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

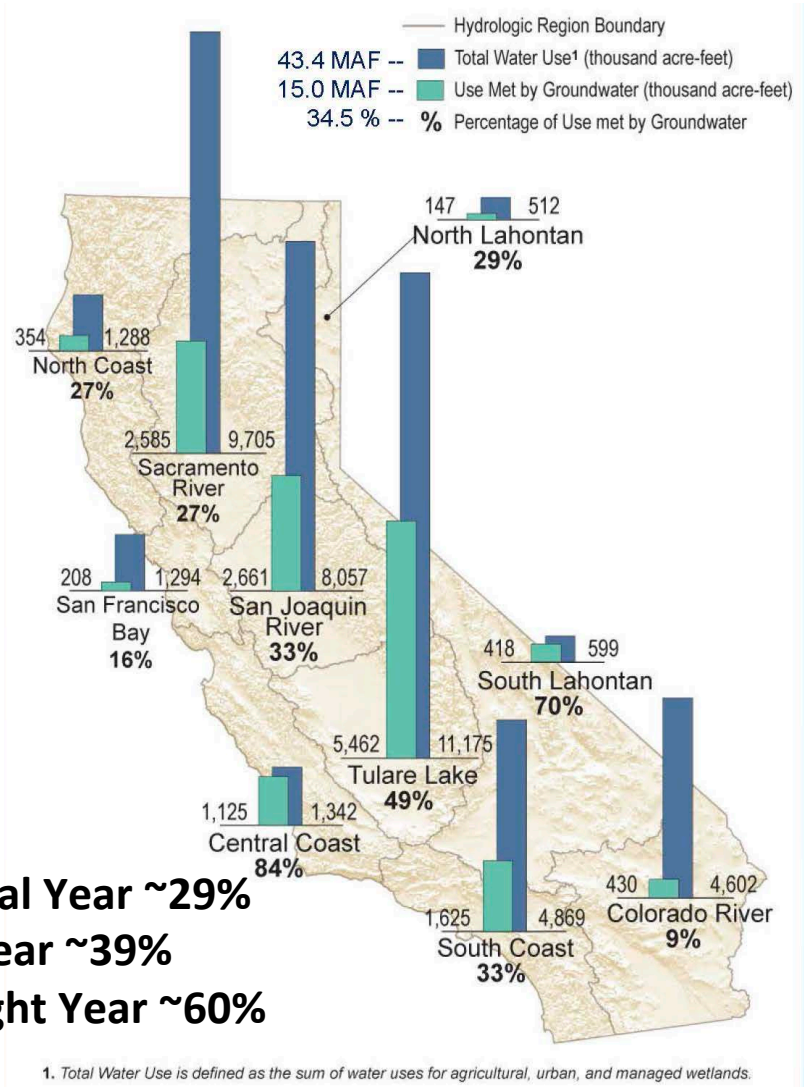
Science based management practices are lacking

Berkeley Lab expertise can help fill the need

Gregory A. Newman

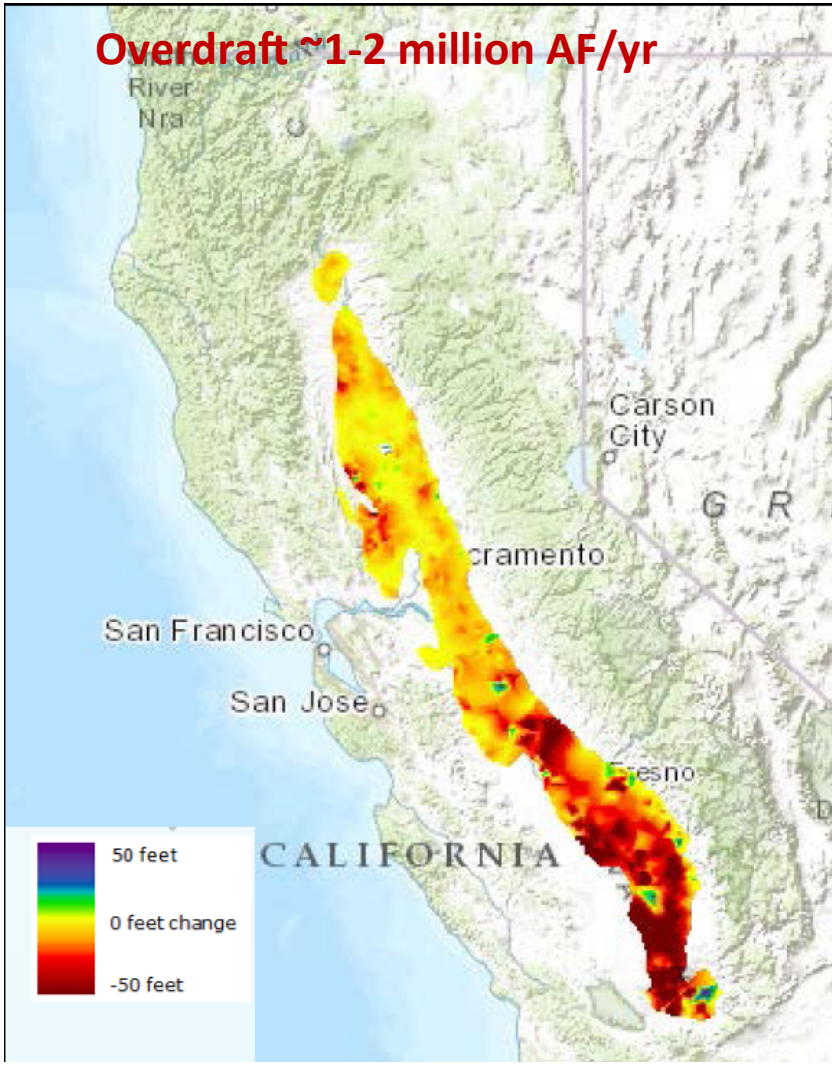
Lawrence Berkeley National Laboratory

Groundwater is Critical to Life in California and Current Use is Unsustainable



1. *Total Water Use is defined as the sum of water uses for agricultural, urban, and managed wetlands.*

