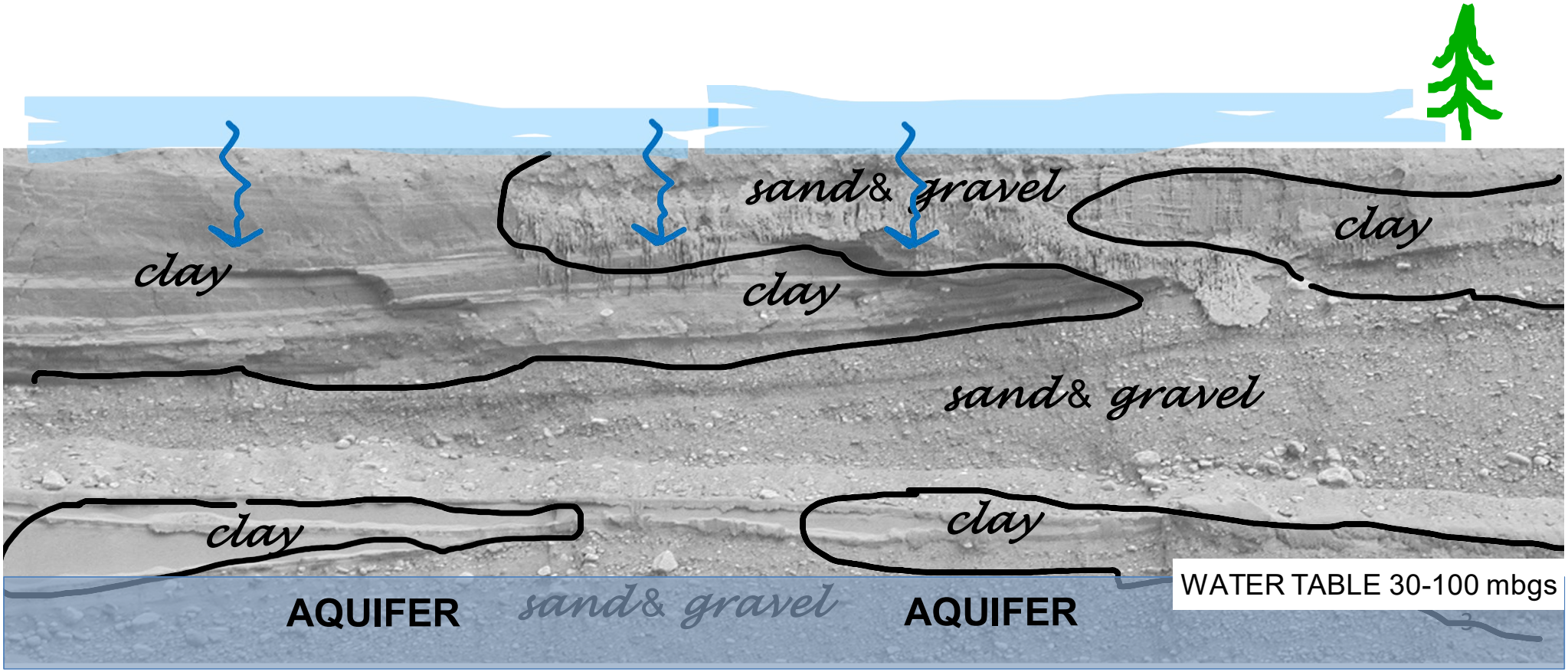
Harnessing the Power of Geophysical Imaging to Recharge California's Groundwater

Rosemary Knight (Professor, Geophysics Dept., Stanford University)

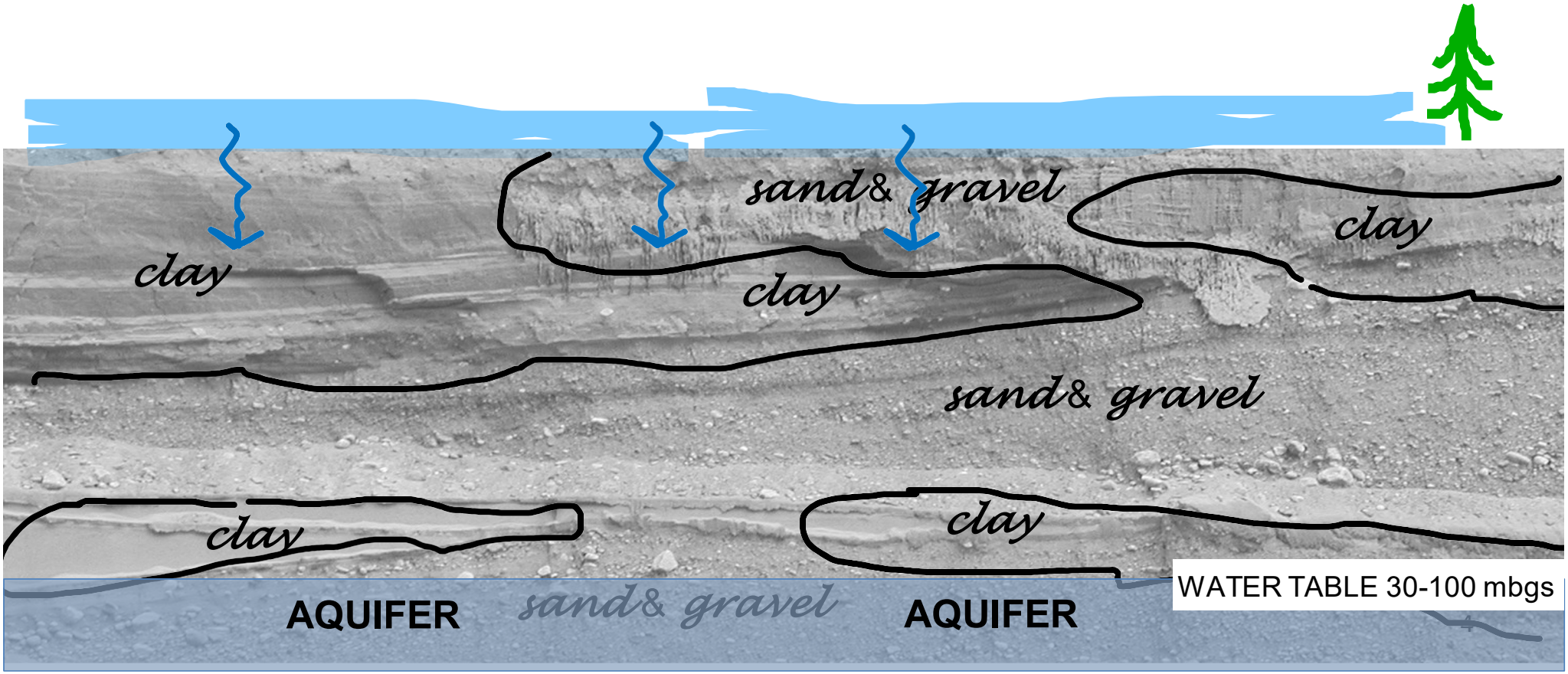
Harnessing the Power of Geophysical Imaging to Recharge California's Groundwater

Rosemary Knight (Professor, Geophysics Dept., Stanford University)
Seogi Kang (Research Scientist, Geophysics Dept., Stanford University)
Meredith Goebel (Research Scientist, Geophysics Dept., Stanford University)

MANAGED AQUIFER RECHARGE (MAR)

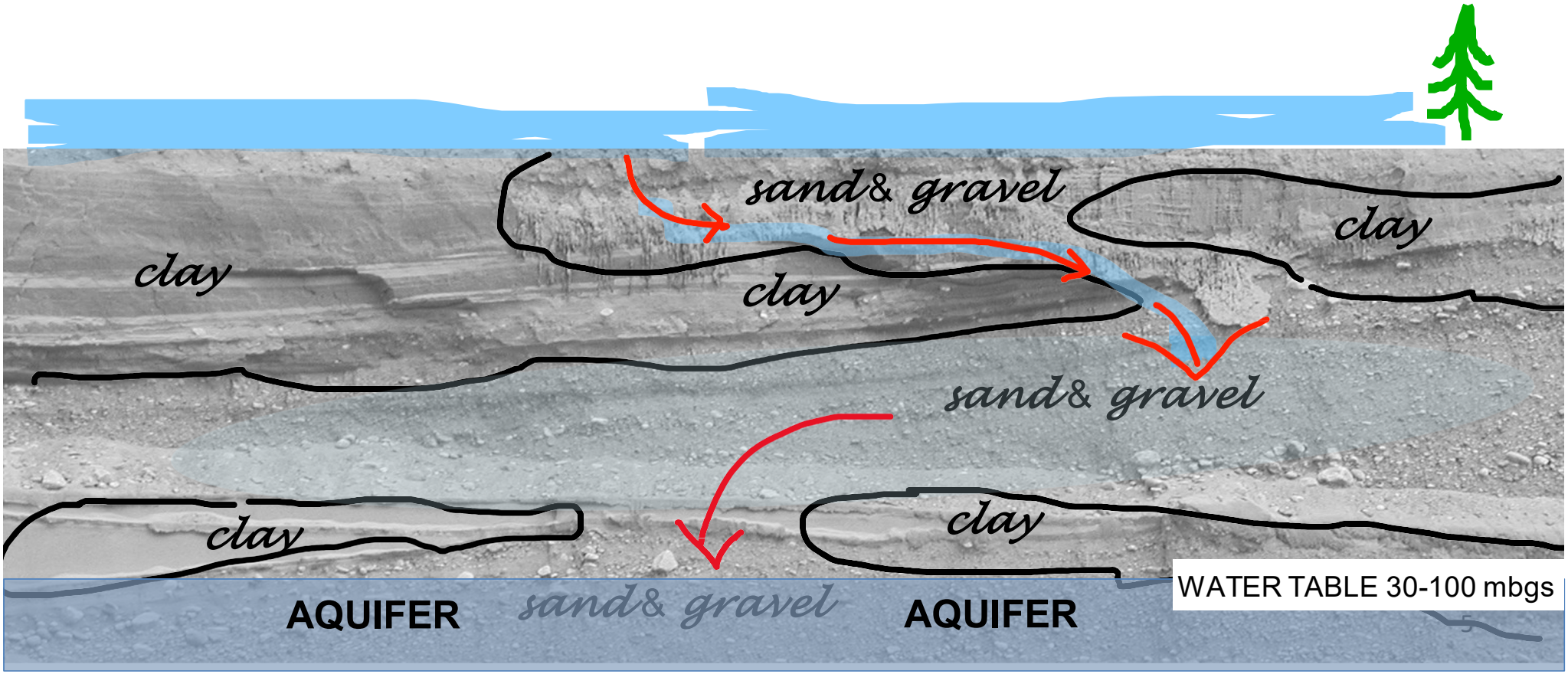


Where to recharge? to maximize quantity and rate of recharge

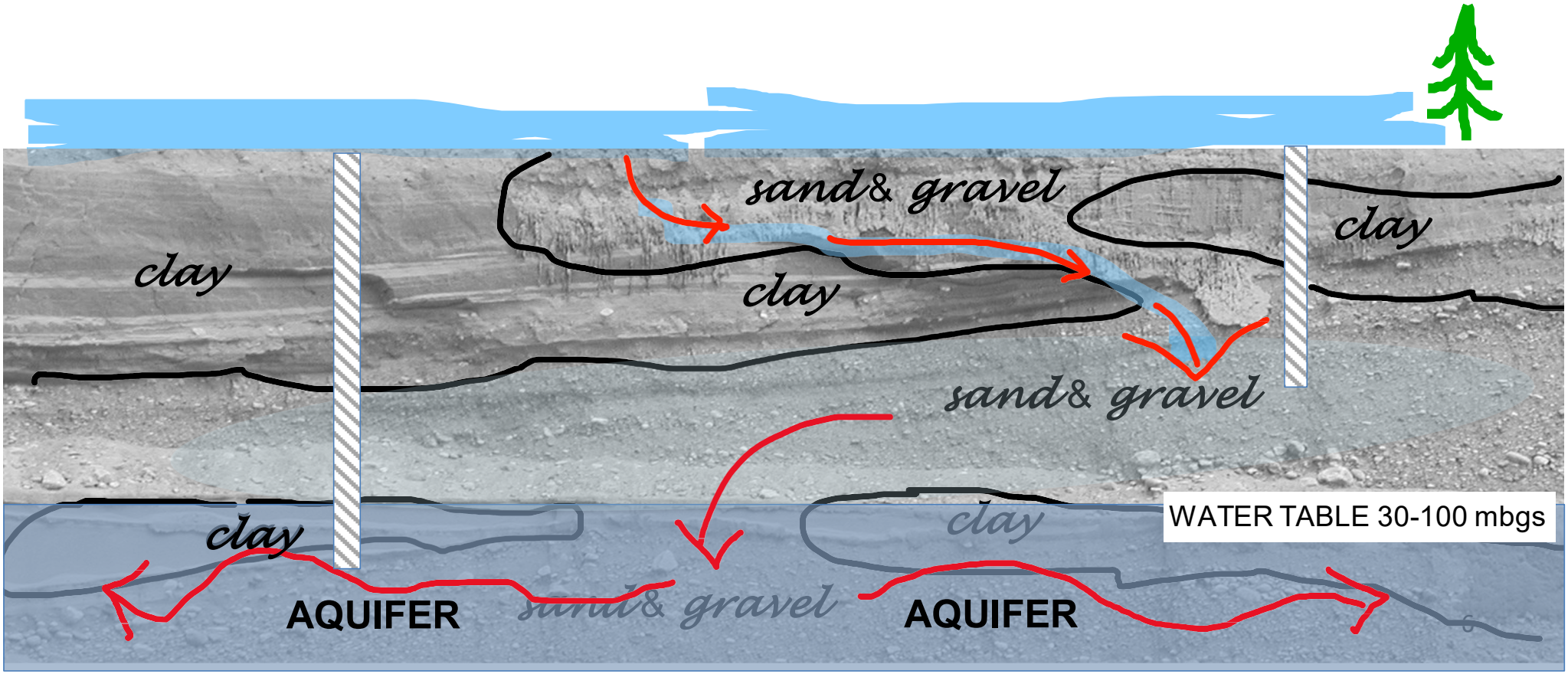


Where to recharge? to maximize quantity and rate of recharge

Sites where we have: inter-connected pathways of coarse-grained materials - *fastpaths*

