Characterization Techniques at an Managed Aquifer Recharge Site

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Air & Waste Management Association, Oklahoma Chapter

January 24, 2024 meeting

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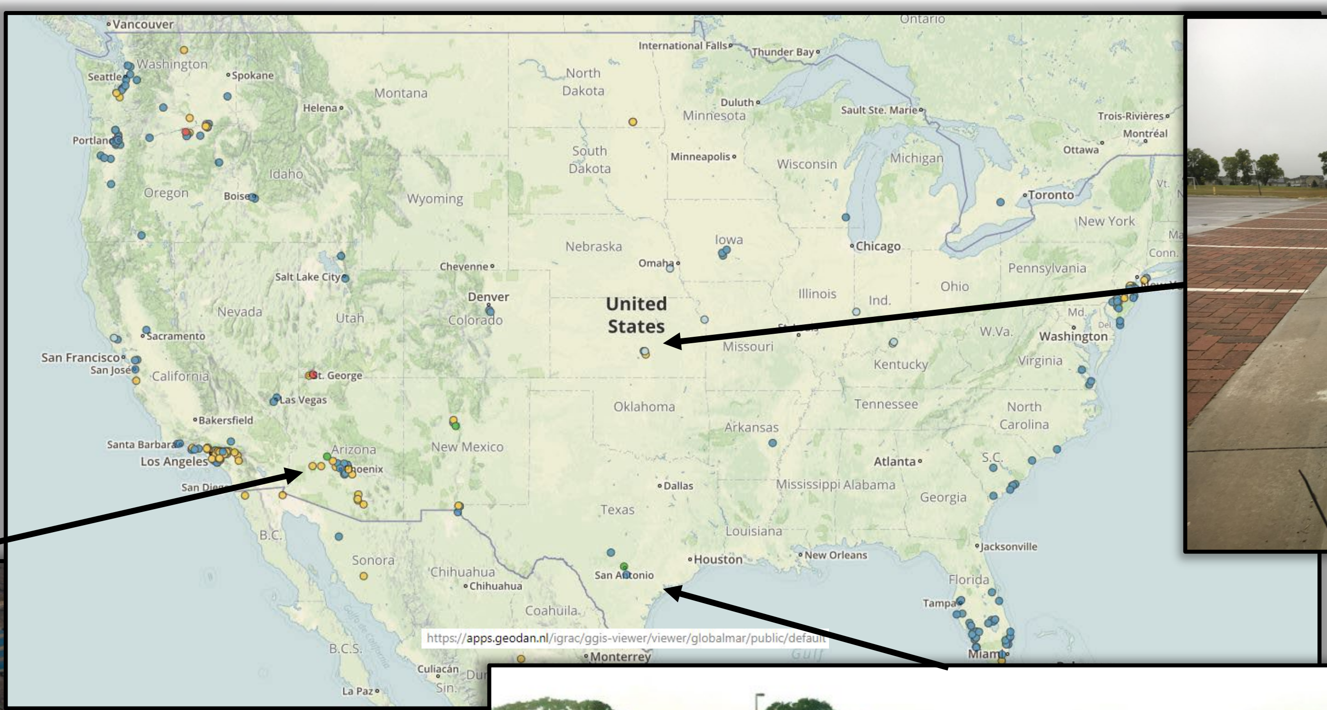
Outline

- Background
  - MAR – Managed Aquifer Recharge
  - Research site
  - Local Geology
- Recharge characterization efforts
  - Water quantity
  - Water quality
- Conclusion, accomplishments and next steps

ASR vs MAR vs EAR - Similar Basic Goals:

Store surface water and/or groundwater in aquifers, when available



Spreading basins more common in Western US

Tonopah, AZ

Green Infrastructure Permeable Pavement

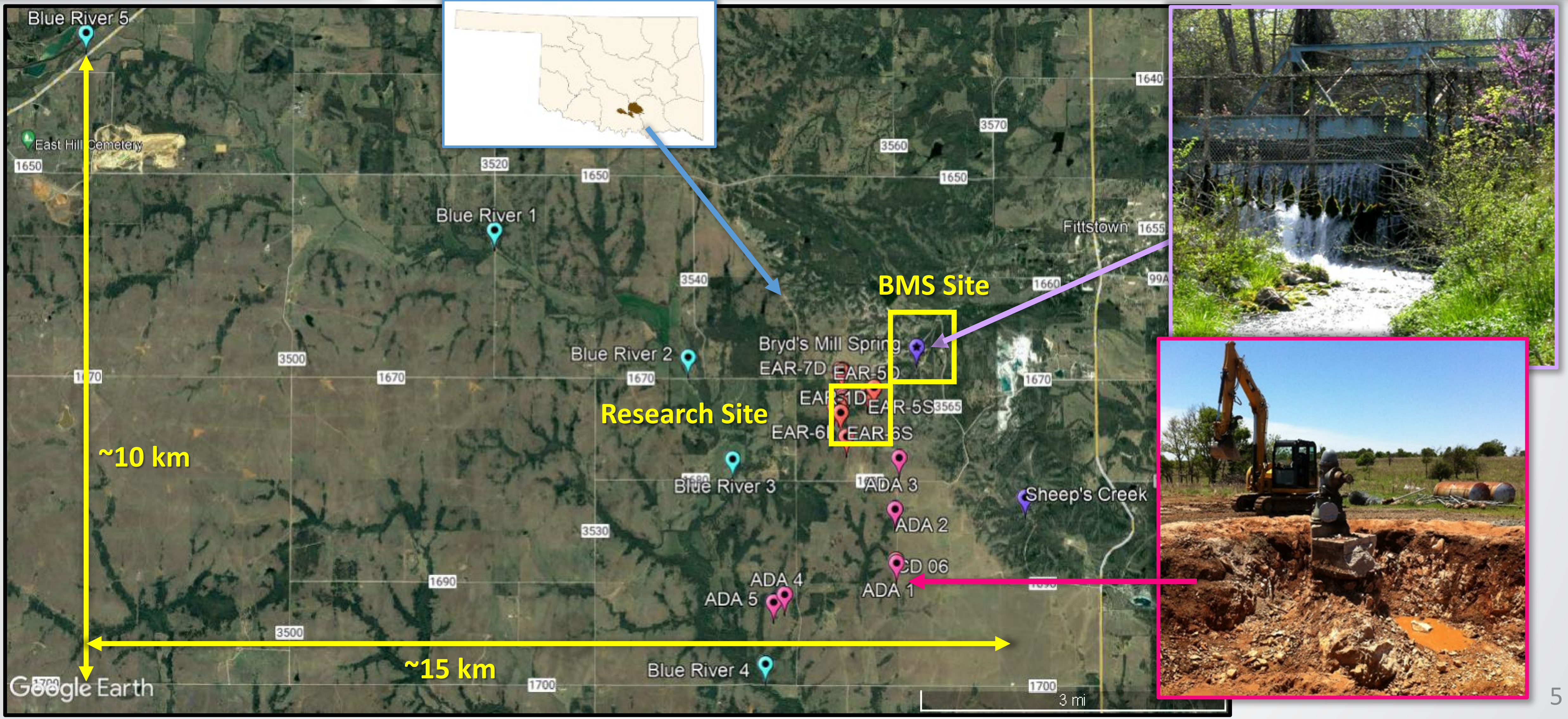
Fort Riley, KS

Groundwater injection wells common along coasts and interior US

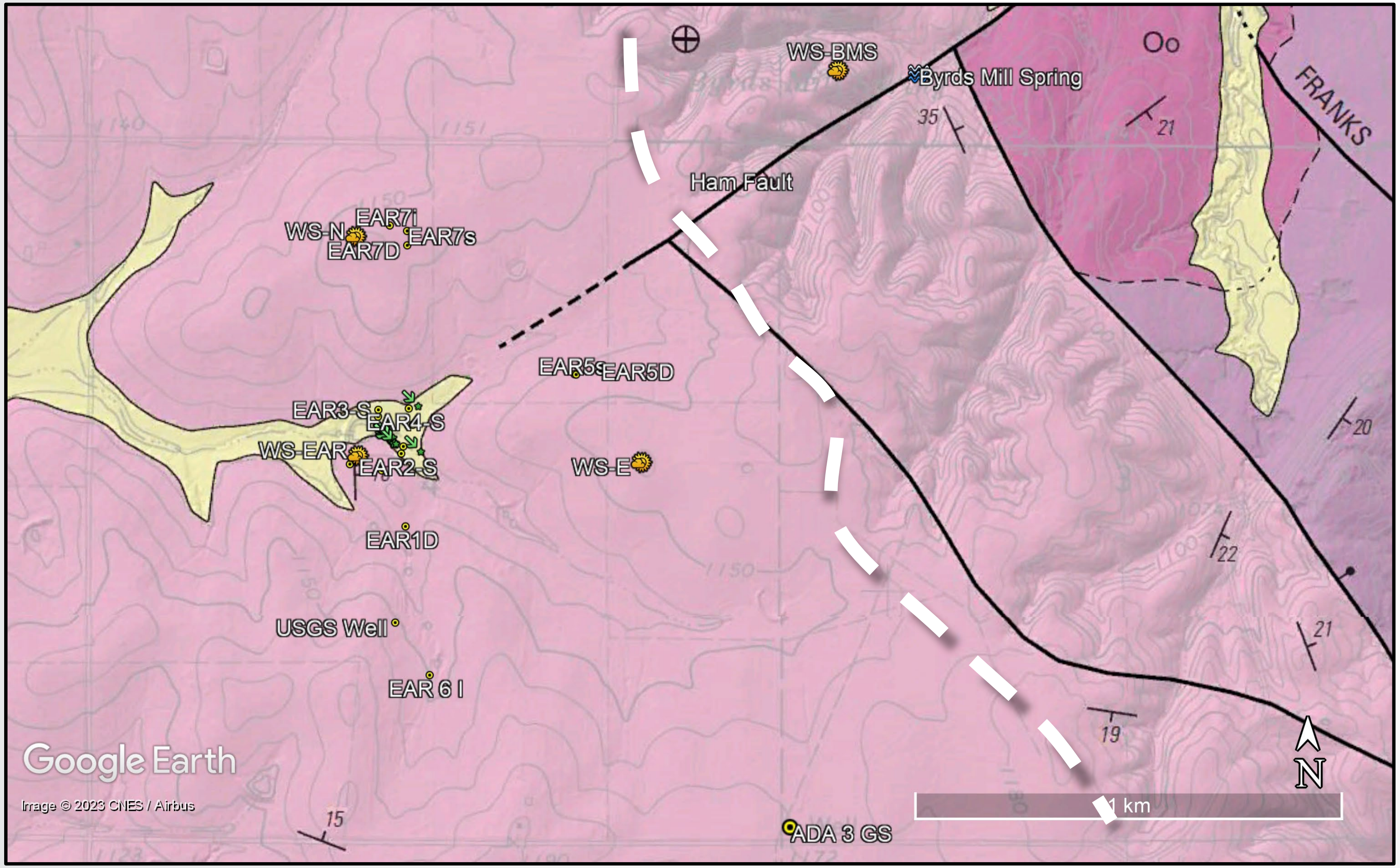
San Antonio, TX

Objective – Evaluate impact of direct recharge of overland flow via karst features with respect to water quality and quantity.