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



Groundwater Level Change Spring 2012 to Spring 2015

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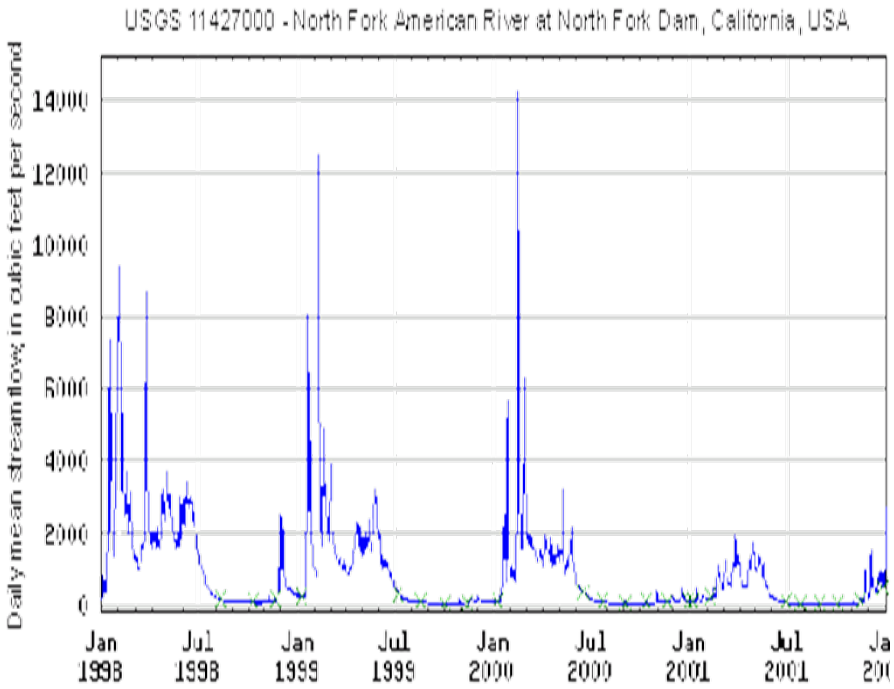
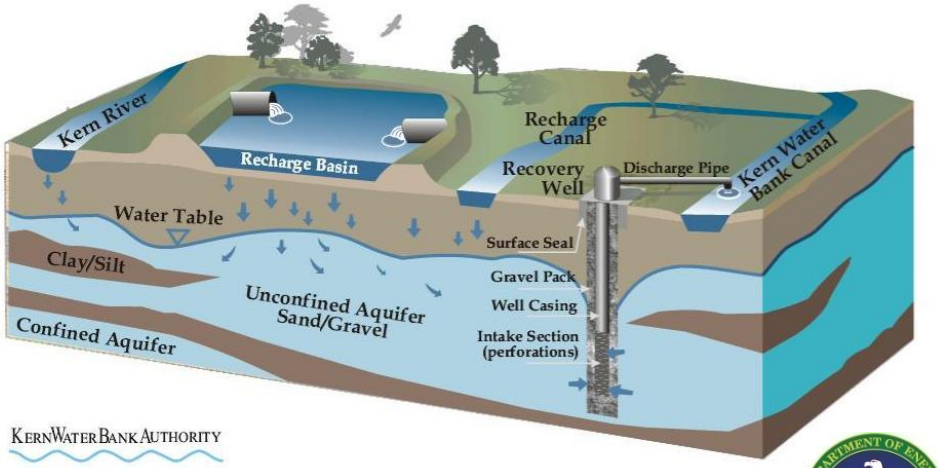
Groundwater Recharge or Banking: building a ~~rainy~~ sunny day fund

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

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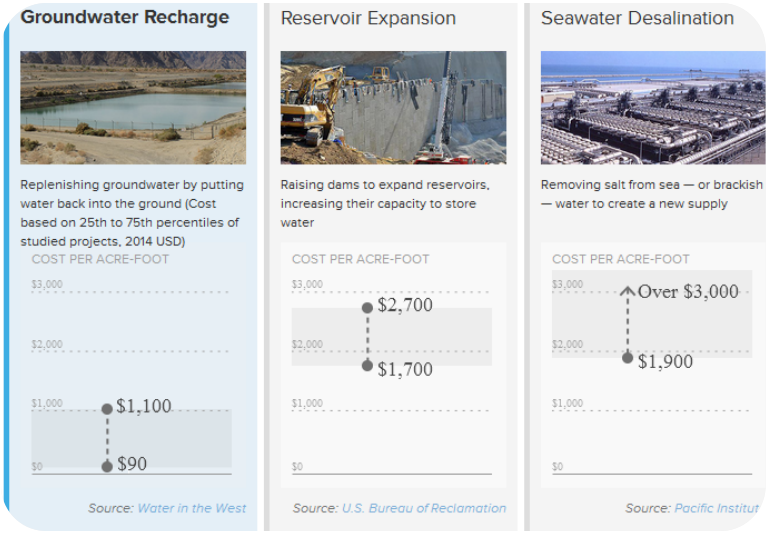
Groundwater Recharge or Banking: building a ~~rainy~~ sunny day fund



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?

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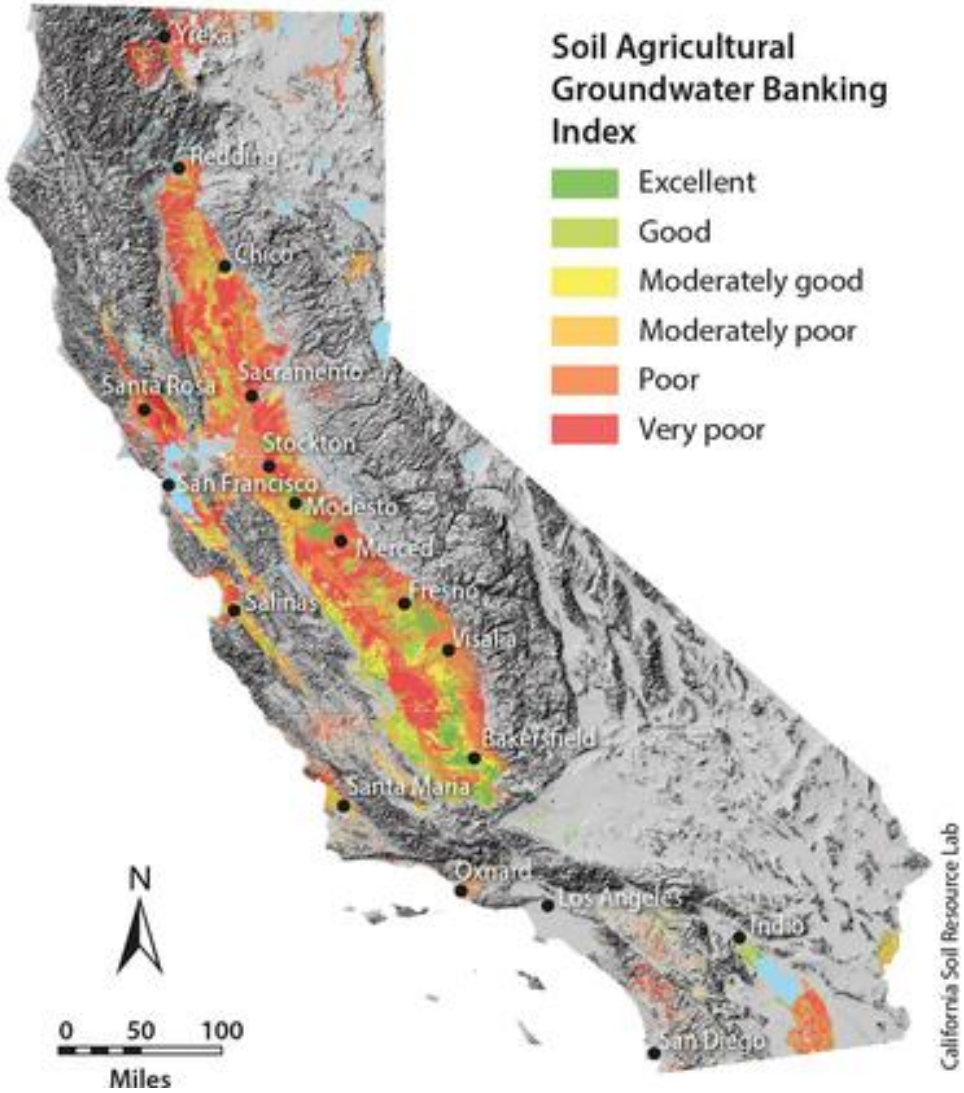
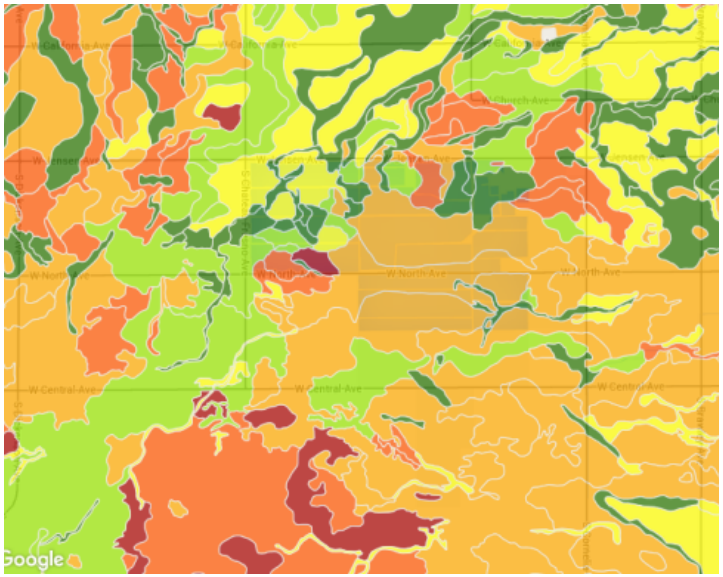
Detailed Knowledge of Surface Soil Properties and Suitability



