Statewide Mapping of California’s Aquifers with Airborne Electromagnetics (AEM)
Presentation Outline

• California Hydrology

• Sustainable Groundwater Management Act and Drivers

• California Statewide AEM Project
  • Stanford Groundwater Architecture Project (GAP)
  • Statewide SGMA Priority Groundwater Basin Mapping Program

• Airborne Electromagnetic (AEM) Geophysics
  • Innovative tool for improved understanding of the hydrogeology of the groundwater basins

• Examples
  • Mapping Regional Hydrogeological Formations
  • Mapping Saltwater Intrusion in Coastal Areas
  • Mapping Brackish Water in Desert Basins
California’s Water Supply: ~15-15-15MAF
GW-SW-Snowpack

MAF = Million Acre Feet = 1.2335 km³

850-1,300 MAF
Groundwater Basins

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CAPACITY

50 MAF
1400 Dams/Reservoirs

Seasonal Snowpack

15 Million Acre Feet
Snow Pack Storage
(1956 - 2000 average)

25% reduction
(4.5 Million Acre Feet)
Mismatch of Precipitation Location to Demand

Nearly one-half precipitation in north portion of state, and nearly one-half demand in south, so a massive surface water conveyance system was constructed.
California Groundwater Use: Normal Years ~ 40 %
Dry Years + 60%

Intensity
- None
- D0 (Abnormally Dry)
- D1 (Moderate Drought)
- D2 (Severe Drought)
- D3 (Extreme Drought)
- D4 (Exceptional Drought)
- No Data

JUNE 18, 2022

Groundwater Basins
Cumulative Change in Storage in GW Basins
Central Valley 1962-2014: Loss of 100 km$^3$ in 52 years

$100 \text{ km}^3 = 81 \text{ MAF} = 26 \text{ Trillion Gallons} = 2,200 \text{ Cubic Feet/Second}$

Ref: USGS
Perfect Storm: 2014 The Year of Groundwater

• Early 2000s Revelations on Nitrate in Central Valley
• Historic Drought with Subsidence, Infrastructure Damage, Dry Wells
• Governor’s Water Action Plan
• $7.5B Water Bond Passed
• Historic Groundwater Legislation (100 years after surface water permitted)
  • Making the invisible groundwater visible
SGMA Steps to Groundwater Sustainability

**Step one**
Form Groundwater Sustainability Agency
June 30, 2017

**Step two**
Develop Groundwater Sustainability Plan
January 31, 2022
January 31, 2020**

**Step three**
Achieve Sustainability 20 years after adoption of plan*
January 31, 2042
January 31, 2040**

* DWR may grant up to two, five-year extensions on implementation upon showing good cause and progress.

** Critically overdrafted basins have two years less for GSP and to achieve sustainability.
Requires Groundwater Sustainability Agencies & Plans

- Required in high and medium priority basins
- Excludes 26 adjudicated basins except for reporting
- Creates state “backstop”
- Sets timeframe for accomplishing goal of sustainable groundwater management
- Raises bar on groundwater management
  - Big driver for state and local agencies to better understand the subsurface
AEM Statewide Project Background – Proof of Concept

Stanford Groundwater Architecture Project

Three 800 km Pilot Projects Conducted:

• Data management system set up for sharing all the datasets
• Integration of digital well data for confirmation
• Aarhus Workbench used for processing, inversion, and visualization of geo-datasets
• Model approaches tested for transform resistivity to lithology and populating cells in the model
• Developed approach for quantifying uncertainty
• Prepared Report and Recommendations for Statewide Program
• Funded by California State Agencies, Kingdom of Denmark, Butte County, San Luis Obispo County, and Indian Wells Valley Water District

https://mapwater.stanford.edu/
Regional-scale AEM surveys in California’s SGMA priority groundwater basins

• Project Goal:
  • Provide a standardize dataset to improve the understanding of large-scale aquifer structures and support the implementation of SGMA.

• Project Objectives
  • Assist local managers implement SGMA to manage groundwater sustainably.
  • Help with the development or refinement of hydrogeologic conceptual models and to identify areas for recharging groundwater.
Regional Mapping of Groundwater Systems

• We need to know more about the subsurface

• Geophysics
Airborne Electromagnetic (AEM)

- Flight height: 30-50 m (100-165 ft)
- Speed: 100 km/hr (60 mph)
- Daily production: 200 line-km/day (125 line-miles)
- Depth: 200-300 m (650-1,000 ft)
- No need for direct contact to the ground / fast data acquisition
- AEM Line spacing
  - Focused studies – 250m to 500 m
  - Regional scale – 1 to 2 km or more
A recent AEM survey in California
AEM Principles

- Transmitting signal into the ground
  - TEM system – sender and receiver
  - Magnetic data acquisition system
  - Two inclinometers
  - Two altimeters
  - Two Differential GPS units
  - Video camera on helicopter
AEM Principles

• Receiving Earth’s response
What does AEM measure?

