Airborne Electromagnetics: AEM and Insights on Recharge Projects in Nebraska and Colorado

February 22, 2024

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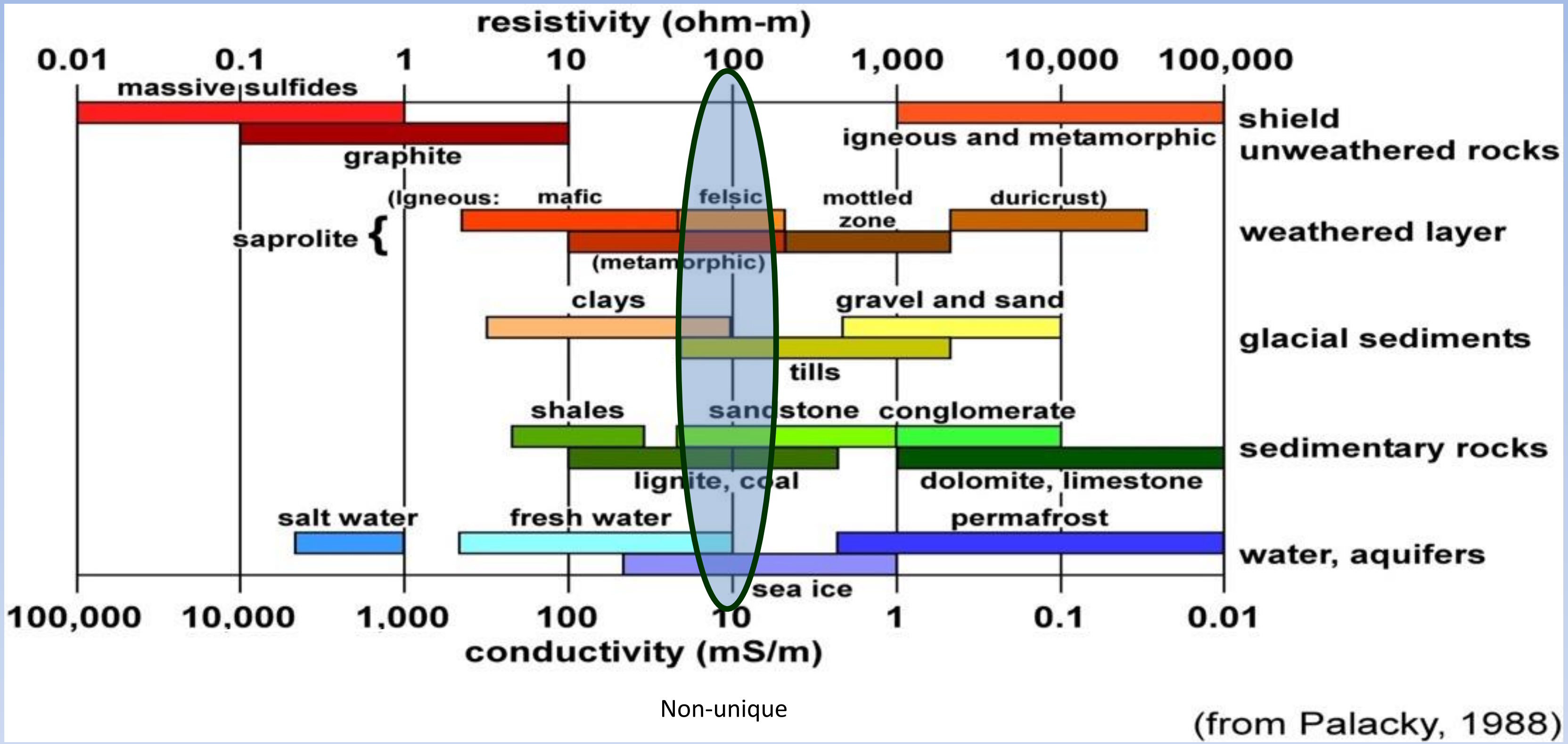
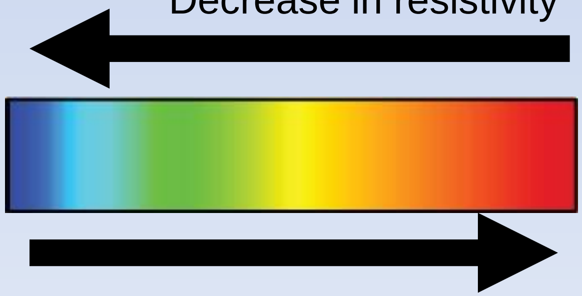
Basics: Resistivity and Rocks



(from Palacky, 1988)

Finer-grained sediment

Decrease in resistivity



Increase in resistivity

Coarser-grained sediment

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Why airborne geophysics?

Scale of Measurement

For Groundwater Exploration -

Typical Coverage from Airborne to Borehole:

Airborne coverage: Townships (36 square miles or 23,040 acres)

➘

Ground-based coverage: Sections (640 acres)

➘

Boreholes coverage: ~ 1 to 36 inches around the borehole

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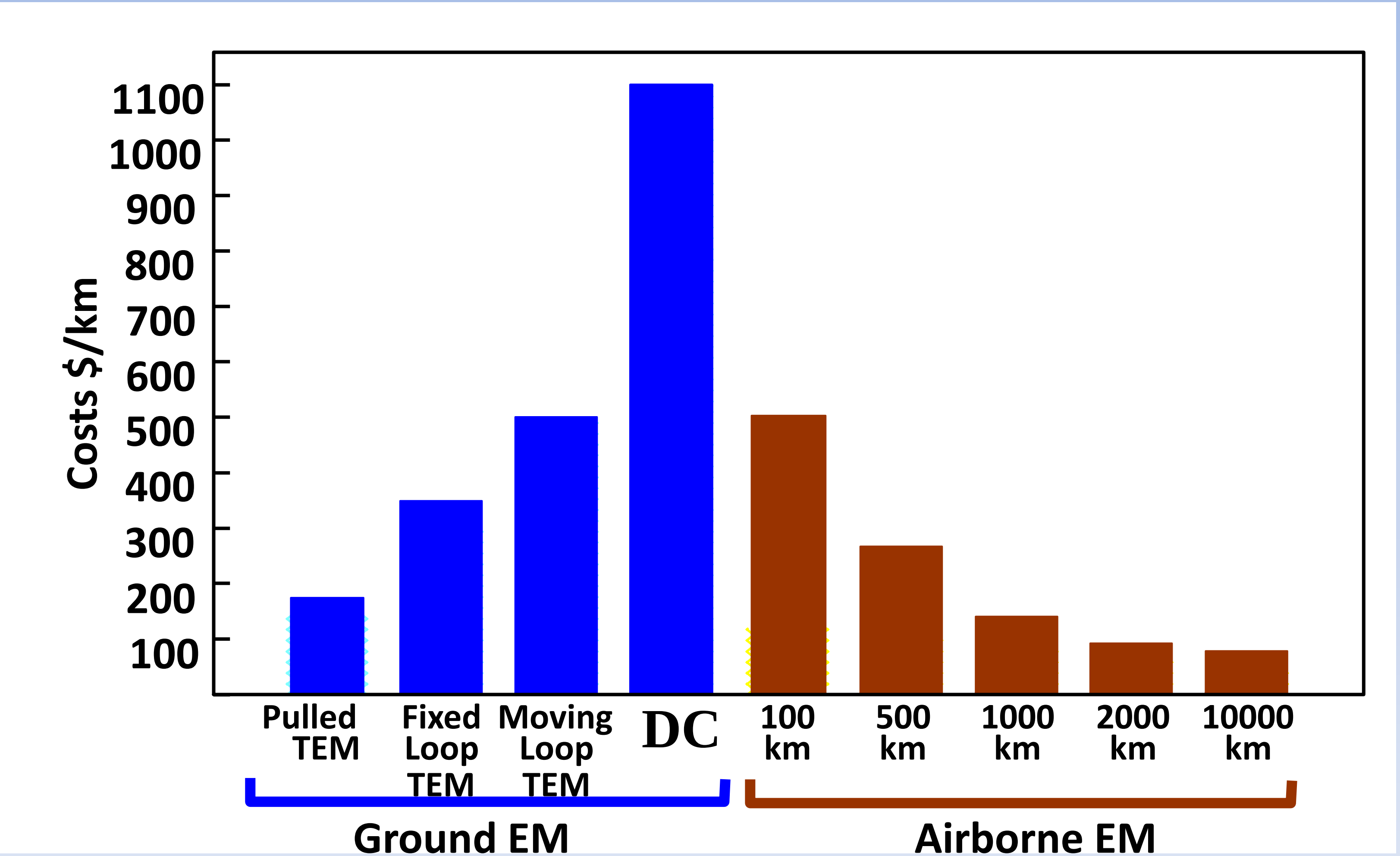
Why airborne geophysics?

COST - Ground vs. Airborne $



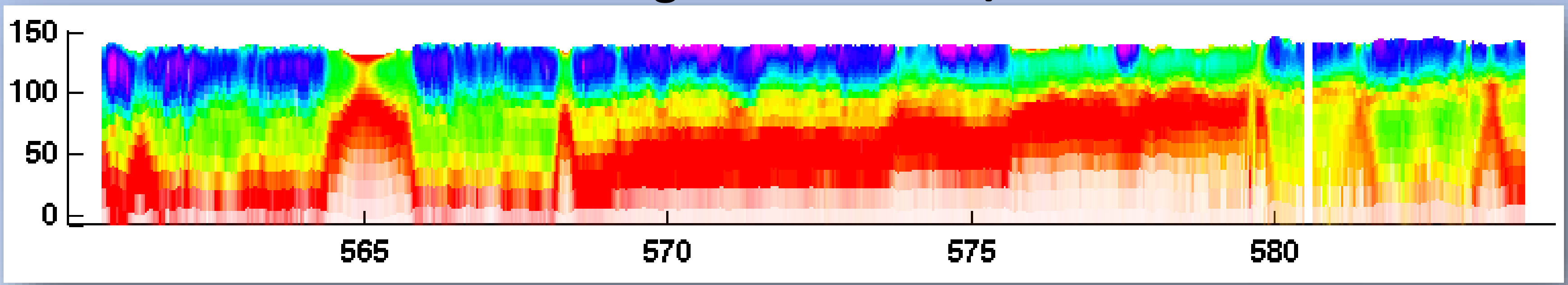
*** Costs are representative only, and do not constitute a contract!**

Why airborne geophysics?