10 km



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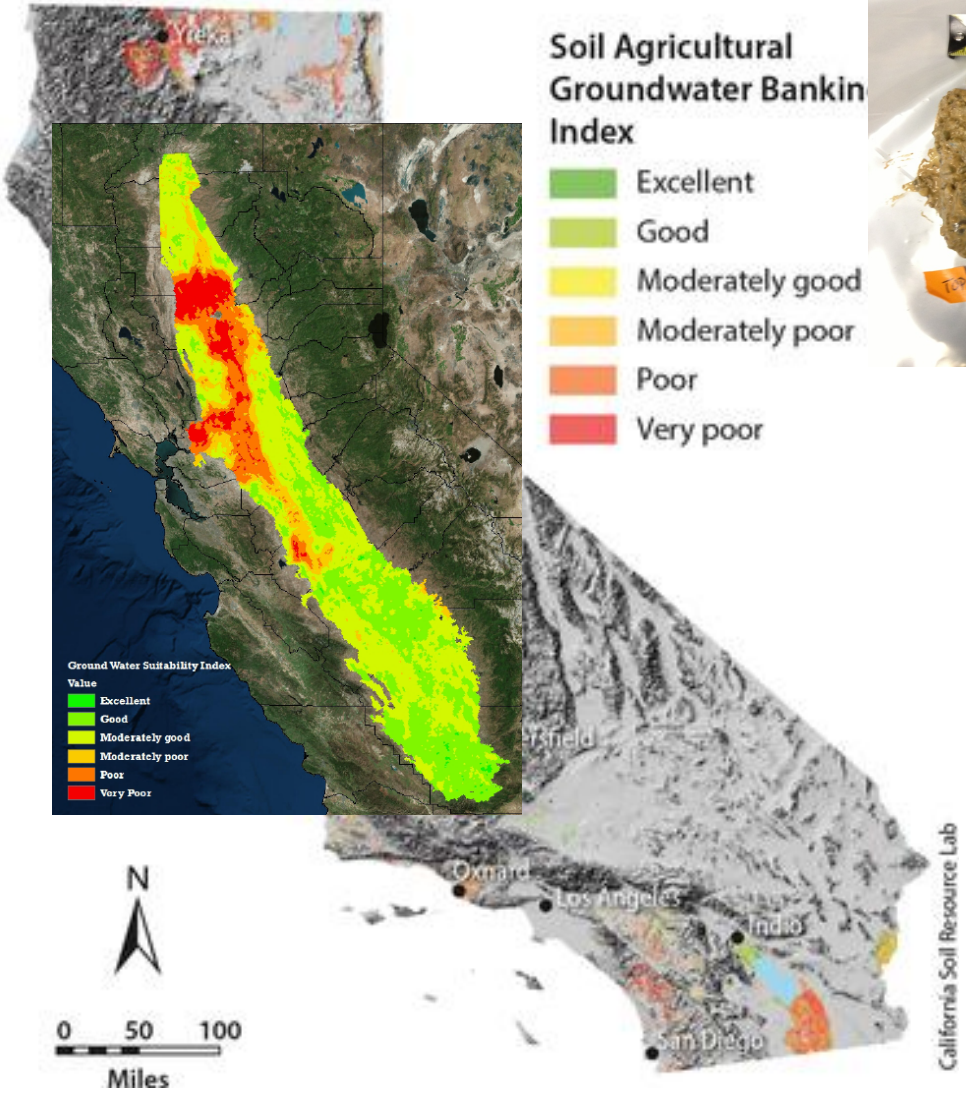
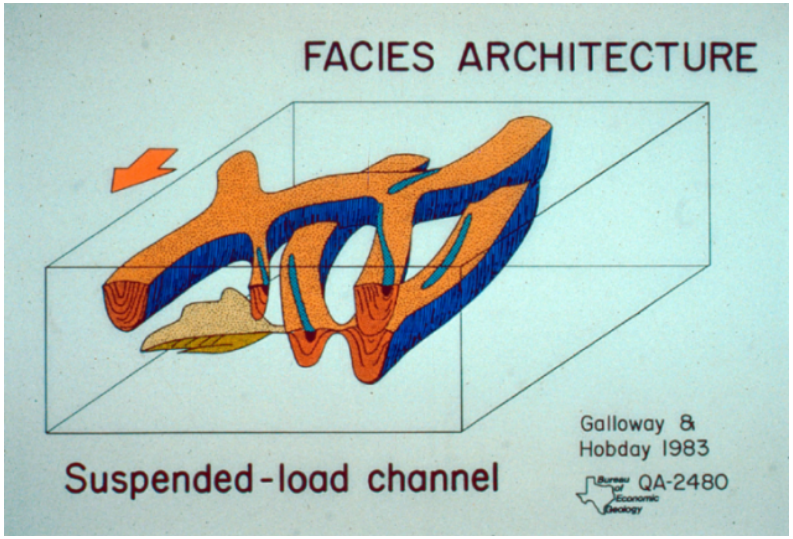
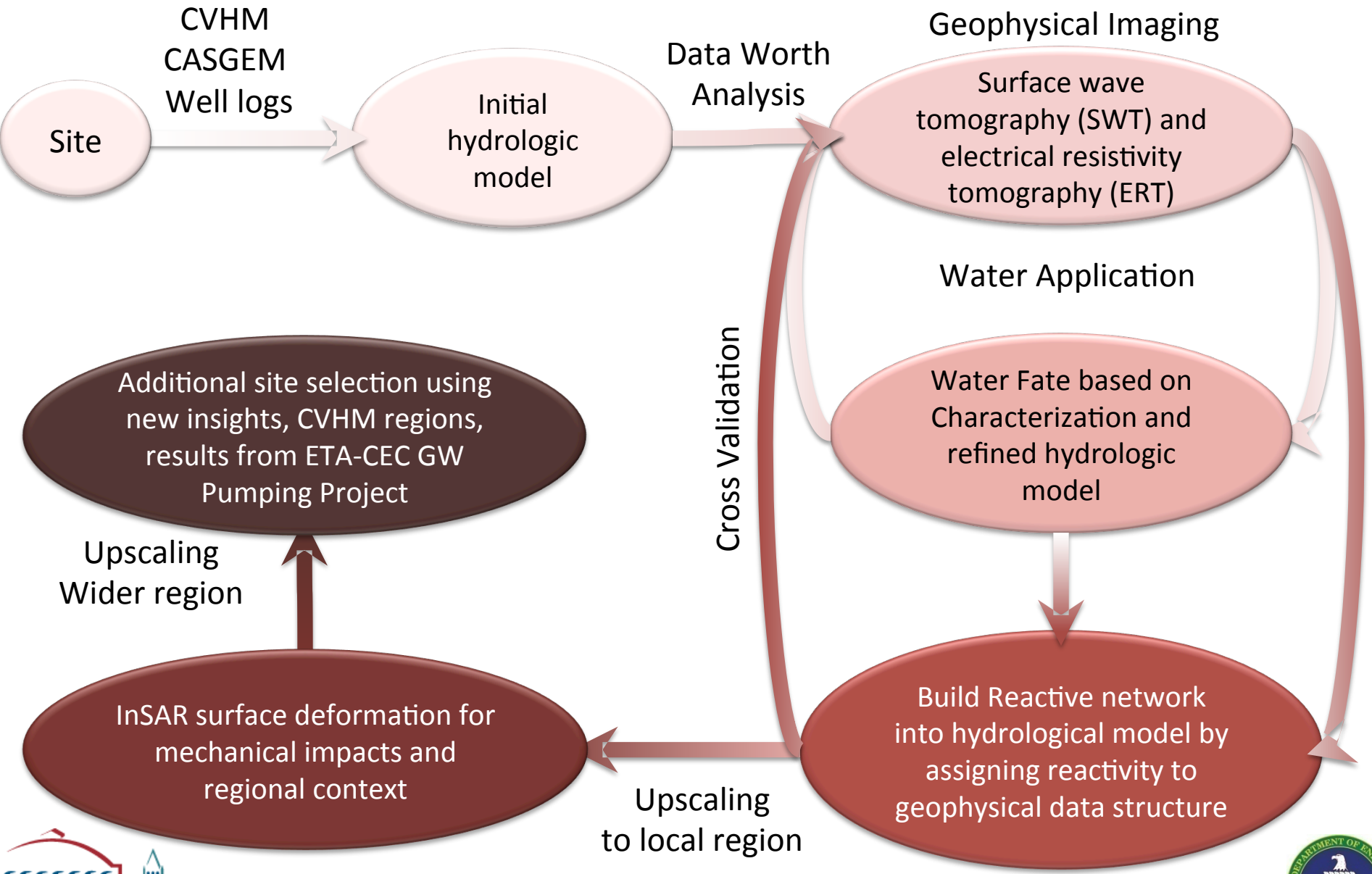
Course Knowledge of Subsurface Suitability