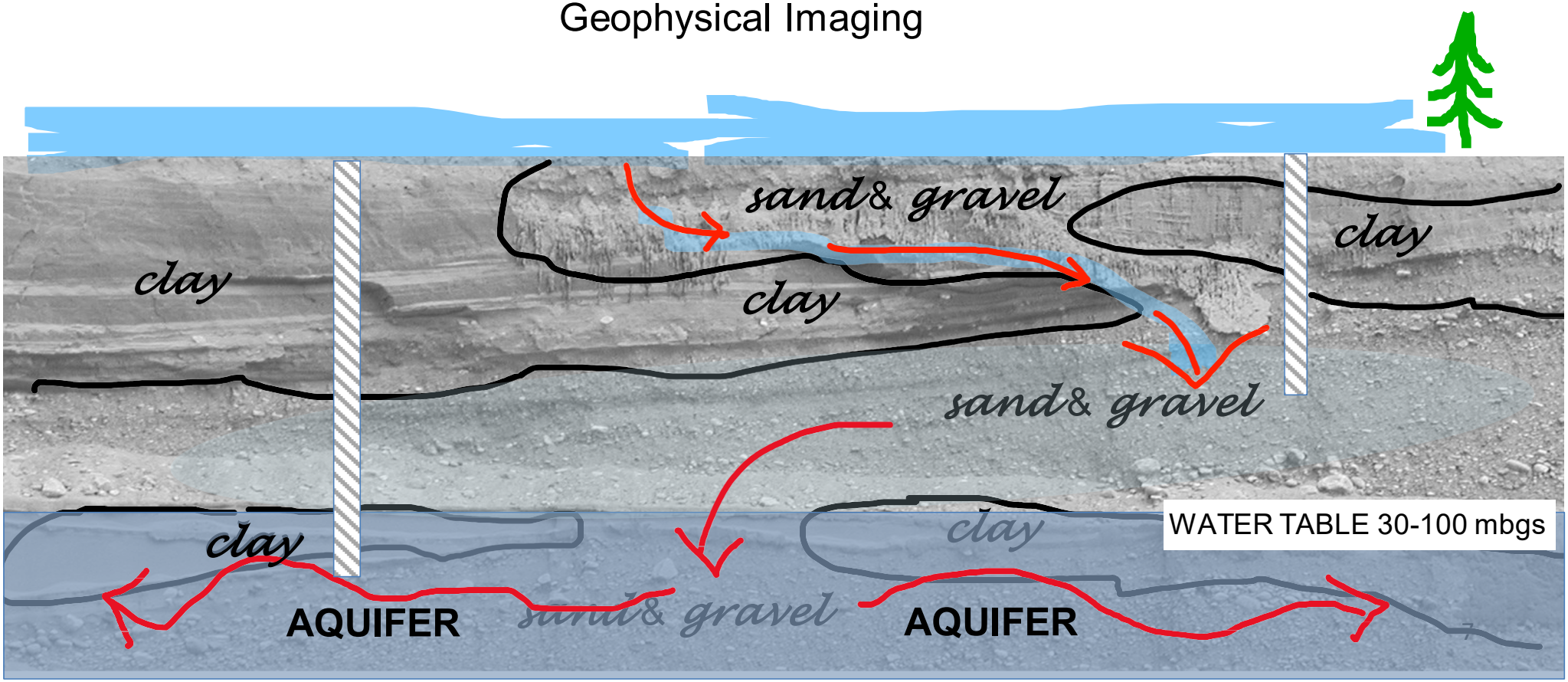


We need a fast, reliable, cost-effective way to find these fastpaths.



We need a fast, reliable, cost-effective way to find these fastpaths.

We need –
Geophysical Imaging



October 27, 2015

Electrical Resistivity π Model

π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π
π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π
π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π
π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π
π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π

Linking what you measure to what is there

Electrical Resistivity π Model

↓

sediment type

π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π
π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π
π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π
π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π
π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π

Knight et al., 2018, Groundwater

Knight, Gottschalk, Dewar, 2021; Field-Scale Rock Physics for Near- Surface Applications, Encyclopedia of Geology, 2nd edition.

