Summary Notes from Groundwater Data Workshop #4: Geophysical Methods for Sustainable Groundwater Management

Workshop Date: Oct. 13, 2016

Introduction

The following are summary notes from a one-day workshop hosted at Stanford University focusing on the use of geophysical methods for sustainable groundwater management under the recently enacted Sustainable Groundwater Management Act (SGMA). This workshop was the fourth in a four-part workshop series convened by Stanford University's Water in the West program and the Gould Center for Conflict Resolution, in partnership with California State University's Center for Collaborative Policy. Held on October 13, 2016 the workshop brought together a select group of groundwater managers, county and state representatives, and technical experts to (1) jointly identify opportunities or barriers for the use of geophysical methods under SGMA; (2) develop ideas for best management practices for the use of geophysical methods at local and state levels; and (3) identify key areas for relevant workshop outputs.

The workshop was a mix of presentations and discussion, which are summarized in the following notes. These notes intend to capture broad themes identified during workshop discussion, including the benefits, challenges, and opportunities of using geophysical methods for sustainable groundwater management under SGMA. Case studies presented during the workshop are also summarized in tabular form and include links to case studies and related publications.

A workshop agenda and participant list can be found at the end of the summary notes. Additional information on the groundwater data workshop series as a whole or about Water in the West's Sustainable Groundwater program can be found at the links above or by visiting waterinthewest.stanford.edu.

Broad Themes

SGMA presents a significant step forward for groundwater management in California by requiring local agencies to develop groundwater sustainability plans (GSPs) to achieve sustainable groundwater management within 20 years of plan implementation. As part of plan development, agencies will need to characterize regional geology, including the lateral basin boundaries and the physical properties of principle aquifers and aquitards in the basin (California Code of Regulations (CCR) §354.14(b)(1-4)); develop robust and representative groundwater monitoring networks capable of demonstrating short- and long-term trends in basin conditions, including water quality, groundwater levels, and the impacts of groundwater pumping on surface water users (CCR §354.34(a)&(c)); and implement management actions, like groundwater recharge, to achieve their basin-wide sustainability goal (CCR §354.44(a). Geophysical methods provide a significant opportunity to meet many of these goals. However, the variety and versatility of these methods to inform water management decisions can make it difficult to determine which methods are best suited to different applications. Workshop discussion focused on these and other topics relating to the use of geophysical methods to meet the data collection and reporting requirements under SGMA.

1. **Potential Benefits of Using Geophysical Methods**
   Workshop presenters and participants discussed applications where geophysical methods could be used to meet legal and regulatory data requirements under SGMA. Some potential benefits of geophysical methods for sustainable groundwater management include:
   a. Providing continuous data at a variety of scales. They can provide information about pore scale processes influencing contaminant transport locally to field-scale data on subsurface suitability for groundwater recharge through to regional scale estimates of land subsidence derived from satellite data.
   b. Providing consistent regional-scale information about the basin (e.g., subsidence, groundwater flow, subsurface geology). Developing consistent datasets between hydrologically-connected basins may improve basins' ability to work together and reduce conflicts between basins.
   c. They are often a cost effective "reconnaissance" tool, identifying areas where further study is needed.
   d. They can provide improved understanding of the subsurface in data-sparse areas.
   e. They can be used to optimize the number and location of wells and maximize the use of limited funds available for data collection, monitoring, and site specific studies.
   f. They can be used to increase the spatial resolution of existing or uncertain datasets. Additionally, geophysical methods can extend the temporal record of certain datasets back before traditional monitoring methods were in place (e.g., subsidence datasets).

2. **Potential Challenges in Using Geophysical Methods**
   While geophysical methods present a significant opportunity to meet the data collection and monitoring requirements under SGMA, workshop participants expressed concerns about the use of geophysical methods. Some concerns include:
   a. Having the expertise to select the appropriate geophysical method for different applications.
   b. Ensuring skilled interpretation and communication of geophysical methods to water managers, hydrogeologist, and other decision makers.
   c. Ensuring that the uncertainty in geophysical methods is conveyed appropriately to water managers and other decisions makers when presenting the results of geophysical analysis.
   d. The lack of consultants and professionals with training and experience in integrating geophysics methods into existing hydrogeological analyses.
   e. A lack of familiarity with many geophysical methods can make people less comfortable choosing to use them over more traditional methods. This is particularly true when trying to "sell" the use of geophysical methods to board members or the public who are concerned about liability and financial risk.
   f. The cost of deploying geophysical methods.