Scalable Approach to Water Banking Validation and Verification



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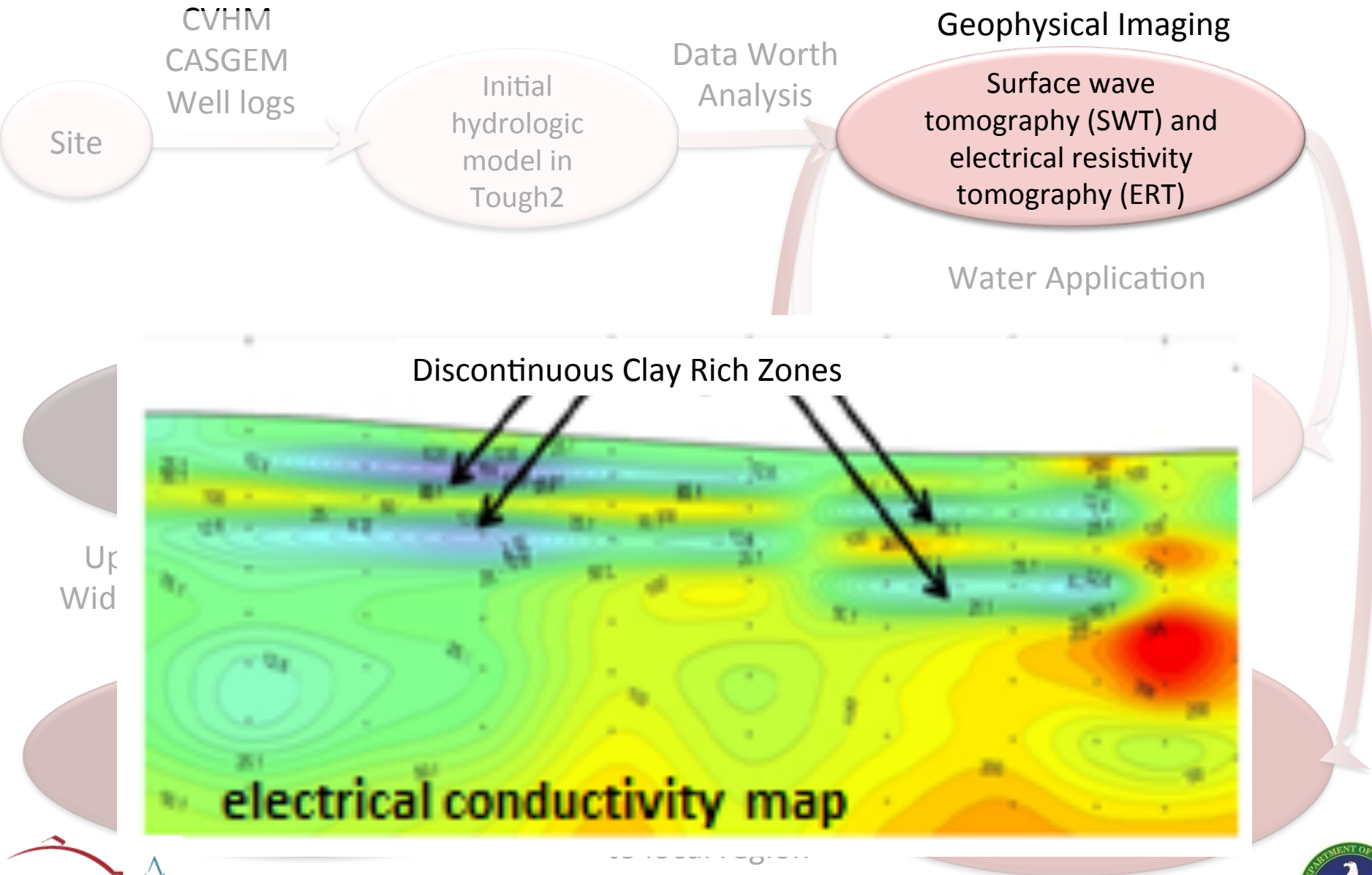


