Characterizing, Quantifying, and Optimizing Groundwater Recharge at a CA Almond Orchard Flood-MAR Site

Craig Ulrich[1], Sebastian Uhlemann[1], Baptiste Dafflon[1], Michelle Newcomer[1], Yuxin Wu[1], Hannah Waterhouse[2], Helen Dahlke[2], Peter S. Nico[1], and Peter Fiske[1]

[1]Lawrence Berkeley National Laboratory, [2]University of California, Davis

PRESENTED AT:

BACKGROUND

As a result of climate change, California is experiencing the impact of more extreme weather patterns including longer drought periods and atmospheric rivers resulting in extreme snow pack and heavy flood flows. CA faces a significant challenge to mitigate these impacts while simultaneously providing resilient sources of water under uncertain future conditions. Future meteorological climatic forecasts indicate episodic drought years followed by short wet years that will require GSAs to be strategic in capturing water and infiltrating it into aquifers during sparse wet years. One approach that addresses both flood mitigation and water storage is the use of Managed Aquifer Recharge (MAR). Specifically, Flood-MAR entails diverting surface water from high river flows during the rainy season onto agricultural lands for spreading and infiltration. Determining where to divert the water and recharge efficacy is often a big unknown. This study was conducted at a 14-acre almond orchard in Modesto, CA and used geophysics (ERT and seismic) to characterize and monitor recharge; and integrated modeling codes to quantify infiltration/recharge during multi-year water application events. Geophysical and soil core data were used to characterize the subsurface. Spatially distributed clayey and sandy soil zones were observed across the study area both extending from the surface to 40 ft below the surface. Timelapse resistivity collected during single water application events showed complex infiltration patterns with fast paths conveying most of the water to depths greater than 40 ft within days of application. Timelapse resistivity data coupled with novel fate and transport codes permitted the quantification of spatially dense recharge rates along the resistivity profiles that ranged from <0.34 ft/day in clays to double that (0.72 ft/day) in sandy soils. 3D seismic and resistivity data coupled with soil core information permitted the extrapolation of total recharge volume along the resistivity profile (0.02 acre-ft/day, 2017) to the entire flooded area which resulted in total estimated recharge, during a single application event, of 1.68 acre-ft. This new non-invasive method offers farmers and water managers a way to more accurately understand and quantify the amount of water recharged that reached the unconfined aquifer.

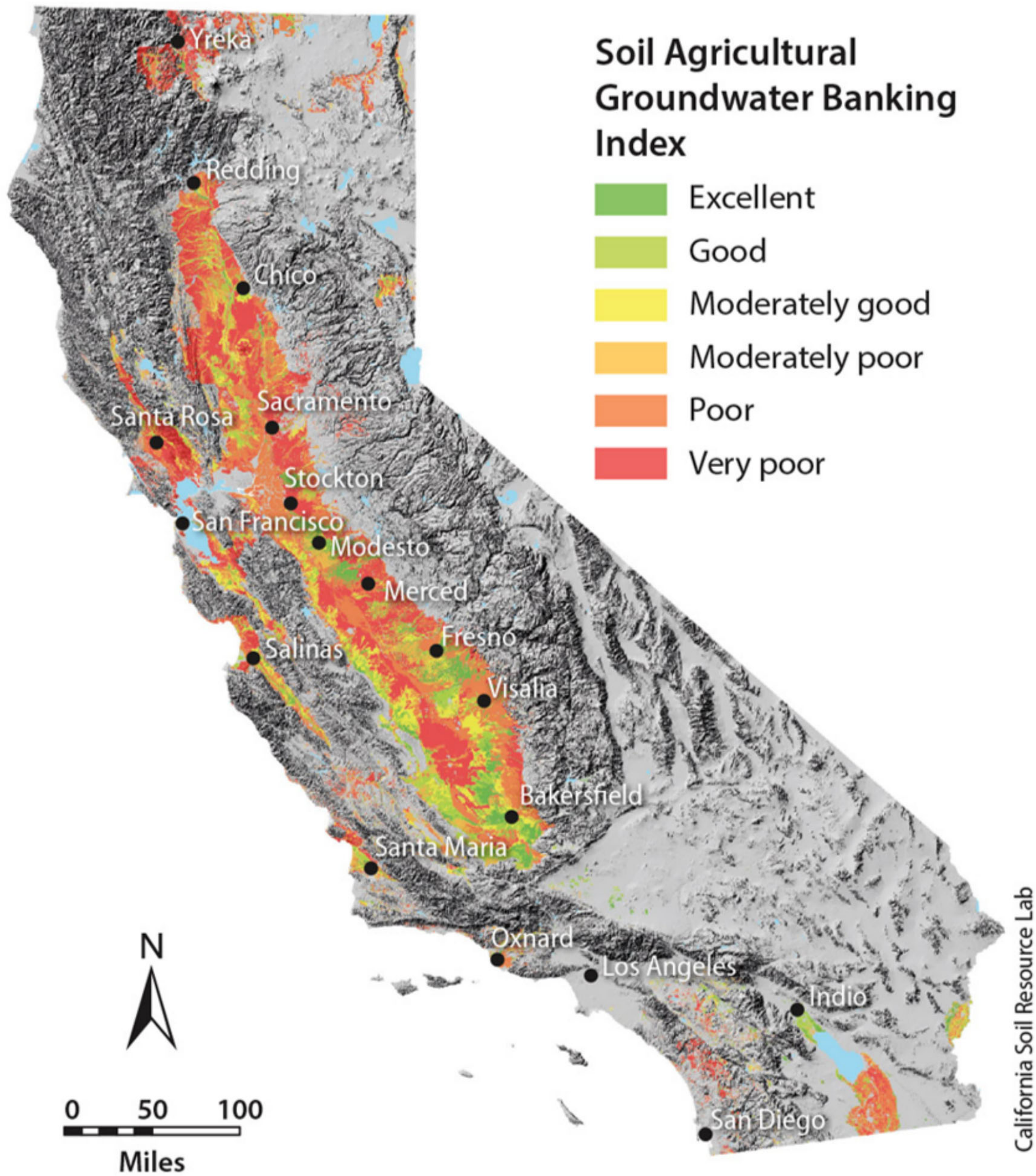
SELECTING A RECHARGE SITE - LIMITATIONS?