Managed Aquifer Recharge Research Site



Study Area Geology



Qac	Alluvium
	Carbonates:
Obm	• Bromide
Oo	• Oil Creek
Ow	• West Spring Creek

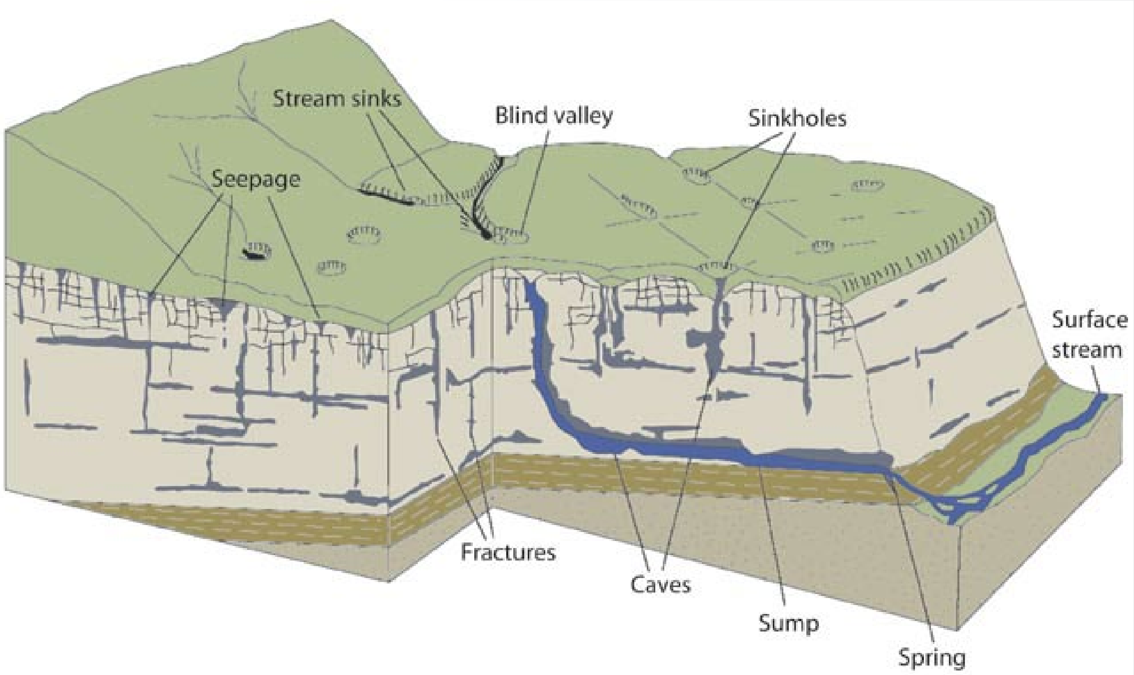
Well ◎ Sinkhole ★

Weather Station ✷

Surface drainage divide – –

Karst Hydrogeology

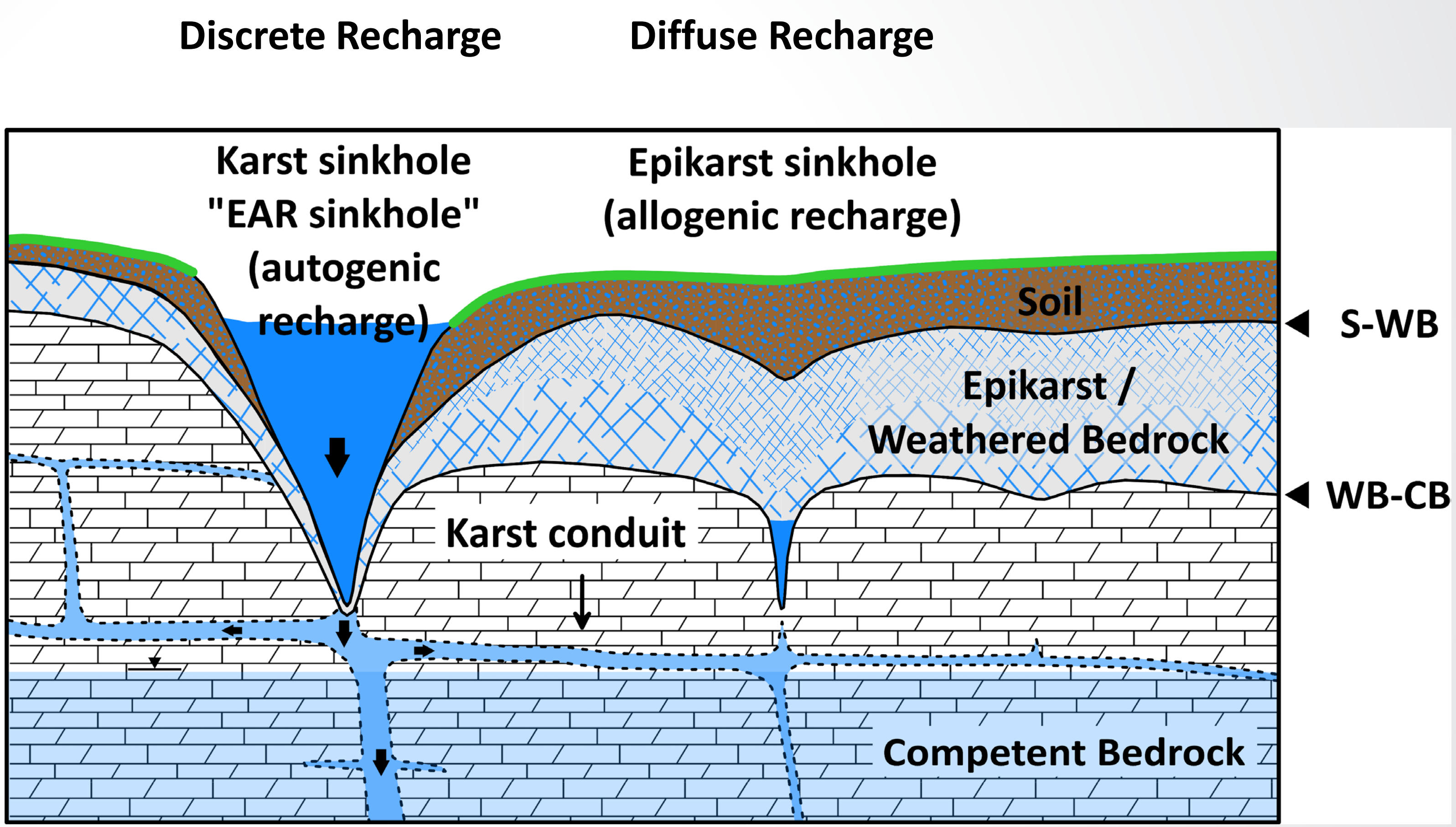
- Primarily composed of carbonates (i.e., limestone and dolomite)
- Preferential flow paths develop through dissolution and expansion of faults, fractures, bedding planes, etc.
- Groundwater travel times vary by orders of magnitude (hours to years)



Source: *Wisconsin Geological and Natural History Survey, 2021*

Recharge mechanisms

- Epikarst sinkholes (highly fractured bedrock; karst 'skin')
- Karst sinkholes (dissolved bedrock; sinkholes and caves)



Source: *Fields et al., 2022*

MAR Research Site

Recharge in Action!

Game cam footage of 2.8 inch recharge event.

MAR Characterization

Water Quantity and Water Quality

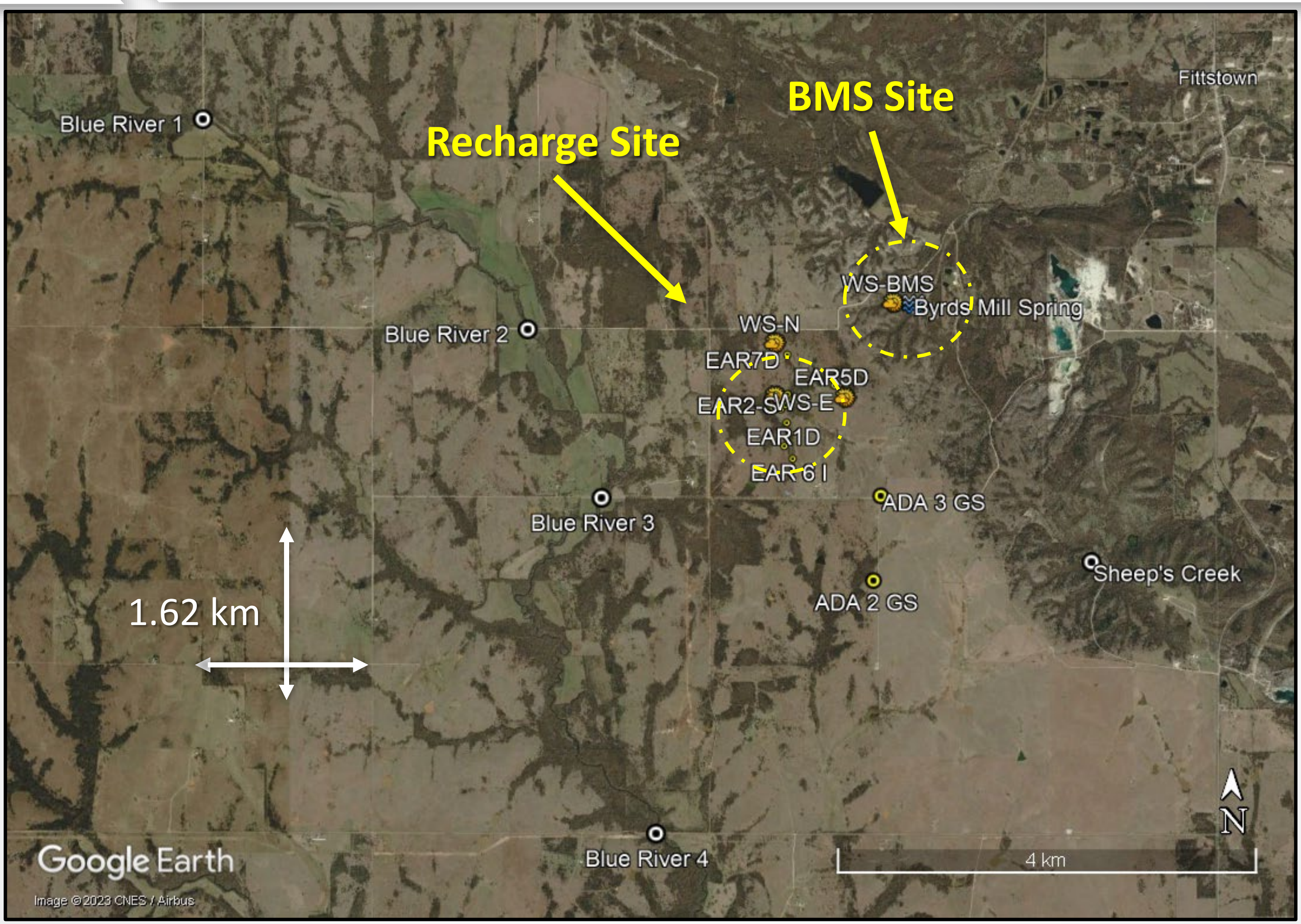
Data Collection Activities

- Hydrology/Geology
  - Aquifer testing
  - Surface and Borehole Geophysical data collection
  - Soil and rock core
  - Infiltration capacity
  - Sinkhole recharge capacity
- Water Quality
  - Precipitation/runoff (source water)
  - Groundwater (wells, springs)
  - Surface water (pond, Blue River)
  - Soil porewater (vadose zone)
- Climatic Data

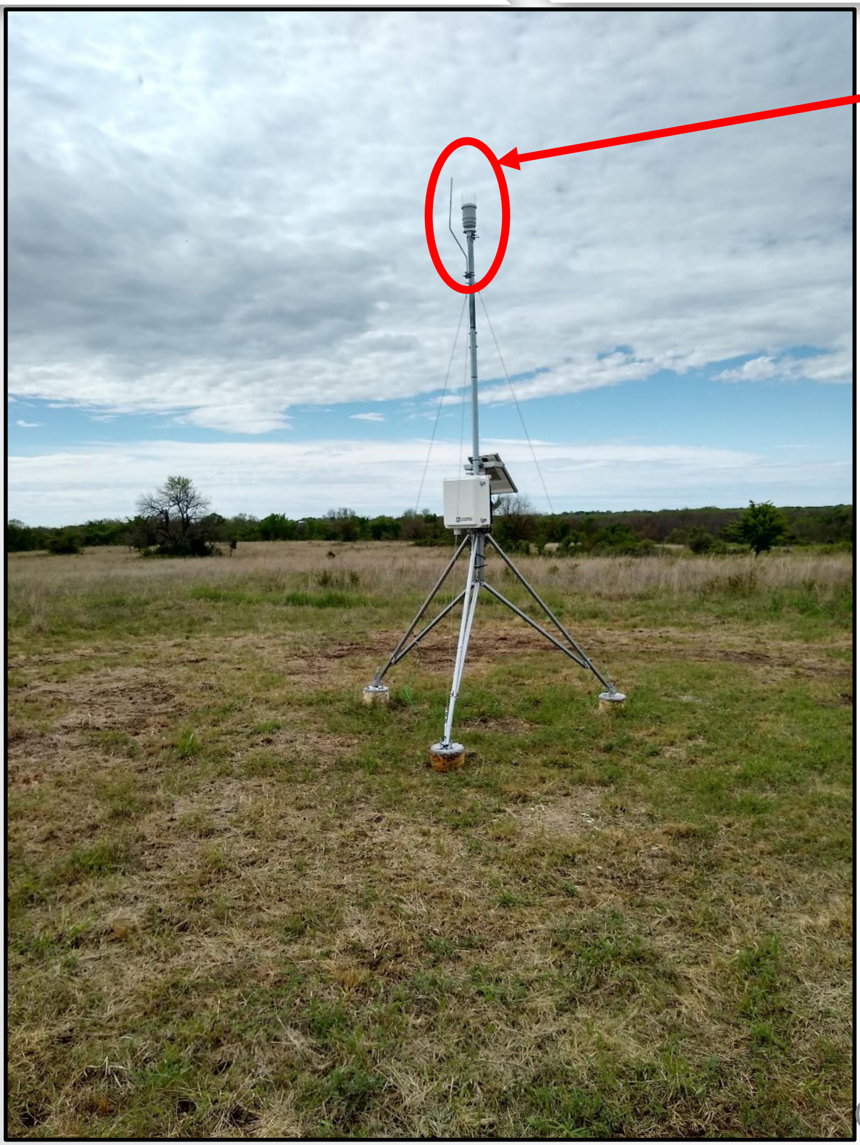
Groundwater sampling in February 2021

Picture showing the type of runoff sampler to be installed at the MAR site.

