Summary of Airborne Electromagnetics in the Indian Wells Valley

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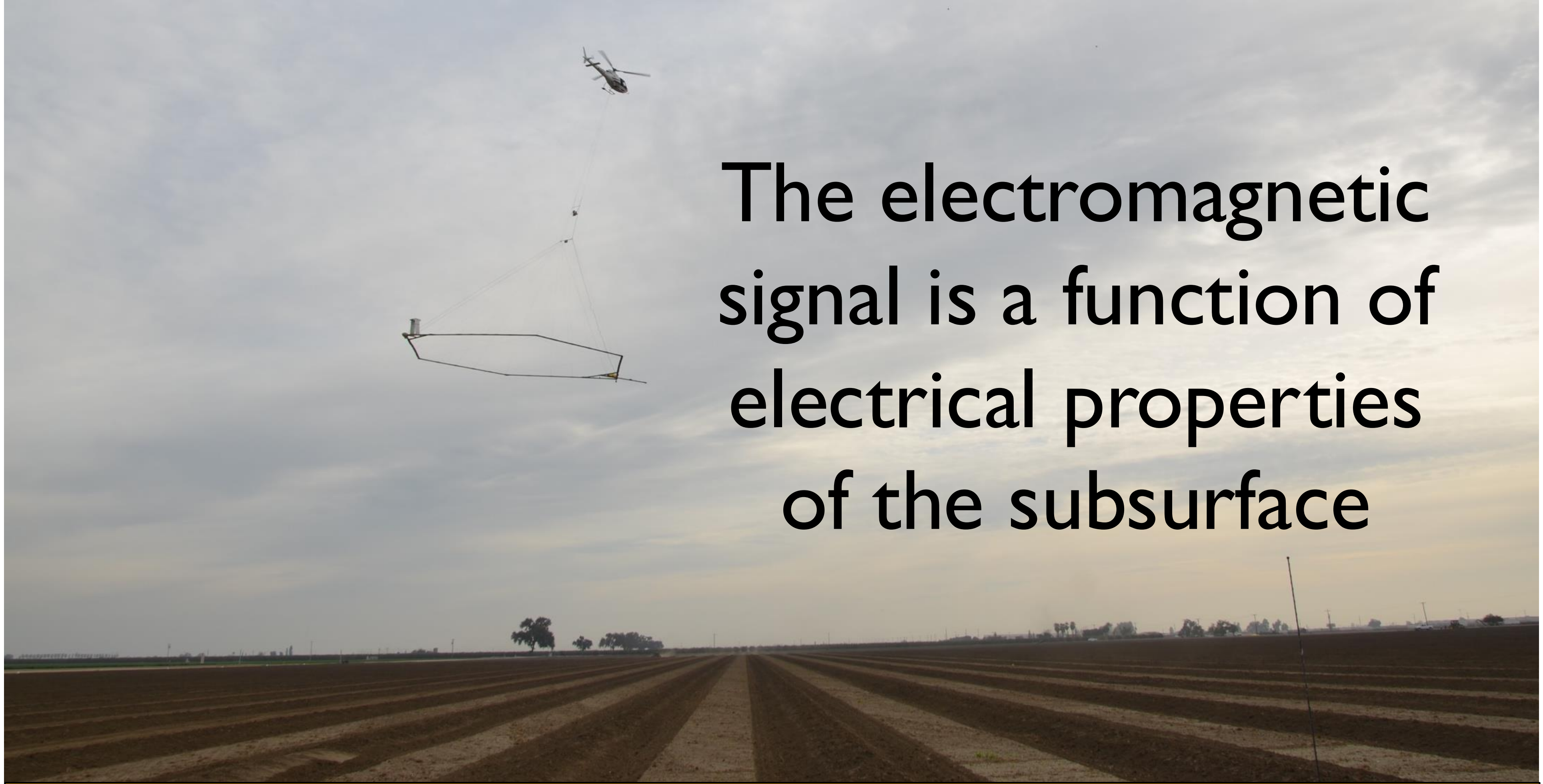
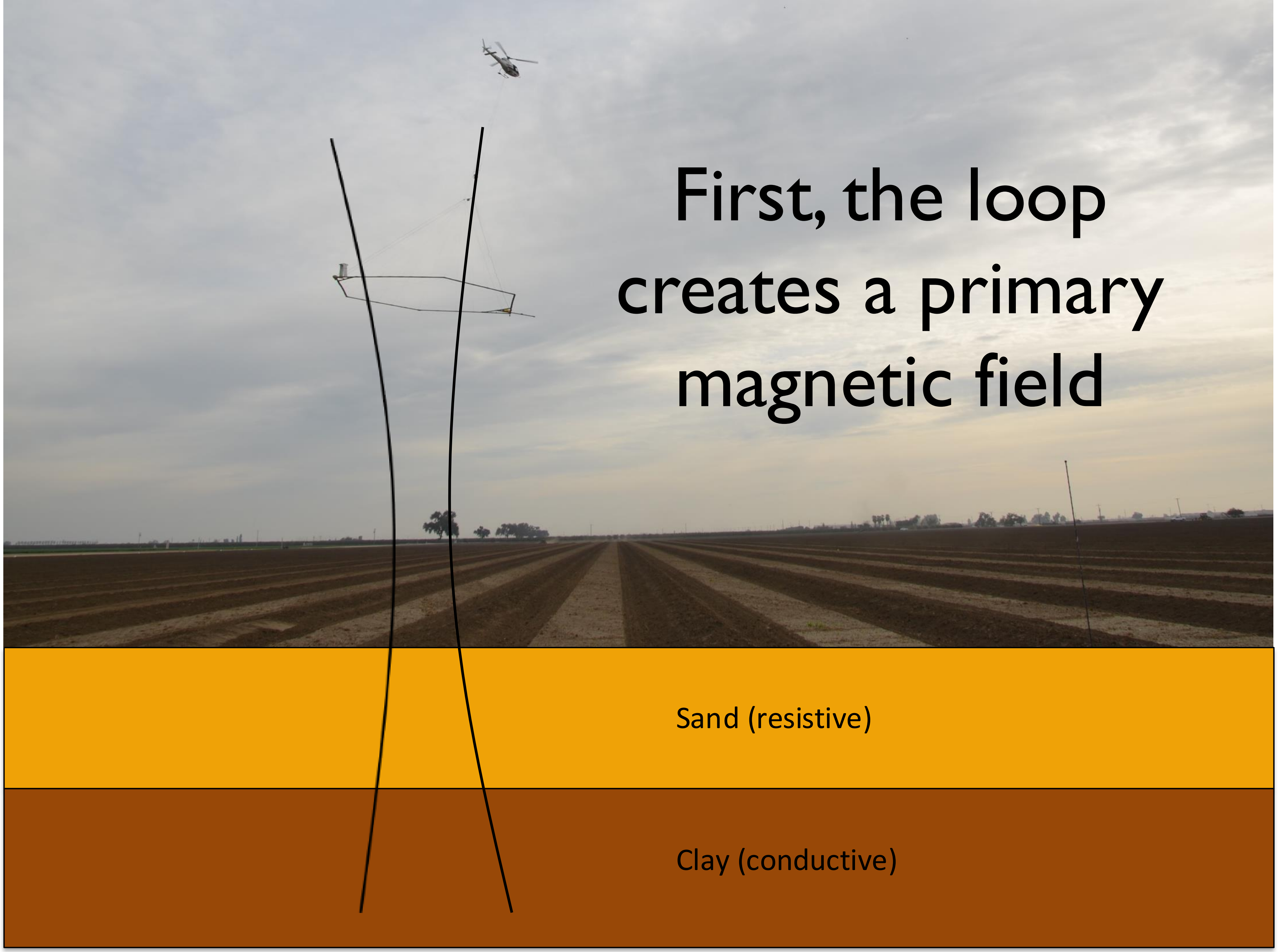
Outline

