Using Sediment Texture to Estimate Infiltration Rates at a Managed Aquifer Recharge Site

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Abstract

UCSC GEOPATHS is an NSF-supported initiative to improve undergraduate success in the geosciences, driven by a desire to broaden academic engagement. One component of the program is a funded undergraduate summer program that provides authentic, professional experiences – across all employment sectors – to increase commitment in the geoscience pipeline. Many hydrologic basins rely on groundwater to supply domestic, municipal, and agricultural demand, but resources are increasingly stressed by rising demand, changes in land use, and a shifting climate. Consequences of groundwater overdraft include drying surface water systems, land subsidence, and seawater intrusion. Managed aquifer recharge (MAR) can help improve groundwater resources by increasing infiltration of excess surface water. We are part of a research team assessing hydrologic conditions during MAR on an active vineyard in Central California, through diversion of high flows from an adjacent river, a strategy known as "flood-MAR." Our team collected soil samples from the upper 100 cm below ground surface at 24 locations across the 785-acre field site. We analyzed samples for soil texture at 10-cm spacing using a particle size analyzer based on laser light scattering. Preliminary analysis of fractions of sand, silt, and clay-sized particles indicate some lateral continuity from site to site. The northern part of the field area appears to be finer grained, on average, consistent with regional soil maps, but there is also considerable variability with depth. These data will be used to assess variations in expected infiltration rates by combining soil texture (to estimate infiltration capacity) and potential flood and saturation depths (to bracket vertical head gradients). Studies of this kind are helpful for assessing the efficacy of flood-MAR as a strategy to improve groundwater supplies and quality.

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The Recharge Initiative
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Introduction

California and much of the western U.S. have experienced intense droughts and water shortages in recent decades; ongoing and future climate change will create additional challenges. Groundwater meets ~40% of freshwater demand in California during normal years, and ≥60% in dry years; some basins almost entirely depend on groundwater. Chronic groundwater overdraft has led to many problems, including disconnection and drying of streams and wetlands, loss of aquatic habitat, and subsidence.

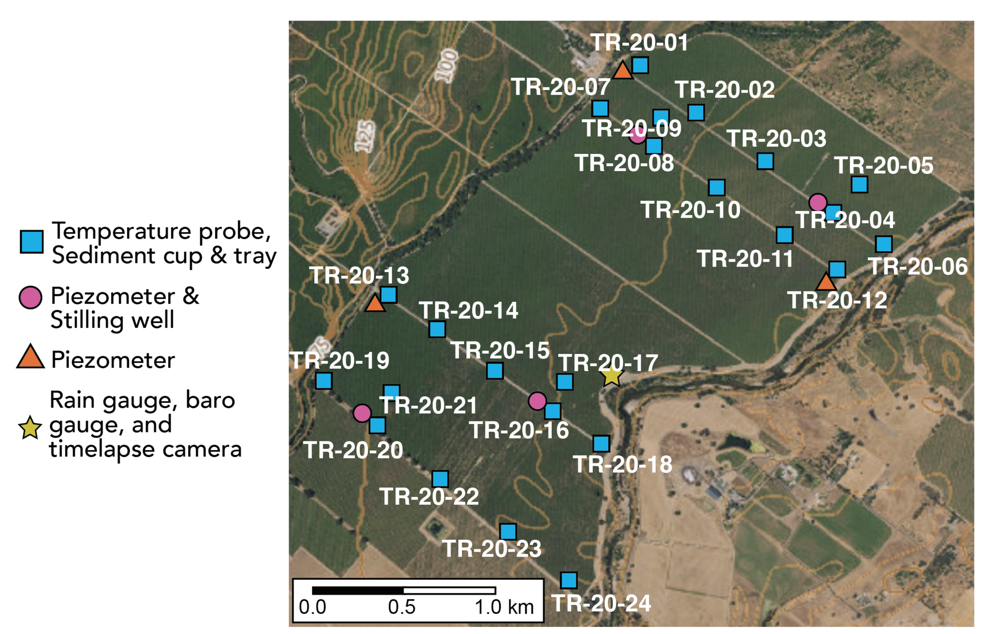
WY21, diverted flow from the Cosumnes River. Photo: H. Dahlke.

Managed Aquifer Recharge

Managed aquifer recharge (MAR) is a set of methods used to enhance inflow to aquifers with excess surface water. Intense rainfall and snowmelt events can contribute to enhanced groundwater recharge, if this water can be infiltrated quickly into the ground. MAR often targets small areas using infiltration basins or wells. Another technique known as "flood MAR" uses excess flows to inundate large areas, including farms and rangeland. Members of the UCSC Hydrogeology group are participating in a pilot flood MAR project on a 785-acre vineyard near Elk Grove, CA to evaluate how much water can be infiltrated on the floodplain of the Cosumnes River.

