Geophysics to Groundwater: Methods, Modeling, and Measurements to Inform Subsurface Properties

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Outline

• What is the right geophysical method or survey design for a specific question(s)? Using coupled hydrogeophysical modeling to develop effective measurement and monitoring strategies

• What do the red-blue geophysical images mean? Developing hydrogeologic interpretations—with uncertainty—from geophysical models

• A case study: Airborne geophysics to characterize aquifer structure in support of a managed aquifer recharge pilot study in Mississippi
What geophysical method(s) and survey design will best answer my questions?

- Conceptual hydrogeological model(s)
- Hydrologic simulation scenario testing
- hydrogeological – geophysical property relationships
- Simulate geophysical response(s)

Abstract
Hydrogeophysical methods are presented that support the siting and monitoring of aquifer storage and recovery (ASR) systems. These methods are presented as numerical simulations in the context of a proposed ASR experiment in Kuwait, although the techniques are applicable to numerous ASR projects. Bulk geophysical properties are calculated directly from ASR flow and solute transport simulations using standard petrophysical relationships and are used to simulate the dynamic geophysical response to ASR. This strategy provides a quantitative framework for determining site-specific geophysical methods and data acquisition geometries that can provide the most useful information about the ASR implementation. An axisymmetric, coupled fluid flow and solute transport model simulates injection, storage, and withdrawal of fresh water (salinity ~500 ppm) into the Dummmun aquifer, a tertiary carbonate formation with native salinity approximately 6000 ppm. Sensitivity

Minsley et al., Groundwater, 2011
What geophysical method(s) and survey design will best answer my questions?

Conceptual hydrogeological model (s)

Hydrologic simulation scenario testing

hydrogeological – geophysical property relationships

Simulate geophysical response(s)

Al-Awadi et al., Hydrogeology J. (2005)
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Fluid mass balance:
\[ \rho S \frac{\partial p}{\partial t} + \phi \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho q) = \rho Q \]

Solute transport:
\[ \phi \rho \frac{\partial c}{\partial t} + \rho q \cdot \nabla c = \nabla \cdot (\rho \phi D \cdot \nabla c) \]
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Modeled pore pressure \( \rightarrow \) seismic velocity: change after one year of injection

Modeled fluid salinity \( \rightarrow \) electrical resistivity: change after one year of injection
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Predicted change in seismic waveforms
Predicted change in surface or borehole resistivity data

\( \Delta \rho \)
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<table>
<thead>
<tr>
<th>Seismic</th>
<th>Resistivity</th>
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<tbody>
<tr>
<td>• monitor pressure changes during injection / recovery (diffusive)</td>
<td>• monitor extent of freshwater plume (advective)</td>
</tr>
<tr>
<td>• baseline structural mapping</td>
<td>• baseline structural mapping</td>
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<tr>
<td>• information is primarily near injection location</td>
<td>• depth of freshwater plume is a challenge for surface resistivity</td>
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What do the red-blue geophysical images mean? Developing hydrogeologic interpretations, with uncertainty, from geophysical models

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Easy: given known properties, what is the geophysical response?

Hard: given geophysical data, what are the unknown hydrogeologic properties?

Uncertainty and non-uniqueness from geophysical data -> geophysical model -> hydrogeologic properties
What do the red-blue geophysical images mean? Developing hydrogeologic interpretations, with uncertainty, from geophysical models.
Mississippi Alluvial Plain (MAP): An economic engine

Withdrawals by county
(from Lovelace et al., 2020 based on 2015 data)

Crop Revenue by County
(from Lovelace et al., 2020 based on 2015 data)

$12 B
Agricultural Economy

Economic Importance
(Alhassan et al. 2019)
MAP AEM surveys 2018 - 2022

Total completed 82,000+ line-km over more than 250,000 km² covering parts of 7 states

Radiometric: Upper 20-30 cm Soils & recharge

Resistivity: 1-300 m Lithology & salinity

Magnetic: 100 m - kms Basement structure

Minsley et al., Communications Earth & Environment, 2021
Examples of translating geophysical results to hydrogeologic properties of interest
Bank filtration, transfer, and injection: Mapping aquifer structure to inform aquifer recharge pilot project installation

1 extraction, 2 injection wells
1.8 mile transfer

Tallahatchie River
AEM survey shows complex geological heterogeneity

- Higher resistivity (warmer colors) represent coarser sediments
- Heterogeneity is a key control on groundwater flow and quality
- Variations in lithology likely contribute to soil piping at injection & extraction wells
Resistivity models provide a 3D window into the subsurface.
Summary

- **Identify the question:** Before deciding on geophysical methods, think about the hydrogeologic question(s) that are most important to answer.

- **Find the right balance of technical approach, cost, and logistics.**

- **Communicate uncertainty:** What do the geophysical results tell us (or not) about the subsurface?

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References


