Organized in cooperation with

Long term monitoring of low moisture and flux conditions in the vadose zone using multiple geophysical methods

November 14, 2023

Dory Linneman and Chris Strickland

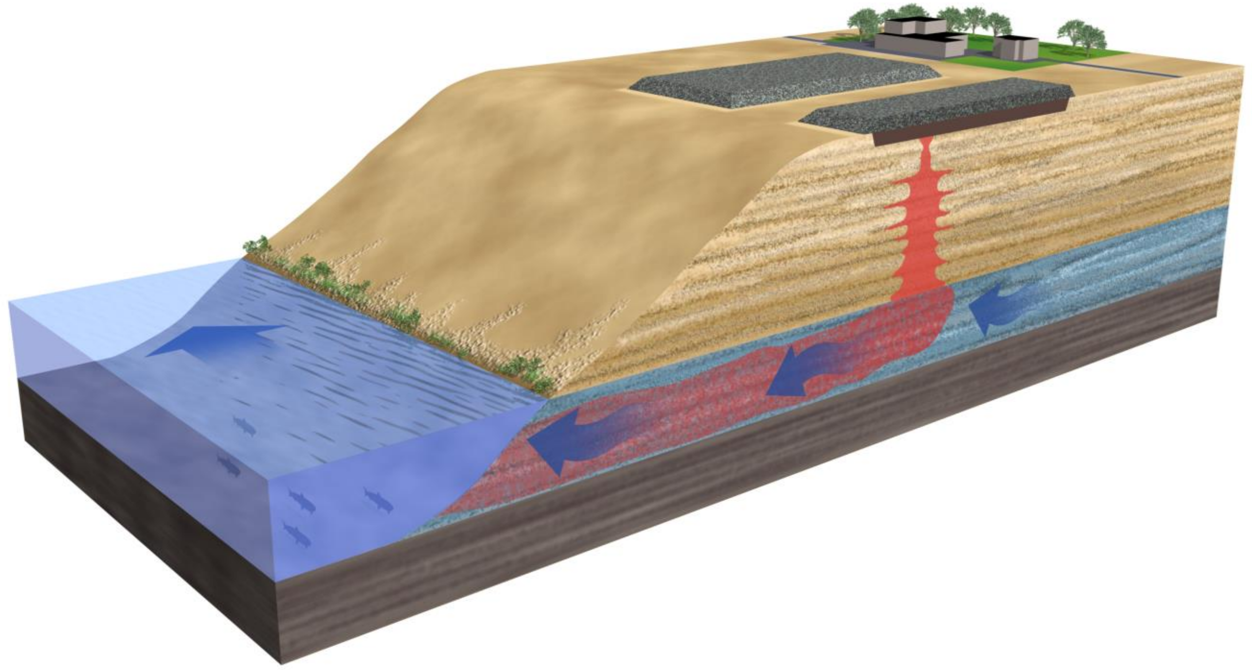
2023 Global Summit
on Environmental Remediation
@REMPLEX

PNNL is operated by Battelle for the U.S. Department of Energy

2023 Global Summit

Background

- Contaminants located in the deep vadose zone (DVZ) flow toward the water table contributing to groundwater plume
- Contaminant flux in the DVZ is often difficult to quantify both in space and time
- In arid (or desiccated) sites, water flux can be very low but high enough to produce unacceptably high contaminant flux



Vadose Zone Contaminant Flux Measurement

- DVZ water and contaminant flux can be measured using several approaches
- Each have advantages and limitations
- Water and/or contaminant flux can be estimated using geophysical methods.
- Two approaches will be presented here: electrical resistivity and seismic velocity

