

Transforming resistivity data to lithology for large scale airborne electromagnetic (AEM) surveys

2025 CWEMF Annual Meeting

Session 14: Update on DWR's Basin Characterization Program

May 13th, 2025

Authors:

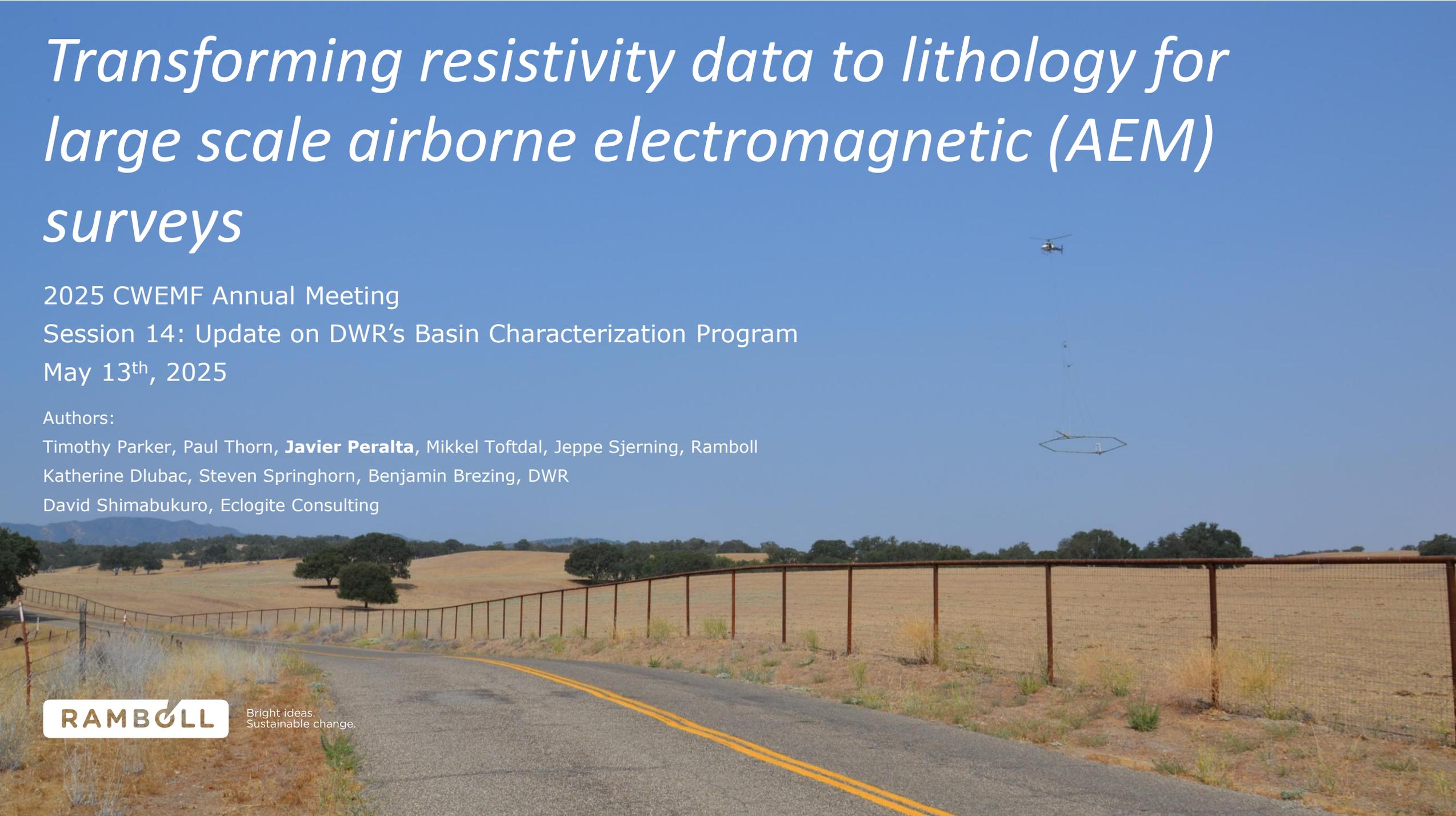
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RAMBOLL

Bright ideas.
Sustainable change.



Transforming resistivity data to lithology for large scale airborne electromagnetic (AEM) surveys

1. Brief background on the California's Statewide AEM Survey
2. Theory behind AEM and the correlation between resistivity and lithology
3. Resistivity to lithology transformation
4. Well lithology used in the lithology transformation process
5. Results from the resistivity to lithology transformation
6. Opportunities and limitations



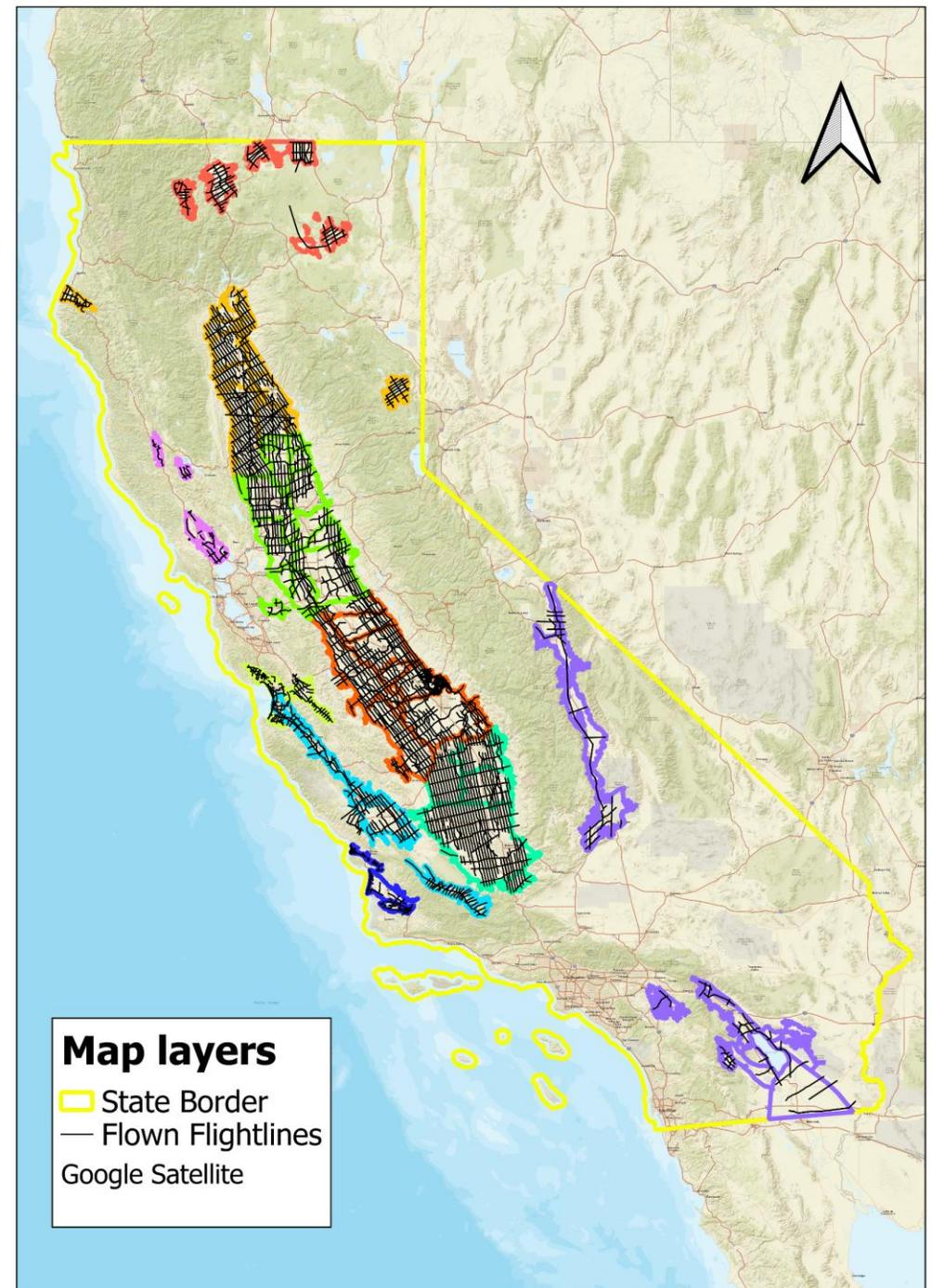
Transforming resistivity data to lithology for large scale airborne electromagnetic (AEM) surveys

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2. Theory behind AEM and the correlation between resistivity and lithology
- 3. Resistivity to lithology transformation**
- 4. Well lithology used in the lithology transformation process**
5. Results from the resistivity to lithology transformation (AEM and tTEM)
6. Opportunities and limitations



California AEM Statewide Survey

- The Statewide Airborne Electromagnetic (AEM) survey was flown for the California Department of Water Resources
 - AEM surveys provide electrical resistivity profiles of the earth's geological layers and structures down to depths of as much as 300 m (1,000 ft).
 - For the survey, all medium and high priority groundwater basins were flown
 - 25,010 line-kilometers flown between July 2021 and November 2023
 - Lines conducted were a screening survey on a 3 x 12 km line spacing grid



