Understanding Recharge Complexity and Estimating Recharge Rates from Time-Lapse Monitoring at a Multi-Year MAR Site

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Blom Orchard Modesto, CA
Developing Science Based Scalable Approaches to Groundwater Banking

- Groundwater is critical to life in California (and much of the world) and current use is unsustainable
- By law and by necessity groundwater management must change
- Science based management practices are lacking
- How do we perform studies without negatively affecting working lands?
- How do we scale up small scale observations?
LBNL Water Focus Areas

Snowpack to Watersheds complexities and modeling

Understand and predict current and future water cycle perturbations

How do we adapt and develop new water management approaches?
Electrical Resistivity Tomography

- Electric current applied to the ground via series of metal electrodes inserted into the ground and voltages read at each electrode pair
- Multichannel system collects a rapidly dense data set (5000 data/hr)

- Deployed Jan/Feb 2017 and Jan 2018
- Autonomous system collects full data set in 1 hr continuously
ERT Results N-S and E-W Profiles

- Dynamic soil and saturation spatial variability along both profiles
- Red is sandy material vs blue more silty/clayey
- N-S test after 2 water applications in 2017 (water table ~18m) and E-W test during 1st water application in a dryer winter (deeper water table)
Low infiltration zone between dashed lines
4.5 days for water to infiltrate
ERT Time-lapse E-W

- Horizontal flow outside of the flooded area = complex infiltration paths
- 3 days for water to fully infiltrate
Multi-Point Geostatistical Simulations

- Simulation of sedimentary patterns and geostatistical distributions within those facies
- Training image required (Can’t excavate to observe subsurface, use ERT)

1. MPS simulation using ERT data as training image to represent prior using MPSLIB C++ library
2. Latin Hypercube sampling of prior
3. Send prior to Bayesian MCMC parameter estimation algorithm
4. Bayesian MCMC parameter selection from prior for facies geostatistical distributions
5. Create facies and hydraulic conductivity realization
6. Send K-field realization to forward model MIN3P
7. Compare modeled water content to ERT data at each time step

200 Vertical Hyd. Cond. Kz-field realizations
Recharge Rates & Total Recharge

- 120 m$^3$/day of infiltration for 2D profile (150mx25mx1m)
- **130 m$^3$/day (34k gal) of recharge beyond 25 m depth**
- Excess from low-permeability storage zones and prior wet conditions (initial conditions of a more saturated system)
- Antecedent dry conditions would potentially create upward flow gradient
3D Full Waveform Seismic

- 138 shot points, 120 receivers
- 10 stacks per shot
- Source PEG40, elastically propelled 40kg (88 lbs) weight
3D Seismic Results

Laplace-Fourier Images
• Very good fit between real modeled data

Comparison of S-Wave and ERT time-lapse
• High velocity S-wave corresponds to ERT low infiltration zone
• Blue zones good for infiltration (ERT fast) and red not
Deuterium Infiltration Test

2017 Experimental Design

- ~3 mm of highly deuterium enriched water was applied to a circular plot between two almond trees adjacent to the ERT line 18 hours before the flood
- Water samples were recovered from lysimeters for 10 weeks post flood.
- Soil cores from within the D₂O area 2-, 4-, and 10-weeks post flood
- Water from several depths was extracted from the core to determine water content and the isotopic composition of the water

2018 Experimental Design

- Two cores were taken at each site (1 shallow and 1 deep)
- The area for 2 m on either side of the ERT line was planted with grass
- The plot where D₂O was applied is located at ~110 m on the 2017 ERT line
2017 and 2018 D$_2$O Tracer Results

- Area between trees retains moisture due to clay-rich layer at ~90cm depth
- Water in grassy area in between tree rows infiltrates very rapidly as indicated by 2017 geophysical measurements

- 2 months later
- Fast path infil. not btn trees
2017 and 2018 $D_2O$ Tracer Modeling Background

- Soil data coupled with ERT to extrapolate soil characteristics/permeability

Conditioning points

Loamy sand

Sandy loam

D$_2$O Sites

Depth (m)

Profile Distance (m)

Resistivity (Ohm-m)

2017

1 2

3 4

34.5 38.5

2018

ERT line

Grass Row

Outside

Inside applied zone

- 3D iTough2/EOS7 Model
- Heterogeneous field honoring ERT baseline
- Brine is used to mimic tracer

- Two scenarios:
  - Low permeability ($k$) layer at 90cm below surface
  - No low k layer present
2017 and 2018 D$_2$O Tracer Modeling

**With 90cm Clay Layer**

- #1 Outside
- #5 Inside

**Without 90cm Clay Layer**

- #1 Outside
- #5 Inside

- Modeling with and without 90cm depth low perm clay can reproduce D$_2$O movement
- Vertical and lateral tracer flow

- Higher infiltration capacity and depth in grass area
- Again lateral and vertical flow can be reproduced
- Scenario explanation potential
- Potential for modeling other chemicals like Nitrates (Hannah & Nic)
Estimating volume changes from InSAR observations as a **scale up option**

Interferometry Synthetic Aperture Radar

- InSAR data can be used to calculate ground surface elevation changes over time at millimeter scale
- Easy method for large scale monitoring of landform processes
- Vital technology in scaling up small scale observations
- 2017-2016 saw 80cm (31 inches) subsidence in some parts of the San Joaquin Valley
Estimate volume changes from InSAR range change data, constrained by well locations.
Largest subsidence appears associated with deeper wells

- This methodology can help isolate the wells and zones that are over pumping and contributing to the greatest subsidence
- Pumping plans can then be outlined for wells in this area for subsidence mitigation
Conclusions

• Geophysics methods such as ERT and Seismic can be used to characterize/investigate viability of selected recharge sites.

• Geophysics time-lapse data coupled with novel modeling codes can estimate tracer/contaminant movement and volumes of water recharged.

• D$_2$O is a viable no impact tracer for recharge studies.

• InSAR can be used to scale up small scale observations, Is recharge in an area showing observed rebound?

• InSAR is another tool to evaluate area subsidence and the potential causes, allowing for GSAs/ID to better manage area groundwater usage.
Questions?

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