Areal Coverage:

Airborne resistivity

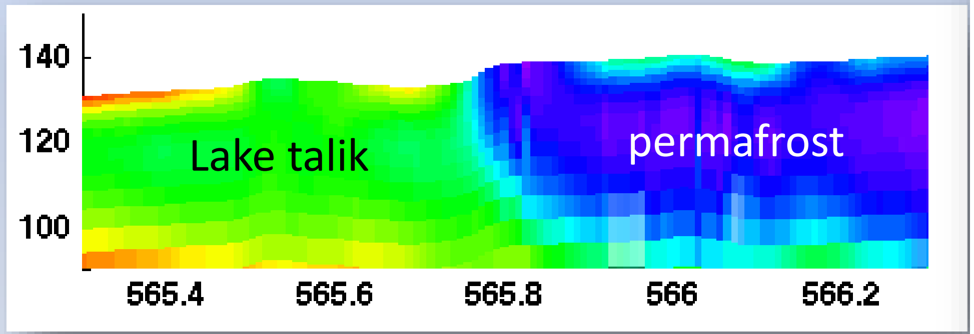
Coverage at ~ 100 km / hour

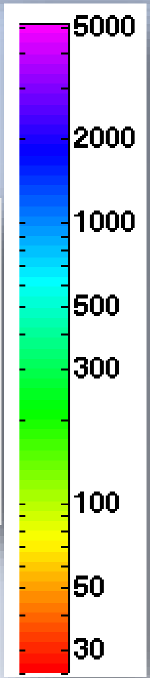


Abraham, 2012
Minsley et. al., 2012

Ground-Based resistivity

Coverage at ~ 1 km /day

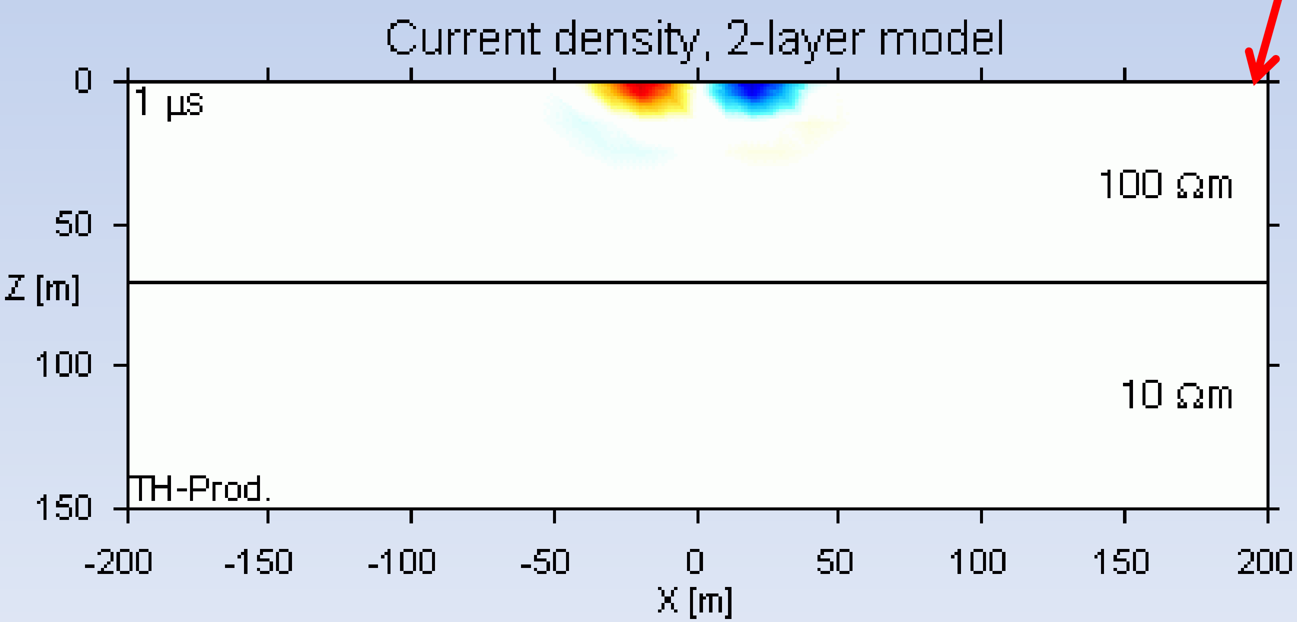


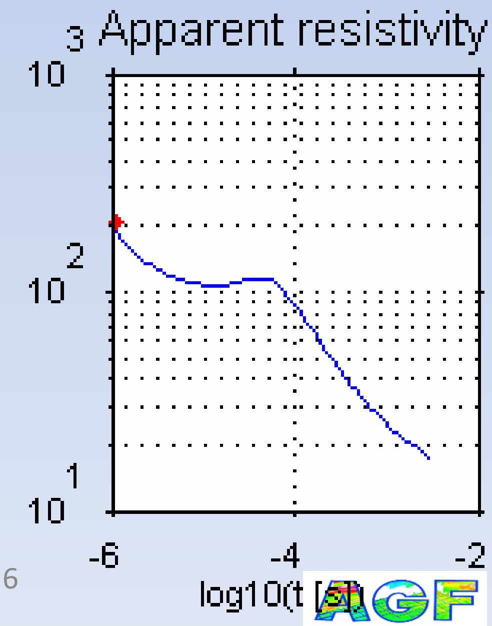


What's happening in the earth:

The current induced in the earth diffuses downward and outward

What we measure in the receiver coil





Auken, Aarhus University

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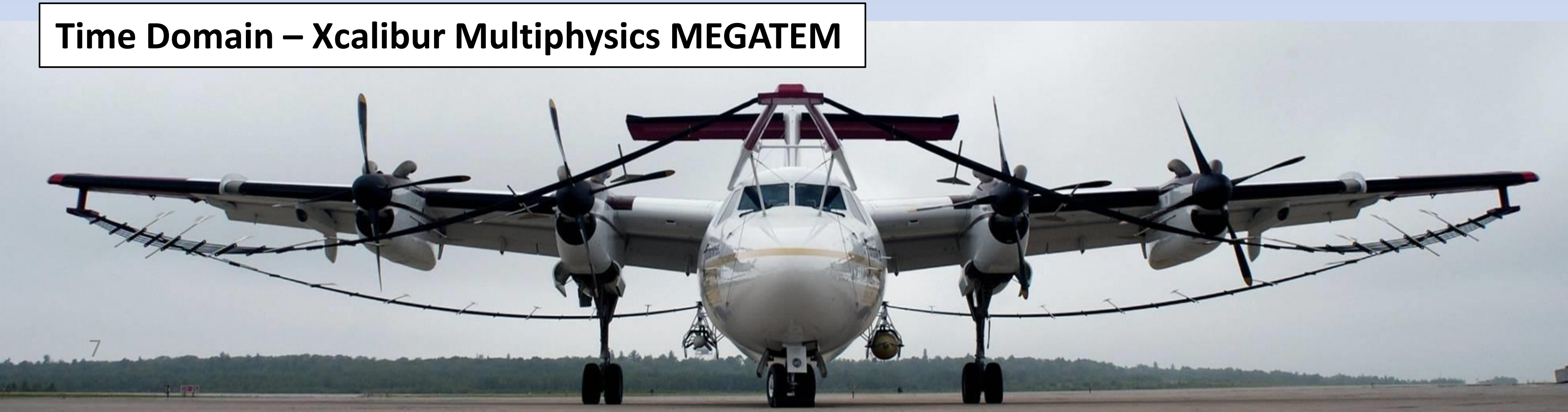
System Selection: Fixed-Wing AEM Systems

Frequency Domain - Sander Geophysics FGEM

Time Domain – Xcalibur Multiphysics TEMPEST

Time Domain - Spectrem Air

Time Domain – Xcalibur Multiphysics MEGATEM



System Selection: Helicopter AEM Platforms

Frequency Domain
Xcalibur RESOLVE / DIGHEM

Time Domain -
NRG Xcite

Time Domain -
SkyTEM

Time Domain
Geotech VTEM

Time Domain
Xcalibur
HeliTEM

Natural Source
Geotech ZTEM

Additional Considerations when using Airborne EM

- Contractors fly surveys
- Elevation control, attitude control
- System calibration
- Infrastructure
- Public awareness

Paradox Valley, Colorado 2011

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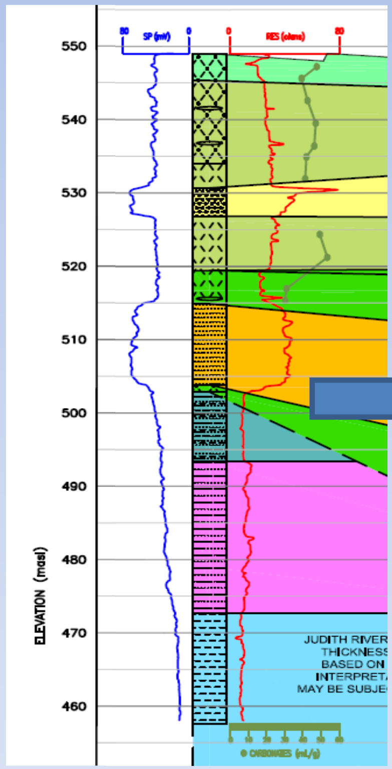
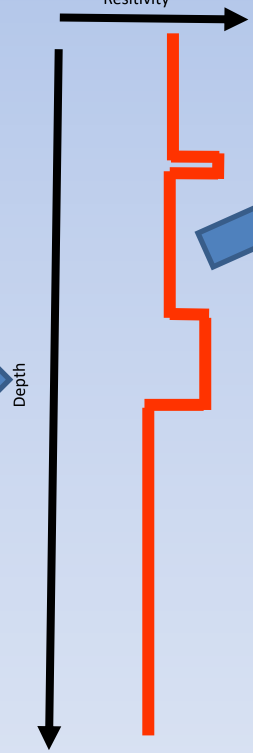
Forward Modeling

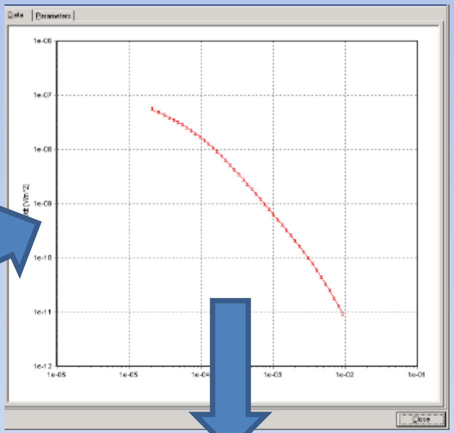
Geologic Model "Truth"