Many factors will limit site selection for a groundwater (GW) recharge site such as:

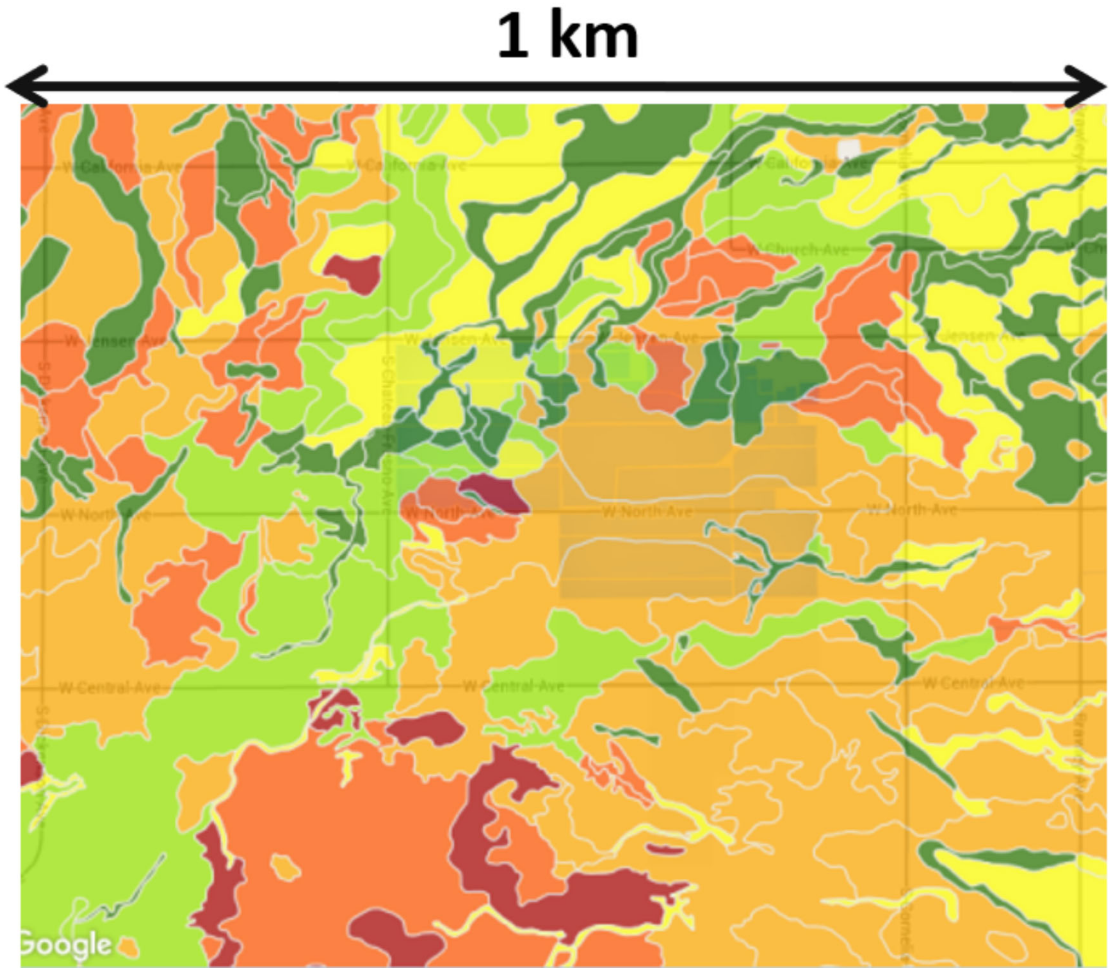
- What type of recharge site: dedicated basins or flooded agricultural land?
- What are the available sites to choose from?
- Is there easy access to water conveyance infrastructure?
- What are the ***subsurface soil conditions*** being the most important?

In 2015, UC Davis developed an online tool that used a number of factors (soil type, topography, root zone residence time, surface condtions, & chemical limitations) to calculate the Soil Agricultural Groundwater Banking Index (SAGBI) and it's spatial distribution throughout the state of CA.