2023
Global
Summit

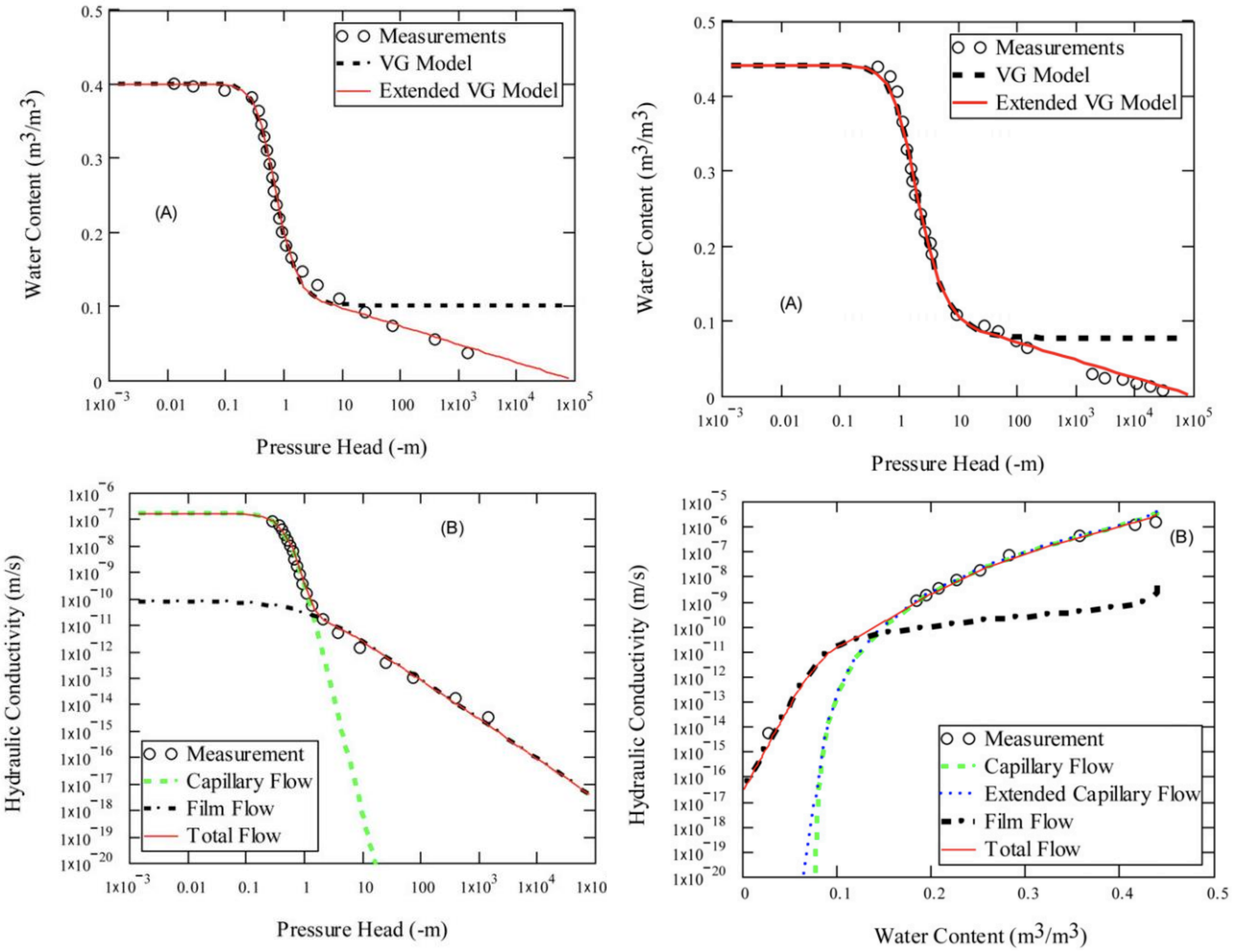
Unsaturated Hydraulic Properties

- Hydraulic conductivity depends on moisture conditions (water content or potential) in variably saturated porous media
- The water retention curve defines the relationship between water content and water pressure/potential
- Unsaturated water flux is dependent on moisture conditions
- Flux can be inferred if both unsaturated hydraulic conductivity and water pressure/potential gradients are known

2023 Global Summit

Unsaturated Hydraulic Conductivity

- Under dry conditions, extended water retention and hydraulic conductivity models must be used