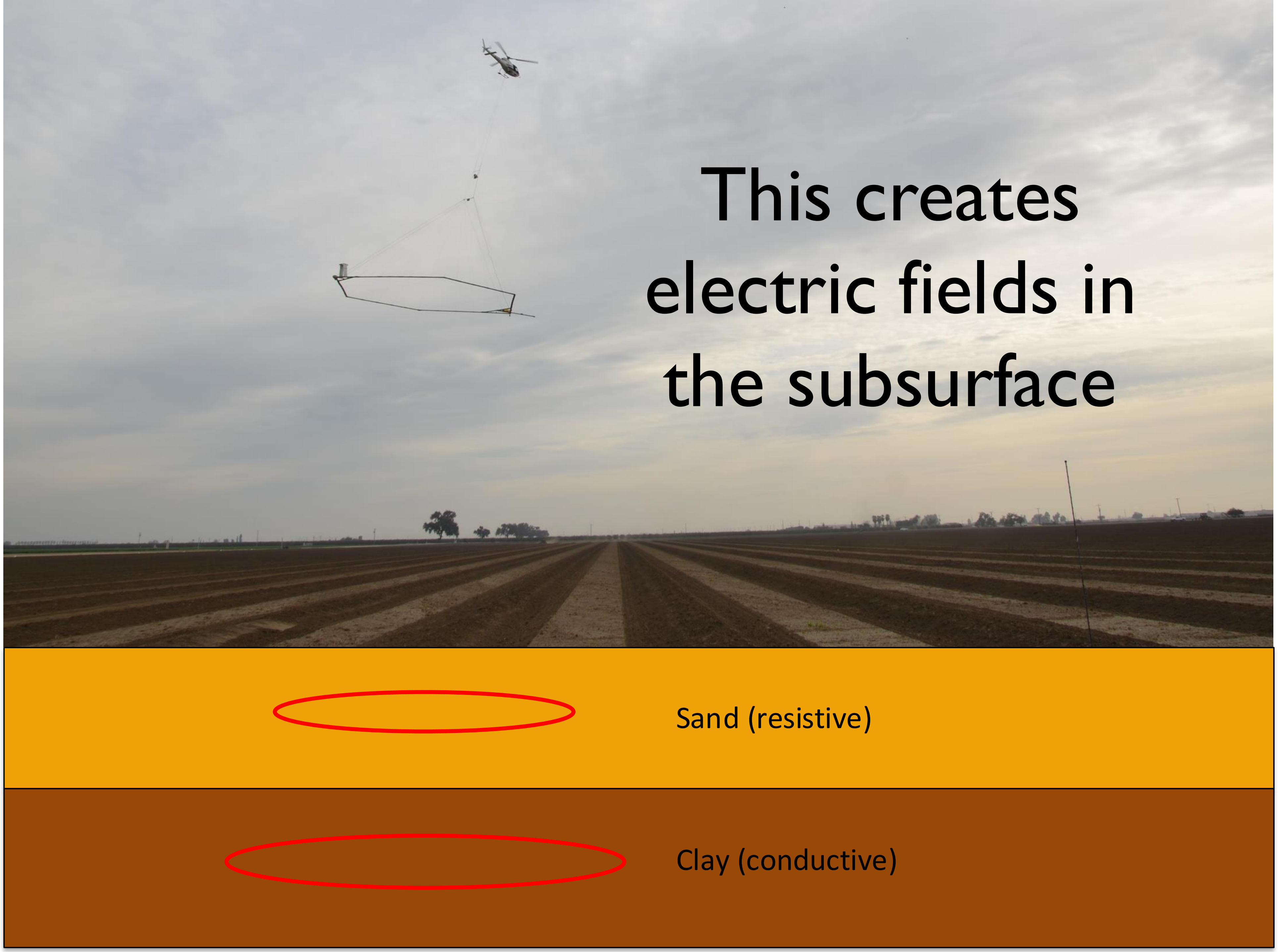
- Overview: what is AEM?
- Best practices for using AEM for groundwater characterization
- Methodology used in the Indian Wells Valley
- Implications for groundwater model

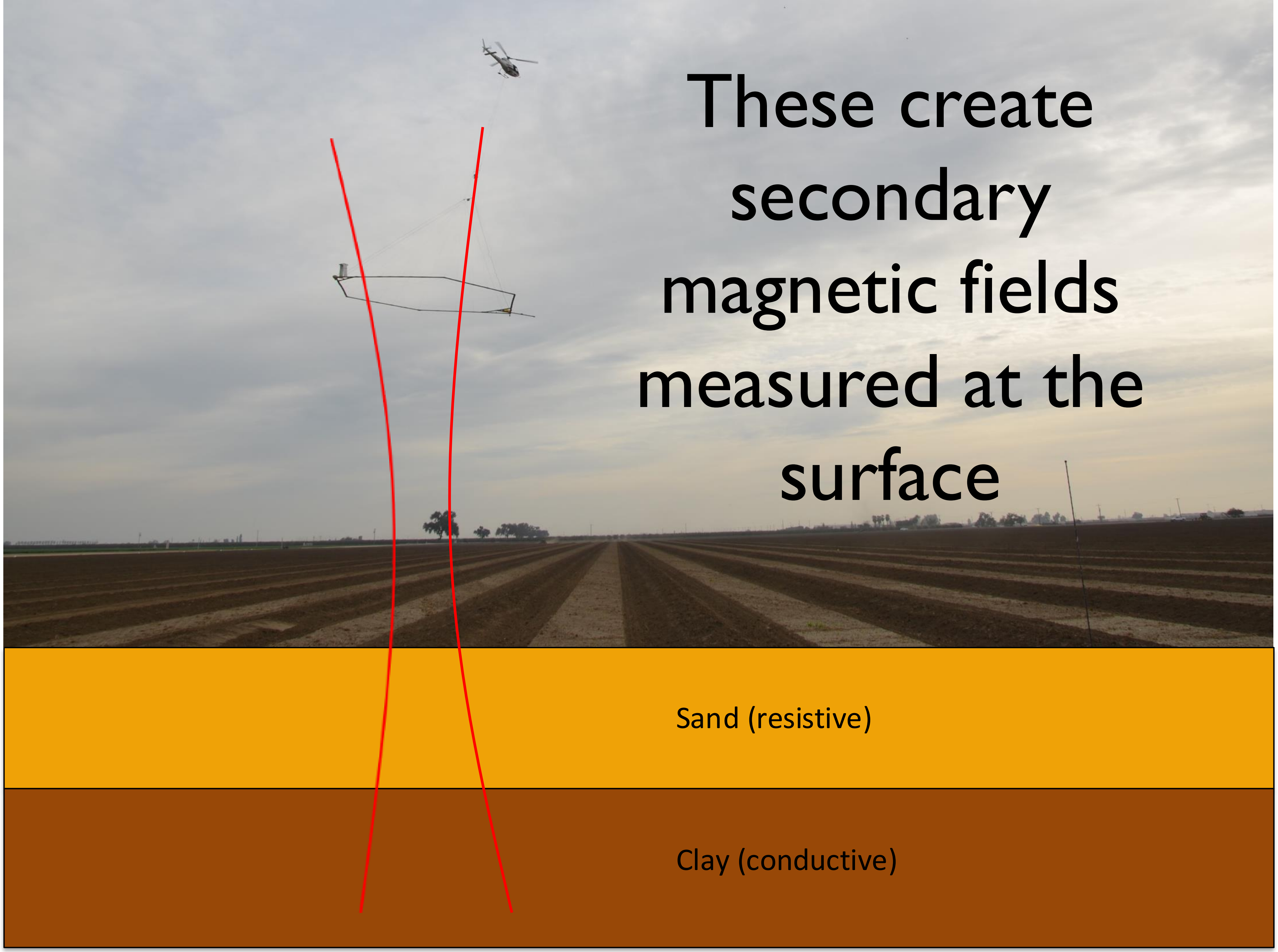

AEM Stands for
Airborne
ElectroMagnetics
SkyTEM is a company that
acquires AEM data

