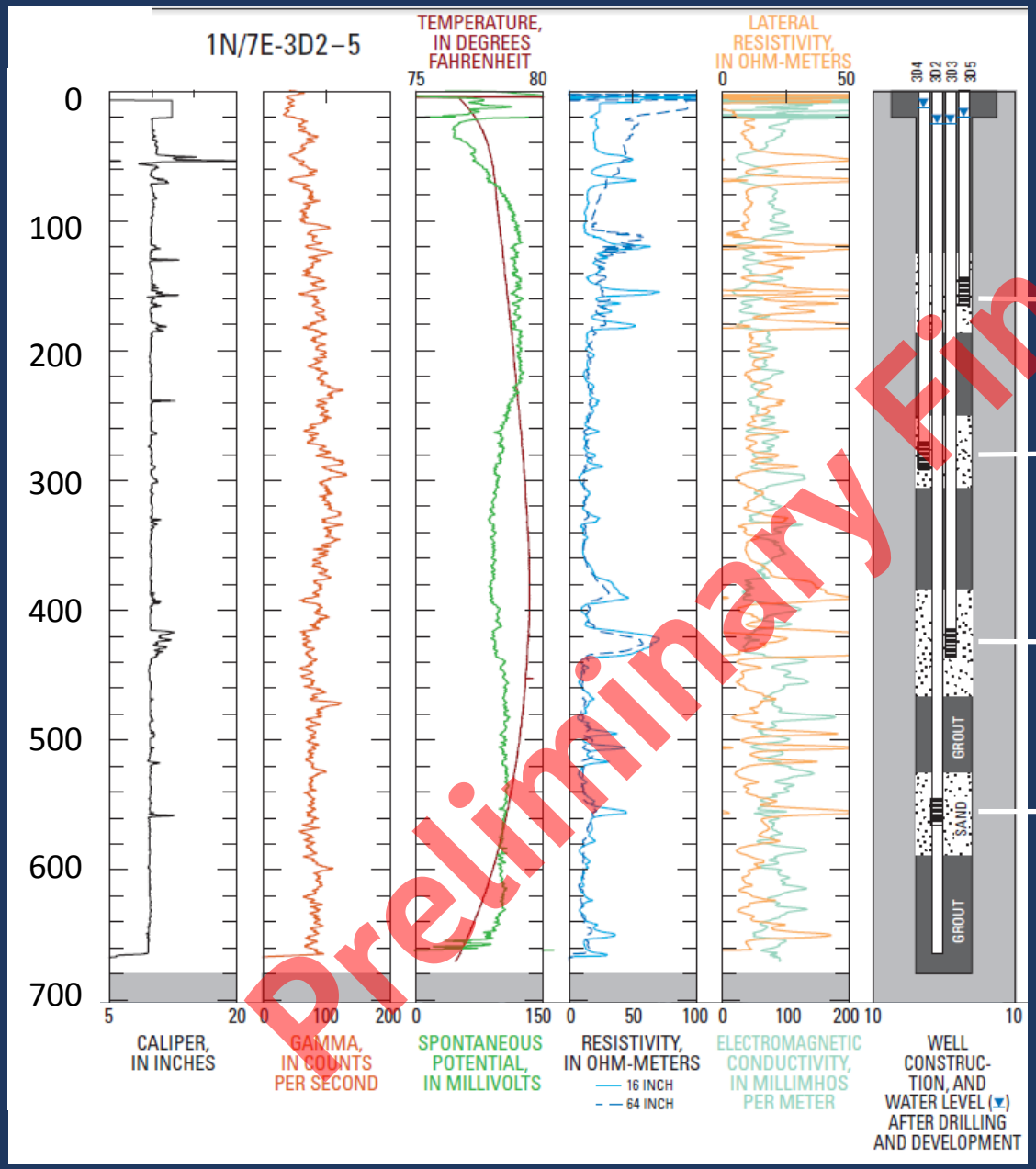
Monitoring Site 3D2-5 (“*STK-7*”)



pmC

95.05 [412 ybp]