Linking what you measure to what is there

Use Driller's Logs

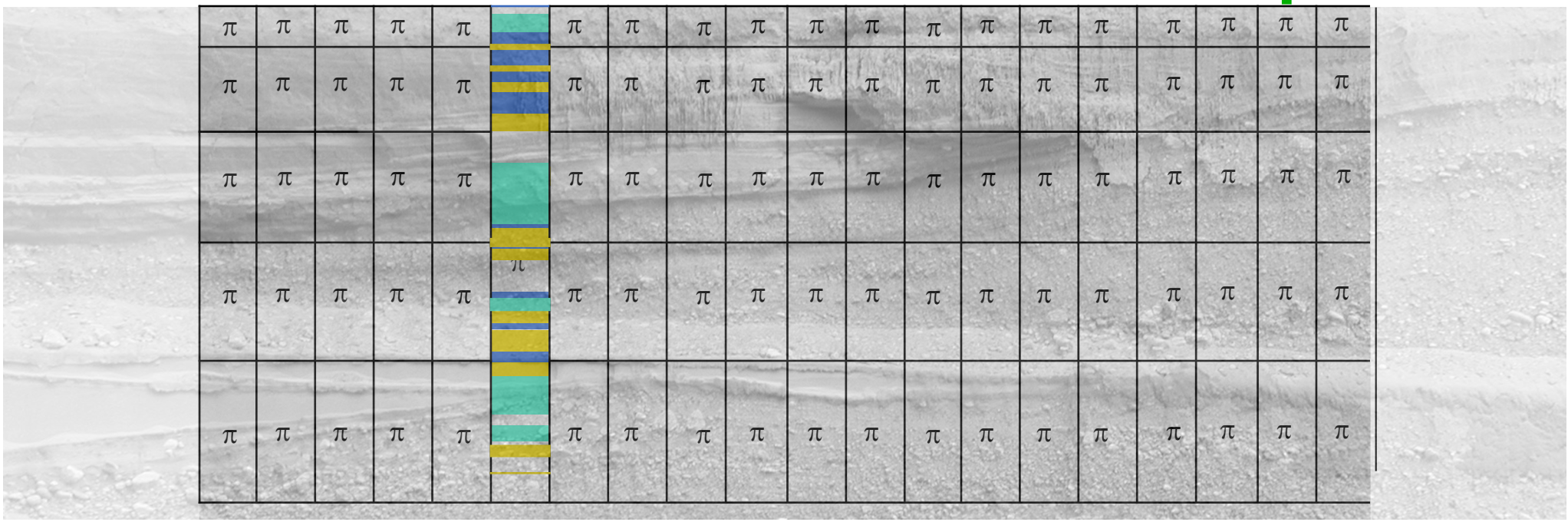
+

Electrical Resistivity π Model

sand & gravel

mixed coarse & fine

clay



Linking what you measure to what is there

Use Driller's Logs

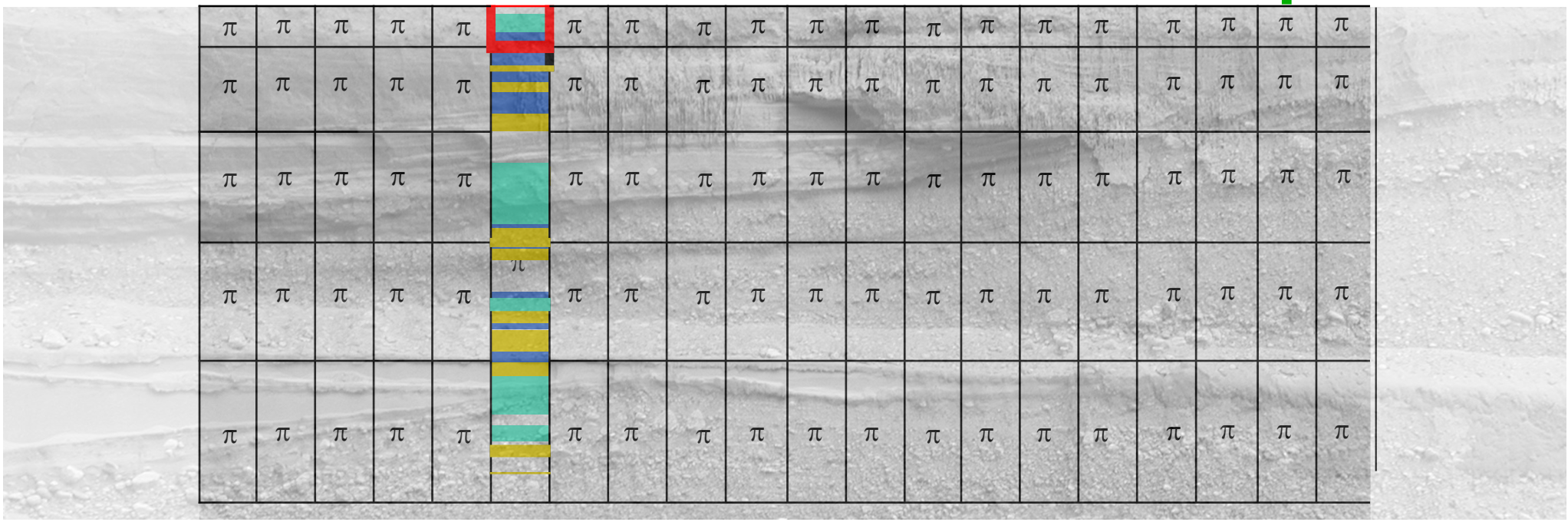
+

Electrical Resistivity π Model

sand & gravel

mixed coarse & fine

clay



Linking what you measure to what is there

Use Driller's Logs

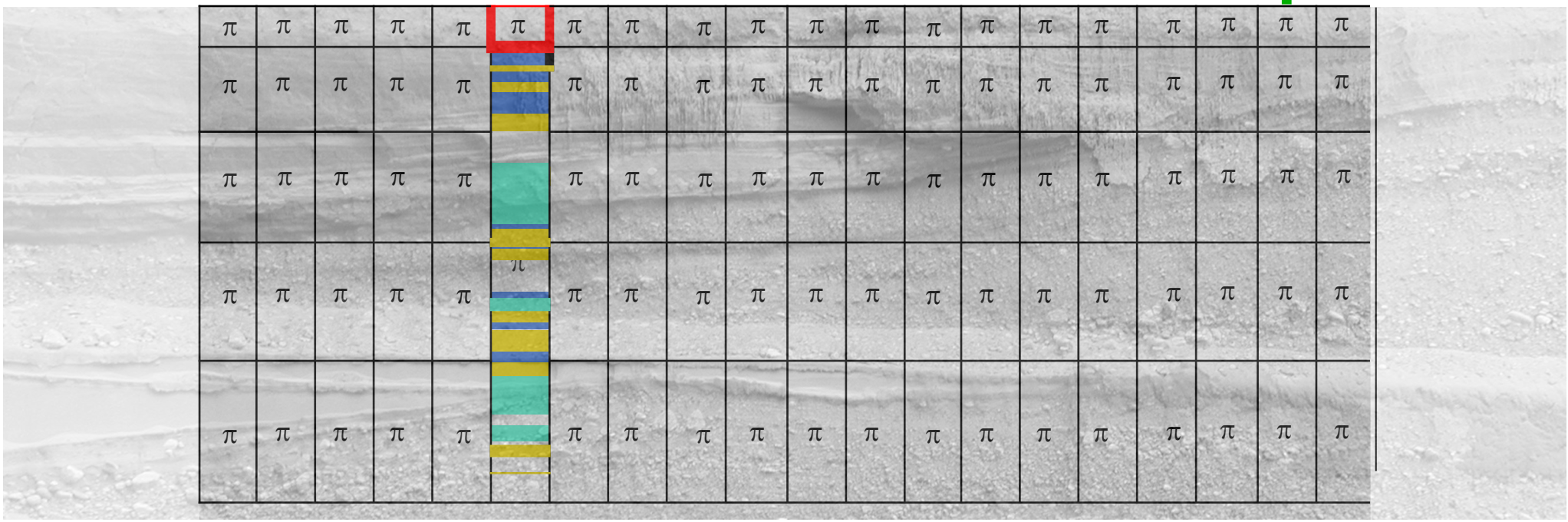
+

Electrical Resistivity π Model

sand & gravel

mixed coarse & fine

clay



Linking what you measure to what is there

Use Driller's Logs

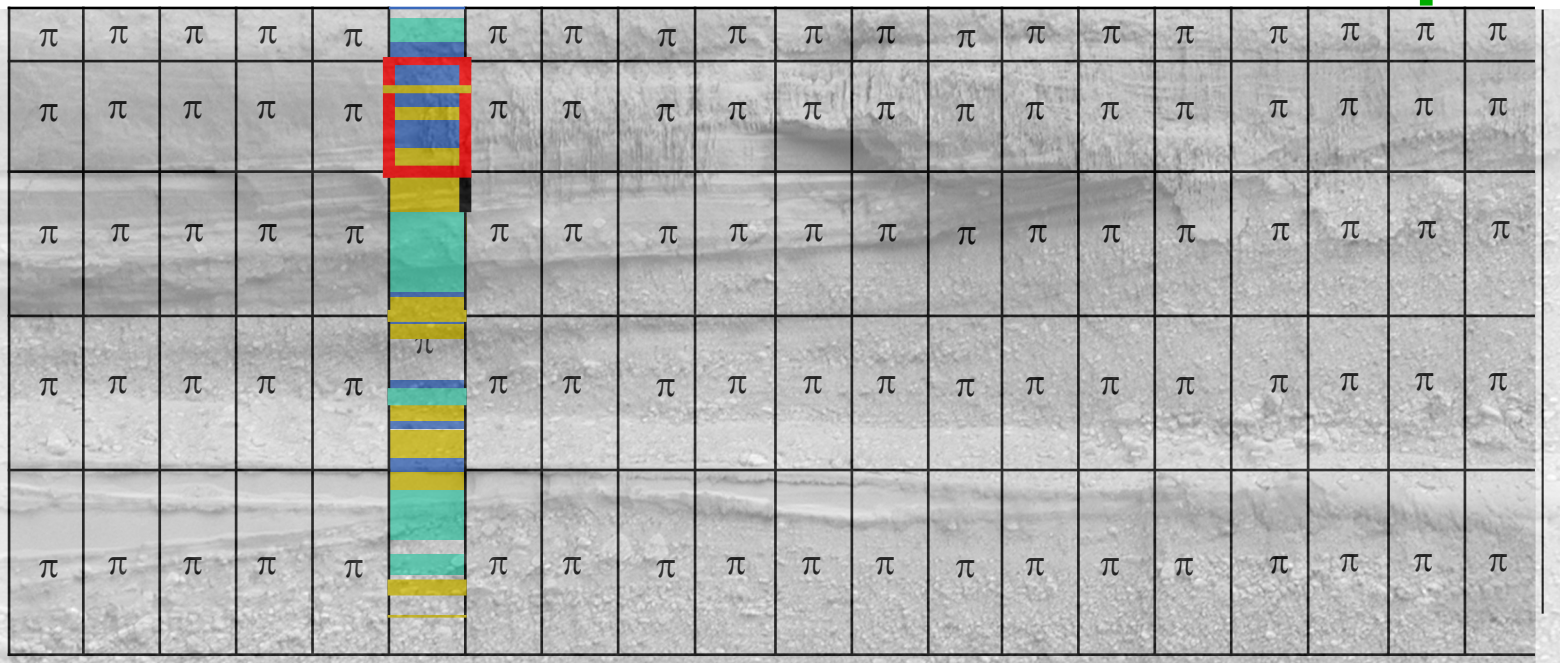
+

Electrical Resistivity π Model

sand & gravel

mixed coarse & fine

clay



Linking what you measure to what is there

Use Driller's Logs

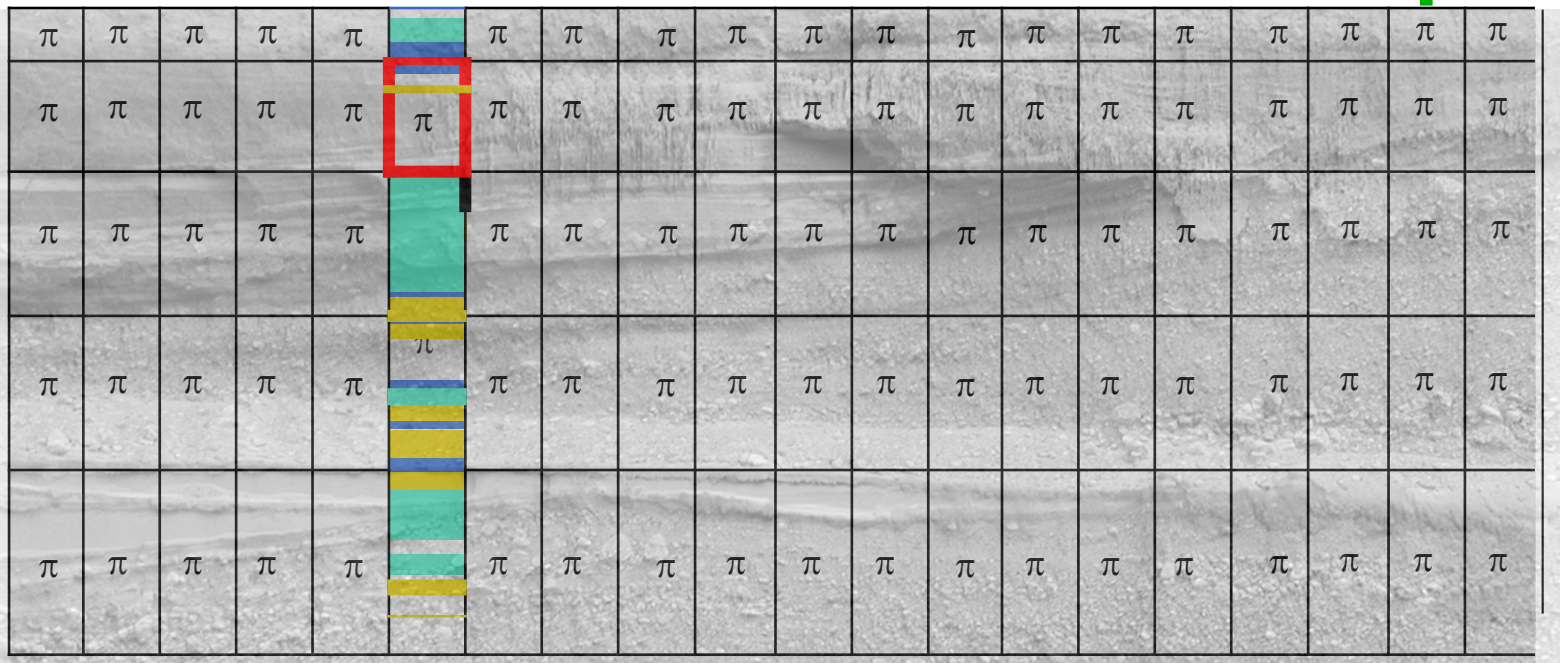
+

Electrical Resistivity π Model

sand & gravel

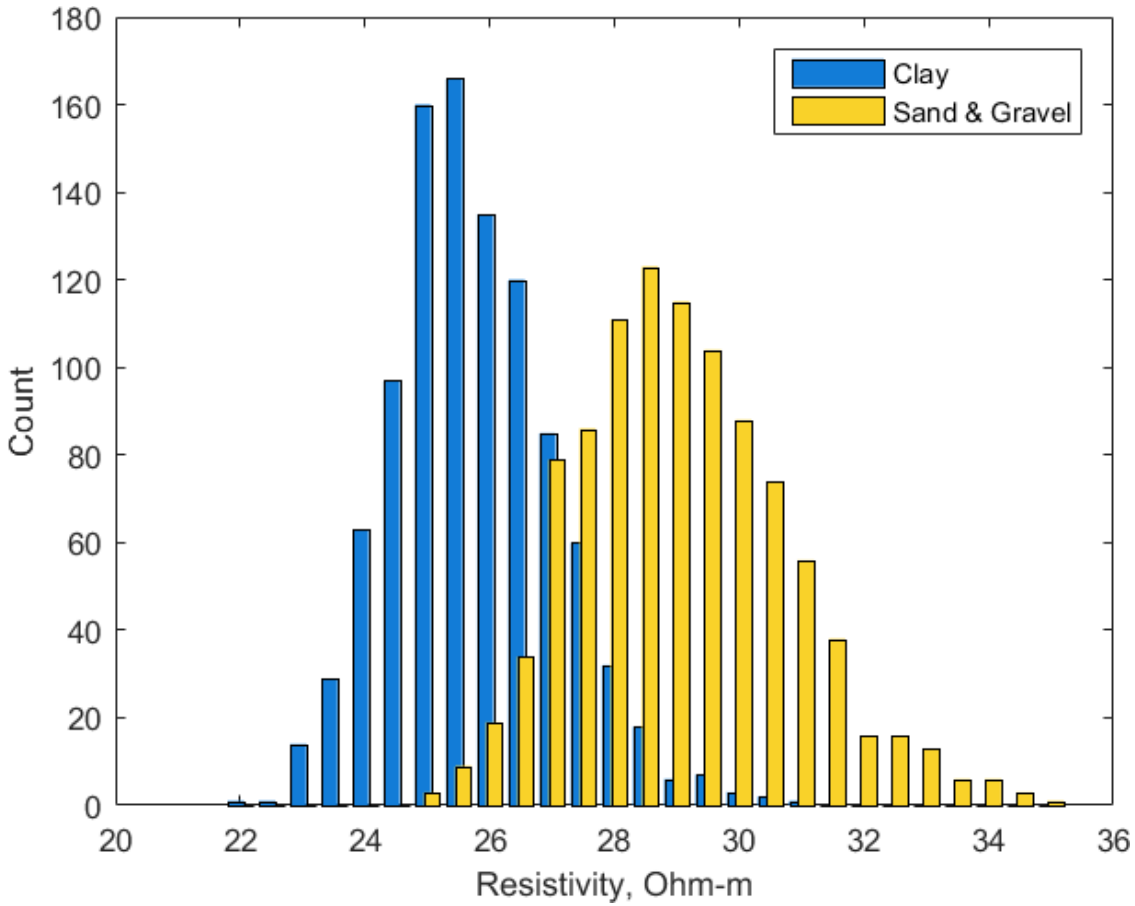
mixed coarse & fine

clay



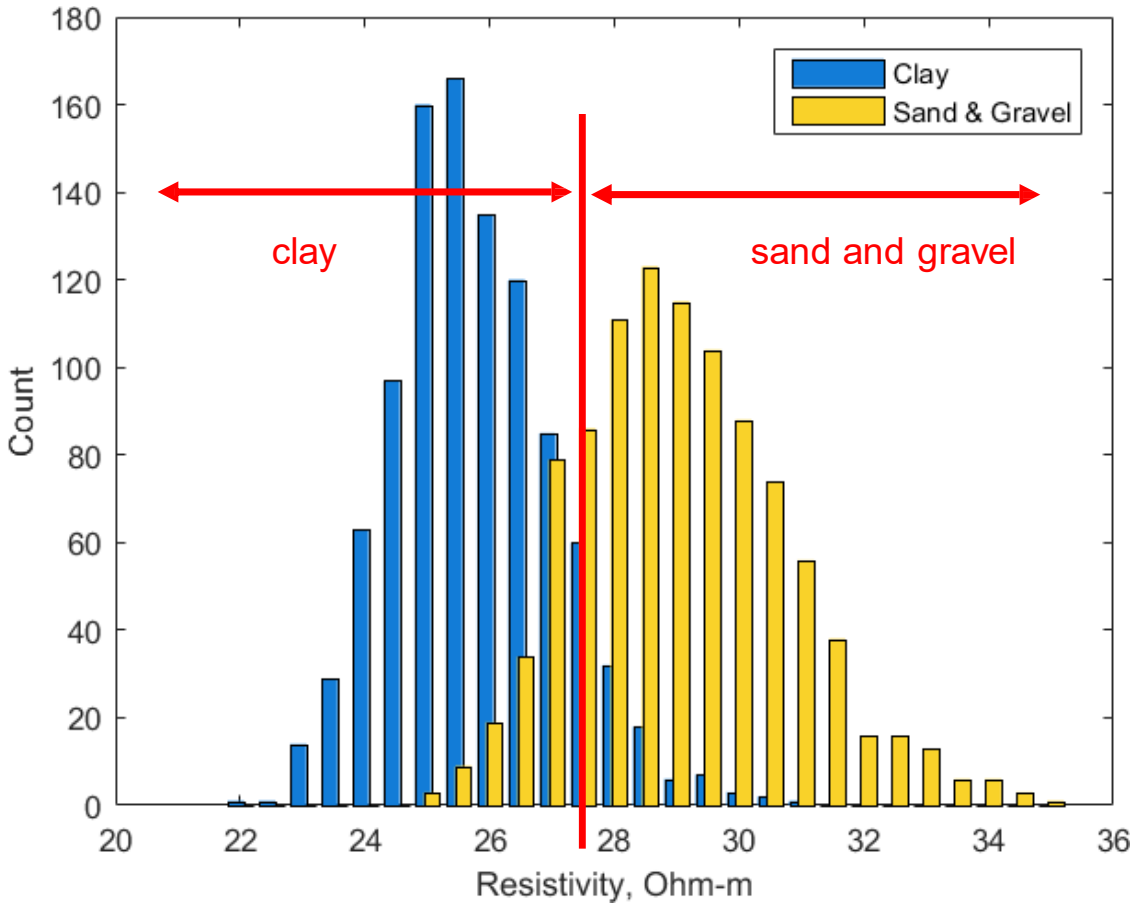
Linking what you measure to what is there