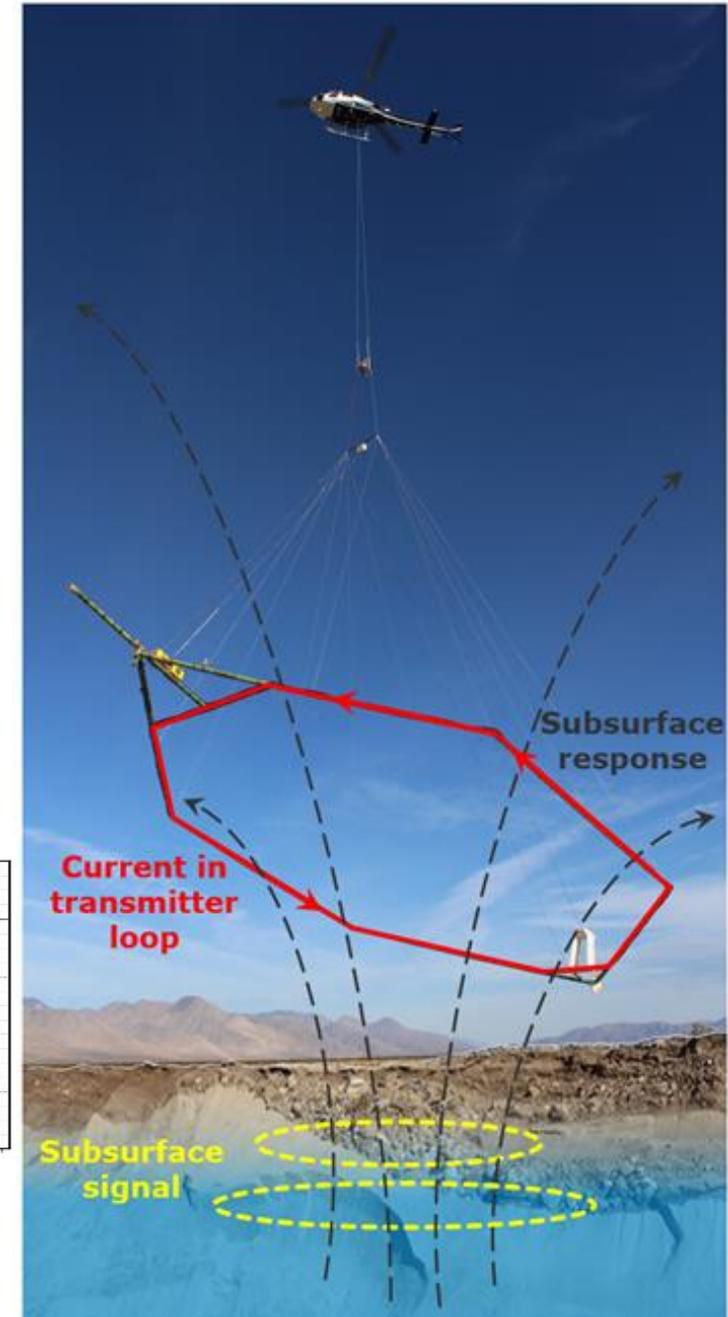
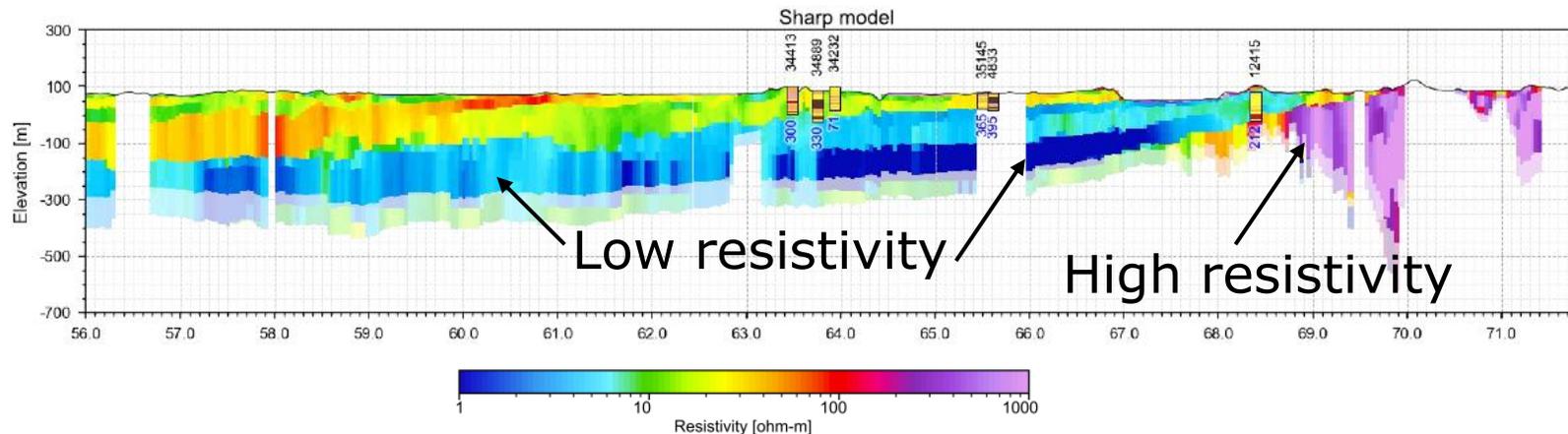
California AEM Statewide Survey



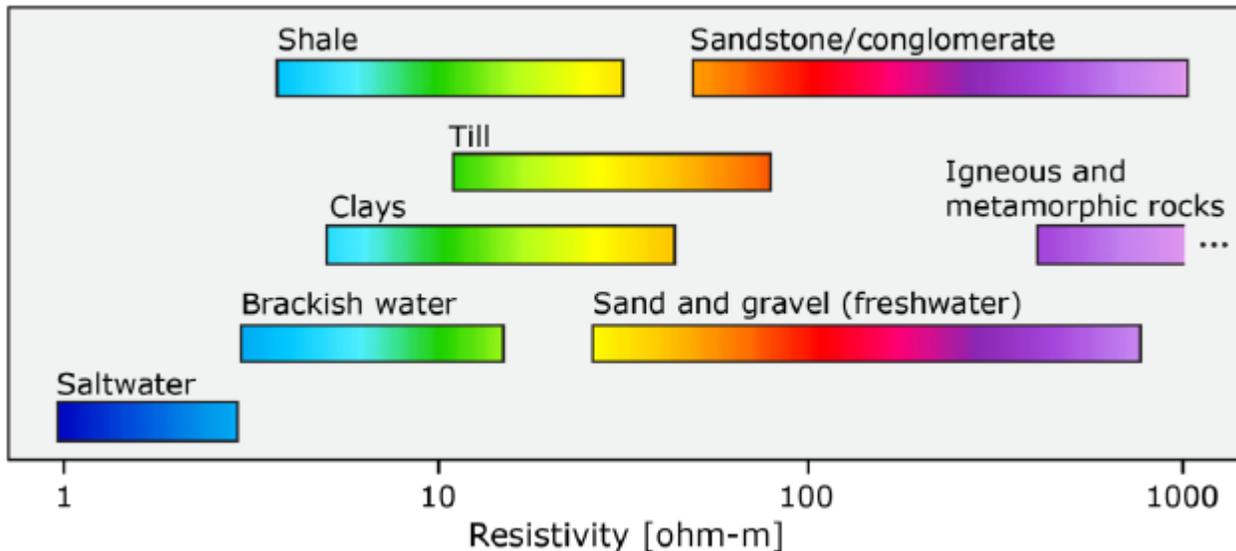
- The Statewide AEM Survey included:
 - Collection of well data along the AEM flight lines:
 - Well lithology
 - Electrical logs
 - Water level measurements
 - Water quality (TDS) measurements
 - Processing and inversion of the AEM Data
 - Resistivity to lithology transform of the data
 - Development of an initial hydrostratigraphic model

Theory – resistivity and the correlation between resistivity and lithology

- AEM is a transient electromagnetic method
 - Induces electrical currents into the subsurface and receives the Earth's response over a short period of time
 - The raw data is processed and inverted yielding information on the subsurface resistivity structure (as resistivity models)
 - The resistivity is recorded as ohm-m, from 1 – 1000 ohm-m



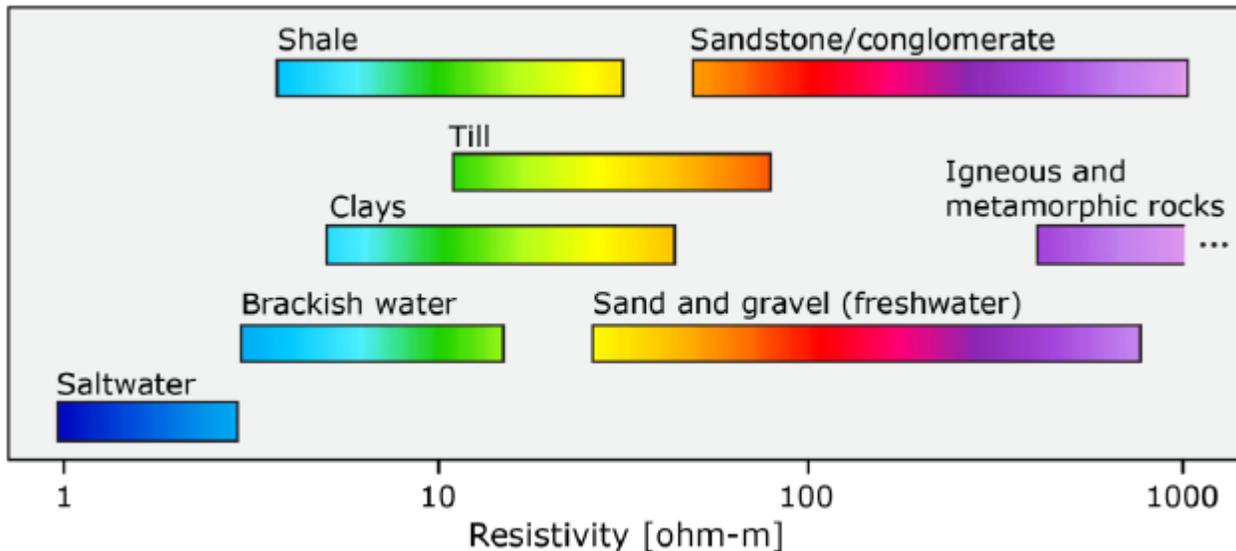
Theory – resistivity and the correlation between resistivity and lithology



After Palacky, G., 1987. *Resistivity Characteristics of Geological Targets*.