Scalable Approach to Water Banking Validation and Verification

CVHM
CASGEM
Well logs

Site

Initial hydrologic model

Data Worth Analysis

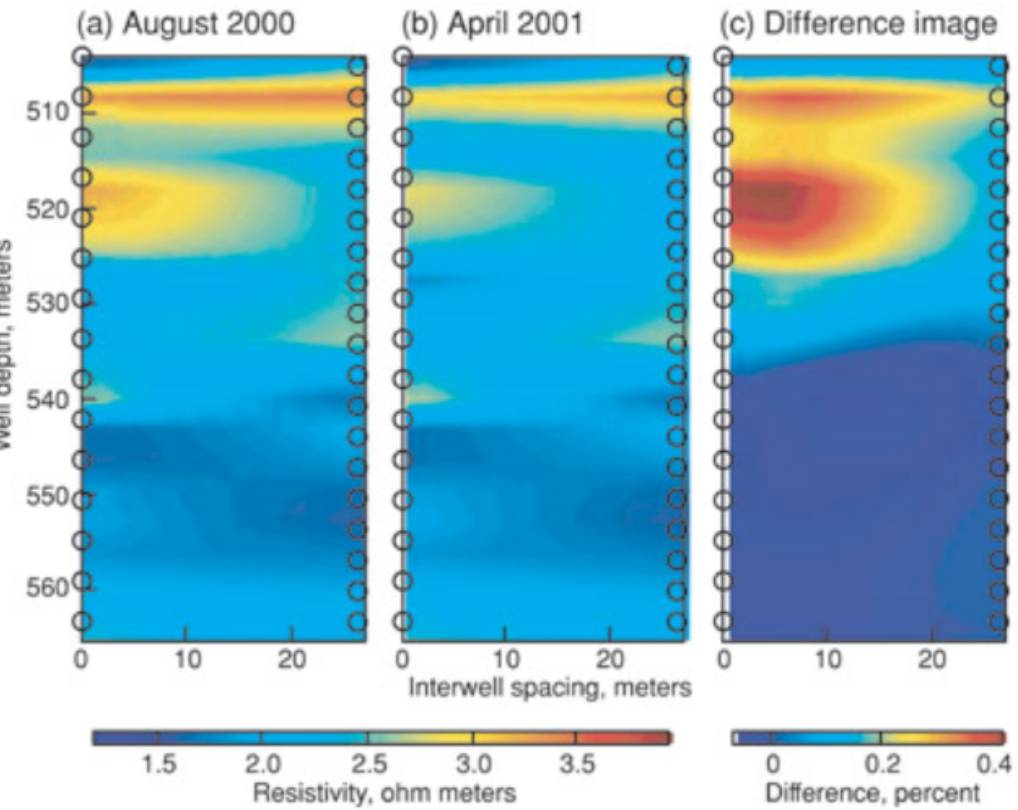
Geophysical Imaging

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

Water Application

Water Fate based on Characterization and refined hydrologic model

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



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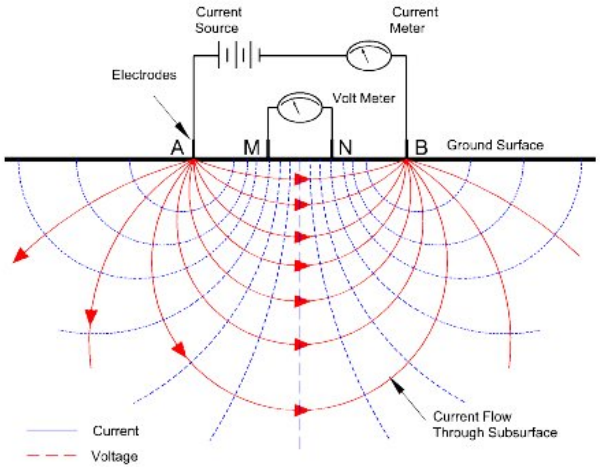
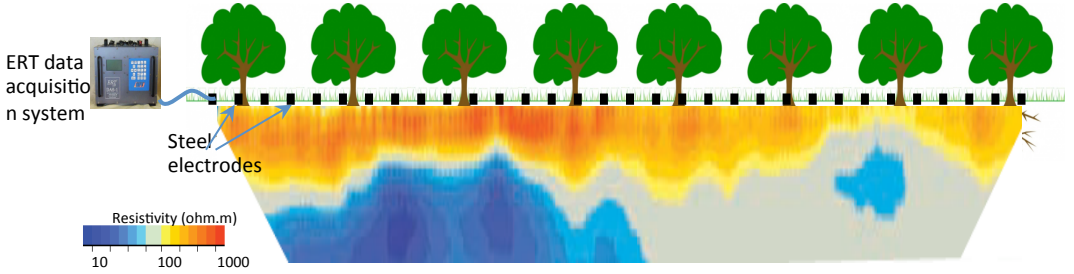
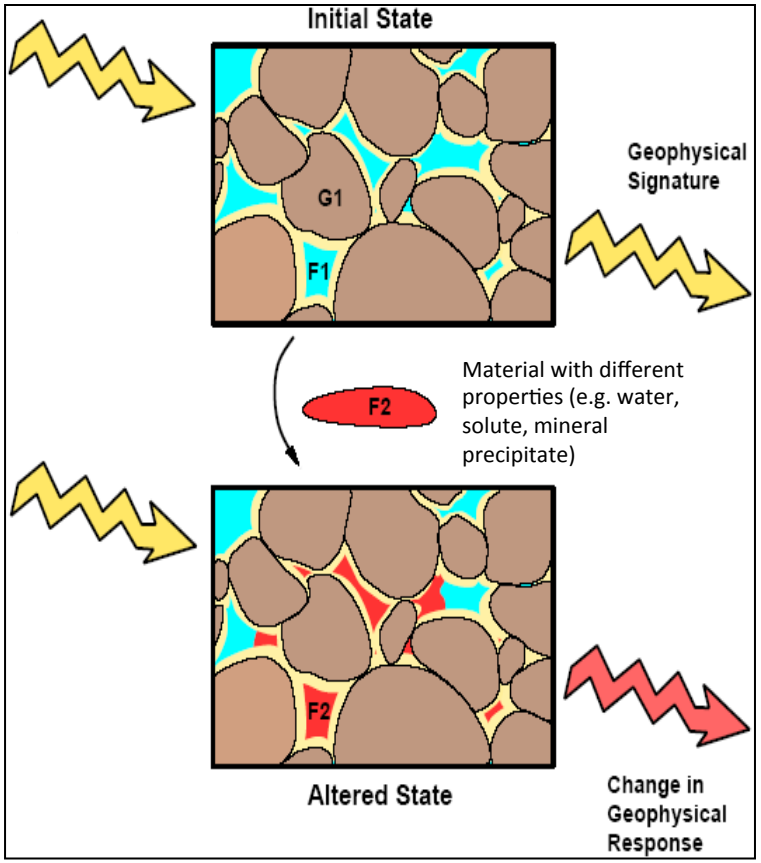
Electrical Resistivity Tomography for Almond Groundwater Banking



