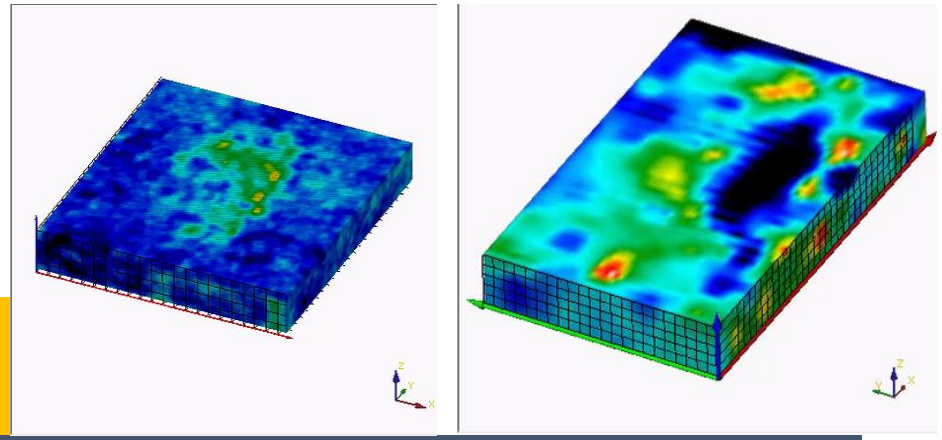
remediation technologies symposium
October 2019



Two Case Studies in Achieving Site Closure

3D Salt Plume Volume Estimates Using OhmMapper Resistivity Surveys, Calibrated with Physical Analytical Soil Data

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CASE STUDY REVIEW: REMEDIATION OF CHLORIDE IMPACTED SITES

- Introduction and outline of site regulator requirements and challenges
- Geophysical Investigation Methods:
  - EM31 - Fixed Frequency Electromagnetic Method
  - RCV – Rapid Conductivity Volume
    - OhmMapper – Capacitively Coupled Resistivity
- Case Study #1
  - Site History
  - Additional Phase II Environmental Site Assessment
  - Tier 2b Guidelines using the Subsoil Salinity Tool
  - Geophysical Results
  - Excavation
- Case Study #2
  - Site History
  - Traditional EM Surveys, Tier 2b SST development, and volume estimates based on soil data
  - Geophysical Results
  - Excavation
- Final Review and Volume Comparisons

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PROBLEM: CONTAMINATED SOIL

- Soil contamination by salts is regulated in Alberta and effects a variety of users.
- Receptors of concern from impacted soils: drinking water, irrigation, plant growth, fresh water ecology, and soil ingestion by animals or humans.

Industry	Source
Upstream Oil and Gas	Produced Water
Commercial Development	Salt Storage (Transportation)
Agriculture	Fertilizer: Use or Storage
All	Natural Sources

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2019 UPDATES TO REMEDIATION REGULATION

Environmental Protection and Enhancement Act

REMEDIATION CERTIFICATE AMENDMENT REGULATION

- Came into effect on January 1, 2019
- Impacts over criteria need to be addressed within two years of discovery though a remedial action plan (RAP), risk management plan (RMP), or remediation.

REMEDIATION OR RISK MANAGEMENT??

What are the plans for the future? What is the risk? What are the stakeholder requirements?

What is it going to cost?

What is the chance of staying on budget?

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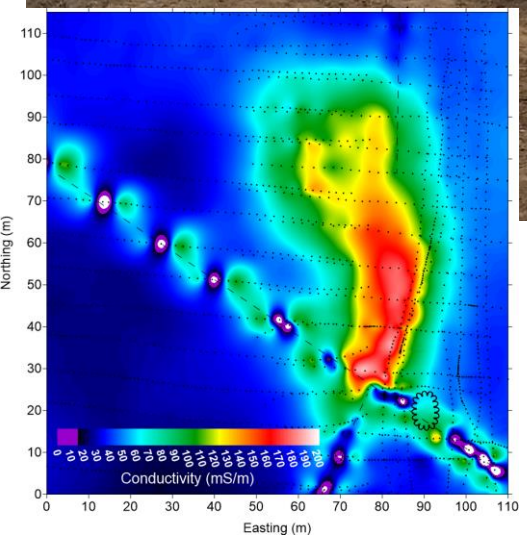
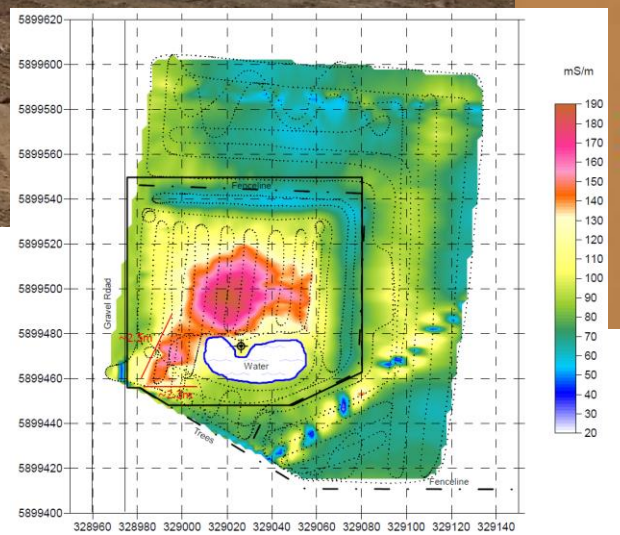
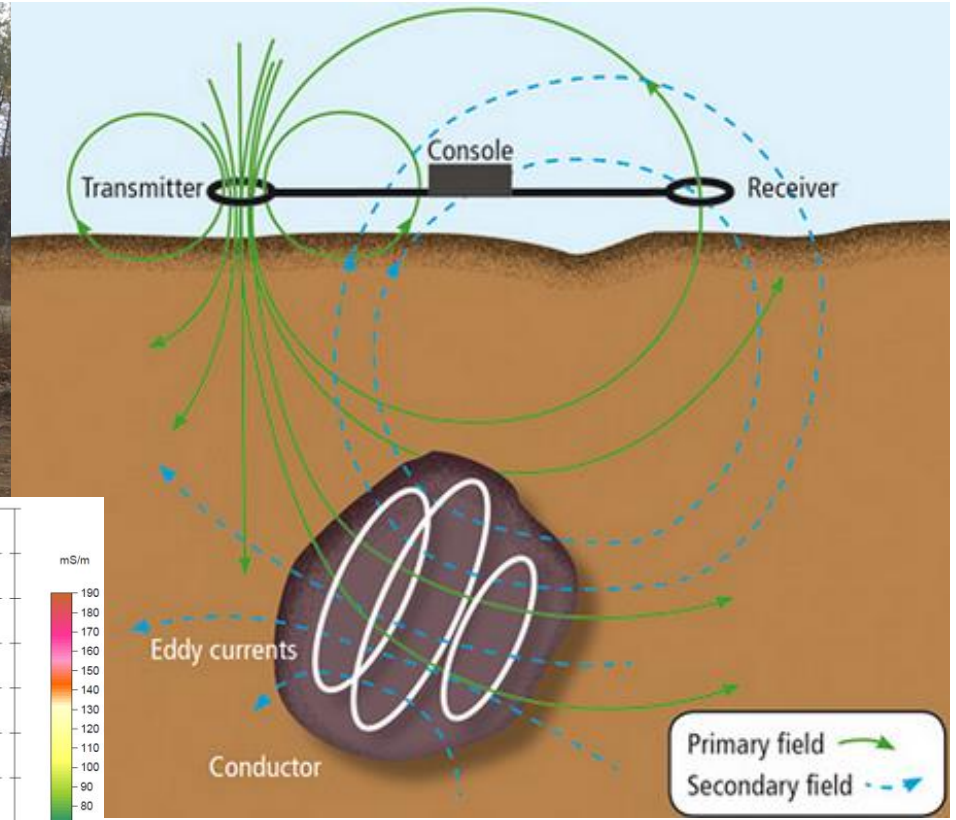
EM31 - FIXED FREQUENCY ELECTROMAGNETIC METHOD







- Average over 5-6m
- Large area of influence
  - Ambiguous
- Good for recon before RCV survey (OhmMapper or ERI)

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HOW TO GET MORE SPECIFIC DEPTH INFORMATION?

- 2D Electrical Imaging of Conductivity in vertical profiles
  - Relative high effect from salt plumes.

- Two methods:
  - Electrical Resistivity Imaging (ERI, AKA ERT)
  - OhmMapper Capacitively Coupled Resistivity Imaging.

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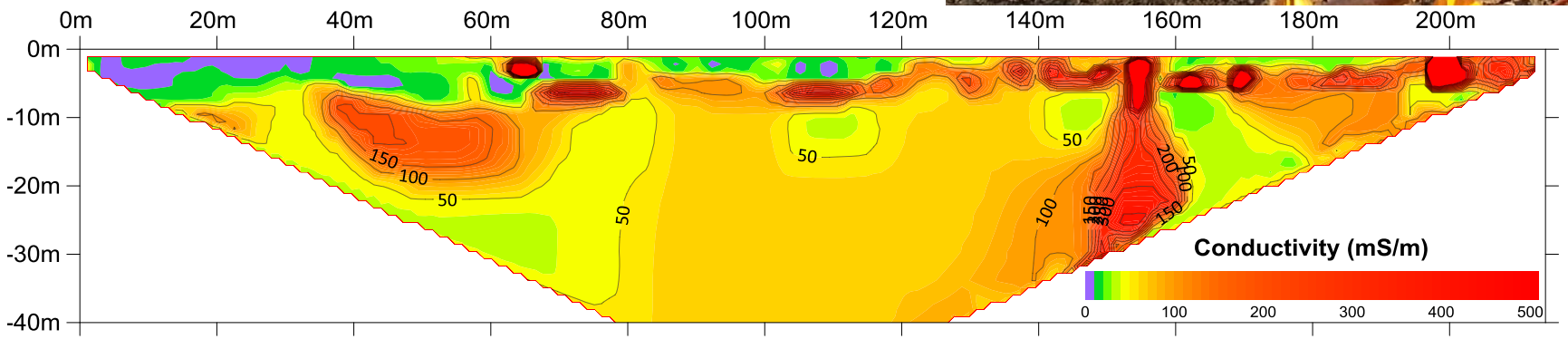
RCV – RAPID CONDUCTIVITY VOLUME
ELECTRICAL RESISTIVITY IMAGING (ERI, AKA. ERT)

- Conventional Resistivity, Direct Current Injection.
- Up to Ten 100m long lines at 2.5m electrode spacing possible per day with 2 people.