The electromagnetic signal is a function of electrical properties of the subsurface

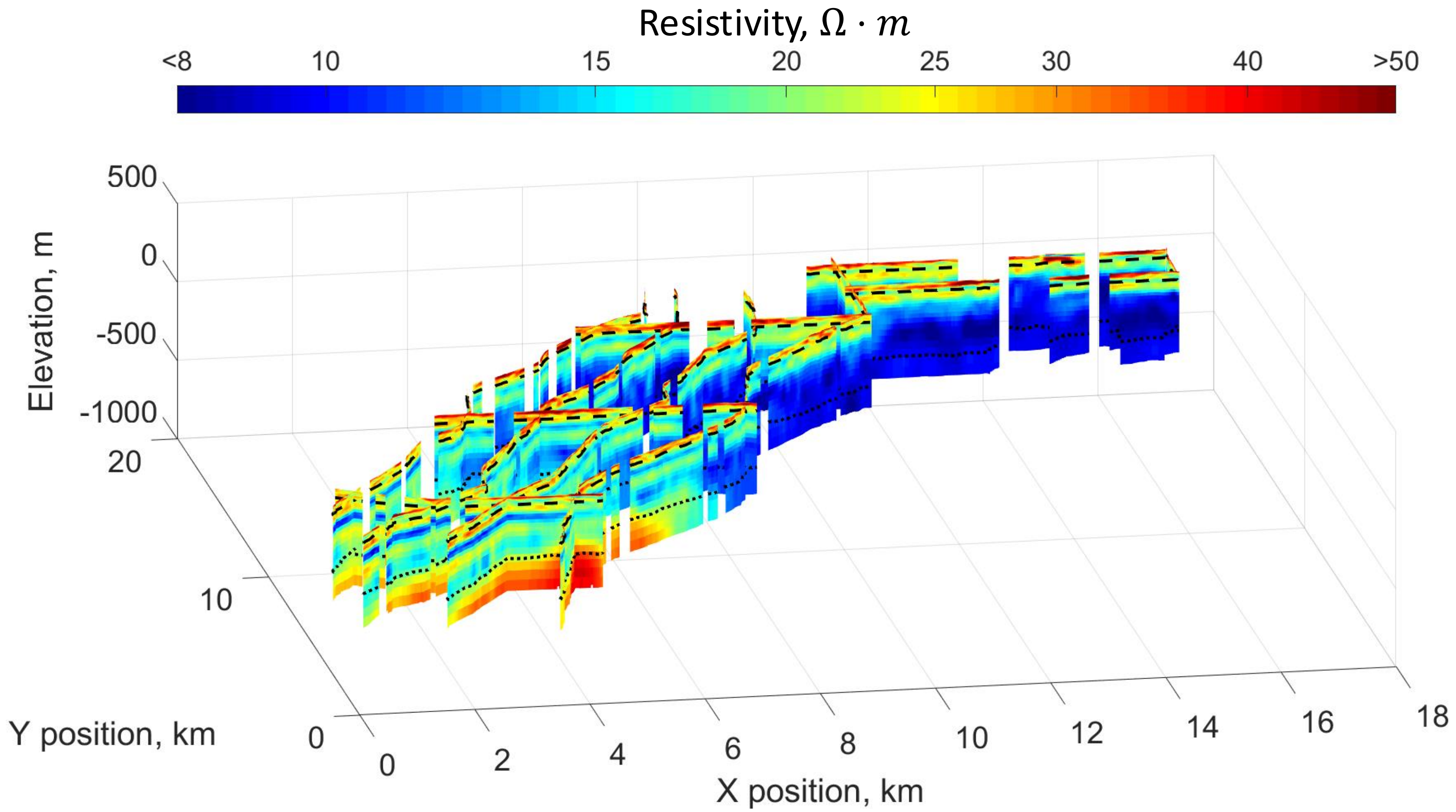



First, the loop creates a primary magnetic field
Sand (resistive)
Clay (conductive)


This creates electric fields in the subsurface
Sand (resistive)
Clay (conductive)


These create secondary magnetic fields measured at the surface
Sand (resistive)
Clay (conductive)

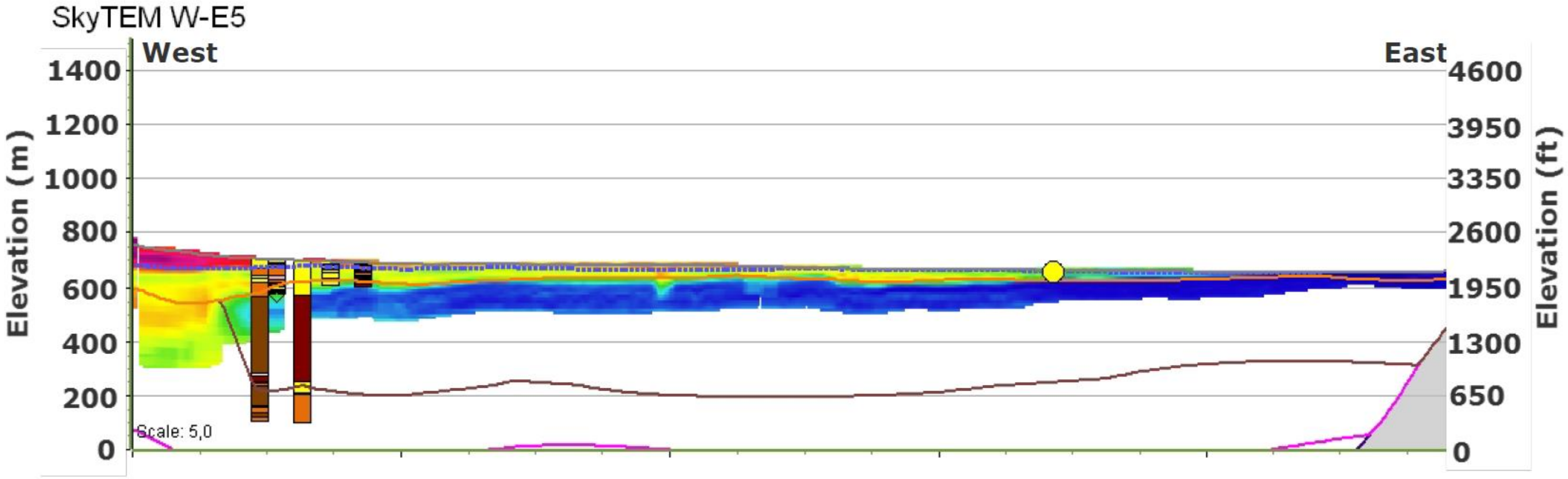
Inverting the Data Gives Resistivity Cross-sections



Knight et al. (Groundwater, 2018)

How Deep Can it See?

- In resistive settings, up to 500 m.
- In conductive settings, as low as 50 m.



Appendix 1, Ramboll (2019)

What can resistivity of the subsurface tell us?