		Electrodes array	K
2D	Wenner	A–a–M–a–N–a–B	2πa
	Wenner-Schlumberger	A–na–M–a–N–na–B	πn(n+1)a
	Dipole-Dipole	A–a–B–na–M–a–N	πn(n+1)(n+2)a
	Pole-Pole	B–x–A–a–M–x–N	2πa
	Pole-Dipole *Forward*	A–na–M–a–N	2πn(n+1)a
	Reversed	M–na–N–a–A	
3D	Square	A–B, a, M–N	2πa / 2- √2



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**

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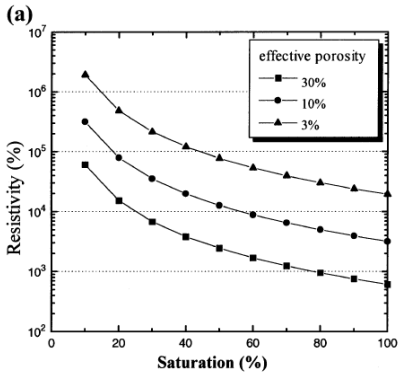
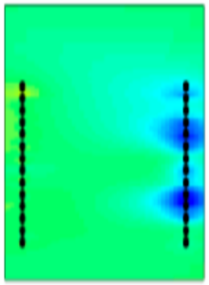
ERT for Water Infiltration Studies

Demonstrated sensitivity of resistivity to changes in soil water content

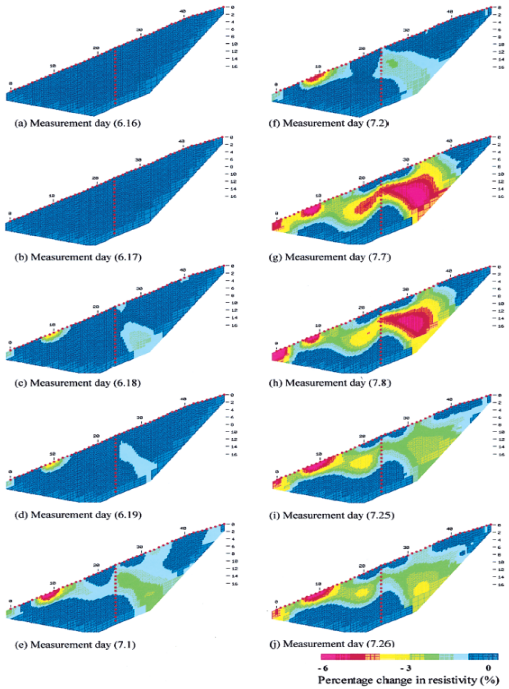


Surface based
Large spatial coverage



Cross well
Better vertical resolution

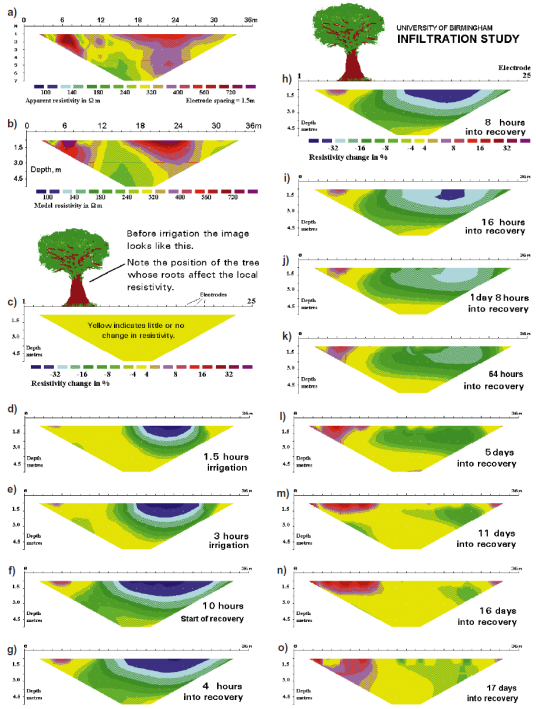
Rain water infiltration
$\Delta\rho$ over time



