Geophysical Methods for GW/SW Interaction
Water in the West, 10/13/16

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Outline

• Why geophysics?
• Why geophysics for GW/SW?
• Methods:
  1. Direct current electrical methods
  2. Electromagnetic Induction methods
  3. Temperature
• Conclusions
Why geophysics?

• Filling in gaps in space
  – Large areal coverage
  – High resolution

• Filling in gaps in time
  – Long-term continuous monitoring

• Limitations:
  – Indirect
  – Need multiple methods
  – Not a substitute for direct measurements
Airborne/Satellite Methods
Surface Methods
Crosshole Methods
Borehole logging
Bench-scale Experiments

RELATIVE SCALE OF INVESTIGATION

Lab or Point
Local
Regional

RELATIVE RESOLUTION

High
Moderate
Low

~10^{-4} to 1
~10^{-1} to 10
~1 to 100

[Modified from Hubbard and Rubin, 2005]
Airborne/Satellite Methods
Surface Methods
Crosshole Methods
Borehole logging

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Why geophysics for GW/SW?

- Reconnaissance
  - Mapping bed materials (electrical, EM, seismic, GPR)
  - Mapping groundwater salinity (electrical, EM)
  - Mapping relative exchange (thermal imaging, fiber optic temperature, time-lapse electrical)
- Quantifying fluxes (temperature)
- Monitoring (fiber optic temperature, electrical)
(1) Electrical Resistivity

- Mapping subsurface resistivity
  - Geology/structure
  - Salinity
- Performed from land, on stream bed, or from boat
- Requires electrodes in contact with ground or water

Earth’s resistance (R)
Continuous Resistivity Profiling

Numerical methods + Inverse modeling [with appropriate constraints on water layer thickness and conductivity]
CRP Example: Columbia River, WA

- 30 km of waterborne electrical line
- Water depths varied from 1-14 m (in channel)
- Focus on near shore where water depth of a few meters only
- Chargeability stronger indicator of lithology at this site than resistivity
- Also waterborne seismic and GPR, land-based electrical; DTS; 1D vertical temp, not shown here
Electrical cross sections

Hanford-Ringold contact defined along river corridor

Interpreted paleochannel incised below H-R contact

Locally-incised paleochannels?

Inverted image at 7 m

GPR

Line 20 (20 m from shore)
(2) Electromagnetic Induction

- Many tools/platforms for different target depths and scales of investigation
  - Geology/structure
  - Salinity
- No electrode-contact required
Mapping fresh water discharge to the CO River

Current fresh groundwater discharge estimate based on a zone of constant thickness across the wetland area...
• Unpublished results
(3) Temperature Methods

- Conventional 1D Vertical profiles
- Fiber-optic distributed temperature sensing
- Thermal imaging
DTS Example – Columbia River

- DTS provides high-resolution in space and time
- Temperature anomalies coincide with known uranium seeps, but there are many additional temperature anomalies/seeps
- DTS results consistent with electrically estimated Hanford thickness

Estimated variation in thickness of uranium contributing area from IP

Slater et al., 2007
Mwakanyamale et al., 2012
Mwakanyamale et al., 2013
• Probes installed in transect vertically through water column and into streambed
• Data calibrated using various models include 1DTempPro (USGS)
• Study of dwarf wedge mussel cold water refugia
HRTS: Delaware River cold water plume

Briggs et al., ES&T, 2013
1DTempPro V2

- USGS software
- Calibrates heat transport model to determine vertical exchange
- Used VS2DH numerical model
- Exploring extension to unsaturated zone
- [http://water.usgs.gov/ogw/bgas/1dtemppro](http://water.usgs.gov/ogw/bgas/1dtemppro)

Koch et al., Groundwater, 2015
GWSW-MST

- Groundwater/Surface Water Method Selection Tool
- Excel-based Decision Support System
- Still in active development

Similar to the Fractured Rock Geophysical Toolbox Method Selection Tool (Day-Lewis et al., 2016, Groundwater)
Conclusions

- Geophysical methods can contribute:
  - Qualitative and recon information for early conceptual system understanding
  - Higher resolution and greater coverage \(\rightarrow\) gaps in space
  - Repeat snapshots or continuous monitoring \(\rightarrow\) gaps in time
  - Quantitative information for fluxes, in the case of temperature
  - Thermal imaging – powerful technology amenable to UAS deployment

- [http://water.usgs.gov/ogw/bgas](http://water.usgs.gov/ogw/bgas)
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