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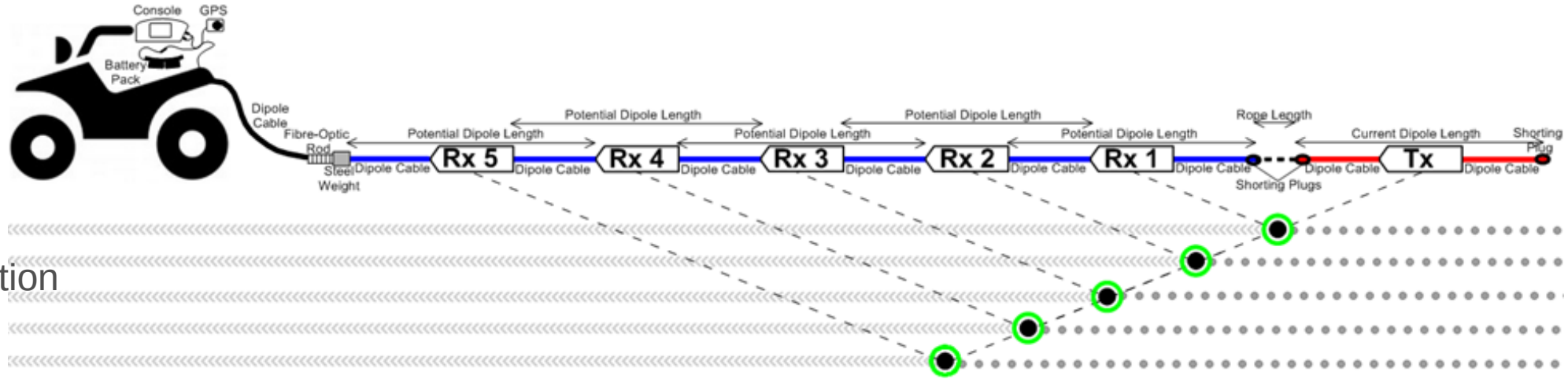
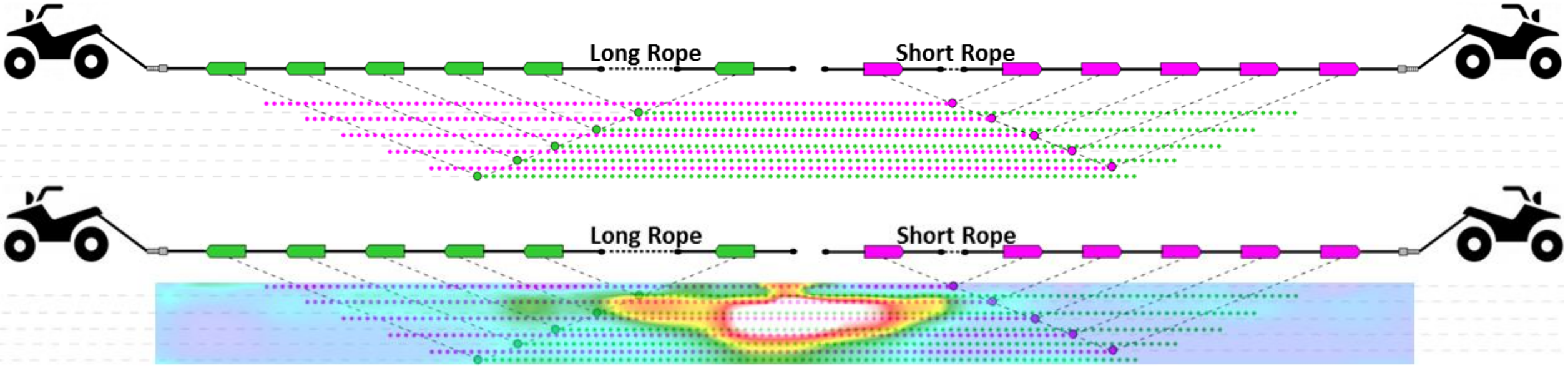
OHMMAPPER – CAPACITIVELY COUPLED RESISTIVITY

- Quick
- High data density
- Variable Dipoles
  - Variable depths
- Variable Rope Separation
  - Variable depths
  - Double data density





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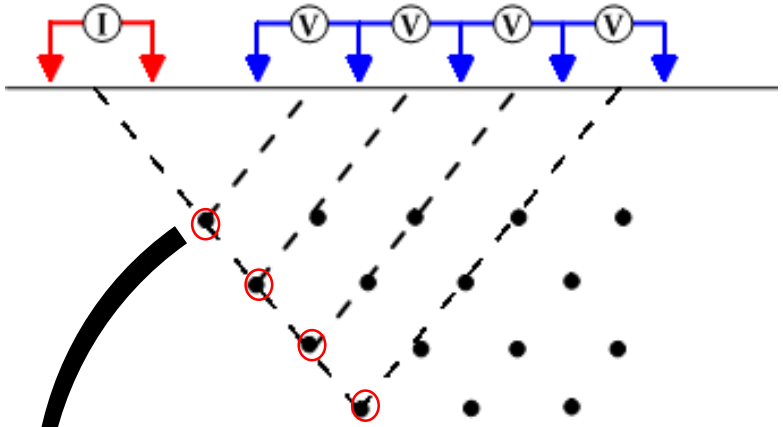
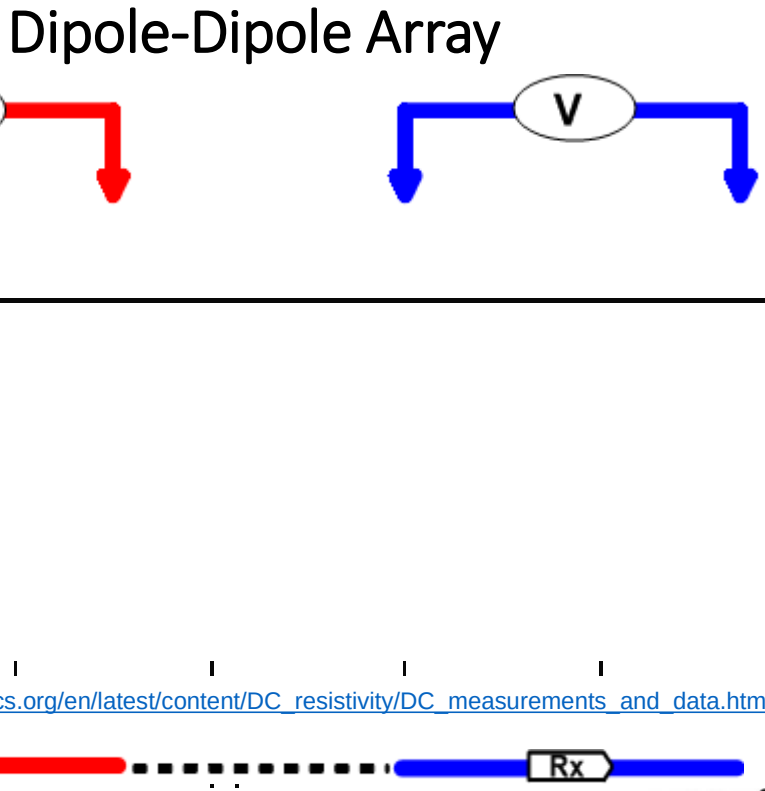
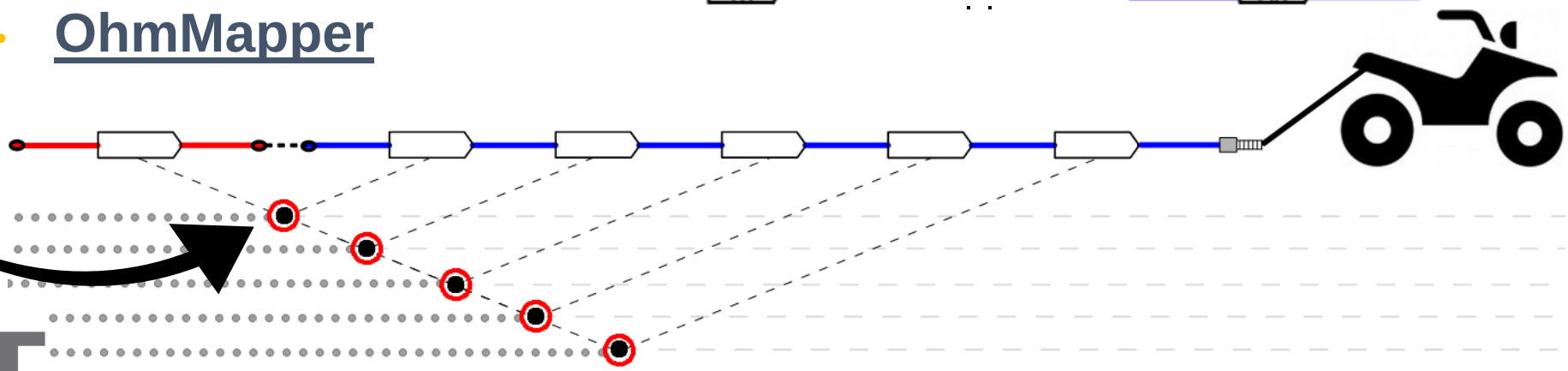
ERI Vs. OHMMAPPER

- **Conventional ERI**





- **OhmMapper**



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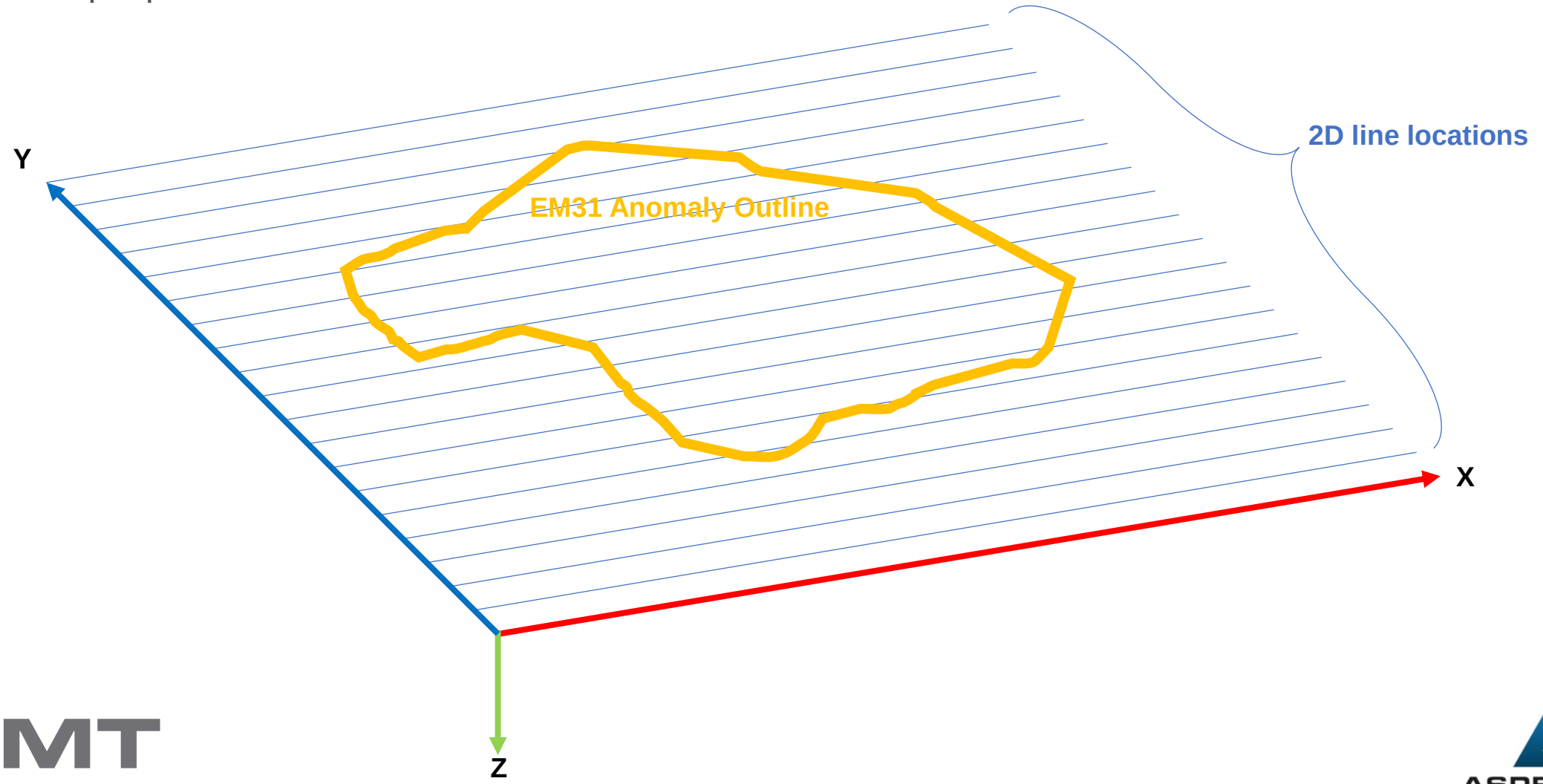
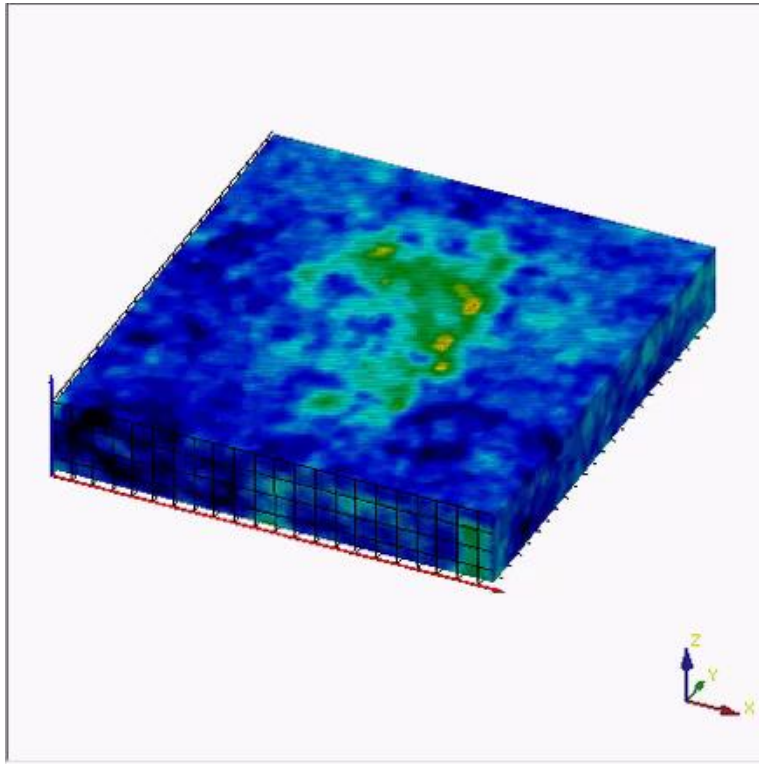
RCV – RAPID CONDUCTIVITY VOLUME METHOD

- Data acquisition method to produce pseudo-3D volumes of conductivity data.
- Multiple parallel 2D lines combined.

