Preliminary Data from the U.S. EPA MAR site in the Arbuckle-Simpson Aquifer in Oklahoma

Doug Beak, Randall Ross, Jon Fields, Lee Rhea, Catherine Clark, Russell Neill, Justin Groves, and Evan Stallings

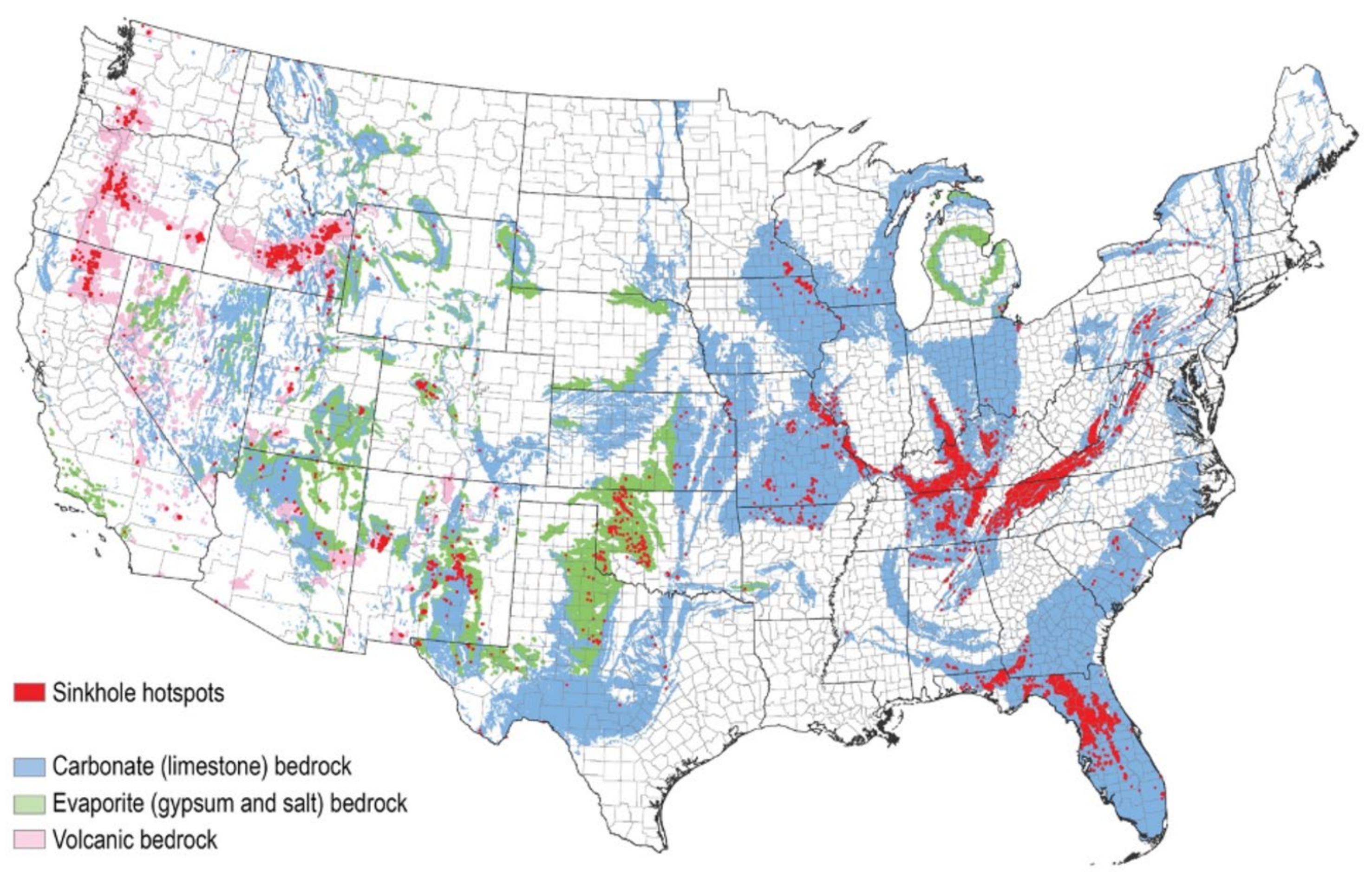
Groundwater Protection Council Annual Forum:

Aquifer Storage & Recovery / Managed Aquifer Recharge

September 13, 2023

Importance of Karst and Fractured Rock Aquifers

- USGS, 2021
  - 40 % of US groundwater drinking water supplies comes from karst aquifers
  - Groundwater storage is in the rock matrix
  - Groundwater transport is through openings
  - Karst aquifers are highly heterogeneous and anisotropic
  - Research needs: “developing innovative approaches for better understanding and managing these valuable water resources”



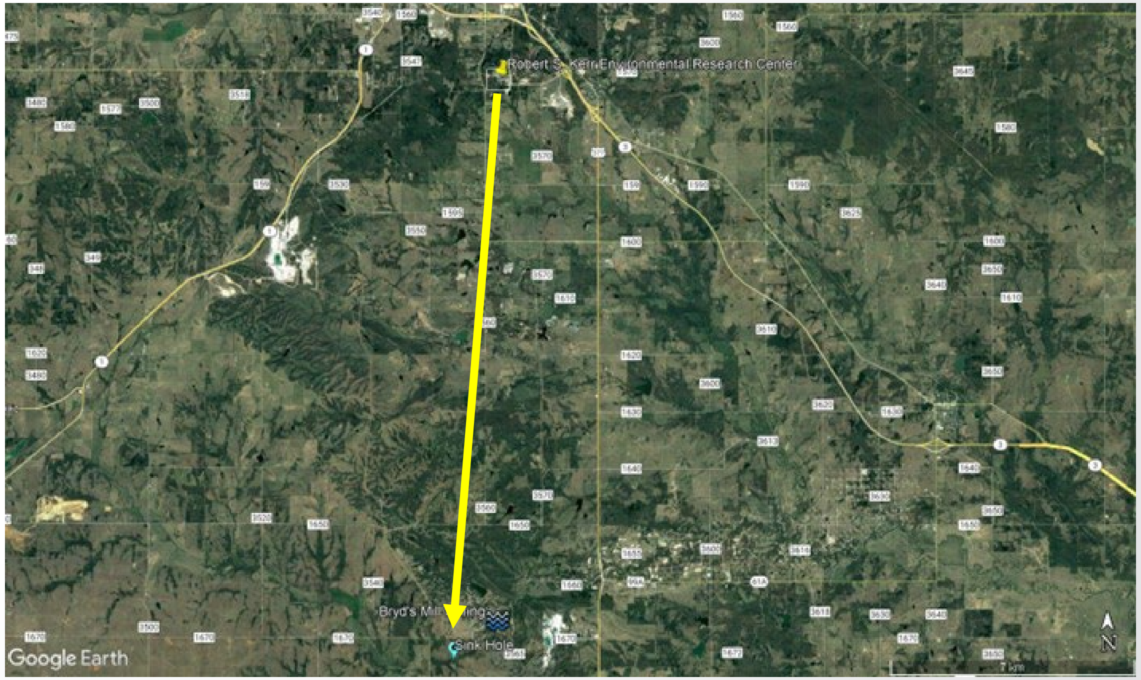
Source: USGS. 2021. Karst Aquifers. https://www.usgs.gov/mission-areas/water-resources/science/karst-aquifers

Research Questions

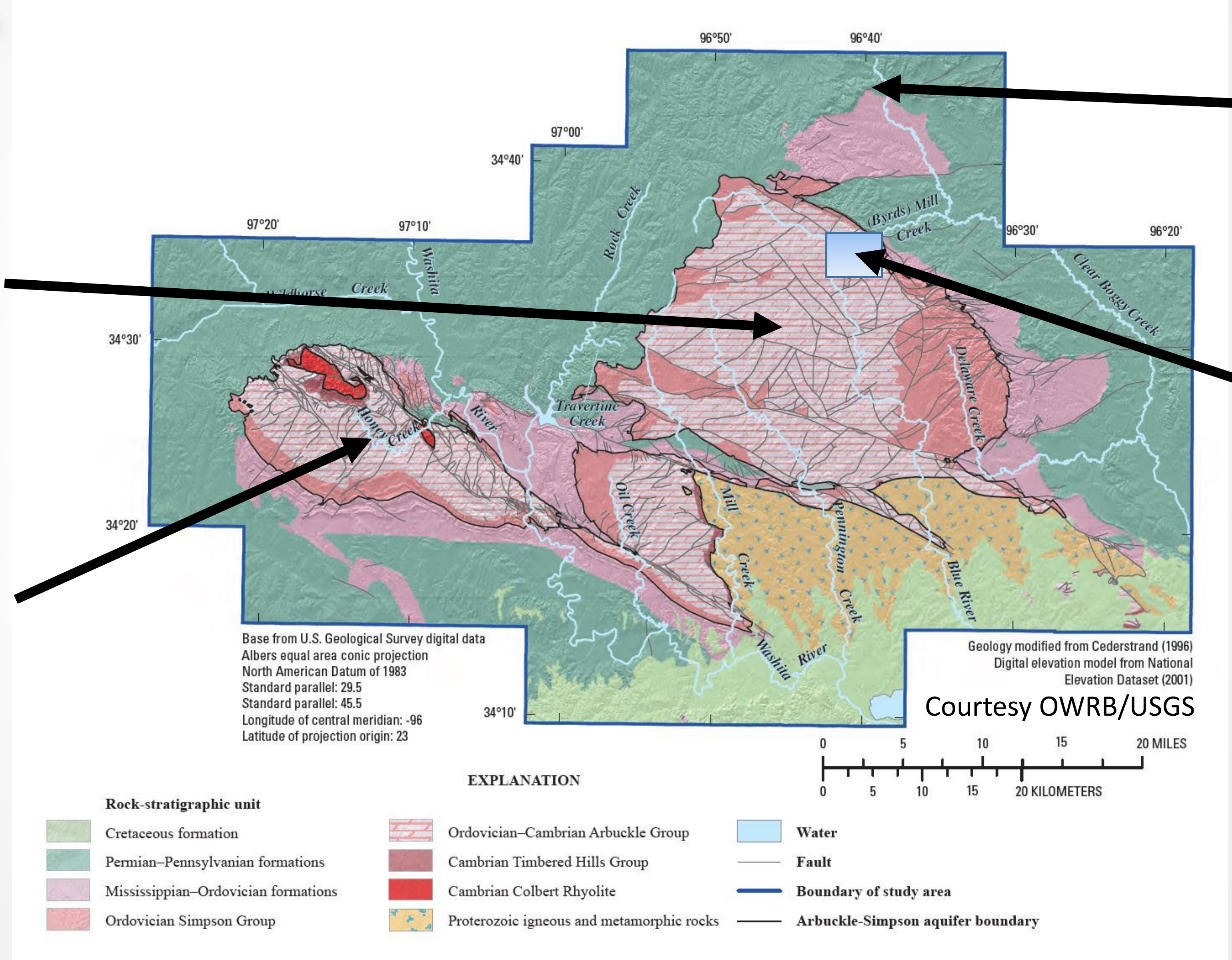
- Primary Research Questions
  - Q1: Does infiltration of stormwater using EAR alter the water quality (chemical and biological) and/or native biochemical processes?
  - Q2: Technologies that can be employed when using EAR to monitor water and chemical movement?
  - Q3: How does the hydrology of a karst or fractured rock aquifer affect the fate and transport of constituents and the monitoring needs for EAR in a karst or fractured rock system?
  - Q4: What is the contribution of infiltration through the vadose zone (diffuse recharge) to water quantity and quality in the area surrounding an EAR structure?
  - Q5: What is the capacity of the vadose zone to sequester contaminants?
- Secondary Research Questions
  - SQ1: Are natural karst features (sink holes) suitable for enhance aquifer recharge of stormwater?
  - SQ2: Will stormwater infiltrated by EAR enhance the water quantity at Byrds Mill Spring?
  - SQ3: Does the use of EAR impact water quality at Byrds Mill Spring?
  - SQ4: Etc.

