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

February 22, 2024

Jared D. Abraham, PG, PGP
Aqua Geo Frameworks, LLC
Fort Laramie, WY
Basics: Resistivity and Rocks

Increase in resistivity
Finer-grained sediment

Decrease in resistivity
Coarser-grained sediment

(from Palacky, 1988)
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
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

Lake talik  permafrost
What's happening in the earth:

The current induced in the earth diffuses downward and outward.

What we measure in the receiver coil:

Current density, 2-layer model

Apparent resistivity

Auken, Aarhus University
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
  - HeliTEM
  - Geotech VTEM
  - SkyTEM
  - 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
Forward Modeling

Geologic Model “Truth”

Simplified Model

AEM Response

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

Modified from D. Di Massa et al., 2016
Line Spacing and Targets

55 to 65 metres
1200 m line spacing

55 to 65 metres
4800 m line spacing

Powers, 2011
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/m²] 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!!

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

A Flight line map

B Inphase and Quad response (ppm) vs Frequency (Hz)

C CDI/constrained Inversion

D Interval conductivity map

Adapted from Fitterman et al. 1999
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)
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
AEM Mapping Example
Bedrock Comparison

Top of Bedrock Elevation
Topper, 2008

Top of Bedrock Elevation
Borehole Only

Top of Bedrock Elevation
AEM-Derived

Map Legend

- AEM/Study Boundary
- UBSCGWM Boundary

Elevation of the Top of Bedrock
(ft asl)

5.384 - 5.500
5.500 - 5.600
5.600 - 5.700
5.700 - 5.800
5.800 - 5.900
5.900 - 6.000
6.000 - 6.100
6.100 - 6.200
6.200 - 6.300
6.300 - 6.400
6.400 - 6.500
6.500 - 6.600
6.600 - 6.700
6.700 - 6.800
6.800 - 6.831

N
0 2 4 8 Miles
Unsaturated Qal Thickness

Map Legend
- UBSCGWMD Boundary
- AEM/Study Boundary
- Flight Line

Thickness of the UNSATURATED Alluvium (ft)
- 0 to 10 ft
- 10 to 20 ft
- 20 to 30 ft
- 30 to 40 ft
- 40 to 50 ft
- 50 to 60 ft
- 60 to 70 ft
- 70 to 80 ft
- 80 to 90 ft
- 90 to 100 ft
- 100 to 110 ft
- 110 to 120 ft
- 120 to 130 ft
- 130 to 140 ft
- 140 to 150 ft
- 150 to 163 ft

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
Recharge Areas

Recharge Target Zones
Unsaturated Alluvium

Map Legend:
Depth to Unsaturated Clay - 40 ohm (feet below ground surface)
- < 20
- > 20
Total Thickness of Unsaturated Alluvium (feet)
- < 20
- 20 to 40
- 40 to 60
- 60 to 80
- 80 to 100
- > 100

Date: September 2023
Datum/Projection: NGVD88/
Colorado State Plane Central, feet
Sources: BLM PLSS, USGS DEM
10m; USCGWMD-AEM data
(summer 2023); DWR CDSS database

Recharge Target Zones
Unsaturated Quaternary Deposits

Map Legend:
Depth to Unsaturated Clay - 50 ohm (feet below ground surface)
- < 20’
- > 20’
Total Thickness of ALL Unsaturated Quaternary Deposits (eolian plus alluvium) (feet)
- < 20
- 20 to 40
- 40 to 60
- 60 to 80
- 80 to 100
- > 100

Date: September 2023
Datum/Projection: NGVD88/
Colorado State Plane Central, feet
Sources: BLM PLSS, USGS DEM
10m; USCGWMD-AEM data
(summer 2023); DWR CDSS database
Recharge Areas
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
AEM Data and Borehole Control
AEM Interpretation

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

Jared D. Abraham, PG, PGP
Aqua Geo Frameworks, LLC
10848 Ridge Road
Fort Laramie, WY 82212
jabraham@aquageoframeworks.com
www.aquageoframeworks.com
(303) 905-6240