- Subsurface resistivity is dependent upon the following factors
 - The subsurface geology
 - Lithology of unconfined sediments
 - Consolidated sediments, volcanics and basement
 - Groundwater salinity
 - Degree of saturation
 - Unsaturated sediments have a higher resistivity than saturated sediments
- The different sediment types have a relatively wide, and often overlapping range of resistivity, and thus other information, including well lithology descriptions, is needed to convert the subsurface resistivity to lithology

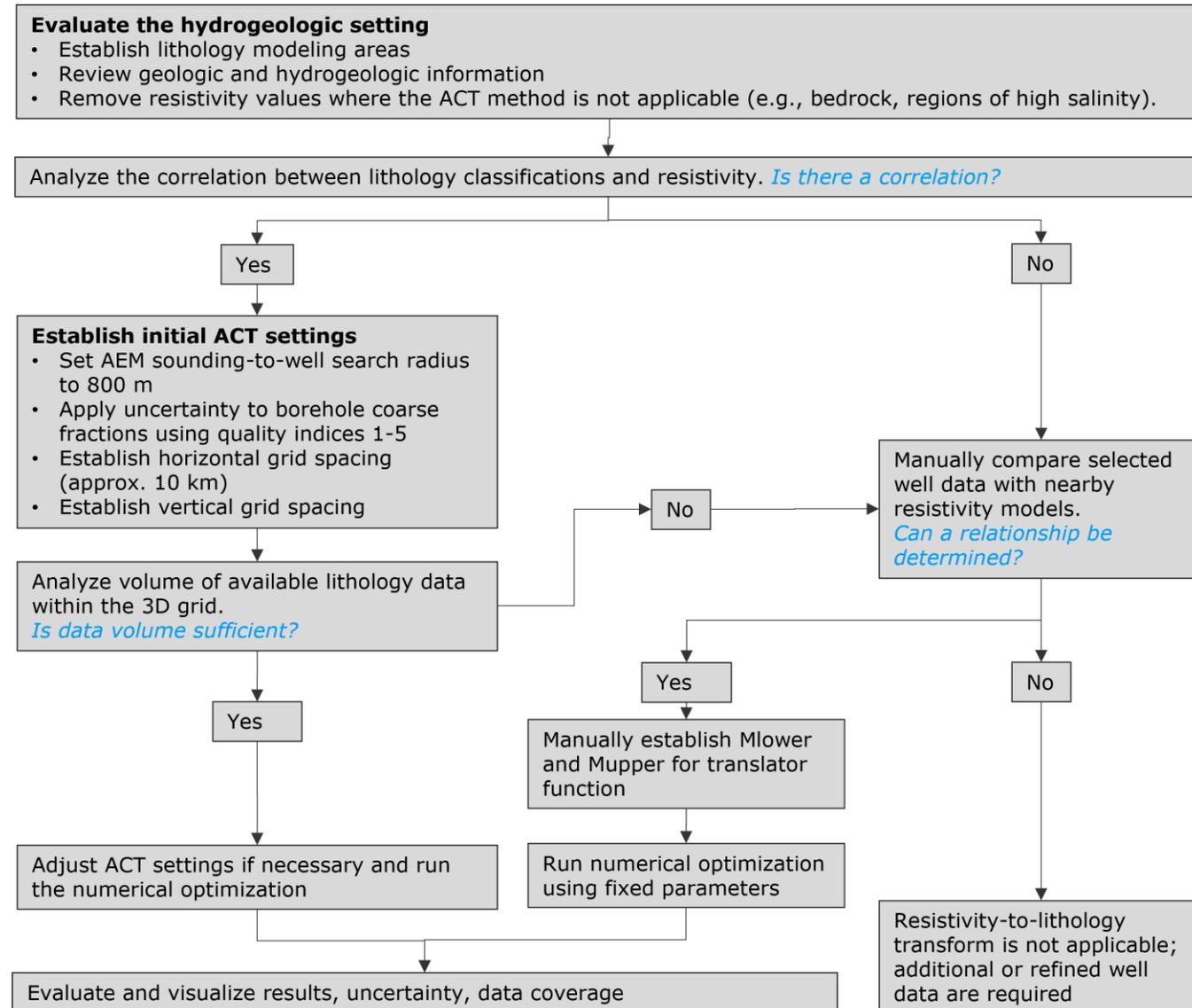
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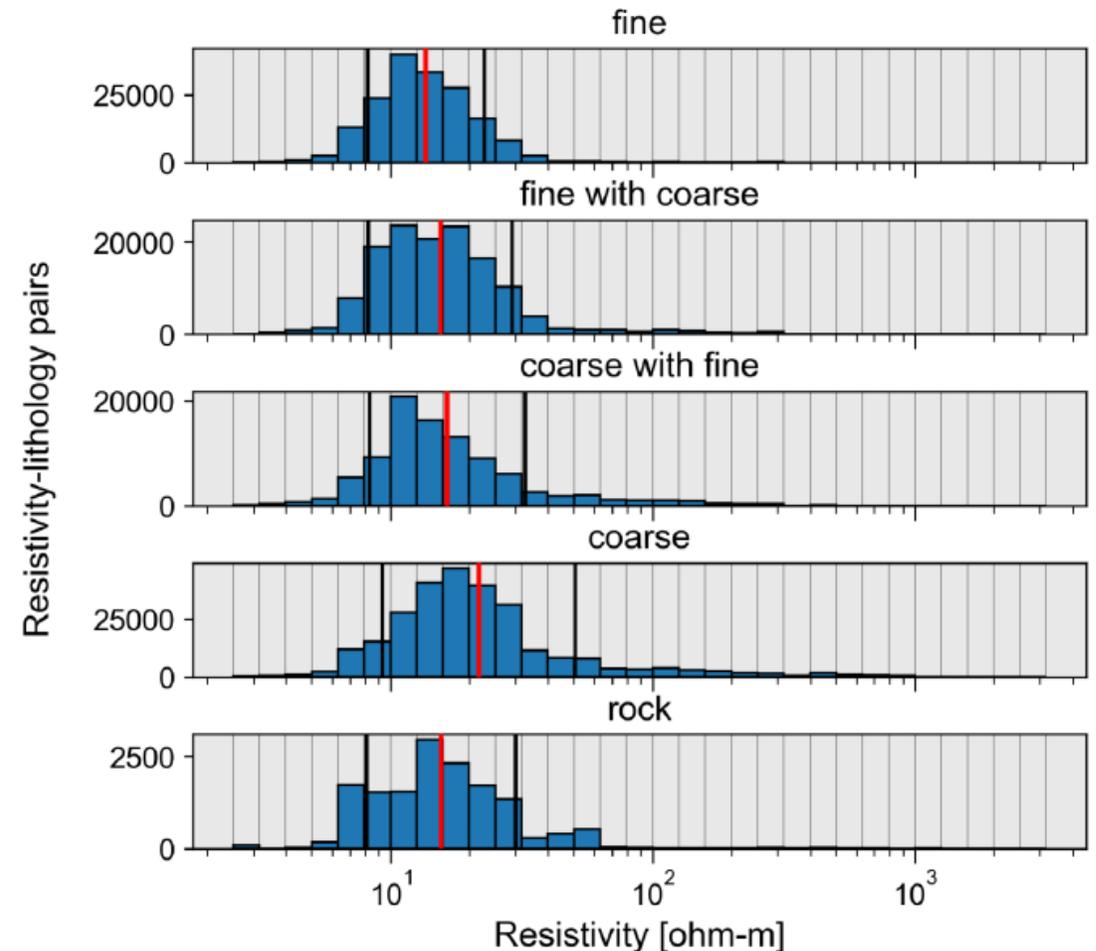
Resistivity to Lithology Transformation via the ACT Method



Resistivity to Lithology Transformation

How the ACT Method Works

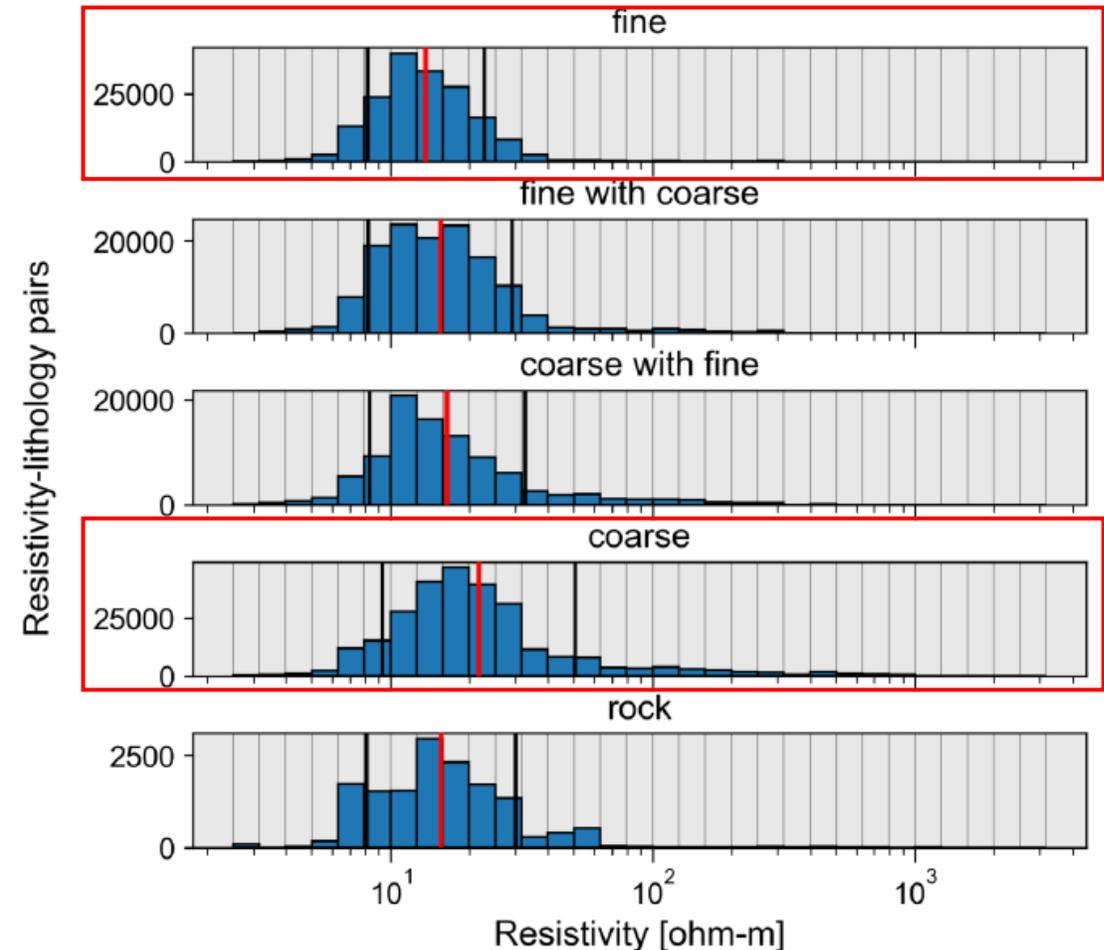
1. Every lithology layer described in the wells is simplified to being either coarse or fine sediments (i.e. sandy clay is classified as fine and gravelly sand with clay streaks is classified as coarse),
 - m_{lower} is set by the mean resistivity value for all lithology descriptions classified as fine
 - m_{upper} is set by the mean resistivity value for all lithology descriptions classified as coarse
2. A statistical comparison of the resistivity models with the simplified lithology to produce an initial translator function, converting resistivity to a coarse fraction (CF) from 0 to 1