EAR Research Site

- Location:
  - ~10 miles south of Robert S Kerr Environmental Research Center (RSKERC)
  - ~ 1 mile southwest of Byrds Mill Spring (BMS), the City of Ada Water Supply



Arbuckle-Simpson Aquifer



Courtesy OWRB/USGS

Ada (GCRD)

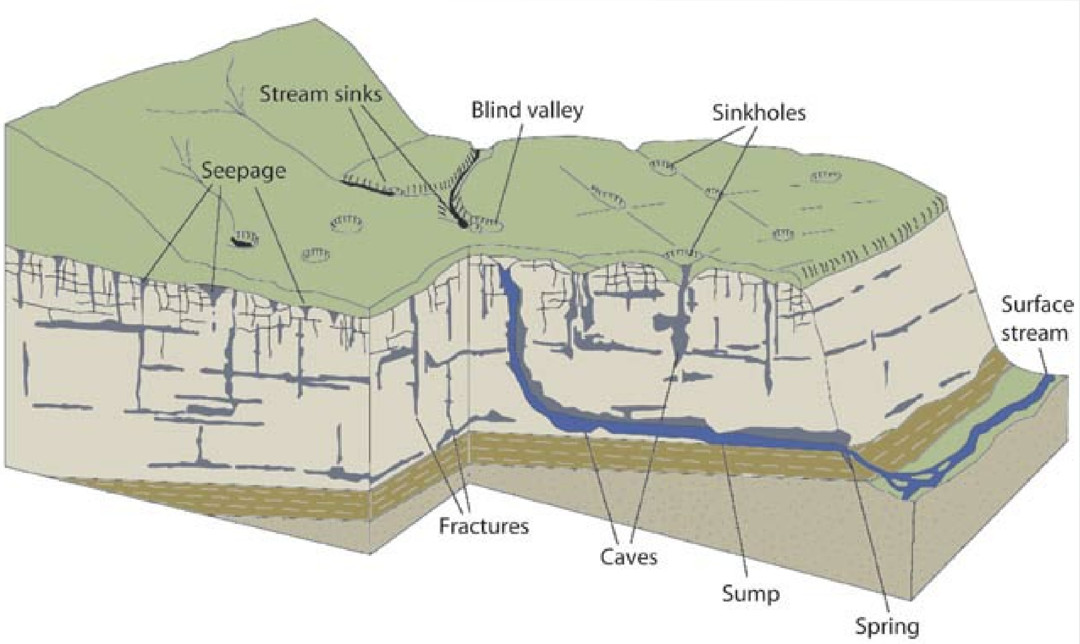
Hunton Anticline

EAR Study Area

Arbuckle Mountains

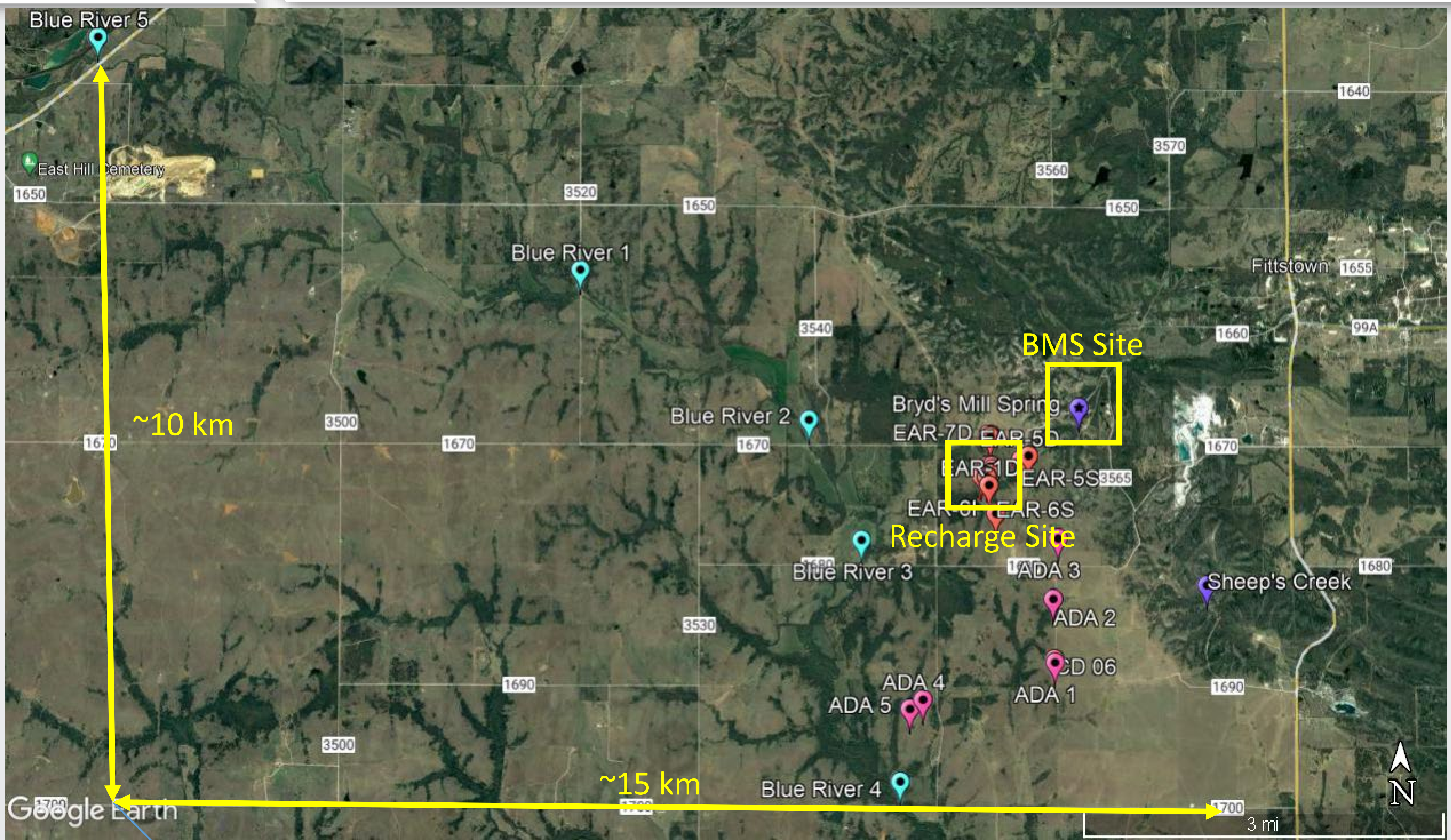
Arbuckle-Simpson Geology/ Hydrogeology

- Primarily composed of carbonates (i.e., limestone and dolomite)
- Karst aquifer
  - 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