3. **Potential Opportunities to Improve the Use of Geophysical Methods**
   Workshop participants discussed opportunities to address some of the concerns raised above. Some opportunities include:
   a. Developing a technical advisory committee to advise the state and local entities on the use of geophysical methods for groundwater management.
   b. Writing a white paper providing an overview of geophysical methods, potential applications for each method, and a framework or list of questions to help guide water managers and other decision makers on the use of geophysical methods.
   c. Providing short courses and workshops to improve understanding of geophysical methods for hydrogeologists and groundwater managers.
   d. Geophysicists need to ensure that they convey the value of the information being provided. The value of geophysical methods should be conveyed within the context of (1) alternative costs that would be incurred if the information provided by geophysical methods were acquired through other methods, or (2) the cost of alternative management scenarios that would be undertaken without the information provided by geophysics.
   e. Developing a geophysical method selection toolbox for different management actions likely under SGMA.
   f. Developing a consortium of geophysical experts who can provide feedback, advice, and case studies on the use of geophysical methods for sustainable groundwater management.
   g. Developing an association of "vetted" geophysics consultants who can provide geophysical services for sustainable groundwater management.
   h. Writing a one-page summary of geophysical methods and their potential applications that could be used to inform board members of other decision-makers on the use of geophysical methods.

4. **Funding for the Use of Geophysical Methods**
   The question of how to fund the use geophysical studies was threaded throughout the workshop. Funding-related conversations focused on:
   a. Uncertainty over the amount, timing, and source of funding for SGMA. Workshop participants expressed concern that initial funding for SGMA implementation would be slow to come.
   b. Uncertainty in the types of data that the state plans to provide and the corresponding inability for local agencies to prioritize local data needs.
   c. Overcoming the perceived financial risks of using a more innovative technology to collect information over a traditional and proven method.

Geophysical Case Studies

In California, some geophysical logging methods (e.g., gamma and electrical resistivity logging) have been used for decades in wells and boreholes to obtain information about lithology and/or water quality. However, surface-based methods are not commonly deployed. Over the past decade there have been improvements in surface-based geophysical methods (both in terms of data acquisition and processing/interpretation), and growing interest in the use of these methods for a wide range of applications related to groundwater evaluation and management.

The following table presents case studies that use surface-based geophysical methods for improved basin characterization. These case studies can serve as examples of where geophysical methods can provide data for sustainable groundwater management under the Sustainable Groundwater Management Act (SGMA). The case studies focus on the development of the conceptual model; siting, planning and monitoring of recharge operations; and studies of groundwater-surface water interaction, subsidence, water quality, and seawater intrusion. These were identified in the previous workshops in our groundwater data workshop series as areas with critical data needs.

Table 1. Summary of the geophysical methods, data provided, and case studies presented.

Data Provided	Geophysical method(s)	Case Study	Resources
Conceptual Models			
Continuous map of subsurface resistivity values, which can be used to estimate subsurface lithology	Aerial Electromagnetic (AEM) Method surveys	Tulare Irrigation District, CA	Stanford University's Center for Groundwater Evaluation and Management (GEM Center)
Estimate permeability and determine aquifer structure/properties including bound versus mobile water content	Logging NMR (Javelin)	Indian Wells Valley, CA	Indian Wells project overview
Mapping of fault zones, estimates of depth to basement, and characterization of basin-fill lithologies	Magnetic detection; Truck-towed magnetometer system; Gravity models	Death Valley (South Amargosa)	• Belcher et al. (2016) Report • Oatfield et al. (1991) Publication
Map stratigraphy and faulting	Seismic lines; Borehole geophysical logs	Los Angeles Basin	Ponti et al. (2014) Report
Characterization of sediments, depth to bedrock, and classification of hydrogeologic units	Absolute gravity; Surface transient electromagnetic (TEM) surveys; Aerial transient electromagnetic (TEM) surveys	San Pedro, AZ	Dickinson et al. (2010) Report
Estimate depth to basement	Aerial transient electromagnetic (TEM); Time domain electromagnetic (TDEM); Absolute gravity; Airborne electromagnetic modeling	Ft. Irwin National Training Center, CA	Project Overview
Estimate depth to basement	Gravity; Seismic surveys	California Desert Basins	Nishikawa et. al (2016) Report
Recharge			
Determine suitability for artificial recharge, aquifer thickness and depth to water, and identify barriers to groundwater flow	Regional gravity survey; seismic surveys; DC resistivity surveys	Amargosa Creek Recharge Facility	Christensen et al. (2015) Report