Resistivity to Lithology Transformation

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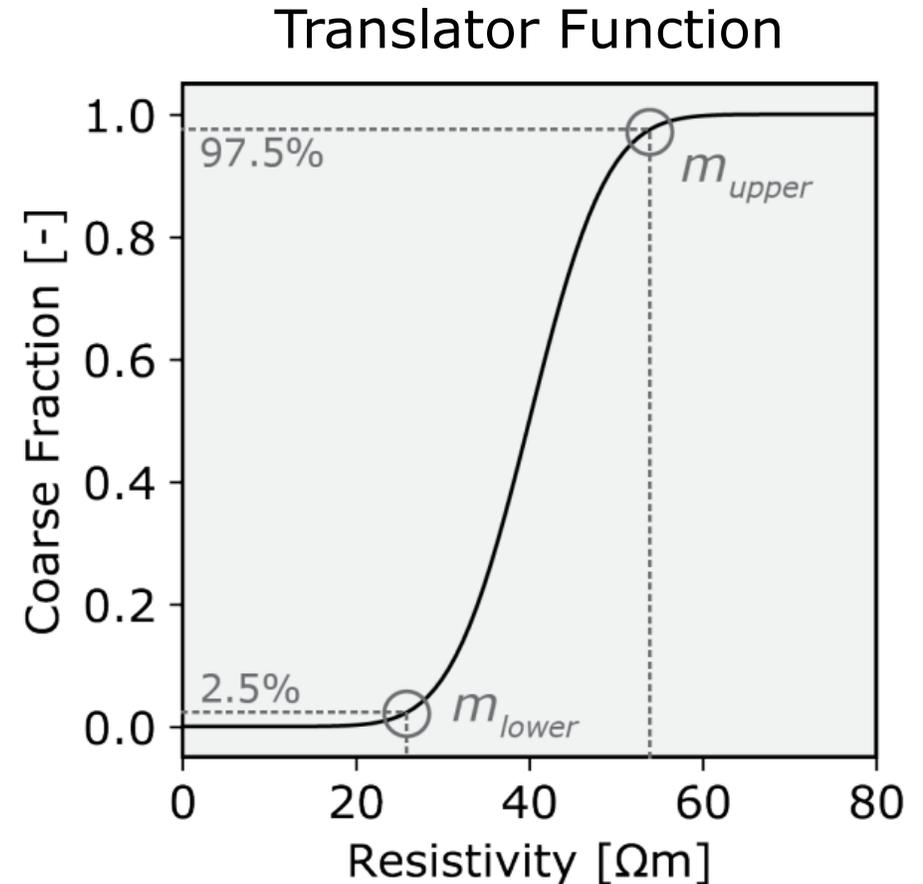
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How the ACT Method Works

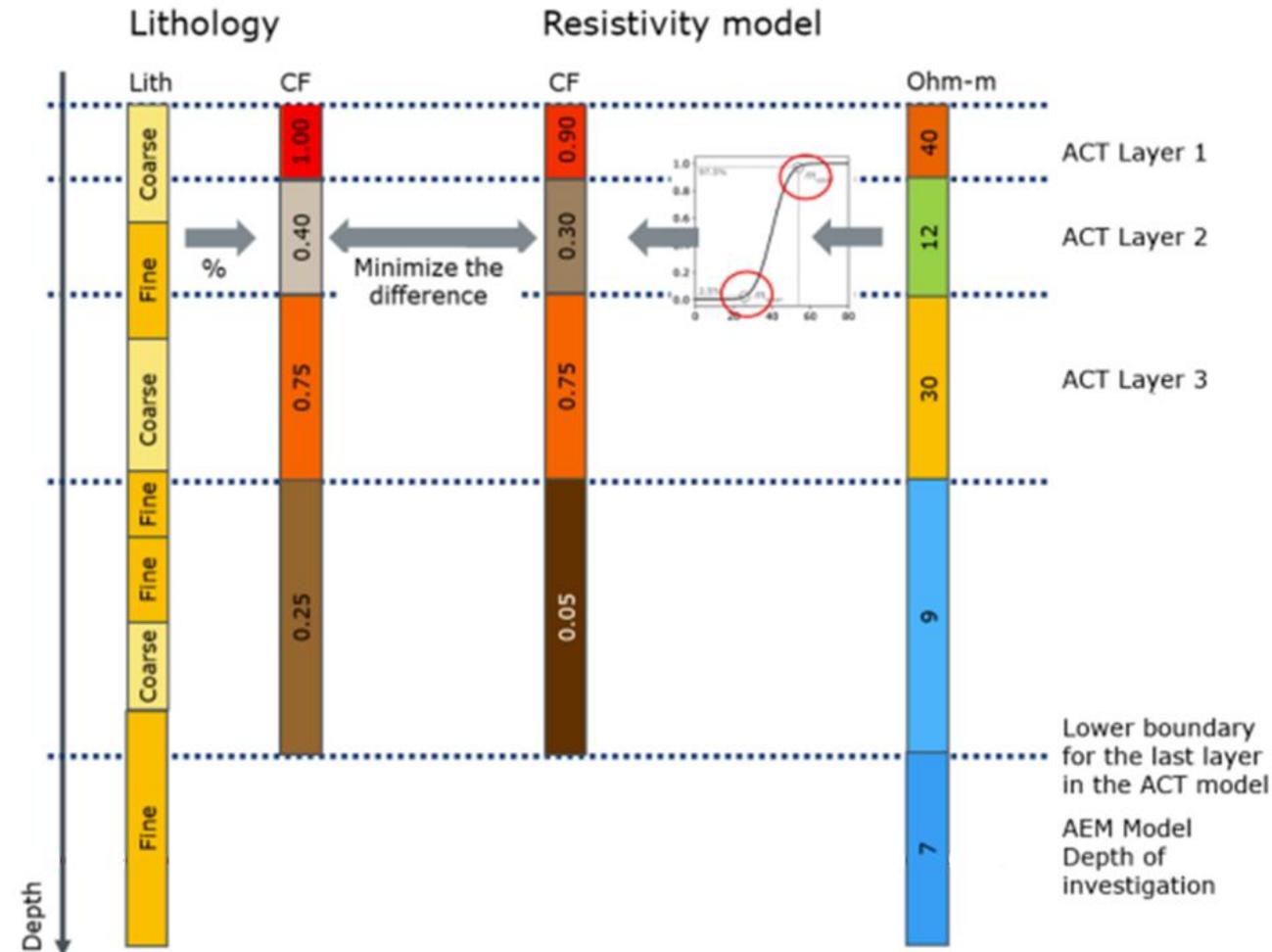
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Resistivity to Lithology Transformation

The ACT Method Works

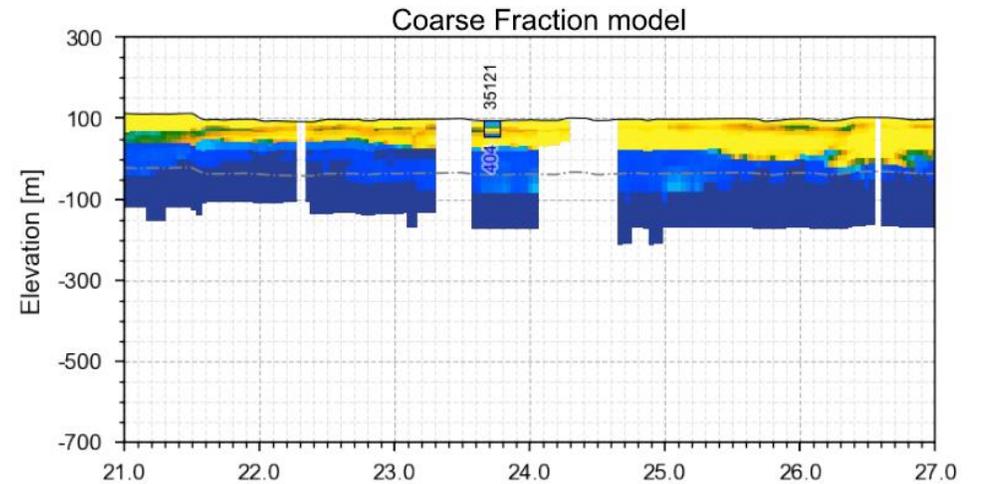
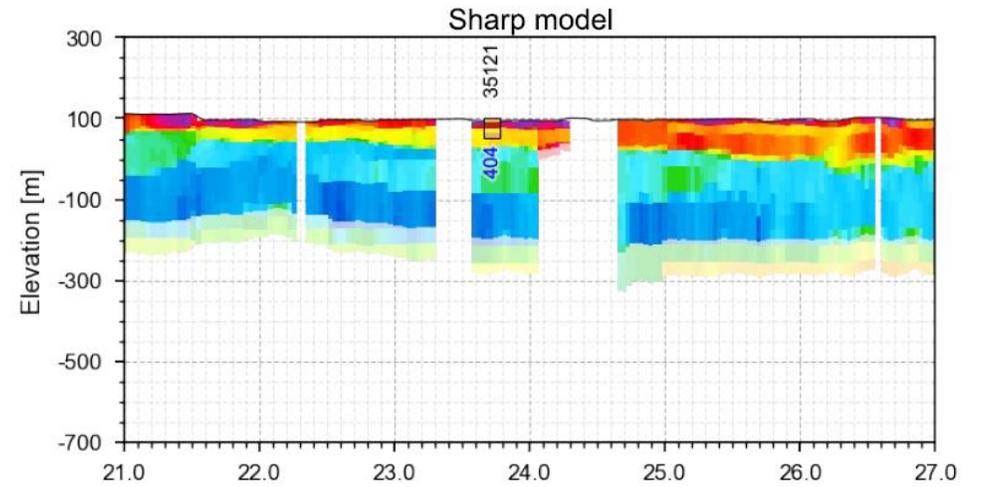
3. The ACT modelling layers are defined from the 30 layer sharp model, restricted to the AEM model Depth of Investigation
4. A horizontal modelling grid is established along the AEM lines – each grid is 5 – 10 km wide
5. The translator function for each ACT layer is then optimized within each grid network
 - a. The resistivity for each ACT layer is converted to coarse fraction using the initial translator function
 - b. This is then compared to the CF from the lithology from wells within 800 meters
 - c. The algorithm then adjusts the translator function to minimize the difference between the lithology coarse fraction from the well lithology and the resistivity within each grid cell



Resistivity to Lithology Transformation

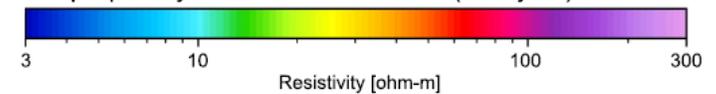
- **How the ACT Method Works**

6. Once the translator function has been optimized for each ACT layer in each grid, the resistivity is then converted to a coarse fraction model along all of the AEM survey lines



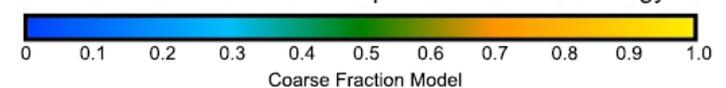
Sharp model

Sharp Spatially Constrained Inversion (30 layers)



