Investigating the Critical Shallow Vadose Zone: Modeling Water Flow Characteristics and Nitrate Transport with HYDRUS-1D Using Tensiometers

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Introduction

The critical zone is considered the ecological layer, extending from the vegetational surface to the vadose zone to the aquifer, which is vital to sustaining life, as it includes the implementation of cultivation and water resources for drinking or irrigation purposes (Field et al., 2016; Naylor et al., 2023).

Agriculture has been identified as a significant contributor to nitrate concentrations in the groundwater system due to the excessive application of nitrogen-rich manure and fertilizer (Foley et al., 2012; Puckett, 2016).

Water flow characteristics and soil properties influence solute transportation in the vadose zone. The transportation rate of a solute is described by the behavior of the wetting front and its preferential flow path. Understanding these factors is crucial to determining the solute's threat to the groundwater system.

Scope

The scope of the project is to contribute valuable information in hydrogeology, hydrology, environmental, and soil sciences for water flow and solute transport in the critical shallow vadose zone for a short-term water flux event. We aim to add valuable contributions from previously similar research topics for long-term precipitation events and information for agricultural management.

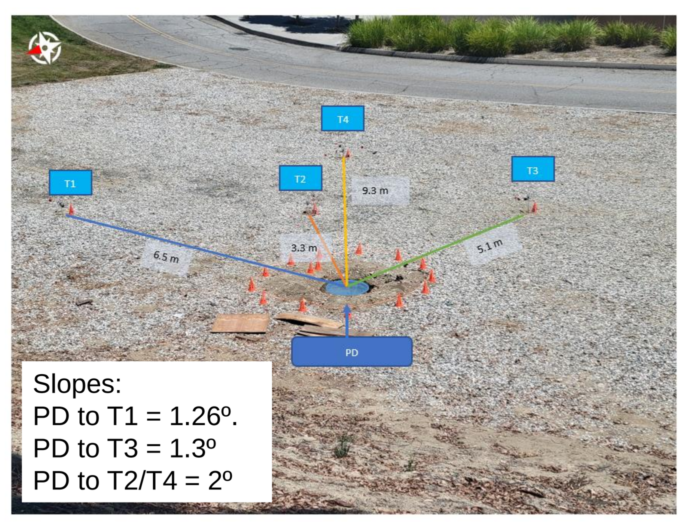
Objectives

1. Evaluate the behavior of the wetting front by investigating soil moisture, infiltration rate, soil matric potential, and porosity through field and lab work.
2. Assess transient properties and determine if the water flow models created by HYDRUS-1D could capture the processes and characteristics of the wetting front observed in the field study.
3. Assess solute transport model using water flow models and through the mechanisms of advection, dispersion, and diffusion.

Materials and Methods

FIELD AND LAB WORK OUTLINE

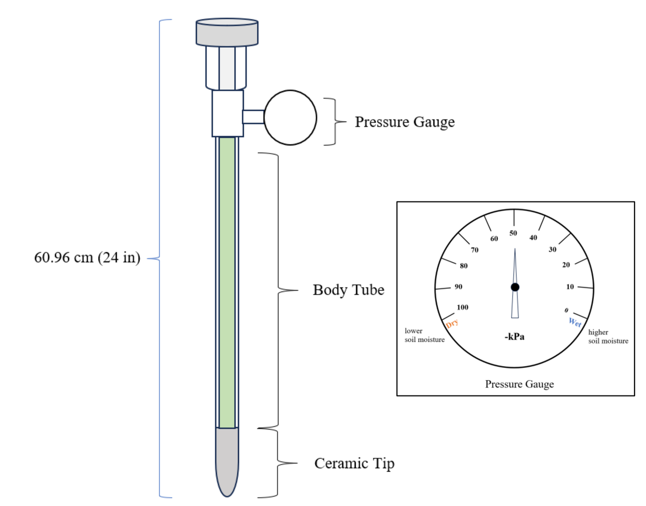
Phase one	Phase two	Phase three
Loss on ignition (LOI)	Loss on ignition (LOI)	Percolation test w/ manure
Percolation test	Percolation test	Nitrate grab samples: natural and contaminated
Soil sieving		