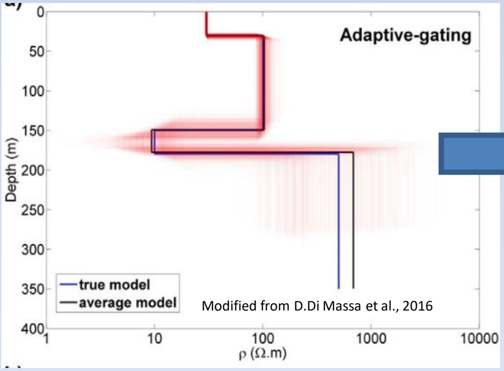


Simplified Model



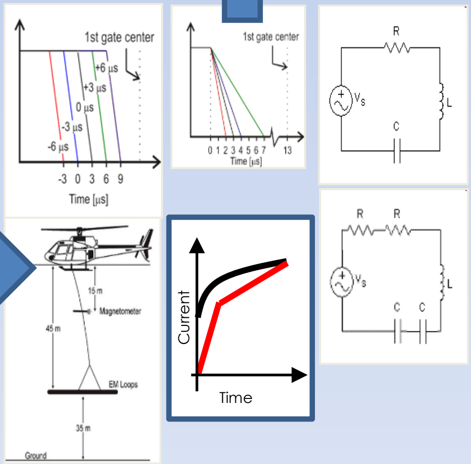
AEM Response





System Specifications

- On Time
- Off Time
- Transmitter Current/Moment
- Rx Time Windows



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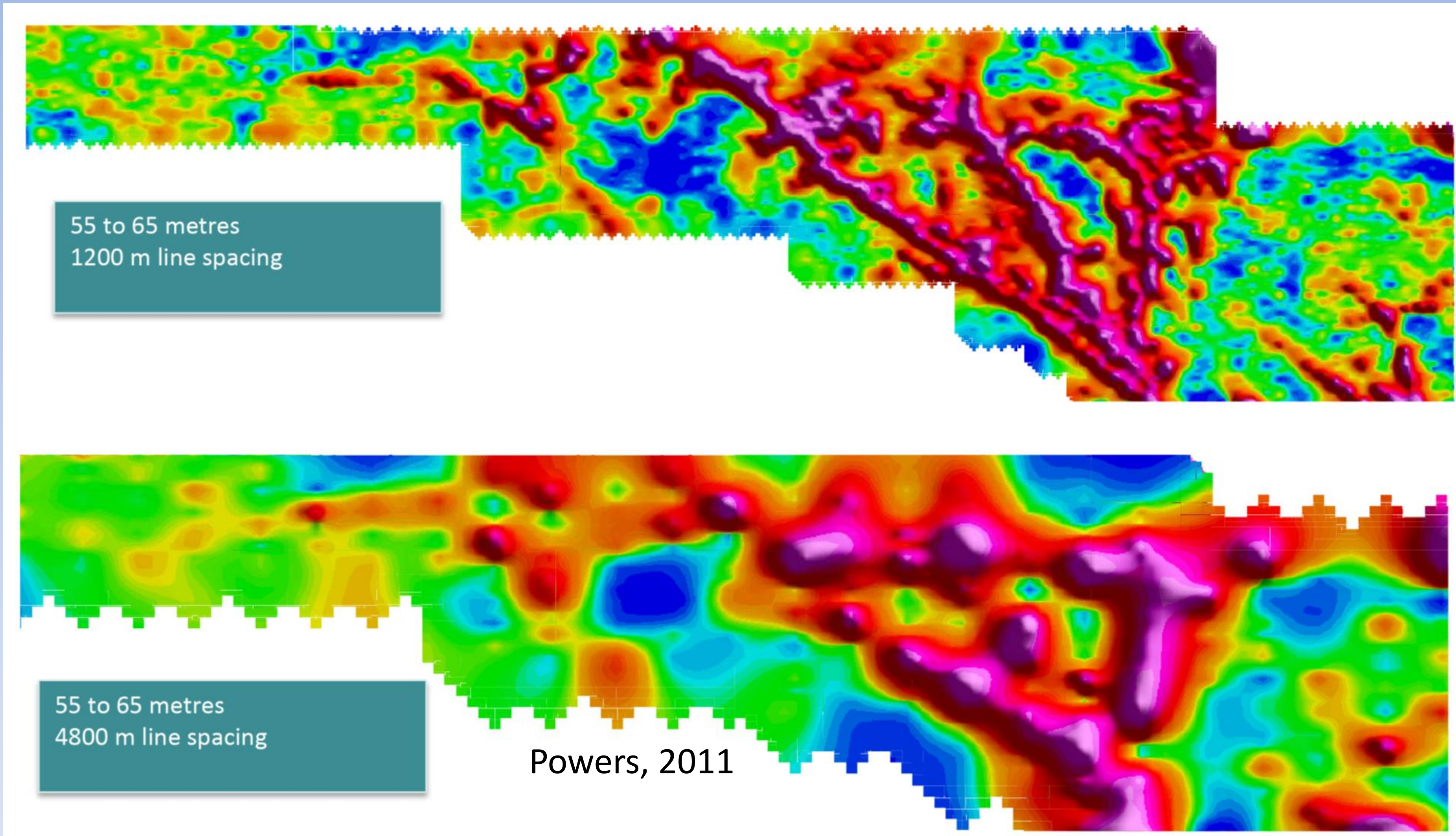
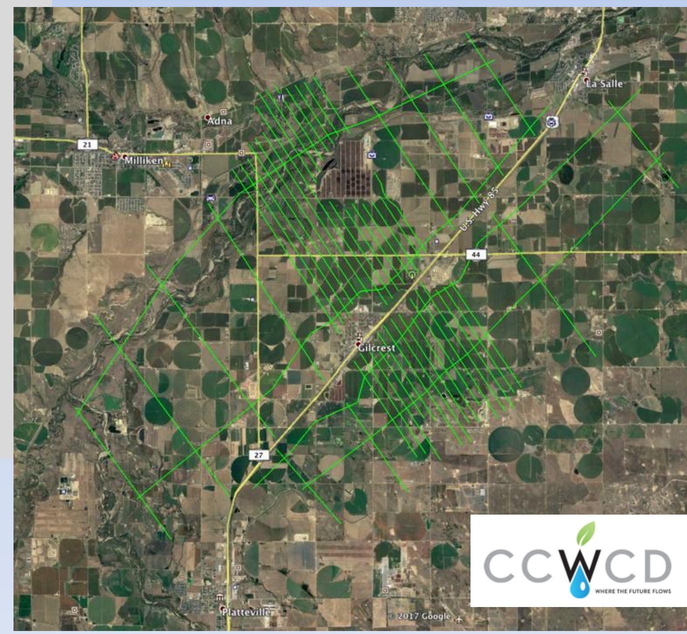
Line Spacing and Targets



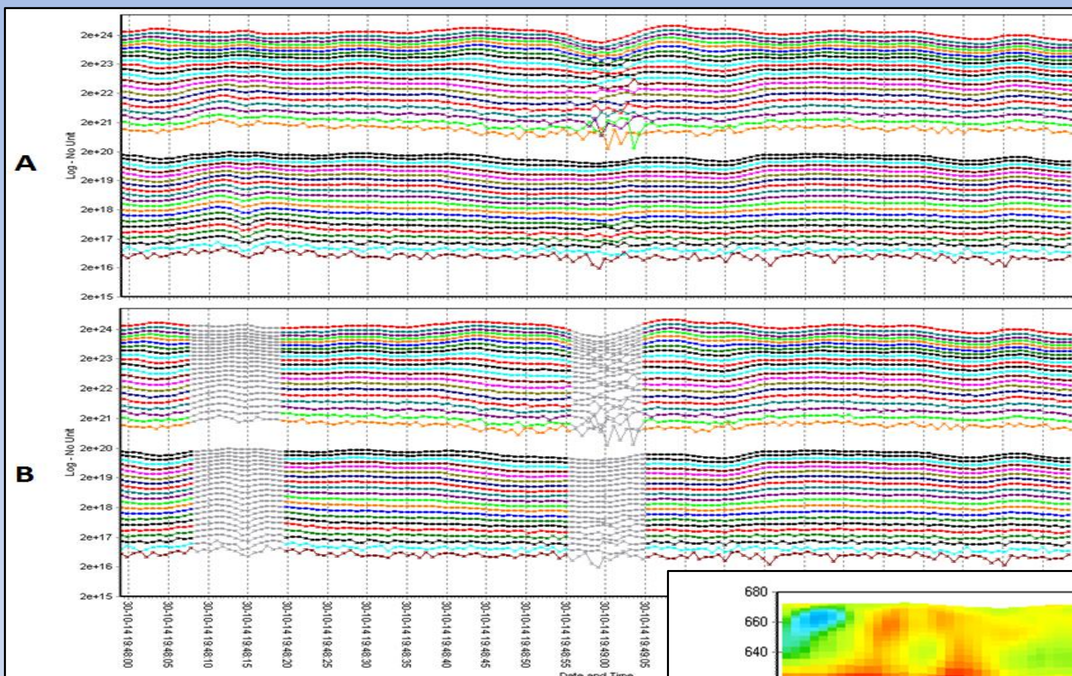
Flight Line Planning

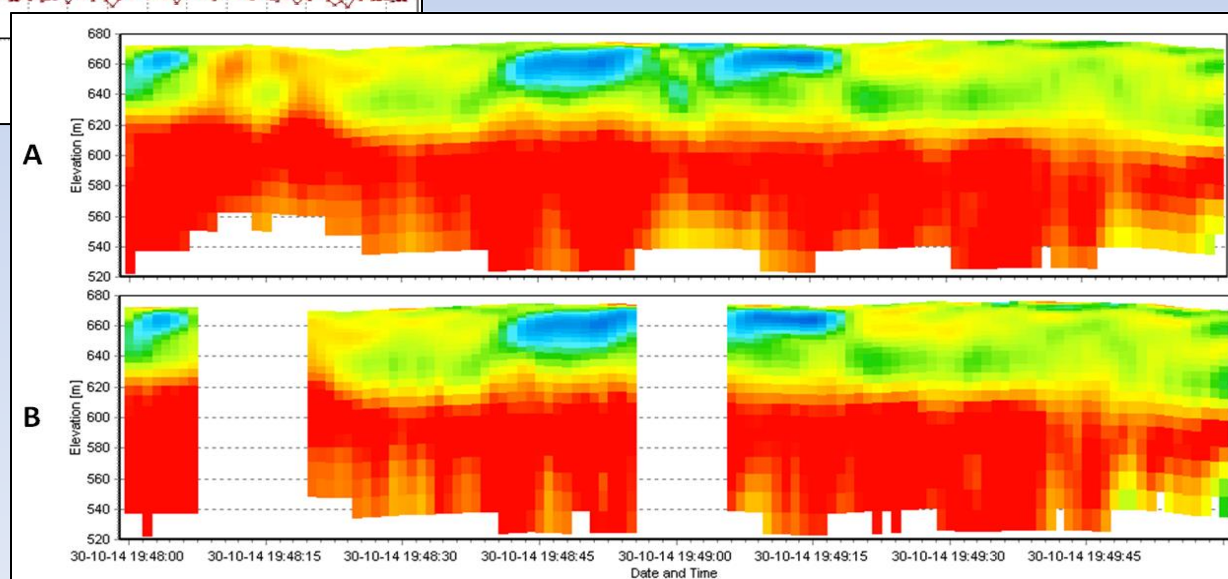
- Pipeline maps
- Local agencies required to facilitate the access to power grid infrastructure maps
- Railroads
- Confined feeding operations
- Seasons and length of daylight
- ***Flight lines need to be adjusted to optimize data collection***



In Field QA/QC and Inversion

- Within 24 hours we invert and compare to boreholes





Data, apparent data, and models

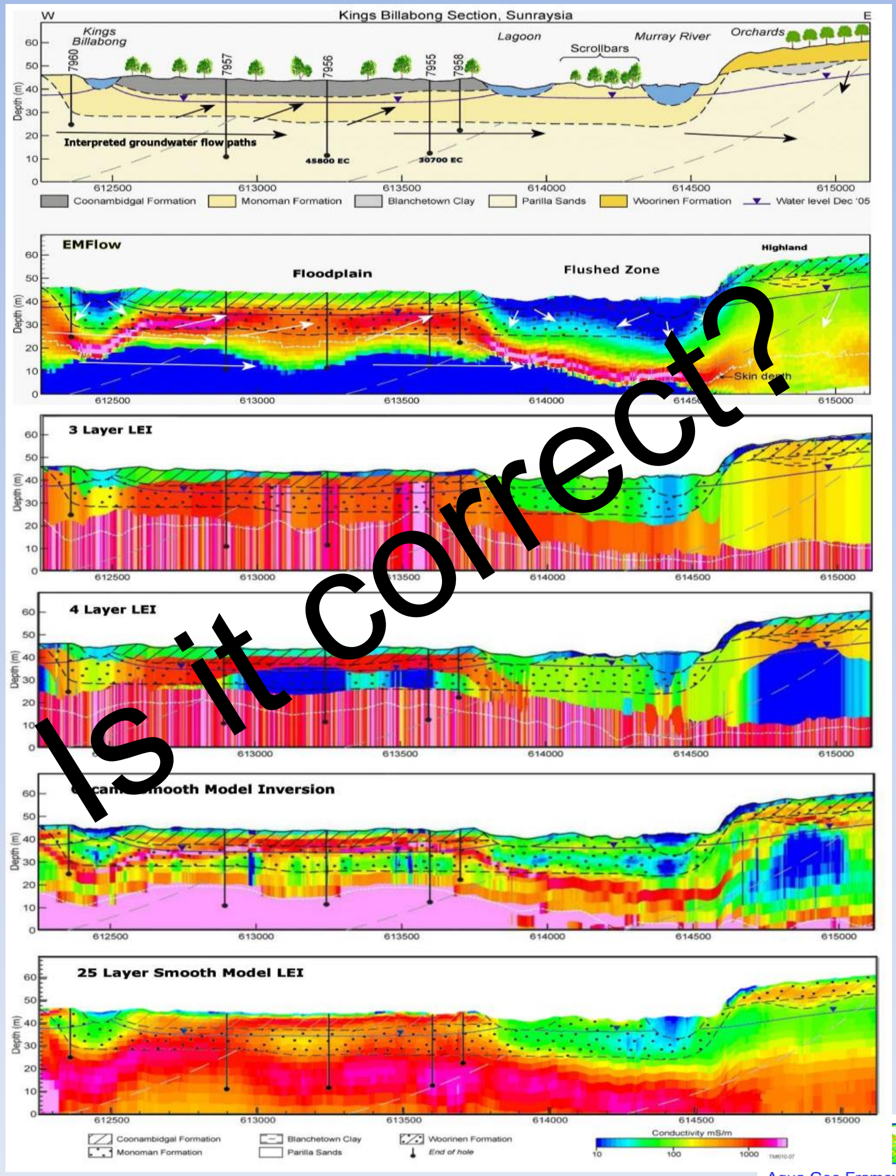
- Data:
  - Response in ppm for In-Phase and Quadrature channels at different frequencies (FDEM)
  - dB/dt [V/m^2] response as a function of time after transmitter turn-off (TDEM)