Coarse Fraction Model

Coarse Fraction based on Sharp Model and well lithology

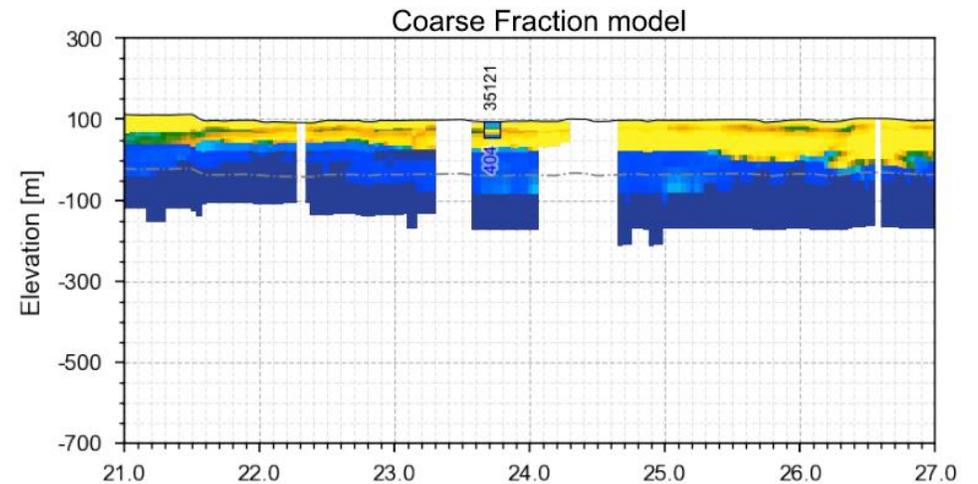
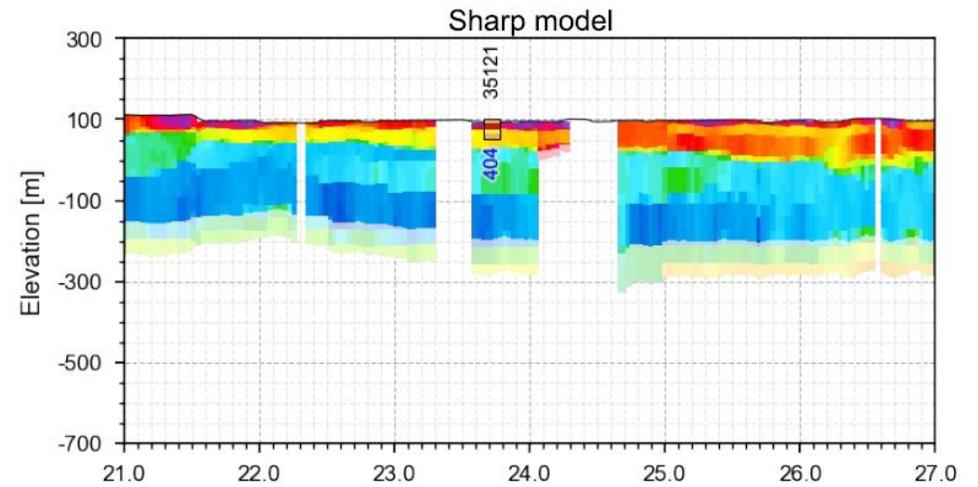


Resistivity to Lithology Transformation

- **How the ACT Method Works**

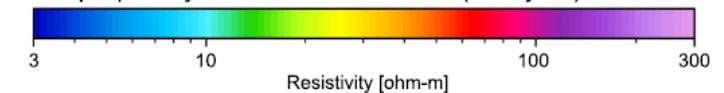
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***But this translator function is
reliant on lithology data***



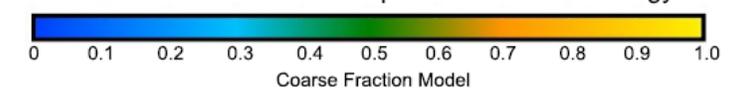
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Coarse Fraction Model

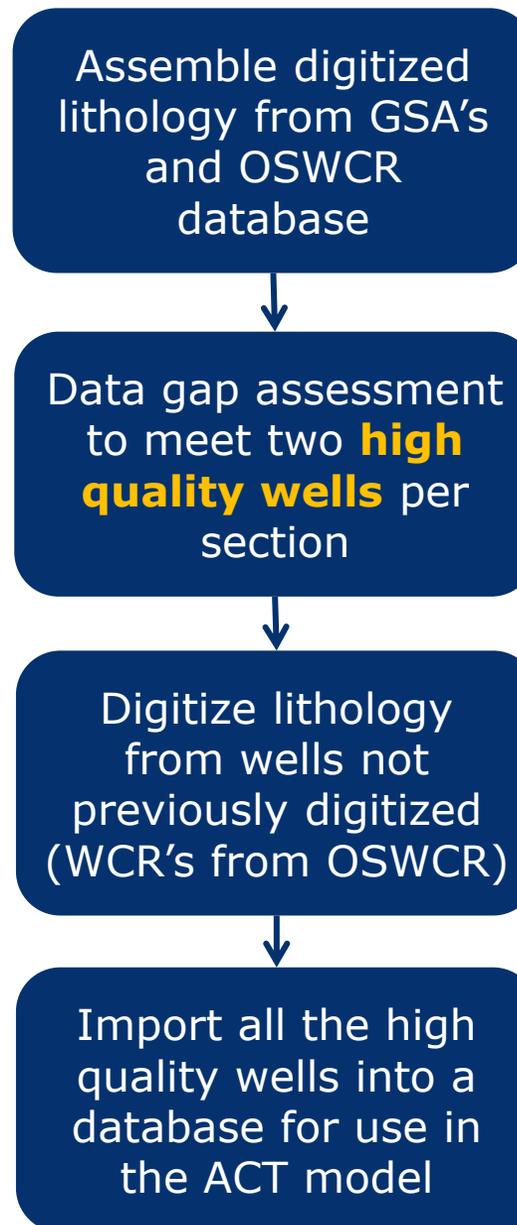
Coarse Fraction based on Sharp Model and well lithology



Well Lithology for the ACT modeling

Having as many good, high quality lithology descriptions from wells near the AEM lines is important to get a reliable resistivity to lithology transformation

- For the Statewide AEM survey, there was an objective to, wherever possible, *have a minimum of two high quality lithology descriptions per section that crosses an AEM line*
- Digitized data was provided to DWR from the local Groundwater Sustainability Agencies (GSA's) and obtained from the OSWCR database



High quality wells include:

1. *Coordinates confirmed within 50 meters*
2. *Minimum depth of 100'*
3. *Description intervals of less than 100' on average*

Prioritization for digitizing includes:

1. *Well depth – wells over 1000' deep had the highest priority*
2. *Description interval – average intervals of 25' had the highest priority*
3. *Description quality – average descriptions of more than 5 words had the highest priority*

Well Lithology for the ACT modeling

Confirming the well location is essential for the ACT modeling process

- Coordinates for the wells with digitized can be imprecise (i.e. center of section) or even registered in a completely different section or township than the well is actually located
- The coordinates are confirmed via areal photos, supplemented by maps, location descriptions and addresses available on the WCR
- If a well was not able to be located, it was not used in the ACT modeling

Example of confirmed coordinates



WELL LOCATION			
Address	1 mi. west of San diago 1/2 mi. no. of Belmont		
City	FRESNO		
County	FRESNO		
APN Book	012	Page	170
		Parcel	02s
Township	13	Range	14
		Section	32

Well Lithology for the ACT modeling

Confirming the well location is essential for the ACT modeling process

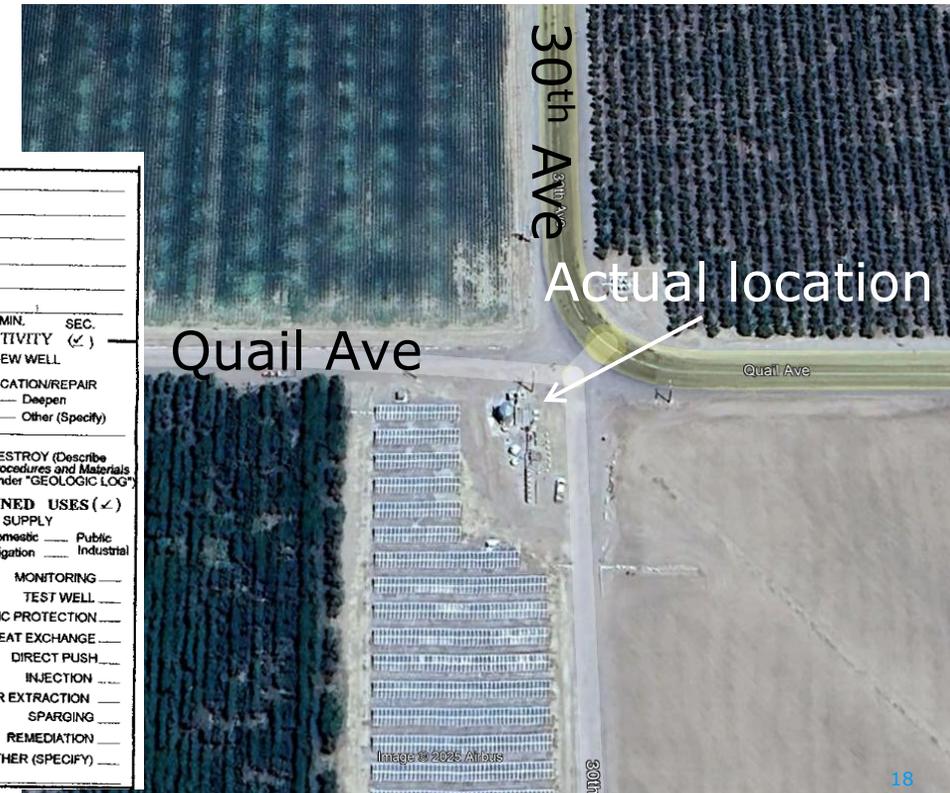
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New coordinates obtained from information in the WCR

Address QUAIL AND 30TH		WELL LOCATION	
City KETTLEMAN CITY CA			
County KINGS			
APN Book 038	Page 070	Parcel 050	
Township 22 S	Range 18 E	Section 10	
Latitude			
DEG.	MIN.	SEC.	DEG. MIN. SEC.
LOCATION SKETCH		ACTIVITY (✓)	
NORTH		<input checked="" type="checkbox"/> NEW WELL	
		MODIFICATION/REPAIR	
		— Deepen	
		— Other (Specify)	
DESTROY (Describe Procedures and Materials Under "GEOLOGIC LOG")		PLANNED USES (✓)	
WATER SUPPLY		<input checked="" type="checkbox"/> DOMESTIC	
— Domestic		— Public	
— Irrigation		<input checked="" type="checkbox"/> INDUSTRIAL	
MONITORING		TEST WELL	
CATHODIC PROTECTION		HEAT EXCHANGE	
DIRECT PUSH		INJECTION	
VAPOR EXTRACTION		SPARGING	
REMEDICATION		OTHER (SPECIFY)	

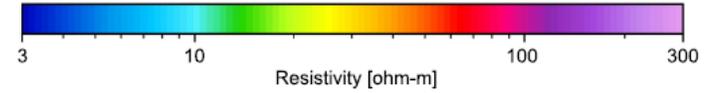
Illustrate or Describe Distance of Well from Roads, Buildings, Fences, Rivers, etc. and attach a map. Use additional paper if necessary. PLEASE BE ACCURATE & COMPLETE.