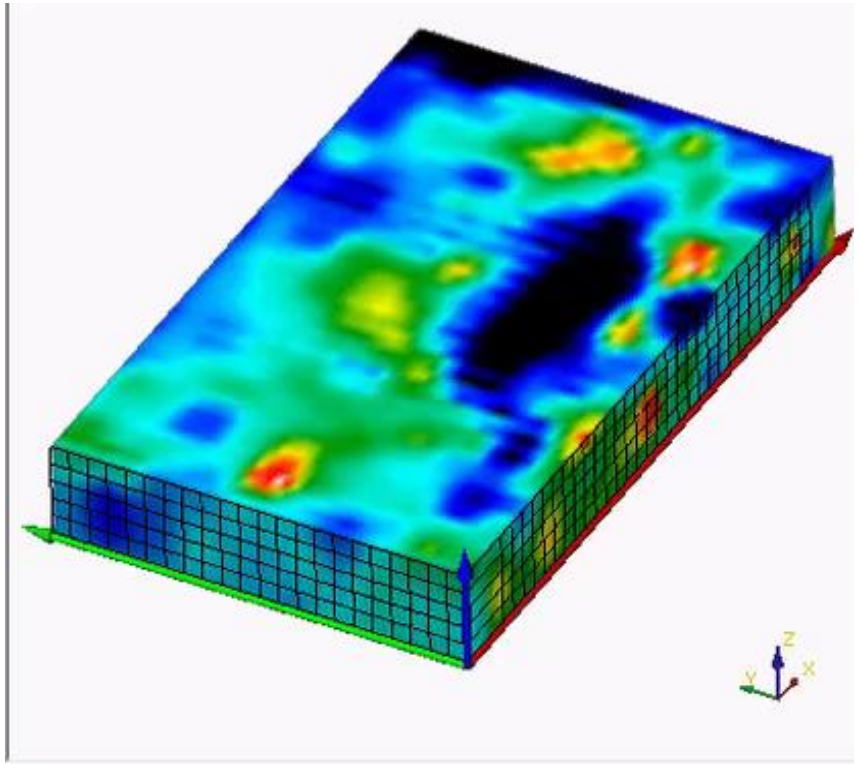


RCV – RAPID CONDUCTIVITY VOLUME
OHMMAPPER – CAPACITIVELY COUPLED RESISTIVITY

Case Study #1



Case Study #2



CASE STUDY #1
SITE HISTORY – Pipeline Leak

- Produced Water Pipeline break
  - ~29m^3 of crude oil.
  - ~75m^3 of produced water.
  - 945 m^3 of soil excavated during initial cleanup.
- Initial Phase II assessment performed
  - Estimated 5775m^3 of impacted soil.
  - Was not delineated (no outer edges found).
  - ➔ **A Guess.**
- Site re-assessed with traditional methods to:
  - Establish background conditions.
  - Perform an EM31 survey.
  - Create Subsoil Salinity Tool (SST) guideline.

  13,000m^3 = New volume of impacted soil
- ALE now involved Pinchin and DMT to review the site and gather better data.

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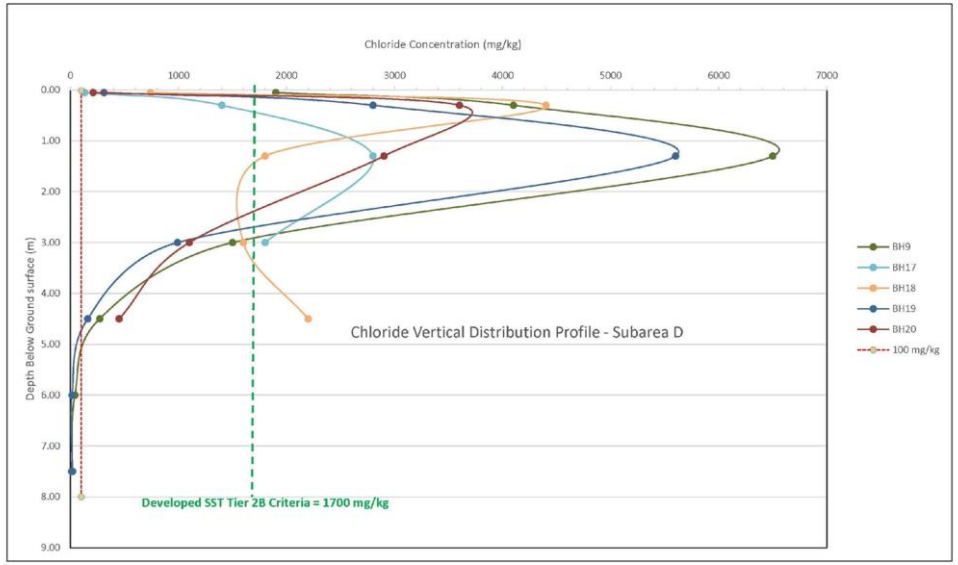
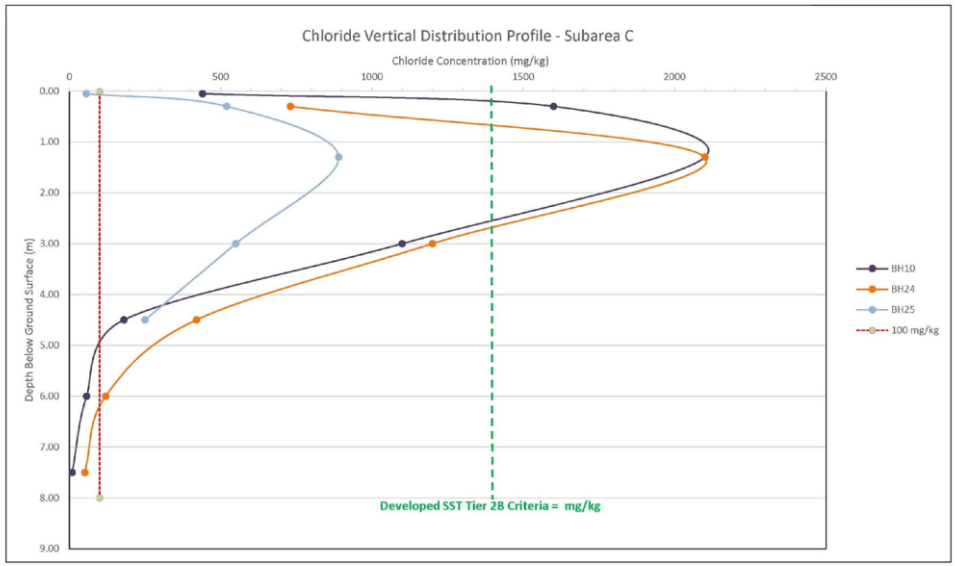
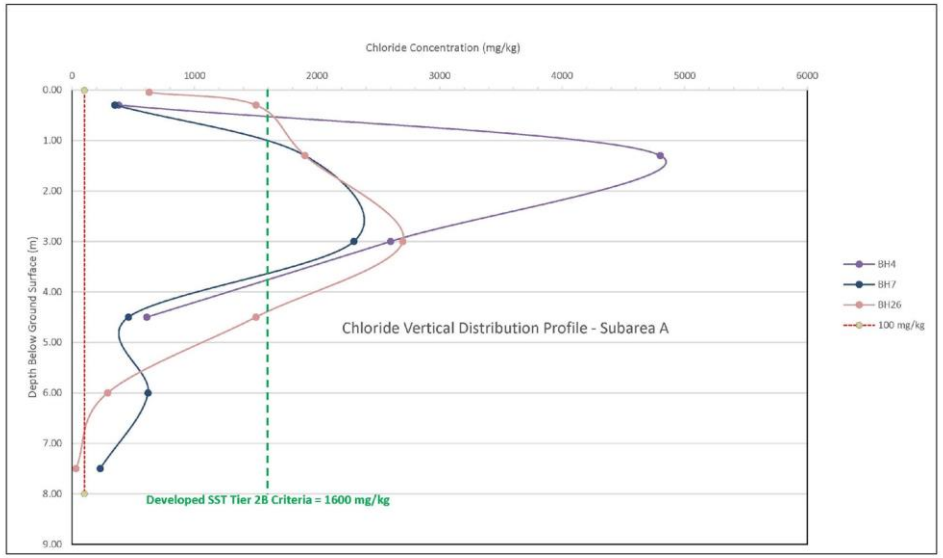
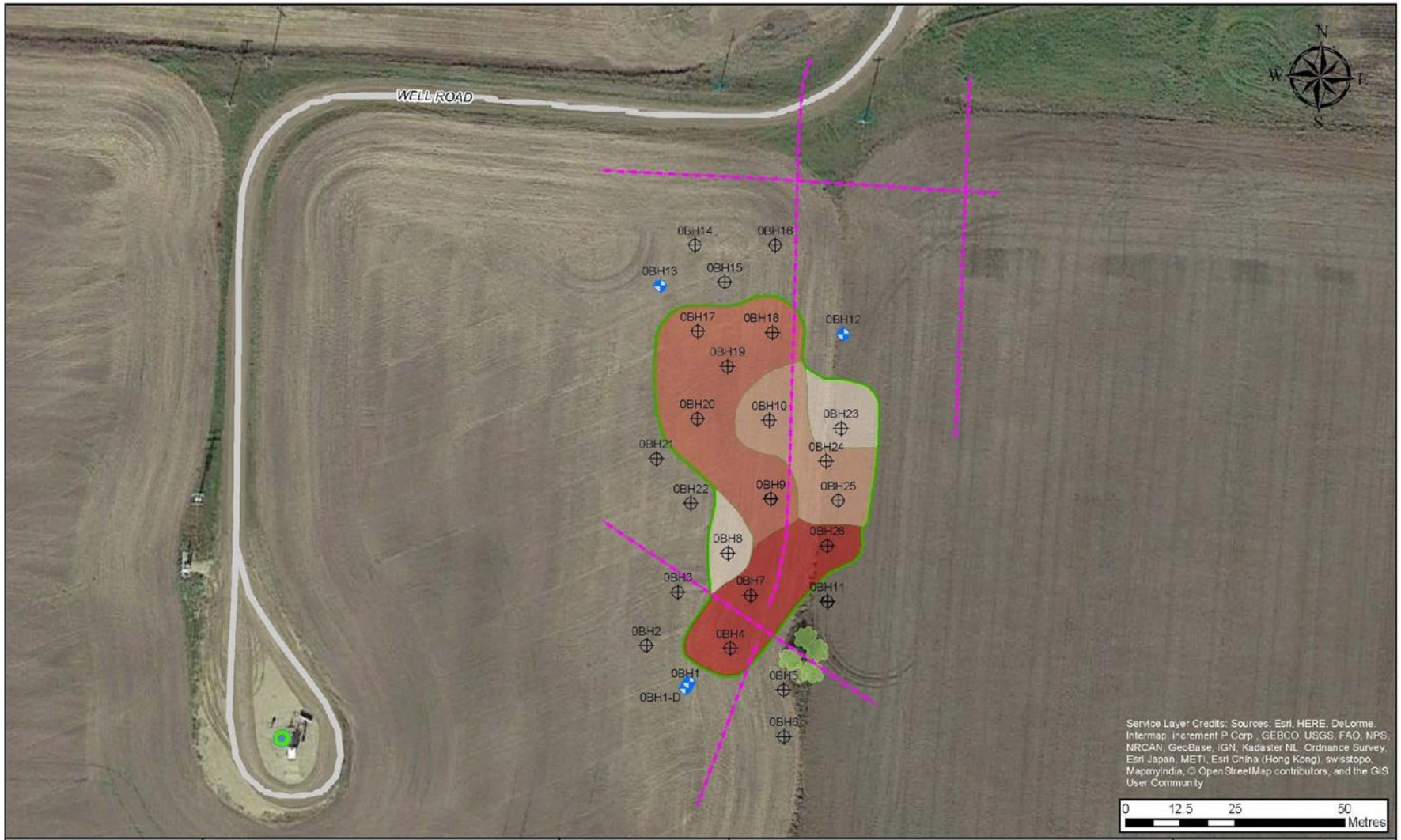
ADDITIONAL PHASE II AND SST ANALYSIS

- Tier 1 Alberta Soil and Groundwater Remediation Guidelines are applicable to the majority of sites and soils 1.5 m deep or less on this Site.
- To create a site specific Tier 2b guideline using the SST more samples were gathered laterally and vertically, to better delineate and characterize, plus new groundwater data.
- Divided site into multiple sub areas to match vertical concentrations with a difference excavation plan and criteria for each.