42.58 [6900 ybp

28.52 [10100 yb

19.89 [13000 yb

GOES satellite system for real-time transfer of data to the web

Preliminary Findings

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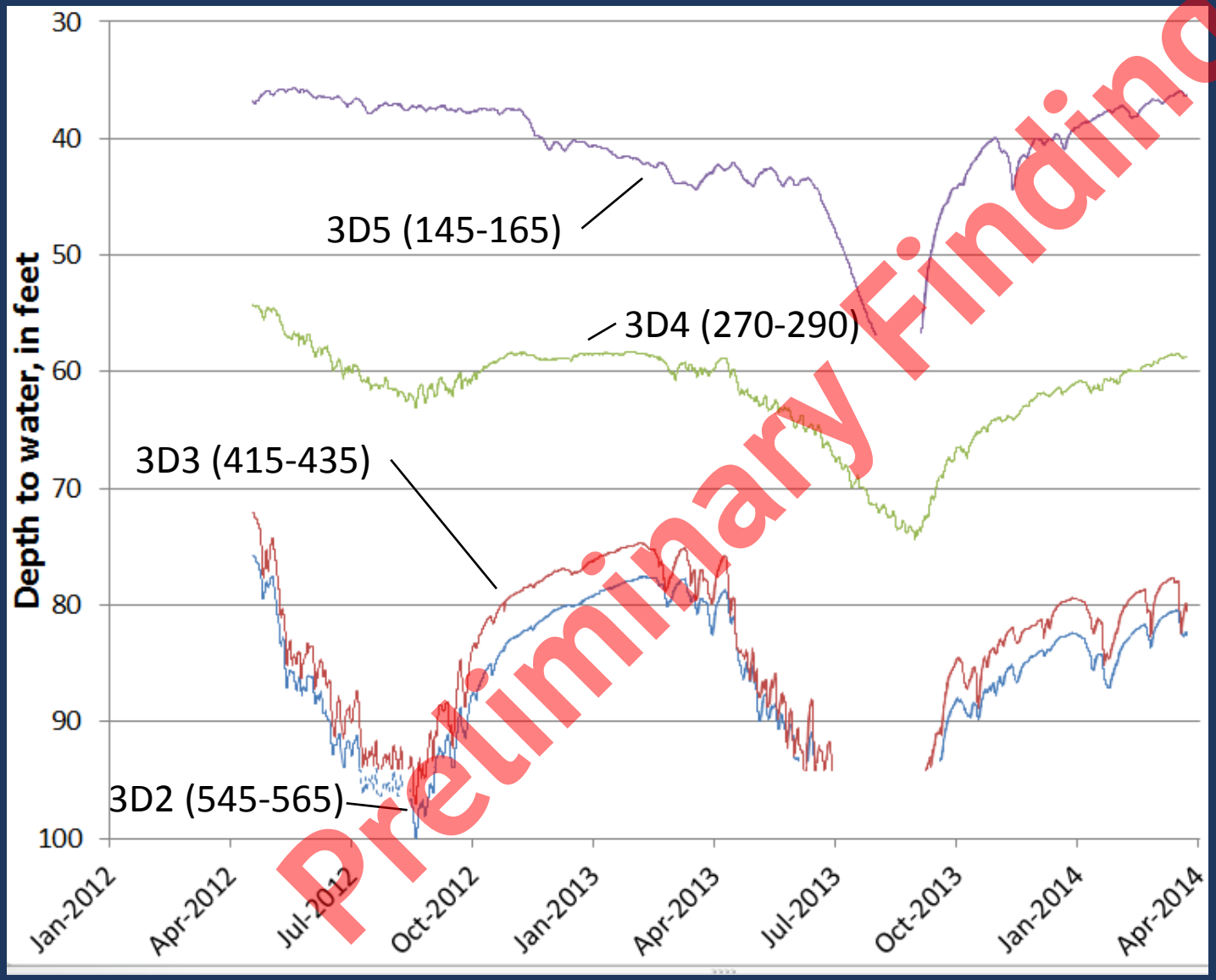
STK-7 Hydrographs



Preliminary Findings

- Downward gradient
- Pumping responses at depth
- Maximum pumping depression = potential for upward gradient?