Data Provided	Geophysical method(s)	Case Study	Resources
Recharge (con't)			
Characterization of hydrogeological properties and processes under recharge pond	Electrical resistivity probes (ERP)	Harkins Slough Recharge Pond, Watsonville, CA	• Project Overview • Project publication
Estimate spatial and temporal infiltration variability	Electrical resistance tomography (ERT)	Prairie Water Project, Aurora, CO	Prairie Waters Project Overview
Create spatial maps of gravity/storage change	Time-lapse gravity data	Arizona artificial recharge facility	Kennedy (2015) Report
Groundwater-surface water interactions			
Map of subsurface resistivity, which can be used to estimate bed materials (lithology), and identification of subsurface features influencing groundwater-surface water exchange	Waterborne electrical imaging; distributed temperature sensing (DTS)	Columbia River, WA	• Slater et al. (2010) publication • Mwakanyamale et al. (2012) publication • Johnson et al. (2012) publication
Mapping groundwater discharge	Thermal imaging camera, Temperature probes, and USGS temperature exchange software (1DTempPro V2)	Upper Delaware River, PA	Briggs et al. (2013) publication
Subsidence			
Measure subsidence	InSAR, LiDAR, continuous GPS	San Joaquin, CA	San Joaquin subsidence monitoring overview
Water Quality			
Determine effects of seepage from liquid manure lagoons on groundwater	Electrical resistivity and electromagnetic surveys	Central Valley Dairy Representative Monitoring Program Lagoon Investigations	Till E. Angermann, Luhdorff & Scalmanini Consulting Engineers
Water Quality			
Map geology/structure and salinity	Electrical Resistivity	Columbia River, WA	Johnson et al. (2012) publication
Determine aquifer thickness and suitability for artificial recharge, identify barriers to groundwater flow affecting groundwater recharge	Regional gravity survey; Seismic surveys; DC resistivity surveys	Amargosa Creek Recharge Facility	Allen Christensen, USGS
Seawater intrusion			
Measure salinity, and determine subsurface properties influencing seawater intrusion	Electrical resistance tomography (ERT); Time domain electromagnetics (TDEM)	Sunset Gap	Roy Herndon, Orange County Water District with support from Legette, Brashears & Graham
Increase understanding of artificial recharge, pumping, and other effects on groundwater (including seawater intrusion)	Seismic surveys	Los Angeles Basin	Ponti et al. (2014) Report

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GEOPHYSICS IN THE SGMA CONTEXT:
Geophysical Methods for Sustainable Groundwater Management

October 13, 2016

WORKSHOP GOALS

This is the final workshop in a four-part series focusing on the technical and data challenges local and state agencies are likely to face during implementation of the Sustainable Groundwater Management Act (SGMA). Based on learning from the first three data workshops and a groundwater data survey conducted by Water in the West and the Gould Center for Conflict Resolution, it is clear that many groundwater basins across the state lack basic data or information to make effective management decisions. Some specific areas of data uncertainty include locating groundwater recharge areas and estimating recharge potential; characterizing groundwater-surface water interactions; estimating groundwater extractions; and characterization of groundwater quality. The improvements in geophysical methods for groundwater characterization that have occurred in the past decade present a significant opportunity for meeting SGMA information needs.

Using case studies, this workshop will provide examples of areas where geophysical methods have been used to address management actions required under SGMA that have critical data needs.

Workshop participants will actively participate in plenary discussion to:

1. Identify opportunities or barriers for the use of geophysical methods under SGMA.
2. Develop ideas for best management practices for the use of geophysical methods under SGMA.
3. Shape meeting outputs.