Monitoring Locations



4 Weather Stations and 3 Precipitation Collectors



Sensors

Automated Lid

Sample Collection Container

Rain Sensor

Recharge Site

Drainage Area ~ 325 acres

Overland Flow Balance

Inlet Weir

$$Q_{in} - Q_{out} = Q_r$$

Outlet Weir

Direct Measurement of Recharge

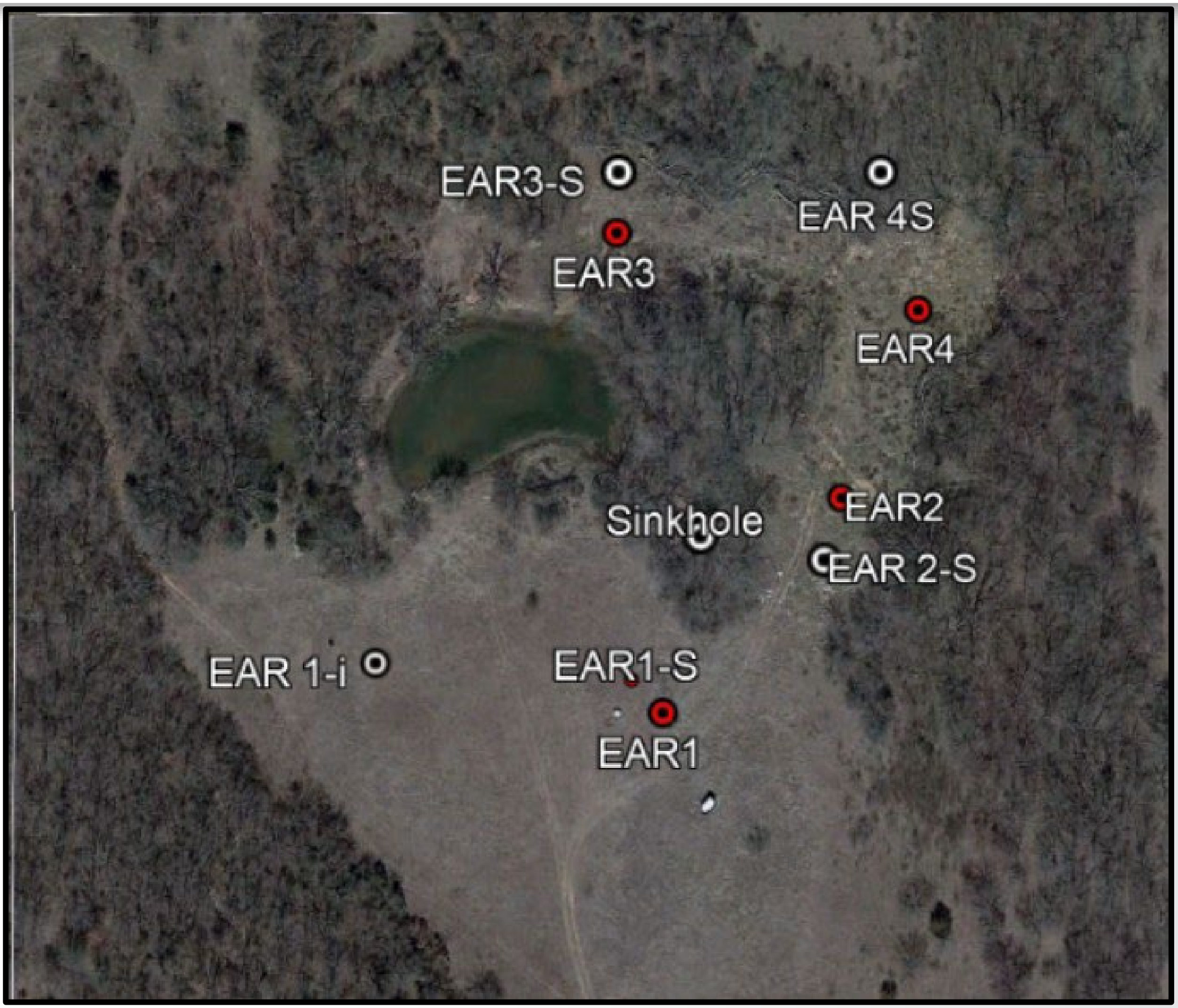
Biological Tracers?

Shallow Well Locations

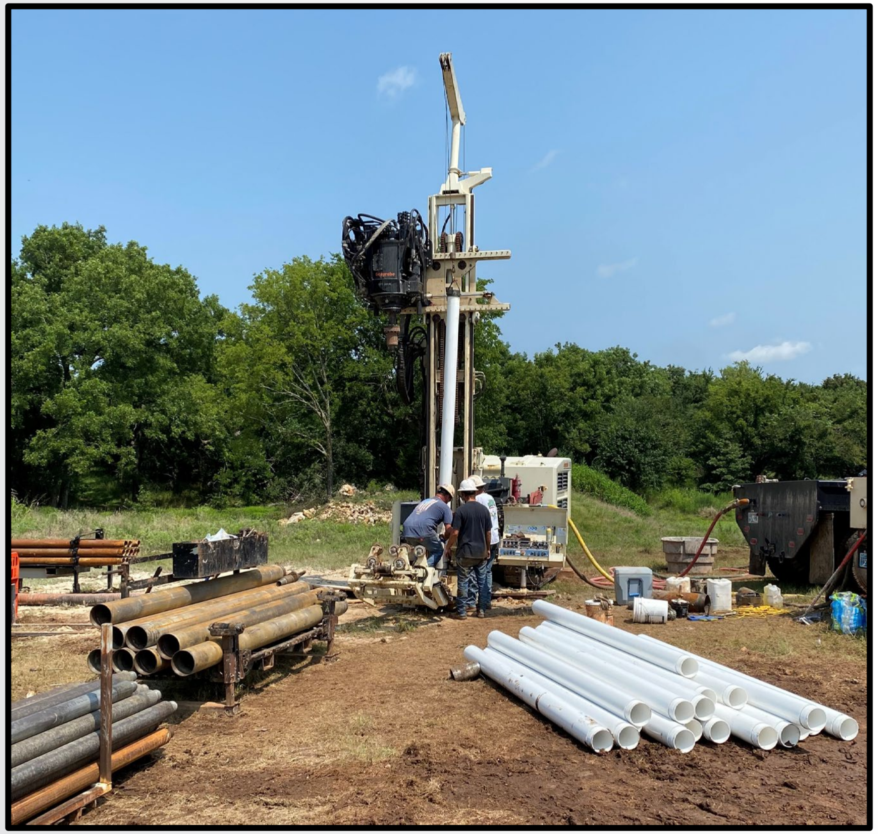
11 – Shallow Zone Wells

- 4 - Open hole and ~ 35-120’
  (EAR-1, EAR-2, EAR-3, EAR-4)

- 7 – Screened ~ 100 – 120’
  (EAR-1S, EAR-2S, EAR-3S, EAR-4S, EAR-5S, EAR-6S, EAR-7S)



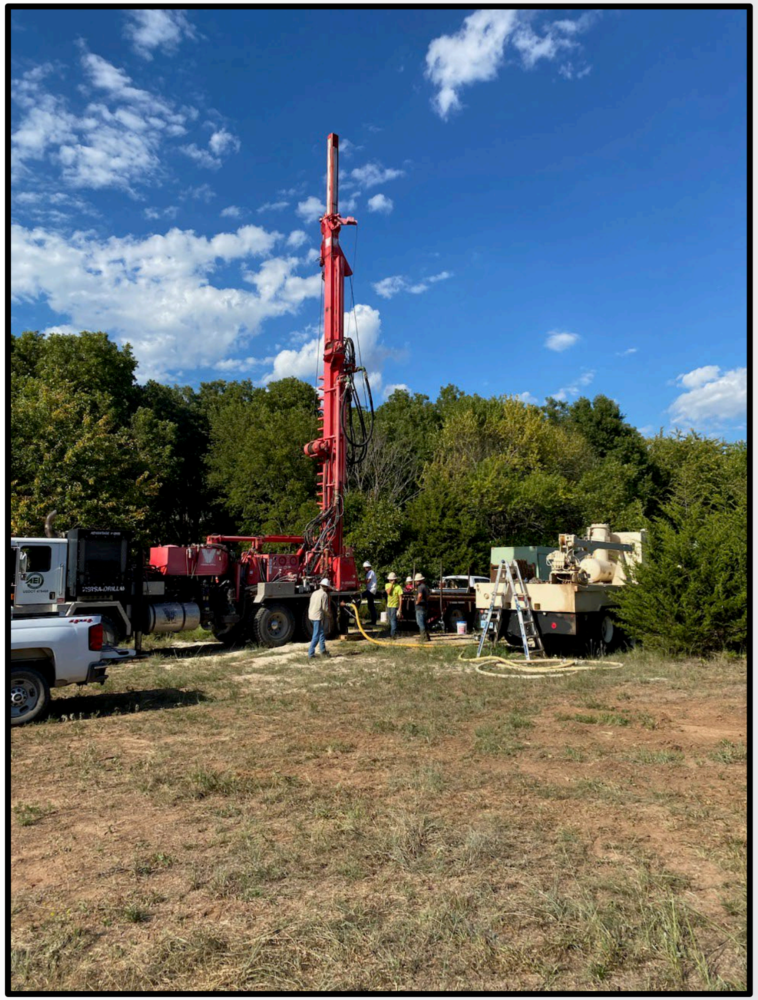
Intermediate & Deep Well Installation



11 – Shallow Zone Wells
(Open hole; 100’-150’)

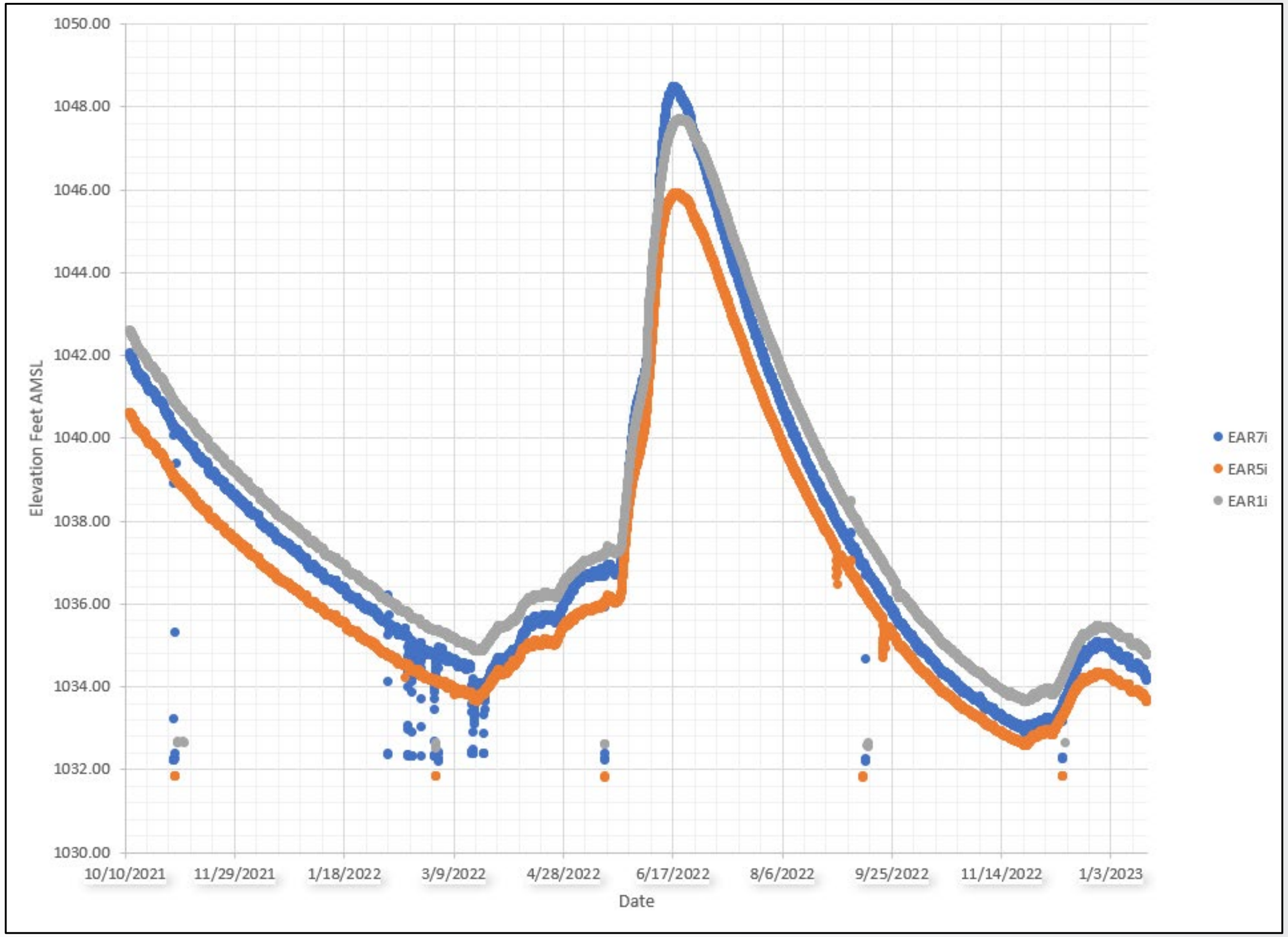
3 – Intermediate Zone Wells
(Open hole, 200’ – 250’)