- Apparent resistivity (or conductivity):
  - Data *mapping* from response to the resistivity value of a uniform half-space that would produce the measured data at each frequency/time gate
  - Useful, but not necessarily a quantitative mapping tool

- Models:
  - *Inversion* aimed at accurately mapping the spatial distribution of resistivity values with depth
  - Non-uniqueness & uncertainty must be quantified

Why Calibrate?

- Need to provide accurate models of conductivity and depth for environmental applications
- Two types of data errors: Random & Systematic
- Calibration addresses systematic errors
  - Improper system timing
  - Systematic elevation errors
  - Improper removal of primary field
- Calibration errors are not always easy to detect, and can produce seemingly realistic, but incorrect, model features!!



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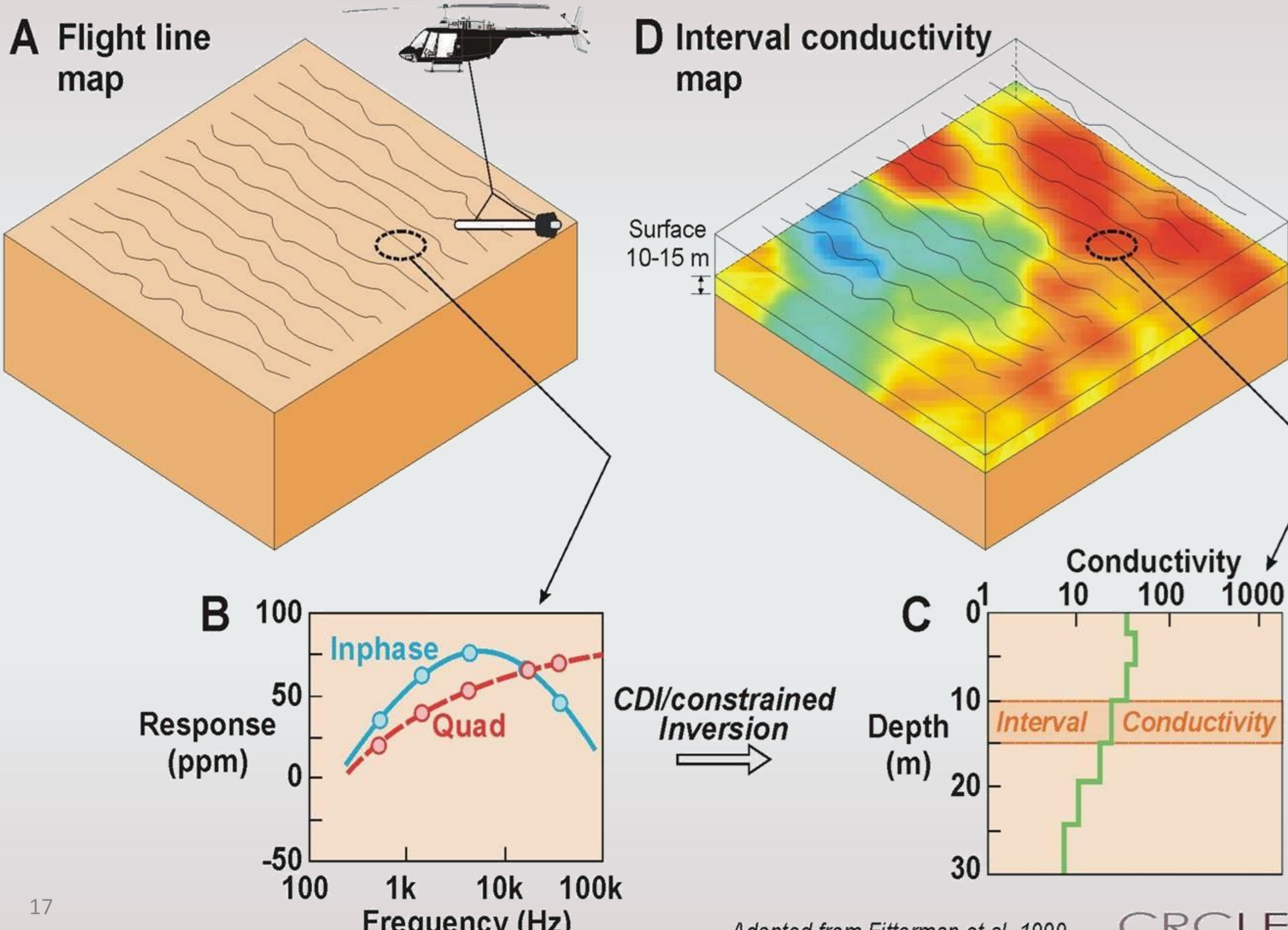
Andrew Fitzpatrick, 2010

INVERSION

Turning ‘voltages with time’ into ‘resistivity with depth’

- Model type Deterministic/Stochastic
- 1D, 2D, Quasi-2D, 3D
  - Smooth model
  - Sharp models
  - Fixed-Layer models
- Inversions are not unique What this means is multiple layering and resistivity scenarios will equally well-fit the data
  - How do you get around this?
    - Geology
    - *A priori* information (Borehole Logs…)
    - Uncertainty analysis

Inversion of EM data



Adapted from Fitterman et al. 1999

CRCLEME

TMs024-03

So what is it that goes into an AEM Survey?

- System Selection (TDEM, FDEM, Helicopter, Fixed-wing)
- Calibration (data space, model space)
- Flight planning (line spacing, direction)
- Noise (infrastructure, pipelines, power lines, spherics)
- Processing (EM-coupling, averaging, filtering, stacking, calibration)
- Inversion (1-D, 2-D, 3-D, Deterministic, Stochastic)
- Interpretation (geological model, lithology, geophysical logs, water quality, aquifer testing, reporting, and communication of results)
- Cost (Budget)

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Upper Black Squirrel Creek Ground Water Management District

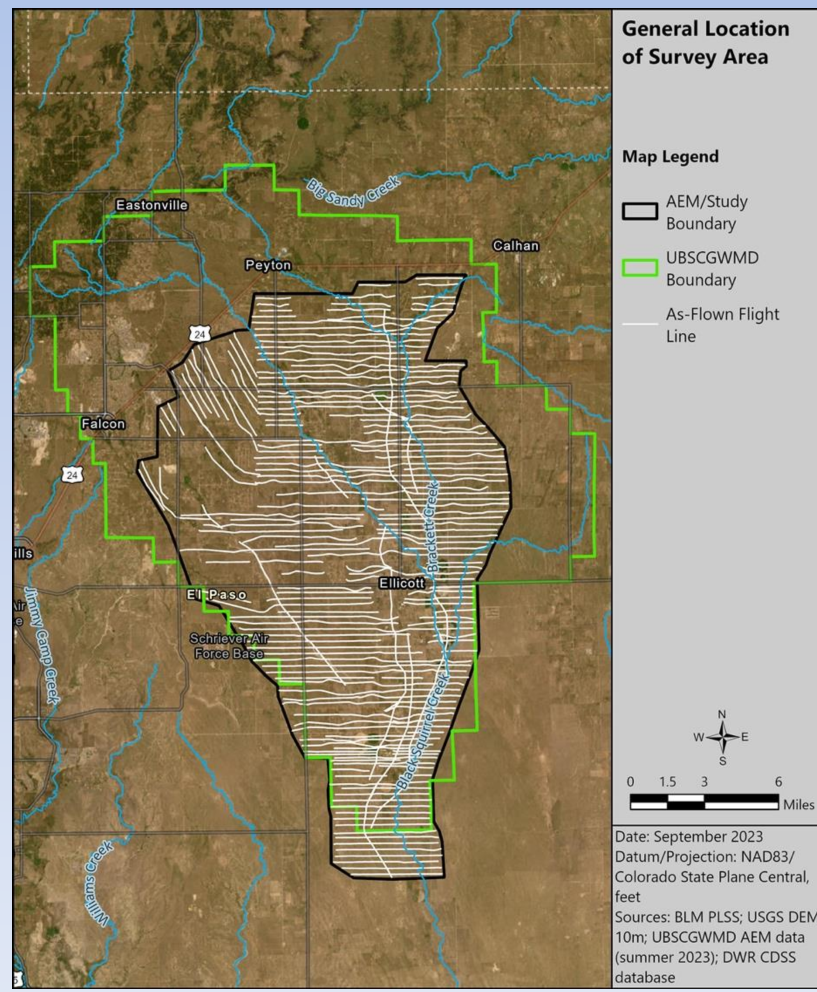
Upper Black Squirrel Creek
GROUND WATER MANAGEMENT DISTRICT

Objectives:

- Map the shape of the alluvial basin
- Map the water table
- Map bedrock units
- Identify clay layer
- Identify best recharge sites

Schedule:

- Acquisition June 9-13, 2023
- Preliminary Results June 10-14, 2023
- Results to technical staff Sep 2023
- Draft report October 11, 2023
- Presentation to Board Dec 5, 2023