Sample Collection

We deployed instruments to measure flood and infiltration conditions, and collected soil samples, to assess properties that control infiltration rates and impacts on water quality. The first flood MAR diversion at the field site occurred in January of 2021. Laboratory experiments with intact cores recovered from the field site are being run to assess how flood MAR infiltration could influence water quality, particularly if soils are augmented with bioavailable carbon.



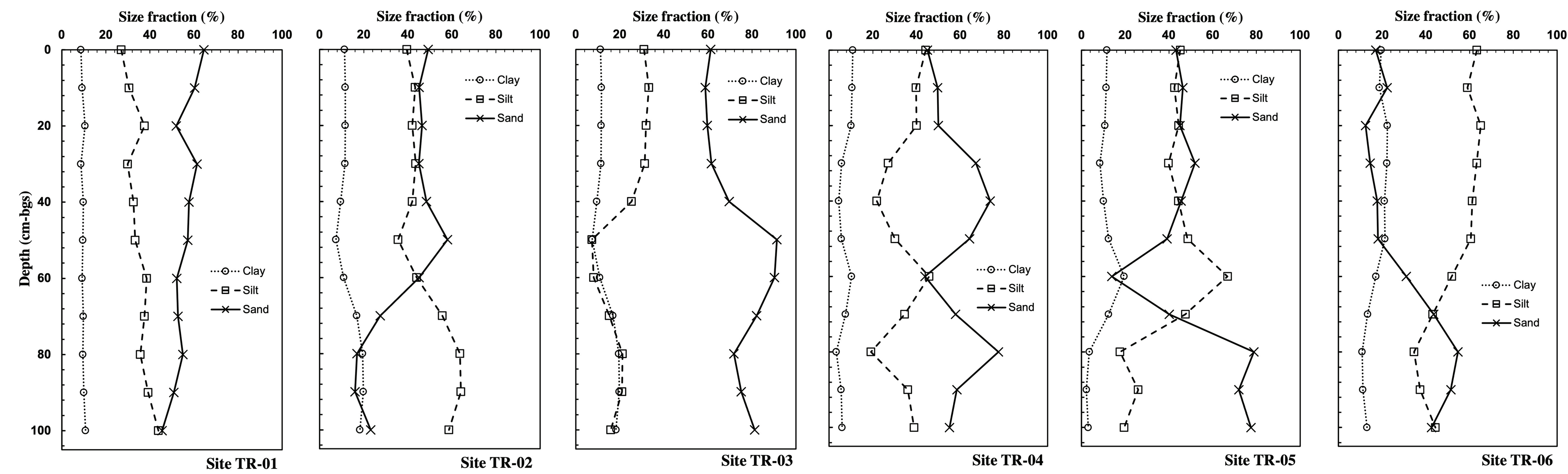
785-acre vineyard outside Elk Grove, Calif.