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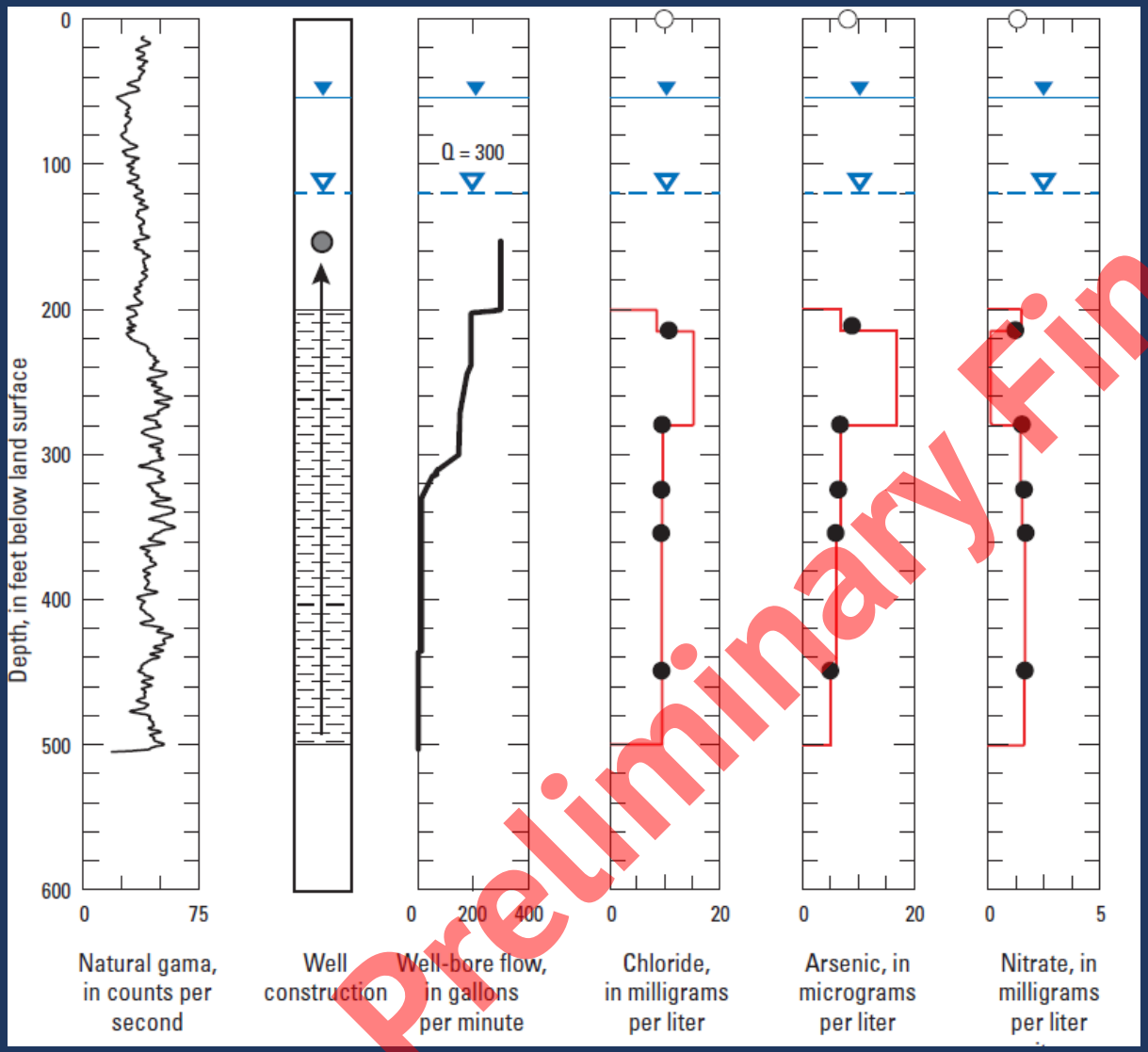
Production well 4G1 flow logging and sampling