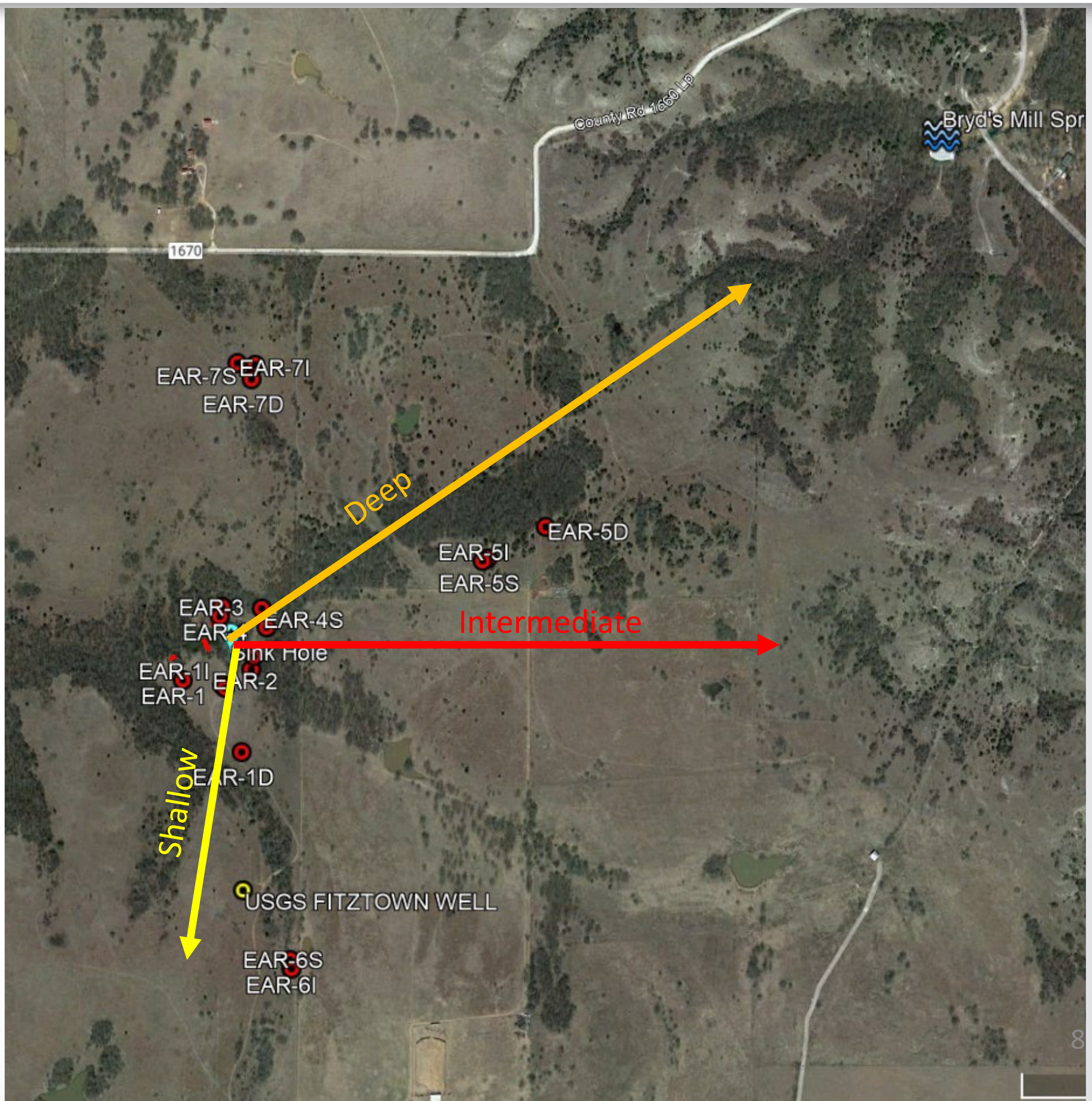
EAR Study Area



Potential Groundwater Flow Systems

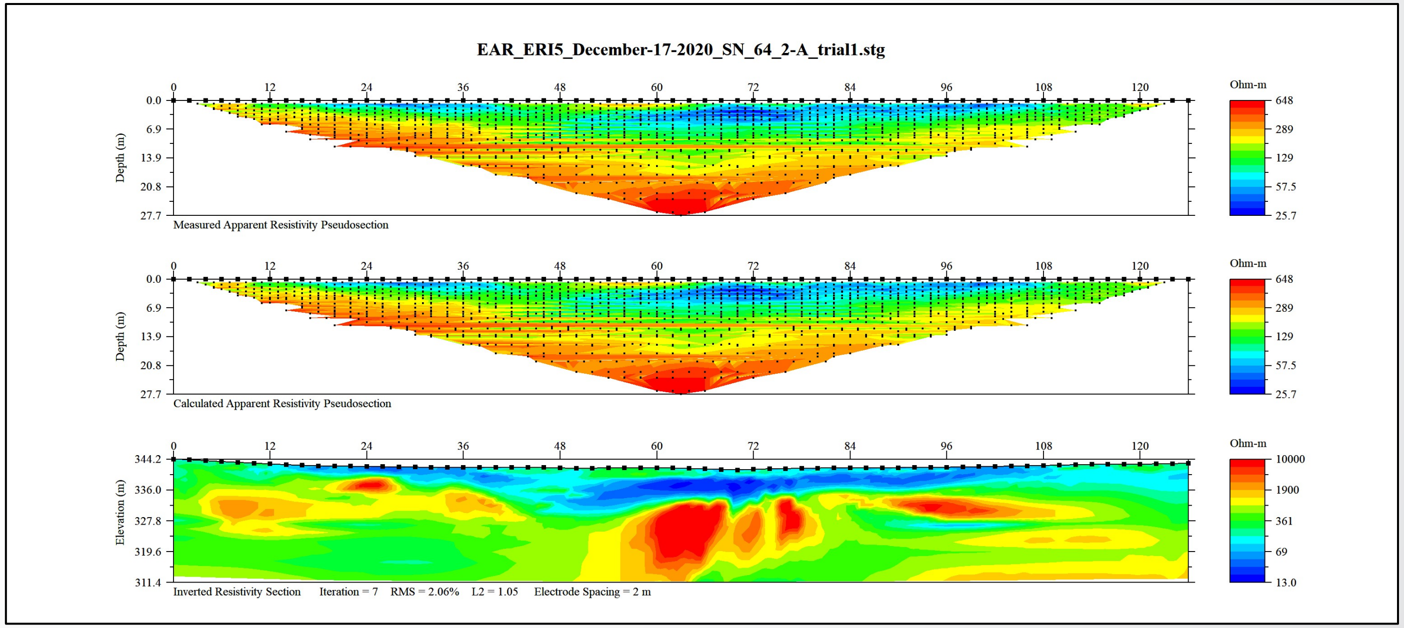
- USGS suggest that groundwater flows towards Byrds Mill Spring (BMS)
- EPA data suggest at least 3 groundwater flow systems
  - Shallow System < 150 ft
  - Intermediate System ~ 250 ft
  - Deep System ~750 ft

- Water age at BMS < 50 yrs
- Vertical groundwater movement needs to be determined



Electrical Resistivity Imaging (ERI)

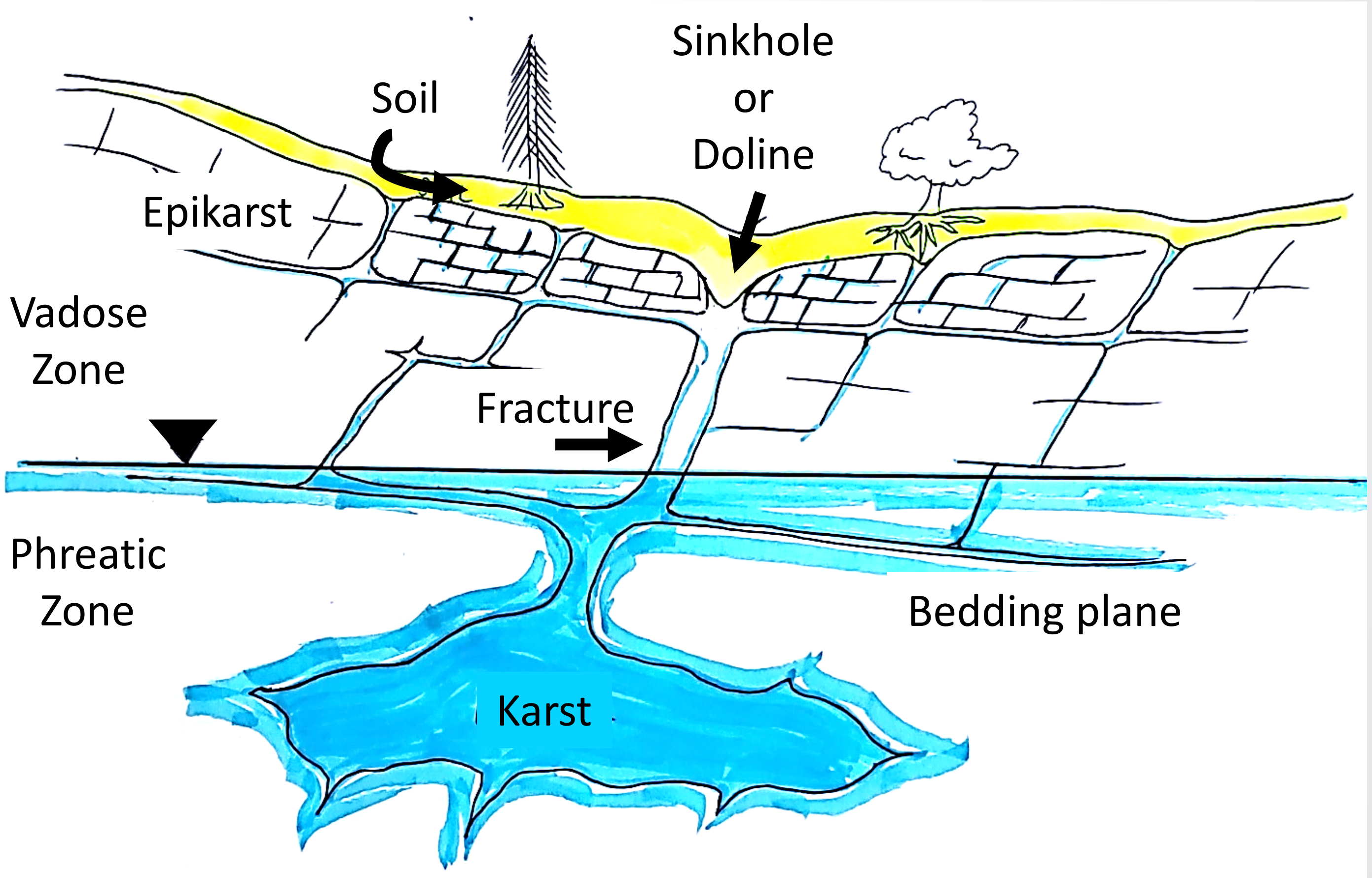
- ERI is a geophysical technique which measures the apparent electrical resistivity of the subsurface in order to create a 2D image of these measurements.
- ERI is regularly used for high resolution site characterization of:
  - contaminated sites,
  - groundwater presence,
  - flow and transport, and
  - geologic structures.



Screenshot of data processing

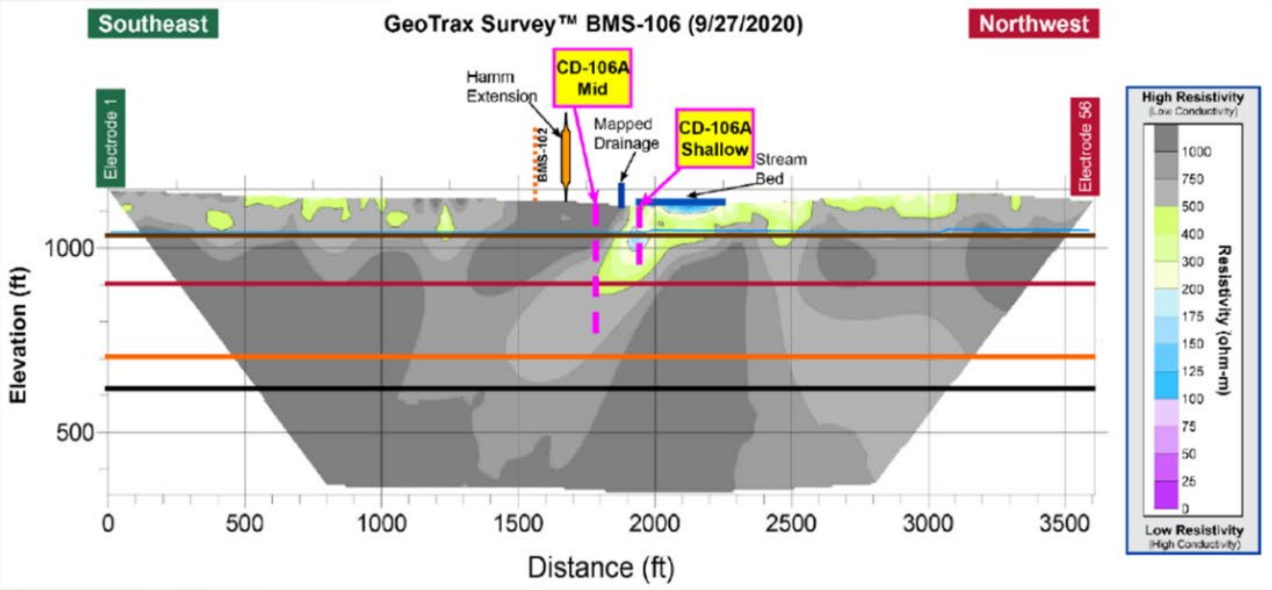
Fractures and conduits

- Preferential flowpaths
- Fracture zones
  - Higher porosity and permeability
  - Relatively linear signatures
- Karst / epikarst
  - Microbial and geochemical influences
  - Large potential for conduits