3 – Deep Zone Wells
(Open hole, 250’ -750’ & 250’ - 1000’)



Water Level Elevations Over Time

Intermediate Aquifer Zone (200 – 250 ft) Hydrographs

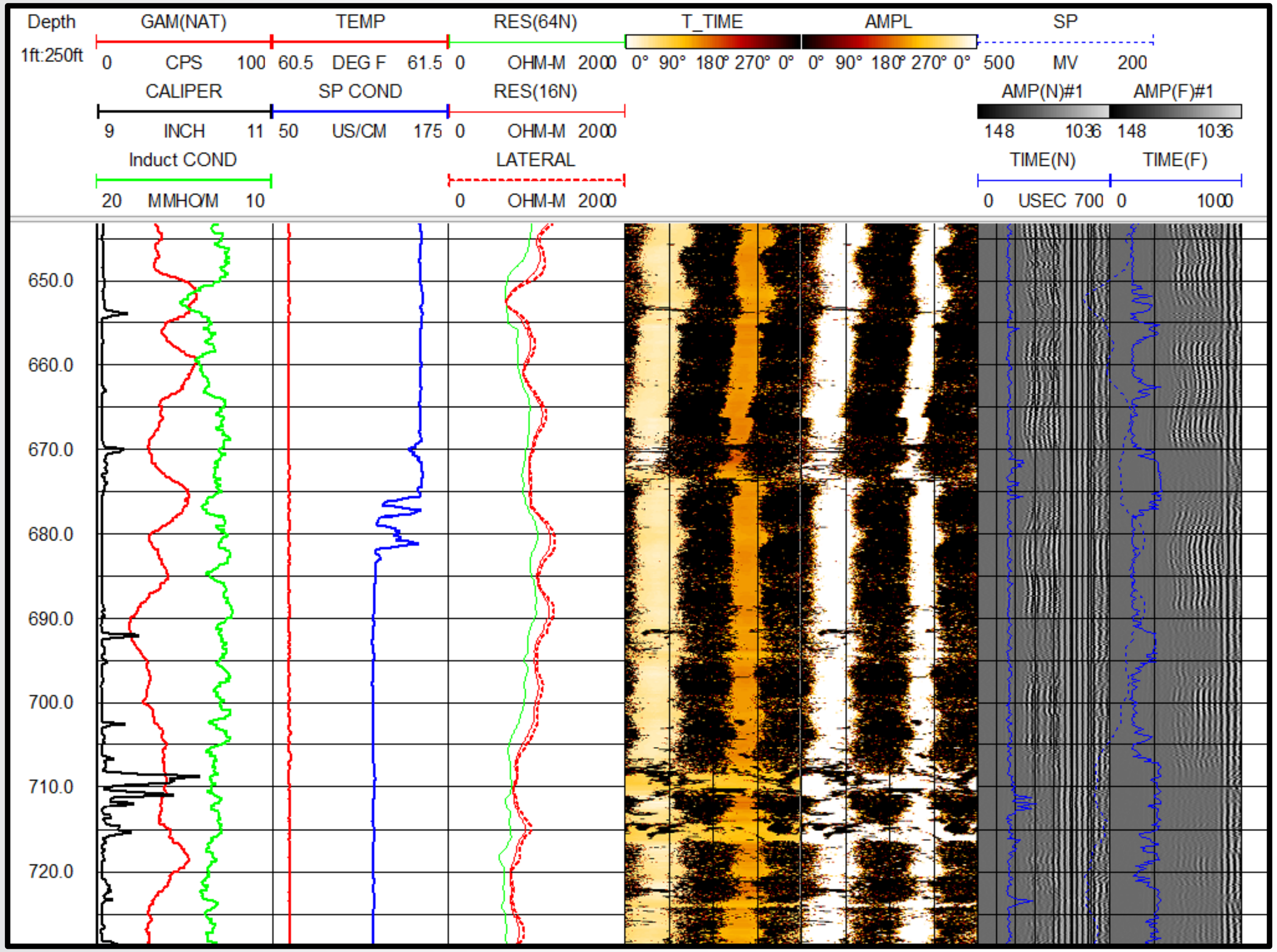


Borehole Geophysics

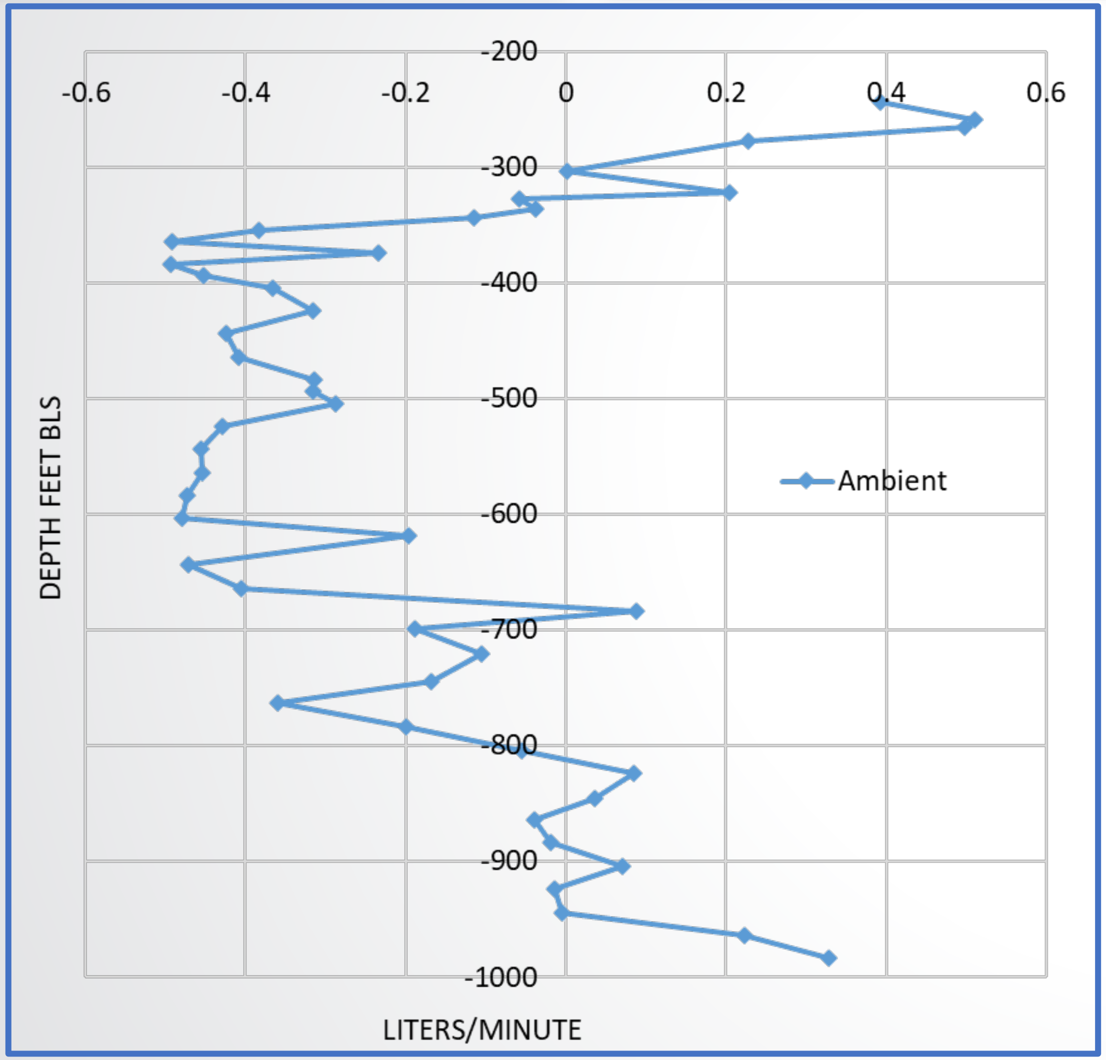
Logging Tools:

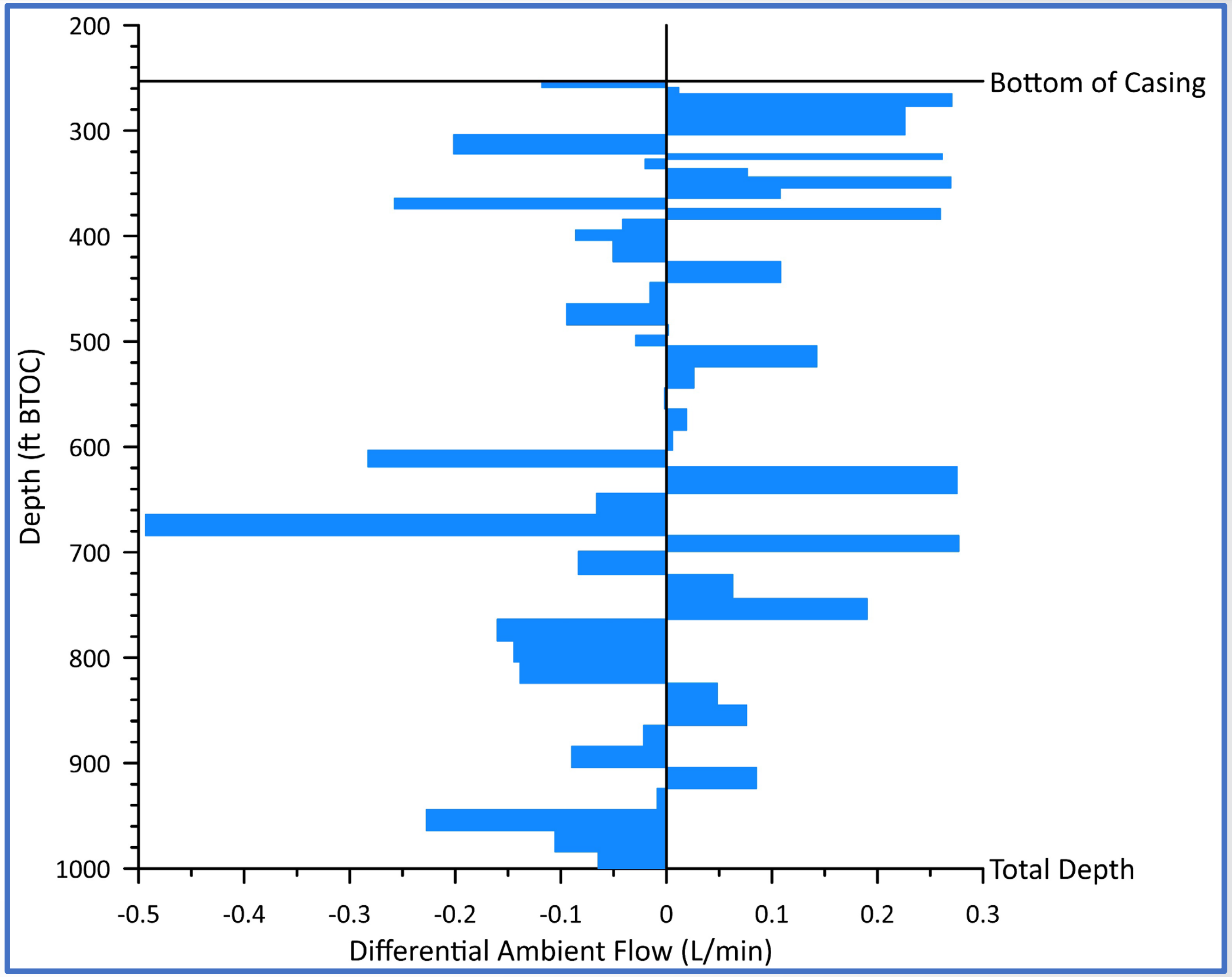
- E-Log (Resistivity, SP, Temperature, Natural Gamma)
- Induction Conductivity
- 3-Arm Caliper
- Acoustic Televiewer
- Full-wave Sonic
- Electromagnetic Borehole Flowmeter
- Fluid Sampler
- Optical Televiewer