ABOVE THE WATER TABLE

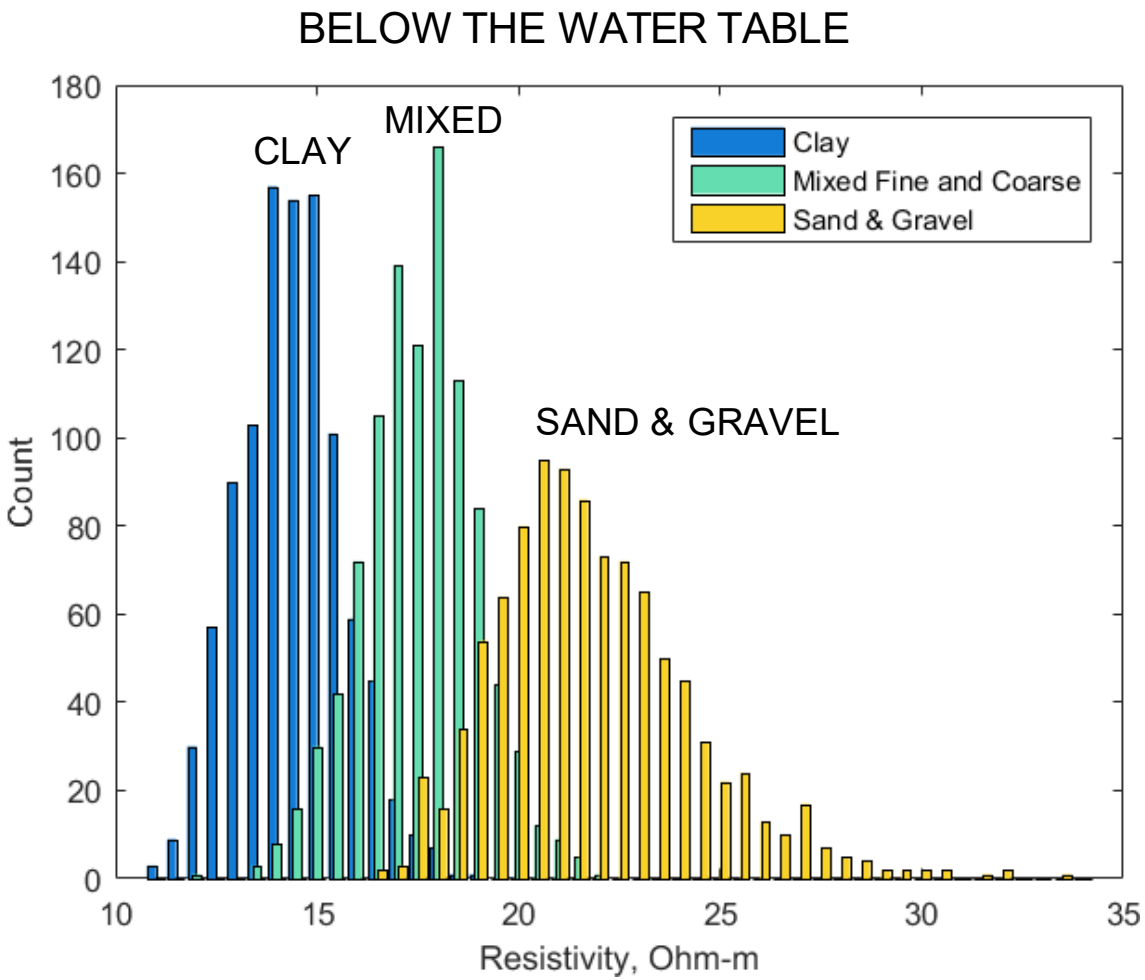


Linking what you measure to what is there

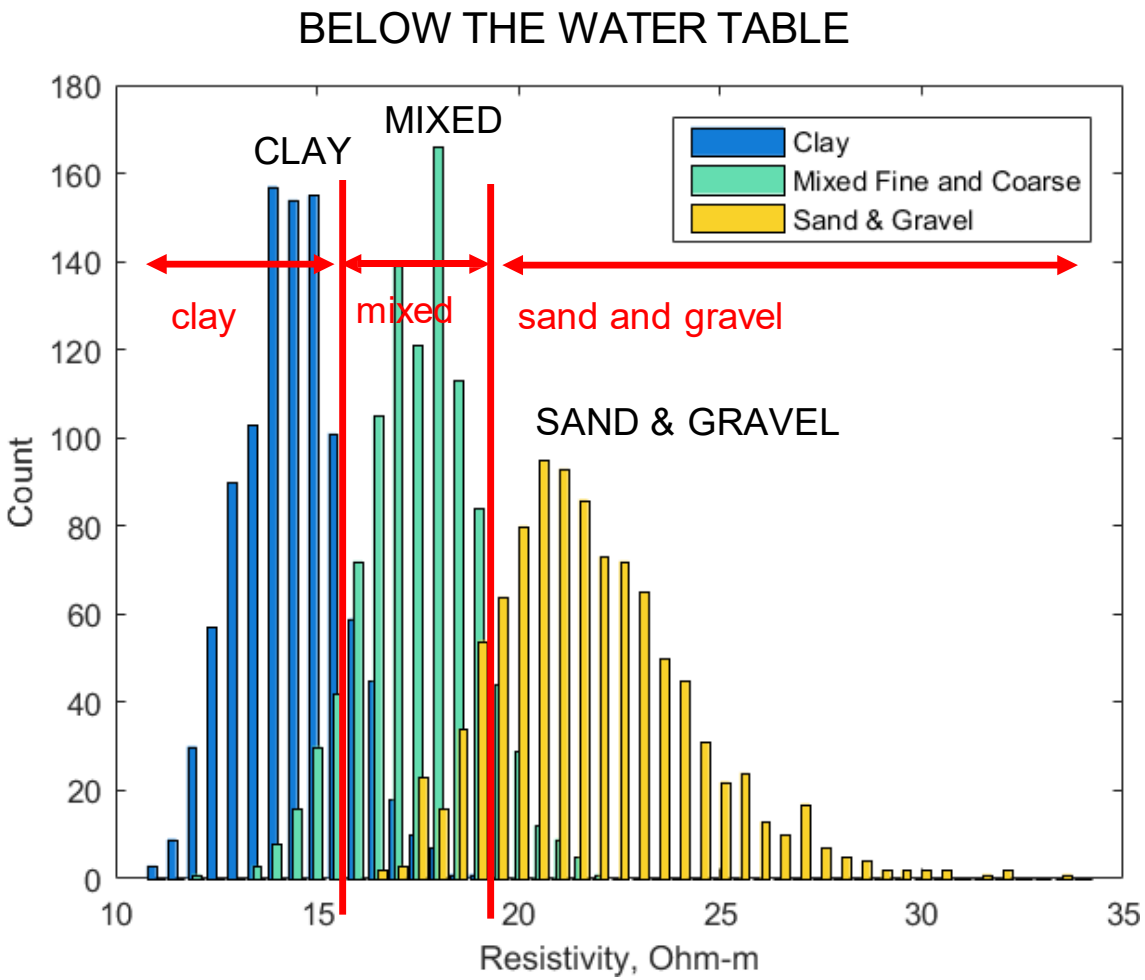
ABOVE THE WATER TABLE

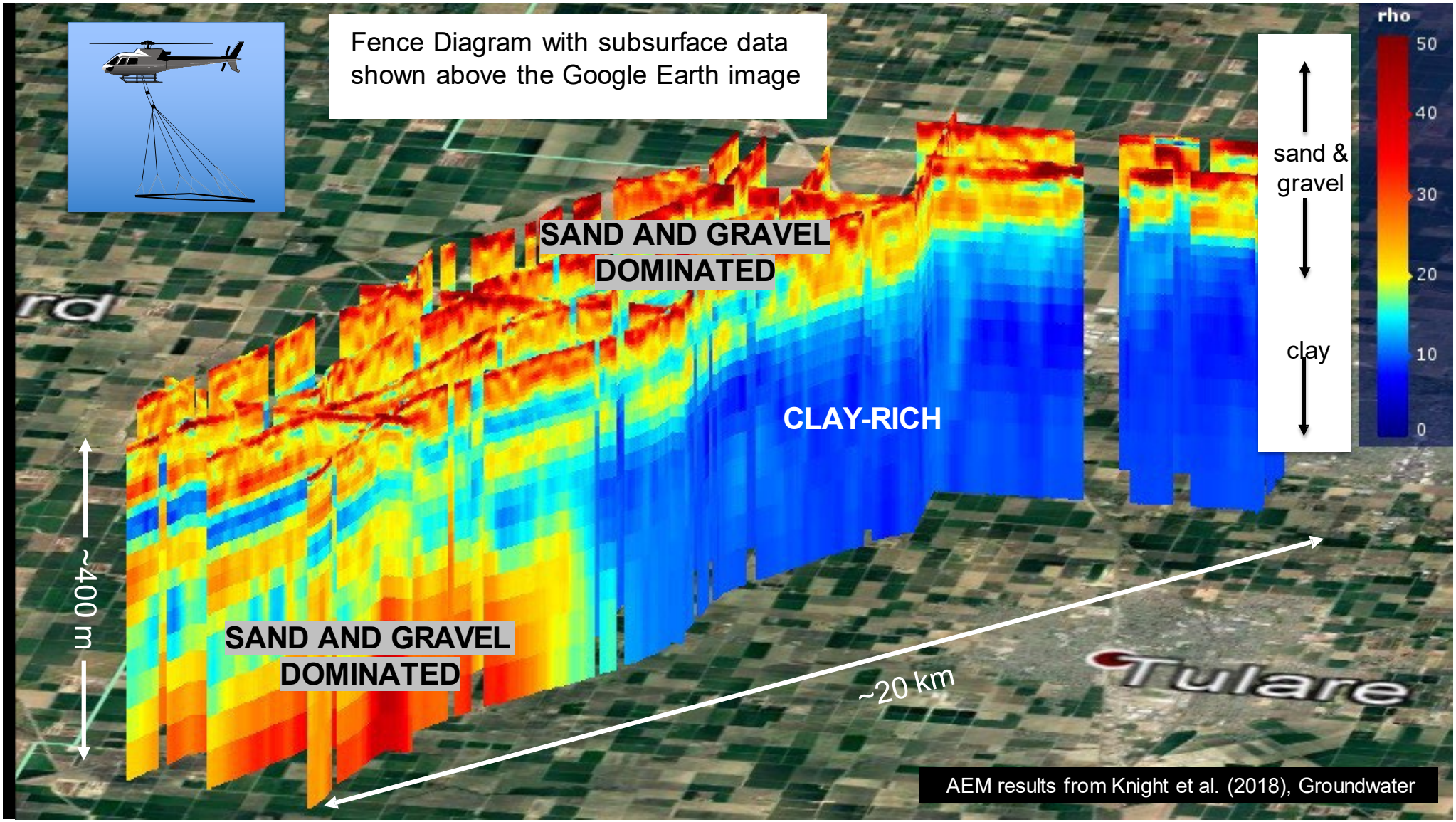


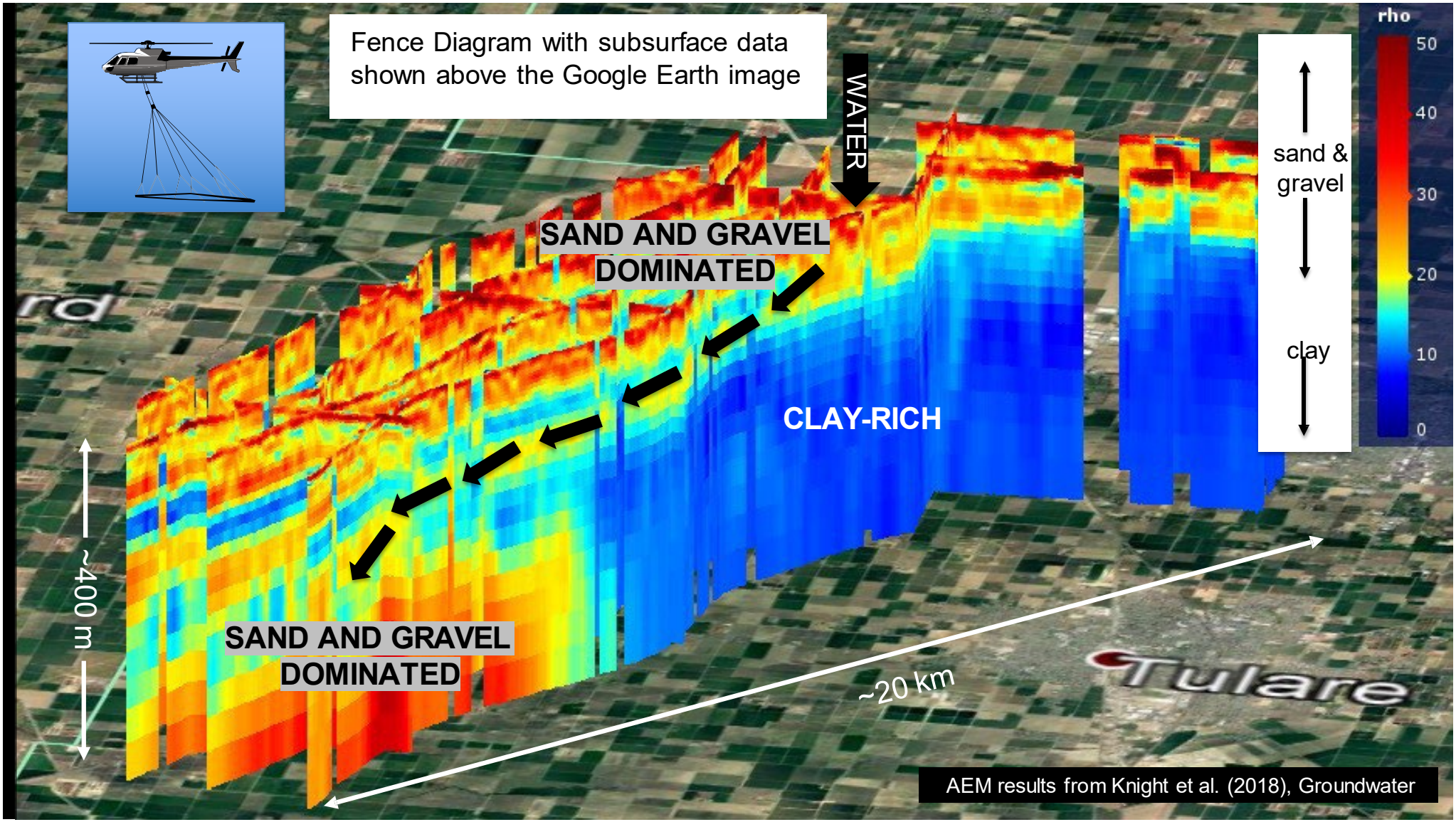
Linking what you measure to what is there



Linking what you measure to what is there

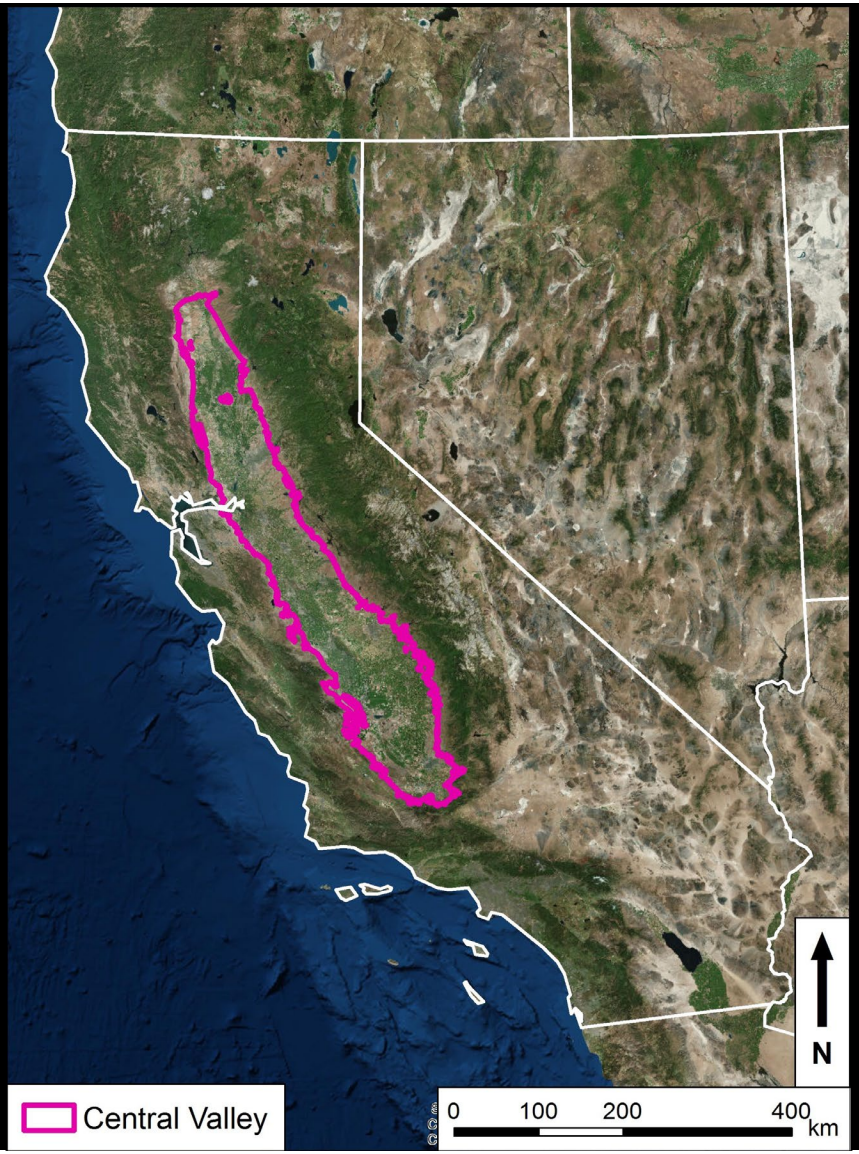



Fence Diagram with subsurface data shown above the Google Earth image
SAND AND GRAVEL DOMINATED
CLAY-RICH
SAND AND GRAVEL DOMINATED
sand & gravel
clay
rho
50
40
30
20
10
0
~400 m
~20 km
Tulare
AEM results from Knight et al. (2018), Groundwater


Fence Diagram with subsurface data shown above the Google Earth image
WATER
SAND AND GRAVEL DOMINATED
CLAY-RICH
SAND AND GRAVEL DOMINATED
~400 m
~20 km
sand & gravel
clay
rho
50
40
30
20
10
0
Tulare
AEM results from Knight et al. (2018), Groundwater

Where to recharge?