Study area

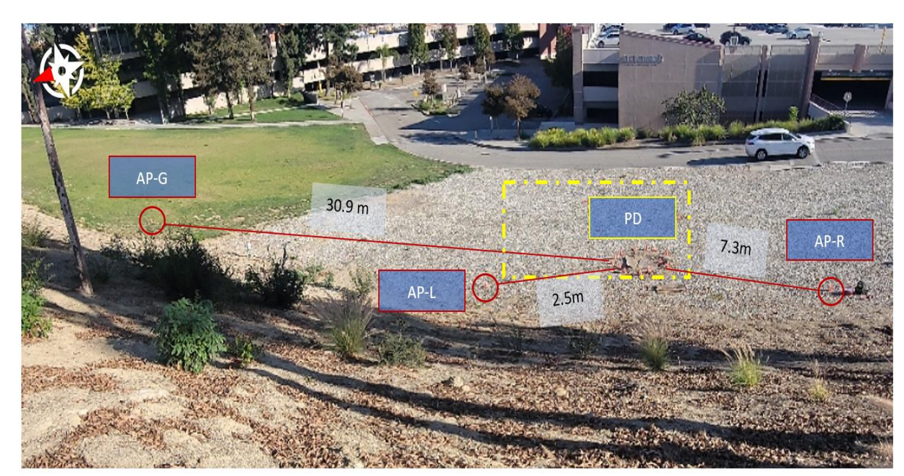
Percolation test

Pressure reading



Tensiometer diagram

Percolation test with manure added



Nitrate grab samples
(natural and contaminated) locations

Field blank sample of manure

Results

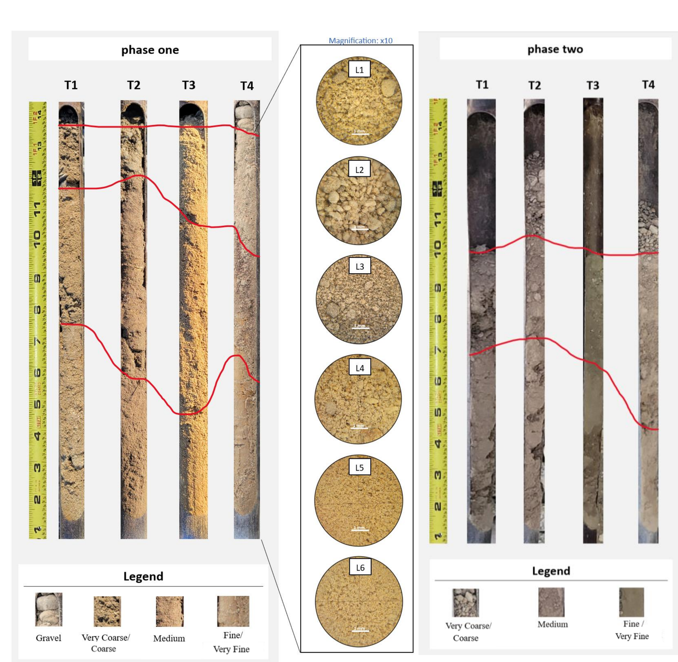


Figure 18. Soil distribution profiles for phase one and phase two. Layers (L1 to L6) from borehole site T4 represent the overall grain size distribution of the soil column. The material appears coarser near the surface and gets finer as we increase in depth.

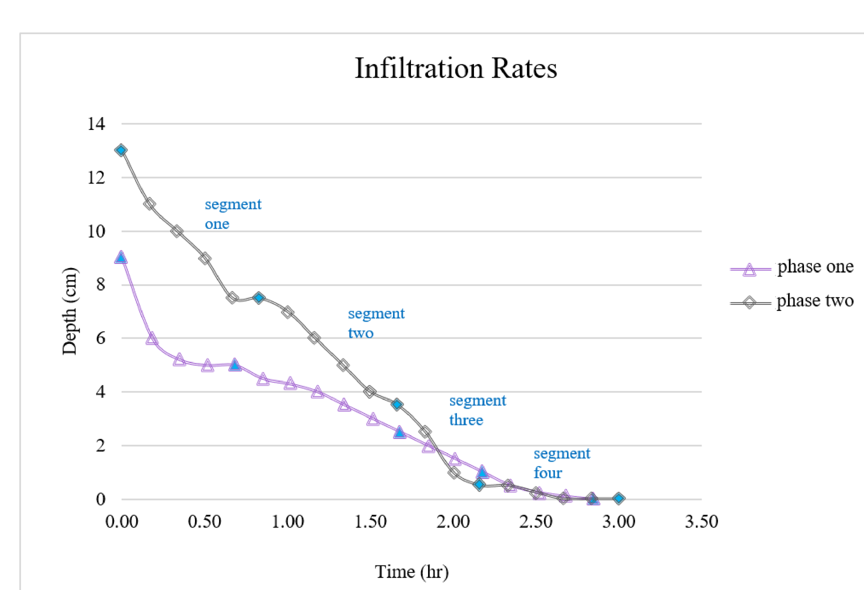


Figure 21. Infiltration rates for phase one and phase two. The data is segmented into four distinct sections. The blue points on the data trends segregate these sections.

