Groundwater

Guest Editorial/

# Geophysics Is Not a Silver Bullet, but Worth a Shot

by Kamini Singha

Hydrogeologists have long been interested in using geophysical measurements to answer questions about the Earth. Originally used to find ore bodies or oil and gas, geophysics' sensitivity to water was originally considered a nuisance. While looking for metallic ore using electrical-induced polarization, for instance, early geophysicists found that groundwater controlled most of the measured signal. Others later capitalized on this "nuisance" by using geophysical methods to explore for water directly, or to attempt to estimate hydro(geo)logic properties. Unfortunately, no universally reliable relations between measured geophysical properties, such as seismic velocity, and hydrologic properties of interest, like a concentration flux, exist in the field. For instance, both positive and negative correlations were found between hydraulic conductivity and electrical conductivity. So, early hydrogeophysics research capitalized on imaging spatial differences in geophysical properties to map potential hydrogeologic facies as much as the more difficult problem of attempting to estimate hydrologic properties directly.

While Doll et al. (2012) note that the field of near-surface geophysics was booming in the 1980s, environmental applications of geophysics were still only about 0.1% of reported geophysical activity in 1990. From early years, some thought geophysics could be made to "see" whatever the user wanted (e.g., Blau 1936), such that the methods were in "ill repute" within hydrogeology. Fortunately, opinions are changing.

The field of hydrogeophysics really came into its own in the early to mid 2000s, in part by addressing problems of interest to the hydrogeology community. To me, this evolution was about asking the right questions with geophysics, and using geophysics to complement traditional methods and fill in gaps, rather than using it to substitute for hydrologic measurements. I'd always prefer a single borehole with a pressure transducer to trying to find the water table with a geophysical method. That said, there is no better way to see *between* the sparse "hard" data than with geophysics. Geophysics can also map time-lapse changes over broad spatial and temporal extents, and the change in the geophysical properties is sometimes closely related to a hydrologic process. Scientists have successfully used geophysics to map the movement of water or tracers in groundwater, the vadose zone, and in groundwater-surface water exchange. We continue to push the envelope by imaging root-water uptake, which can help us parameterize rooting depths for climate models. We can also map how microorganisms influence biogeochemical processes related to bioremediation. We can image potential water stores in the subsurface.

We are also scaling up; I believe airborne electromagnetics (AEM) platforms will become a game changer for hydrogeology: Just as Light Detection and Ranging (LiDAR) has changed the way we think about surface morphology, AEM can do the same for characterizing subsurface variability.

Geophysical methods are not only being commonly used for hydro(geo)logic research, but they also have become practical tools for consultants. Valuable decision-support tools now help hydrogeologists find appropriate geophysical methods, for instance, for fractured-rock systems (Day-Lewis et al., 2016). Ongoing innovations will continue to establish geophysical tools as part of a hydrogeologist's toolbox for the decades to come. While geophysics will continue to have utility in mapping changes in subsurface properties, we have not yet succeeded in directly and reliably measuring properties like hydraulic conductivity in the field. I am not convinced we will ever be able to robustly estimate these properties at all field sites, but if someone builds a geophysical instrument that can non-invasively measure hydraulic conductivity directly at any site, I promise to buy two!

**Editor's Note:** Prof. Kamini Singha is the Darcy Lecturer for 2017.

## References

Blau, L.W. 1936. Black magic in geophysical prospecting. *Geophysics* 1, no. 1: 1–8.

Day-Lewis, F.D., C.D. Johnson, L.D. Slater, J.L. Robinson, J.H. Williams, C.L. Boyden, D.D. Werkema, and J.W. Lane. 2016. A fractured rock geophysical toolbox method selection tool. *Groundwater* 54, no. 3: 315–316.

Doll, W.E., R.D. Miller, and J. Bradford. 2012. The emergence and future of near-surface geophysics. *The Leading Edge* 31, no. 6: 684–692.

Geology and Geological Engineering and Hydrologic Science and Engineering, Colorado School of Mines, Golden, CO 80401; ksingha@mines.edu



doi: 10.1111/gwat.12495