- SAGBI is a great starting point to evaluate, on a large scale, potential recharge site locations



California Agriculture 69(2):75-84. DOI: 10.3733/ca.v069n02p75.

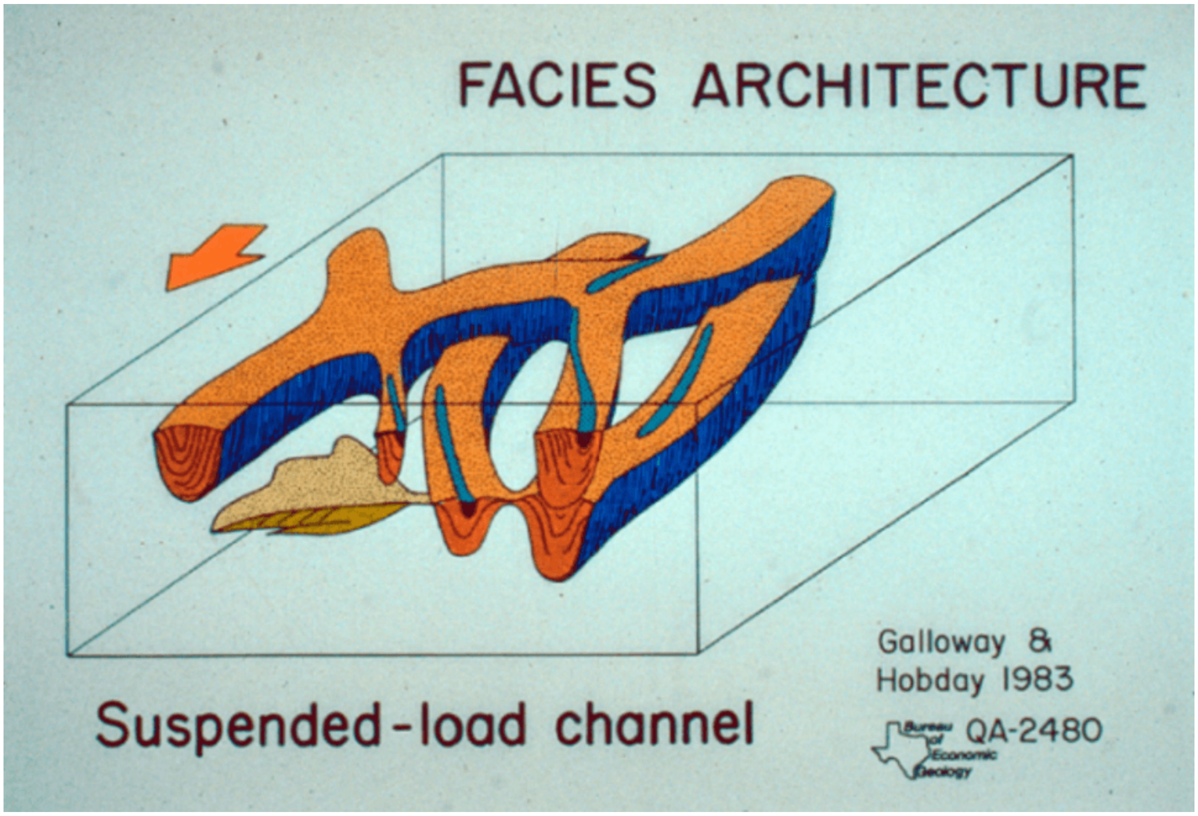


Limitations

- Mapped soil units ranged in size from 5 - 500 acres (2-202 hectares) & don't capture soil type distribution at the local site scale.
- Information based on soil surveys in top few feet shallow subsurface (3-6 ft; 1-2 m).
- Won't capture deeper limiting recharge layers (low permeability).

Missed Opportunity

Optimizing agricultural land or dedicated recharge basins for recharge would greatly benefit from identifying recharge fast paths to maximize infiltration and, in the case of ag lands, minimizing agro-chemical flushing into the aquifers.



Need local site characterization to ensure site <u>efficacy</u> and <u>suitability</u>!

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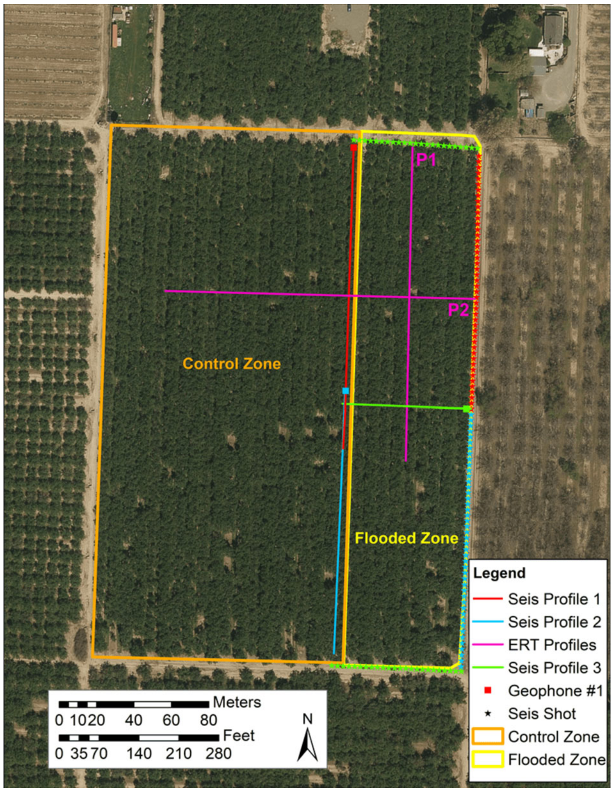
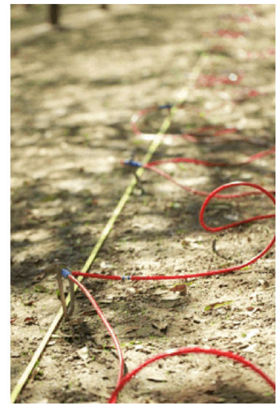
SUBSURFACE CHARACTERIZATION