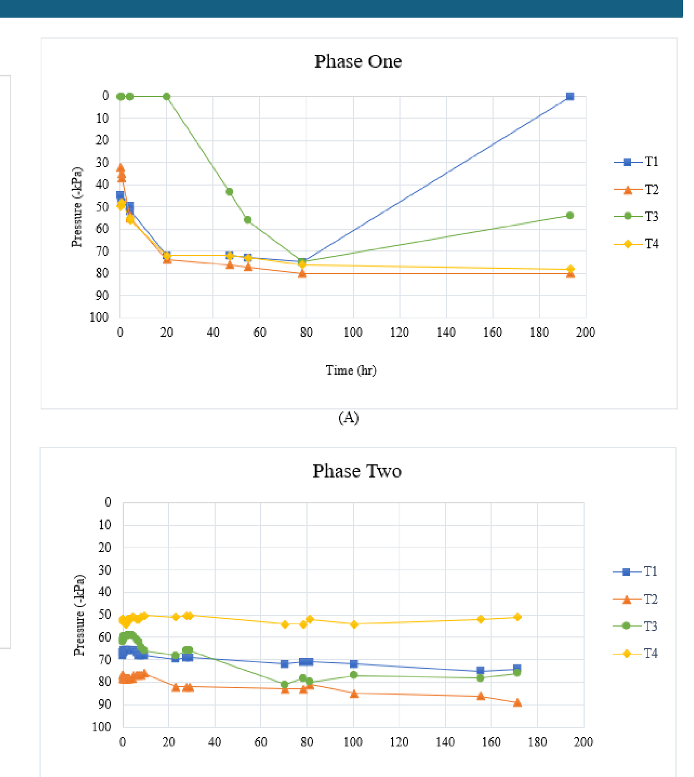


Figure 22. Recorded pressure (tension) readings for (A) phase one and (B) phase two.

Discussion

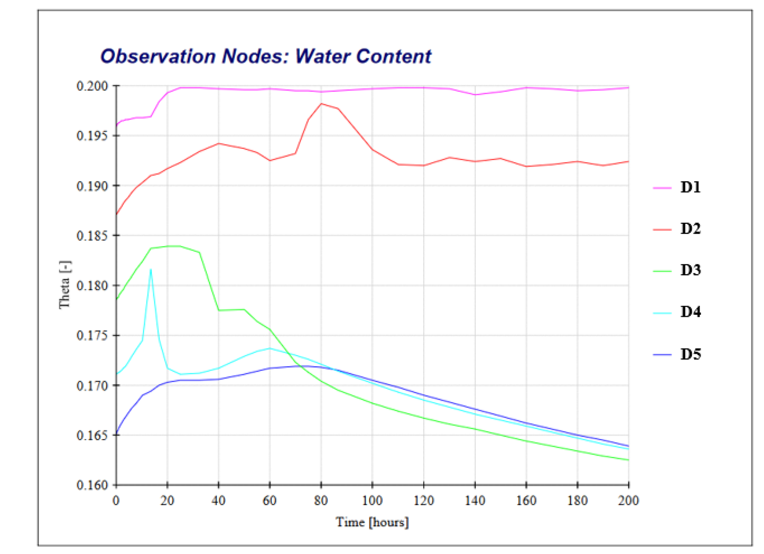


Figure 27. Water content or soil moisture distribution at five different depths (D1 to D5) along a 35 cm soil profile of uniform sandy loam.