Examples of Lithology Transformation Results

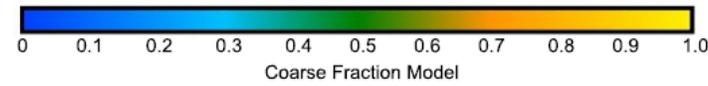
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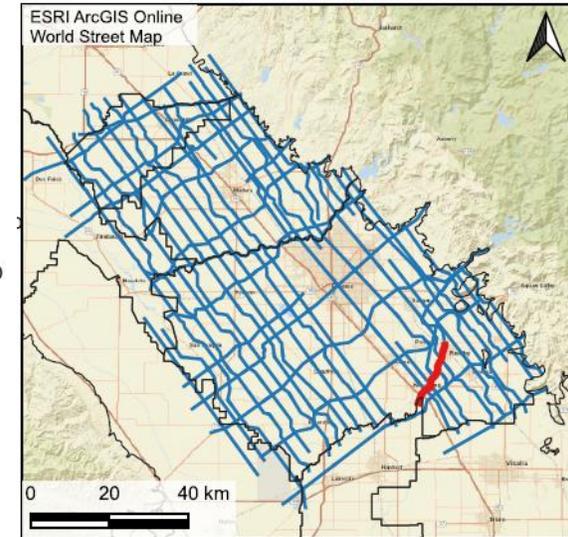
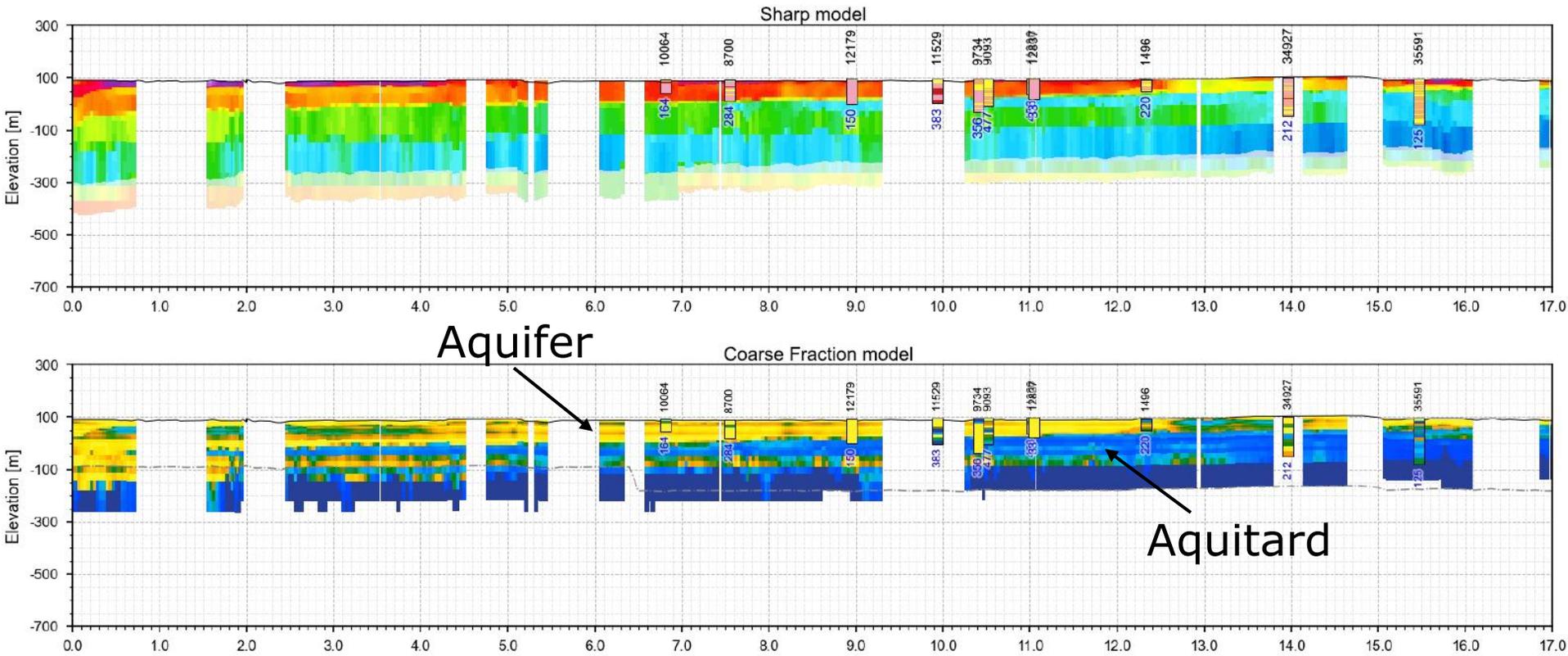
Coarse Fraction Model

Coarse Fraction based on Sharp Model and well lithology



Boreholes

- Fine
- Fine with coarse
- Coarse with fine
- Coarse
- Soil
- Rock

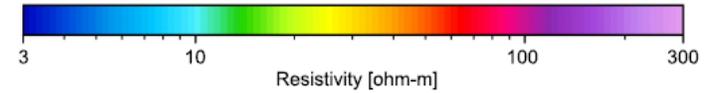


Profile location: Central San Joaquin Valley

Examples of Lithology Transformation Results

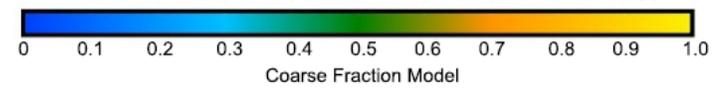
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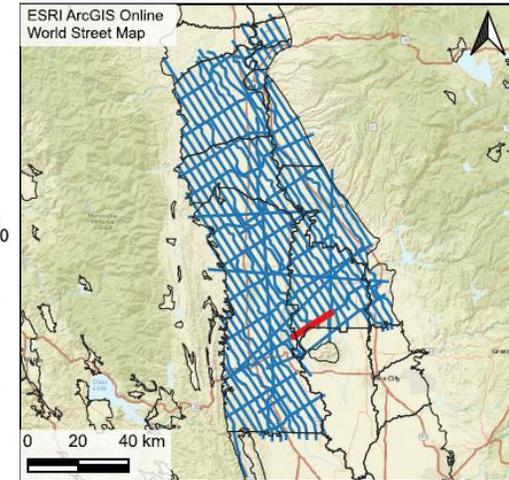
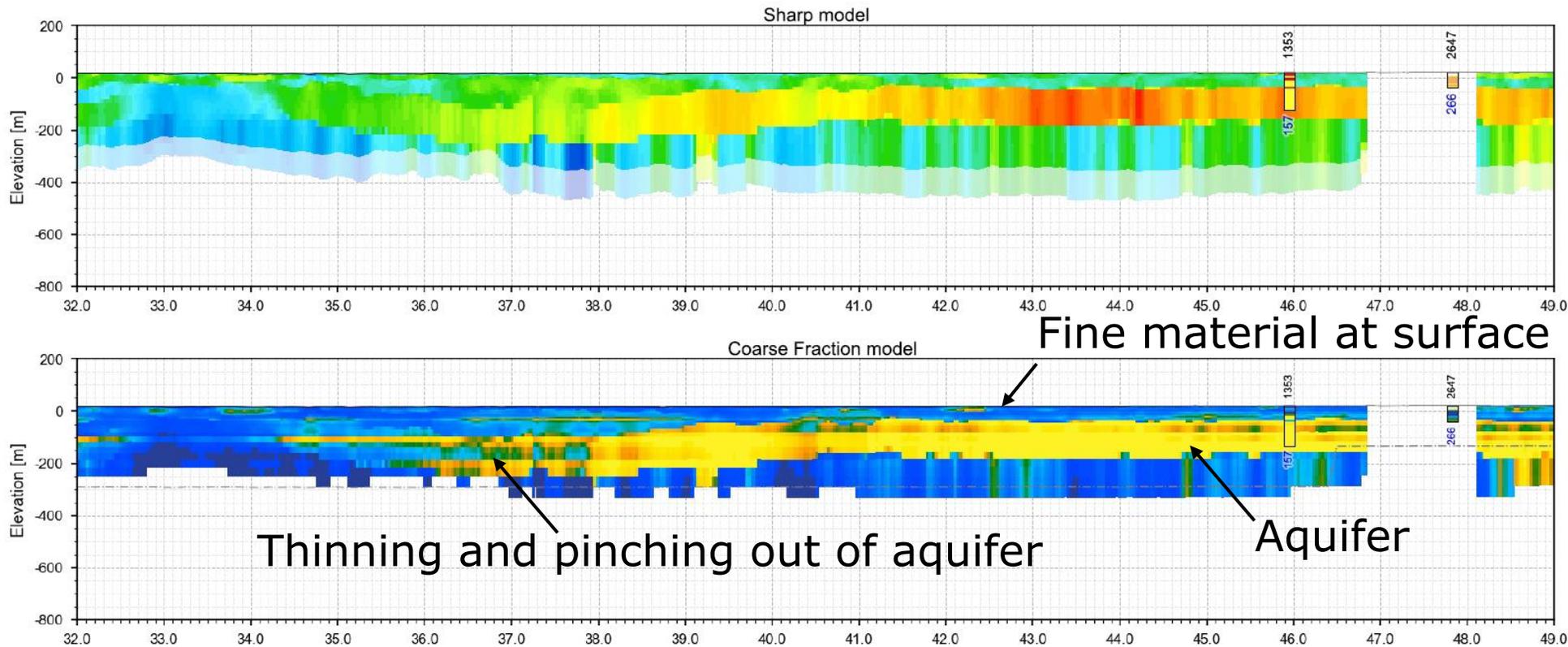
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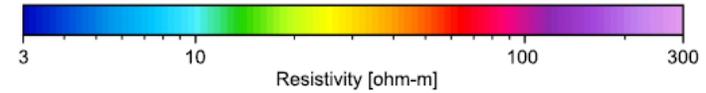