MEETING DETAILS

When: Oct. 13, 2016 8:30 am - 4:45 pm
Where: Frances C. Arrillaga Alumni Center, 326 Galvez St., Stanford CA 94305
Hotel: Stanford Guest House, 2575 Sand Hill Road, Menlo Park, CA 94025

Meeting Contact: Tara Moran, 650-721-2421, tamoran@stanford.edu
Logistics Contact: Athena Serapio, 650-724-7609, athena3@stanford.edu

AGENDA

8:30am **Breakfast**

9:00am **Welcome, Meeting Overview and Introductions (15 mins)**
Speakers: Leon Szeptycki, Stanford University and David Ceppos, Center for Collaborative Policy

9:15am **SGMA Overview and Workshop Goals (10 mins)**
Speaker: Tara Moran, Stanford University

9:25am **Introduction to Geophysical Case Studies (5 mins)**
Speaker: Rosemary Knight, Stanford University

9:30am **Session 1**: **Improved Conceptual Models (90 mins)**
Moderator: Paul Gosselin, Butte County Department of Water and Resource Conservation

- Speaker 1: Claudia Faunt, U.S. Geological Survey (12 mins)
- Speaker 2: Rosemary Knight, Stanford University (12 mins)
- Speaker 3: David Walsh, Vista Clara Inc. (12 mins)

Plenary Discussion (45 mins)

11:00am **Break (15 mins)**

11:15am **Session 2**: **Planning, Mapping and Monitoring Groundwater Recharge (90 mins)**
Moderator: Brian Lockwood, Pajaro Valley Water Management Agency

- Speaker 1: Rosemary Knight, Stanford University (12 mins)
- Speaker 2: Allen Christensen, U.S. Geological Survey (12 mins)
- Speaker 3: Gregory Newman, Lawrence Berkeley National Laboratory (12 mins)

Plenary Discussion (45 mins)

12:45pm **Lunch (60 mins)**

1:45pm **Session 3: Water Quality and GW-SW Interaction (90 mins)**
Moderator: Thomas Harter, UC Davis

- Speaker 1: Roy Herndon, Orange County Water District (12 mins)
- Speaker 2: Till Angermann, Luhdorff & Scalmanini Consulting Engineers (12 mins)
- Speaker 3: Fred Day-Lewis, U.S. Geological Survey (12 mins)

Plenary Discussion (45 mins)

3:15pm **Break (15 mins)**

3:30pm **Session 4: BMPs for Geophysical Methods under SGMA (65 mins)**
Moderator: Tim Parker, Parker Groundwater and Groundwater Resources Association of California

Plenary Discussion (60 mins)

4:35pm **Meeting Synthesis: Opportunities, Next Steps, Feedback (10 mins)**
Speaker: Janet Martinez, Stanford University

4:45pm **Adjourn** for a light reception

GEOPHYSICS IN THE SGMA CONTEXT:
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PARTICIPANT LIST

First Name	Last Name	Organization
Till	Angermann	Luhdorff and Scalmanini Consulting Engineers
Sam	Boland-Brien	State Water Resources Control Board
Tom	Bostick	Army Corps of Engineers (Retired)
Bruce	Cain	Stanford University
Dave	Ceppos	CSUS Center for Collaborative Policy
Allen	Christensen	US Geological Survey
Esther	Conrad	Stanford University
Jesse	Crews	Center for Groundwater Evaluation and Management, Stanford
Bill	Cunningham	US Geological Survey
Frederick	Day-Lewis	US Geological Survey
Claudia	Faunt	US Geological Survey
Paul	Gosselin	Butte County Department of Water & Resource Conservation
Maurice	Hall	Environmental Defense Fund
Thomas	Harter	University of California, Davis
Paul	Hendrix	Tulare I.D.
Roy	Herndon	Orange County Water District
Jeanette	Howard	The Nature Conservancy
Rosemary	Knight	Stanford University
Mark	Larsen	Kaweah Delta WCD
Brian	Lockwood	Pajaro Valley Water Management Agency
Janet	Martinez	Stanford University
Tara	Moran	Stanford University
Gregory	Newman	Lawrence Berkeley Lab
Peter	Nico	Lawrence Berkeley Lab
Tim	Parker	Parker Groundwater Management
Deb	Perrone	Stanford University
Steven	Springhorn	California Department of Water Resources
Leon	Szeptycki	Stanford University
Buzz	Thompson	Stanford University
Marcus	Trotta	Sonoma County Water Agency
David	Walsh	Vista Clara Inc.