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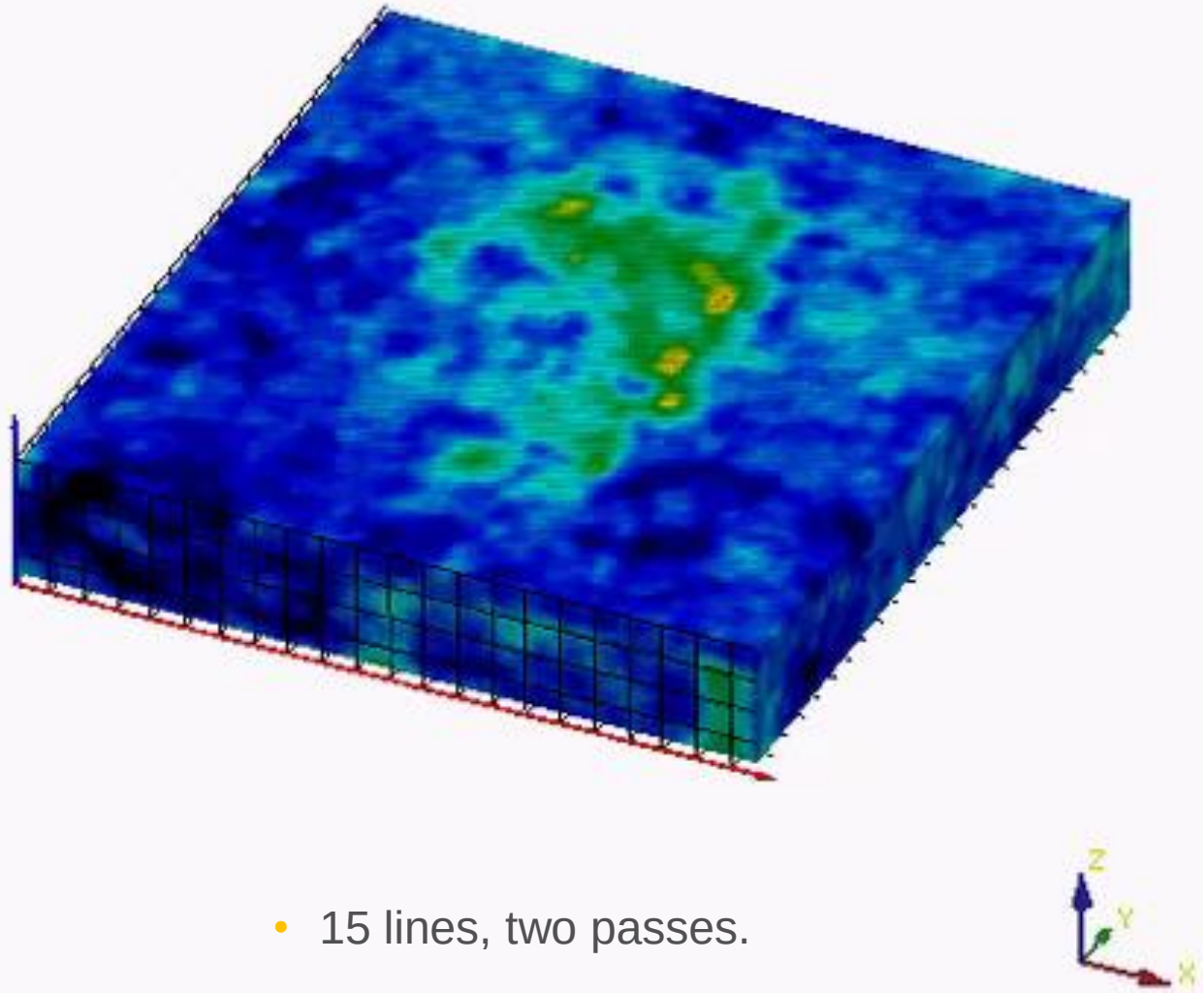
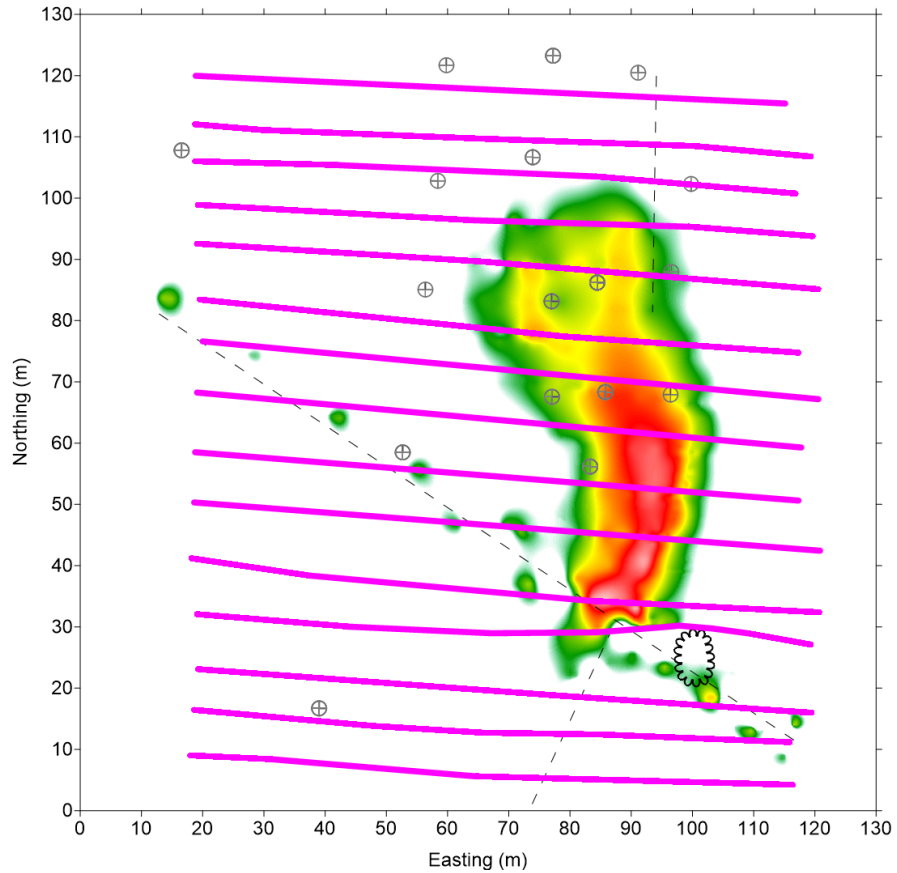
RCV – RAPID CONDUCTIVITY VOLUME