Suzuki and Higashi 2001

Time

Irrigation water infiltration
$\Delta\rho$ over time



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Barker and Moore 1998

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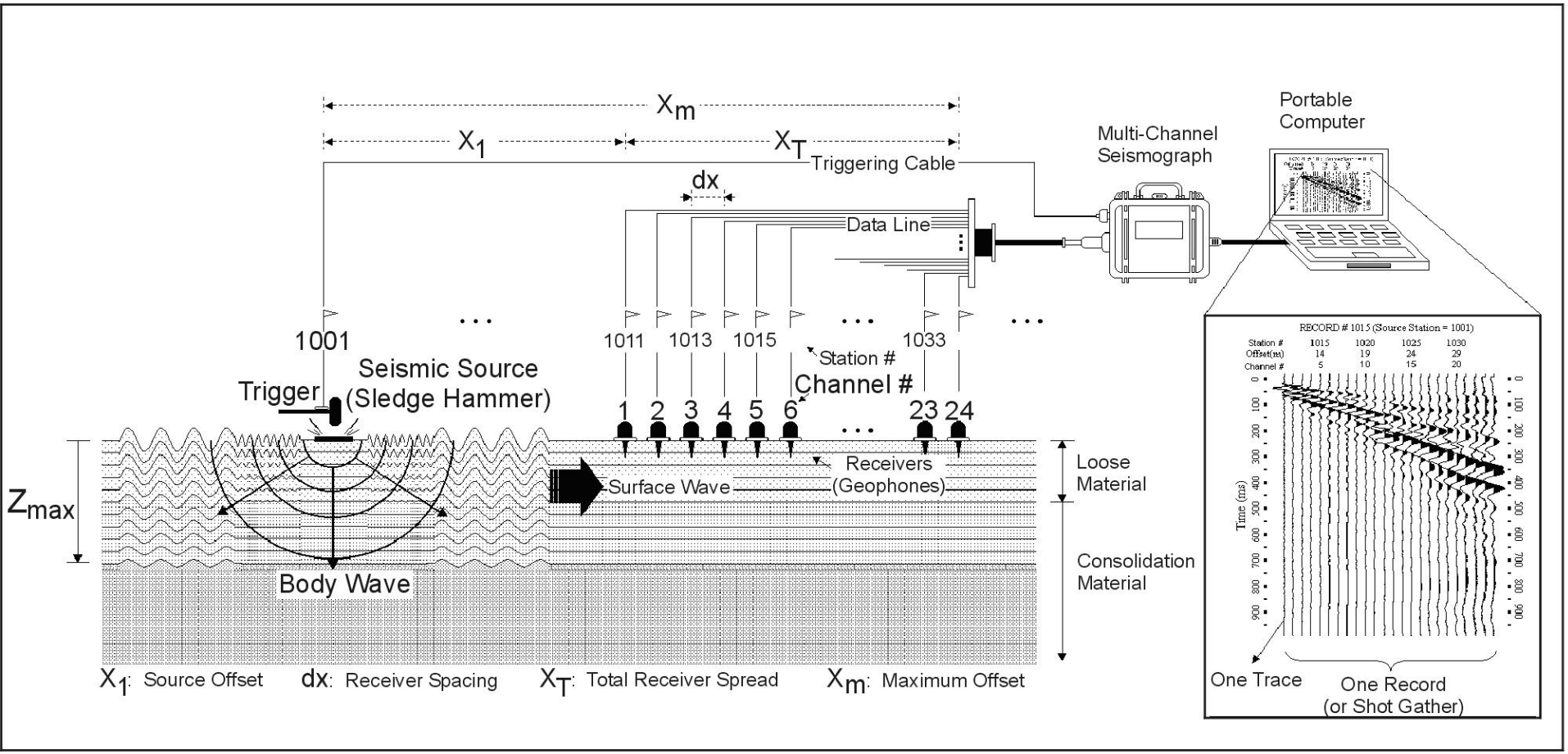
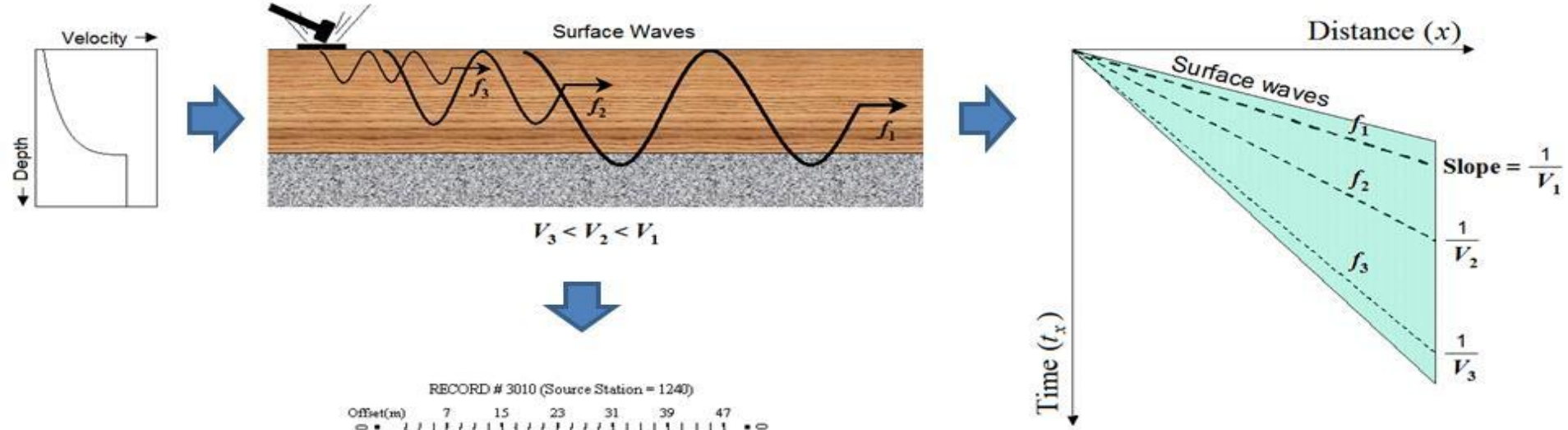
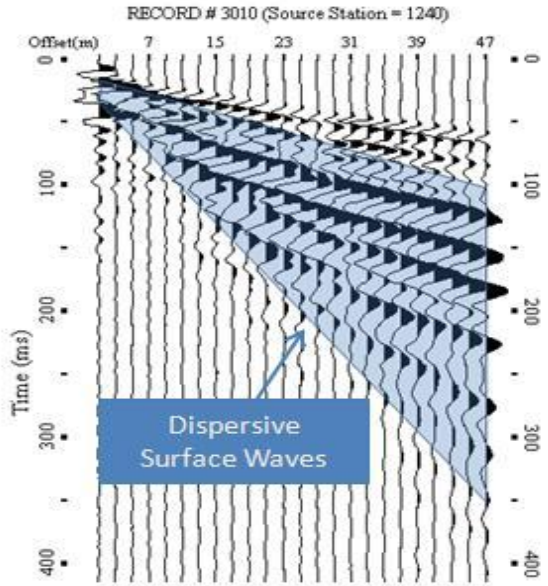
Surface Wave Tomography for Almond Groundwater Banking