- Many factors affect the resistivity of the subsurface. The following cause a *reduction* in resistivity:
  - Saturation (i.e. water table)
  - Salinity
  - Presence of clay
- The following cause an *increase* in resistivity:
  - Unsaturated materials
  - Sands, gravels and most bedrock
  - If saturated, water with fewer dissolved solids is much more resistive

Best practices for using AEM for groundwater characterization

- How can we relate electrical properties (the output of AEM studies) to aquifer properties and groundwater models? Best practices:
  - Rock physics transform by comparing AEM outputs to lithology from wells
  - Inform conceptual model of aquifer system
  - Delineate groundwater model layers
  - Best when done with an integrated team that includes a geophysicist, geologist and groundwater modeler

Overview of Reports Referenced in this Presentation

- Ramboll (2019): original report on interpreted geology from AEM data in Indian Wells Valley
- Kang and Knight (2020): Stanford group report on rock physics transform over Indian Wells Valley
- Rybarski and Bacon (2025): Desert Research Institute report on groundwater model update over Indian Wells Valley, used in 5-year review of GSP

What is a rock physics transform?

- A rock physics transform relates the property measured by AEM—resistivity—to lithology (sand, clay, bedrock)
- This is done by comparing resistivity to lithology at areas with co-located data (well logs near AEM acquisitions)

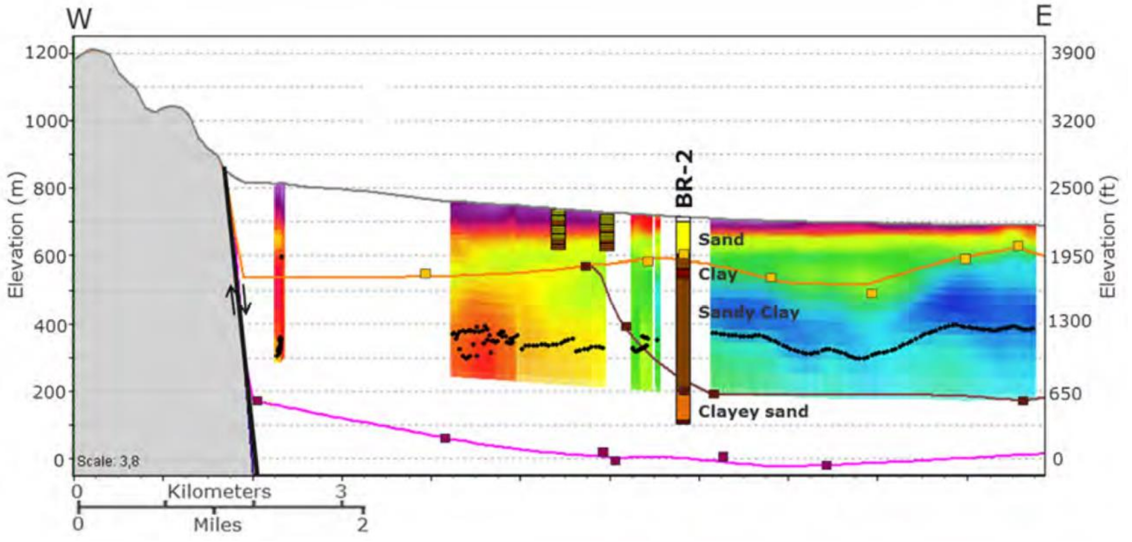


Figure 4-6, Ramboll, 2019

Rock physics transform—challenges

- In simple areas where the salinity of groundwater is low, you can sometimes set a single value as a threshold

  i.e. resistivity $< 15\ \Omega \cdot m$ is clay

  $> 15\ \Omega \cdot m$ is sand

- Areas with salinity are more complex, and the resistivities representing sand and clay vary across the region
- Important to consider both AEM and well data in analysis

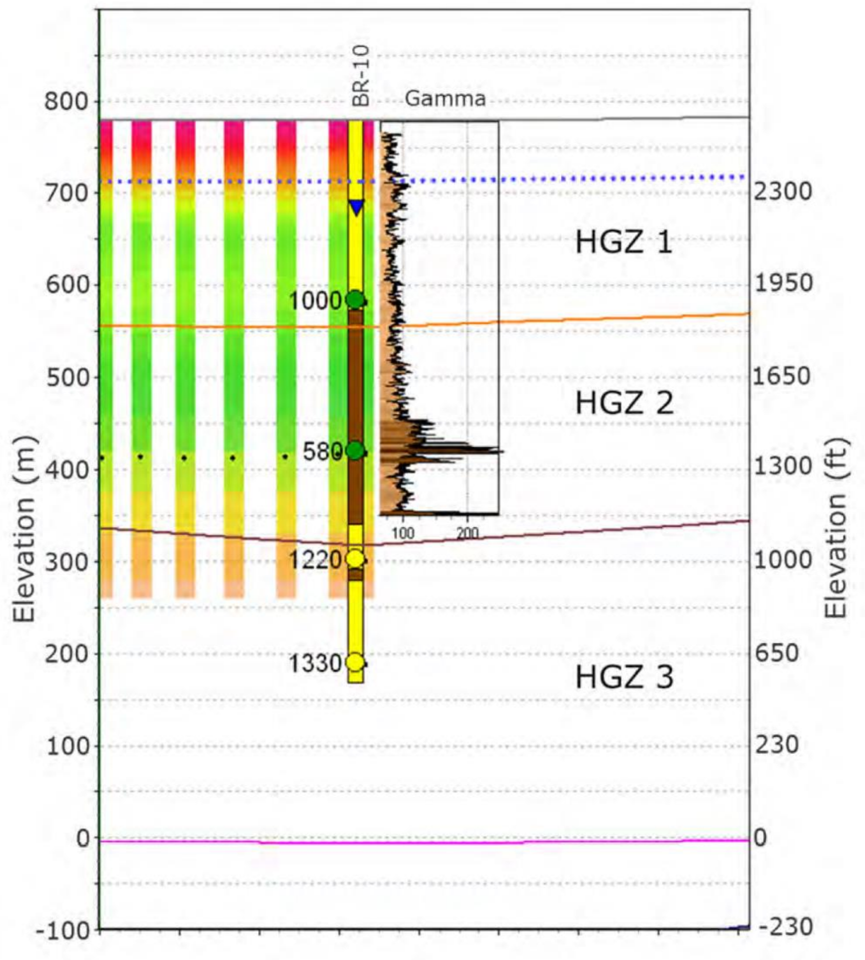


Figure 4-7, Ramboll, 2019

Previous Studies in Indian Wells Valley

- Kang and Knight (2020) produced an Indian Wells Valley Uncertainty Report relating the AEM data to lithology based on well lithology and water salinity data using the Waxman-Smits model (1986)

$$\sigma = F^{-1}(\sigma_f + Q_v B)$$

σ – bulk conductivity of saturated sediment (i.e. values for rock physics transform)