OHMMAPPER – CAPACITIVELY COUPLED RESISTIVITY

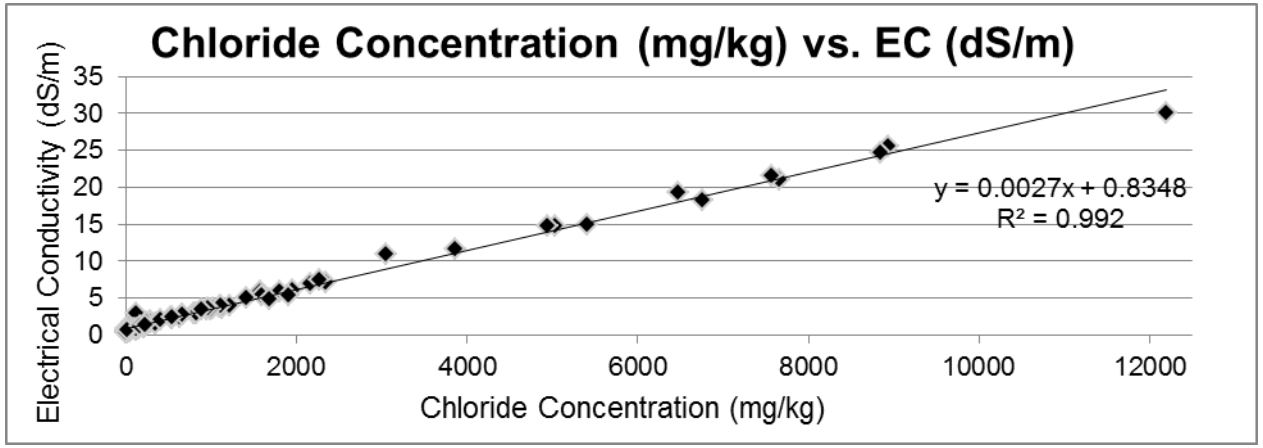


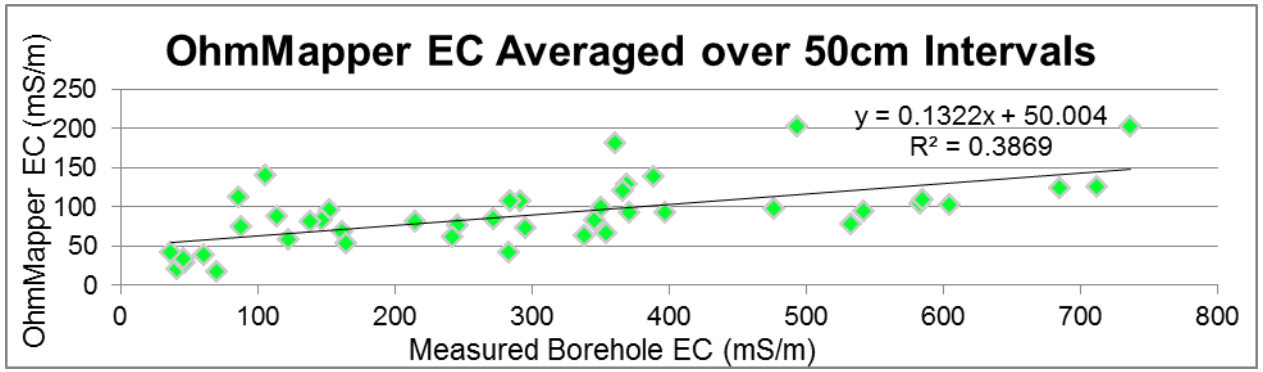


- 15 lines, two passes.
- One day of acquisition.
- One person

GEOPHYSICAL VOLUME RESULTS – Case Study #1

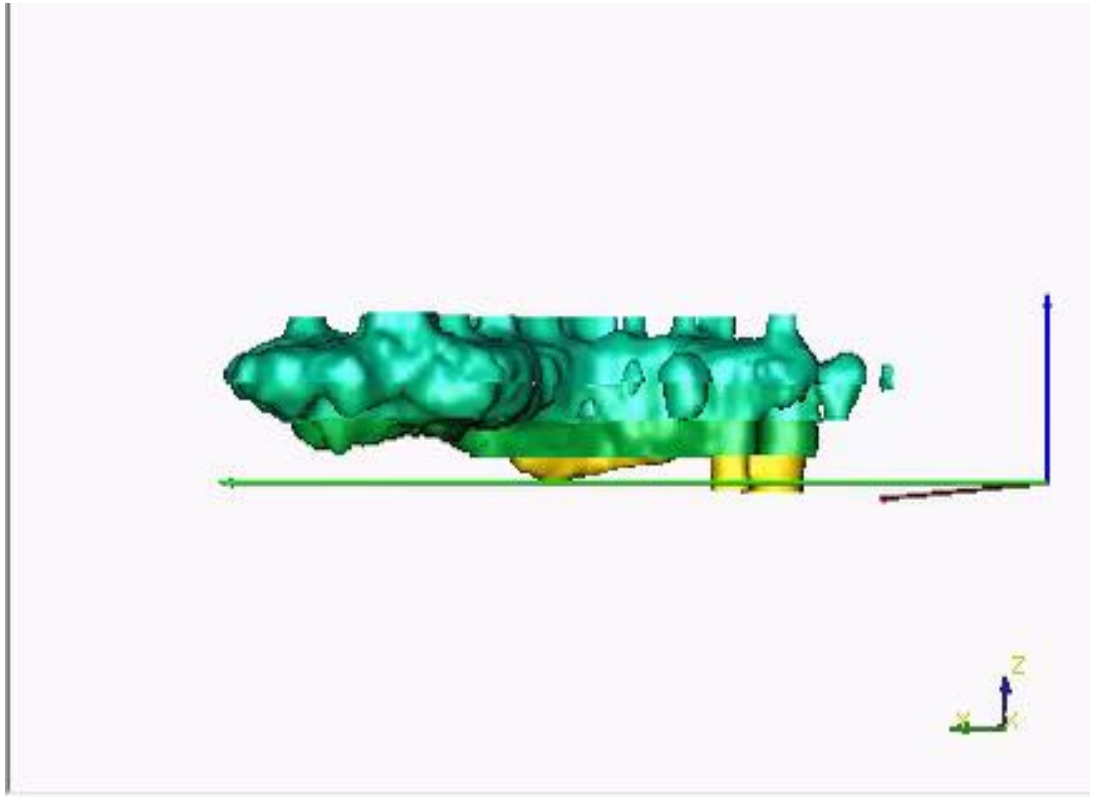
- Plot Chlorides vs. Borehole EC (Plot 1)
  - Take EC at Chloride concentration defined by SST
    - **600mg/kg** from 0 to 2m depth **= 2.45dS/m**
    - **760mg/kg** from 2m to 3m depth **= 2.89dS/m**
    - Etc.
- Correlate OhmMapper EC values from RCV data to EC at borehole locations (Plot 2).
  - Averaged over 50cm intervals centred on Borehole measurement points.
  - Take OhmMapper EC at related Borehole EC
    - Borehole EC **2.45dS/m** → OhmMapper EC **82mS/m**
    - Borehole EC **2.89dS/m** → OhmMapper EC **88mS/m**
    - Etc.



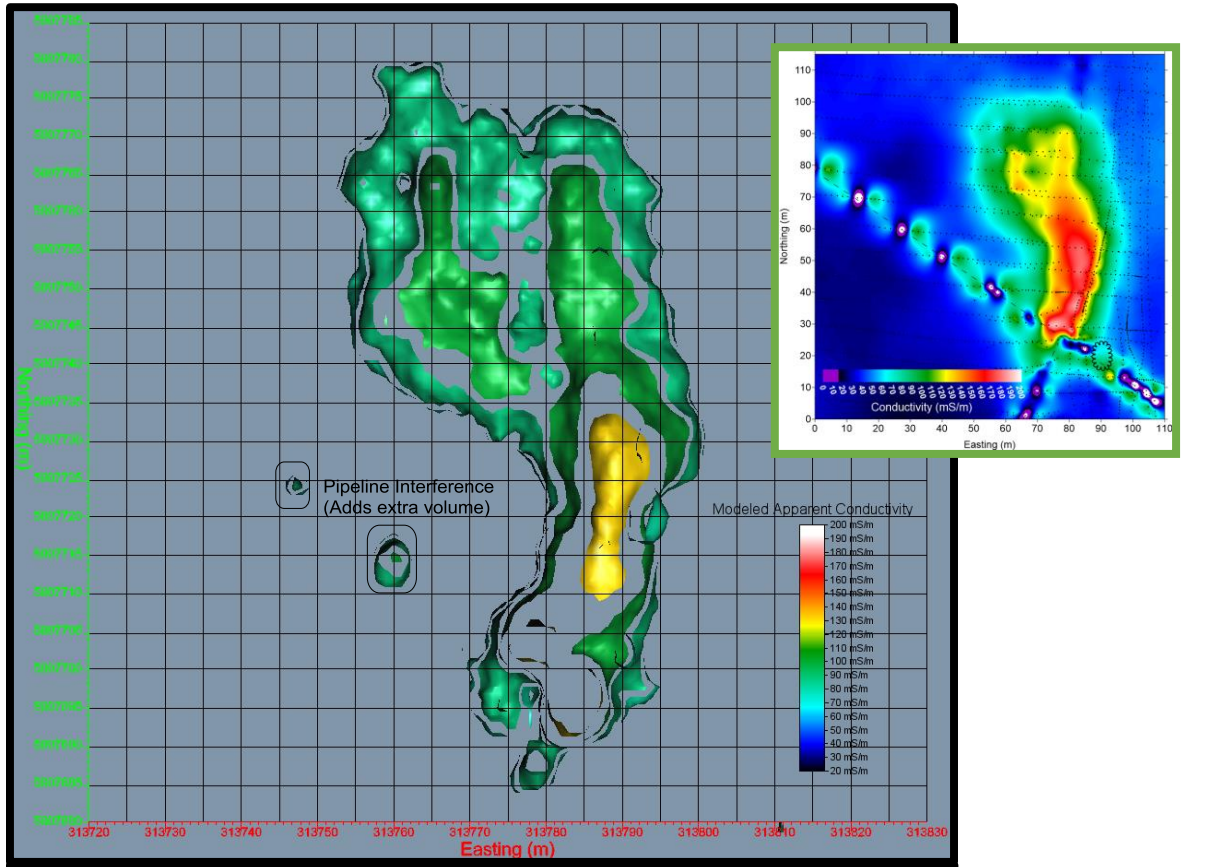


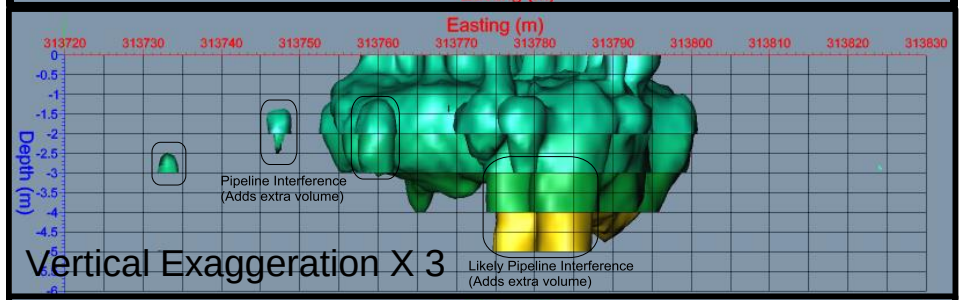
Chloride Concentration within specified Depth range	Iso-Surface Value Correlating to Chloride Concentration	Volume within Iso-Surface down to specified depth
600mg/kg from 0 to 2m depth	82mS/m	**3322m³**
760mg/kg from 2 to 3m depth	88mS/m	**2007m³**
1100mg/kg from 3 to 4m depth	100mS/m	**720m³**
2000mg/kg from 4 to 5m depth	132mS/m	**121m³**
		Total = 6170m³

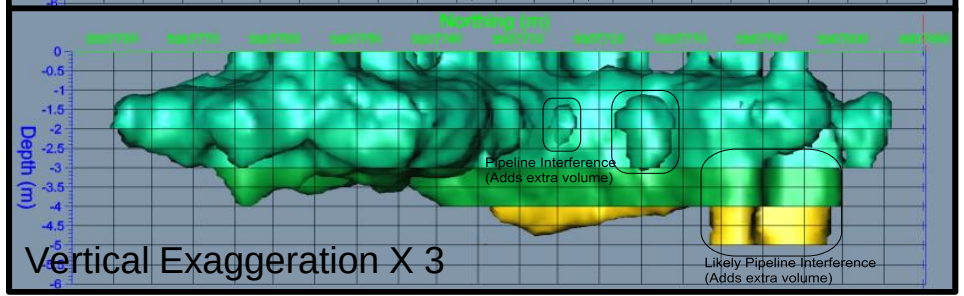
GEOPHYSICAL VOLUME RESULTS – Case Study #2



Chloride Concentration within specified Depth range	Iso-Surface Value	Volume within Iso-Surface
600mg/kg from 0 to 2m depth	82mS/m	**3322m^3**
760mg/kg from 2 to 3m depth	88mS/m	**2007m^3**
1100mg/kg from 3 to 4m depth	100mS/m	**720m^3**
2000mg/kg from 4 to 5m depth	132mS/m	**121m^3**
	Total =	**6170m^3**







EXCAVATION

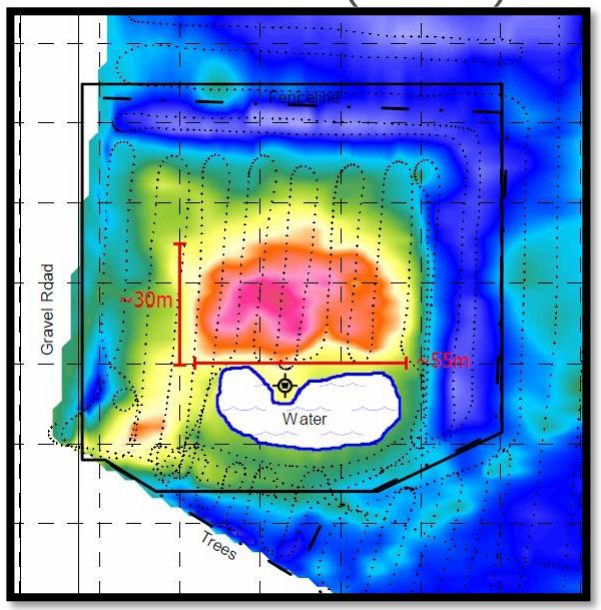
- After using OhmMapper conductivity data, 6170 m^3 was estimated for excavation.
- Total actual impacted volume excavated was 5926 m^3 **(~4% variance)**
  - (219 m^3) was relocated and deep buried where it met criteria onsite.
  - LESS THAN HALF of initial non-3D estimate using geophysical results was proven by excavation.

CASE STUDY #2
SITE HISTORY – Landfarm

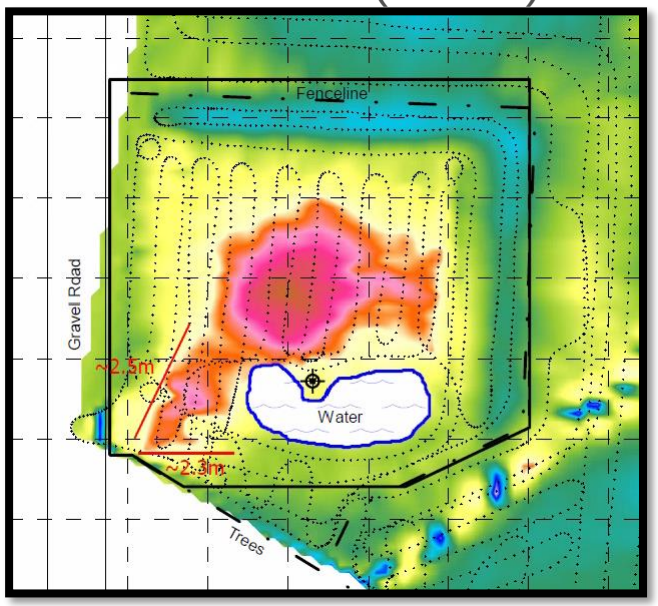
- Historical salt impacted soil treatment landfarm.
  - Vertically leached impacts from surface to 4.5m deep.