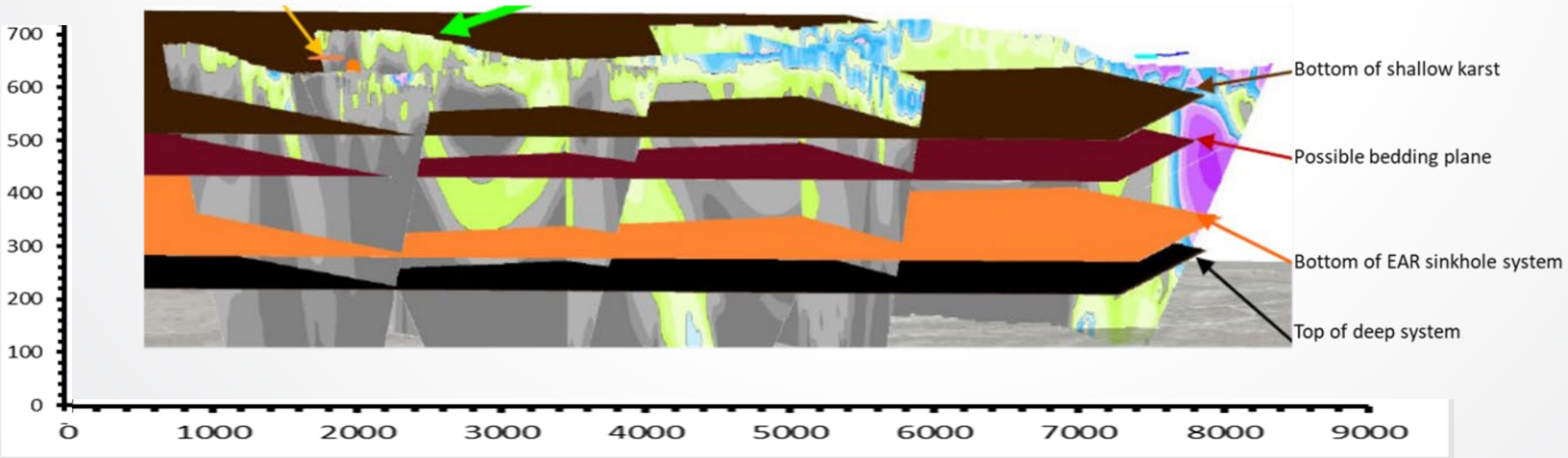


Illustrated by Jon Fields

ERI Investigations ("Plumbing")



Figures from Aestus, Inc., 2020



ERI Investigations (Well Siting)

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

Photo at EAR site

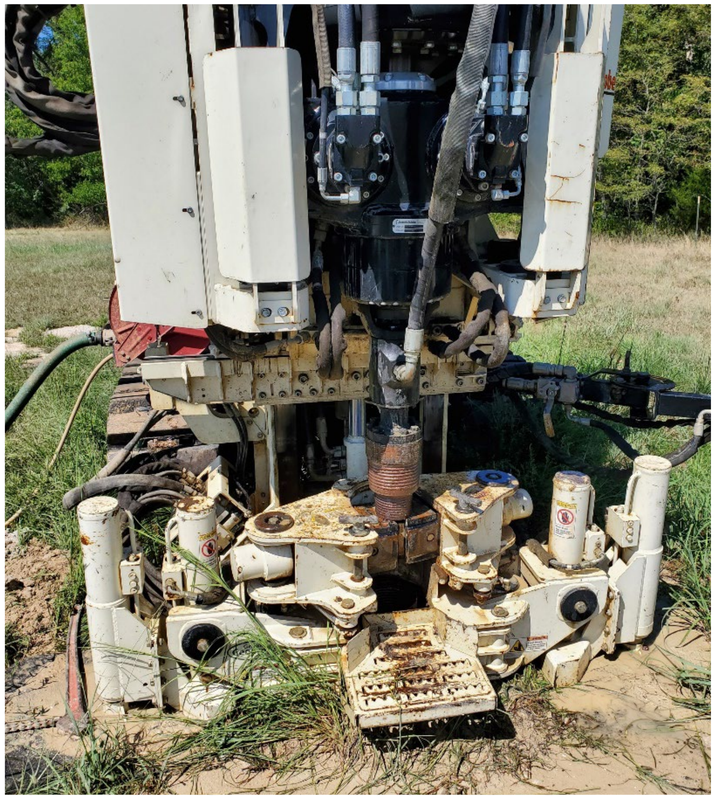
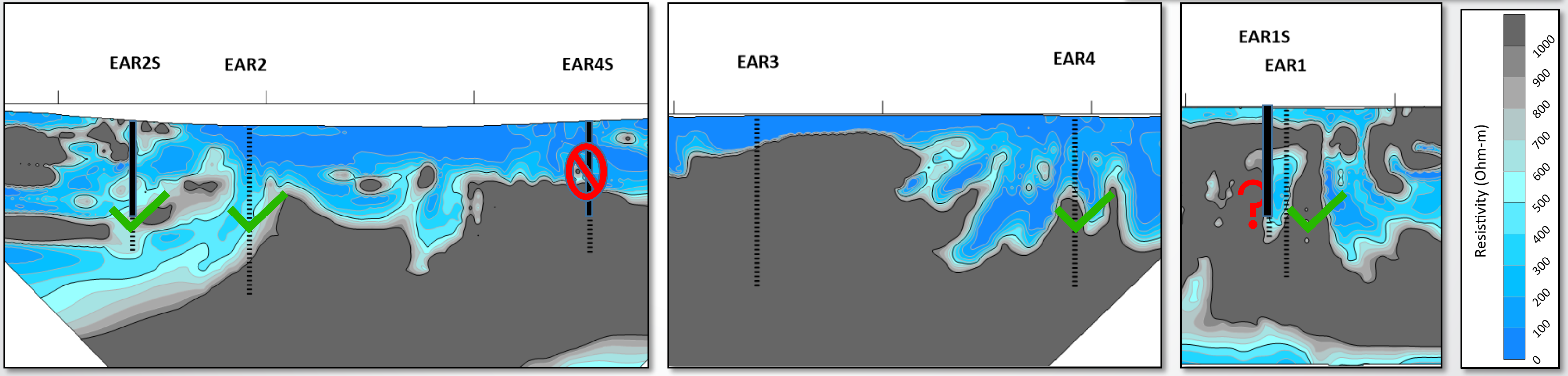


Photo at EAR site

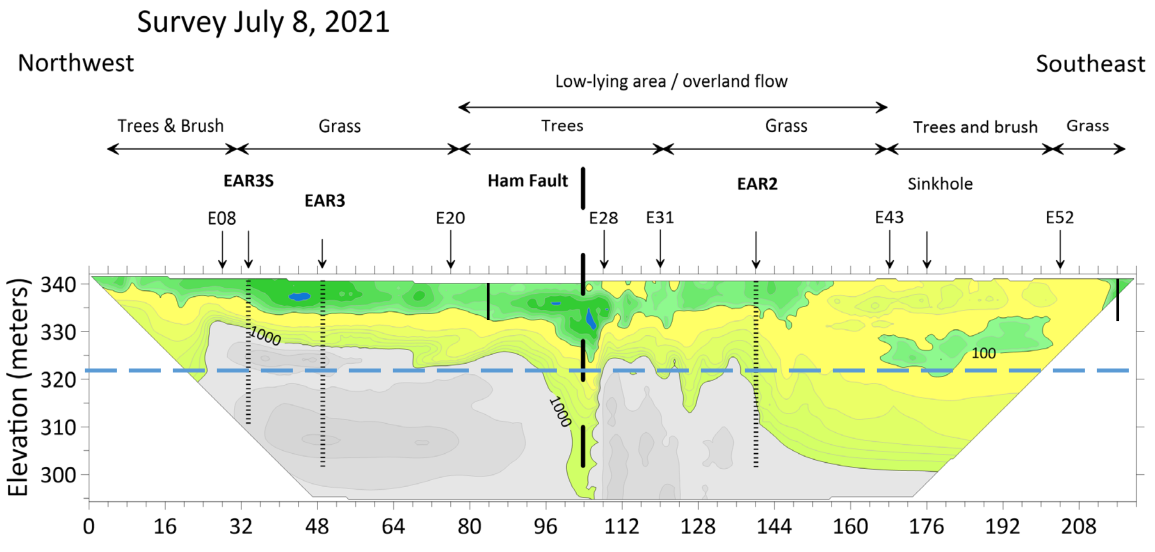
- ERI surveys at the EAR site can indicate potential targets for high flow (drill)

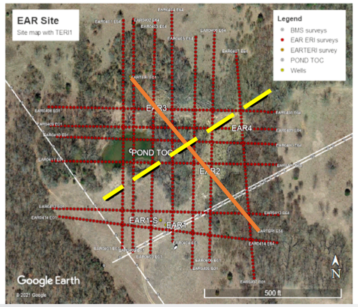
ERI - Well Siting

- Installed without prior use of electrical resistivity imaging to site wells: mixed bag of results
- Low-flow and high-flow wells
- Pre-drilling plan can more efficiently place wells