Profile location: Northern Sacramento Valley

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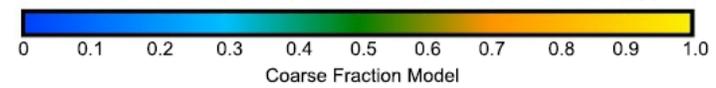
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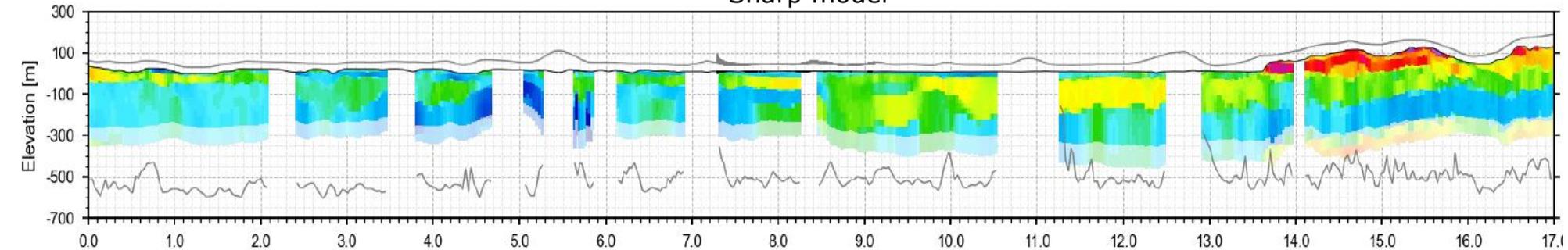
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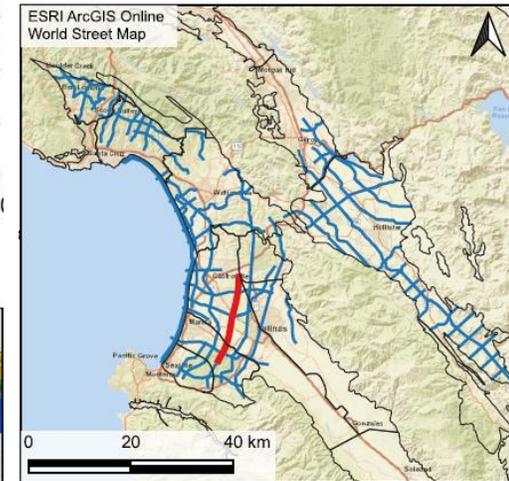
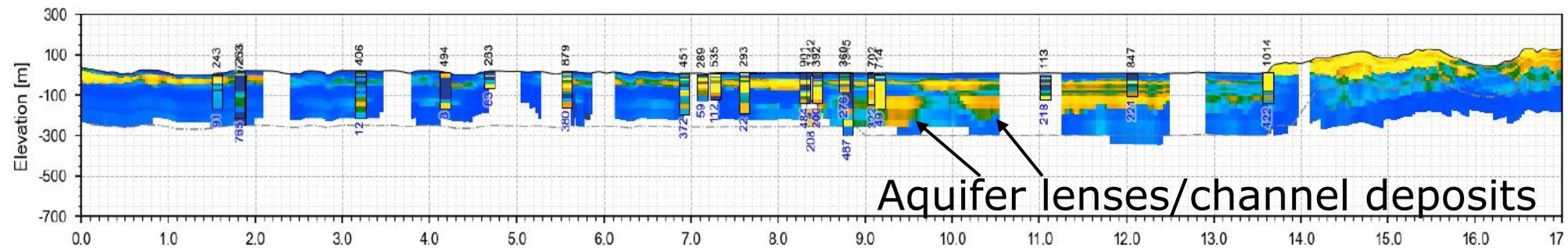
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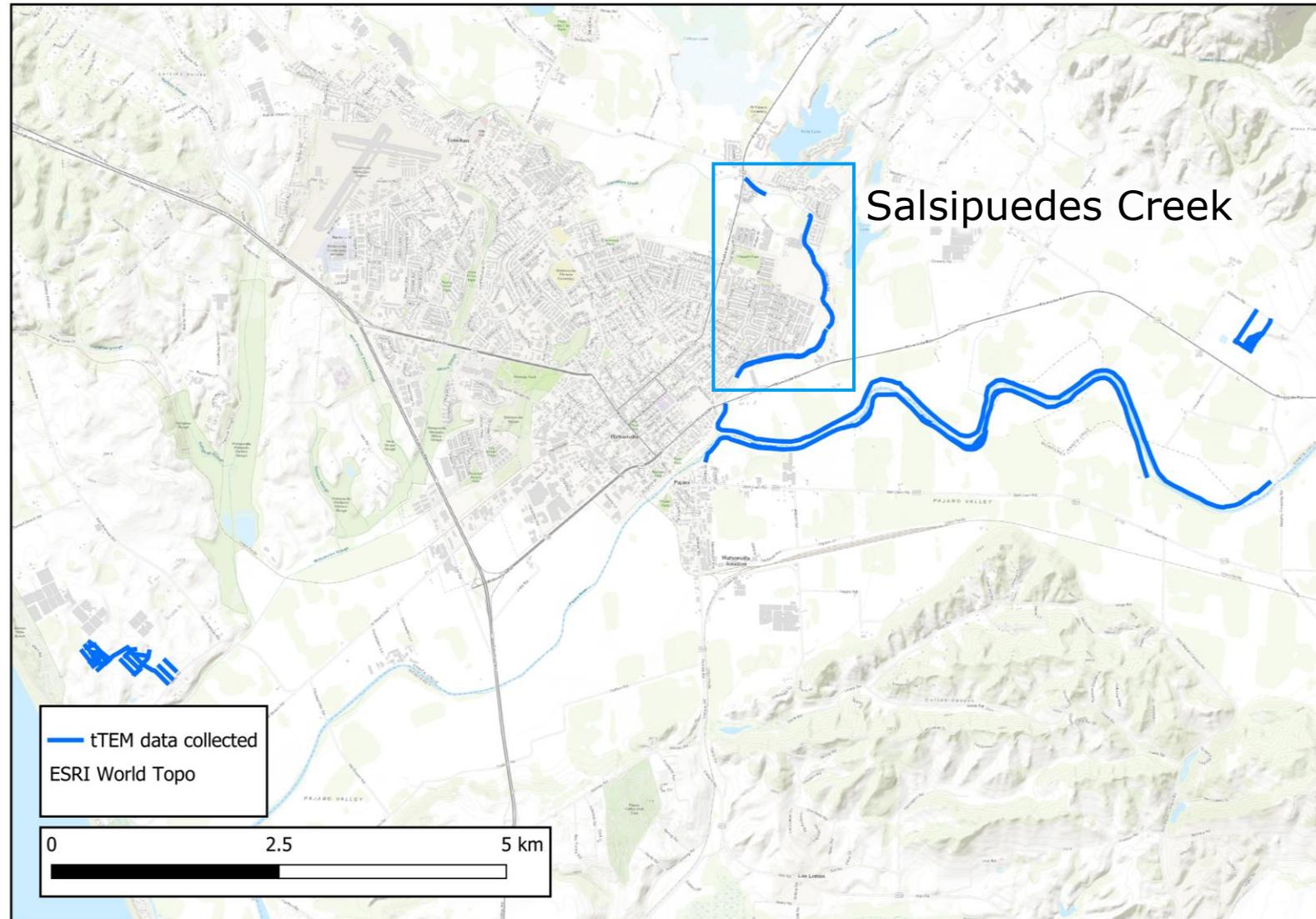
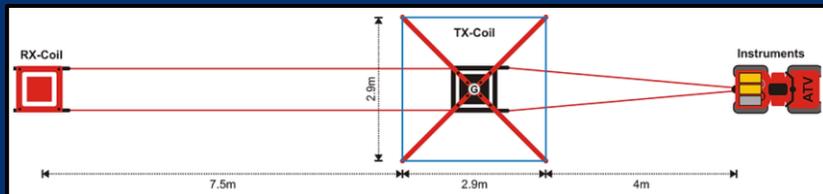
Sharp model