Modesto, CA Almond Orchard



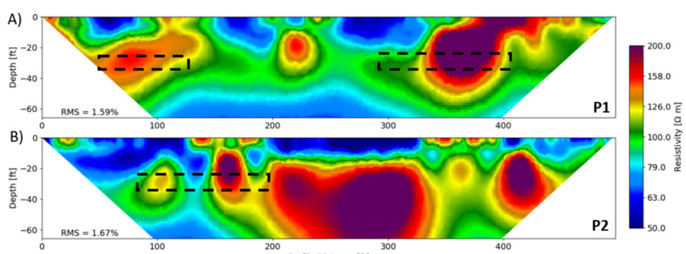
- Electrical Resistivity Tomography
- MASW
- Soil Cores



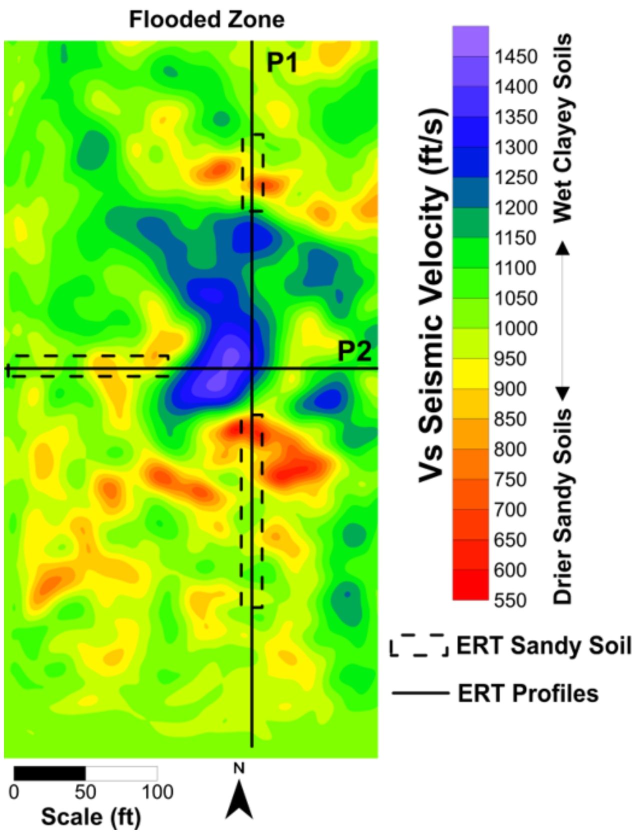



2016 Characterization

Two ERT profiles (P1[A] and P2[B]) were collected to characterize the subsurface in the flood zone.



- P1 & P2 show large spatial resistivity variations.
- Soil cores were collected to a depth of 30ft (9m) at 114ft (35m), 131ft (40m), 147ft (45m), 164ft (50m), 360ft (110m) and 387ft (118m) along P1.
- Clayey soils observed from 114-164ft vs sands at 360-387ft.



- 3D seismic volume slice at 30ft (9m) depth shows mid and low velocity sands (correlated to cores along P1) throughout and a localized zone of clays (blue-purples).
- Dashed boxes are the sands observed in the ERT profiles.