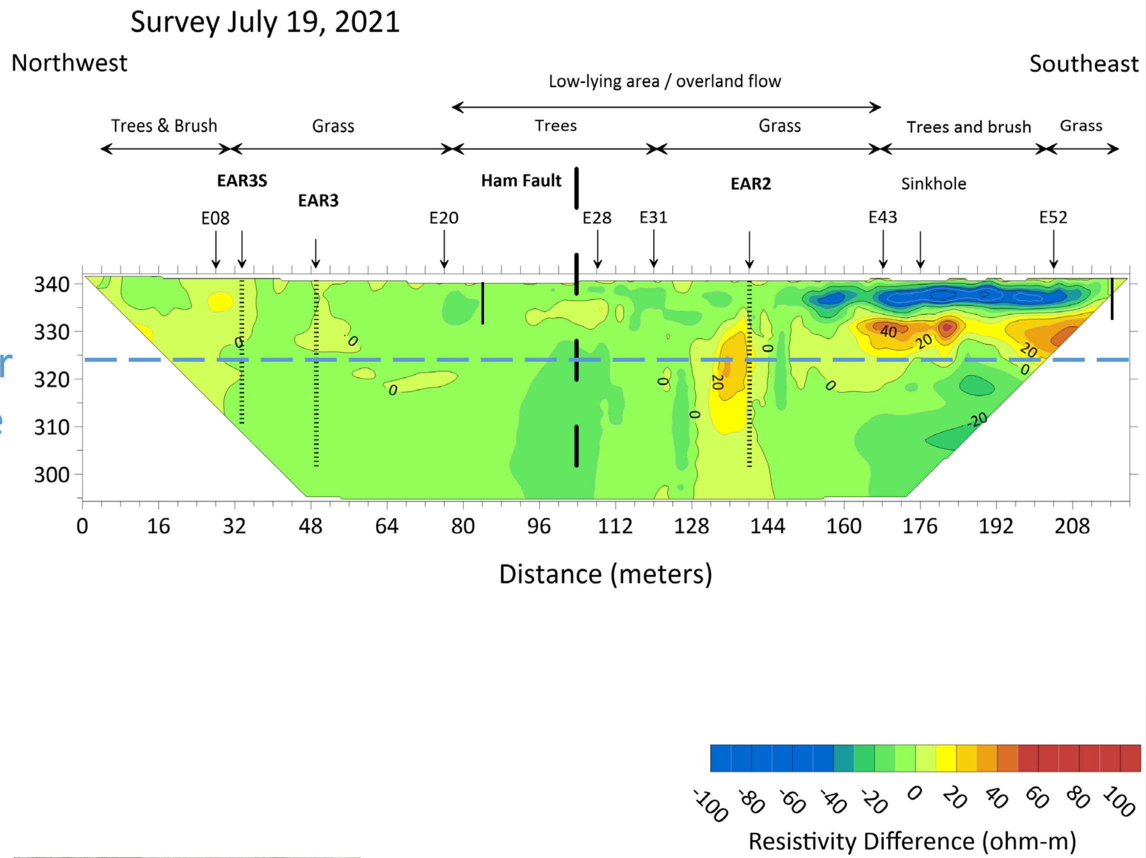


TERI survey showing recharge

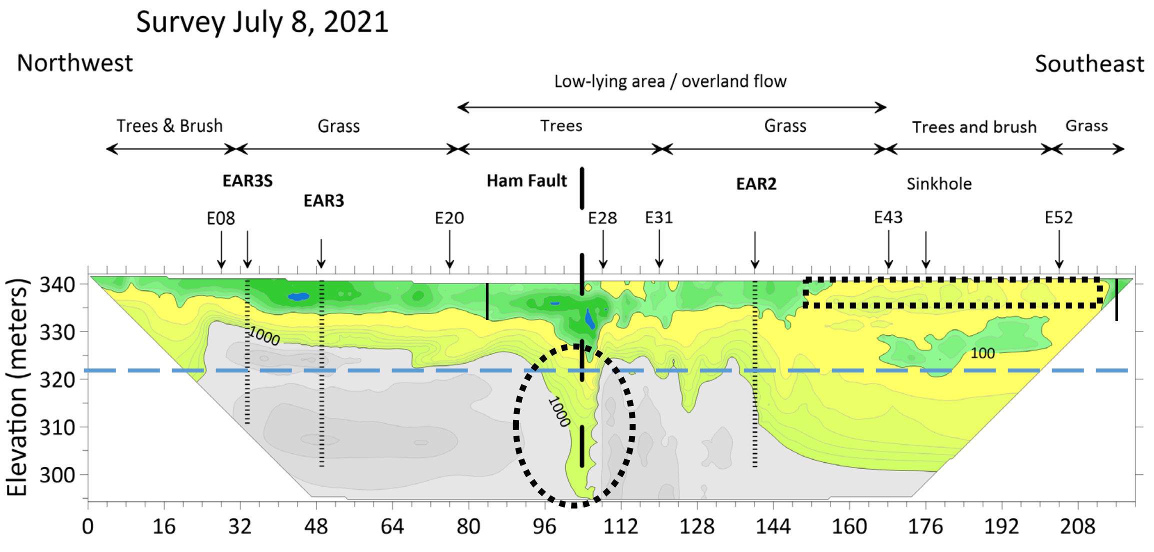


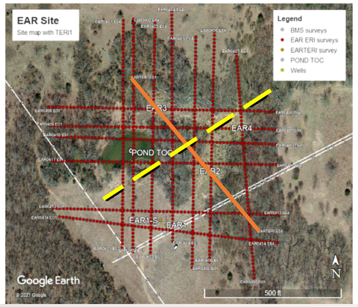


Water Table

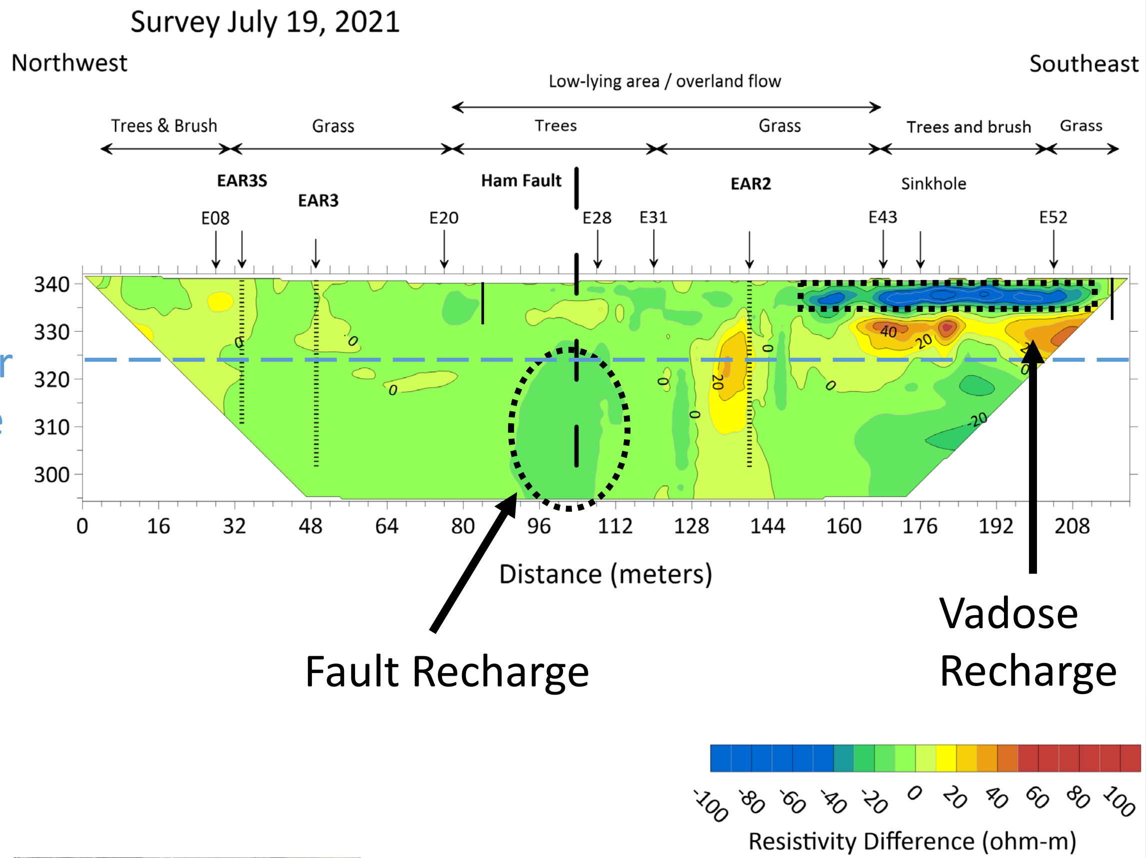


TERI survey showing recharge





Water Table



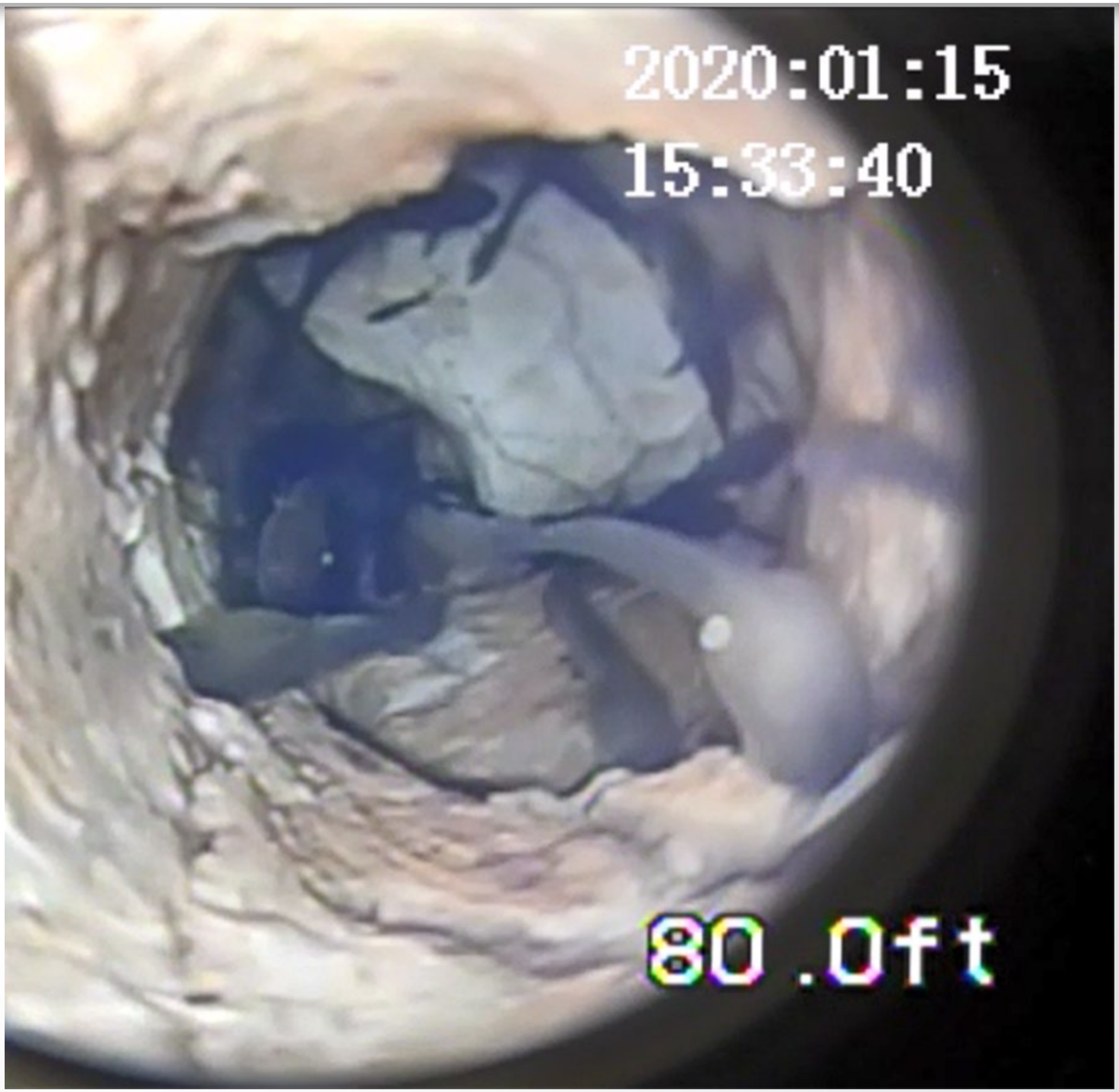
June 2022 Overland Flow Event

- June 6, 2022
  - 64.6 mm (2.54 in) of total precipitation
  - Precipitation over 0.75 hr (45 min)
  - Intensity: 86.0 mm/hr (3.39 in/hr)
- June 7, 2022
  - 26.4 mm (1.04 in) of total precipitation
  - Precipitation over 2.42 hr (145 min)
  - Intensity: 10.9 mm/hr (0.43 in/hr)