PHASE II, SST, & TRADITIONAL VOLUME ESIMATE

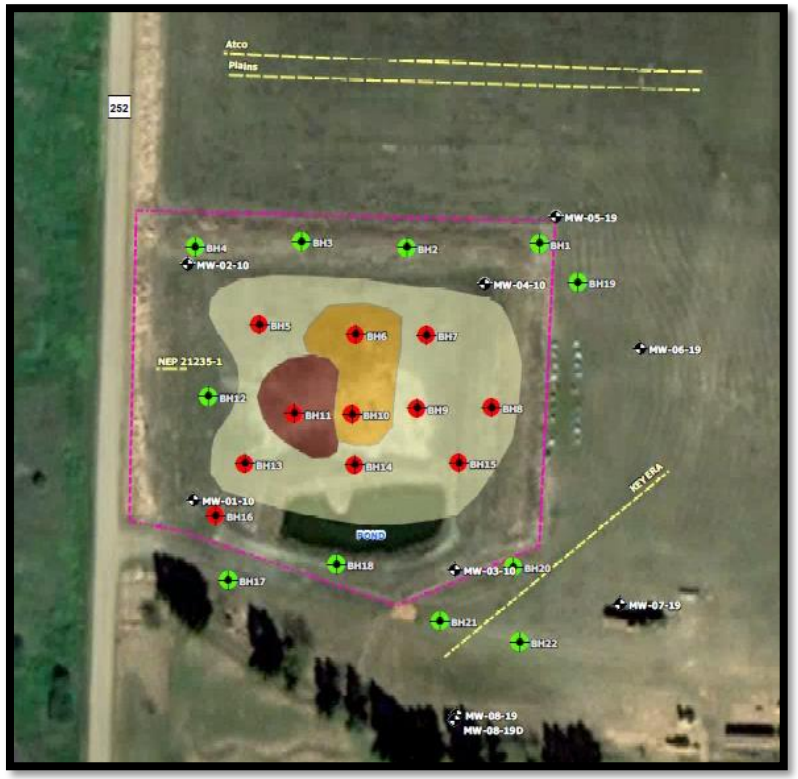
2015 EM38 (<1.5m)



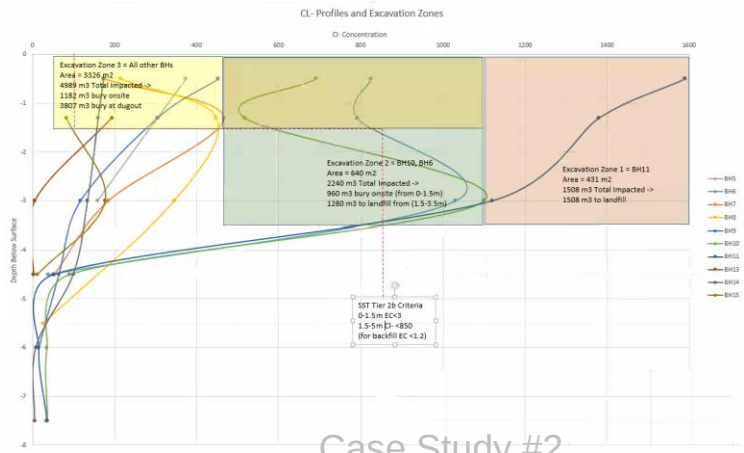
2015 EM31 (<5-6m)



2018 Soil Sampling

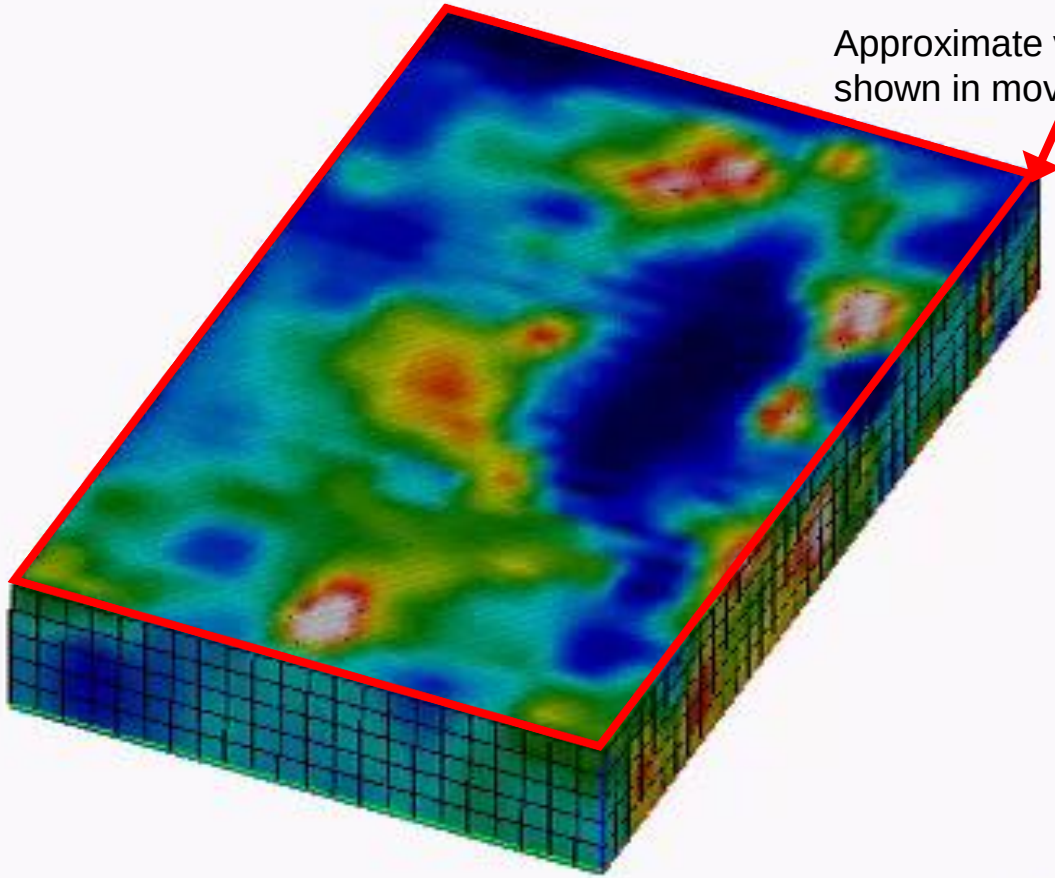


Based on BH logs, sample depths, and splitting impacted area between clean and impacted BHs, **Volume Estimate = 8737 m³**

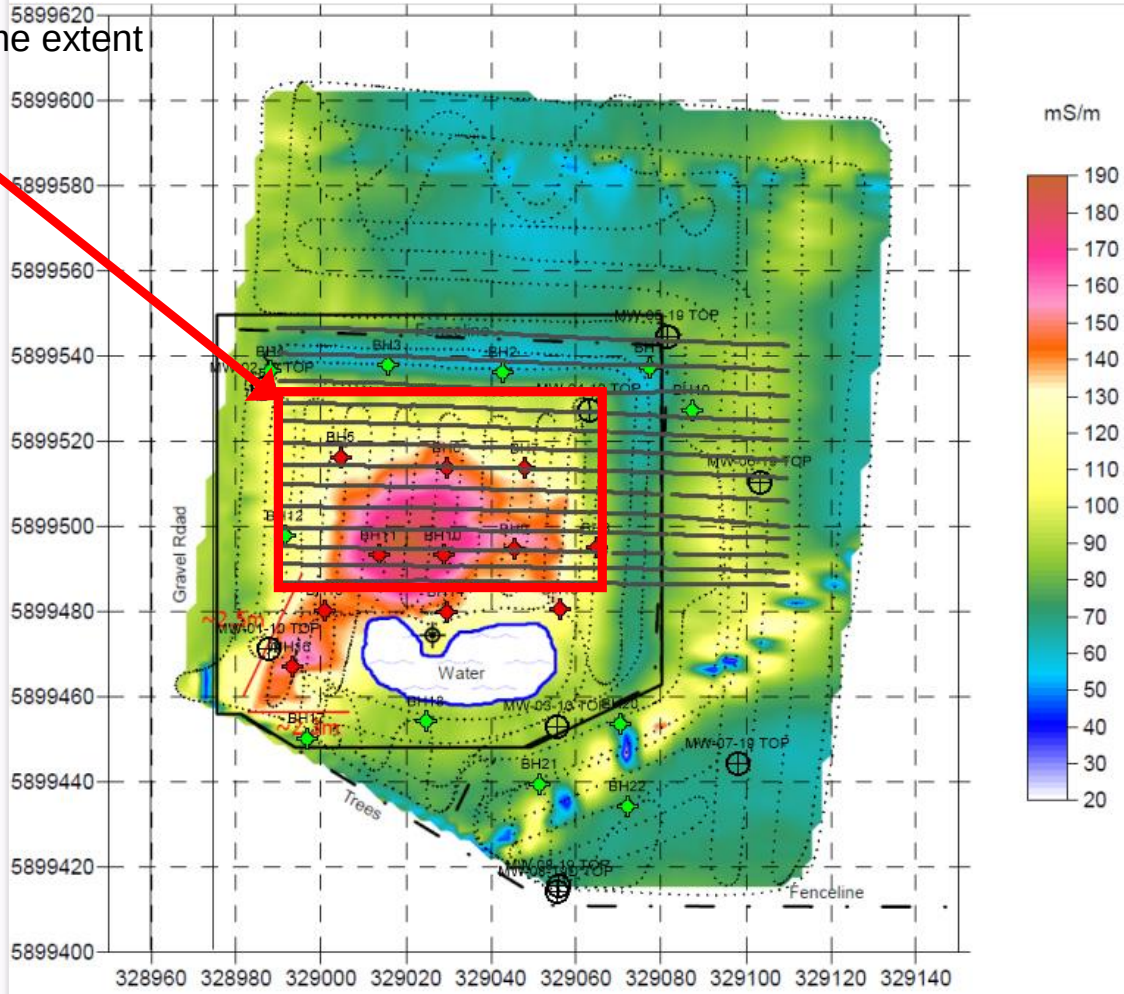


RCV – RAPID CONDUCTIVITY VOLUME

OHMMAPPER – CAPACITIVELY COUPLED RESISTIVITY



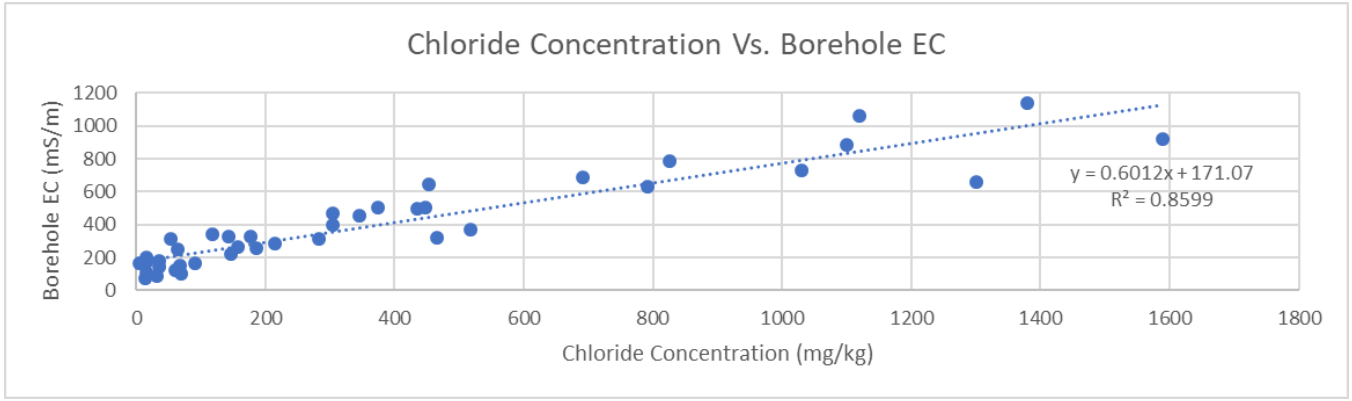
Approximate volume extent shown in movie

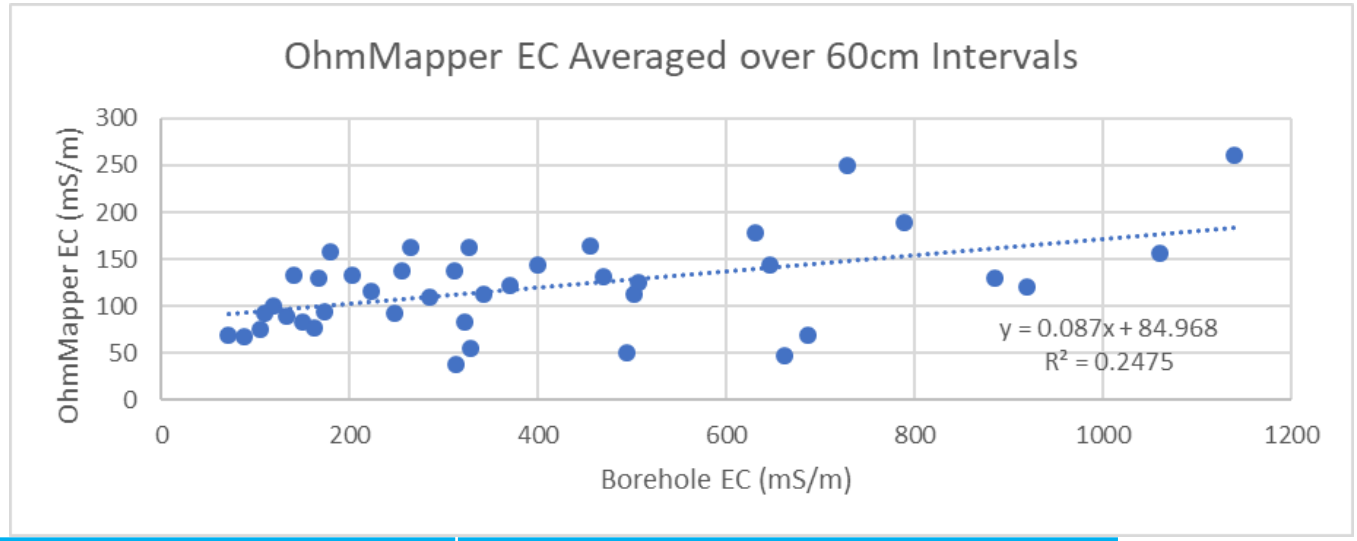


- 13 lines, two passes.
- One day of acquisition.
- One person.