- Electrical resistivity of the formation

![Graph showing typical relationship between resistivity, lithology, and salinity](chart.png)
DWR Statewide AEM Surveys

- AEM Flightline Planning conducted by DWR with input from local, state, and federal agencies on priority areas
- AEM Flightline Plans are reviewed by Ramboll, SKYTEM and Sinton Helicopters and adjusted as needed for potential interferences and safety
- AEM Field Surveys conducted by Ramboll, SKYTEM, Sinton Helicopters
- Ramboll conducts AEM data processing and inversions with assistance from Aarhus University; GEI provides support on datasets, GIS and reporting; Eclogite and RAS provide existing well lithology and borehole geophysics datasets for quality assurance/ control
- Data collected in coarsely spaced grid (2 by 8-mile grid)
AEM Survey Deliverables

• Comprehensive Data Reports
  • Methodologies and Field Collection Observation/Metrics

• GeoDatasets
  • AEM inversion & lithology transform
  • Nearby well lithology, water level, water quality (TDS) data
  • All data digital, delivered online and publicly available

https://water.ca.gov/Programs/Groundwater-Management/Data-and-Tools/AEM
Digitization of well completion reports and geophysical logs for use in validation
Survey Status To Date

- Surveyed flight lines: 22,225 km
AEM Electrical Resistivity Model

Northern Central Valley
AEM Electrical Resistivity Model

North Coast Ranges
Basin-Wide Regional Aquifer Structure

Salinas Valley

120 miles

40 miles
Data Report and Dataset Publication

**Data and Resources**

<table>
<thead>
<tr>
<th>Survey Area Map</th>
<th>Map showing Survey Areas</th>
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<tbody>
<tr>
<td>Survey Area 1 - Salinas Valley Data Report</td>
<td>Provisional Data Report for the Salinas Valley portion of Survey Area 1.</td>
</tr>
<tr>
<td>Survey Area 1 - Cayucos Valley Data Report</td>
<td>Provisional Data Report for the Cayucos Valley portion of Survey Area 1.</td>
</tr>
<tr>
<td>Survey Area 1 - Flown Survey Lines</td>
<td>Provisional from flight lines for Survey Area 1</td>
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<tr>
<td>Survey Area 1 - Salinas Valley AEM Data</td>
<td>Provisional AEM data package containing provisional AEM data acquisition parameters, raw and inverted AEM...</td>
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<td>Survey Area 1 - Support Data</td>
<td>Data package of compiled supporting data used to support the AEM data interpretation, including...</td>
</tr>
<tr>
<td>Survey Area 2 - Flown Survey Lines</td>
<td>Provisional from flight lines for Survey Area 2</td>
</tr>
<tr>
<td>Survey Area 2 - AEM Data (limited)</td>
<td>Provisional AEM data package containing provisional AEM data acquisition parameters, raw and inverted AEM...</td>
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<tr>
<td>Survey Area 2 - Support Data</td>
<td>Data package of compiled supporting data used to support the AEM data interpretation, including...</td>
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<tr>
<td>Survey Area 3 - Flown Survey Lines</td>
<td>Provisional from flight lines for Survey Area 3</td>
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<tr>
<td>Survey Area 3 - Raw Data</td>
<td>Raw Data from Survey Area 3</td>
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<tr>
<td>AEM Data Viewer</td>
<td>The AEM Data Viewer shows resistivity data from 01_KYZ_AEM 02_Sharp VLF 03IP...</td>
</tr>
</tbody>
</table>

**Report**

https://data.cnra.ca.gov/dataset/aem

**AEM Data**

- 01_Raw Data
- 02_Database
- 03_Sections and Thematic Maps
- 04_KYZ_Data
- Readme
- Readme_DWR_Disclaimer

**Supporting Data**

- AEM_WELL_INFO.csv_W01_2022
- AEM_WELL_LITHOLOGY.csv_W01_2022
- AEM_WELL_WATER_LEVEL.csv_W01_2022
- AEM_WELL_WATER_QUALITY.csv_W01_2022
- Geophysics_W01_20221113
- ReadMe
- Readme_DWR_Disclaimer
Example – Indian Wells Valley, Mojave Desert

- Objectives:
  - Delineate the extent of brackish water
  - Connectivity between upper and lower aquifer
  - Map other notable basin structures and features, e.g. faults, buried stream channels, recharge
  - Update hydrogeologic conceptual framework
Connectivity Along Eastern Sierra Nevada Mountain Front
Interpretation of Structures and Lithology

- **Miocene Ricardo Group.**
- **Pleistocene Alluvium**
- **Hydrological barrier dividing the groundwater basin**
- **Potential infiltration sites**
- **Sierra Nevada Frontal Fault**
- **Brackish**
- **Saturated Clay**
- **Sand and gravel**
- **Unsaturated**
- **Bed rock**
Example – Monterey Bay, CA

• **Goal**: improve understanding of freshwater-saltwater interaction in a coastal environment

• 200 line-miles of near shore survey
2 TO 4 M B.S.L.
30 TO 35 M B.S.L.
Goebel Meredith, Knight Rosemary, Halkjær Max, (2019), Journal of Hydrology, Mapping saltwater intrusion with an airborne electromagnetic method in the offshore coastal environment, Monterey Bay, California
Local, Site-Specific Investigations

• Managed Aquifer Recharge
• Geotechnical

• Assess site suitability for infiltration
  • Detect high-K zones
  • Vertical hydraulic connectivity across the site
  • Complex geology (buried channels, thin impermeable layers, ...)

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Local, Site-Specific Investigations
Ideal for Shallow (<200m) Subsurface Survey
Local, Site-Specific Investigations

• Detailed 3D characterization of the subsurface
Thank You

Bright ideas. Sustainable change.

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