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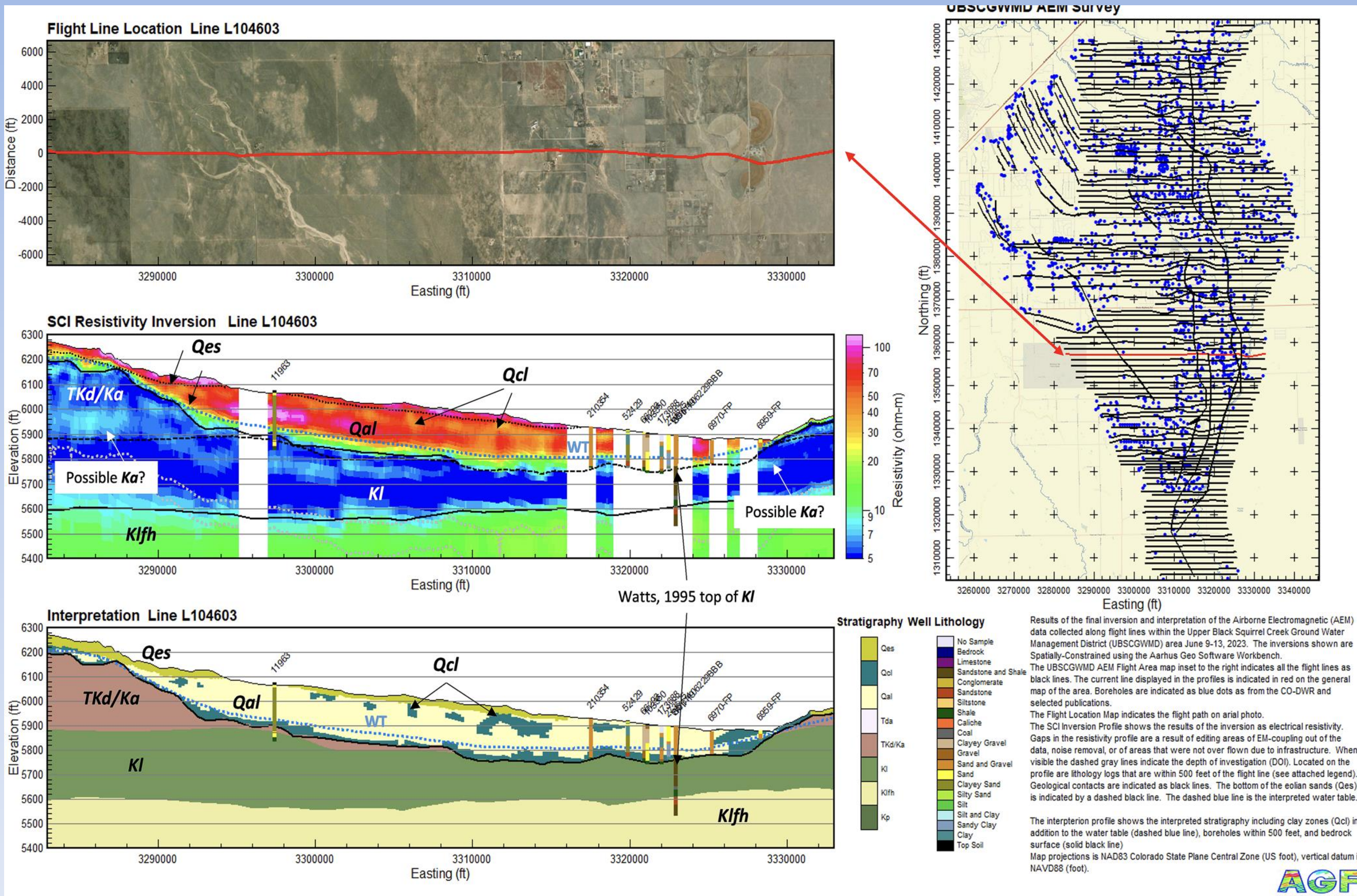
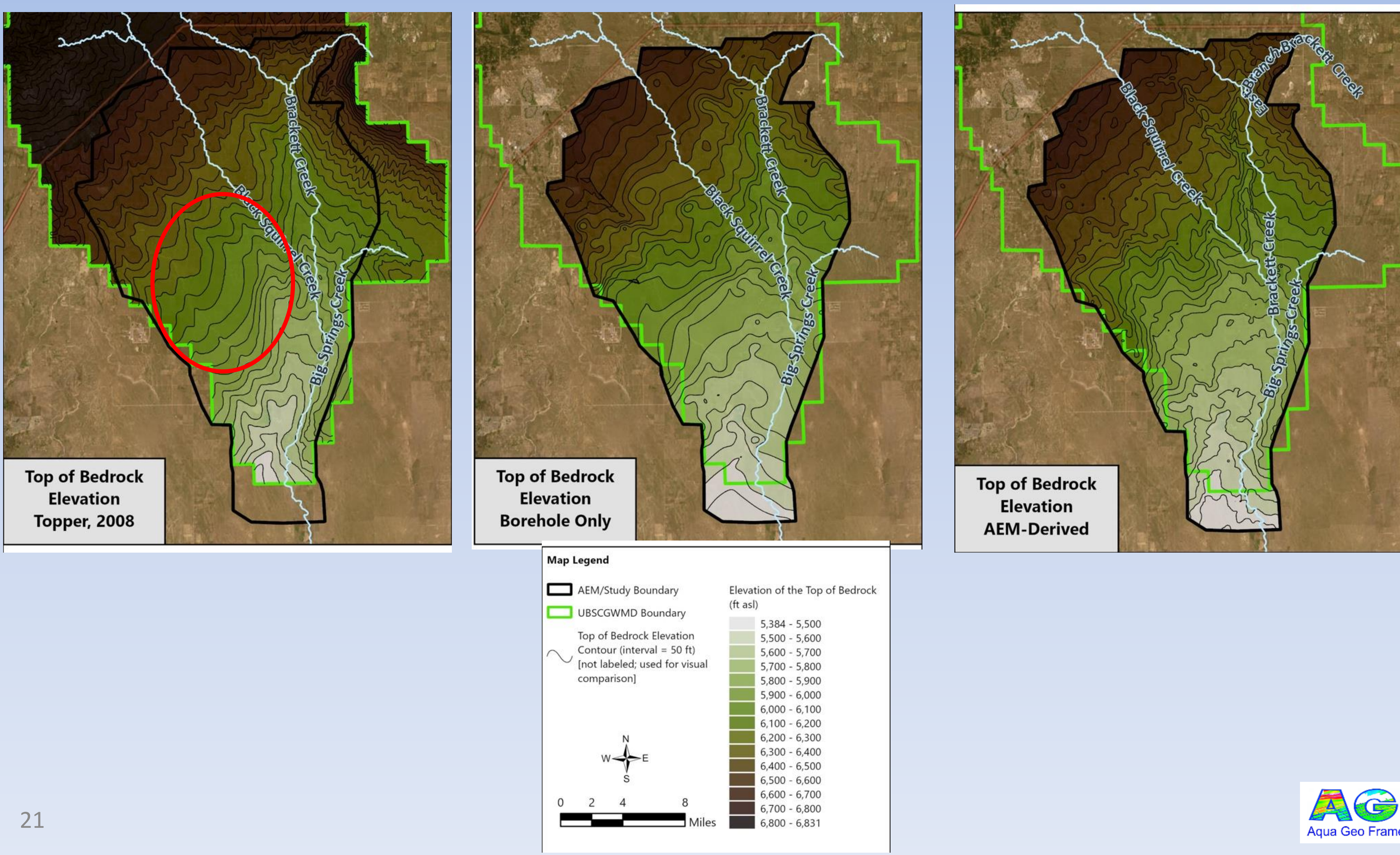
AEM Mapping Example



Upper Black Squirrel Creek
GROUND WATER MANAGEMENT DISTRICT

Bedrock Comparison



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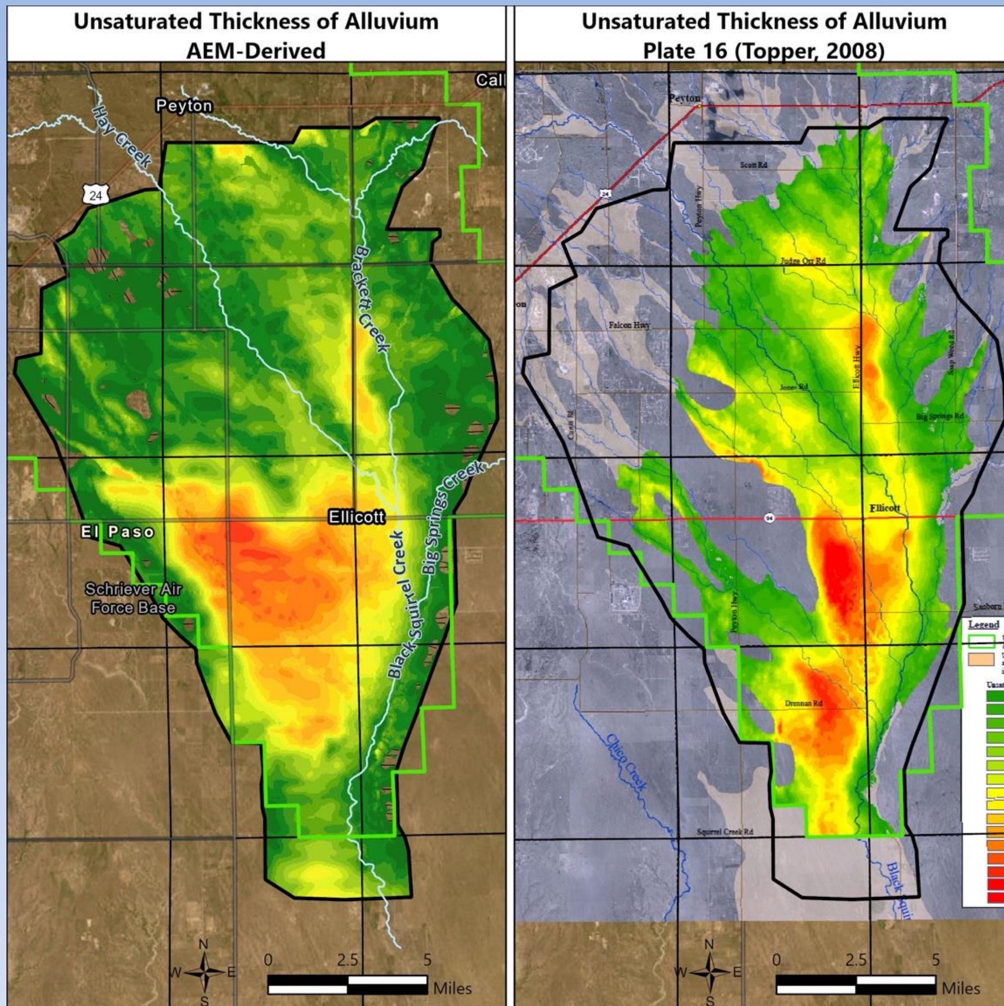
Unsaturated ***Qal*** Thickness

Upper Black Squirrel Creek
GROUND WATER MANAGEMENT DISTRICT



Map Legend

- UBSCGWMD Boundary
- AEM/Study Boundary
- Flight Line

Thickness of the UNSATURATED Alluvium (ft)

0 to 10, 10 to 20, 20 to 30, 30 to 40, 40 to 50, 50 to 60, 60 to 70, 70 to 80, 80 to 90, 90 to 100, 100 to 110, 110 to 120, 120 to 130, 130 to 140, 140 to 150, 150 to 163

Date: September 2023
Datum/Projection: NAD83/ Colorado State Plane Central, feet
Sources: BLM PLSS; USGS DEM 10m; UBSCGWMD AEM data (summer 2023); DWR CDSS database