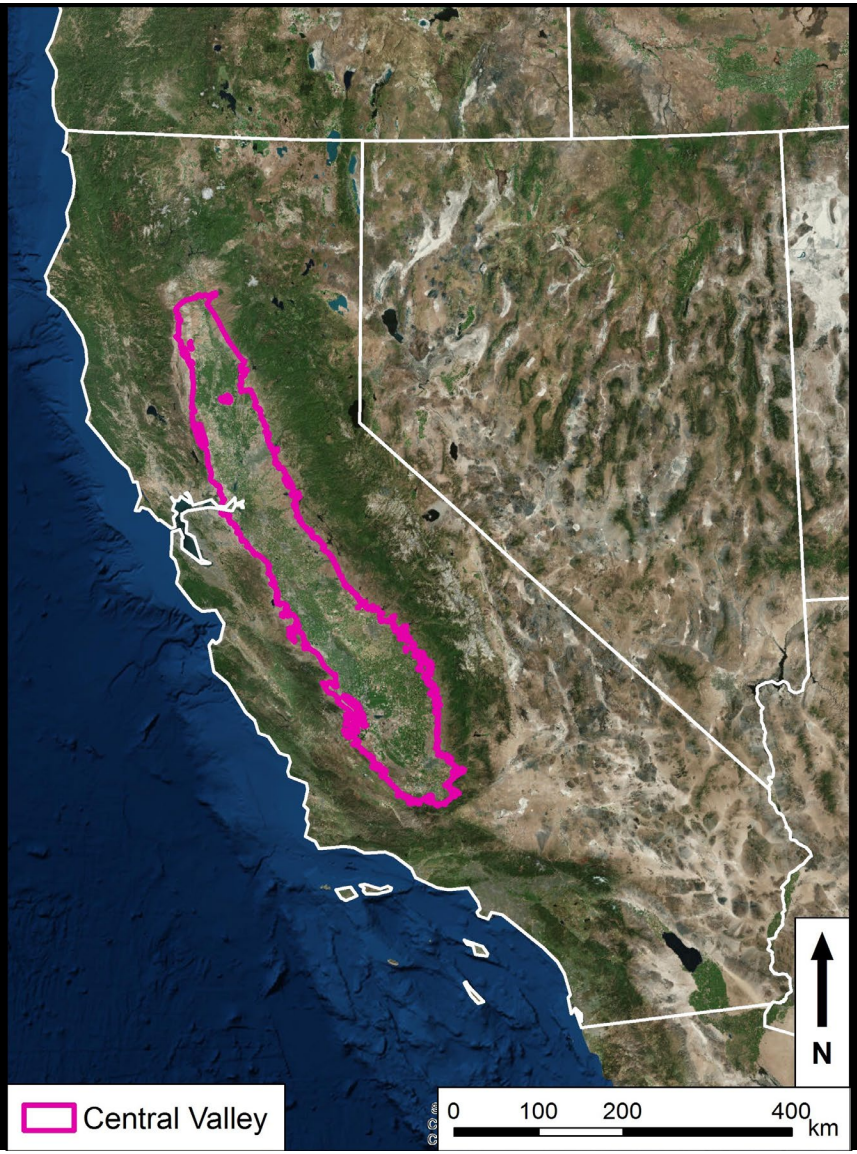
Let’s tap into the natural infrastructure.



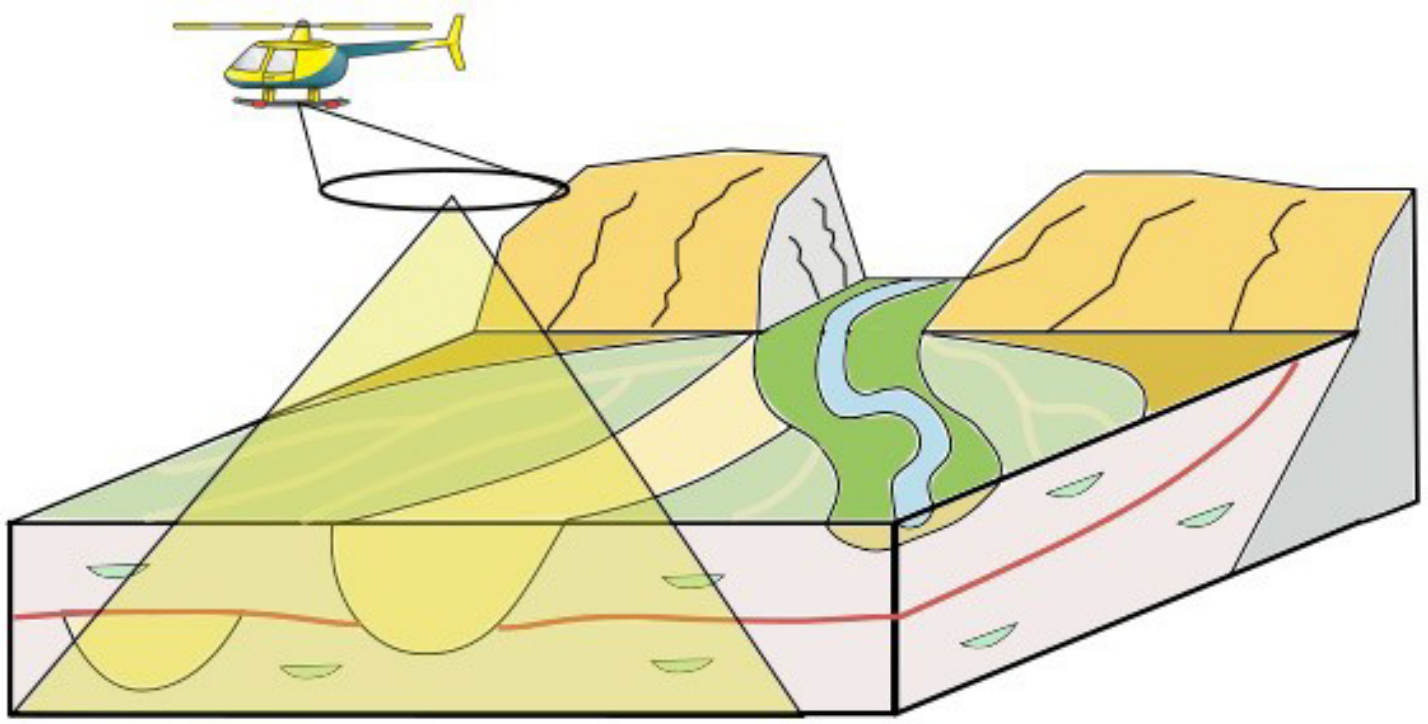
Where to recharge?

Let's tap into the natural infrastructure.

Massive paleovalleys along the eastern edge of the Central Valley.

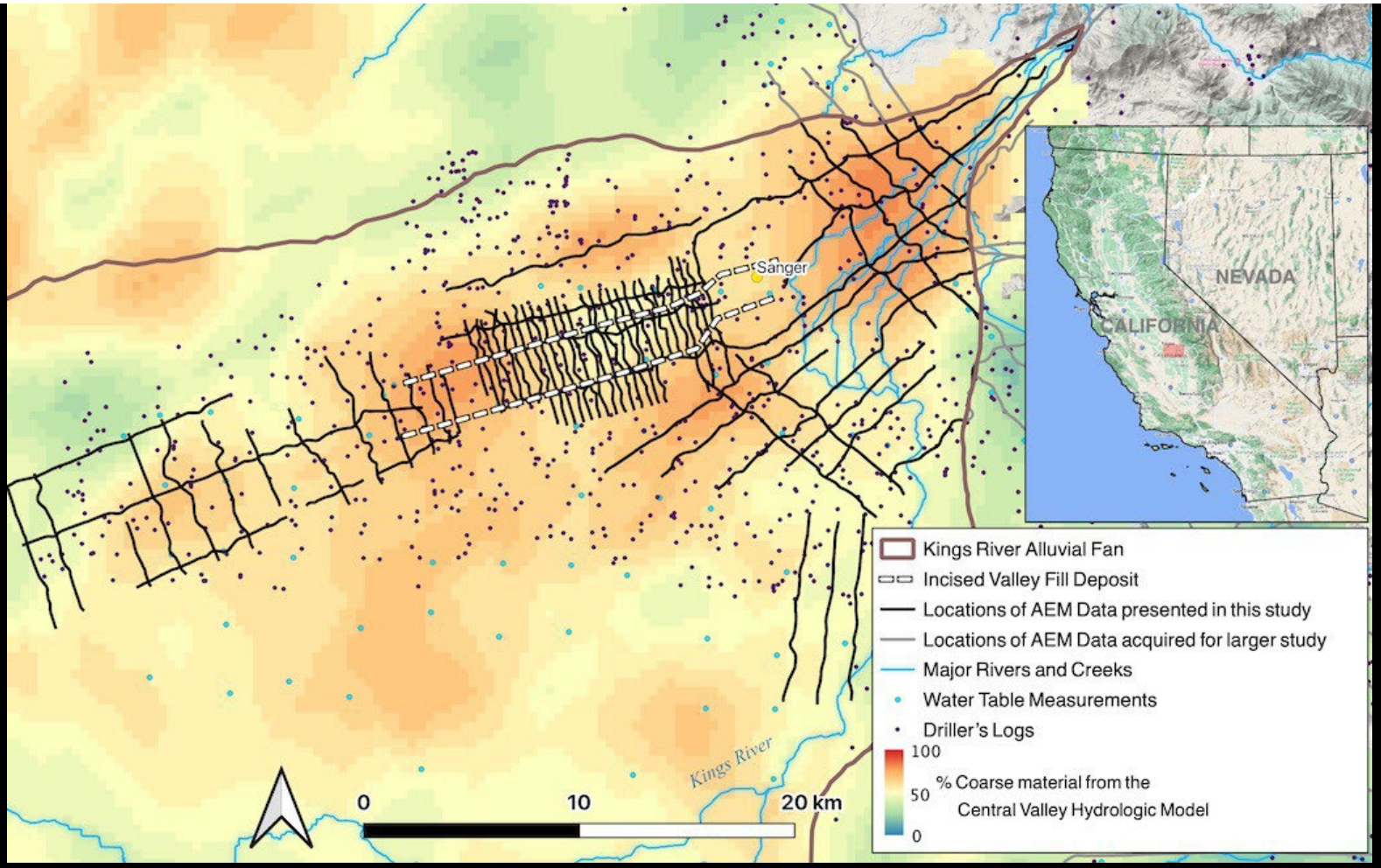


INCISED VALLEY FILL DEPOSITS



Example – in Kings River alluvial fan

Based on Weissmann et al., 2002, 2004



Knight, R., Steklova, K., Miltenberger, A., Kang, S., Goebel. M., and Fogg, G., 2022, Airborne geophysical method images fast paths for managed recharge of California's groundwater, Environ. Res. Lett. 17 124021, DOI 10.1088/1748-9326/aca344 (Open Access)

ACKNOWLEDGMENTS

Funded by a grant from the Gordon and Betty Moore Foundation to R. Knight (grant no. GBMF6189).

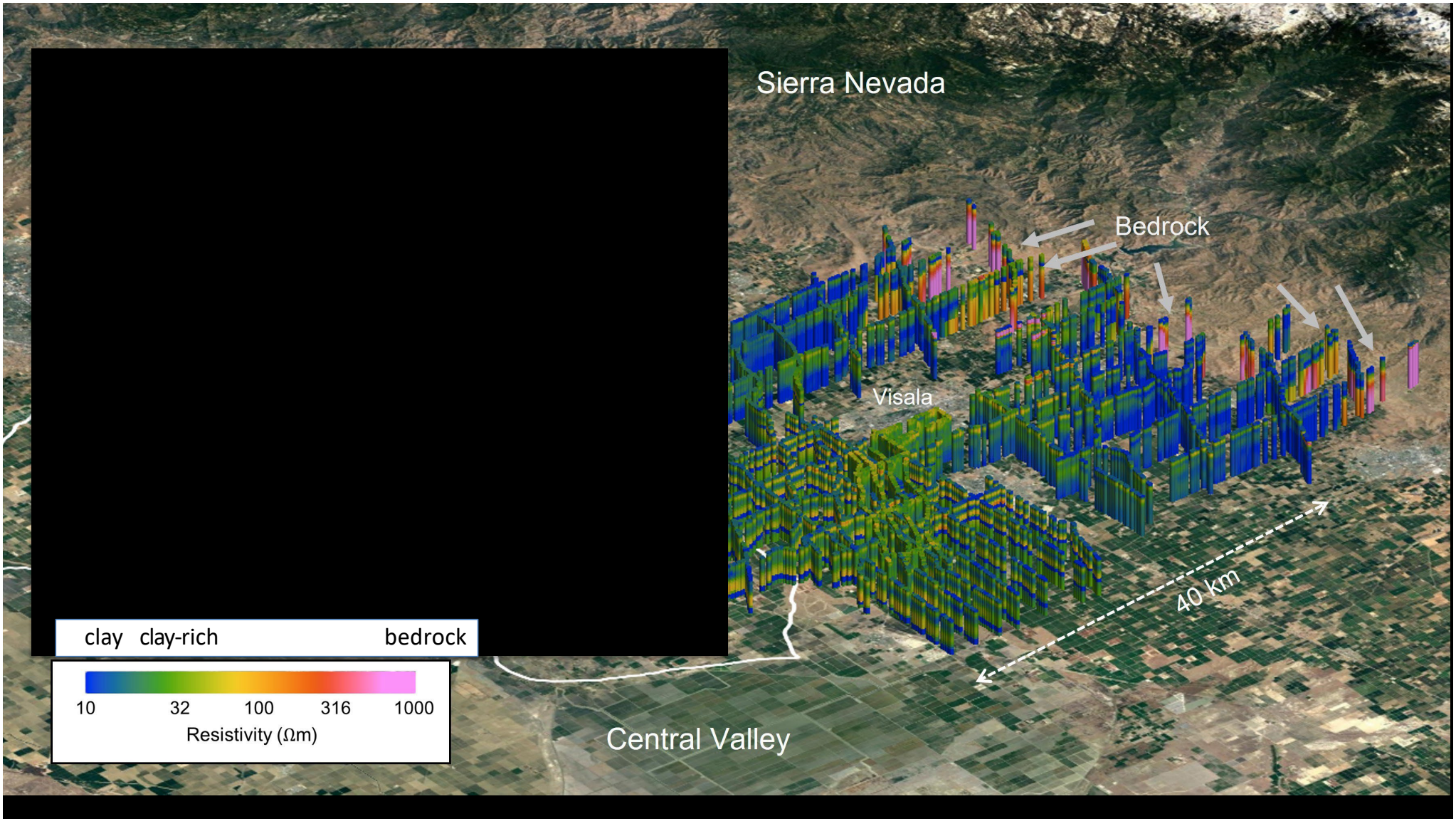
Ted Asch from Aqua Geo Frameworks, Ltd.