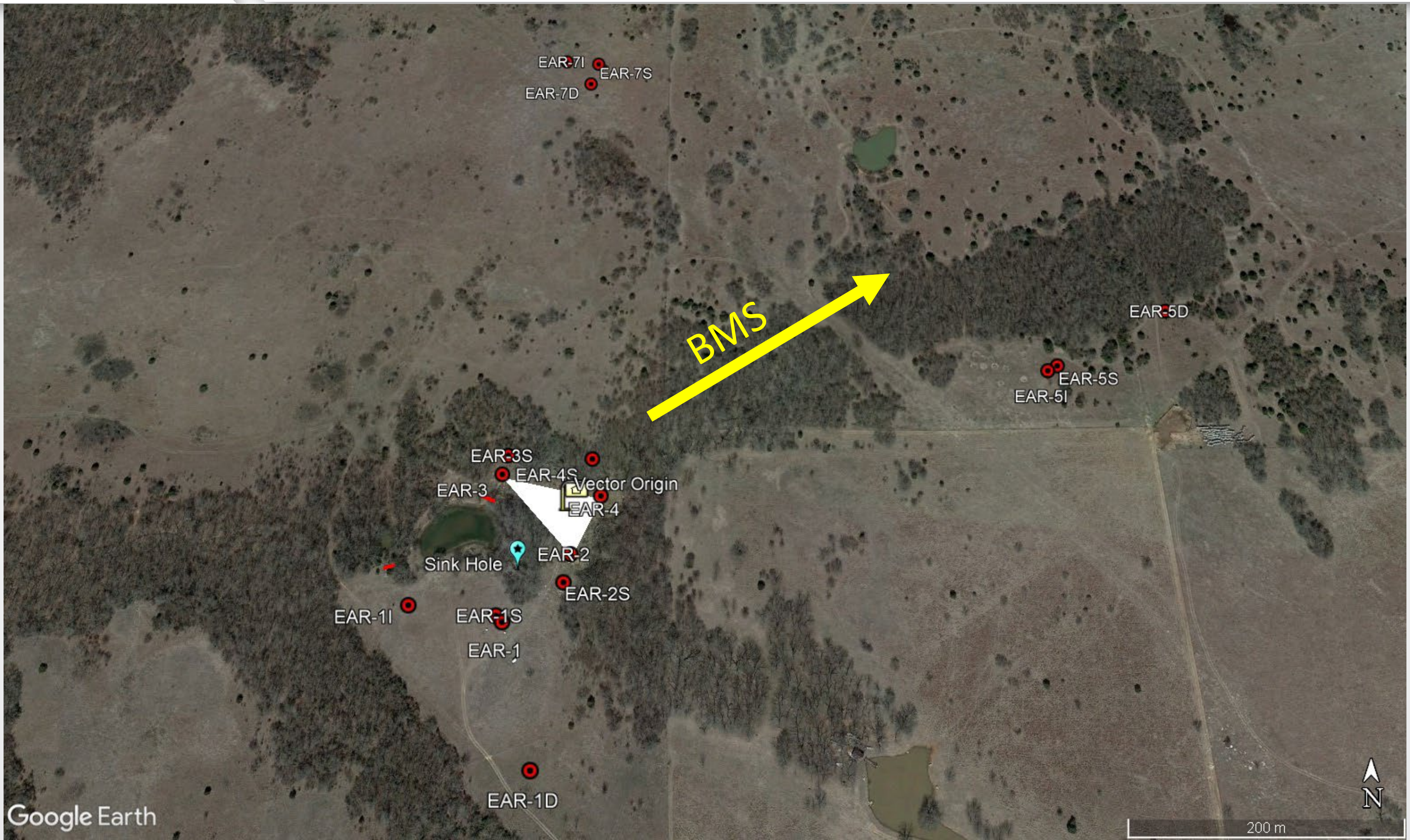
Source: Unsplashed.com/s/photos/rain

Groundwater Observations Overland Flow

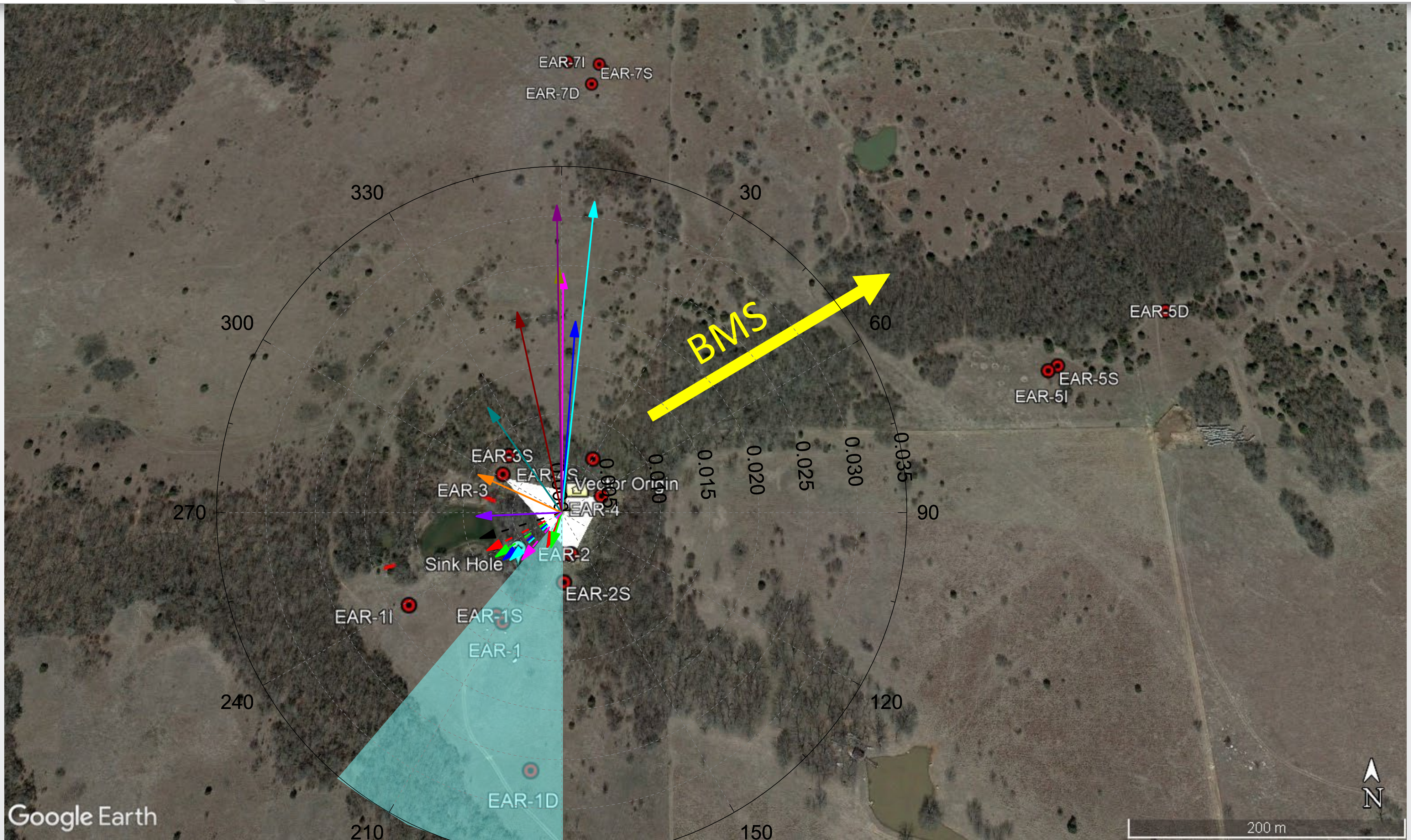
- Rapid water level response to overland flow events in 4 wells.
- Direct connection between sinkhole and EAR-1 (i.e., fish & tadpoles).
- In EAR-1 there will be little attenuation of any contamination.