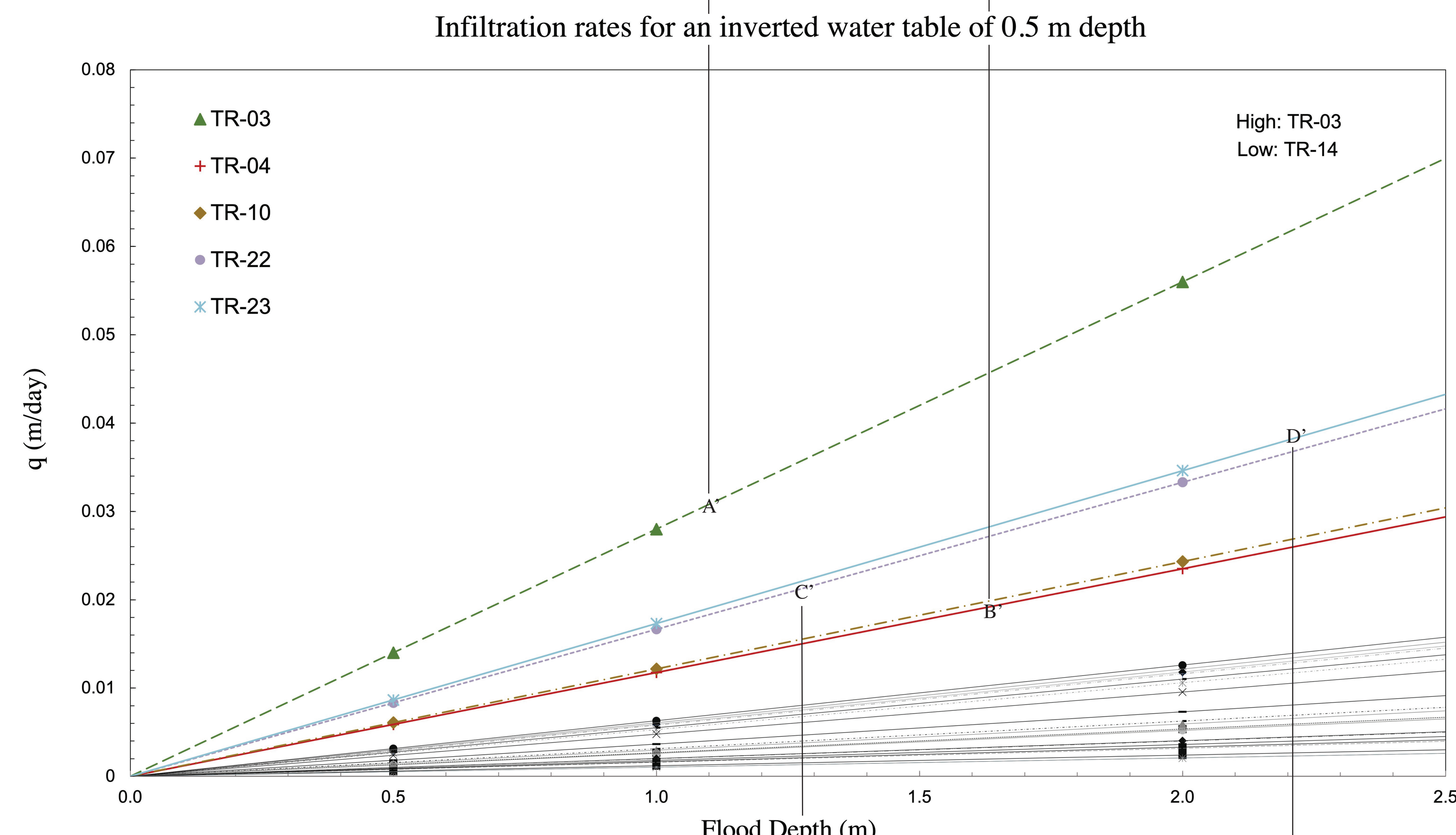
1 meter hand-augered sediment core.

Grain-size Analysis

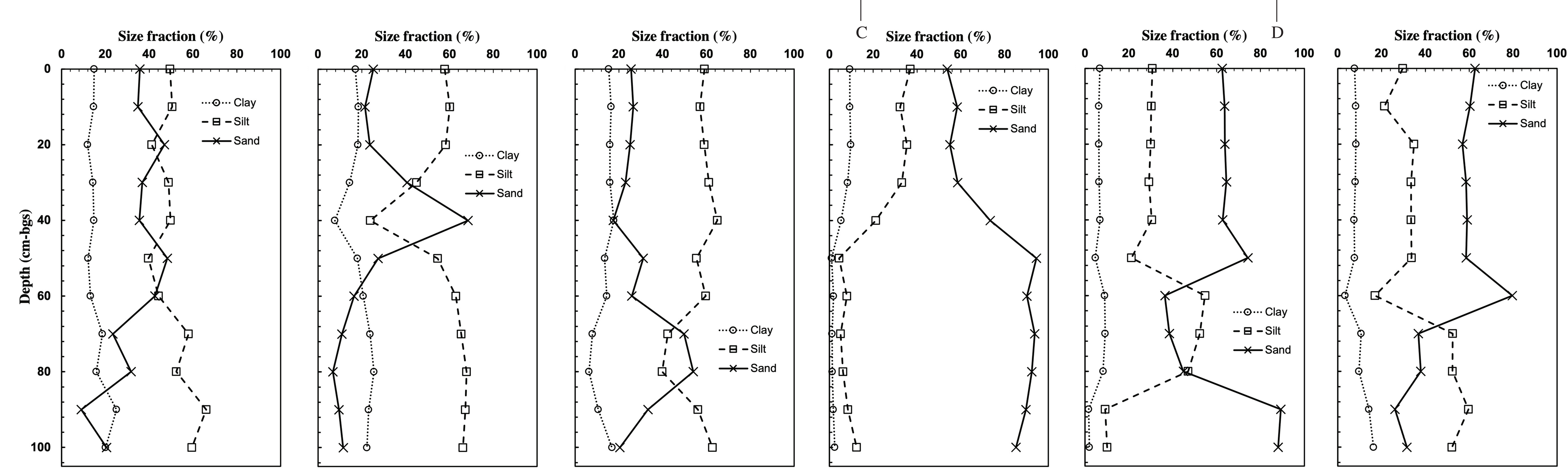
The upper 1 meter of sediment was collected at 24 locations, with measurements made every 10 cm. Samples were processed with 30% hydrogen peroxide to remove excess organic material. Samples were analyzed using scattered laser light diffraction to determine texture. Results were analyzed to determine the sand, silt, and clay fractions, and calculations were made to determine key metrics from the size distributions: d_{10}, d_{20}, d_{50}, d_{60}, and d_{80} (where d_{XX} = diameter of grains finer than the XX percentile).