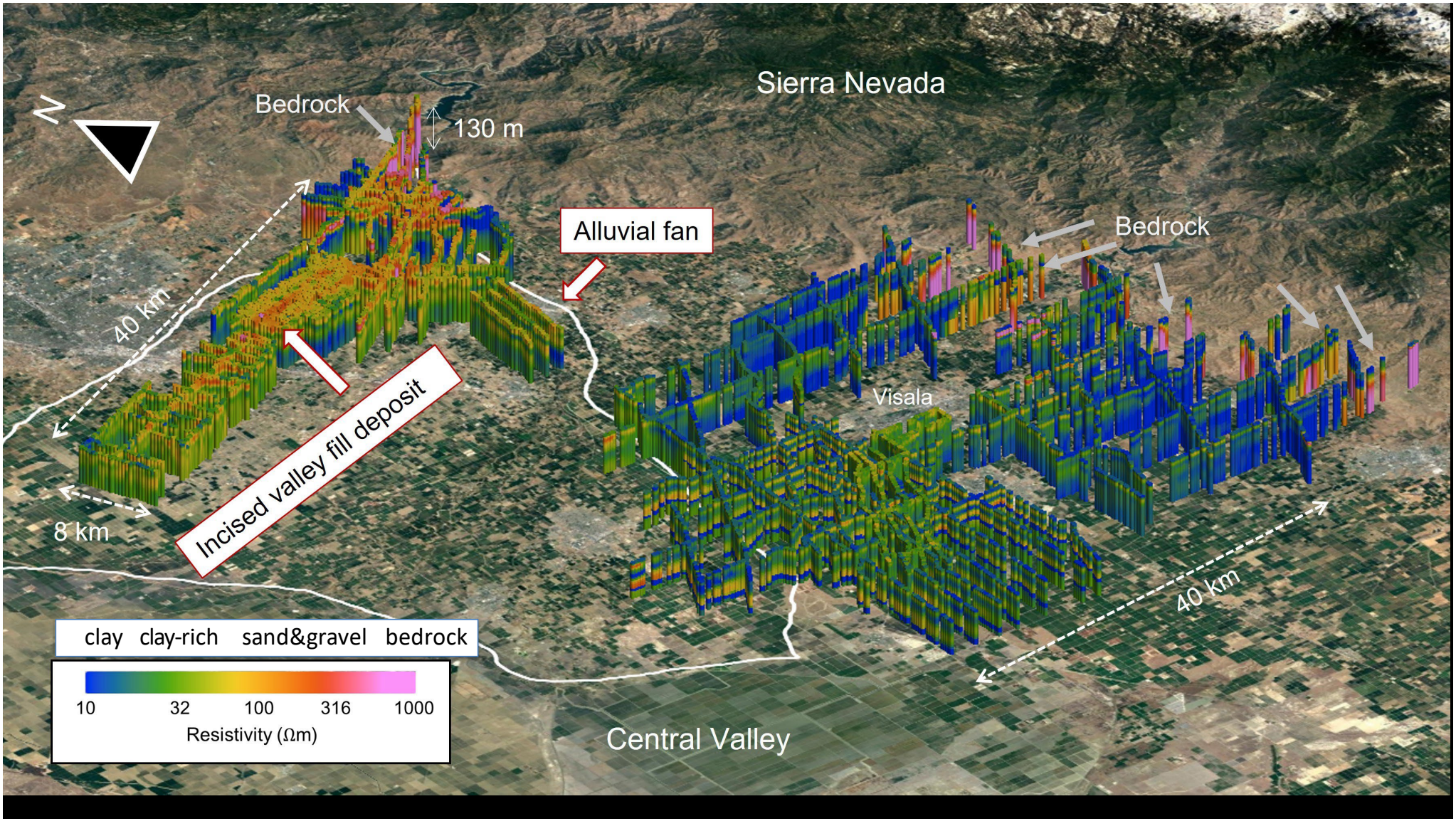
Gary Weissmann (University of New Mexico)

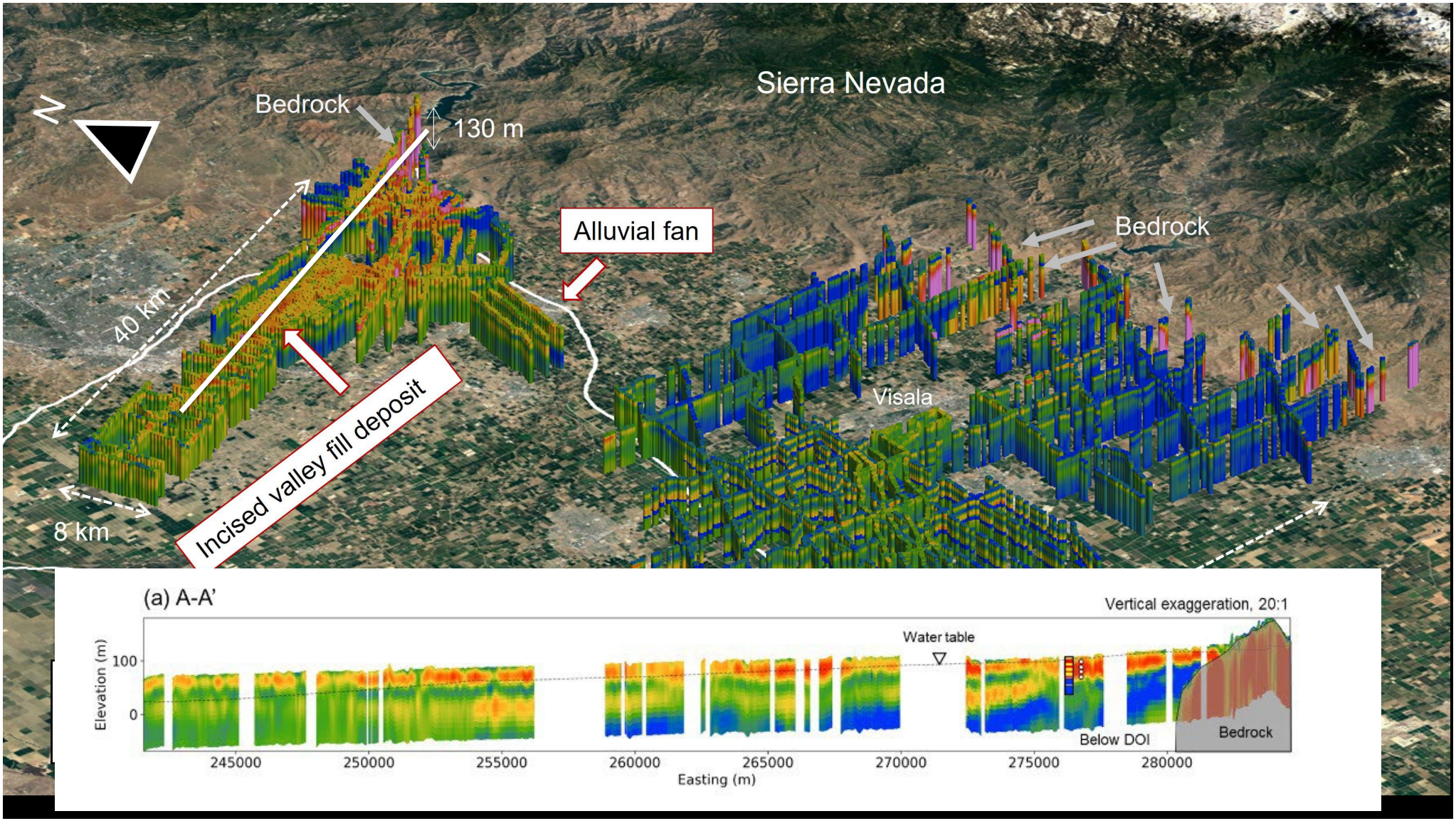
Kassy Chauhan, Executive Officer of North Kings Groundwater Sustainability Agency (GSA)
Phil Desatoff, General Manager of Central Kings GSA and Consolidated Irrigation District
Chad Wegley, General Manager of Kings River East GSA and Alta Irrigation District
Josh Rogers, General Manager of South Kings GSA

We would also like to thank Phil Desatoff, Gavin O'Leary from the Provost and Prichard Consulting Group, and Chad Wegley for providing the additional water level measurements at the time of the AEM survey.

Knight, R., Steklova, K., Miltenberger, A., Kang, S., Goebel. M., and Fogg, G., 2022, Airborne geophysical method images fast paths for managed recharge of California's groundwater, Environ. Res. Lett. 17 124021, DOI 10.1088/1748-9326/aca344 (Open Access)


Sierra Nevada
Bedrock
Visala
40 km
clay clay-rich bedrock
10 32 100 316 1000
Resistivity (Ωm)
Central Valley


Sierra Nevada
N
Bedrock
130 m
Alluvial fan
Bedrock
40 km
Incised valley fill deposit
Visala
8 km
40 km
clay clay-rich sand&gravel bedrock
10 32 100 316 1000
Resistivity (Ωm)
Central Valley


N
Bedrock
130 m
Sierra Nevada
Alluvial fan
Bedrock
40 km
Visala
Incised valley fill deposit
8 km
(a) A-A'
Vertical exaggeration, 20:1
Water table
Elevation (m)
100
0
Below DOI
Bedrock
245000
250000
255000
260000
265000
270000
275000
280000
Easting (m)

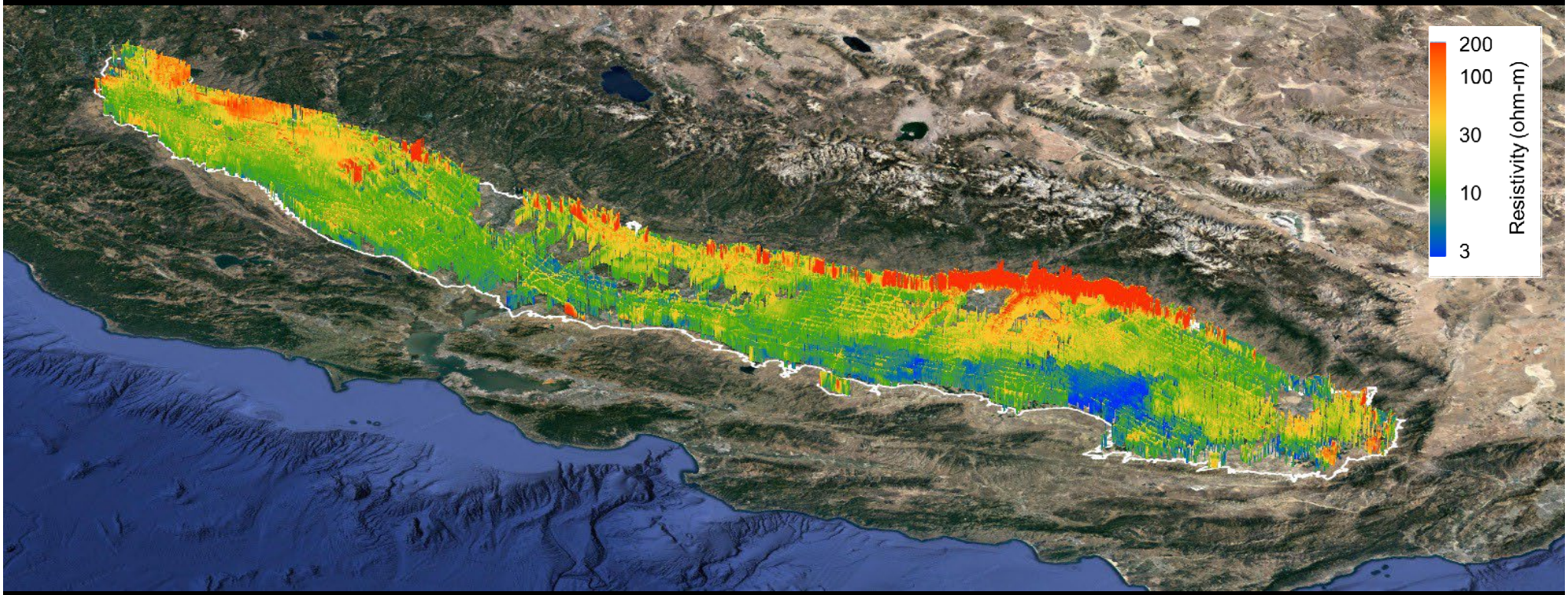
Nov 2016 - Whitepaper sent to Governor's Office of Planning and Research

Acquisition of Airborne Electromagnetic Data in the Groundwater Basins of California: Initial Assessment of a Statewide Reconnaissance Project