Coarse fraction model



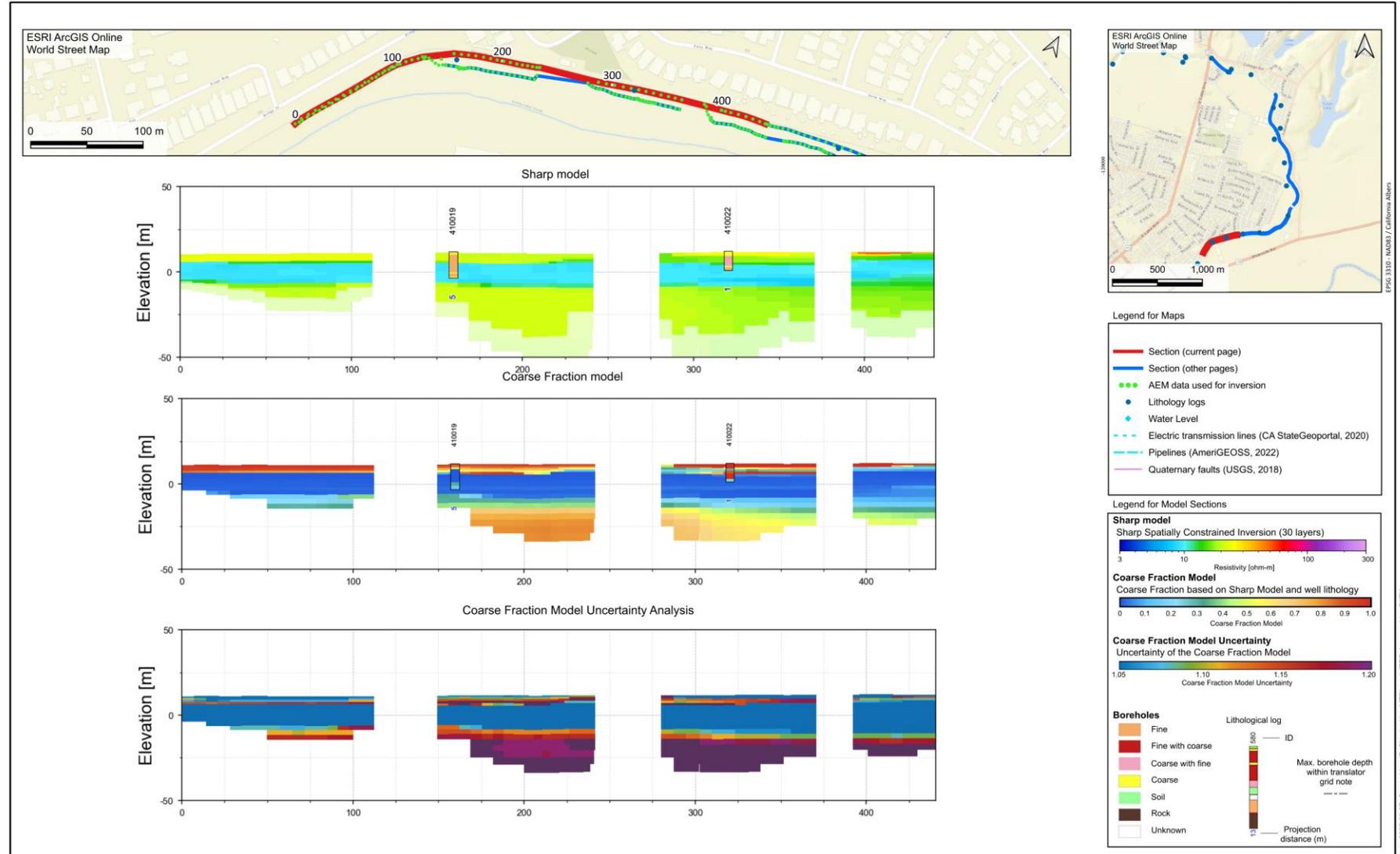
ACT on the tTEM Scale



ACT Results – Salsipuedes Creek

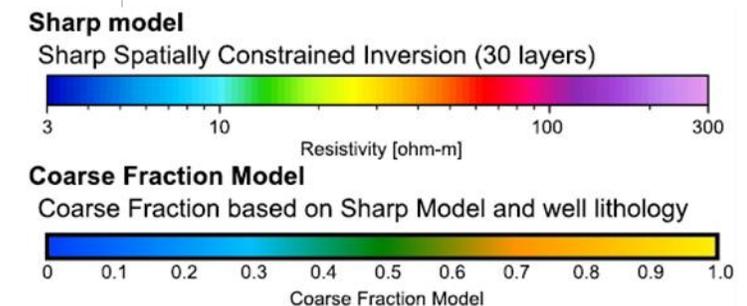
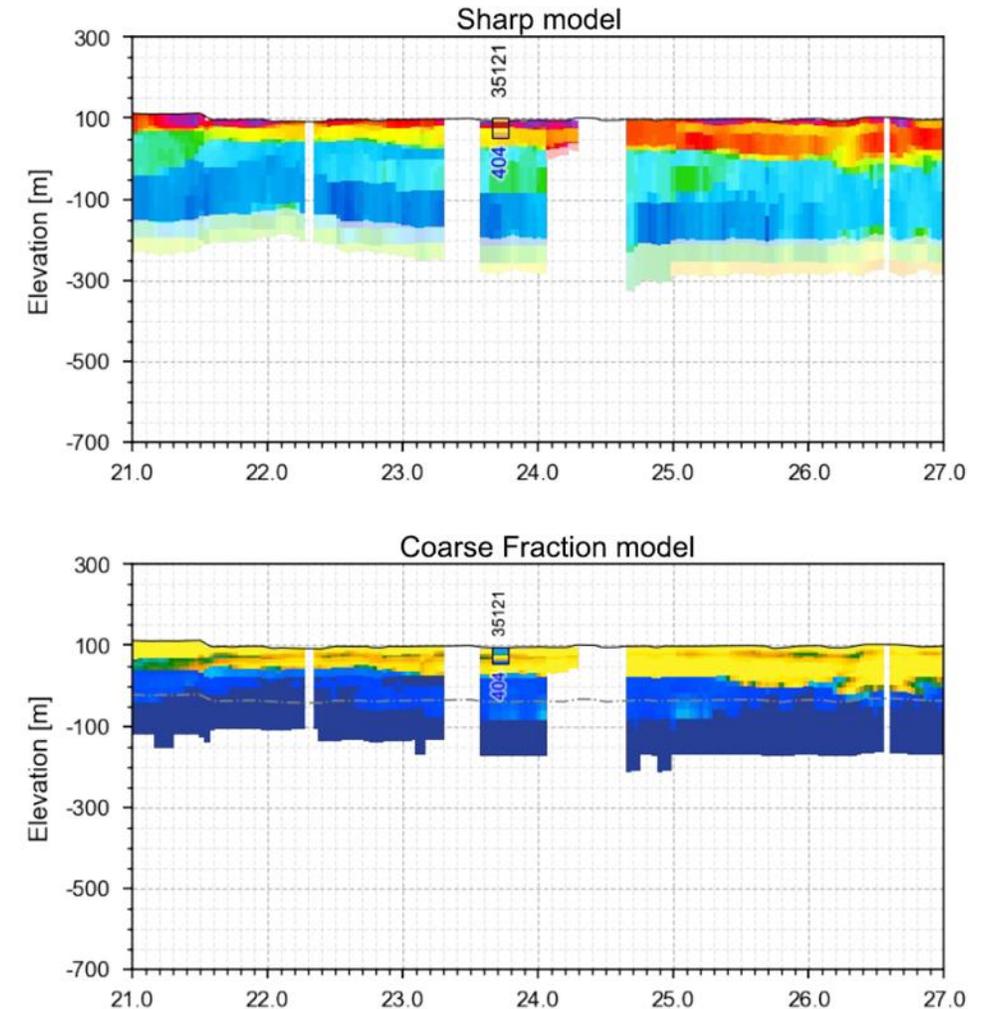
DWR BC: Pajaro Valley Line 310007 0-441 m

tTEM and Coarse Fraction Model Sections



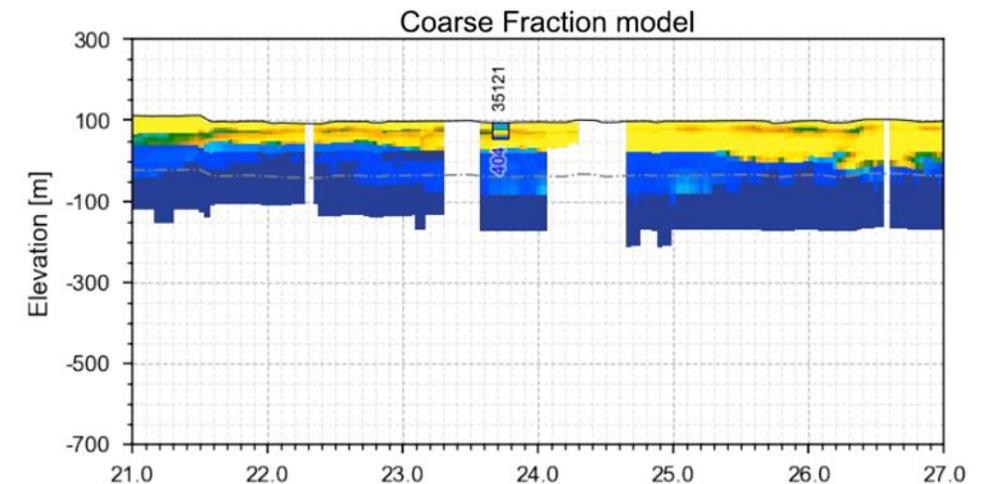
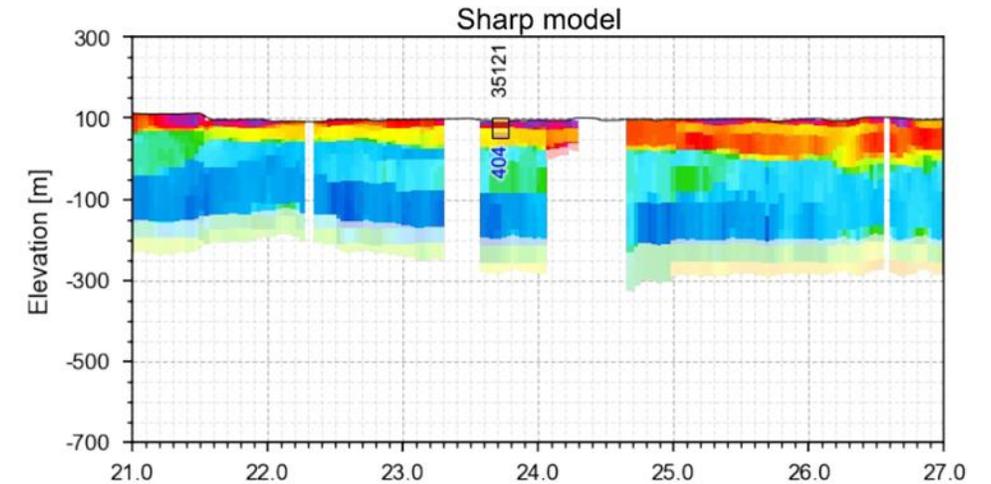
Opportunities, Limitations and Key Take Aways

- Opportunities:
 - Can transform large AEM resistivity datasets to coarse fraction
 - Provides valuable information on the spatial distribution of the coarse and fine sediments
 - Is being used to refine HCMs, identify recharge areas, map interconnectivity of aquifers and the extent of confining layers
- Limitations:
 - Resolution of lithology descriptions vs. 30 layer resistivity model
 - Cannot be used in areas of elevated groundwater salinity (over 3,000 mg/l TDS)
 - Volcanic and consolidated sediments need to be identified and removed, as they can also be a source for error



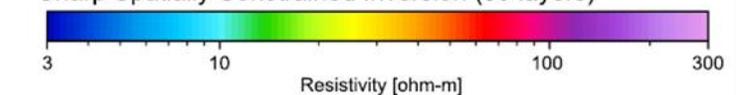
Opportunities, Limitations and Key Take Aways

- Key Take Aways:
 - The ACT modeling is reliant on good well lithology data, including both the descriptions and particularly well locations
 - Poor or incorrectly located lithology data can give an unreliable resistivity to lithology transformation
 - This is particularly relevant in complex hydrogeologic environments
 - When planning an AEM survey where ACT modeling takes part, it is recommended to take into account available lithology data, its quality and invest in collecting as much high quality data as the budget allows



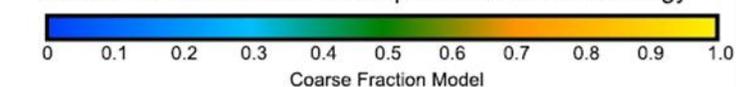
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Bright
ideas.
Sustainable
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Questions?

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