Preliminary Findings

- >95% flow contributed at shallower than 330’
- 30% flow contributed near top of screen (convergent?)
- Generally consistent chemistry with depth
- Elevated As at 215’-280’ (16.8 µg/L)
  Bulk = 8.9 µg/L
  3D4 = 19 µg/L (270’-290’)
  3D5 = 10.4 µg/L (145’-165’)
- High As corresponds to anoxic conditions in 3D4
- Denitrification at 270’-290’ under reducing conditions

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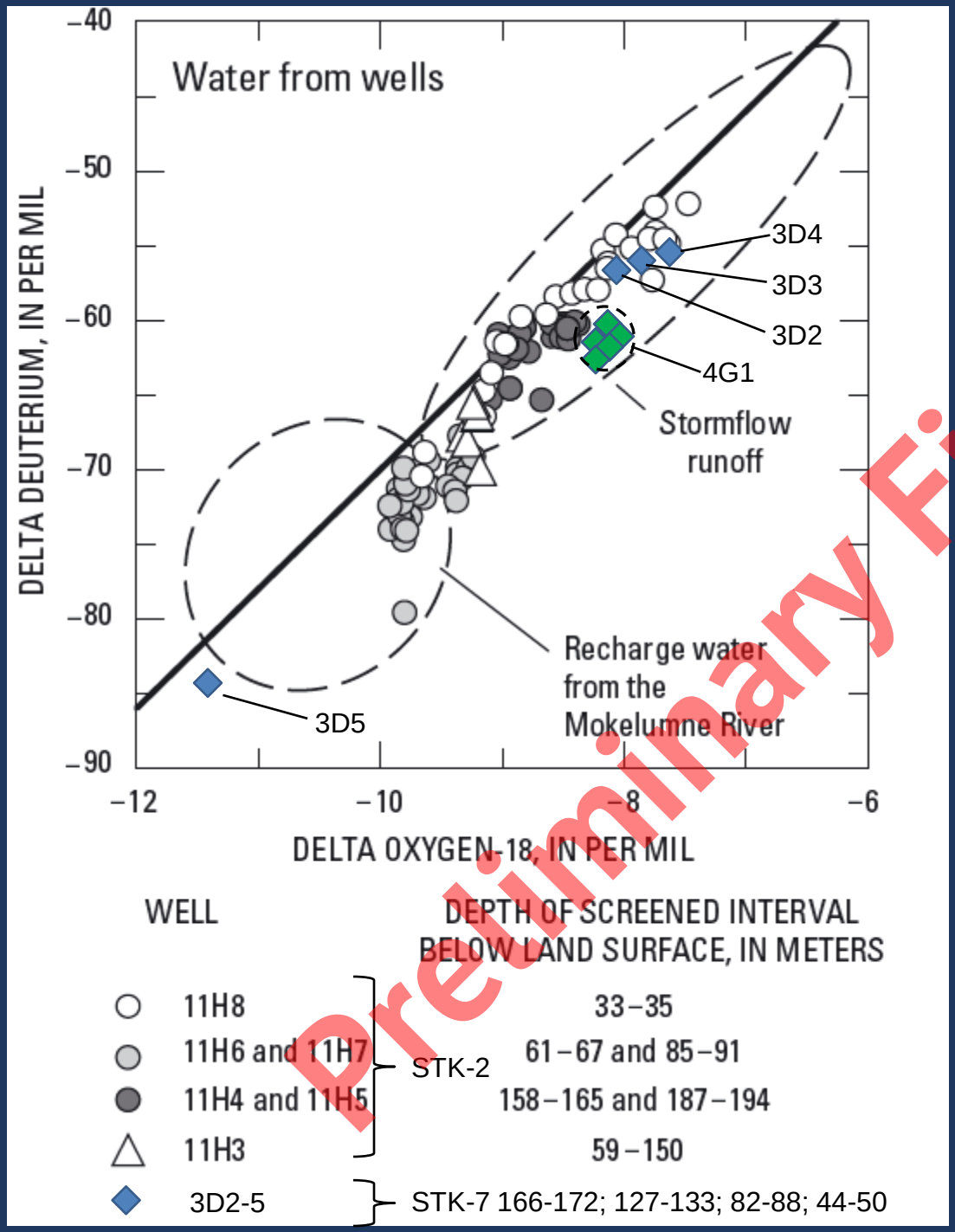
Stable isotopes