EAR-1D Well Log



EAR-1D EMBH Flow Meter



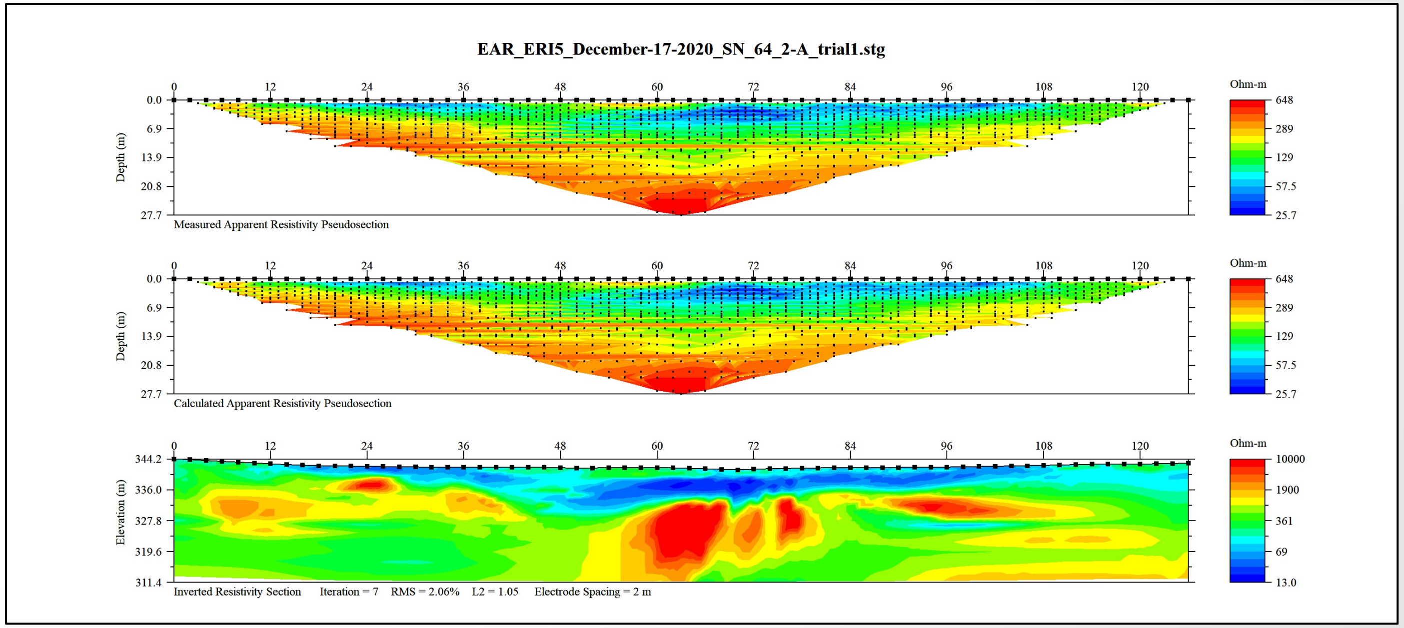


Electrical Resistivity Imaging (ERI)

- Geophysical technique which measures the apparent electrical resistivity of the subsurface in order to create a 2D image of these measurements.

- ERI is regularly used for high resolution site characterization of:
    - contaminated sites,
    - groundwater presence,
    - flow and transport, and
    - geologic structures.

- Transient ERI (TERI)

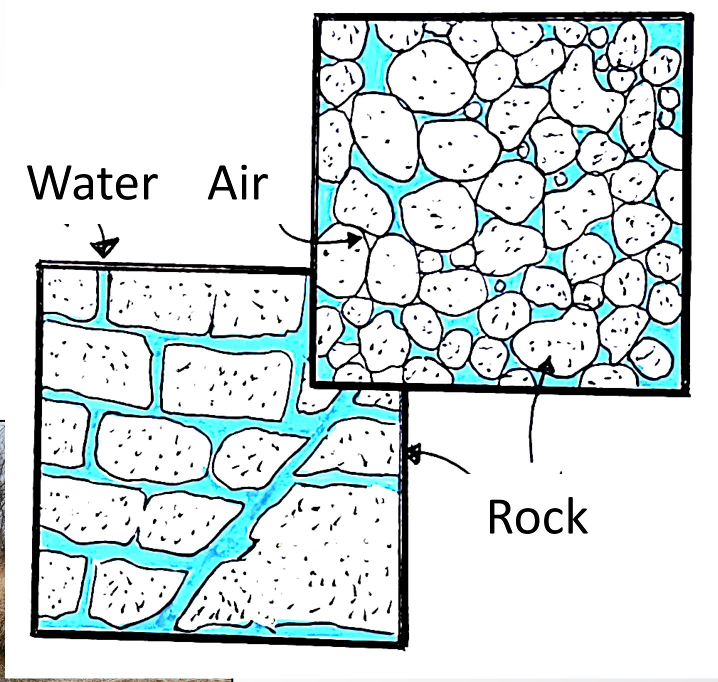


Screenshot of data processing

ERI signatures and effects

- Electrical resistivity signatures are affected by pore space; specific gravity
  - Water is typically less resistive than rock
  - Air is typically more resistive than rock

- Other signatures
  - Microbes
  - Groundwater chemistry
  - Water
  - Lithology



Illustrated by Jon Fields

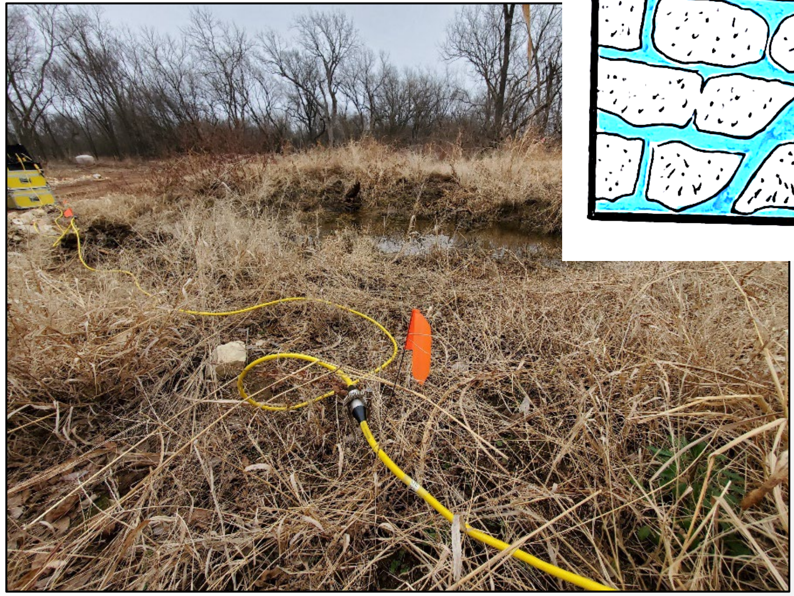
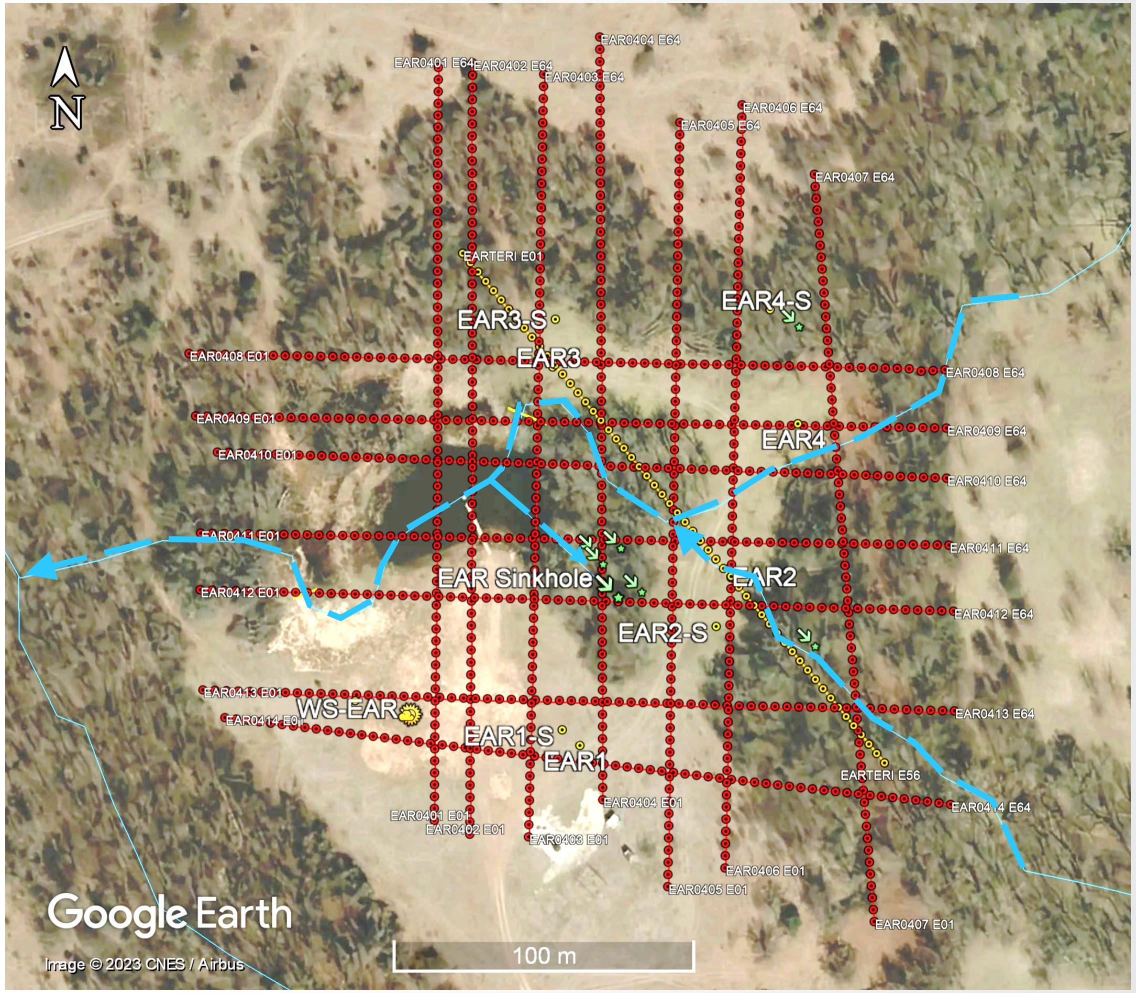


Photo at MAR site

ERI Investigations

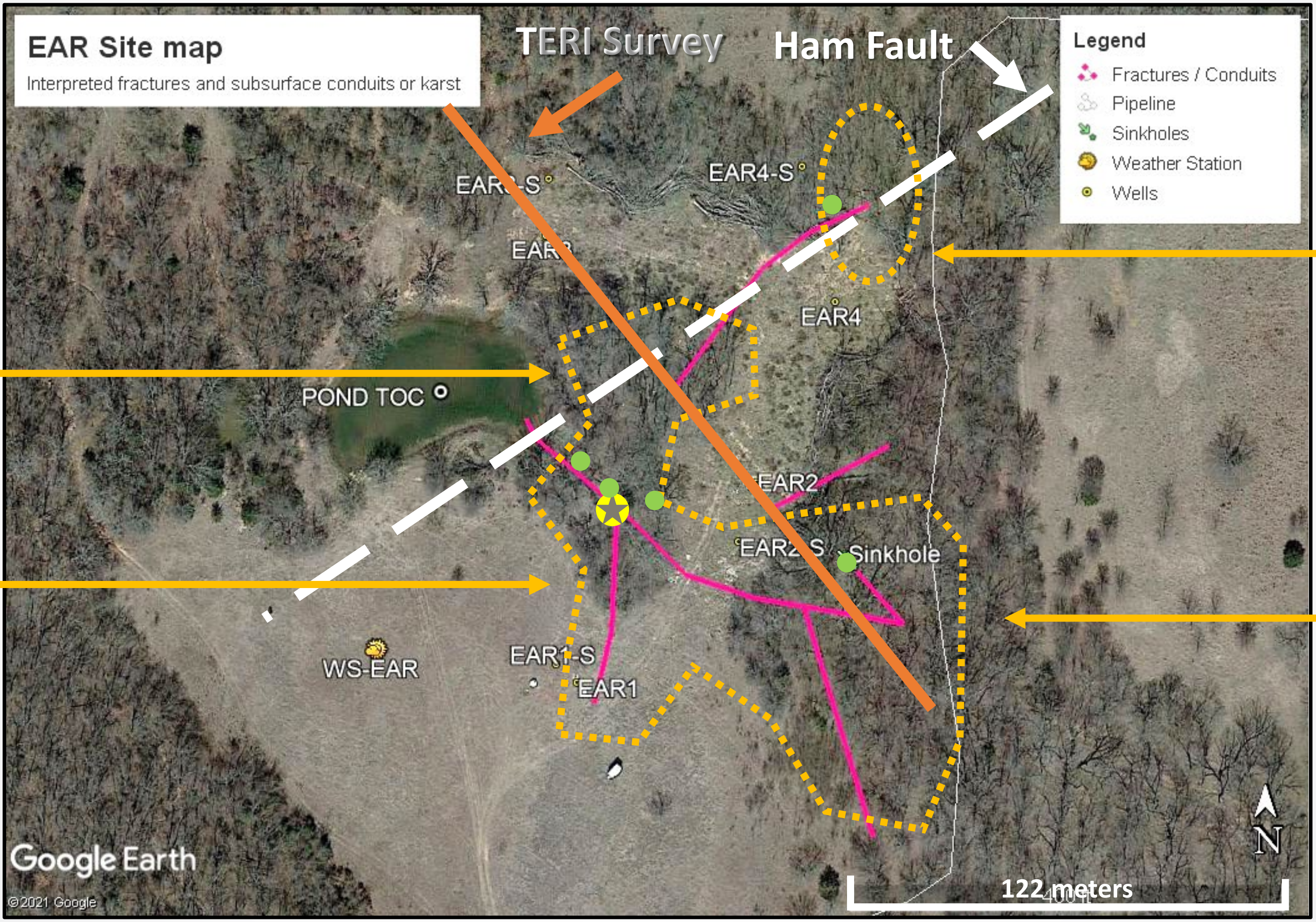
- Data density
  - 5:1 ratio (Length:Depth)
  - 28 ERI surveys
  - 1 TERI survey
  - ~2,600 data points / survey
  - >72,000 total data points
- Effort
  - Data collection (6 mo.)
  - Processing (1 mo.)
  - Interpretation (on-going)