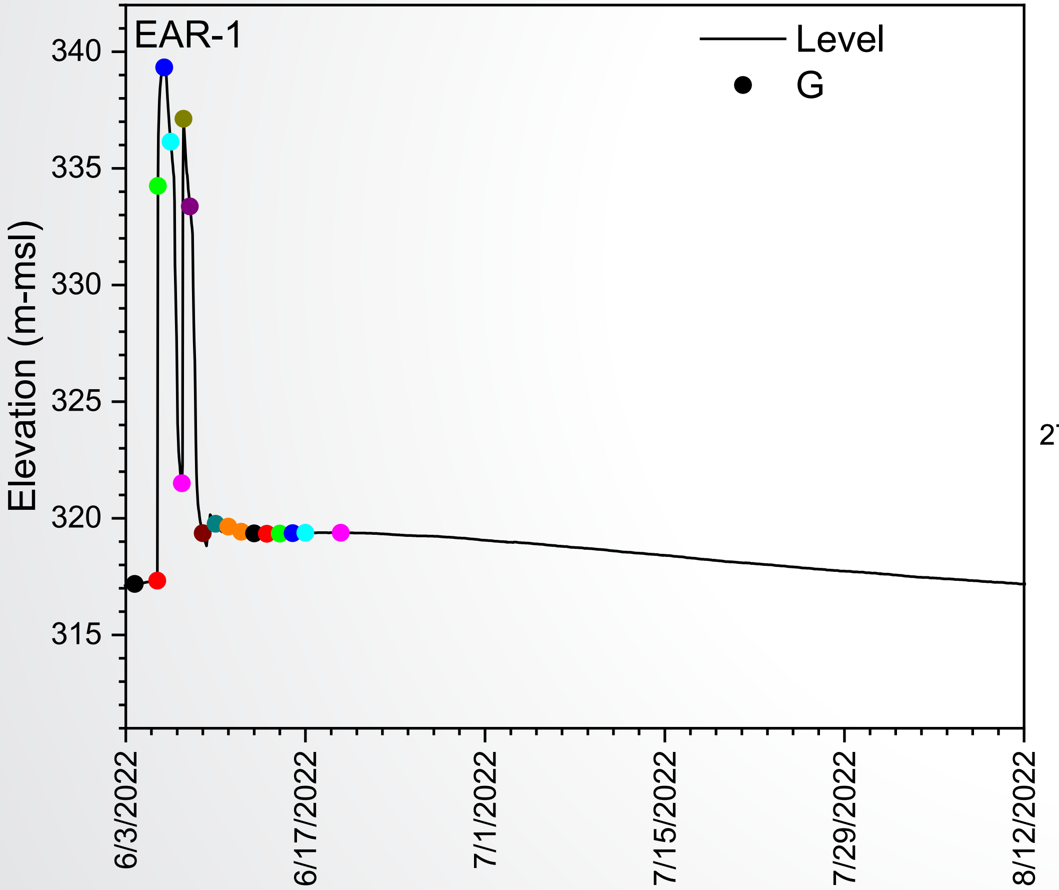
June 2022 Overland Flow Event

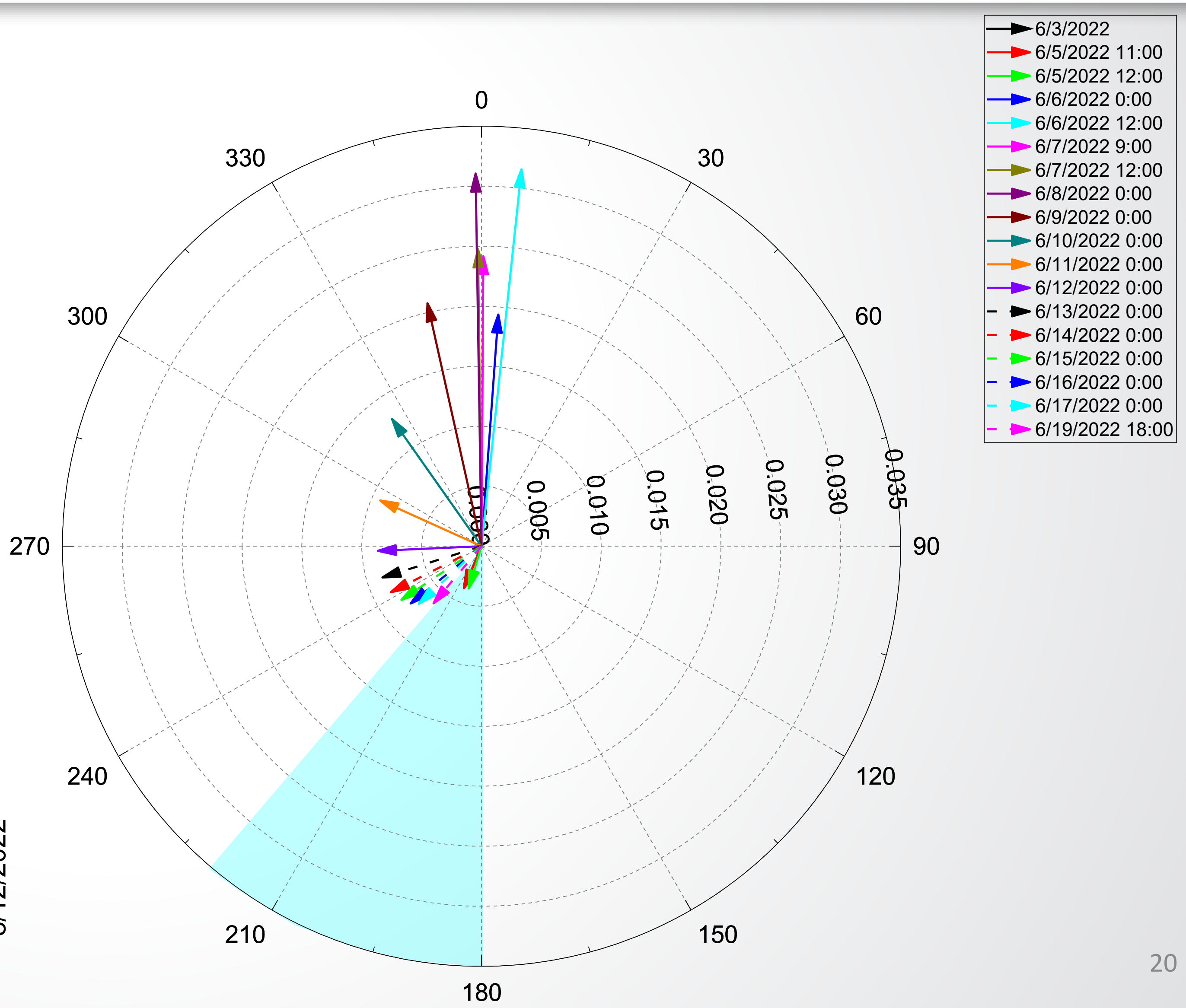


June 2022 Overland Flow Event



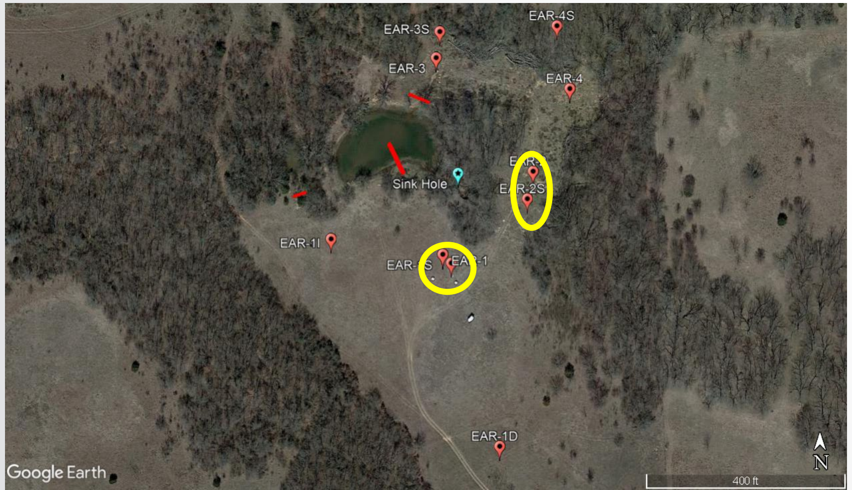
June 2022 Overland Flow Event

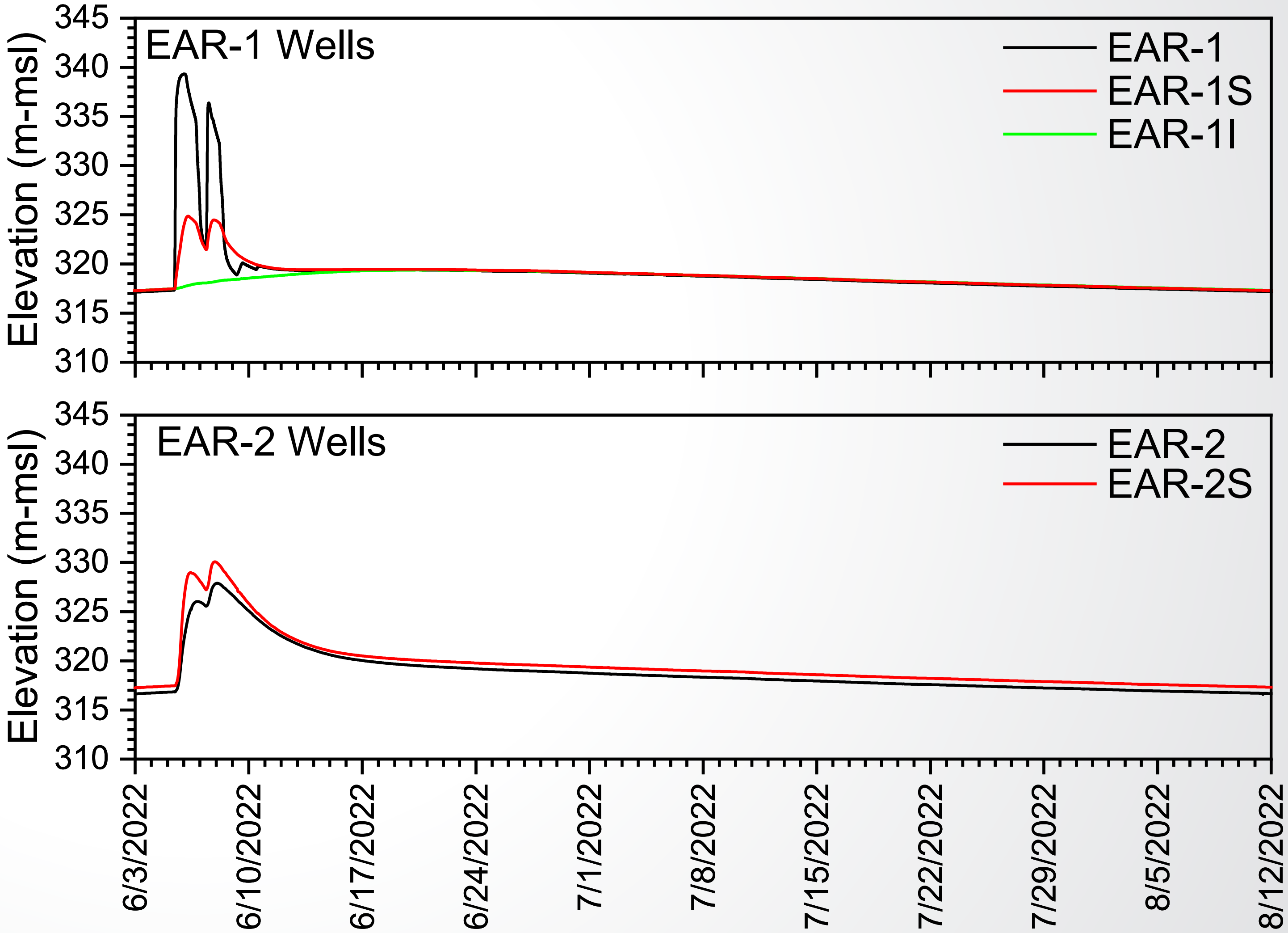




June 2022 “Impacted Wells”