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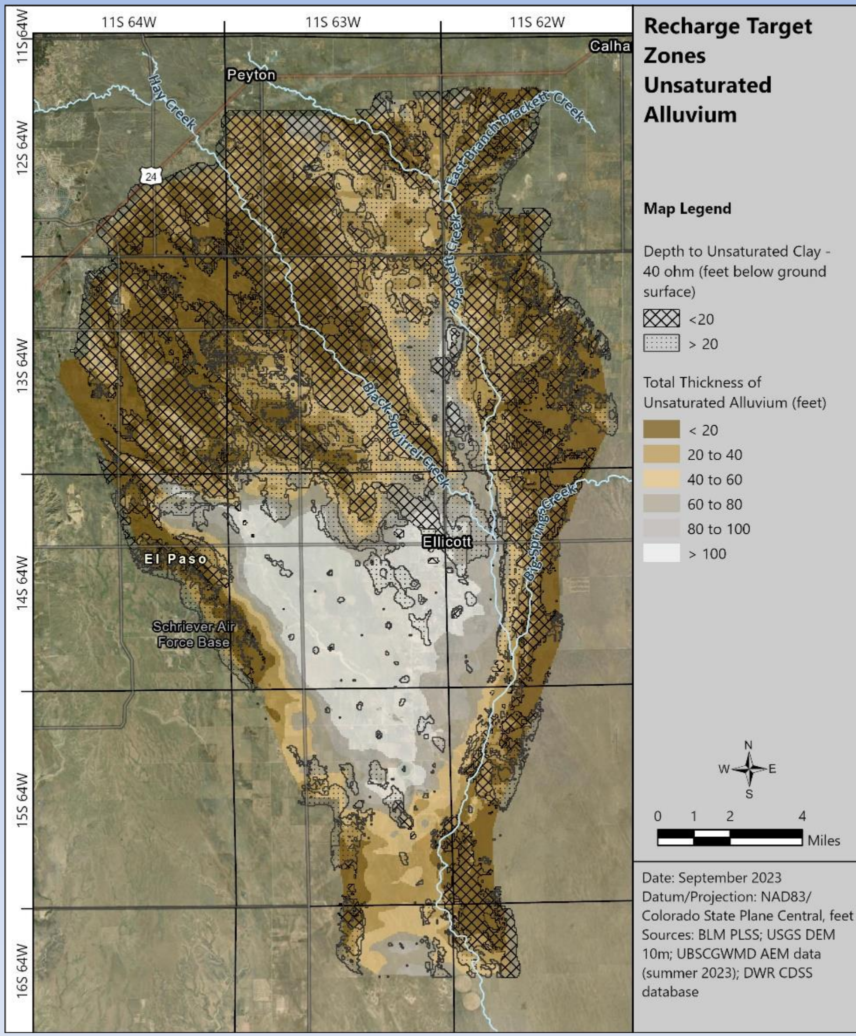
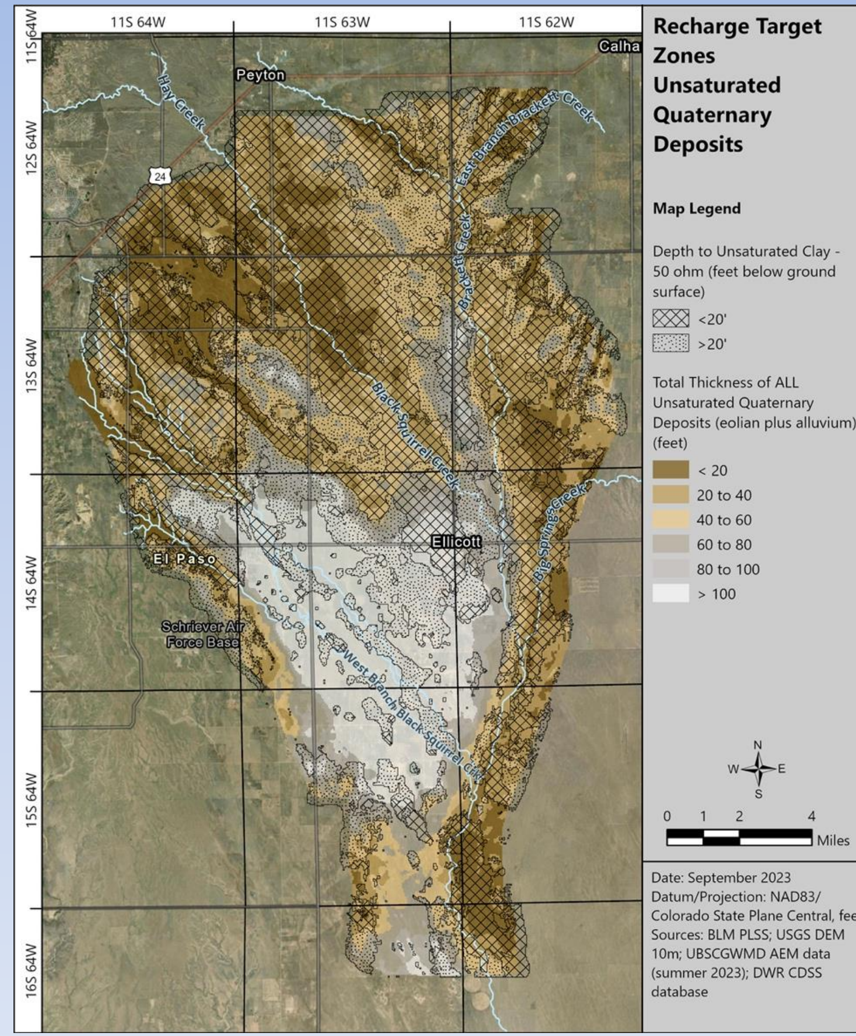
Upper Black Squirrel Creek
GROUND WATER MANAGEMENT DISTRICT

Recharge Areas





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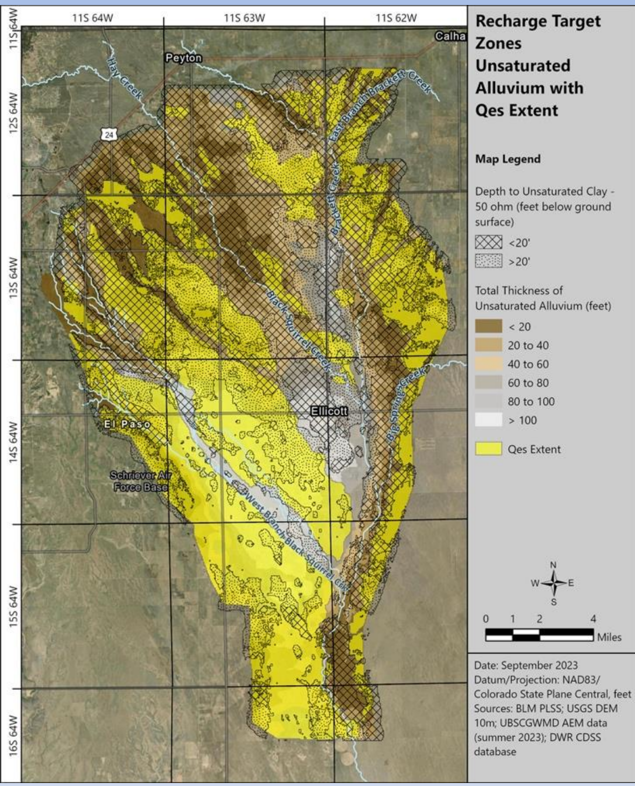
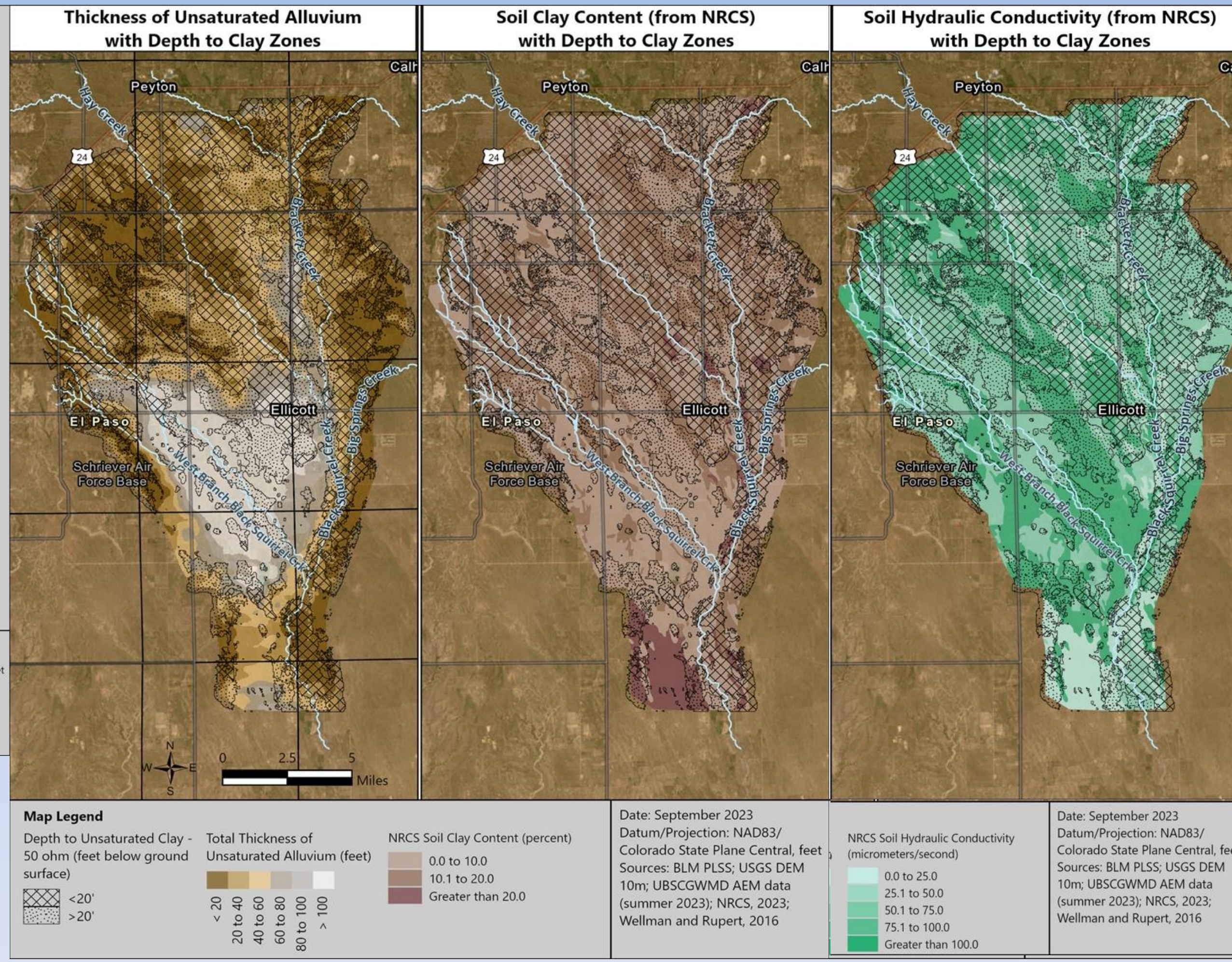
Upper Black Squirrel Creek
GROUND WATER MANAGEMENT DISTRICT