Google Earth map of MAR site; ERI surveys noted

Field effort

ERI Findings



Epikarst

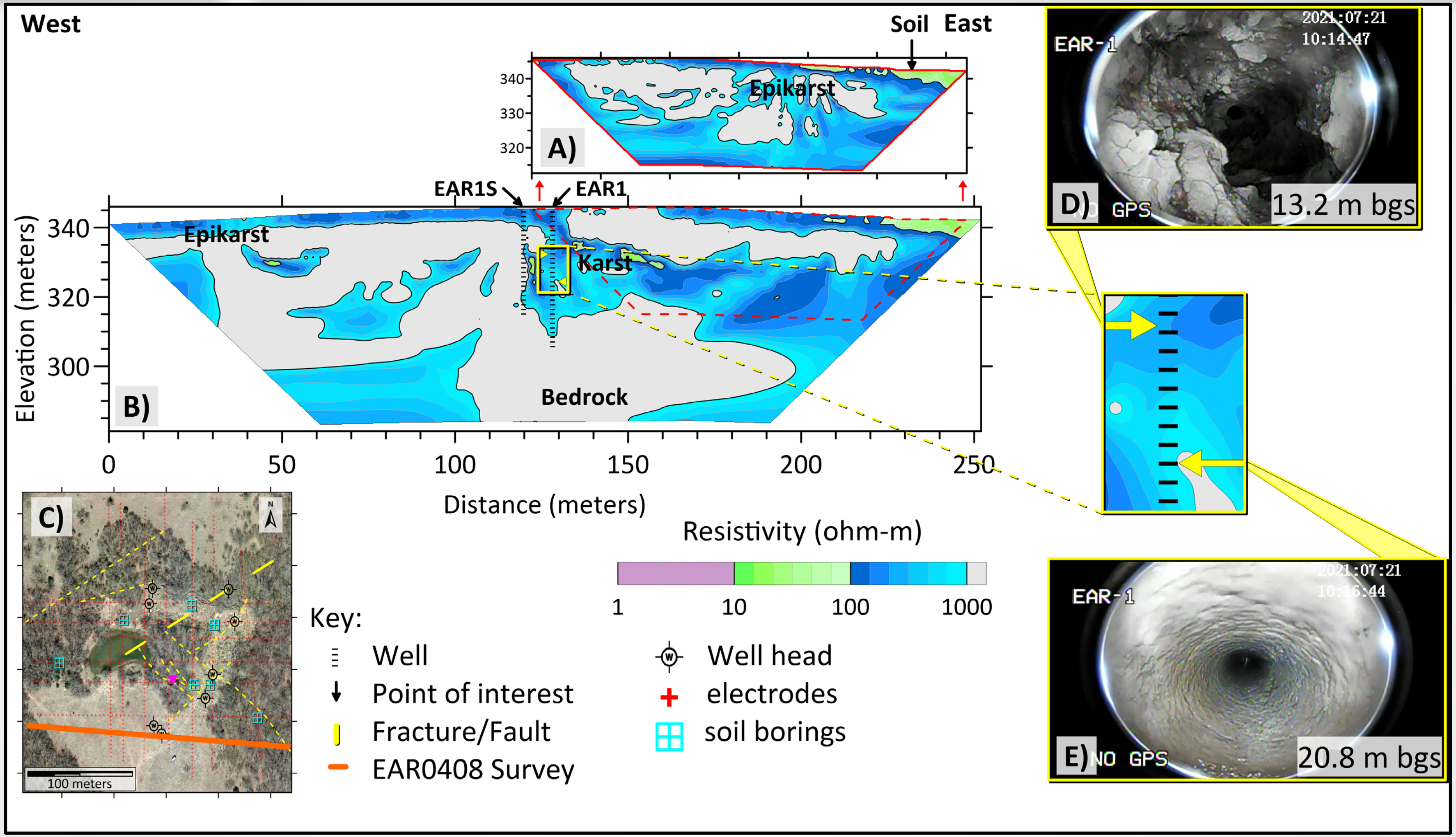
Prominent karst

Thick epikarst

Thick epikarst

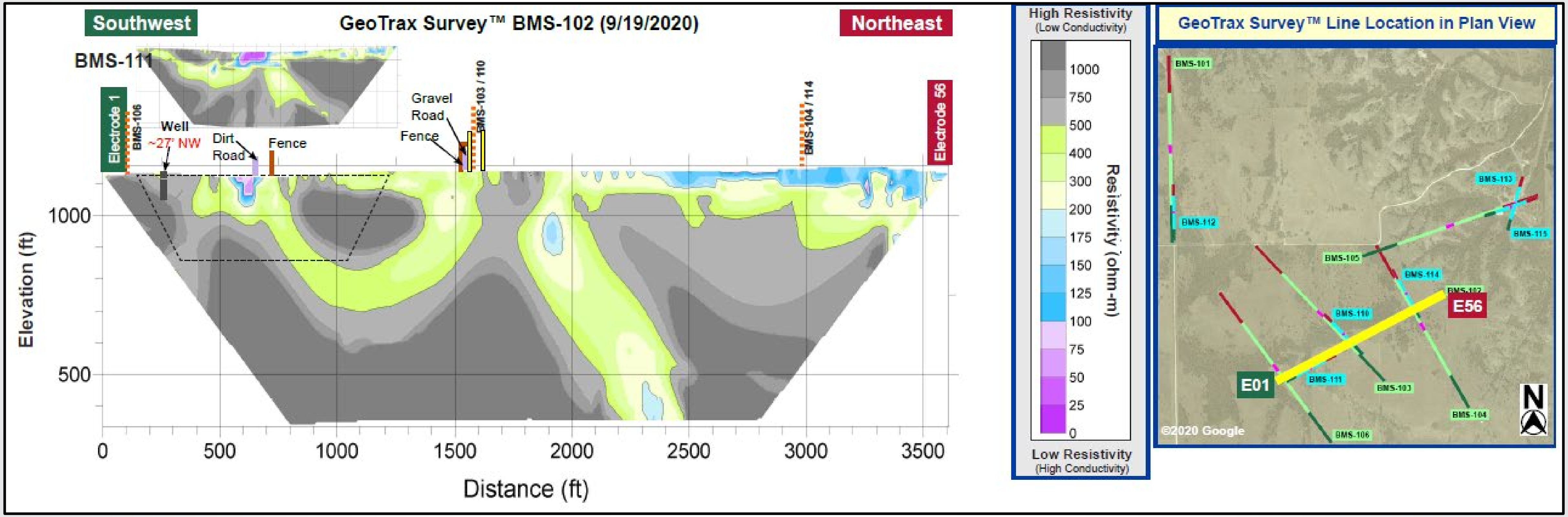
Google Earth Map of MAR site

Shallow “plumbing”



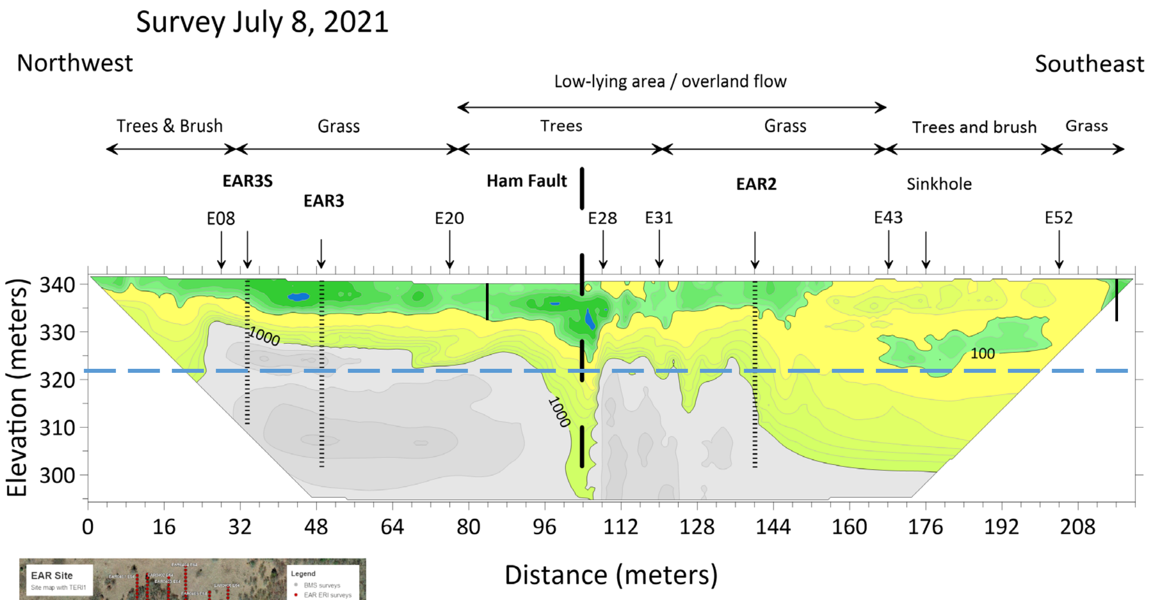
Modified from Fields et al., 2022

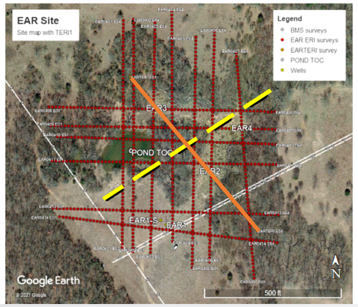
Deep "plumbing"

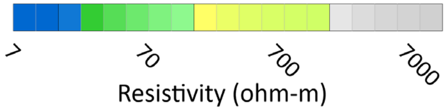


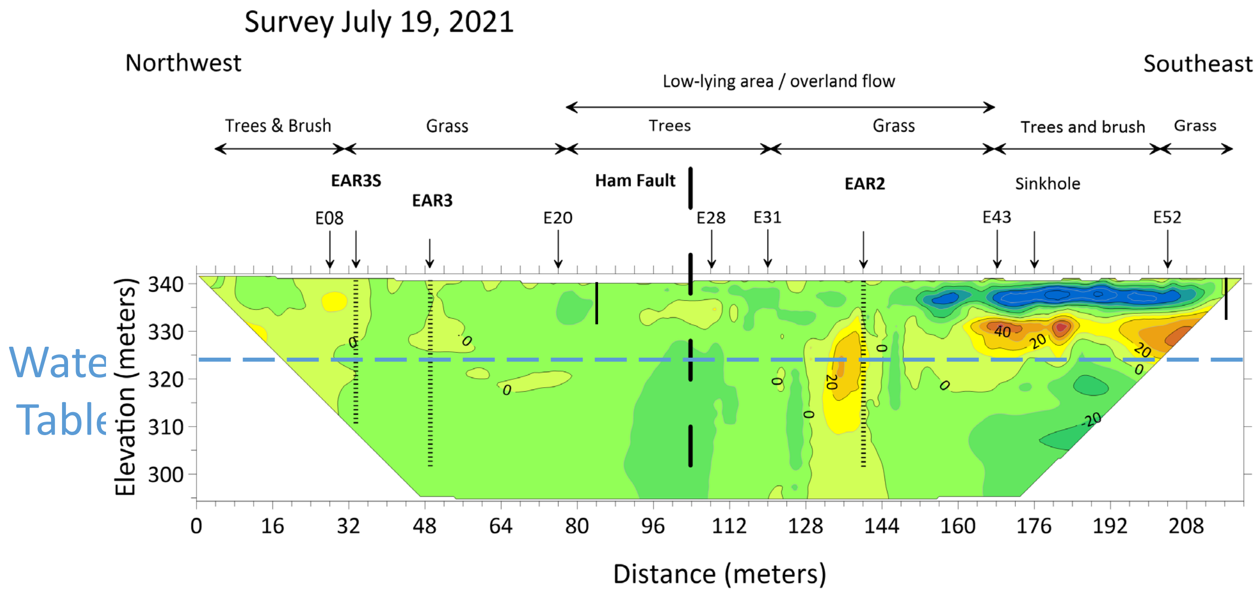
Source: *Aestus, LLC, 2020, GeoTrax CSM+™ Conceptual Site Model Development Process*