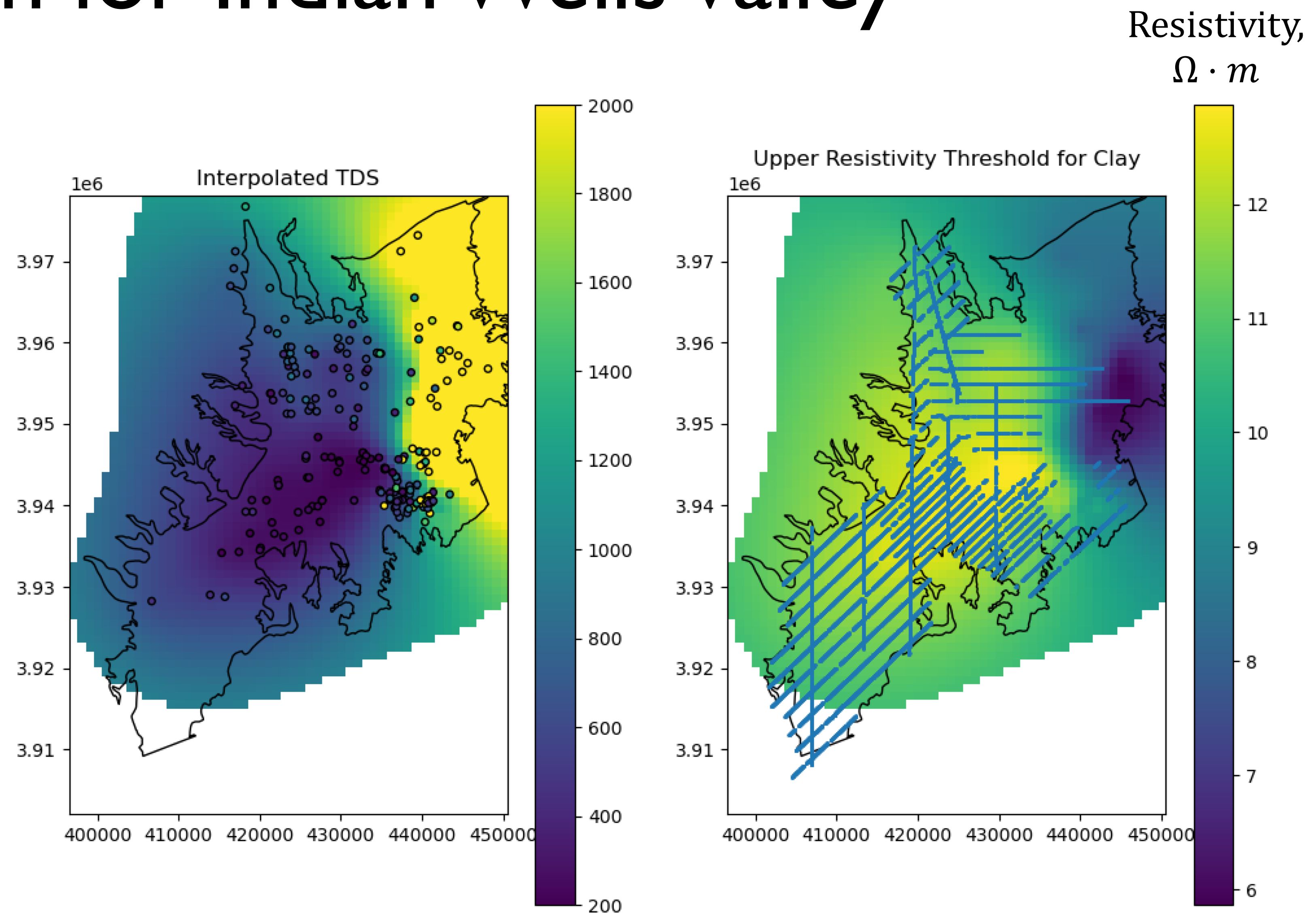
F – formation factor

σ_f – fluid conductivity

$Q_v B$ – represents the additional electrical conductivity from the clay

Approach for Indian Wells Valley

- The approach we used built on the Kang and Knight (2020) and Ramboll (2019) reports
- Defined resistivity thresholds for clay that varied regionally based on TDS



This Process Was Used to Map Subsurface Clay in the Valley

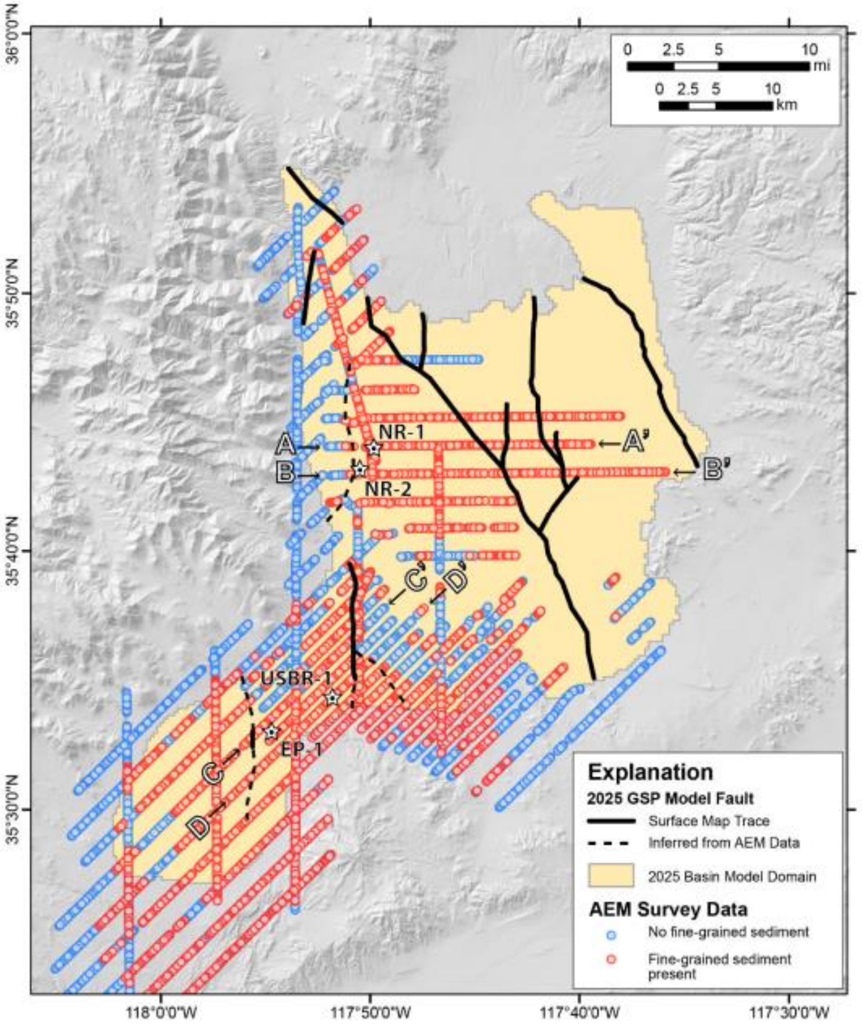
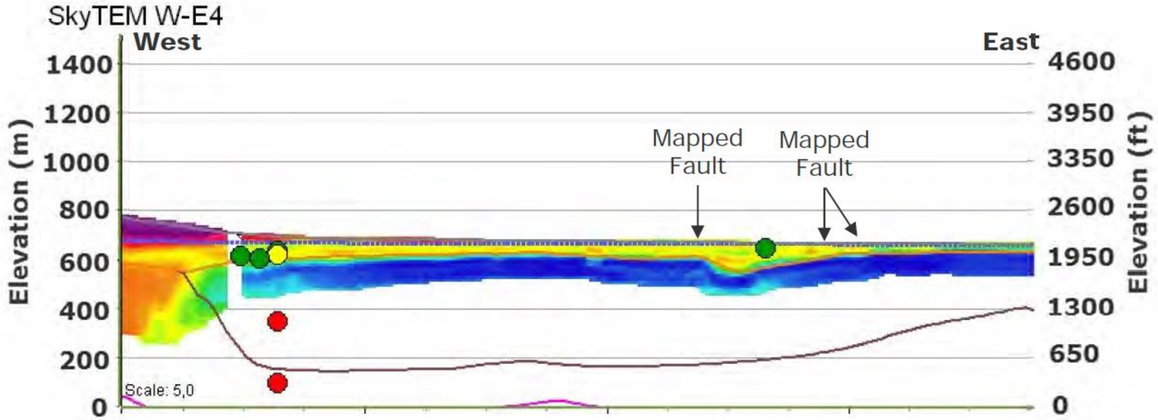