GEOPHYSICAL VOLUME RESULTS – Case Study #2

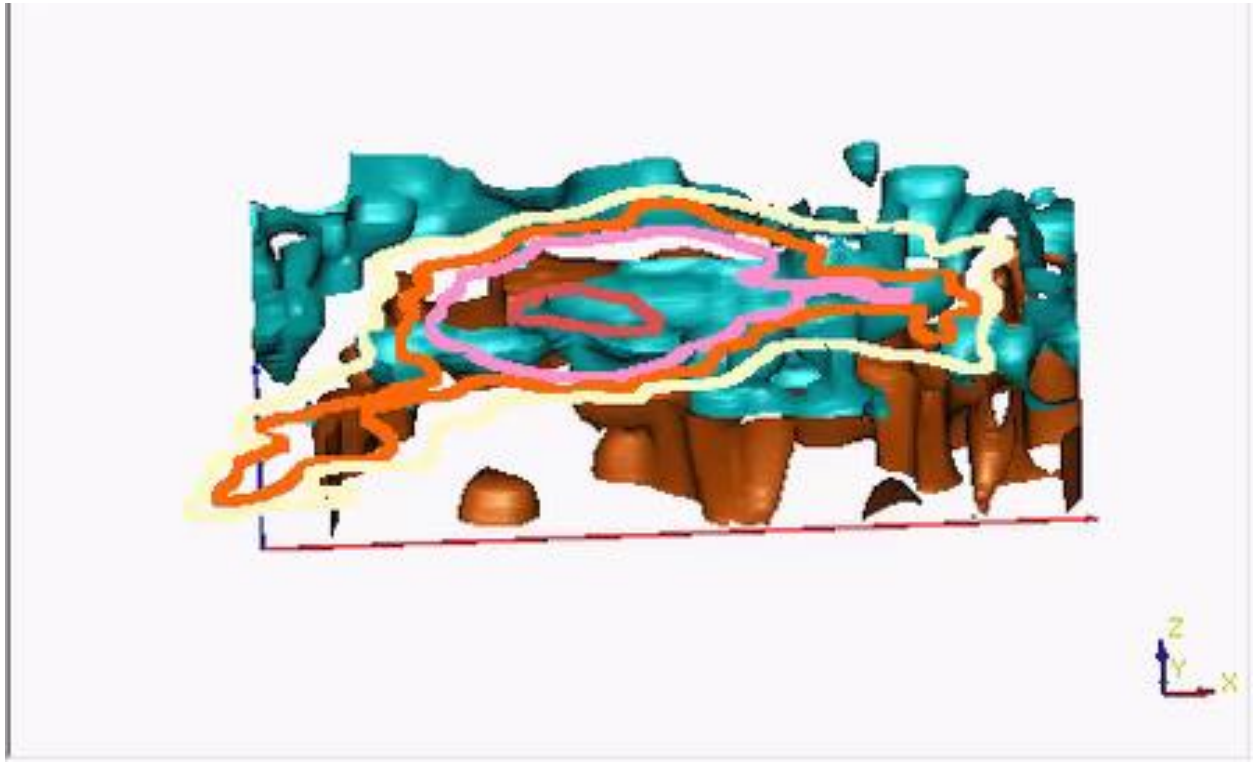
- Plot Chlorides vs. Borehole EC (Plot 1)
  - Take EC at Chloride concentration defined by SST
    - **200mg/kg** from 0 to 1.5m depth **= 291mS/m**
    - **930mg/kg** from 1.5m to 3.5m depth **= 730mS/m**
- Correlate OhmMapper EC values from RCV data to EC at borehole locations (Plot 2).
  - Averaged over 60cm intervals centred on Borehole measurement points.
  - Take OhmMapper EC at related Borehole EC
    - Borehole EC **291mS/m** → OhmMapper EC **110mS/m**
    - Borehole EC **730mS/m** → OhmMapper EC **148mS/m**

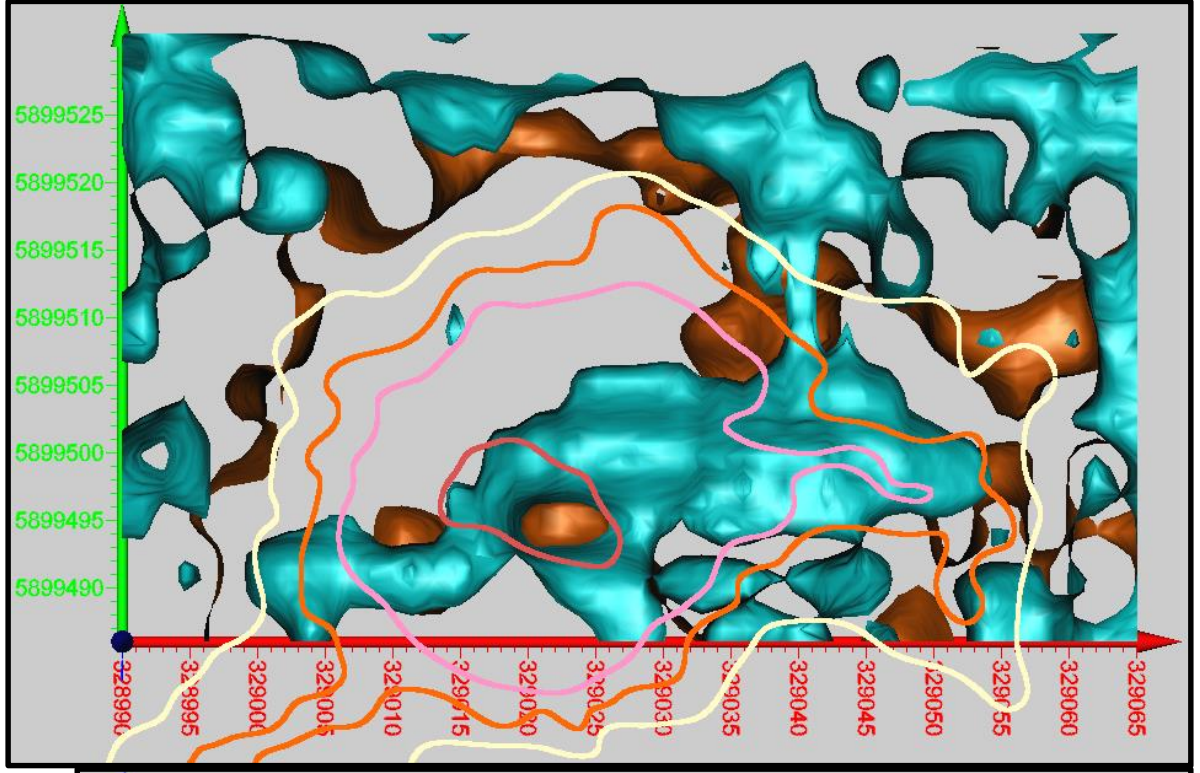


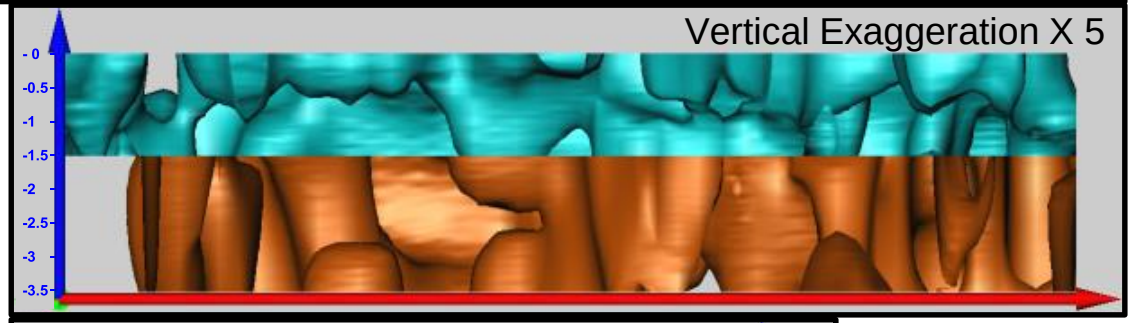


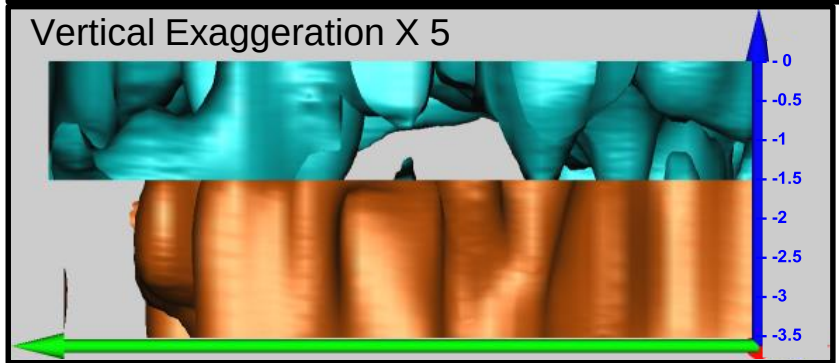
Chloride Concentration within specified Depth range	Iso-Surface Value Correlating to Chloride Concentration	Volume within Iso-Surface down to specified depth
200mg/kg from 0 to 1.5m depth	110mS/m	**3498m³**
930mg/kg from 1.5 to 3.5m depth	148mS/m	**2988m³**
Speculated Area South of Survey Extents from EM38 contour	842m² x 1.5m deep =	**1263m³** (See next slide)
	Total =	**7749m³**

GEOPHYSICAL VOLUME RESULTS – Case Study #2









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Speculated Area South of Survey Extents from EM38 contour	842m^2 x 1.5m deep = (See next slide)	**1263m^3**
	Total =	**7749m^3**