Surface Wave Tomography for Almond Groundwater Banking





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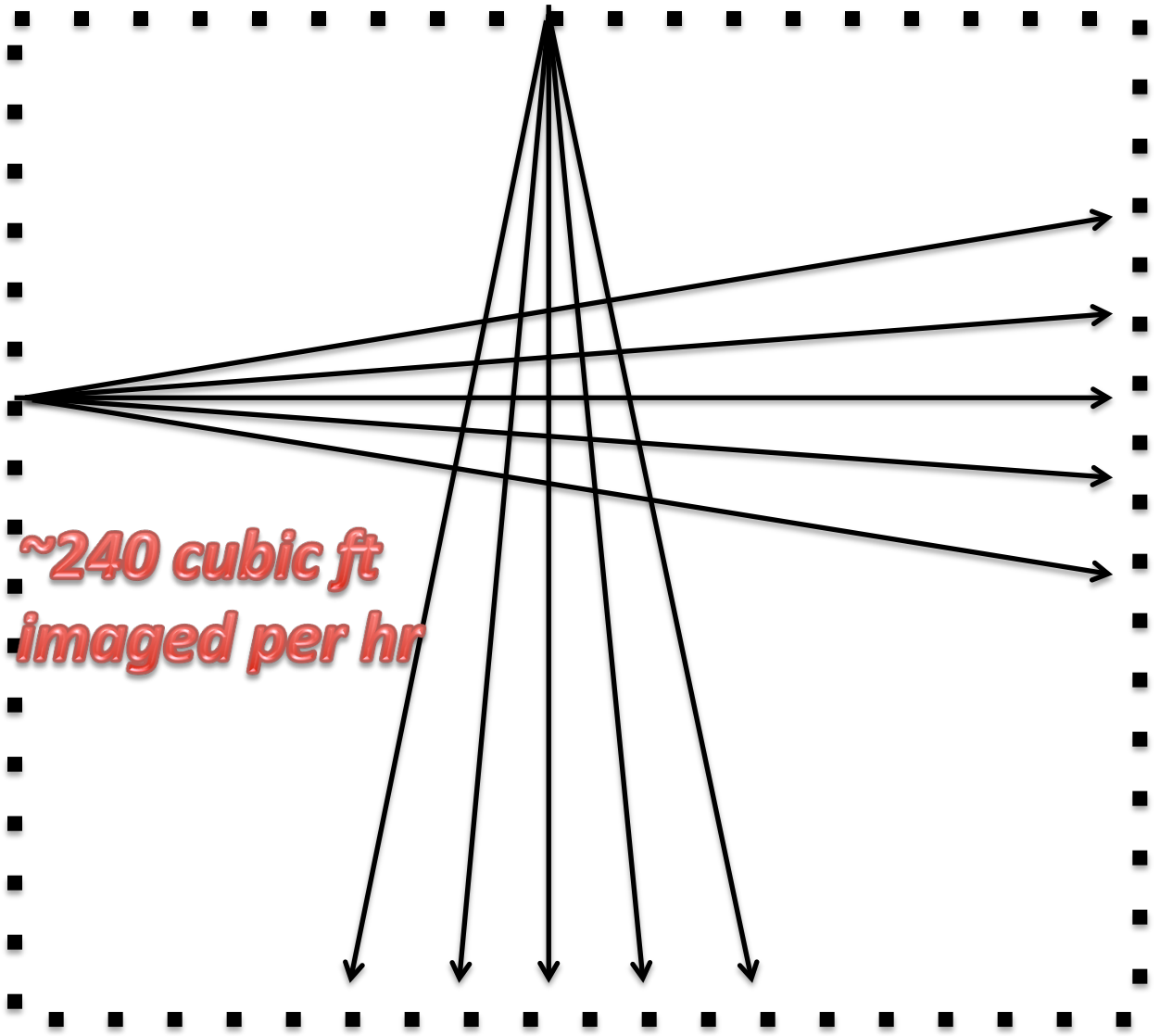
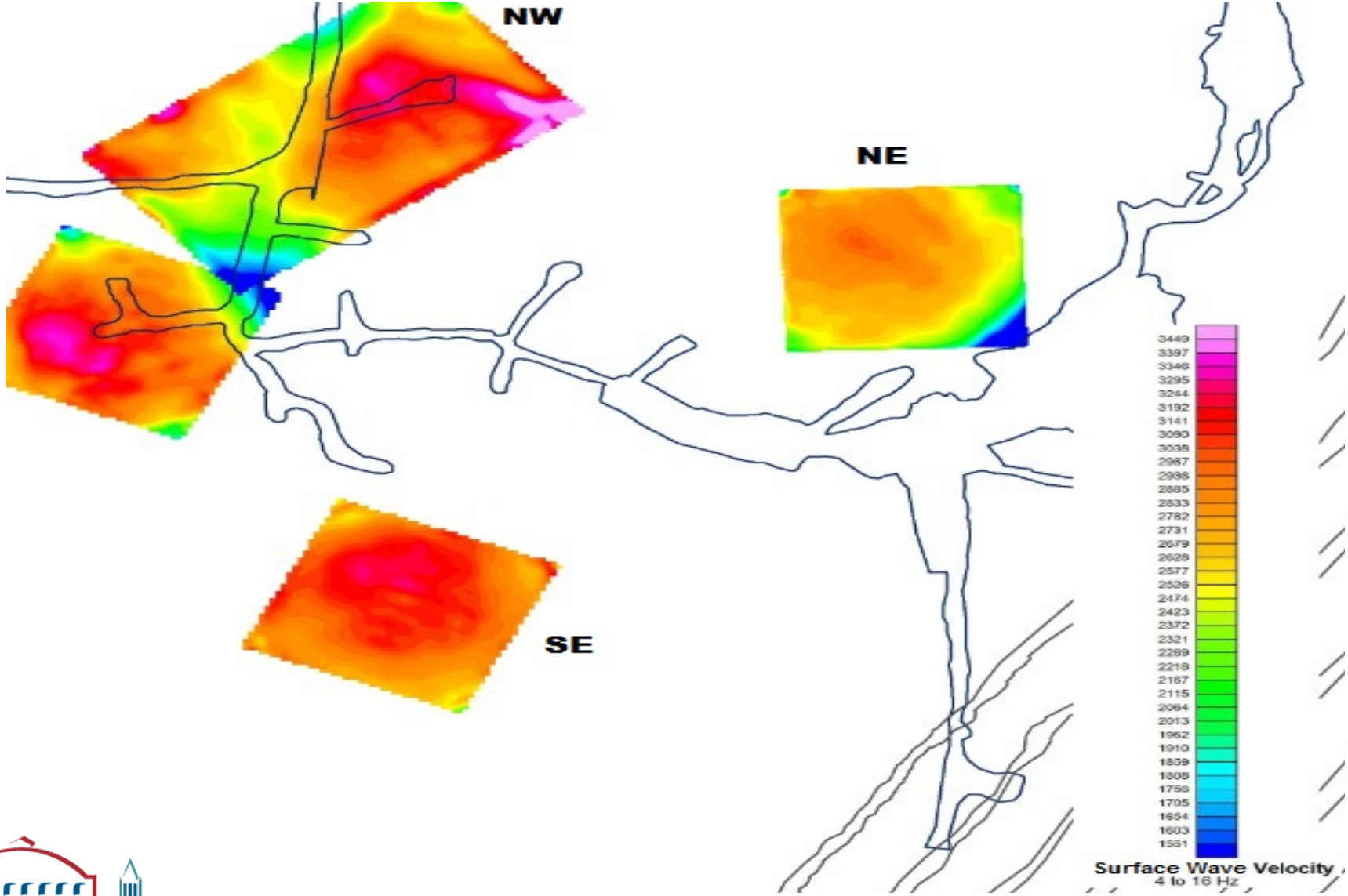
Surface Wave Tomography



Surface Wave Tomography Example -- Abandoned Mine Sites



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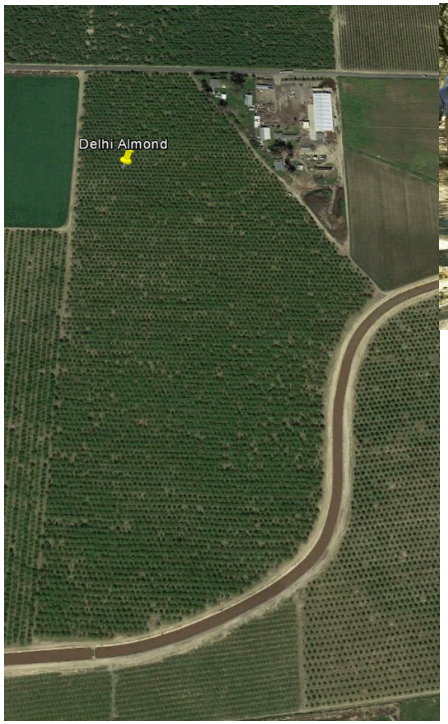
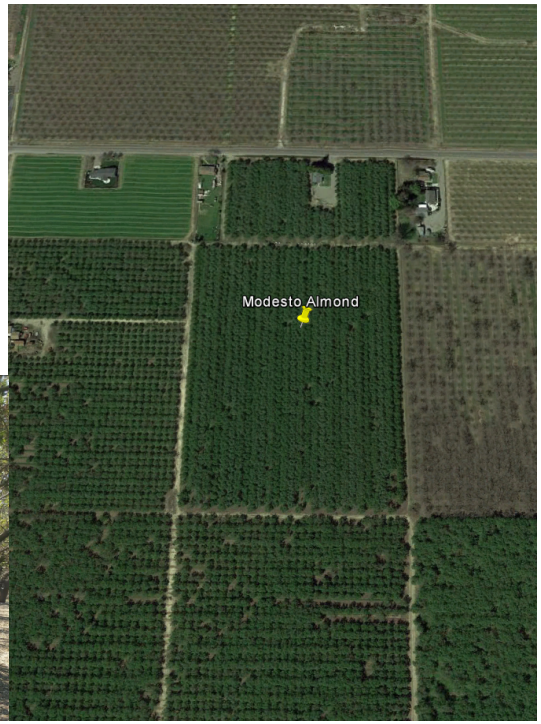
Groundwater Banking Test Sites

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 7ft Wet
Slow infiltration

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Vadose Zone
Hydrological Transport

- Poorly understood
- Transport is controlled by heterogeneous deposits that are geologically that can be 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