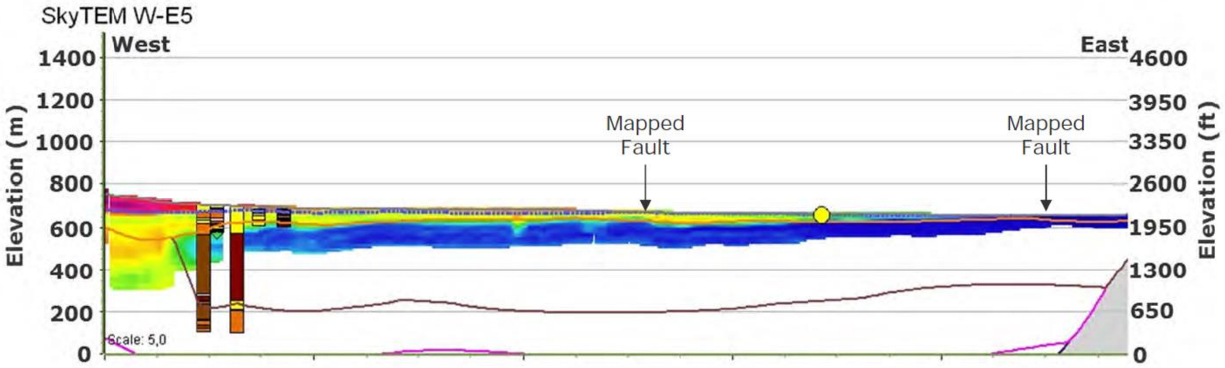
Figure 3-2, Rybarski and Bacon (2025)

Using AEM to Improve Conceptual Understanding

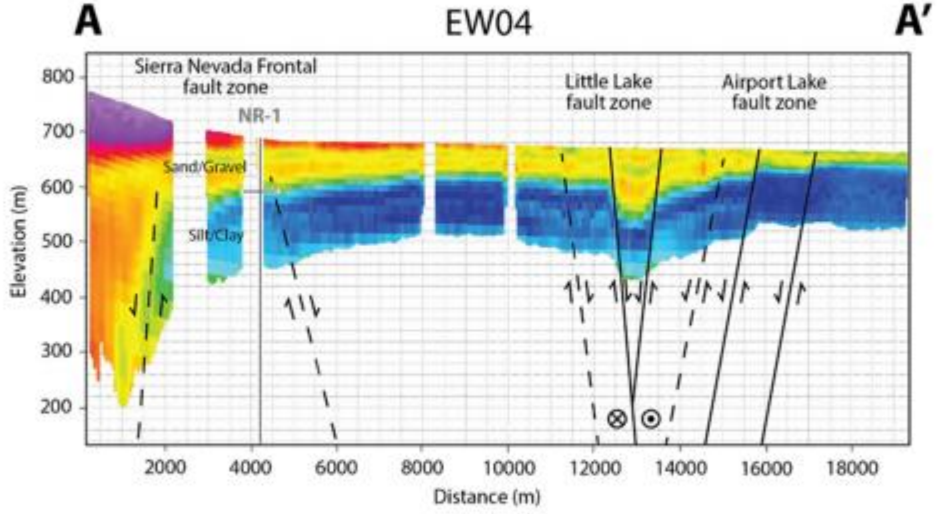
- Groundwater models are impacted by choices such as placement of faults and depth of key layers that hold and transmit groundwater in the subsurface
- AEM data can enhance information on this due to its high spatial resolution

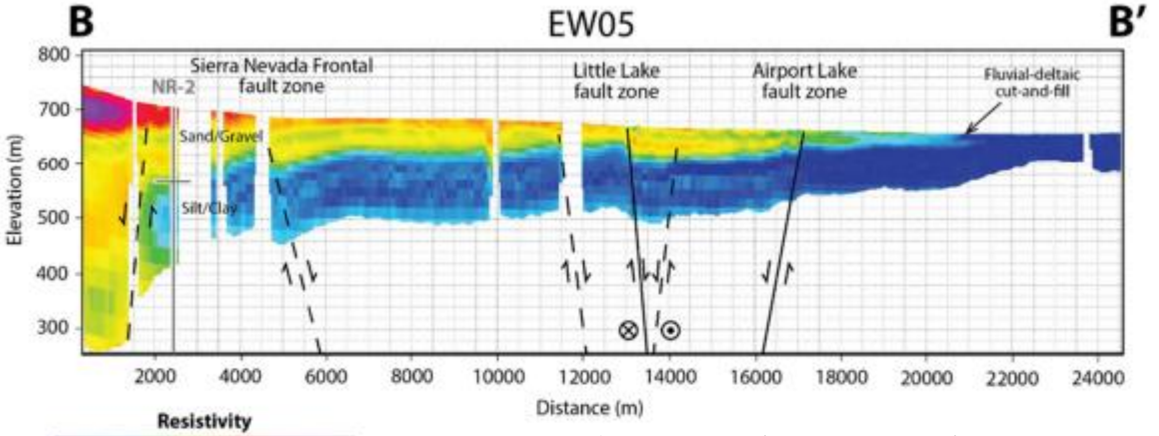
AEM Data Were Used to Map Known and Previously Unknown Faults

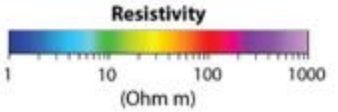




Appendix 1, Ramboll (2019)

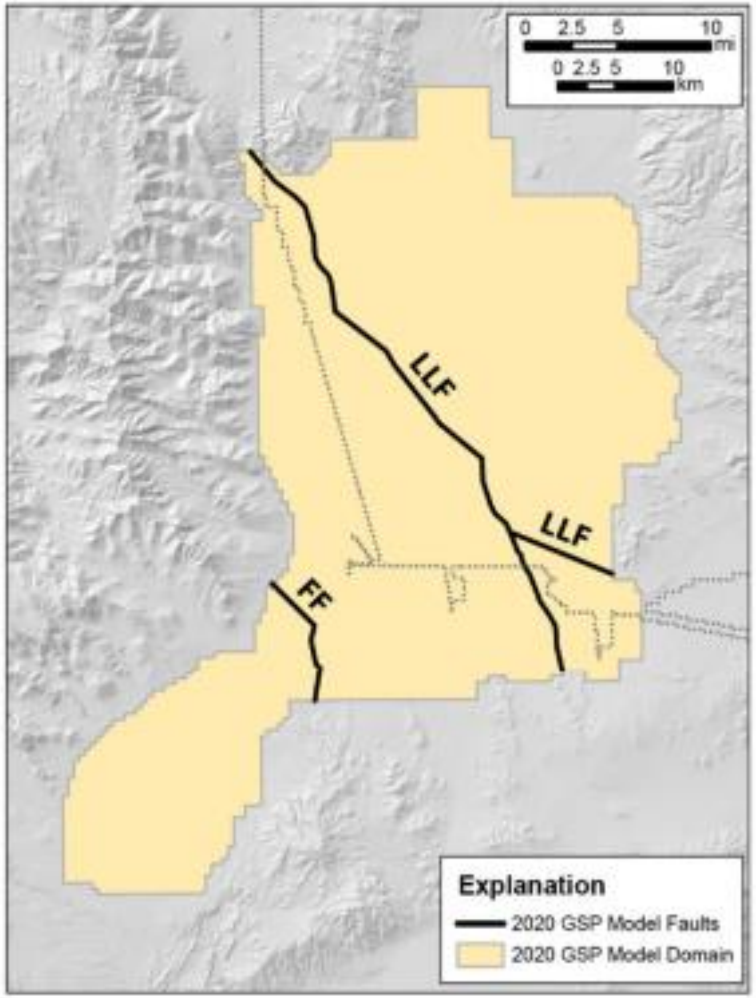






IWV-GA Groundwater Model
Figure 3-3, Rybarski and Bacon (2025)