UNDERSTANDING RECHARGE COMPLEXITY

2 Flooding Events: 2017 (P1) & 2018 (P2)

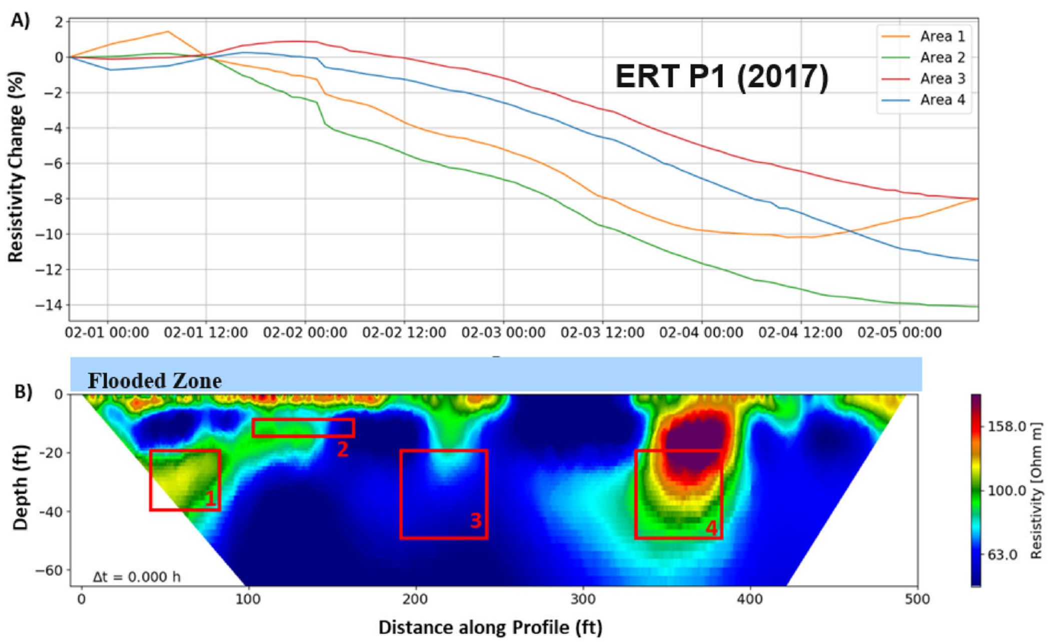
- Jan.-Feb. 2017 timelapse ERT P1 collected every hour over 5 days:
  - 96 timelapse images, over 5k datapoints per image
  - Water depth flooded: 4 inches (11cm) across orchard
  - 4th flooding of the year with heavy rains.
- Jan. 2018 timelapse ERT P2 collected every 2 hours over 3 days:
  - 35 timlapse images, over 5k datapoints per image
  - Water depth flooded: 2.7 inches (7cm) across orchard
  - 1st flooding of the year and low rain events

[VIDEO] https://www.youtube.com/embed/OutJ7uQZc0c?feature=oembed&fs=1&modestbranding=1&rel=0&showinfo=0

Visually Can See the Infiltration

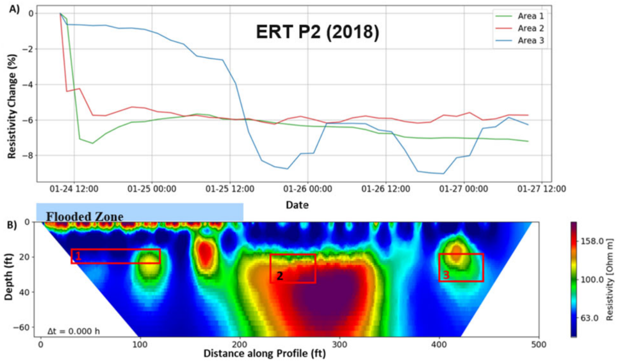
[VIDEO] https://www.youtube.com/embed/WYzyZqgyebw?feature=oembed&fs=1&modestbranding=1&rel=0&showinfo=0

Better Visualization for Understanding



- 4 selected zones (B) in 2017 P1 profile show complex spatial infiltration rates and magnitude at varying depths.
- Fast path infiltration in the sand zones convey more water faster (zones 1, 2, 4) vs clayey zone 3.

- ***Recharge*** observed ***below 35ft*** (10m), well below root and evaporation zone.