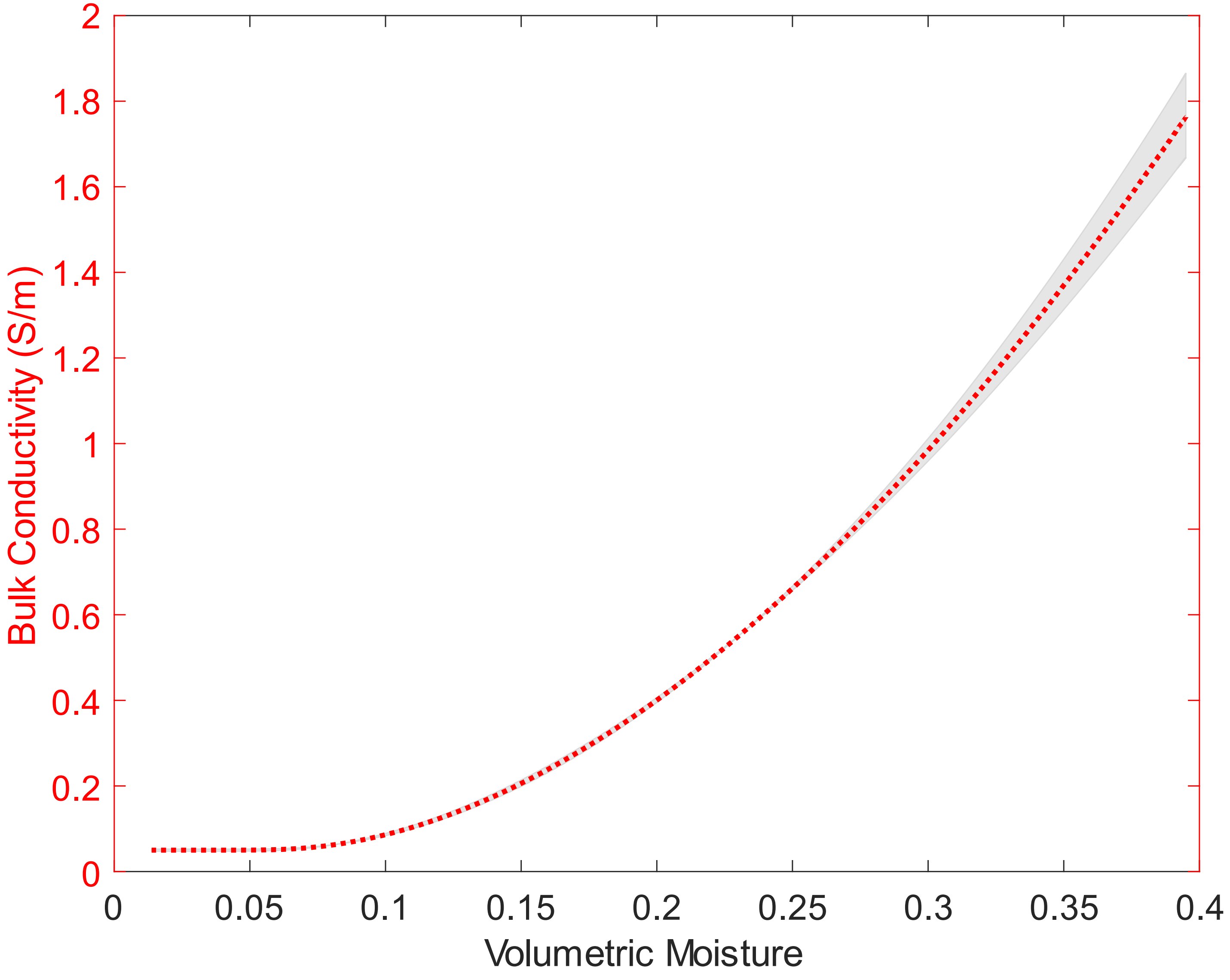
From Zhang 2011

Geophysical Estimation of Hydraulic Conditions

- Geophysical methods are sensitive to water content, water potential, or both along with other parameters
- Geophysics can then be used to estimate moisture conditions and unsaturated hydraulic conductivity
- An additional benefit is that geophysical methods can provide the spatial distribution of hydraulic properties and their spatial gradients.
- Geophysics derived pressure/potential gradients and unsaturated hydraulic conductivity can then be used together to estimate water flux