- Local stormflow heavier than river water
- Shallowest well (11H8) is variable & reflects recharge source (stormflow vs. river)
- 11H4 & 1H5wells similar to wells in east (tritium ND)
- 11H6 & 11H7 similar to Mokelumne (tritium present)
- Deep STK-7 wells similar to stormflow (tritium absent)
- 3D5 (Stockton East) lightest

Preliminary Findings

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Conclusions

- Pressure responses propagate to great depths in response to in to recharge.
- Pressure responses are dampened with depth (in time and magnitude).
- Deeper water relatively isolated based on isotopic and age data, but tracer studies indicate physical movement of water to depth.
- Aquifer system is heterogeneous with highly permeable deposits accounting for majority of water produced from production wells.
- Artificial recharge is an effective method to recharge aquifers, **however:**
    - High groundwater velocities may be of concern in areas with residence time requirements.
    - Artificial recharge may result in changes in redox chemistry with negative implications for water quality (e.g., arsenic).
- Quantitative (physical and chemical) understanding of the effects of aquifer heterogeneity on recharge, storage, and recovery is one of the most effective tools available to understand the physical movement of recharge water.

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Questions?

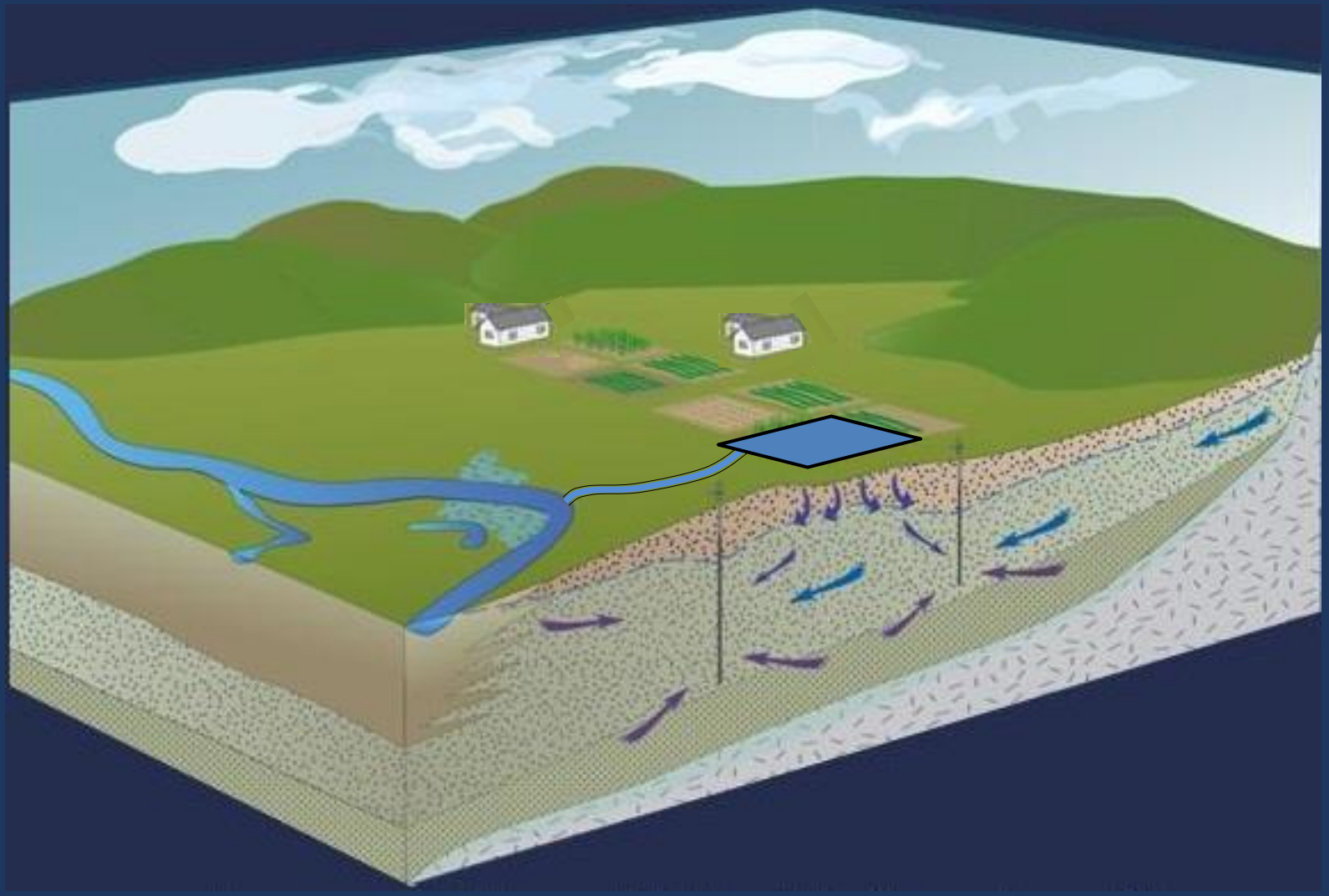

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Table 1
Details of Radial Groundwater Flow Model Construction

Data	Value	Data		Value
Spatial discretization		Assigned hydraulic conductivities of model aquifer		
Grid dimensions	194 m thick by 60,960 m wide	17–35 m	Sand/silt/clay	0.76 m/d
		35–50 m	Clay	0.0003 m/d
Number of layers	1	50–52 m	Sand/silt	1.8 m/d