Rosemary Knight (Stanford University)
Paul Gosselin (Butte County Dept. of Water and Resource Conservation)
Graham Fogg (UC Davis)
1 November, 2016

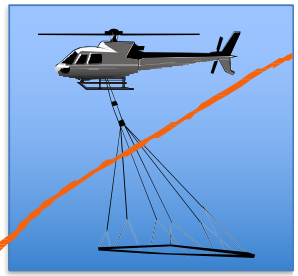
California has embarked on a historic journey to achieve groundwater sustainability through the Sustainable Groundwater Management Act (SGMA). Local agencies are vested with the responsibility for achieving sustainability. For most of the state, the basis for making decisions lacks sufficient understanding of the structure of groundwater basins. Traditional methods of characterizing aquifers are slow, expensive and insufficient. There is a well-established geophysical method, the airborne electromagnetic (AEM) method, which has the potential to make a significant contribution to the way we map and manage groundwater systems in

Released December 22, 2022 by California Department of Water Resources:
25,000 kilometers of Airborne Electromagnetic (AEM) data



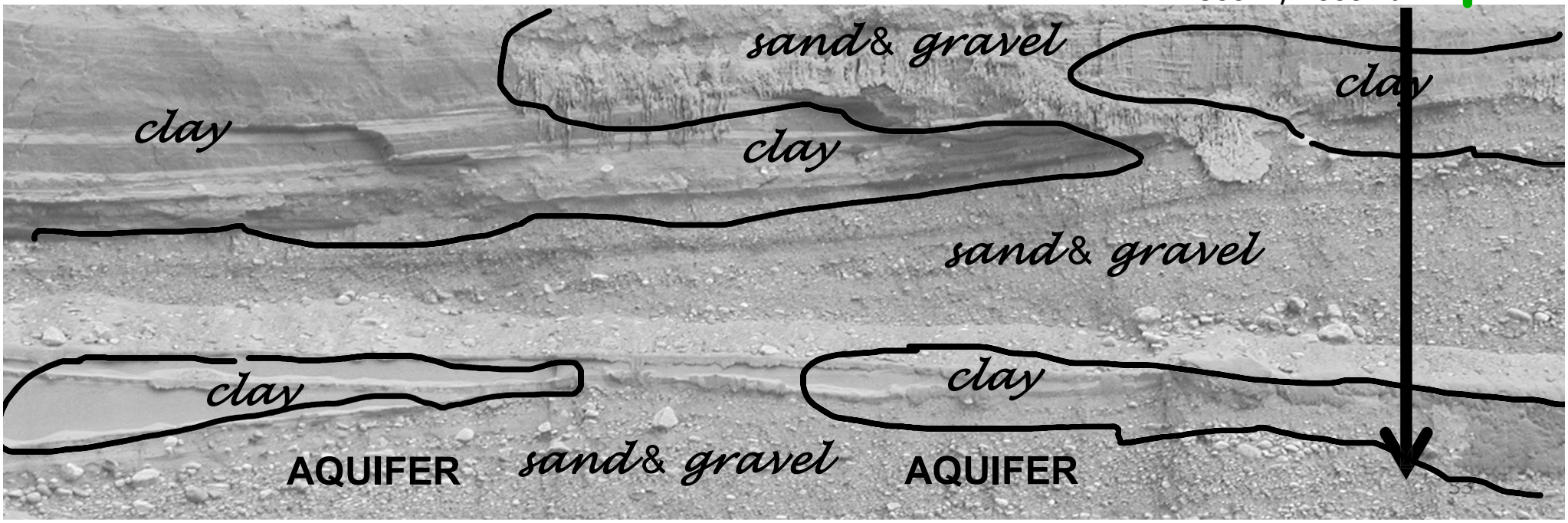
AEM Data from California Department of Water Resources and Stanford Environmental Geophysics

We need a fast, reliable, cost-effective way to find these pathways.

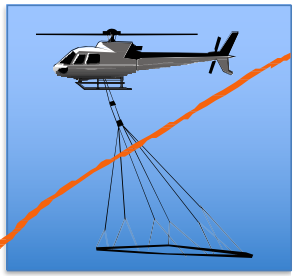


AIRBORNE EM: AEM

DEPTH = 300 m/ 1000 ft



We need a fast, reliable, cost-effective way to find these pathways.

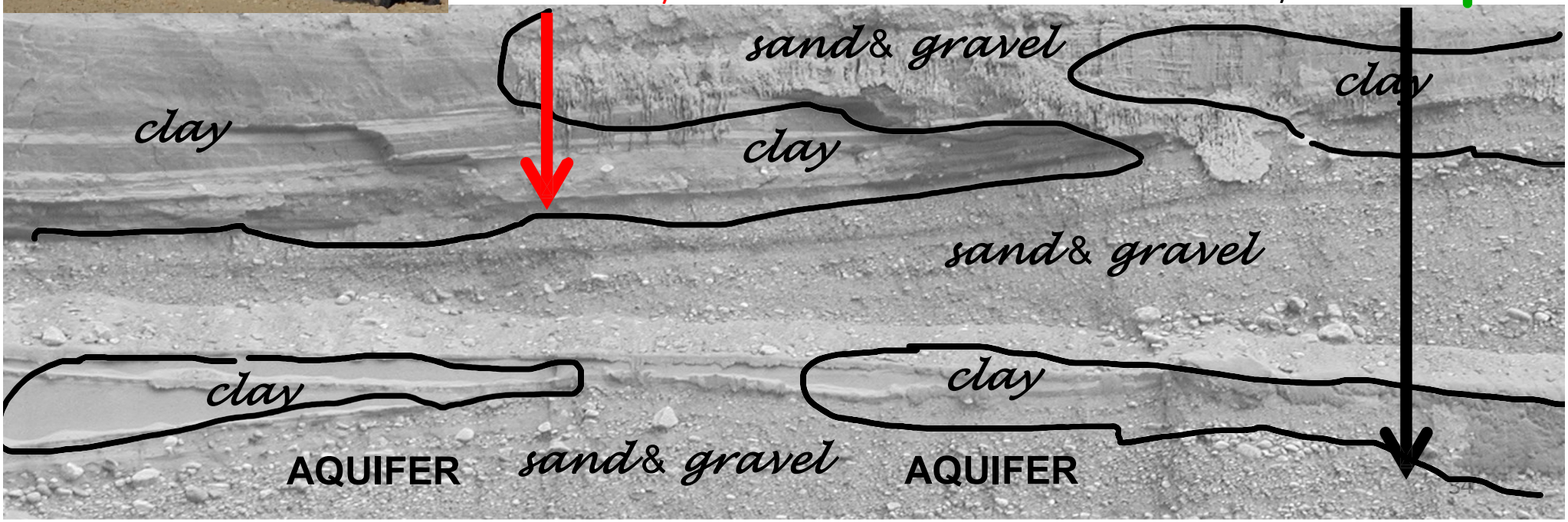


AIRBORNE EM: AEM

TOWED EM: tTEM

DEPTH = 50 m / 150 ft

DEPTH = 300 m/ 1000 ft



Sites for Recharge

Recharge Basin

On-Farm Recharge

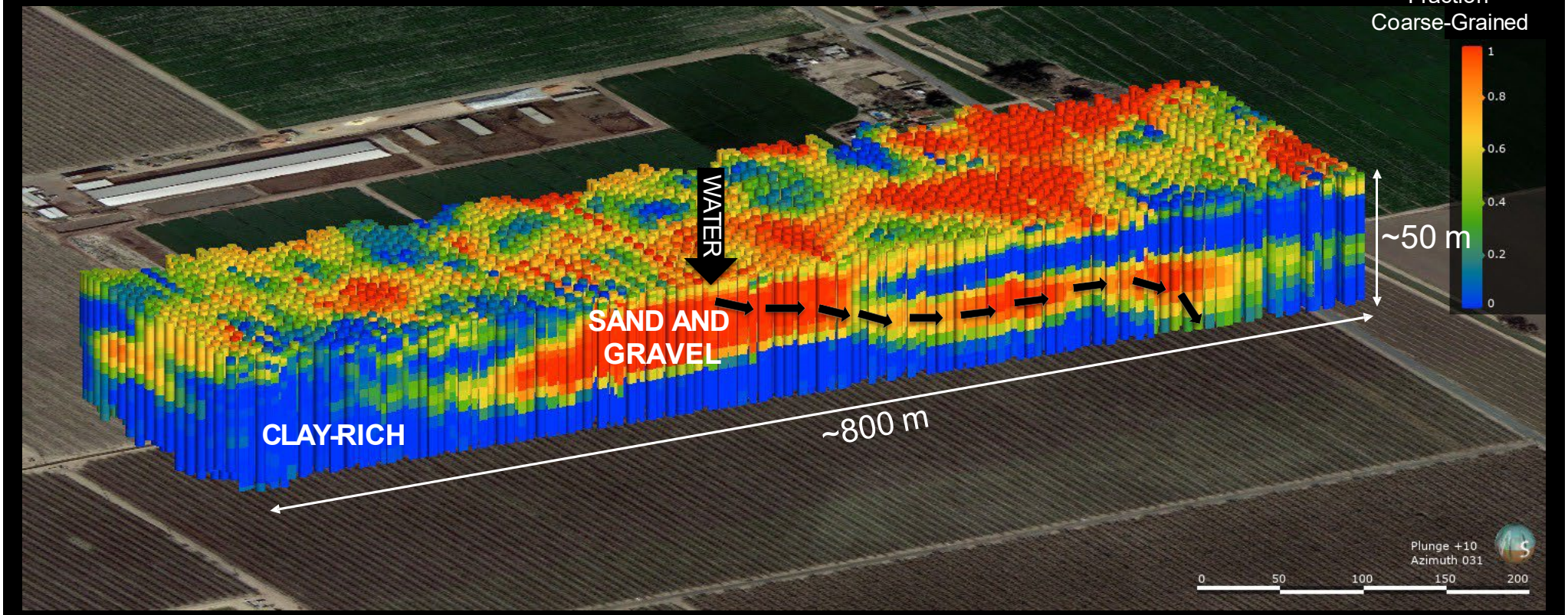
Floodplain Restoration

October 2017 – tTEM comes to California Thanks to Aaron Fukuda for the great drone video shots -

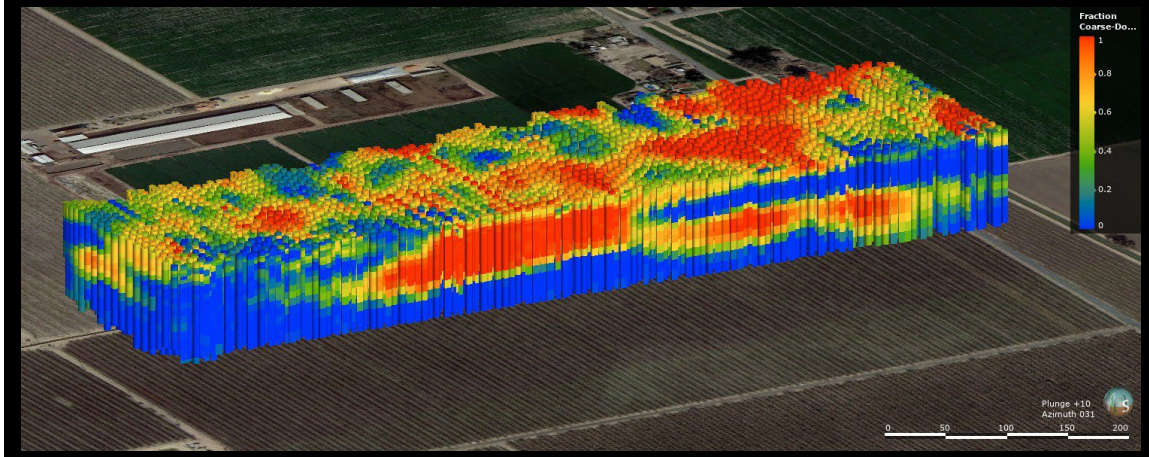
Behroozmand, A., Auken, E., Knight, R., Assessment of managed recharge using a new geophysical imaging method, *Vadose Zone Journal*, 18 (1), 2019.


Stanford

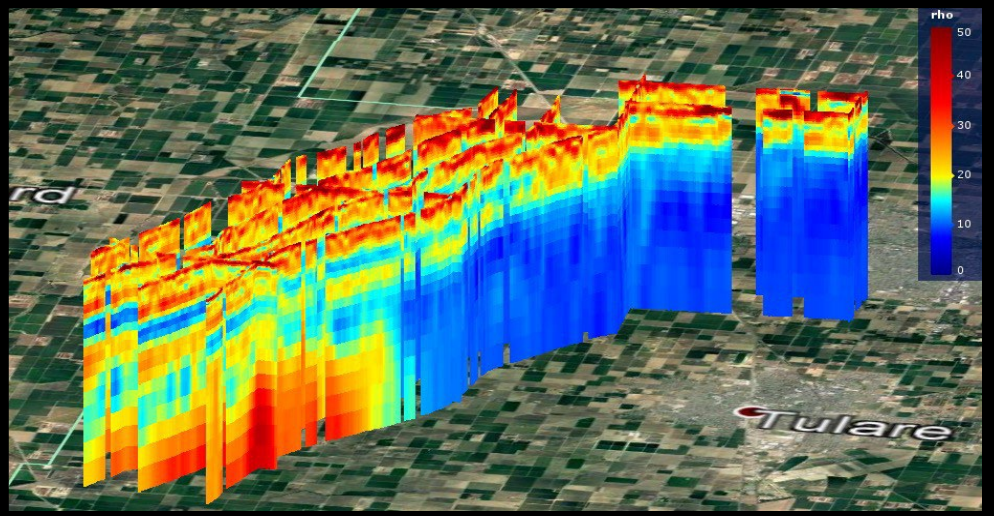
Using Cone Penetrometer Testing, we can obtain from our tTEM data in the almond grove -



tTEM results from Goebel and Knight (2021), Vadose Zone Journal



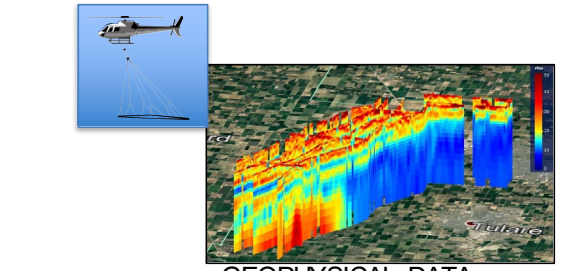
How can we efficiently find the coarse-grained pathways?