AEM Data Were Used to Map Known and Previously Unknown Faults



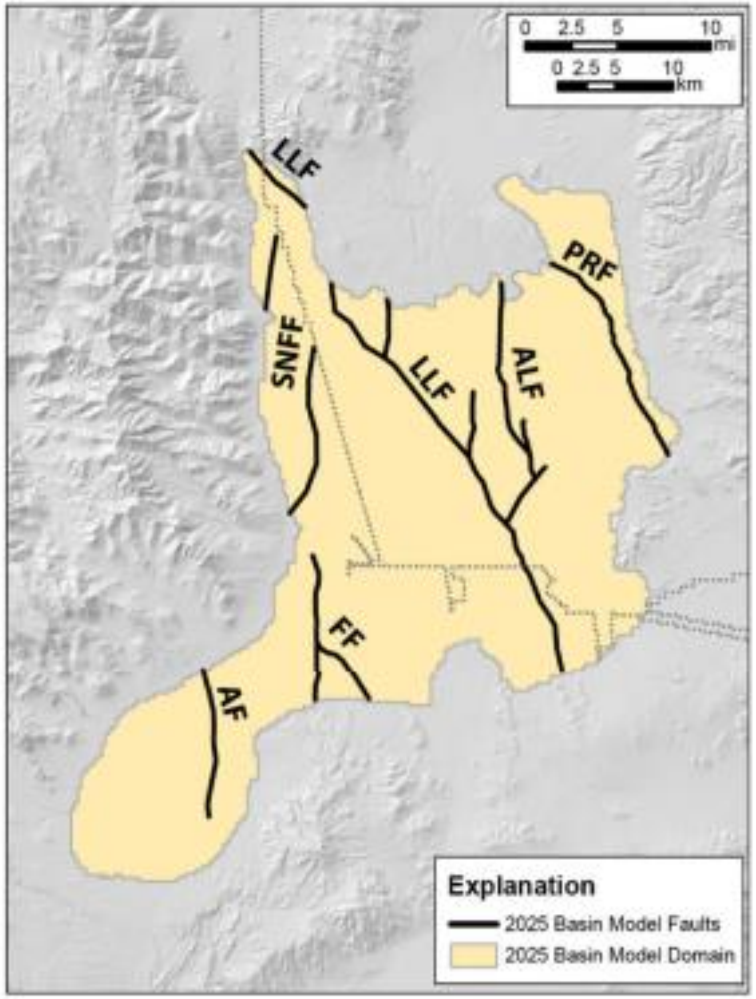


Figure 3-5, Rybarski and Bacon (2025)

AEM Data Were Then Used to Inform Model Zones

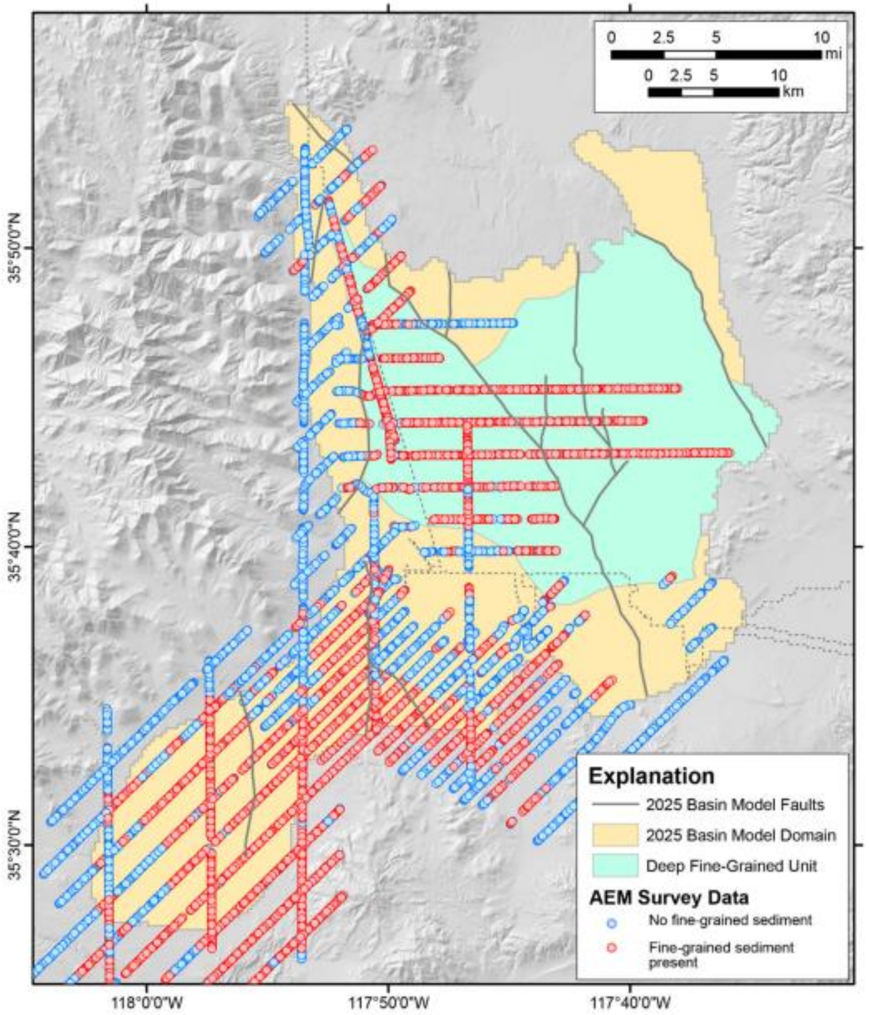


Figure 3-6, Rybarski and Bacon (2025)