Recharge Areas





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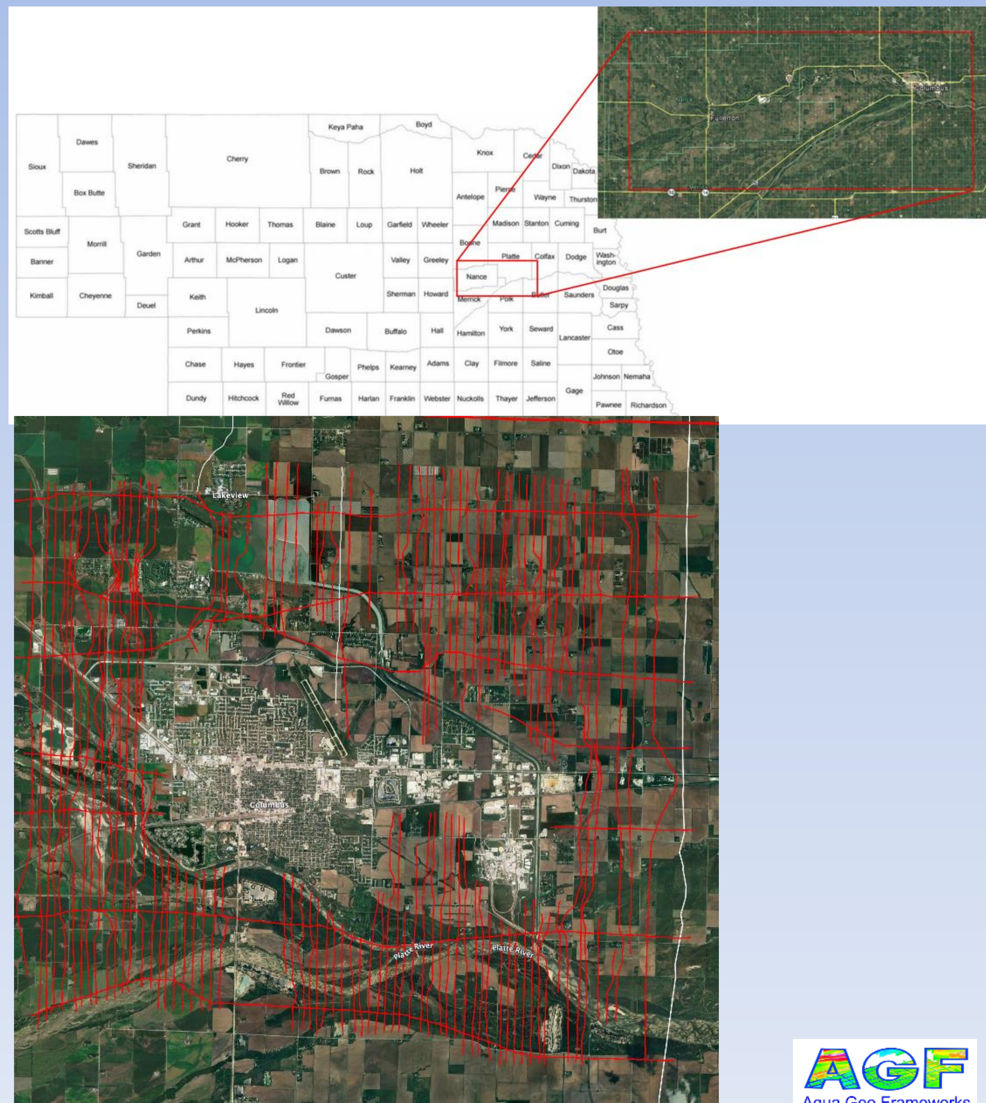
LOWERLOUP
NATURAL RESOURCES DISTRICT

Lower Loup Natural Resources District, Columbus Recharge Project

Objectives:
- Map areas of sand and gravel aquifers
- Identify areas of saturated and unsaturated materials
- Map bedrock units
- Identify clay layers
- Identify best recharge sites

Schedule:
- Water declines in area 2011 and 2012
- RFP for Consulting Services 2015
- AEM survey 2016
- Design feasibility 2018-2019
- Construction 2021-2022
- System comes online 2022
- Successful first year of operation 2023



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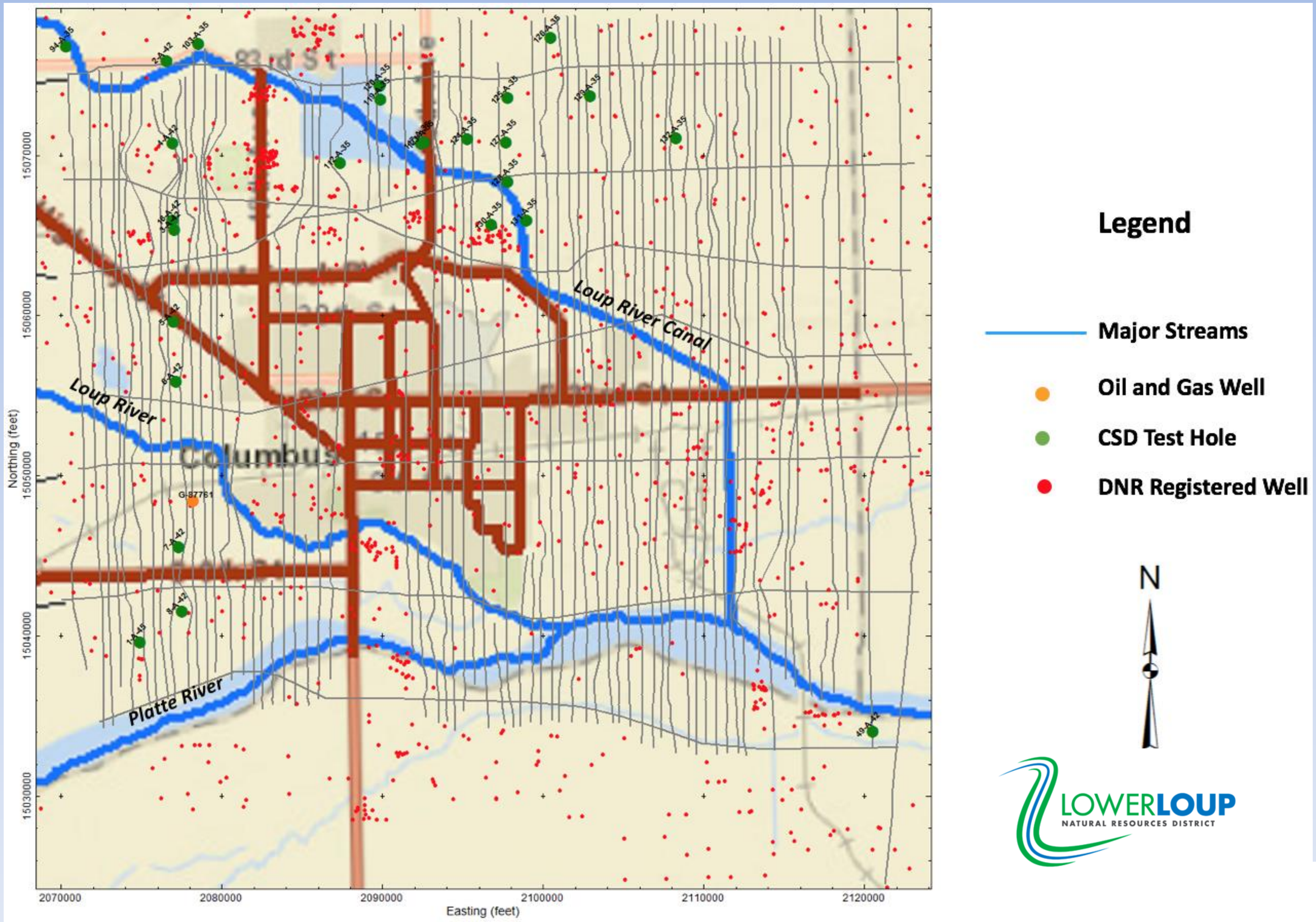
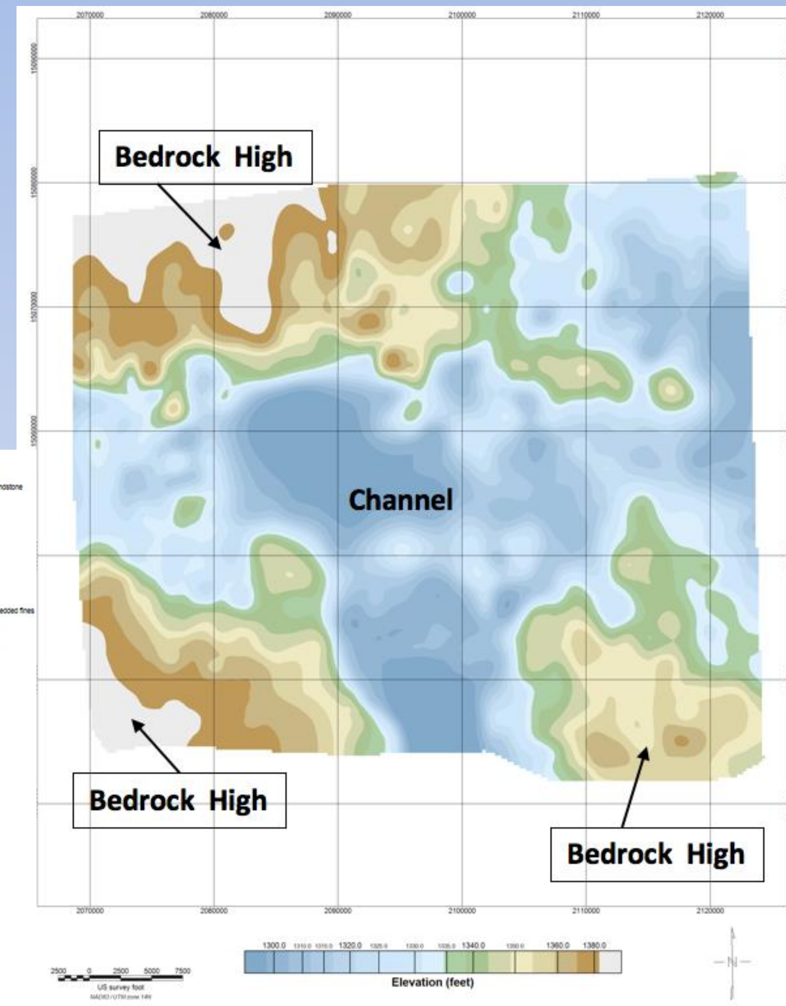
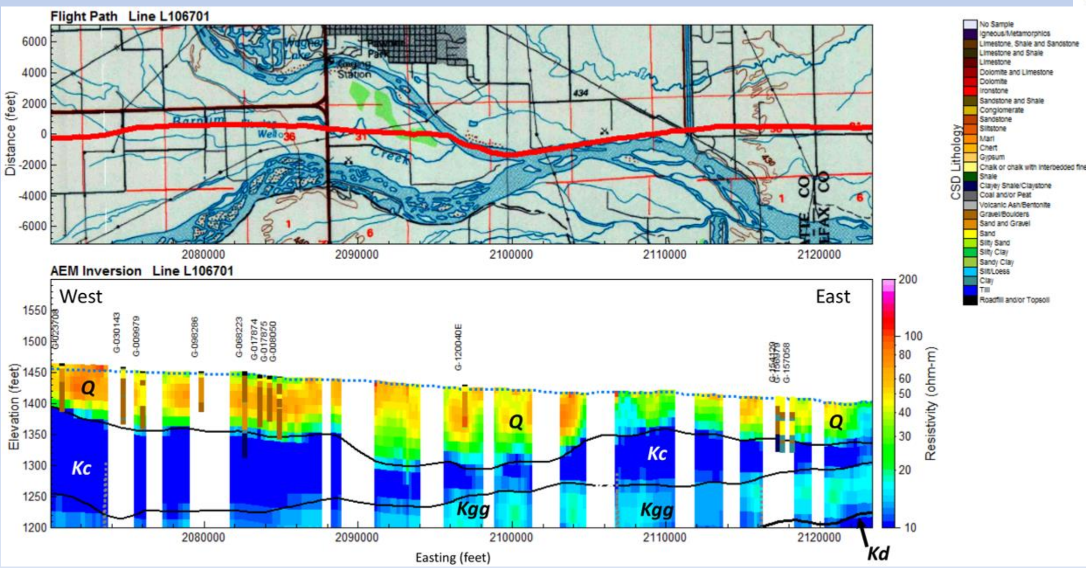
AEM Data and Borehole Control