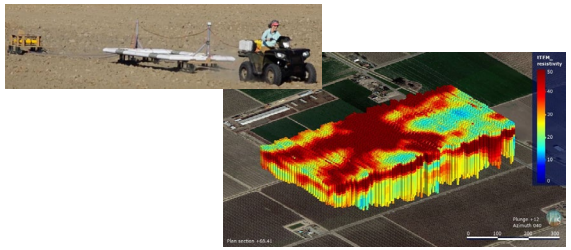
Pepin, Knight, Goebel, Kang, Vadose Zone Journal, 2022

WEB-BASED APPLICATION

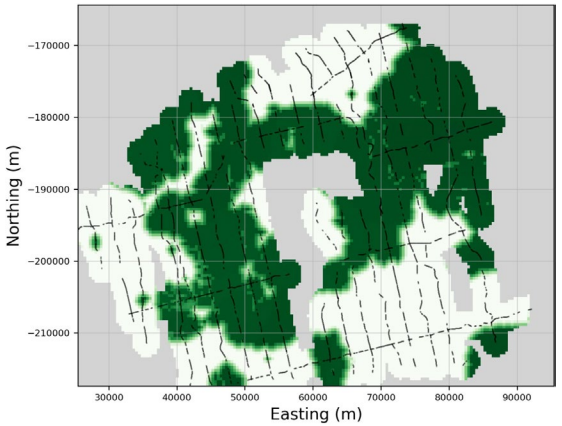
fastpath



GEOPHYSICAL DATA



MAPS OF AREAS (GREEN = RECHARGE here)

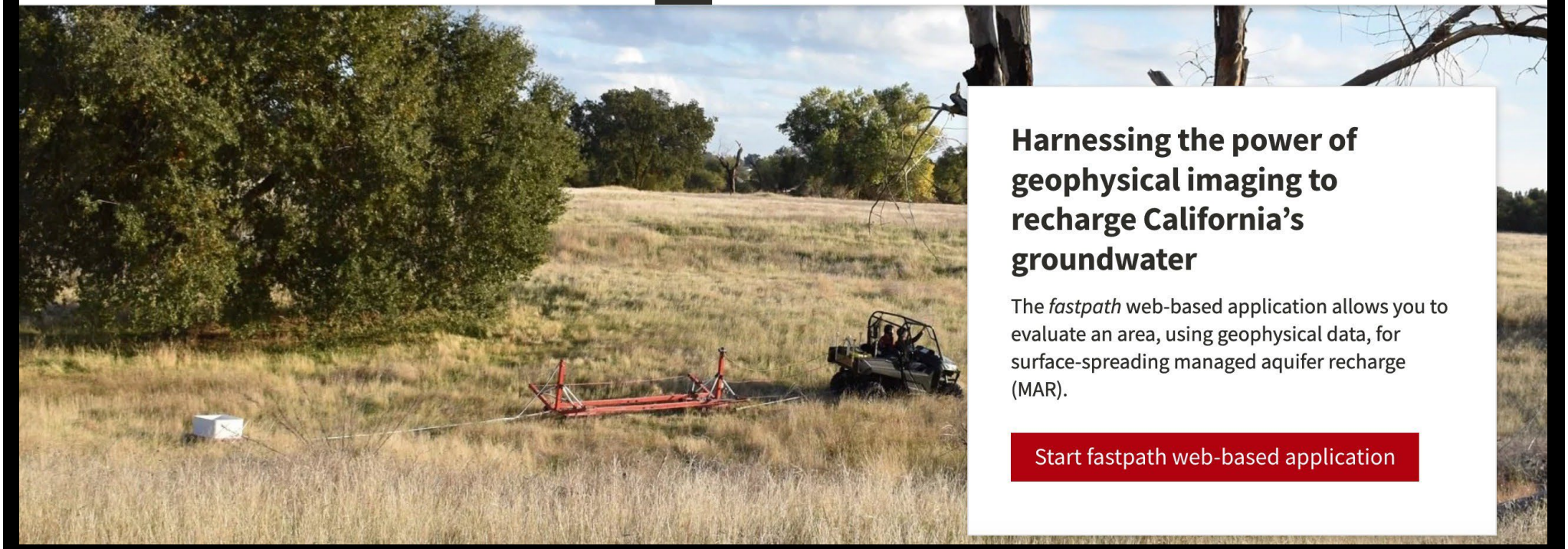


Stanford Doerr School of Sustainability

Recharging California's Groundwater

Fastpath web-based application & online course

Home | Project Participants | Online course | Presentations & Publications



Harnessing the power of geophysical imaging to recharge California's groundwater

The *fastpath* web-based application allows you to evaluate an area, using geophysical data, for surface-spreading managed aquifer recharge (MAR).

Start fastpath web-based application

fastpath.stanford.edu

Completed in collaboration with Curvenote

Co-I: **Paul Godwin** - Deputy Director for Sustainable Groundwater Management, DWR

Co-I: **Mike Lepech** – Professor, CEE, 10 years of experience working with SCPD delivering training

Tim Godwin – Technical and Policy Advisor to the Deputy Director of Sustainable Groundwater Management, DWR

Aaron Fukuda – Manager, Tulare Irrigation District

Kassy Chauhun - Executive Director, North Kings GSA (Fresno County)

Christina Buck - Assistant Director, Butte County Water and Resource Conservation Department

Matt Zidar - Water Resources Manager, San Joaquin Department of Public Works - AEM/tTEM for recharge

Charlotte Gallock - Director of Water Resources/Chief Engineer, Kings River Conservation District

Julie Rentner – President, River Partners – focus on floodplain restoration

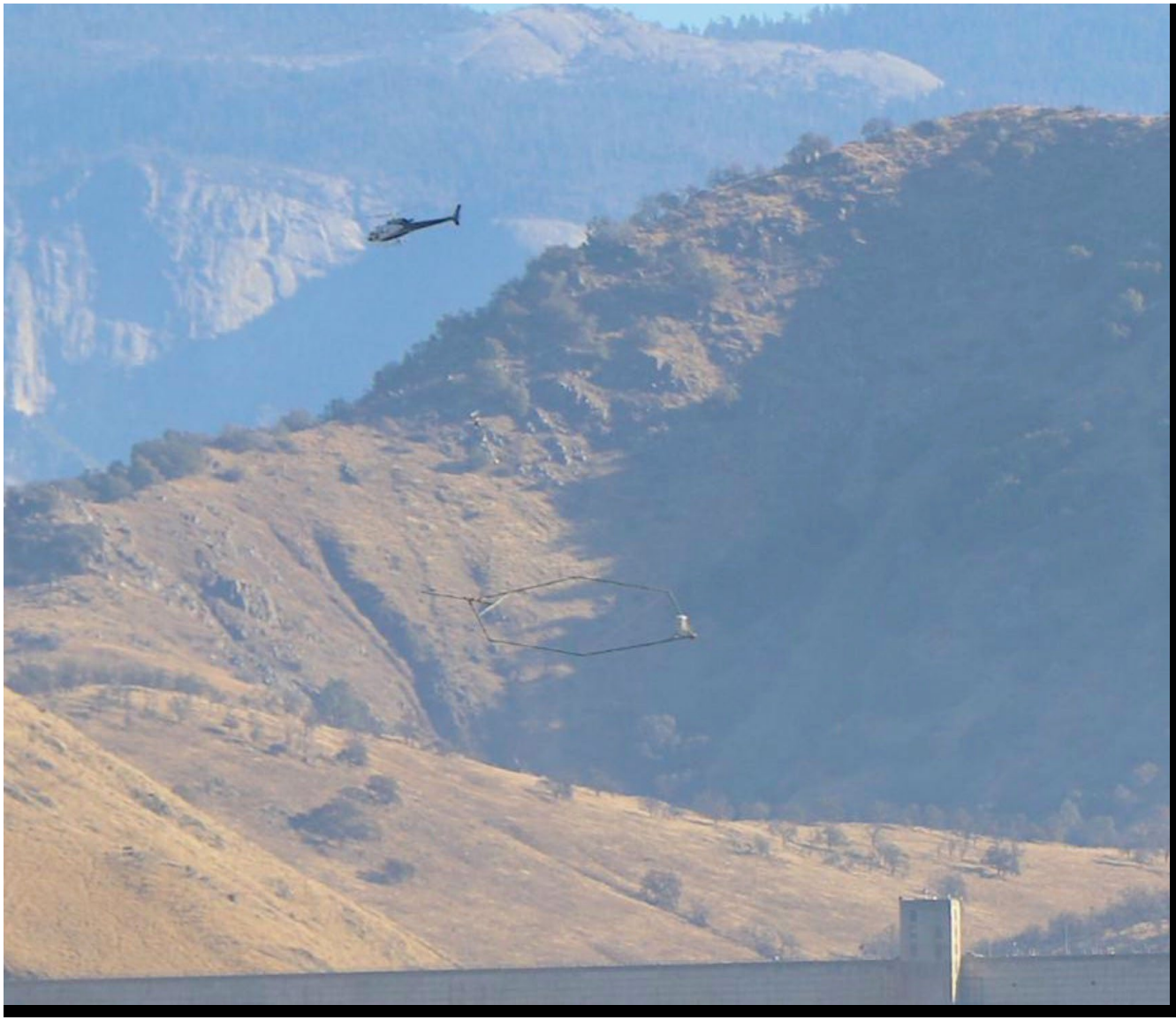
Jenny Marr - Division of Planning, DWR

Jesse Roseman - Principal Analyst, Environmental and Regulatory Affairs, Almond Board of California

Paul Bauman - Principal Geophysicist, BCG Engineering, Inc.

Derrik Williams - Montgomery and Associates

This application capitalizes on eight years of academic investment by Rosemary Knight's **Environmental Geophysics Research Group** at Stanford, in partnership with others throughout the state, to advance the use of geophysical methods to image the groundwater systems of California. The value of the application is due, in large part, to the tremendous success of the state-wide airborne geophysical surveys conducted by the California Department of Water Resources, and the rapid processing of acquired data and distribution of the results.



Acknowledgements - Funded by:

Stanford School of Earth, Energy and Environmental Sciences

The Gordon and Betty Moore Foundation

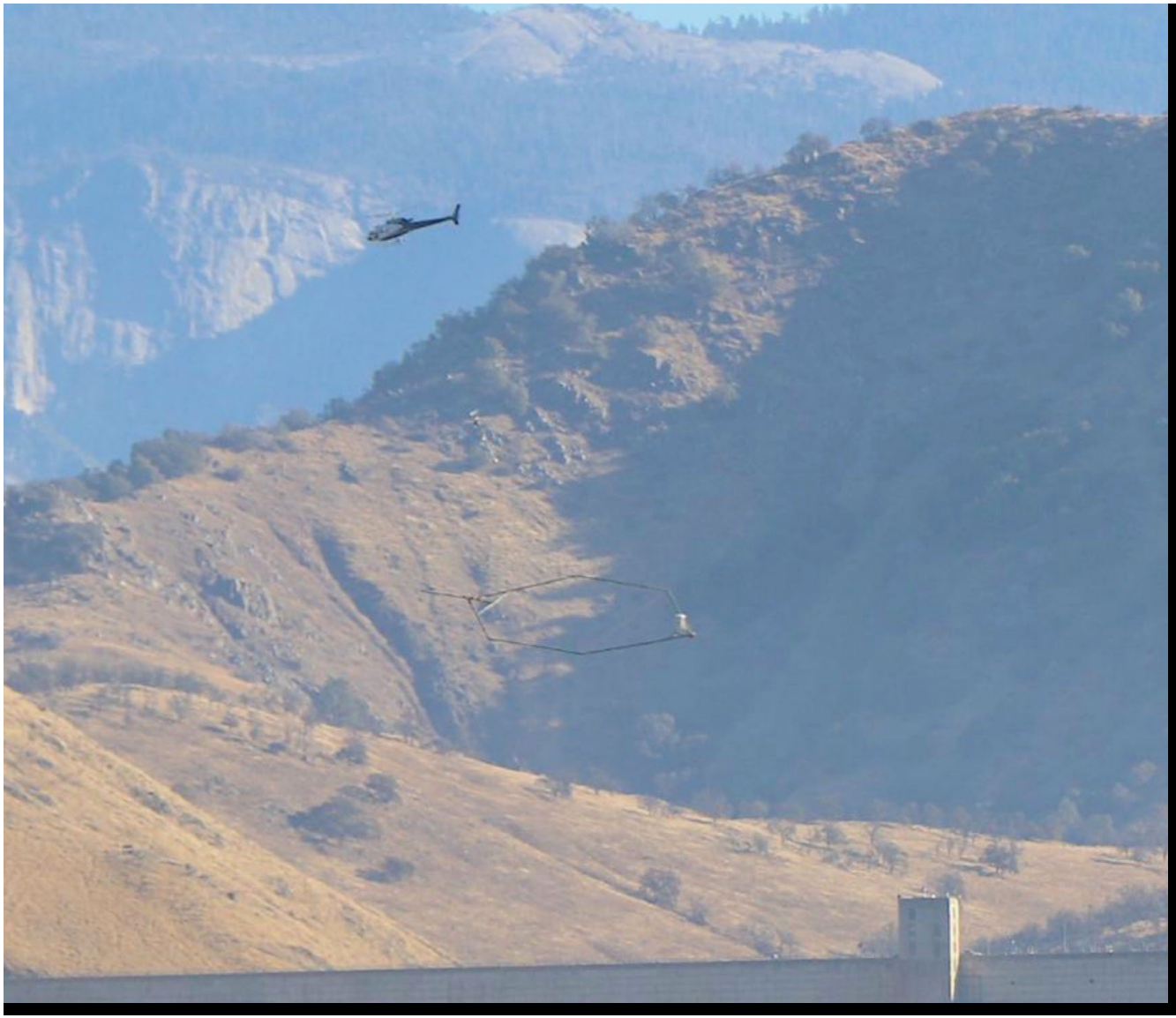
Local Water Agencies

Almond Board of California

Stanford Woods Institute for the Environment

CA Dept of Water Resources
State Water Resources Control Board
Danish EPA

The Accelerator, Stanford Doerr School for Sustainability



And why this all happened –

Students

Post-Doctoral Fellows

Research Scientists

Many Partners

See gemcenter.stanford.edu