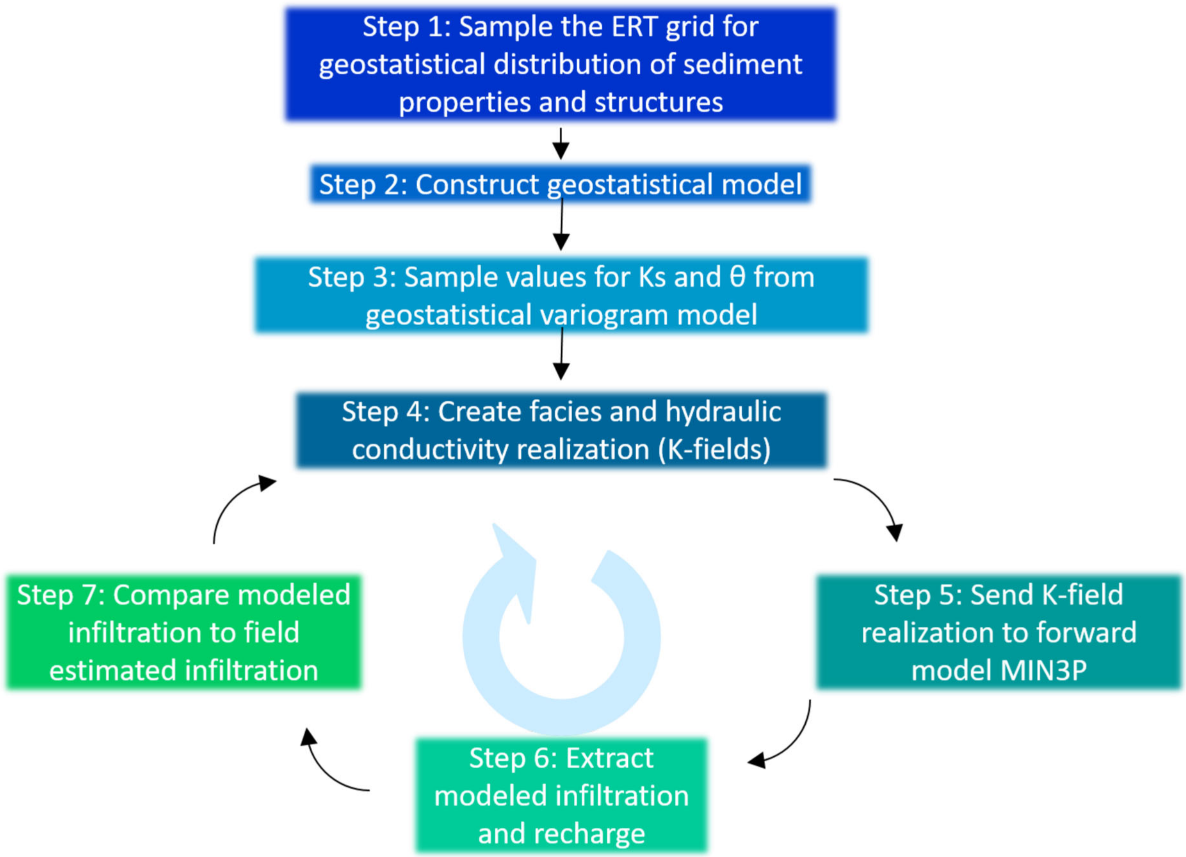


- Only 0-200ft flooded, only 40% of P2 flooded.
- Areas 1 and 2 saturate within 2 hours of flooding.
- Areas 2 and 3 show evidence of ***strong lateral*** flow and ***recharge over 200ft (61m) away*** from flood zone.

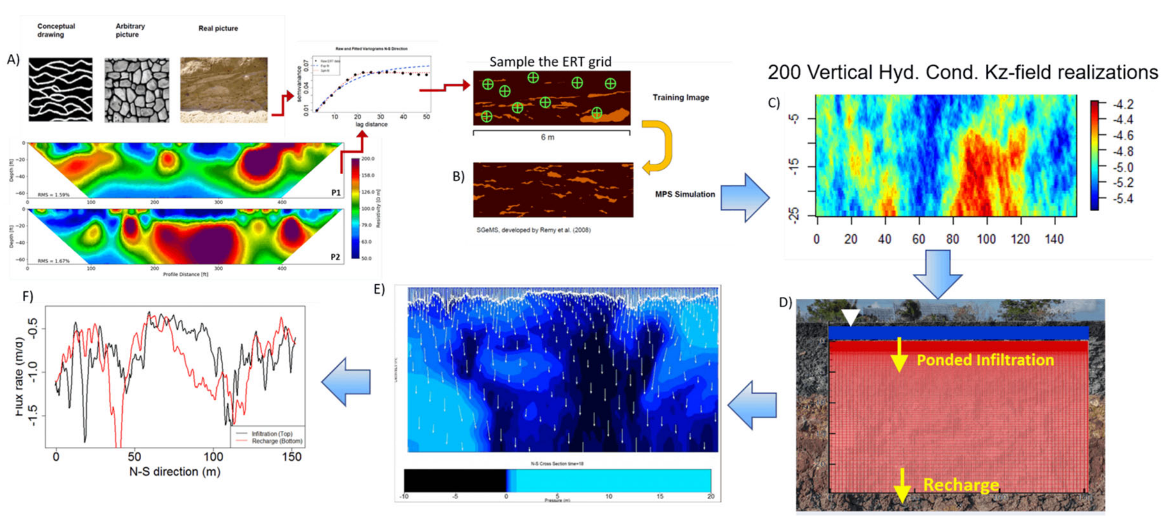
But how much reacharge occured?

QUANTIFY RECHARGE WITH ERT

Recharge rates and volumes were estimated using a novel geostatistical fate and transport model that used the ERT as a training image to estimate hydraulic conductivity (Kz) field realizations.