AEM Data Were Then Used to Inform Model Zones

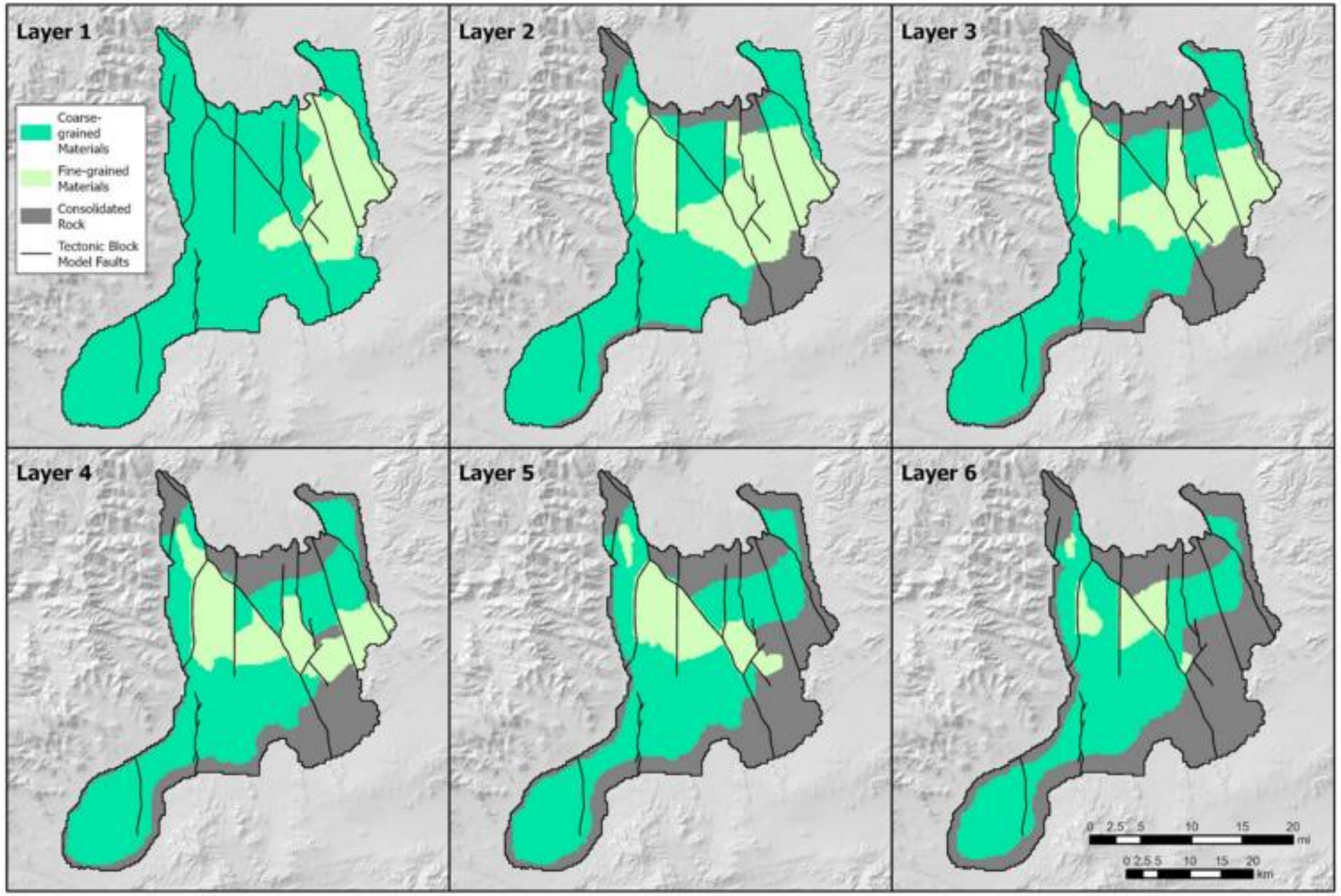


Figure 5-5, Rybarski and Bacon (2025)

These Model Layers Defined Unique Zones of Hydraulic Conductivity, a Key Driver of Model Behavior

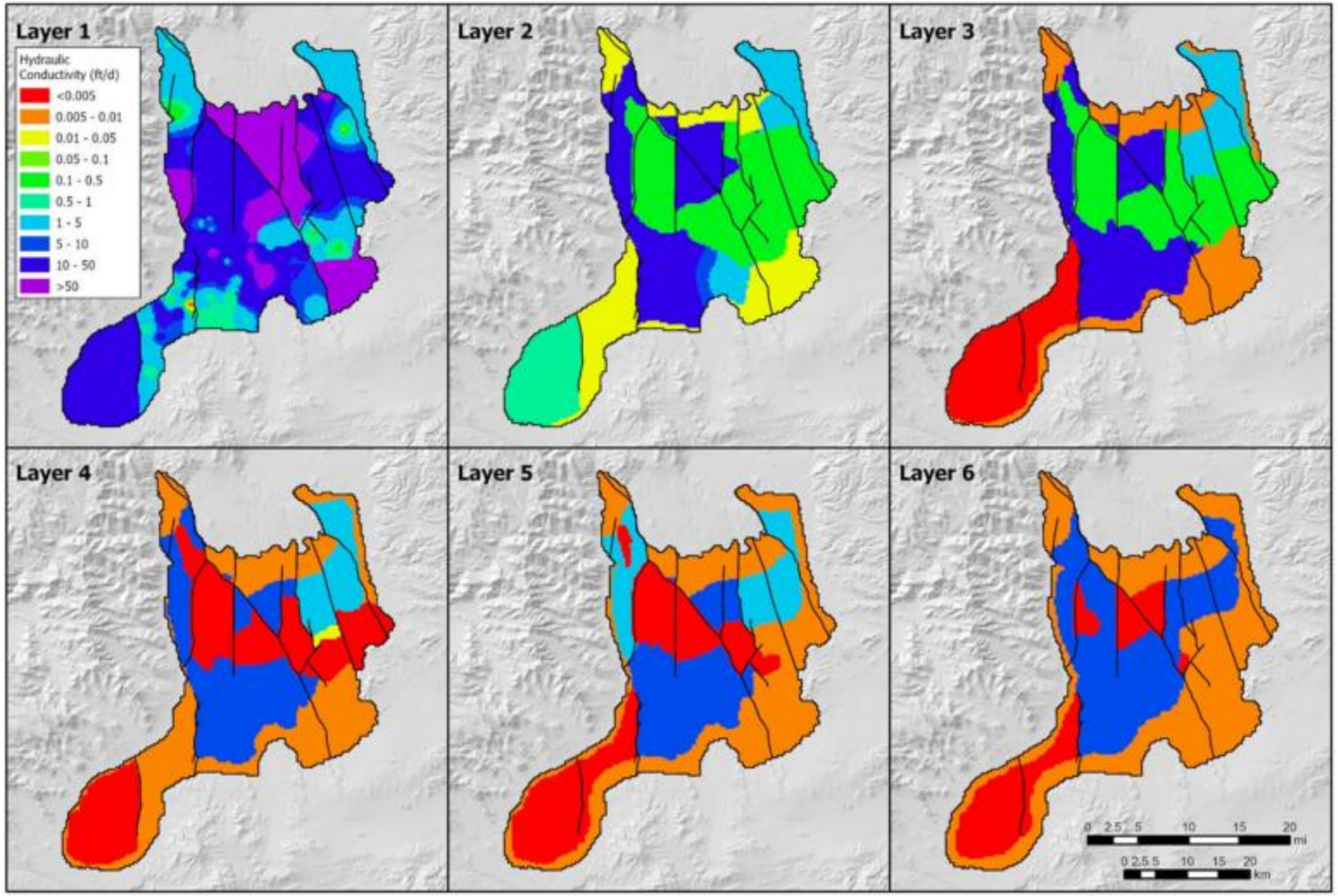


Figure 5-8, Rybarski and Bacon (2025)

This Approach Is Similar to that Used in Other Groundwater Models that Used AEM Data

USGS
science for a changing world

Water Availability and Use Science Program

Simulating Groundwater Flow in the Mississippi Alluvial Plain with a Focus on the Mississippi Delta

Leaf et al. (2023)

Subsurface Properties

Aquifer hydraulic conductivity and storage properties were represented structurally in the MERAS 3 and Mississippi Delta models at multiple scales using a blend of the conceptual models produced by the AEM survey by Minsley and others (2021) and the original MERAS framework by Hart and others (2008). In both models, aquifer properties were represented at the coarsest level using piecewise-constant zones based on the logarithmically binned electrical resistivity facies classes by Minsley and others (2021). In the MERAS 3 model, electrical

Summary

- AEM data provide a valuable dataset for extending lithology estimates beyond what is available from well data
  - They are most effective when used in conjunction with high-quality lithology data
  - One key strength of AEM is in mapping clays due to the resistivity contrast with other materials and importance of clays in groundwater models
- AEM data were used to map the presence of clay in the Indian Wells Valley
- AEM data were also used to improve upon existing fault maps and delineate new faults
- The clay and fault maps were then used to define distinct layers in the groundwater model
- The methodology used by Rybarski and Bacon in the 2025 GSP Model follows best practices, and is similar to other AEM modeling efforts (Leaf et al., 2023)