Electrical Conductivity

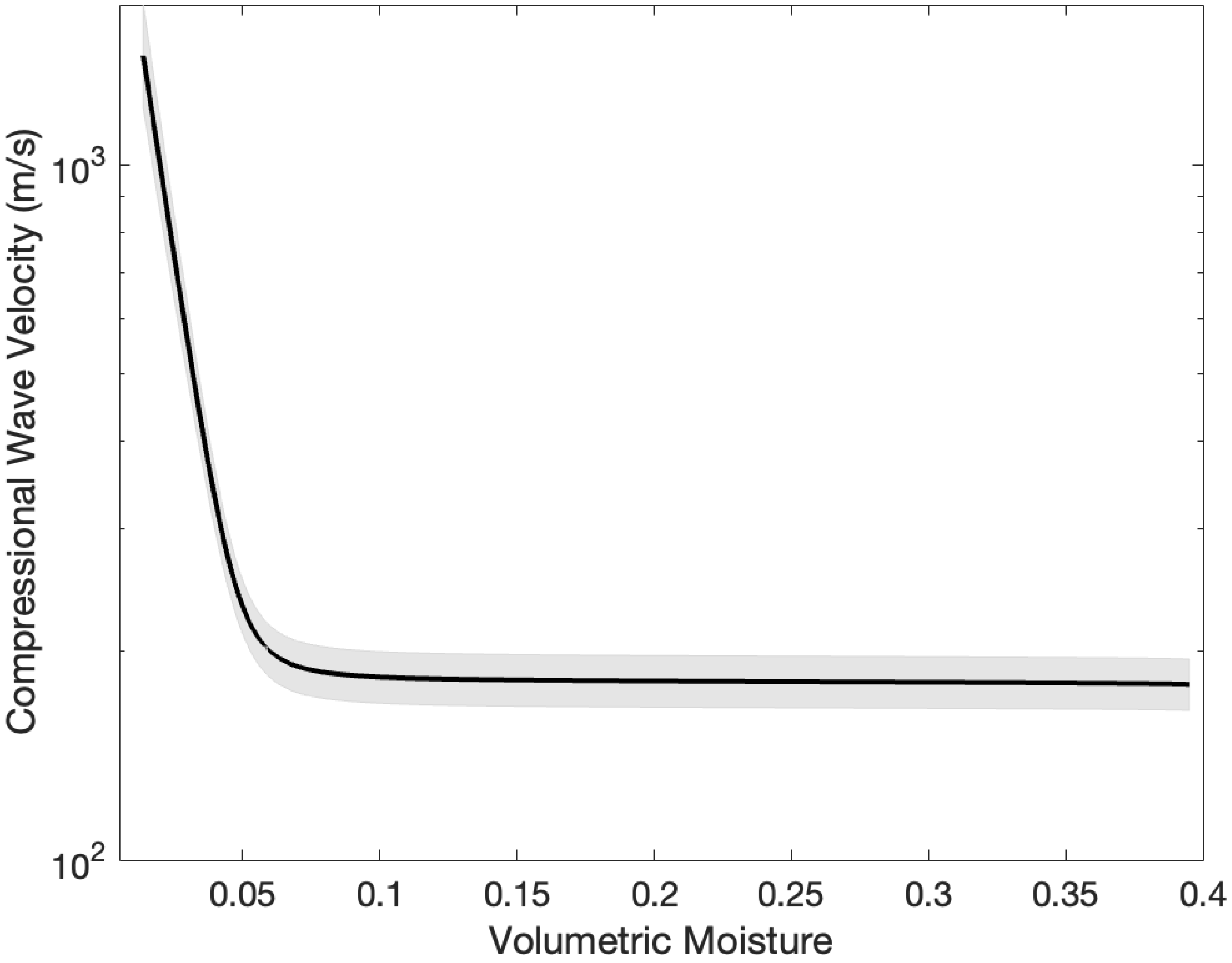
- Archie's law is commonly used to relate saturation to EC
- Assuming typical parameterization for Hanford-like sediments, sensitivity (slope) decreases as moisture content decreases



2023 Global Summit

Seismic

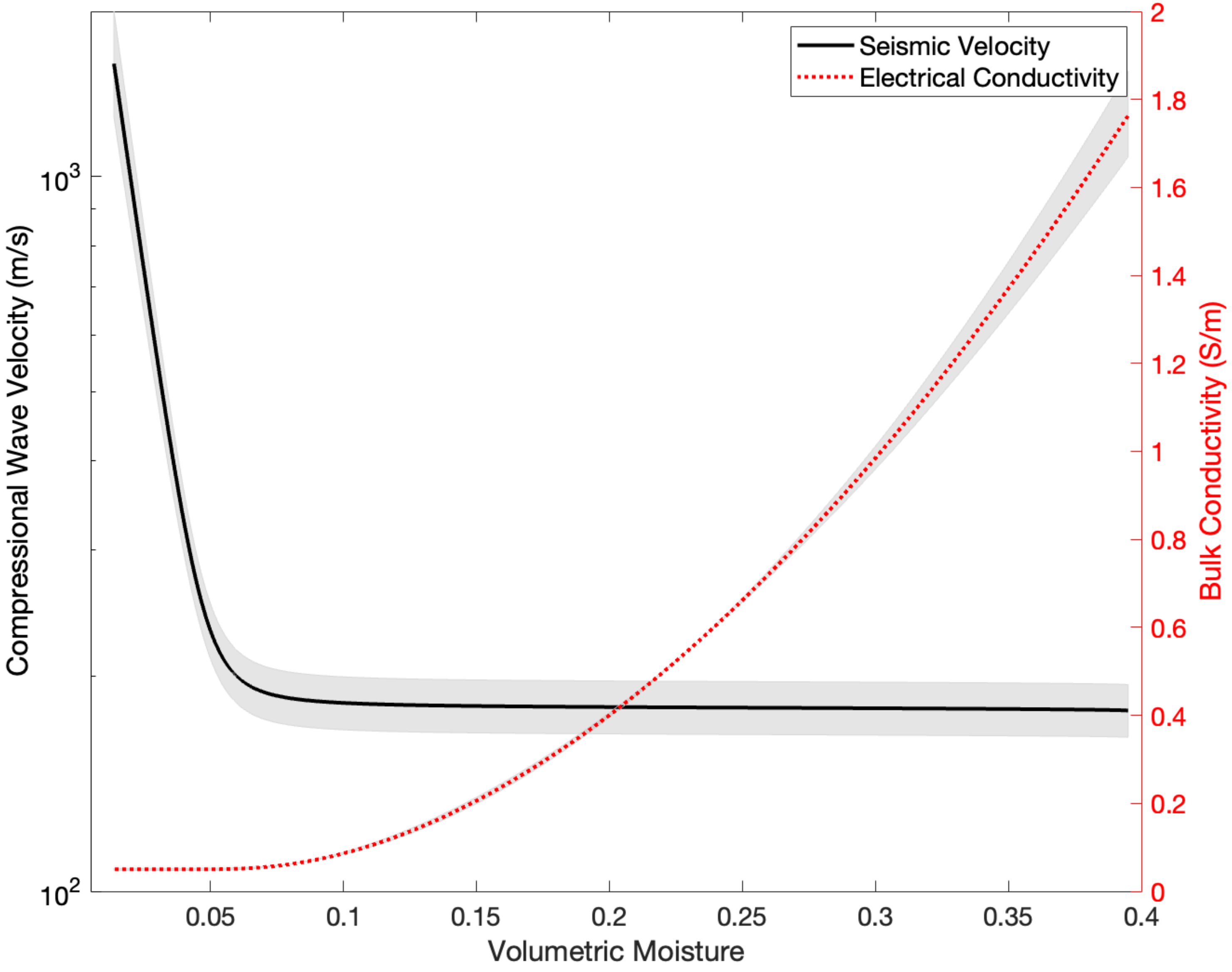
- Seismic velocity is dependent on effective stress state
- One component of effective stress is water potential
- Seismic velocity (and water potential) magnitude increases as moisture content decreases