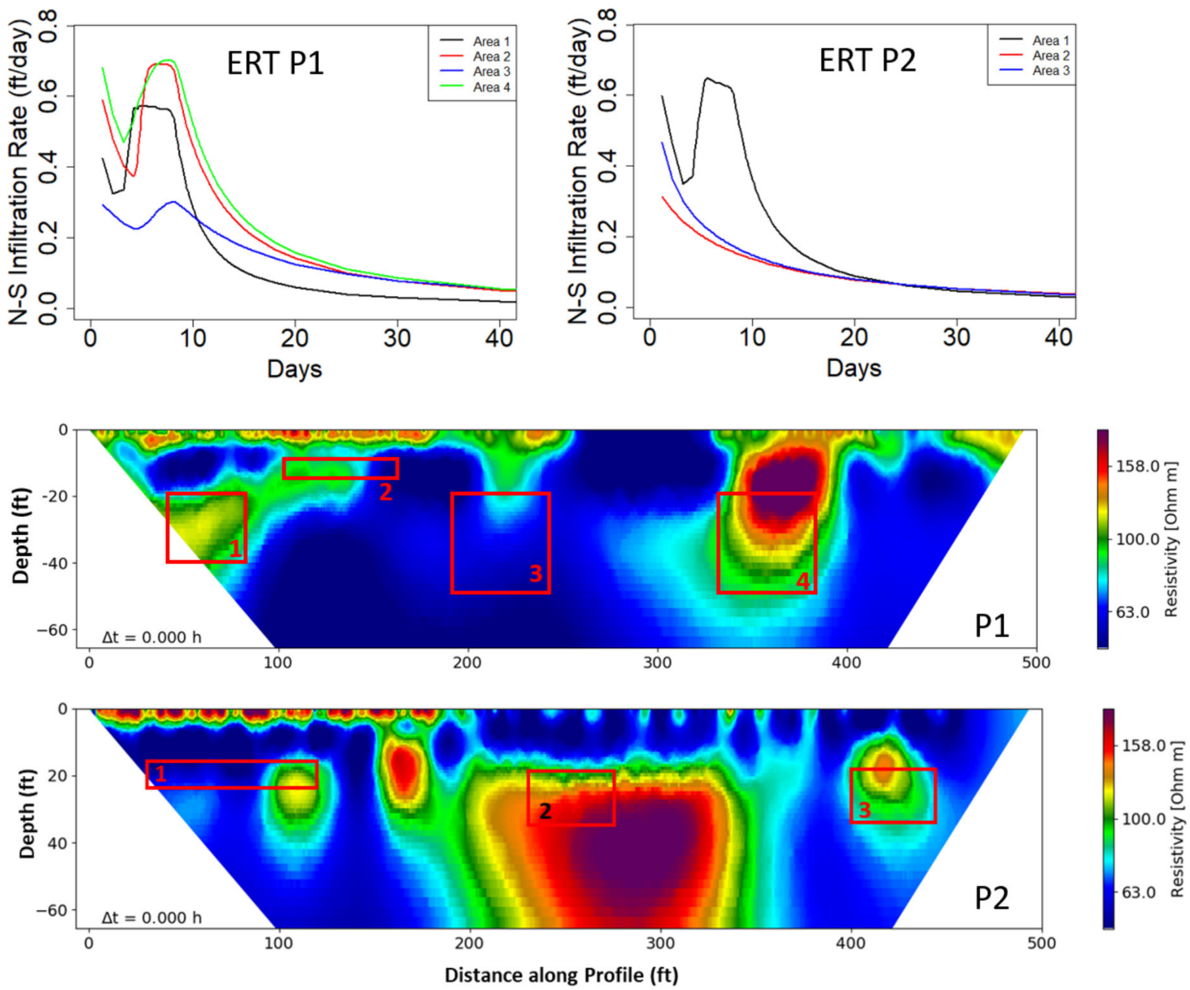
Example of Data Flow



Assumptions within the model

- Kz based on local soil survey info, not done at our site
- Starting saturation estimated
- Our statistical dist of K matches the stat dist of Res. (Our primary assumpiton from B to C

[VIDEO] https://www.youtube.com/embed/-TgrOmJiQw0?feature=oembed&fs=1&modestbranding=1&rel=0&showinfo=0



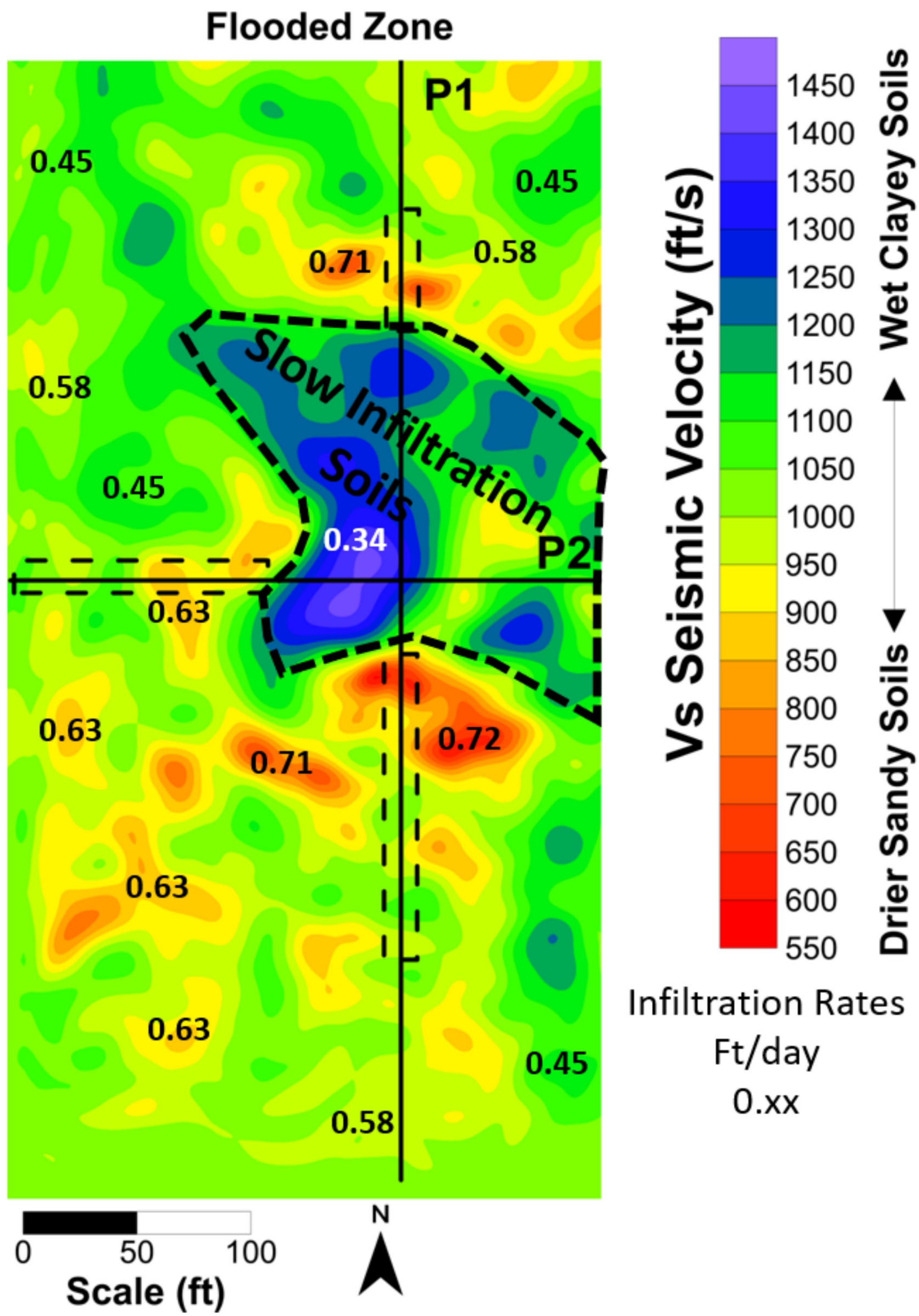
- Infiltratin model allowed to run over 40+ days
- P1 Areas 1,2,4 show similar trends consistent with ERT changes; with Infiltration rates of 0.5-0.6 ft/day at peak infiltration.
- P1 clayey Area 3 shows delayed peak infiltration and magnitude (0.2-0.3 ft/day) in comparison.
- P2
- Total infiltration P1 (assumes 1ft wide): 0.022 AF and recharge 0.019 AF
- Total infiltration P2: 0.011 AF and recharge 0.017 AF