TERI survey showing recharge

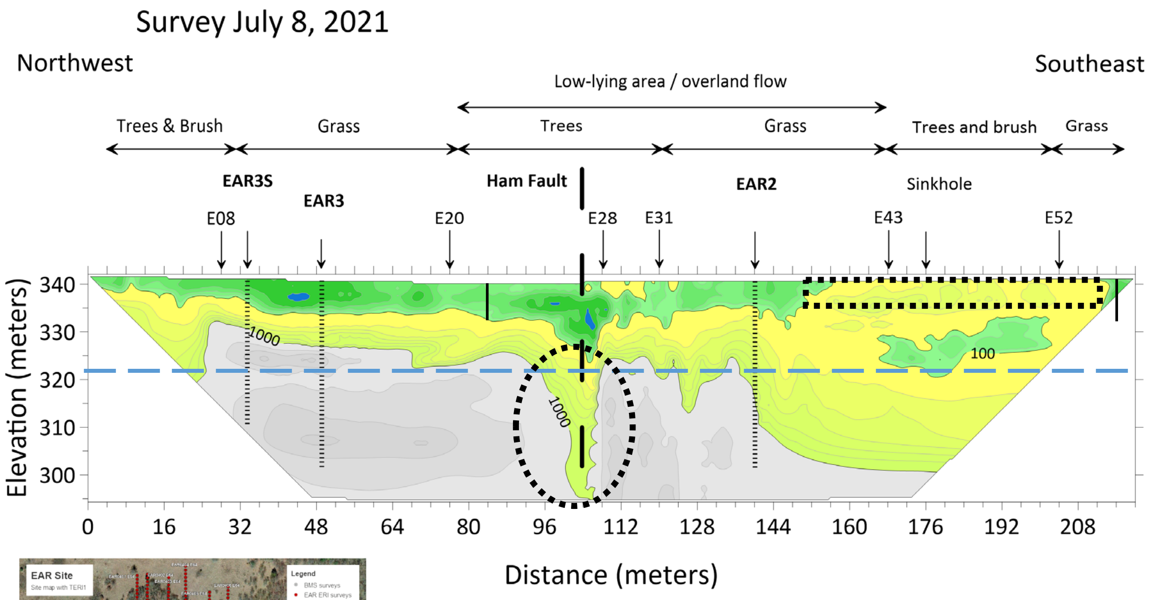


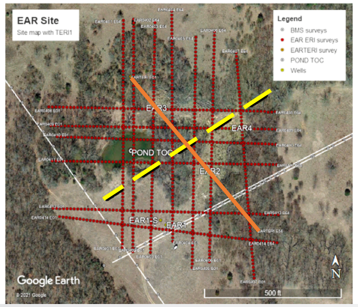




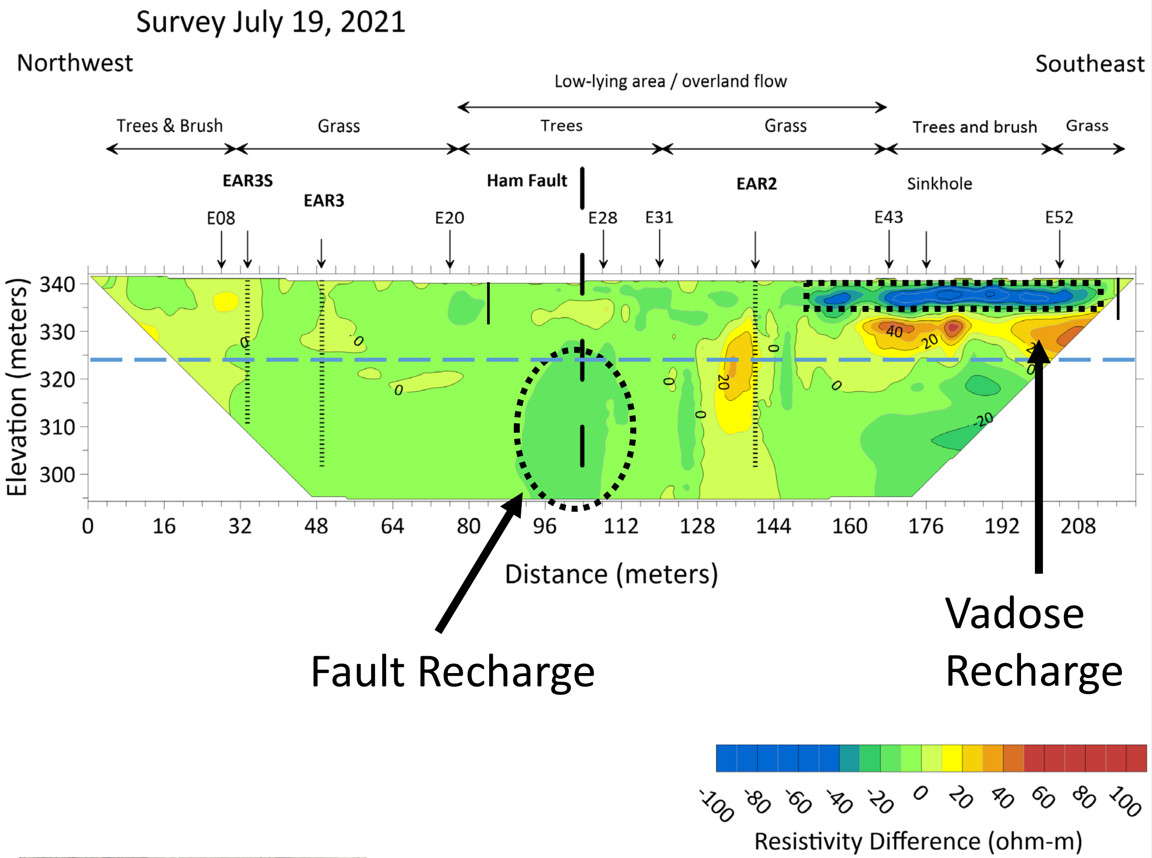


TERI survey showing recharge





Wate
Table



Model calibration

- Doctors don't operate without prior knowledge (scan)


Photo at MAR site

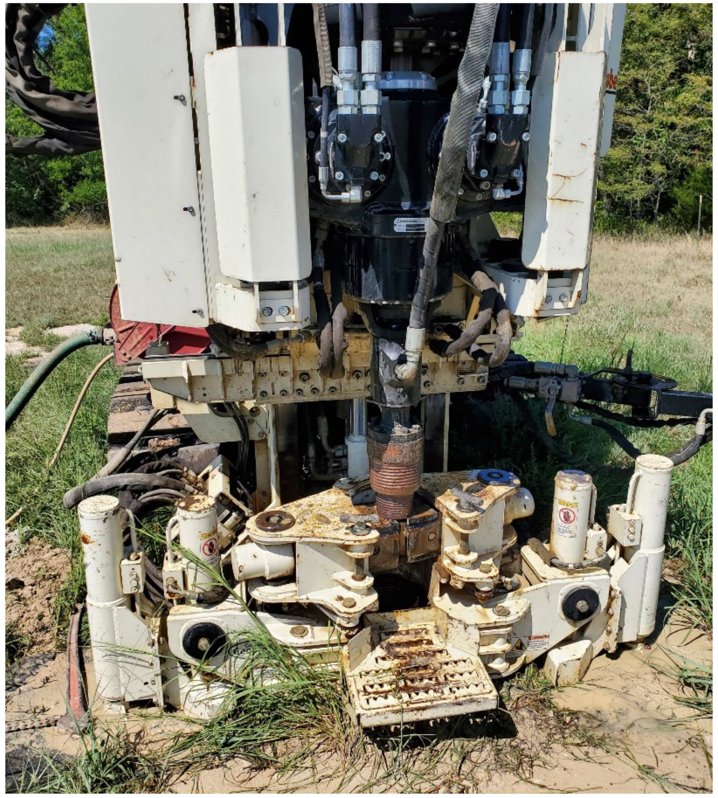


Photo at MAR site

- ERI surveys at the MAR site can indicate potential targets for high flow (drill)

Direct push

- Depth of refusal between 2m-8m
- Deeper along fractures (e.g., 13m, 20m)
  - Soils across site appear 4m thick
  - Soil not thicker in low-lying areas

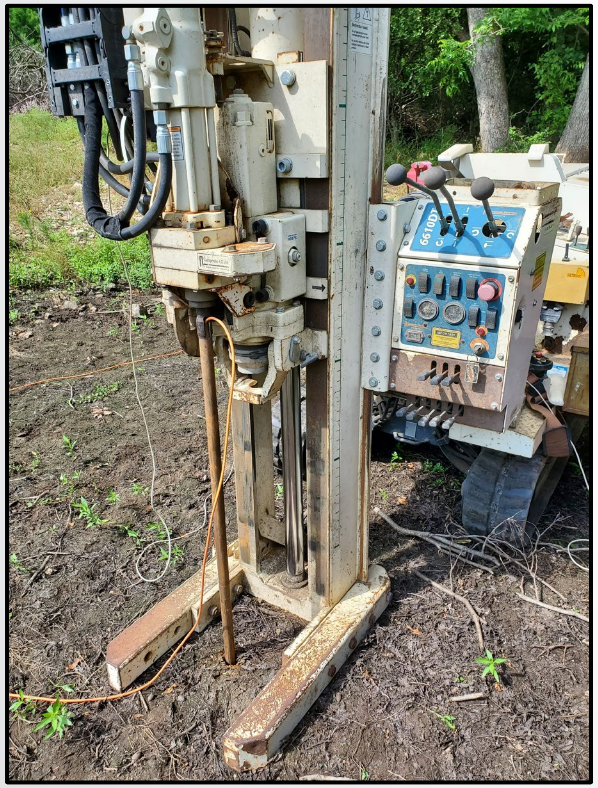
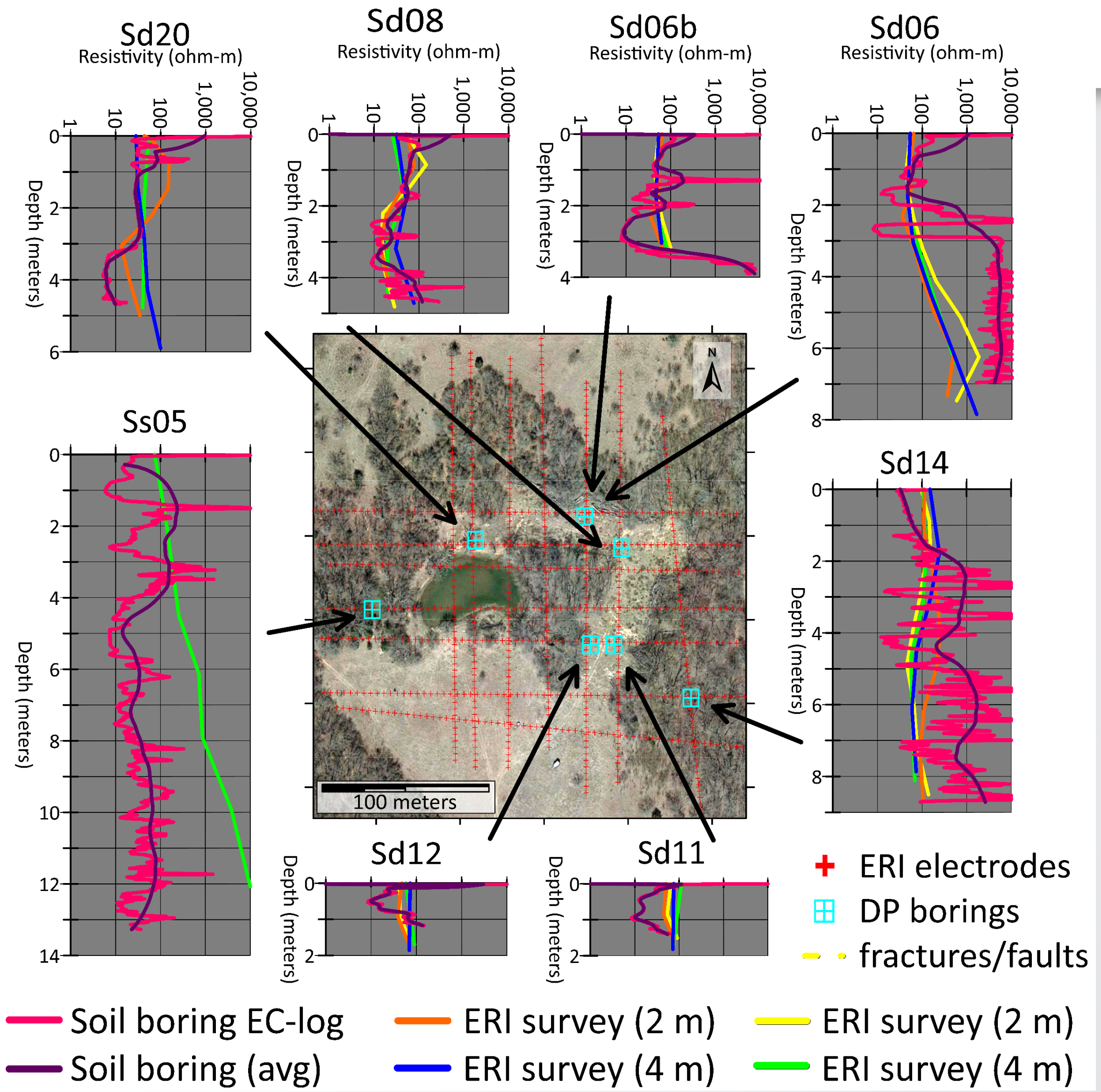