AEM Interpretation

- Map bedrock and aquifer materials
- Boreholes fill in information for the areas with no data





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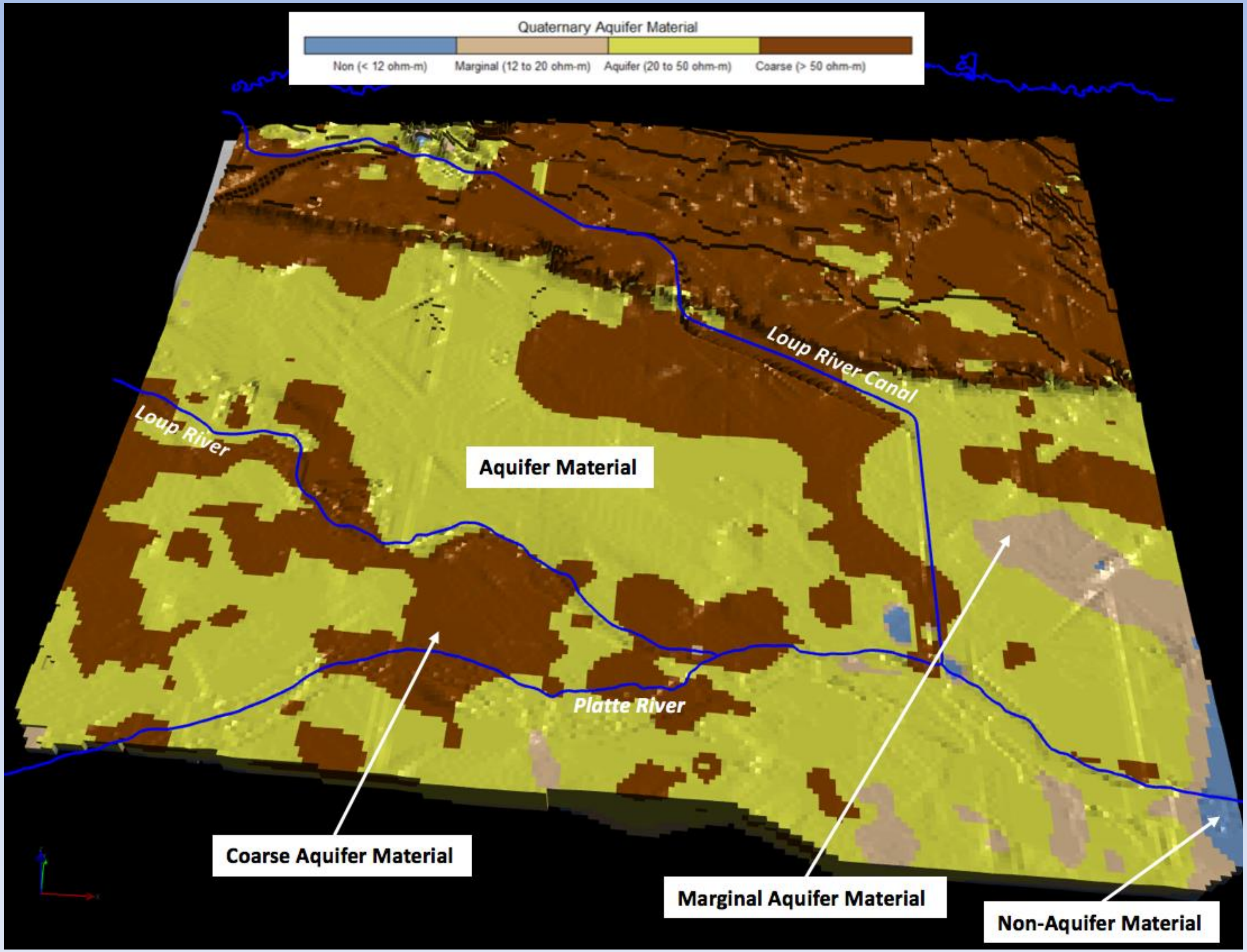
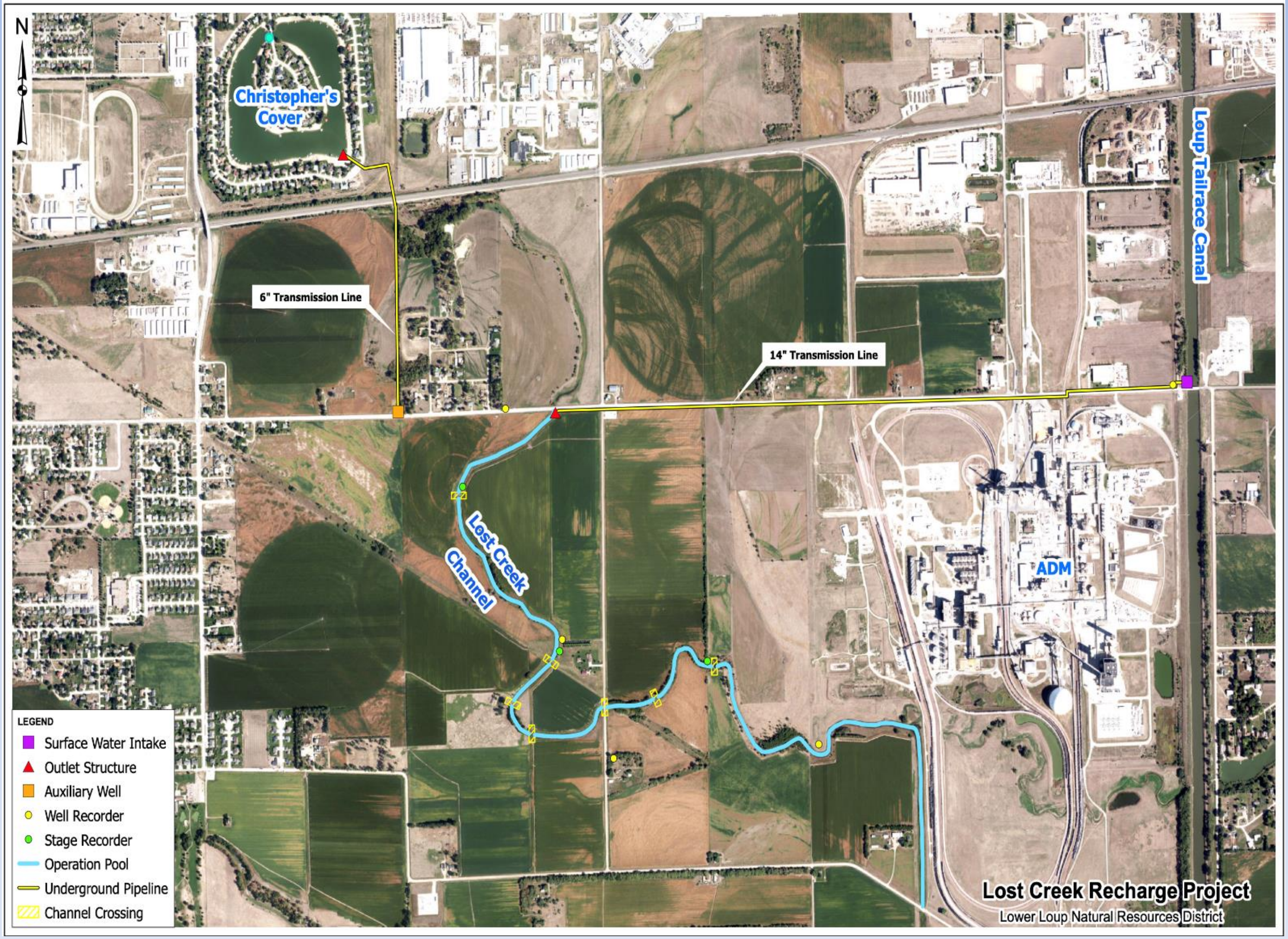
Interpreted Aquifer Materials



Final Project



https://nednr.nebraska.gov/Media/NRC/ColumbusProjectUpdate.pdf

Estimated Costs

- Mobilization/demobilization
  - $10,000-$50,000
- Acquisition (line-km) line-mile
  - $80-$200/(line-km)
  - $128-$321/line-mile
- Flight Planning system selection
  - $25/(line-km)
  - $40/line-mile
- Processing Inversions
  - $25/(line-km)
  - $40/line-mile
- Interpretation (project dependent)
  - $75-$200/(line-km)
  - $120-$321/line-mile
- Roughly ~$250,000 for a township (line spacing dependent)
- ~ $10.00/acre

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Contacts

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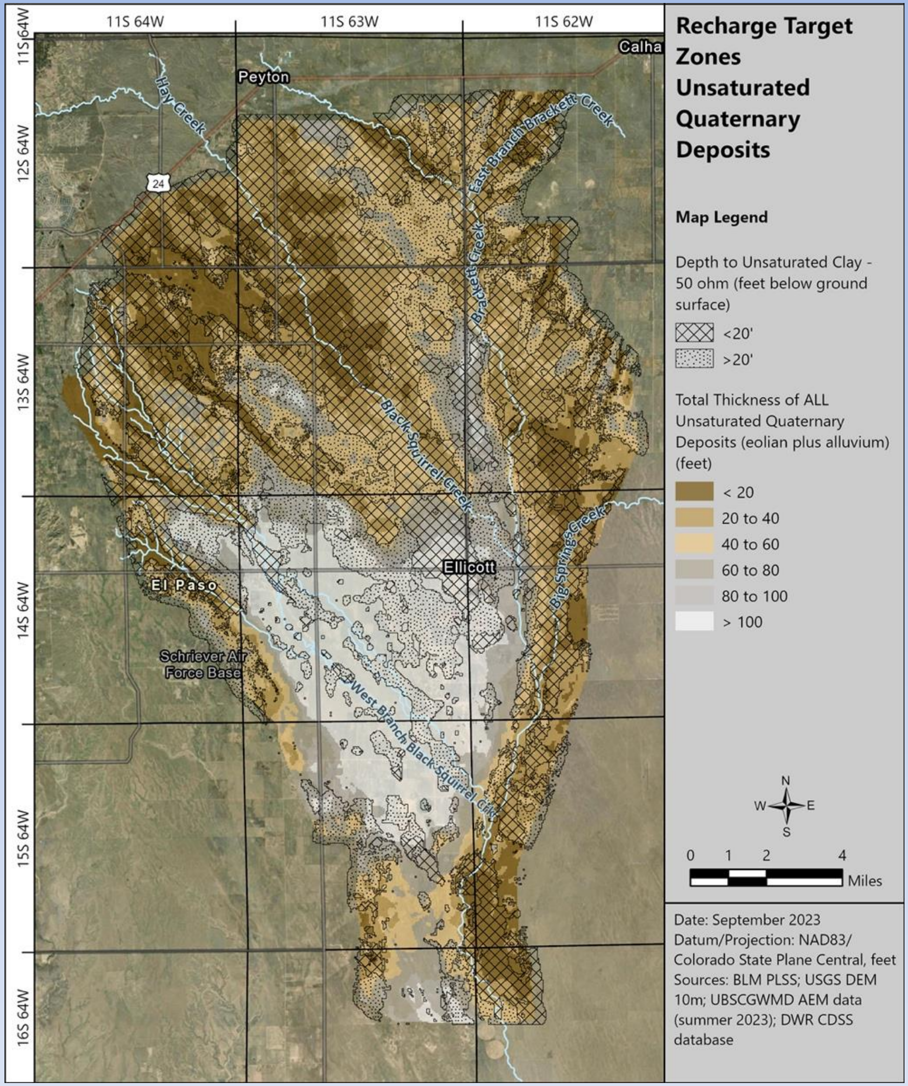

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