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Case Study #2

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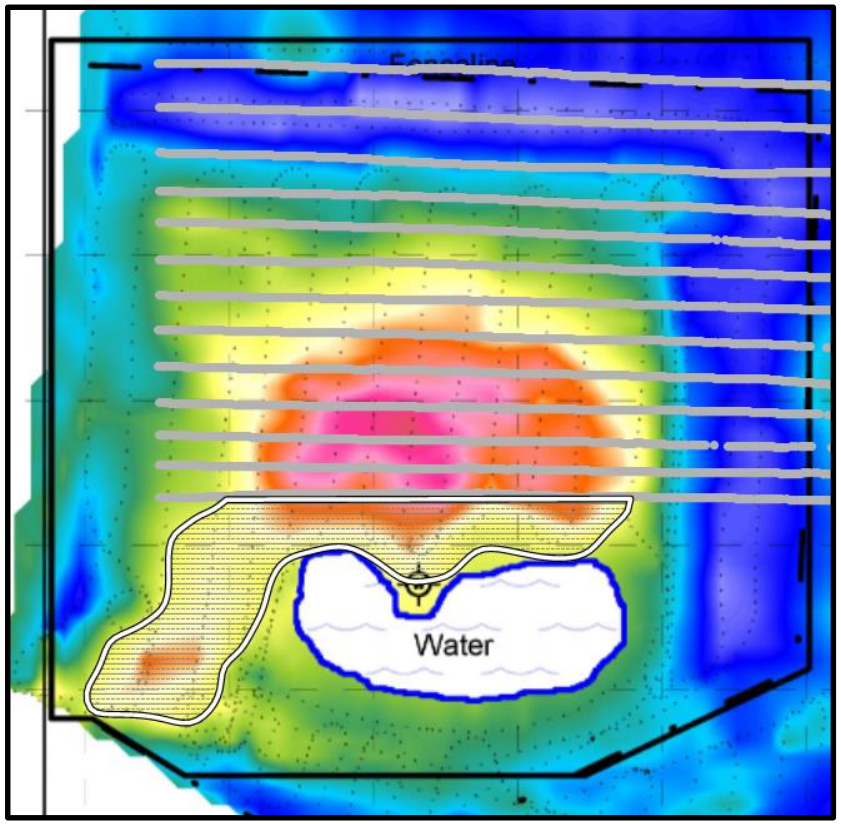
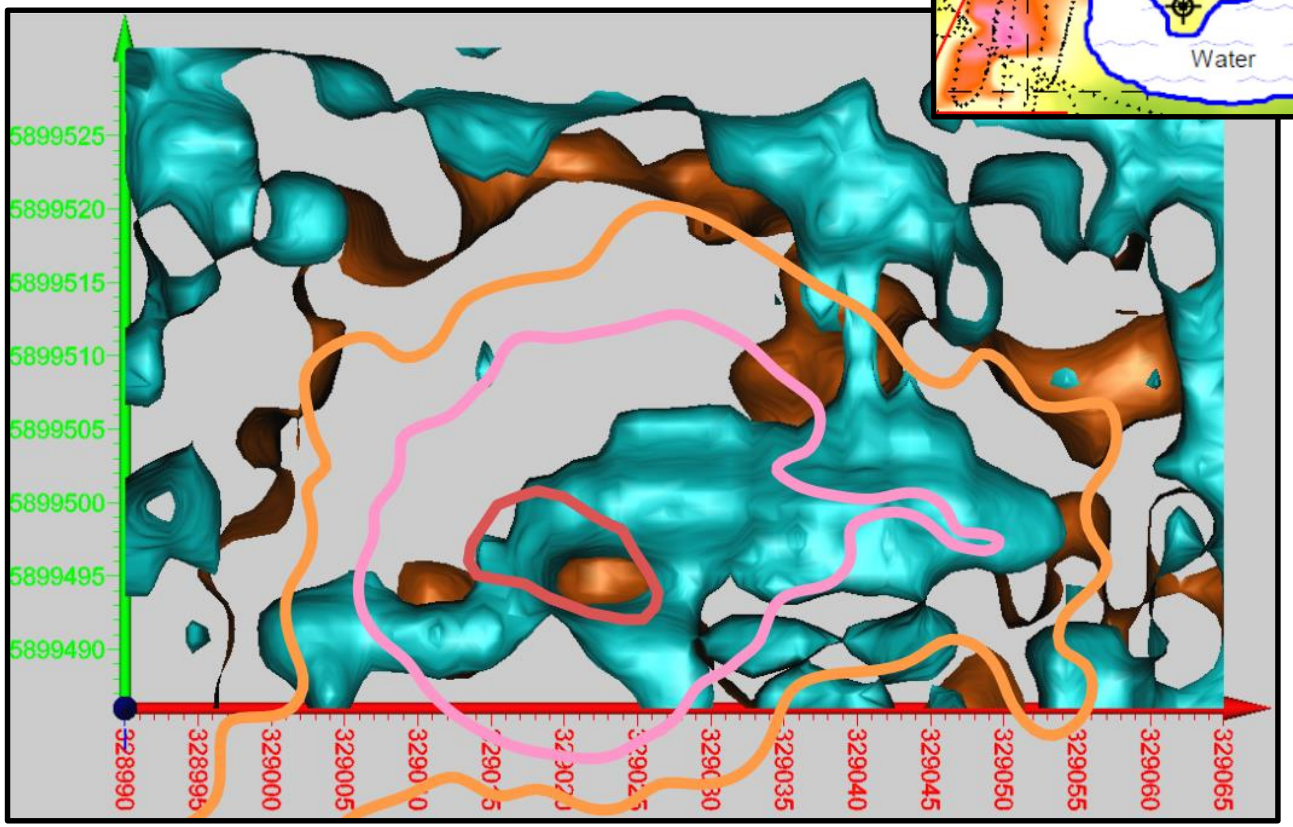
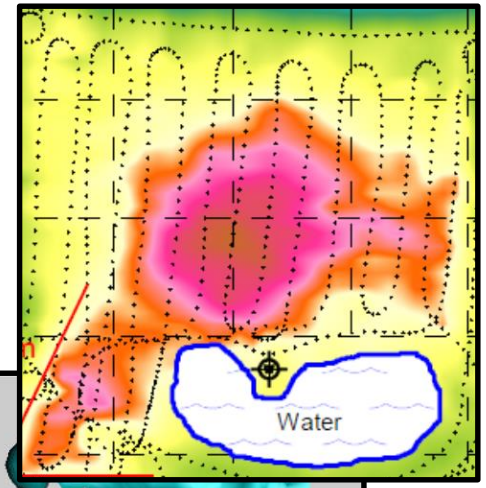
VOLUME COMPLICATIONS

- Available acquisition area for OhmMapper was limited
- Speculated additional upper volume down to 1.5m (White Contour).
  = 842m^2 x 1.5m = **1263m^3**



- OhmMapper Isosurfaces do not match the EM31 as closely when compared with Case Study #1.
- Possibly due to increased Sulphates in the soil.
- Discontinuous anomaly.





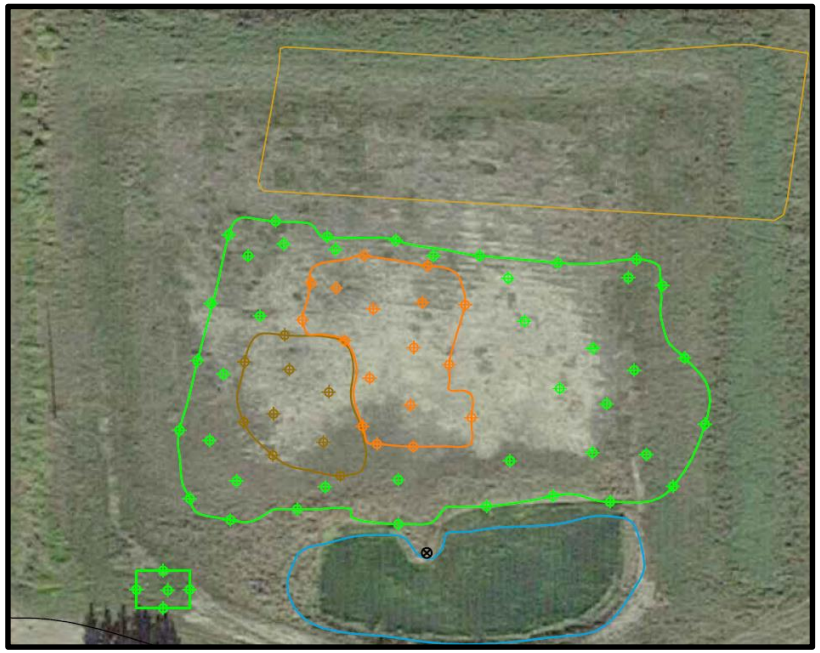
EXCAVATION

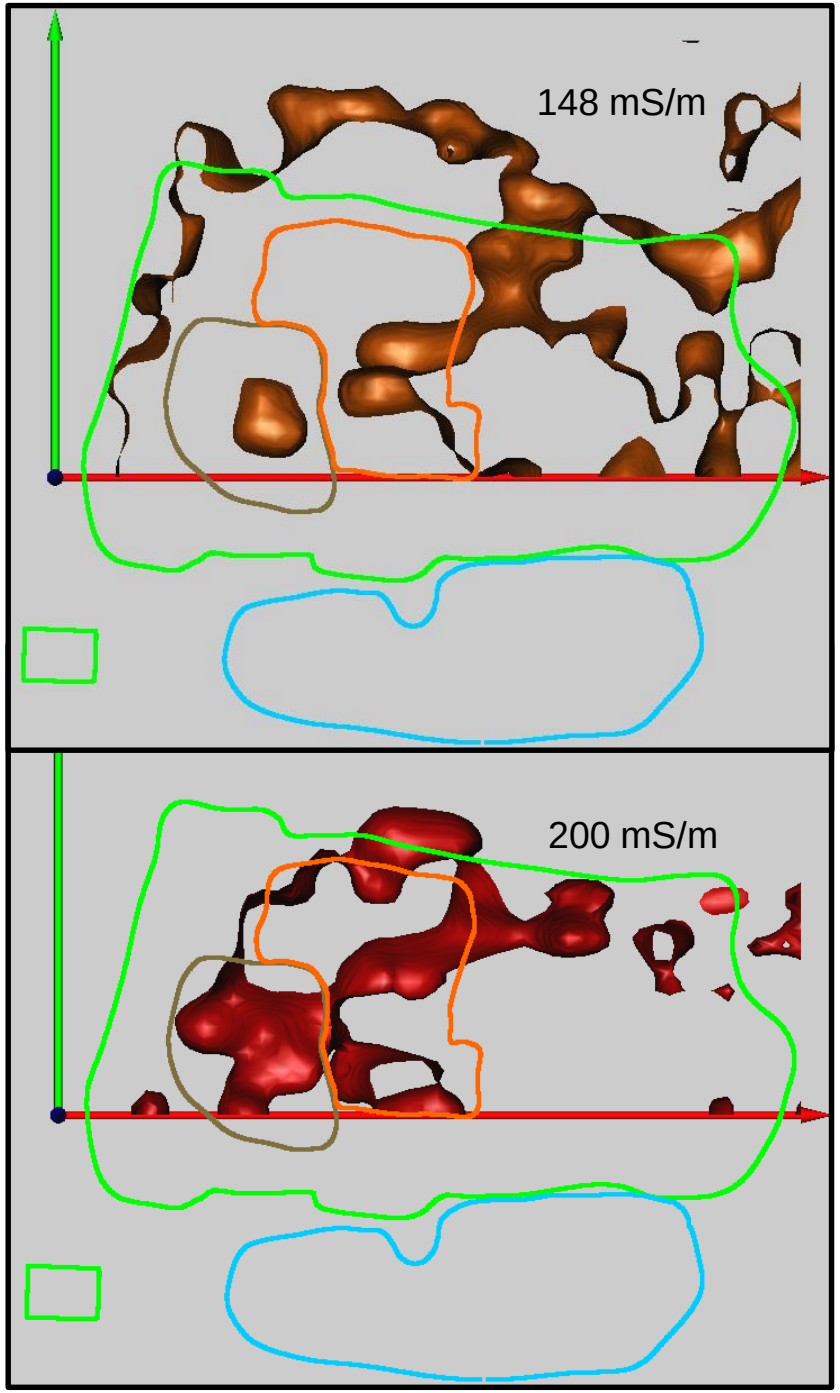
- Estimated impacted volume using traditional method = **8737 m^3**
- Estimated impacted volume using 3D conductivity data = **7749 m^3**
- Final Impacted soil Excavation Volume = **5375 m^3**
  - (2803 m^3 hauled to landfill, 2572 m^3 buried onsite).

- **~30% variance** between conductivity volume and final excavated volume.

Why didn't the volumes match?

- Relatively high Sulphates
- Higher background conductivity
  - Also impacts vertical delineation
- Chlorides not as high as Case Study #1
  - Contrast not as high
- Higher conductivity Isosurface (200mS/m) more accurately outlines deeper impacts.
  - Supports artificially higher conductivities from other ions.





Conclusions / Learnings

- Case Study #1 **~4% Variance**
- Case Study #2 **~30% Variance**

- Site access is a concern (minimal fences, berms, ponds, and infrastructure that can create errors).
  - Choose appropriate method: ERI or OhmMapper
- More data from within the impacted area and overall will aid in model calibration.
- More accurate with higher contrast of impacts compared to background increases model certainty.
- High SAR (driven by $NaSO_4$) might add interference to measured resistivity, overestimating volumes.

QUESTIONS?

Thank you!!!

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