

Coupled Hydrogeophysical Modeling to Characterize Unsaturated Soil Properties Within an Aquifer Recharge Site

Hypothesis or Scientific Gap

Accurate characterization of unsaturated soil hydraulic properties within active recharge basins remains a significant challenge due to spatial heterogeneity and measurement limitations. The most common approaches to determining these parameters result in lab scale results that must be upscaled to estimate field conditions. This introduces a level of uncertainty in predictions of aquifer recharge and flow through the vadose zone. This gap limits our ability to reliably model groundwater movement and optimize managed aquifer recharge sites. We hypothesize that time-domain electromagnetic (TDEM) surveys, integrated within a coupled hydrogeophysical modeling, can directly constrain field-scale unsaturated hydraulic properties. By testing this hypothesis in a controlled recharge environment, this study will evaluate whether TDEM-derived resistivity data can meaningfully improve estimates of vadose zone flow behavior at the field scale. Establishing this capability would provide a non-invasive method for characterizing recharge systems and informing water-resource management decisions.

Scientific & Societal Value

While TDEM and coupled hydrogeophysical modeling have been applied at a small scale, few have used unmanned aircraft system (UAS) based TDEM surveys to characterize van Genuchten properties at the field-scale during transient flow conditions. Demonstrating that UAS-TDEM can be used to resolve hydraulic properties would provide a non-invasive method of parameter estimation beyond point-scale measurement. This will further the scientific field by providing an understanding of how geophysical signals respond to changes within the vadose zone, and evaluating if TDEM has the timescale and sensitivity to record accurate measurements during a transient state. Improving characterization of field-scale unsaturated flow directly supports groundwater sustainability, managed aquifer recharge optimization, and urban water planning. Minimally invasive monitoring tools reduce dependence on more intrusive and costly methods while improving spatial coverage for observation of both regional and urban groundwater issues.

Analysis Plan

Geophysical methods like (TDEM) surveys do not measure hydraulic properties directly. These measurements will provide electrical conductivity observations that must be interpreted through hydrologic relationships. To test the proposed hypothesis, field data will be collected using both a WalkTEM and a drone-based TDEM system to obtain soundings of an active recharge basin. Measurements will be taken over a “dry” basin and during controlled recharge events to capture transient changes in subsurface electrical resistivity associated with evolving moisture conditions. Raw TDEM data is collected and processed into a profile of resistivity with depth via inversion (fig 1). The resultant resistivity profile will then be converted to electrical conductivity and a forward model of unsaturated flow will be developed using Richards’ equation and related to volumetric water content to determine van Genuchten properties and describe soil-water retention and pore size distribution.

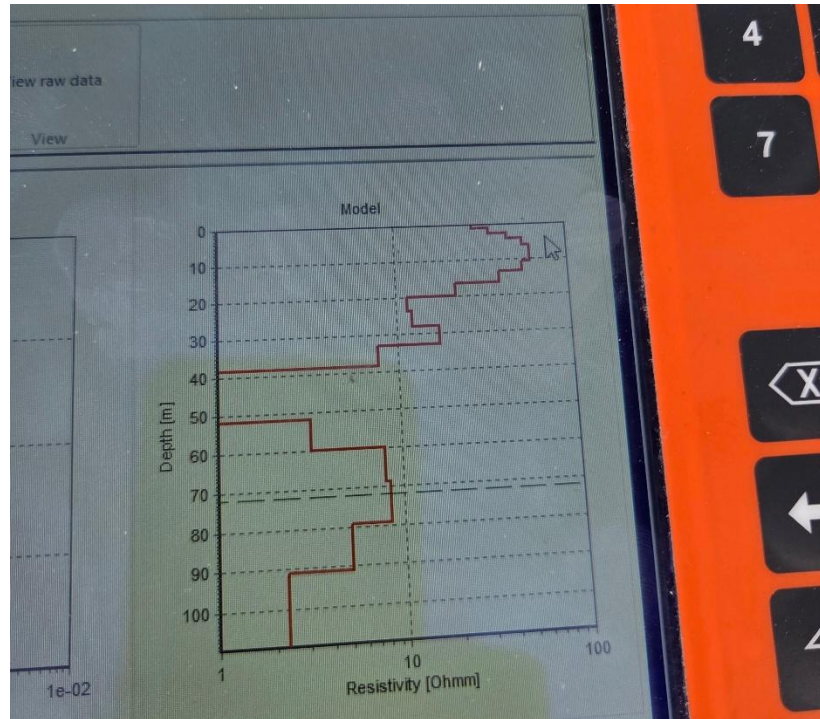


Figure 1: Image of a resistivity with depth profile from measurements of “dry” aquifer recharge basin.

Model performance will be evaluated using sensitivity analysis and uncertainty quantification to determine whether TDEM data provide sufficient temporal resolution and parameter identifiability under transient recharge conditions. This integrated hydrogeophysical method will directly assess whether field-scale TDEM measurements can reliably constrain unsaturated soil hydraulic properties without reliance on laboratory upscaling.

Timeline & Milestones (Timeline ~3months)

1. March: Collect field data (WalkTEM or DroneTEM elevated over basin)
 - a. Find extension for WalkTEM
 - b. Take WalkTEM back to sharp to test for elevated measurements
 - c. Measurements over an active infiltration basin
 - d. Learn about forward modeling and inversion
 - e. Extra: (Continued drone development?)
2. April: Forward modeling and inversion
 - a. Figure out how to apply forward modelling and inversion to collected data
 - b. Apply
 - c. Convert resistivity to electrical conductivity
3. May: Differentiate soils based on VG parameters
 - a. Use EC profile
 - b. Determine VG parameters based on measurements
4. June: Finalize/Write/Defend
 - a. Initial write
 - b. Rewrite