2023 Global Summit

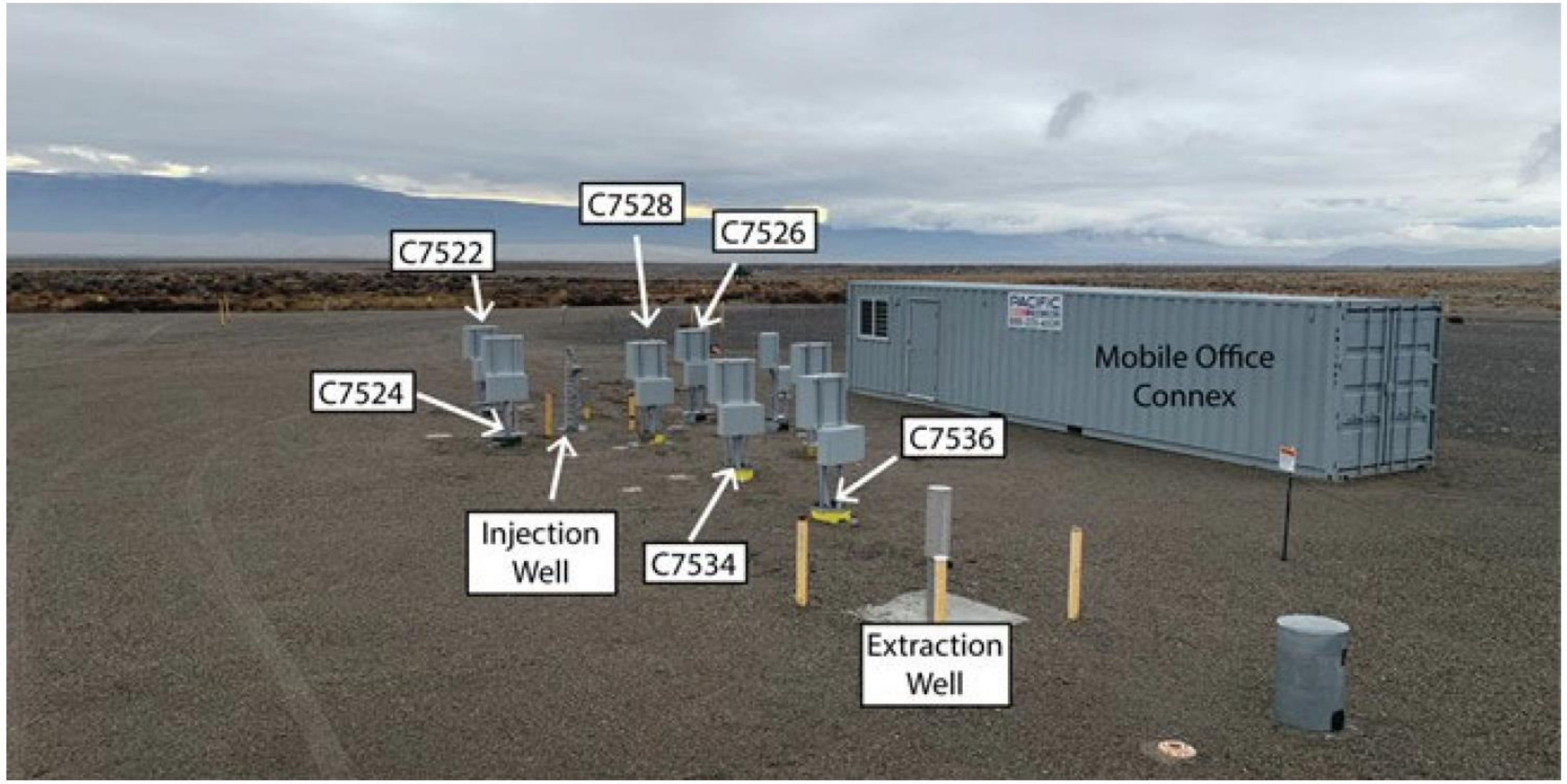
Sensitivity

- EC is more sensitive (slope) to MC changes as MC increases
- Vp is more sensitive to MC changes as MC decreases



Field Testing

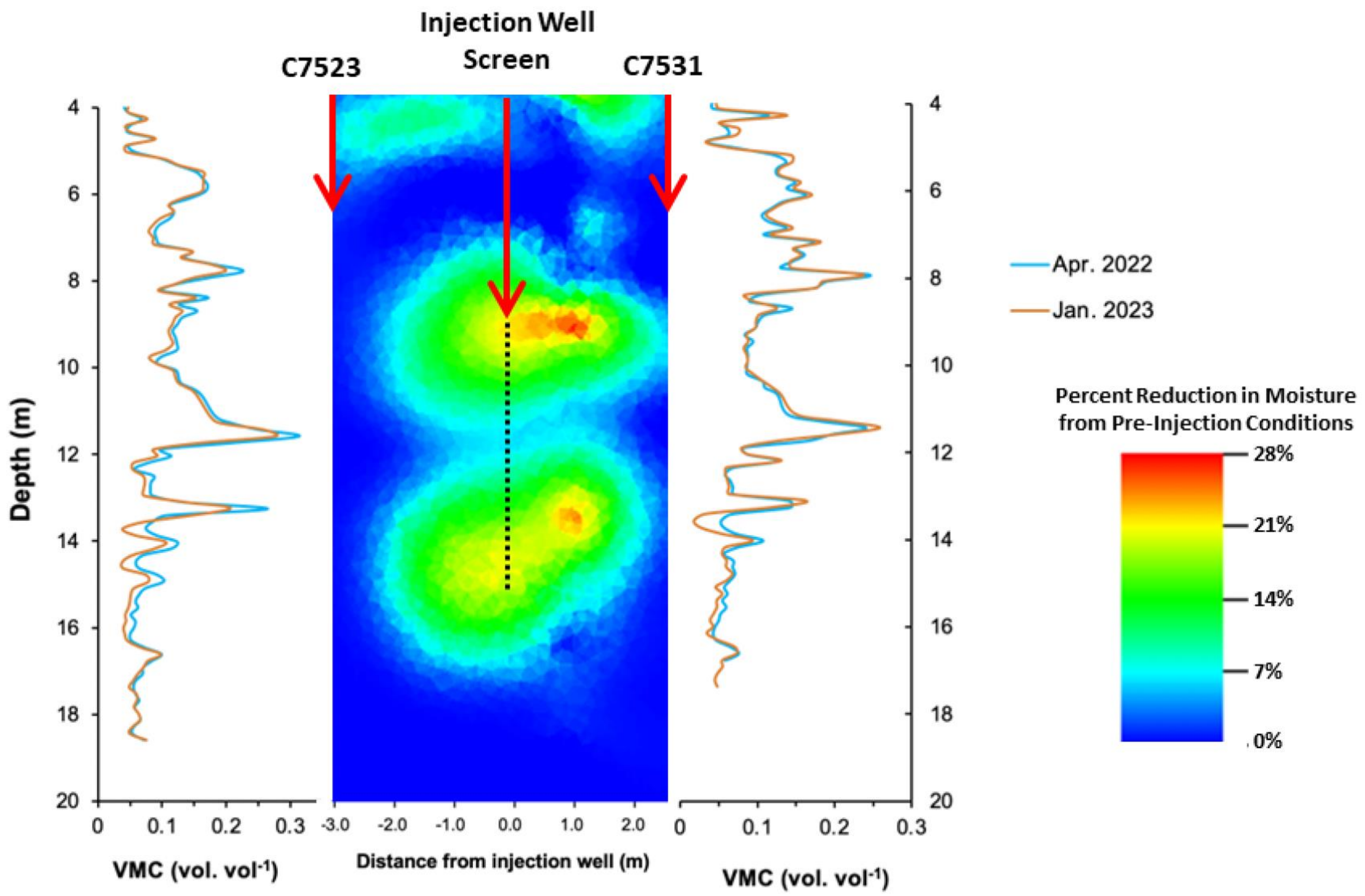
- A desiccation injection test was recently performed to evaluate the utility of geophysical methods for monitoring/characterizing deep vadose zone remedies
- Reoccupied former treatability test bed at Hanford BC Cribs and Trenches