Sediment Texture & Infiltration Estimates





Infiltration estimates depicting high sand fractions.



Conductivity & Infiltration Calculations

Coefficient of grain uniformity:

$$U = \frac{d_{60}}{d_{10}}$$

Empirical equation for porosity:

$$n = 0.255(1 - 0.83^U)$$

Kozeny-Carmen equation for conductivity:

$$K_i = \frac{g}{v} C_{Ko} \frac{n^3}{(1-n)^2} d_{10}^2$$

K: *hydraulic conductivity*; g: *acceleration due to gravity*; v: *kinematic viscosity*; C_{Ko}: *Kozeny sorting constant* (8.3×10^{-3}); n: *porosity*; d_{10}: *grain diameter*

Harmonic mean conductivity for vertical flow:

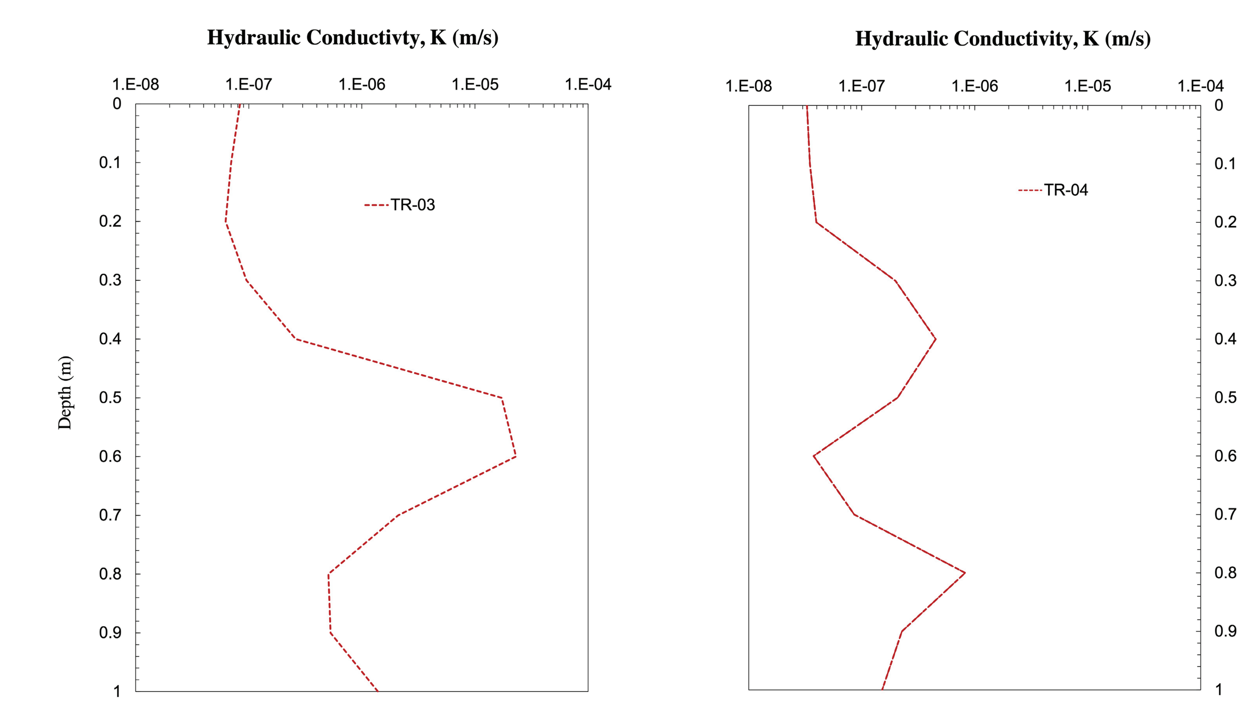
$$K_{vert.} = \frac{\Delta Z_T}{\sum_{i=1}^{n} \frac{\Delta Z_i}{K_i}}$$

ΔZ_T: *total depth*; ΔZ_i: *spacing depth*; ΔK_i: *conductivity at spacing depth*

Darcy's Law for infiltration:

$$q = -K_{vert.} \frac{\Delta h}{\Delta z}$$

q: *infiltration rate*; Δh: *head difference*; Δz: *elevation difference*



Highly variable conductivity at depth.

Next Steps

This study yields conservative estimates of infiltration rates from grain-size. We expect in-field infiltration rates to be greater because of root systems, rodent burrows, and other high permeability pathways. Additional studies will explore soil variability at greater depths.

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