Developing Science Based Scalable Approaches to Groundwater Banking

Groundwater is critical to life in California (and much of the world) and current use is unsustainable.

By law and by necessity groundwater management must change.

Science based management practices are lacking.

Berkeley Lab expertise can help fill the need.

Gregory A. Newman
Lawrence Berkeley National Laboratory
Groundwater is Critical to Life in California and Current Use is Unsustainable

Normal Year ~29%
Dry Year ~39%
Drought Year ~60%

Overdraft ~1-2 million AF/yr

Groundwater Level Change Spring 2012 to Spring 2015

1. Total Water Use is defined as the sum of water uses for agricultural, urban, and managed wetlands.
Groundwater Recharge or Banking: building a rainy sunny day fund

Precipitation Comes in Pulses

How to connect short term extreme events to long term groundwater storage?

Groundwater Managed Long-term

Subsurface Process Knowledge and Modeling:
Geophysical imaging
Hydro-Chem-Mechanical Modeling
Groundwater Recharge or Banking: building a rainy sunny day fund

Use Existing Infrastructure and Agriculture Lands to Restore Groundwater ($40-107 AF)?

Where is there suitable subsurface for banking?

Where will banked groundwater go?

How long will it take to get there?

What will be the water quality?

How will it impact energy use and subsidence?

How much current and future overdraft can be met by different GW banking strategies? (coupled hydroclimate)

What will be the impact on the surface water system Delta?
Detailed Knowledge of Surface Soil Properties and Suitability

Soil Agricultural Groundwater Banking Index
- Excellent
- Good
- Moderately good
- Moderately poor
- Poor
- Very poor

Map showing the distribution of soil agricultural groundwater banking index across California, with various regions colored to represent different soil suitability levels. The map includes major cities and geographic features.
Course Knowledge of Subsurface Suitability
Scalable Approach to Water Banking Validation and Verification

1. **Site**: CVHM, CASGEM, Well logs
2. **Initial Hydrologic Model**
3. **Data Worth Analysis**
   - **Geophysical Imaging**
     - Surface wave tomography (SWT) and electrical resistivity tomography (ERT)
   - **Water Application**
     - Water Fate based on Characterization and refined hydrologic model
4. **Cross Validation**
5. **Upscaling**
   - **Wider Region**
   - **To Local Region**
   - Additional site selection using new insights, CVHM regions, results from ETA-CEC GW Pumping Project
   - InSAR surface deformation for mechanical impacts and regional context
6. **Upscaling**
   - Build Reactive network into hydrological model by assigning reactivity to geophysical data structure

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**Berkeley Lab**
Scalable Approach to Water Banking Validation and Verification

Where is there suitable subsurface for banking?

Water Fate based on Characterization and refined hydrologic model

Build Reactive network into hydrological model by assigning reactivity to geophysical data structure

Cross Validation

InSAR surface deformation for mechanical impacts and regional context

Upscaling to local region

Ini.al hydrologic model in Tough2

CVHM CASGEM Well logs

Data Worth Analysis

Initial hydrologic model in Tough2

Geophysical Imaging

Surface wave tomography (SWT) and electrical resistivity tomography (ERT)

Water Application

Upscaling Wider region

Site

Discontinuous Clay Rich Zones

Additional site selection using new insights, CVHM regions, results from ETA-CEC GW Pumping Project

Surface wave tomography (SWT) and electrical resistivity tomography (ERT)

Discontinuous Clay Rich Zones

electrical conductivity map
Scalable Approach to Water Banking Validation and Verification

Site

CVHM
CASGEM
Well logs

Initial hydrologic model

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Electrical Resistivity Tomography for Almond Groundwater Banking
Geophysical Monitoring of Subsurface Processes

Differencing of geophysical data collected over time highlights changes due to Natural or engineered hydrological or biogeochemical transformations.

Geophysical Imaging can provide understanding of the control of heterogeneity on induced Transformations over field-relevant scales.
ERT for Water Infiltration Studies

Demonstrated sensitivity of resistivity to changes in soil water content

Rain water infiltration $\Delta \rho$ over time

Irrigation water infiltration $\Delta \rho$ over time

Suzuki and Higashi 2001

Barker and Moore 1998
Surface Wave Tomography for Almond Groundwater Banking
Surface Wave Tomography for Almond Groundwater Banking

- Depth
- Velocity
- Surface Waves
- Distance (x)
- Time ($t_x$)
- Slope $= \frac{1}{V_1}$
- $V_3 < V_2 < V_1$

Graph showing surface waves and their dispersion with depth and distance.
Surface Wave Tomography

4.5 Hz vertical geophones

RECEIVER

~240 cubic ft imaged per hr

10 ft

SOURCE

MiniVib
4-80 Hz

SOURCE

CE

S

BERKELEY LAB
Surface Wave Tomography Example -- Abandoned Mine Sites
Groundwater Banking Test Sites

New Collaboration with UC Davis & Almond Board of California

Delhi Site:
Very Sandy down to 10 ft
dry
Fast infiltration

Modesto Site:
Clay rich, confining layer at 7 ft
Wet
Slow infiltration
Vadose Zone
Hydrological Transport

- Poorly understood

- Transport is controlled by heterogeneous deposits that are geologically chaotic in nature

- Understanding is necessary for proper groundwater stabilization strategies of subsurface aquifers
Vadose Zone Characterization

- Mapping of Geological Heterogeneities
- Identification of Transport/Permeable Pathways
- Identification of Potable Waters
Relevant Geophysical Methods

• Cross Well EM
• Surface Methods
  – Transient EM
  – Surface Nuclear Magnetic Resonance
• Airborne EM
• Surface Seismics