2023 Global Summit

ERT Field Test Results

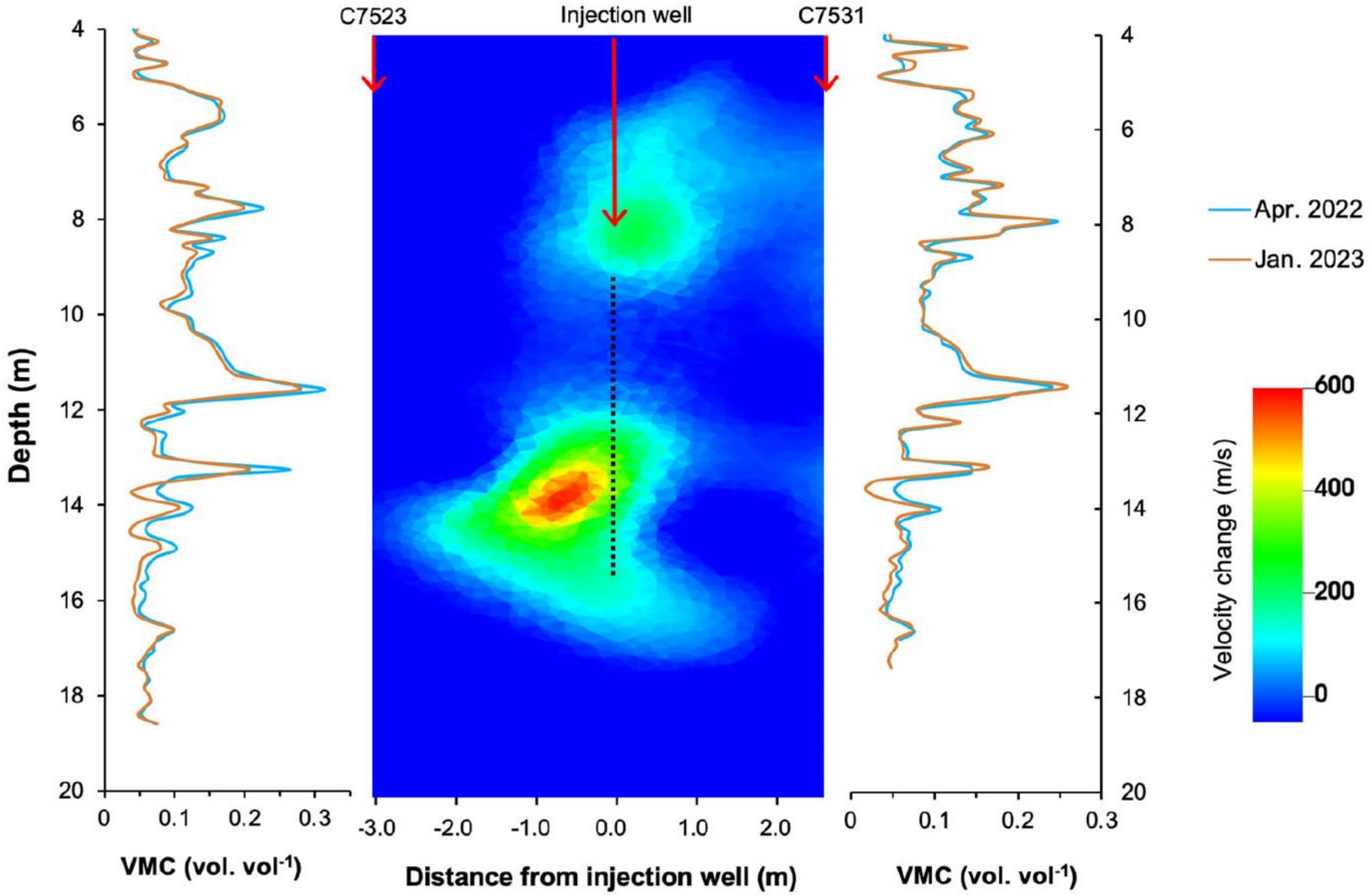
- Drying zone is clearly observed
- Two diffuse lobes above and below low permeability layer