Number of rows	194	52–78 m	Sand/silt/clay	0.76 m/d
Thickness of rows	1 m	78–81 m	Sand/silt	1.8 m/d
Number of columns	80	81–91 m	Silt/clay	0.08 m/d
Size of columns	Variable	91–95 m	Clay	0.0003 m/d
Column 1 (well)	0.25 m	95–99 m	Fine sand	4.0 m/d
Column 2 (casing)	0.013 m	99–107 m	Clay	0.0003 m/d
Column 3 (gravel pack)	0.13 m	107–112 m	Coarse sand	10 m/d
Columns 4–80	Multiplier 1.555	112–113 m	Clay	0.0003 m/d
		113–119 m	Fine/medium sand	6.1 m/d
Side boundary condition	No flow	119–128 m	Sand/silt/clay	0.76 m/d
Bottom boundary condition	No flow	128–130 m	Fine sand	4.0 m/d
Upper boundary condition	Water table	130–140 m	Silt/clay	0.08 m/d
(Initial water level 17 m bls)		140–145 m	Sand/silt/clay	0.76 m/d
		145–148 m	Fine sand	4.0 m/d
Hydraulic properties		148–150 m	Sand/silt/clay	0.76 m/d
Porosity	0.2	150–155 m	Fine sand	4.0 m/d
Specific storage	7.62E-07 /m	155–186 m	Sand/silt	1.8 m/d
Anisotropy	0.5	186–188 m	Clay/silt/lahar	0.003 m/d
Hydraulic conductivity (calibrated)		188–194 m	Fine sand	4.0 m/d
Well casing	0 m/d	Temporal discretization		
Clay	0.0003 m/d	Stress periods		1
Clay/silt/lahar	0.003 m/d	Length of stress period		999 d
Silt/clay	0.08 m/d	Time steps		25
Sand/silt/clay	0.76 m/d	Time step multiplier		1.2
Sand/silt	1.8 m/d	Initial time step		2.1166 d
Fine sand	4.0 m/d	Pumping rate		54 L/s
Fine/medium sand	6.1 m/d			
Coarse sand	10 m/d			
Gravel pack	91 m/d			
Well	30,480 m/d			

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Acknowledgements

San Joaquin County Public Works, California Department of Water Resources, and Lawrence Livermore National Laboratory, Northeastern San Joaquin Ground Water Banking Authority, the City of Stockton, Stockton East Water District, the California State Water Resources Control Board, and Condor Earth Technologies and other local consultants.

