Physical and Chemical Characterization of Vadose Zone Below Almond Orchards

Project No.: **17-WATER10-Nico**

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Objectives:

Successful wide scale implementation of groundwater recharge projects will require both a detailed and expansive understanding of the subsurface hydrologic and geochemical conditions. This type of information is available and has been analyzed relative to water recharge suitability for the surface soil region (O'Geen, et al). However, it is largely unavailable for the subsurface below the soil zone. Key questions in evaluating the efficacy of groundwater banking are:

1) How do you infiltrate the water without reducing land productivity?
2) Where does the water go once it is infiltrated?
3) How does the infiltration of water through the ground and into the aquifer affect groundwater quality?
4) When and where can the recharged water be recovered?

Companion research done at UC Davis and funded by the Almong Board of California (ABC) is primarily addressing the first question. In this study, we are focused on the second and third questions and developing tools to address the fourth question.

Interpretive Summary:

The work planned under this contract has been delayed due to the lack of available water for recharge during the 2017/2018 water year and an assessment that the proposed site at Orland, CA was not worth further investment in time and effort (Dahlke, personal communication). Since no new sites were available to the Berkeley Lab team last year, the proposed work is planned to be conducted in the coming water year, assuming the availability of water and new site selection. However, since this is a continuing project support by the ABC and Berkeley Lab, results from the first phase of the project can be briefly presented here.

The main results of the first phase of the study is that small scale, as small as 10's of feet, variations in sediment texture below the soil zone can have a dramatic impact on the path that applied water takes into the subsurface. Time-lapse imaging of moisture changes underneath a flooded orchard showed that a small number of areas of particularly high sand content were disproportionally responsible for the infiltration of applied water.

These results suggest that even on the scale of a single orchard there are likely better and worse areas for recharge activities. This is in spite of the fact that the surface soil properties appear uniform. In turn, this means that a better understanding of subsurface conditions can help growers and water managers make more efficient and informed land use decisions.

Materials and Methods:

The main method employed in the current work is that of Electrical Resistivity Tomography (ERT) Electrical geophysical imaging methods, such as ERT, have been widely used to characterize the heterogeneity of the vadose zone and monitor hydrological processes, such as water infiltration and groundwater flow (Rubin and Hubbard, 2005; Slater, 2007). The ERT method involves applying electrical current into the ground and measuring the distribution of the resulting electrical potential (voltage) at pre-defined measurement positions, such as along surface transects, grids or cross boreholes. These data can then be inverted to develop a 2D field of electrical resistivity values in the subsurface. The resistivity values can then be related to soil texture when accounting for differences in moisture and dissolved solid conditions. In time-lapse imaging, multiple ERT images are taken over time to develop a series of images. An initial baseline image can then be subtracted from the subsequent images to develop a series of images showing the change in resistivity values over time. Since the subsurface solids will not move over the time scale of the measurements and the fundamental properties, like texture, will not vary over that time, the changes in the images can be attributed to the movement of fluids in the subsurface. In the case of the current system, this time lapse method was used to monitor the movement of surface applied water into the subsurface.

Results and Discussion:

In a previous funding cycle the Berkeley Lab team conducted several important geophysical measurement campaigns at two test recharge locations in the vicinity of Delhi and Modesto CA, respectively. The measurements include baseline ERT images of the sediments under both orchards to a depth of ~20 meters. These data showed large variation in subsurface texture below the surface soil depth of ~1 m. These variations in texture took the form of areas of higher electrical resistivity that suggested drier and coarser materials. These locations were later confirmed to be higher in sand content through a coring campaign in collaboration with H. Dahlke of UC Davis.

Time lapse ERT data was then collected directly before and for several days after the application of recharge water to the study area. The differences in the images over time showed that, as expected, the initially drier/sandier areas were the areas that showed the largest and fastest change in moisture content as determined by changes in the measured electrical resistivity. The rapid changes in moisture content during water application strongly suggests that these areas are acting as preferential flow paths and are disproportionally important to conveyance of water from the surface to depth.

The results from the base line and time lapse ERT images were then used to construct preliminary reactive transport models that can simulate the movement of water and solutes through the subsurface. The preliminary model development was broken into two parts. The first part used the baseline and time lapse ERT images to create a synthetic two-dimensional heterogeneity matrix similar to that seen in the field. The model was then used to simulate the application of the recharge water and confirm the importance of the fast flow paths for water infiltration. The second part of the modeling effort was to build a reactive transport model that can simulate the movement and reactivity of nitrate and the impact that subsurface heterogeneity has on that process. The preliminary simulations show that the presence of fast flow paths or their opposite, aquitard layers, have significant impacts on the rate and amount of nitrate transported to depth based on water recharge simulations.

As stated above, these results support the conclusion that even small-scale subsurface variability can have a significant impact on the functioning of an on-farm water recharge operation. They suggest that there might be smaller areas of particular orchards or farms that are better suited for recharge activities and could potentially be set aside for such activities. In this way land use decisions could be made more efficient by allowing the minimum amount of land to be used for the maximum amount of recharge activity. In addition, the confirmation of the role of preferential flow paths underneath the recharge sites is, while not surprising, important to consider when predicting the impact on water quality from recharge activities. It means that the chemical characteristics of the fast flow path materials will control the changes in applied water quality.

Research Effort Recent Publications:

Nico, et al, 2017, *"Impact of Subsurface Stratigraphy on Water Migration during On-Farm Water Recharge*" US Conference on Irrigation and Drainage, Sacramento, October 2017

Nico, et al, 2018 "*Coupling Geophysical Imaging and Reactive Transport Modeling to Evaluate On-Farm Water Recharge Strategies*" Groundwater Resources Association, San Diego, March 2018

Newman et al, "*3D Full Waveform Seismic Imaging of the Unsaturated Zone: Verification and Application to Groundwater Banking Assessment*," to be submitted, September 2018.

Ulrich, et al, *"Understanding Recharge Complexity and Estimating Recharge Rates from Time-Lapse Monitoring at a Multi-Year MAR Site"* Groundwater Resources Associations: First Annual Western Groundwater Congress, Sacramento, September 2018.

References Cited:

O'Geen, et al, "*Soil Suitability index identifies potential areas for groundwatrer banking on agricultural lands*", Calif Agr 69(2):75-84.

Rubin, Y and S.S. Hubbard, "*Hydrogeophysics*," Series: Water Science and Technology Library; vol50, 2005, Springer, Dordrecht, The Netherlands.

Slater, L, 2007, *Near surface electrical characterization of hydraulic conductivity: From petrophysical properties to aquifer geometries—A review*, Survey of Geophysics, *28*, 169-197.