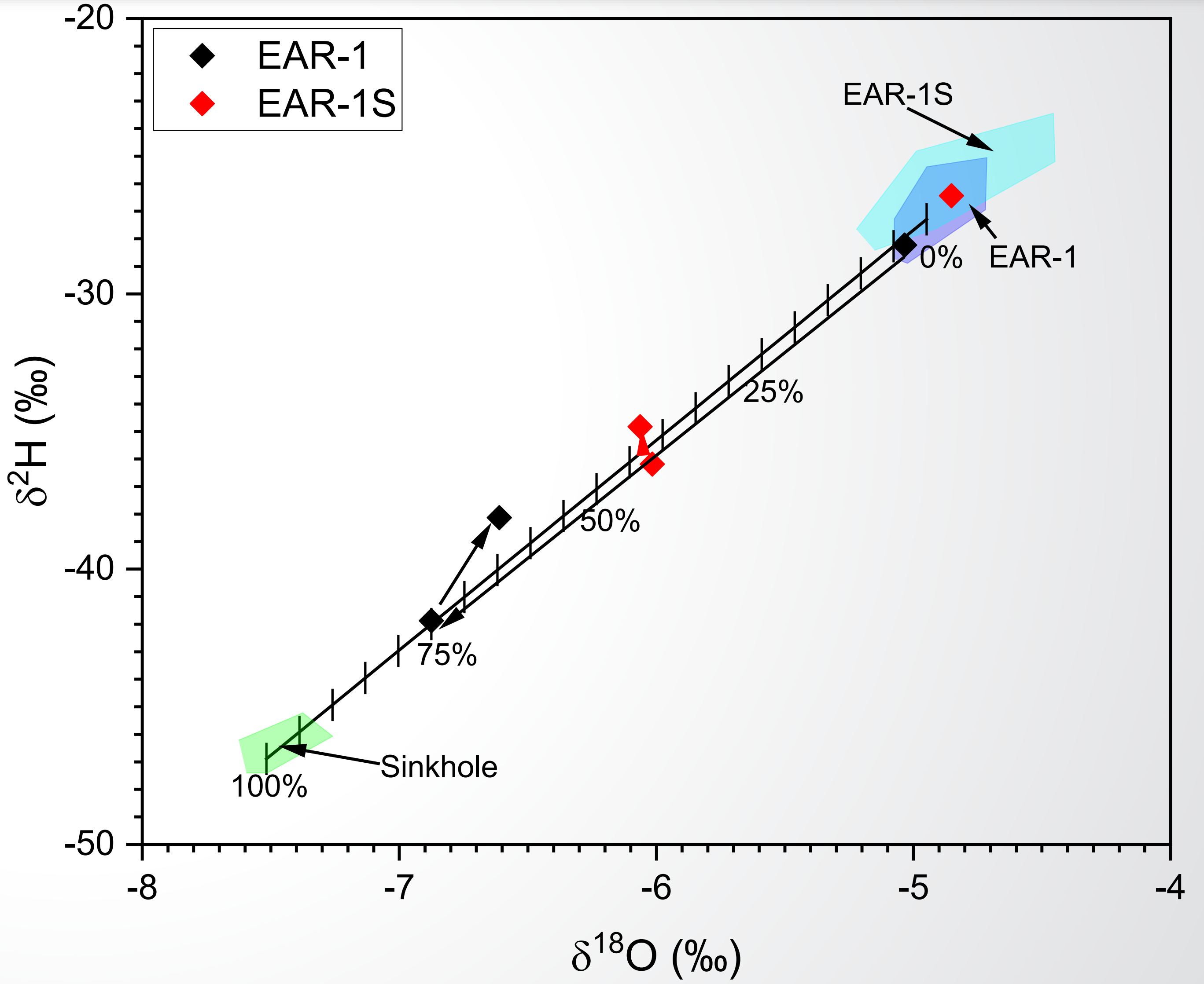
- Water Levels
  - EAR-1, -1S, -2, and 2S show nearly immediate response to sinkhole
  - EAR-1, -1S, -2, and 2S drain until meet overall aquifer rise in water
- Suggests mounding



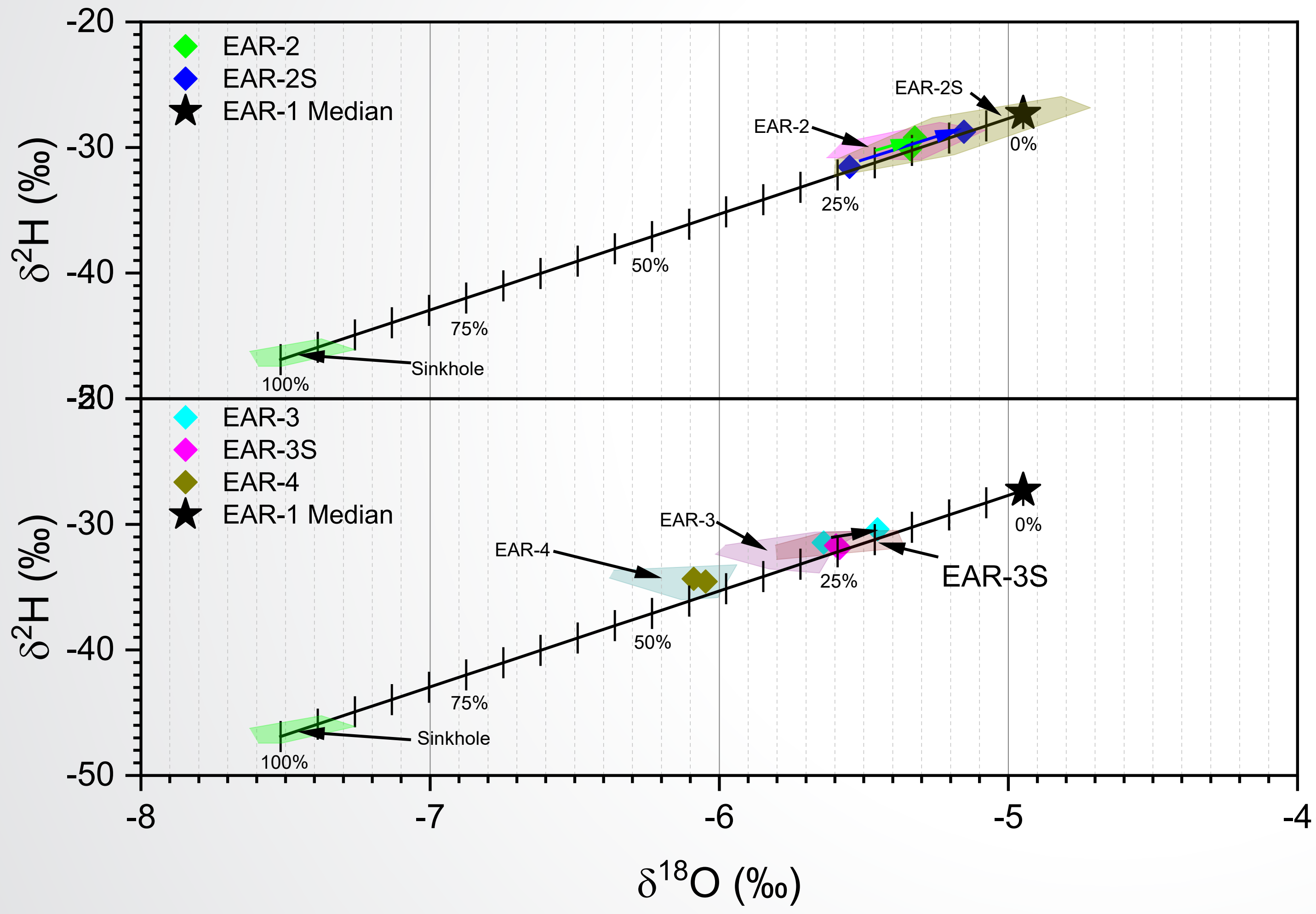


June 2022 Water Isotope Mixing

- EAR-1 and 1S water isotopes show:
  - Mixing of background levels with sinkhole data from event
  - Based on the mixing model using isotopes at peak water levels EAR-1 is 74% infiltrated water
  - EAR-1S is 44% infiltrated water
  - Model fits well for other major anions and cations



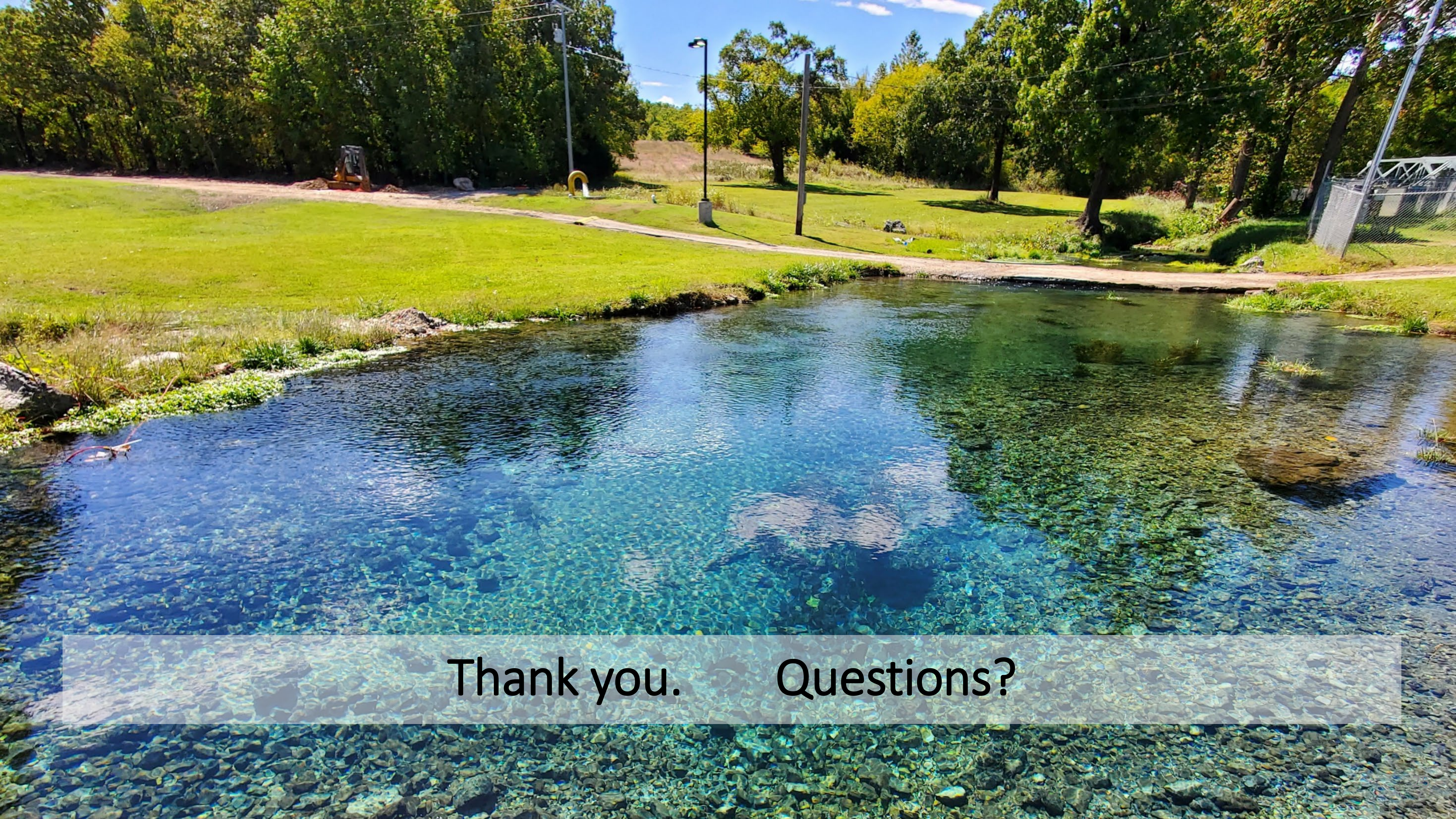
June 2022 Water Isotope Mixing



- Other local wells do not show mixing with sinkhole water
- Isotopic composition is similar to background
- Any shifts in isotopic composition is more EAR-1 and EAR-1S background like
- Suggests mounding?

June 2022 Overland Flow Event

- Water Isotopes should be conservative and will provide insight into volume of water in EAR-1 and EAR-1S
- Sampling of overland flow events will be complicated by
    - Different sampling times for different wells
    - Wells will need multiple sampling
- Questions
    - Can we trace chemical changes over distance/time?
    - Is the monitoring well network sufficient to identify potential changes to water quality?
    - Are water quality changes local and short lived or larger scale and long duration?
    - Role of diffuse recharge to aquifer?


Thank you. Questions?