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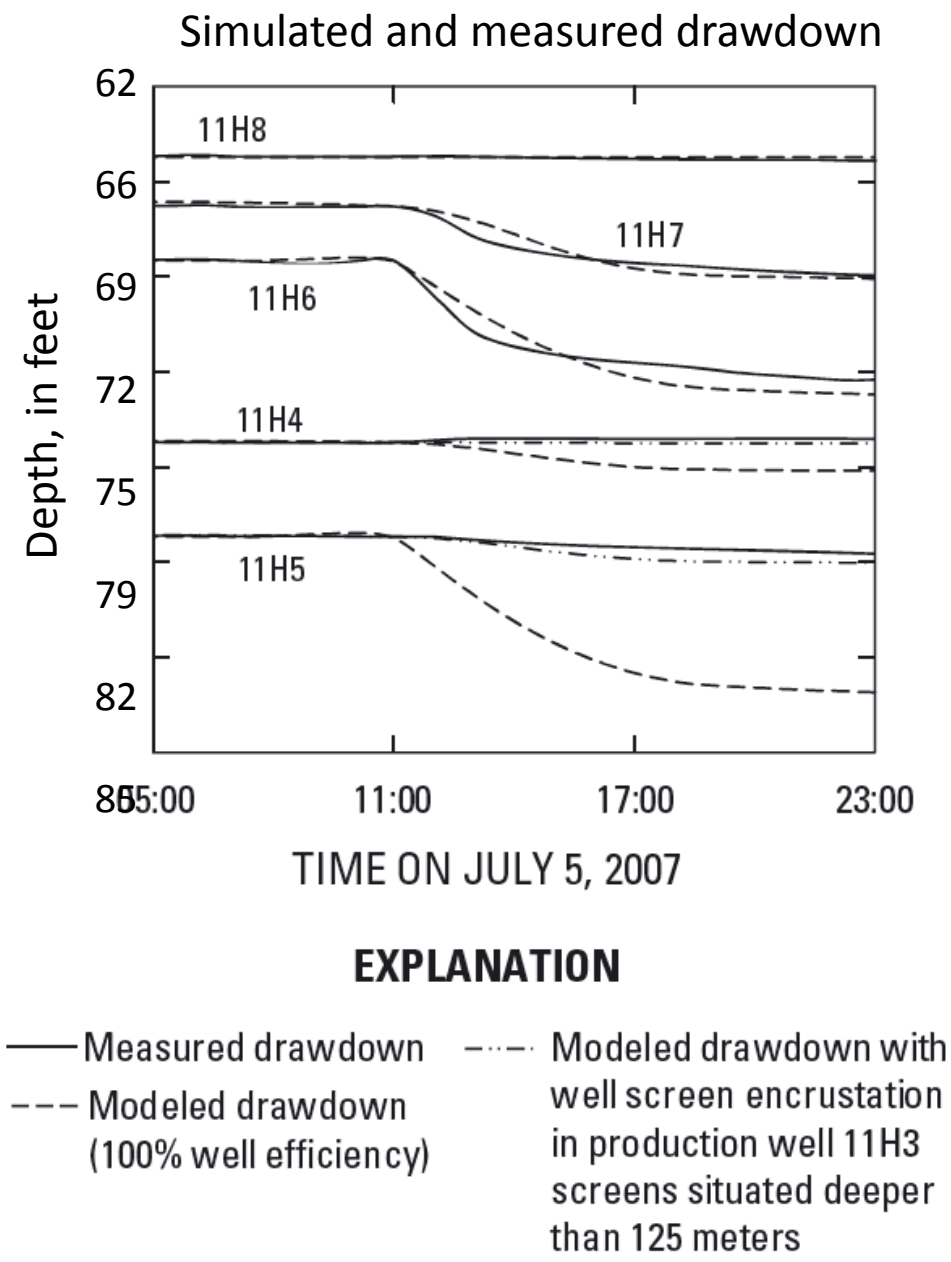
Radial Flow Model



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