Photo of direct push with EC probe at MAR site (left)

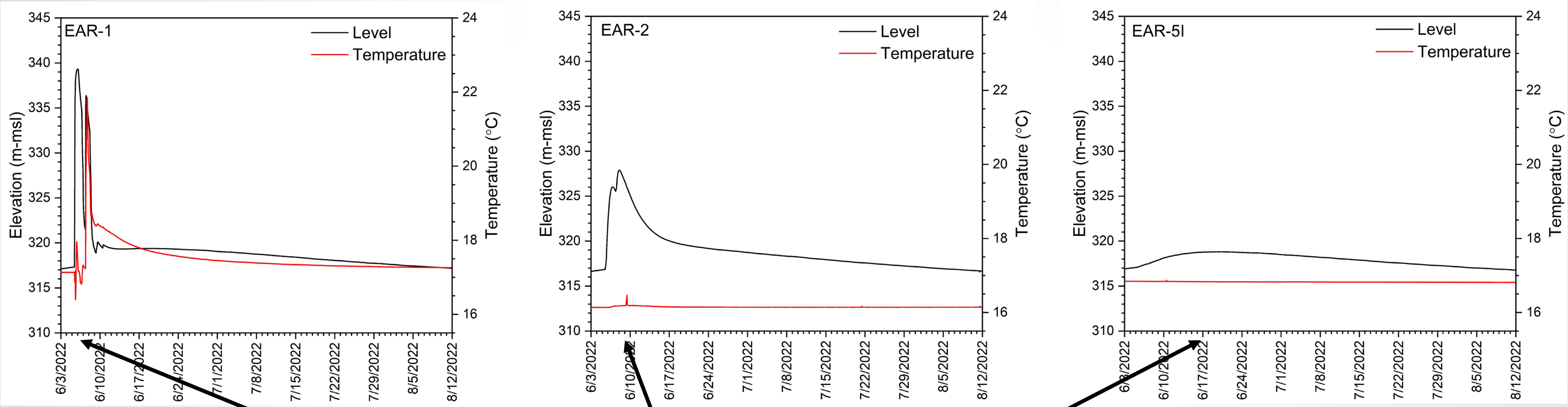
Fields et al., 2022 (right)



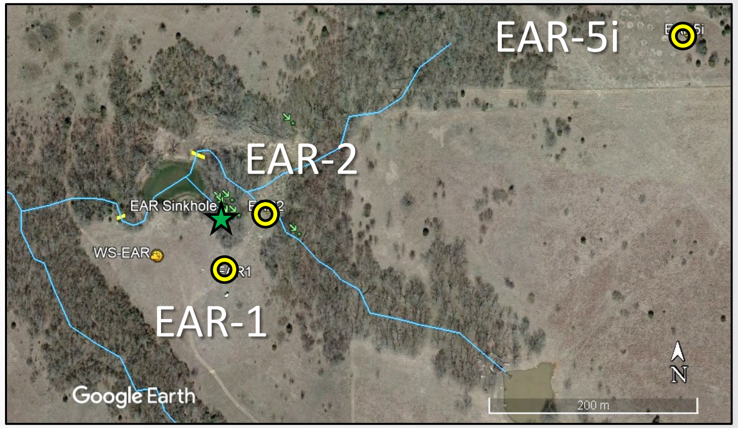
Water Quality Parameters

- Field parameters
  - T, SPC, TDS, DO, pH, ORP, turbidity, alkalinity
- Major anions and cations
  - Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, CO_3^{2-}
- Nutrients
  - NO_3^{-}, NH_3, PO_4^{3-}, TN, TP, DOC, TOC
- Trace elements
  - F^{-}, I^{-}, trace metals
- Isotopes
  - Water isotopes ($\delta^{18}O$ & $\delta^{2}H$)
  - Strontium isotopes ($^{87}Sr/^{86}Sr$, $^{88}Sr/^{86}Sr$)
- Volatile organic compounds (VOC)
- Dissolved gases
  - CO_2, CH_4, N_2O
- Microbial
  - Coliforms, *E. coli*, Enterococci

Capturing chemistry



Time lag:	0.6 days (since recharge)	1.3 days (since recharge)	19.8 days (since recharge)
Distance lag:	53 m (from sinkhole)	75 m (from EAR-1)	435 m (from EAR-2)



Patterns in EAR-1, EAR-1S

- Sampled wells EAR-1 and EAR-1S, also pond and Byrd's Mill Spring (BMS)
- Observed changes in several field parameters
  - Alkalinity, hardness and SPC values ▼
  - DO: ▲ wells ▼ BMS
- Major cations:
  - BMS ▬
  - wells ▼

    (*except potassium in EAR-1*)
- Biotracers

Accomplishments and Next Steps

Accomplishments to Date

- Infrastructure
  - 17 wells (depth range from 100 to 1,000 ft)
  - 4 weather stations
  - 3 precipitation collectors
  - 2, 5-yr weirs (inlet and outlet)
  - 1 modified Parshall flum (sinkhole)
  - 2 runoff samplers
  - 1 transient ERI line (TERI)
- Data Collection Activities
  - 8 quarterly and 3 runoff event water quality samplings
  - 29 ERI surveys
  - monthly TERI surveys
  - Groundwater elevation data
  - Borehole geophysical data collection in all the wells
  - Vadose zone EC and hydraulic profile testing
  - Soil core collection

Next Steps

- Soils (in-progress)
  - More direct push technology
  - Physical and chemical characterization
  - Characterize contaminant properties
  - Infiltration studies
- Chemistry (in-progress)
  - Groundwater and soil

Photos at MAR site

Next Steps (continued)

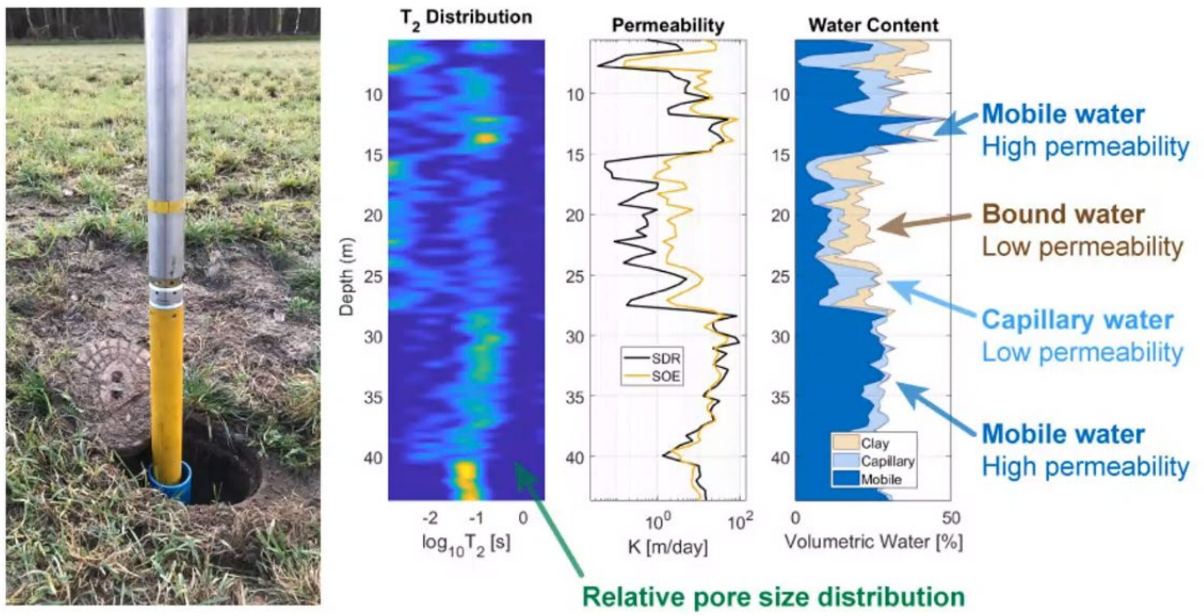
Photo at MAR site

- Characterize intra- and inter-well hydrology to understand groundwater flow during ambient & pumping conditions and recharge events.
  - Transducer data
  - EMBH Flow meter surveys
  - Pumping tests/slug tests
- Continuation of Quarterly Water Sampling

Next Steps (continued)

- Continue application of geophysics to understand and refine geology, geologic model, monitor infiltration events, and siting additional wells
  - Surface (e.g., ground penetrating radar, electromagnetic, TERI)

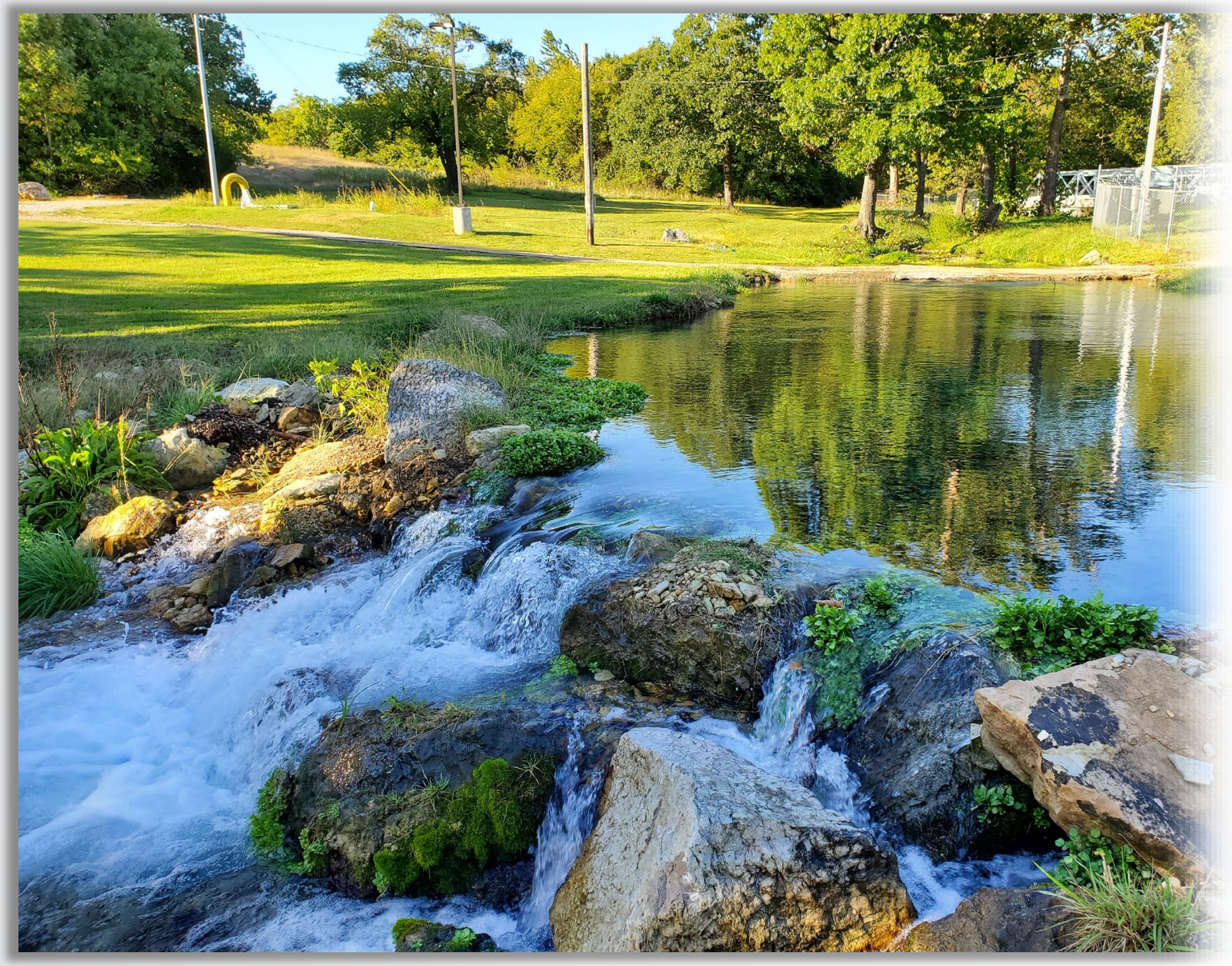
Example suite of logs from NMR survey



- Borehole
  - EM flowmeter with high precision temp. and EC;
  - nuclear magnetic resonance (NMR)

Source: EPA Webinar by Dr. Dale Rucker, hydroGEOPHYSICS, Inc.; August 16, 2022

Thank you, questions?



Special thanks:

Doug Beak, Justin Groves, Russell Neill, Lee Rhea, Catherine Clark, Evan Stallings (ORAU), Tyler Tandy (former ORAU), Todd Halihan (OSU)

References:

Dillon et al., 2019, Sixty years of global progress in managed aquifer recharge, *Hydrogeology Journal*, 27, 1–30.

Fields et al., 2022, Electrical resistivity imaging of an enhanced aquifer recharge site, *Journal of Geophysics and Engineering*, 19(5), 1095-1110.

Wisconsin Geological and Natural History Survey, 2021, “Karst and sinkholes.” https://wgnhs.wisc.edu/water-environment/karst-sinkholes/. Accessed 2021.