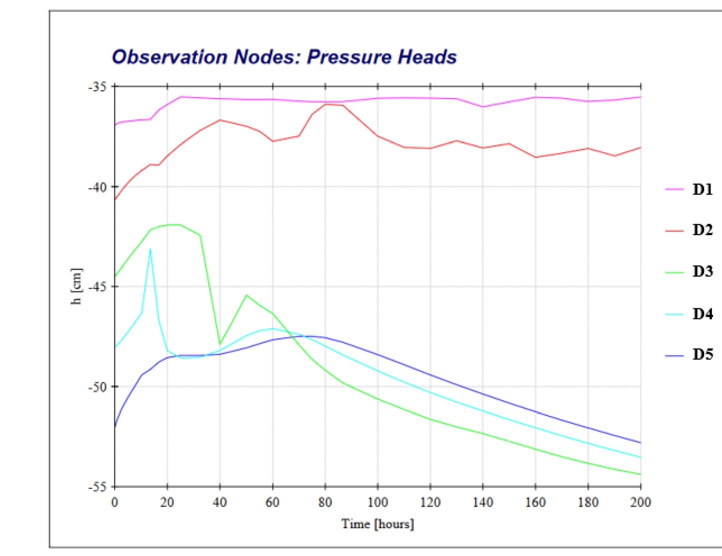


Figure 28. Pressure head or soil matric potential distributions at five different depths (D1 to D5) along a 35 cm soil profile of uniform sandy loam.

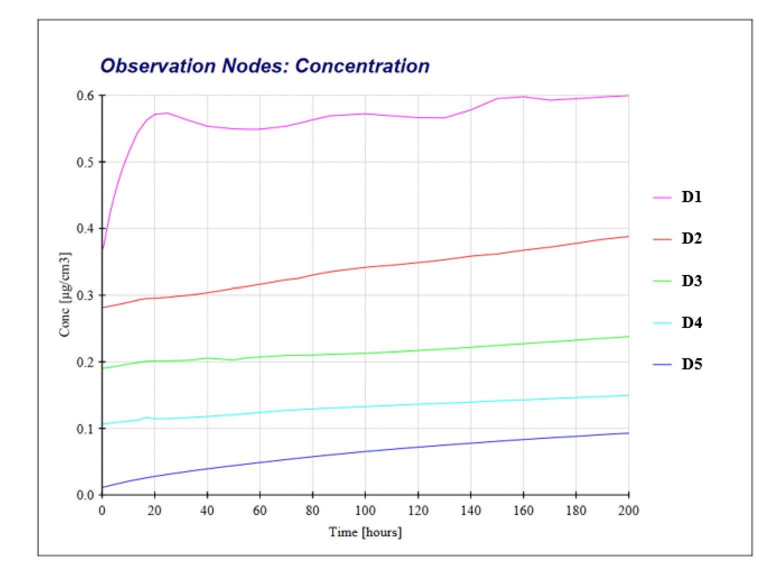


Figure 29. Solute (nitrate) concentration distribution in the liquid phase at five different depths (D1 to D5) along a 35 cm soil profile of uniform sandy loam.

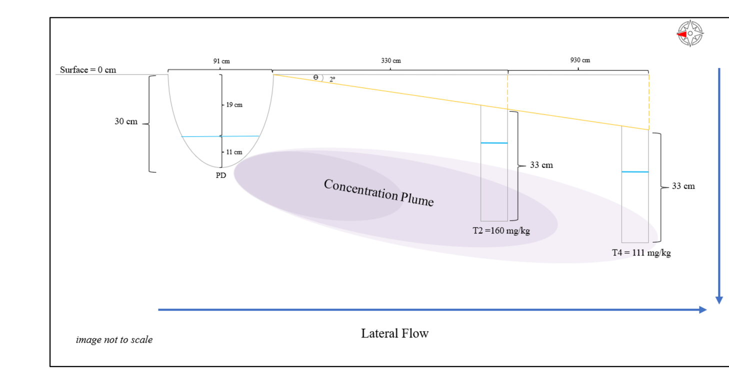


Figure 31. A conceptual diagram depicting the lateral transportation of the nitrate concentration. The solute or solution (nitrate mixed with water) moves downslope from the percolation ditch (PD) parallel to the water flow path. The lateral flow of the solute is evident by comparing the nitrate concentrations of soil grab samples T2 and T4. The observed decrease in the nitrate concentration downslope infers diffusion processes.

Conclusion & Future Work

- A relationship exists between the observed field data and the modeling completed by HYDRUS-1D.
- HYDRUS-1D successfully transcribes the water flow characteristics at specific depths through time in a uniform soil profile.
- The solute transport model had limited parameters. Nonetheless, we can decipher the fundamental aspects of advection, dispersion, and diffusion processes.
- The models did not consider the heterogeneity of the soil profile. Observations through heterogeneous soil profiles may further assess the effects of pore space distribution.

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