- Total recharge P1 (area wide, out bottom): 1.68 AF
- Total recharge P2: 1.45 AF

CONCLUSIONS AND DISCUSSIONS

Take Home Points

- Using SAGBI is a great starting point for GW recharge site selection but has limitations.
- Geophysical methods provide valuable information for determining site design and functionality
- **Timelapse ERT** data provides insight on recharge complexity such as ***fast path zone identification*** and ***extensive lateral flow*** during recharge activity.
- Recharge observed at depths greater than **30ft (9m)**.
- ***Novel modeling codes*** integrating timeseries ERT, permited the ***quantification*** of infiltration rate and recharge volumes, that offers a non-invasive method to water districts to more accurately estimate and track volumes recharged.
- Timeseries ERT infiltration rates can be used to assign those rates by soil type which can be coupled with the seismic 3D volume to understand and rough caluate how much recharge is happening at a certian location within the orchard and to develop estimates in those areas, as seen below. Volumes of recharge can be estimated as another example.


Flooded Zone
P1
P2
0.45
0.45
0.71
0.58
0.58
Slow Infiltration Soils
0.45
0.34
0.63
0.63
0.72
0.71
0.63
0.63
0.45
0.58
0 50 100
Scale (ft)
N
Vs Seismic Velocity (ft/s)
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
Wet Clayey Soils
Drier Sandy Soils
Infiltration Rates
Ft/day
0.xx

ABSTRACT

As a result of climate change, California is experiencing the impact of more extreme weather patterns including longer drought periods and atmospheric rivers resulting in extreme snow pack and heavy flood flows. CA faces a significant challenge to mitigate these impacts while simultaneously providing resilient sources of water under uncertain future conditions. Future meteorological climatic forecasts indicate episodic drought years followed by short wet years that will require GSAs to be strategic in capturing water and infiltrating it into aquifers during sparse wet years. One approach that addresses both flood mitigation and water storage is the use of Managed Aquifer Recharge (MAR). Specifically, Flood-MAR entails diverting surface water from high river flows during the rainy season onto agricultural lands for spreading and infiltration. Determining where to divert the water and recharge efficacy is often a big unknown. This study was conducted at a 14-acre almond orchard in Modesto, CA and used geophysics (ERT and seismic) to characterize and monitor recharge; and integrated modeling codes to quantify infiltration/recharge during multi-year water application events. Geophysical and soil core data were used to characterize the subsurface. Spatially distributed clayey and sandy soil zones were observed across the study area both extending from the surface to 40 ft below the surface. Timelapse resistivity collected during single water application events showed complex infiltration patterns with fast paths conveying most of the water to depths greater than 40 ft within days of application. Timelapse resistivity data coupled with novel fate and transport codes permitted the quantification of spatially dense recharge rates along the resistivity profiles that ranged from <0.34 ft/day in clays to double that (0.72 ft/day) in sandy soils. 3D seismic and resistivity data coupled with soil core information permitted the extrapolation of total recharge volume along the resistivity profile (0.02 acre-ft/day, 2017) to the entire flooded area which resulted in total estimated recharge, during a single application event, of 1.68 acre-ft. This new non-invasive method offers farmers and water managers a way to more accurately understand and quantify the amount of water recharged that reached the unconfined aquifer.