2023 Global Summit

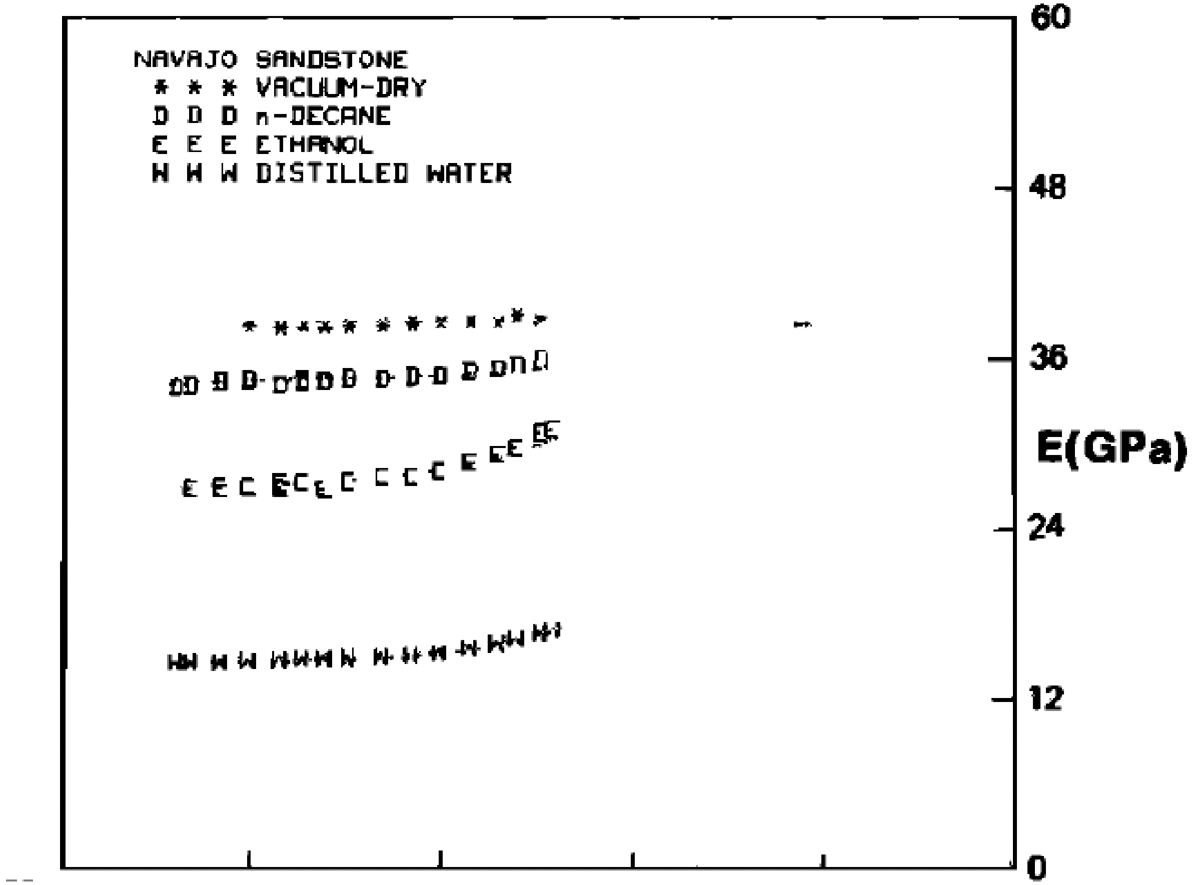
Seismic Field Test Results

- Seismic velocity changes are consistent with dry conditions
- Smaller in size than ERT



Next steps: Impacts of Fluid Properties

- Just like water, other fluids adsorbed at the solid surface create seismic changes
- Fluid salinity also affects ERT responses
- Fluid chemistry is important



From Spencer 1981

Amendment Delivery

- Fluid chemistry impacts both seismic and electrical responses, both saturated and unsaturated conditions
- Geophysical methods can be used to indirectly image amendment delivery
- Each method has different response and can potentially be combined to reduce uncertainties

Conclusions

- Both electrical conductivity and seismic velocity changes can be used to observe changes in moisture conditions
- Changes can be used to estimate unsaturated hydraulic properties and their spatial distributions
- Methods can be combined to improve parameter estimates over the entire moisture range from bone dry to saturated
- Recent advancements in hydrogeophysical inversion offer potential for quantifying water and contaminant flux from a combination of geophysical and traditional measurements

2023
Global
Summit

Acknowledgements

- The material presented here is the composite effort from many great researchers that include:
  - Tim Johnson
  - Dana Sirota
  - Parker Sprinkle
  - James Knox
  - Mike Truex