

Environmental Geophysics to Investigate the 3-D Extent of Subsurface Brine Plumes at a Decommissioned Brine Pond near Hughenden, Alberta

Sean T. Clarke, P.Geoph. and L. M. Drummond, Essis Ltd

Abstract

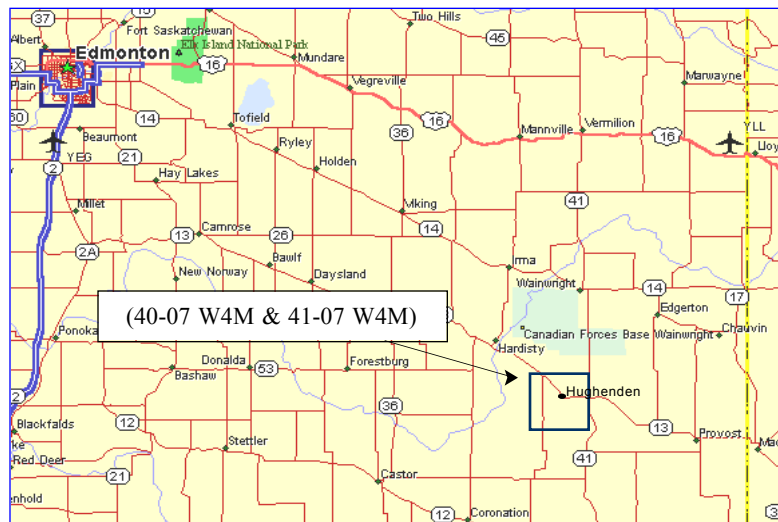
Alkali Lake served as washout disposal from salt caverns in the early 1950's. Set in an environment of buried sand channels, the former brine pond appeared as the likely source of elevated chlorides discovered in distant groundwater wells. A geophysical survey commenced in the winter of 2002 in preparation for a subsequent hydrogeological assessment. The objective of the survey was to delineate lateral and vertical extents of possible chloride plumes from Alkali Lake with high accuracy and acquisition efficiency. The Geonics EM34 (EM induction) was used to delineate the lateral extent of affected soils. The direct-push Geoprobe SC400 (Wenner-Array AC injection) determined the vertical extent of EM identified targets to depths of approximately 30 m.

An area of approximately 14 km x 2 km was surveyed with the EM34 at 200 m line spacing. Lateral closure was achieved on all anomalous trends, enabling the differentiation of naturally saline trends from possible chloride plumes. Two vertical conductivity profiles were targeted across possible chloride plumes. Anomalous conductivities were identified to near 30 m depth yielding response magnitudes typical of very high chloride concentrations.

1. INTRODUCTION

This report describes an environmental imaging (EI) investigation carried out under contract to Alberta Environmental Protection of Red Deer, Alberta. The survey was carried out from March 17th to March 30th of 2002 at a decommissioned brine pond near Hughenden, Alberta (40-07 W4M and 41-07 W4M, Figure 1). The survey objective was to delineate subsurface ion (chloride) occurrences on site.

FIGURE 1: Survey Area



2. ENVIRONMENTAL IMAGING (EI) - DATA ACQUISITION

EI refers to the imaging of the subsurface for anomalous environmental conditions. Various tools are applicable to this process, each of unique capability and purpose. This section describes the tools used to image environmental subsurface conditions on site.

2.1 LATERAL CONDUCTIVITY (GEONICS EM34)

The Geonics EM34 uses electromagnetic (EM) inductive forces to delineate subsurface conductivities. The instrument is digitally synchronized to differentially corrected GPS (DGPS). This arrangement allows positioning and geophysical data to be stored simultaneously on handheld dataloggers. Data are acquired swiftly at high sampling density. Two EM34 readings were taken at each measurement station. The first measurement was taken in the 'EM34 – Horizontal Dipoles at 40 m Spacing' and the second was taken in the 'EM34 - Vertical Dipoles at 40 m Spacing' mode. These two operational modes approximate averaged measurements from surface to 20 and 40 m depths, respectively.

Measurements in the 'EM34 - Vertical Dipoles at 40 m Spacing' mode are prone to noise interference and measurement errors resulting from non-coplanar alignment of the receiver and transmitter coils. Generally speaking, data gathered at vertical dipole orientations are not as reliable as data gathered in horizontal dipole orientations.

Please note that an inherent property of EM signals prevents deep penetration into conductive media. Tabulated depths of penetration are skindepths of the penetrating EM signal and are a function, in part, of overall soil conductivity (conductive soil reduces depth-of-penetration). The various coil orientations are not used to delineate the depth-extent of contamination but rather the depth-onset of contamination.

2.2 VERTICAL CONDUCTIVITY (GEOPROBE SC400)

The Geoprobe SC400 uses alternating current (AC) injection to measure the vertical (depth) distribution of subsurface conductivities. The instrument is driven to depth using the Geoprobe 6600 direct-push. Measurements are digitally recorded at 1.5 cm interval with an approximate resolution of 5 cm. Vertical conductivity data were obtained to varying depths until vertical conductivity closure was achieved for each sounding or until refusal was met.

Vertical resolution refers to the smallest identifiable stratigraphic thickness and is a function of the thickness-conductivity product of individual stratigraphic layers. In other words, a thin stratigraphic unit is mappable only if it possesses large conductivity contrast. A thick stratigraphic unit is mappable with less conductivity contrast. As with most electrical techniques, conductive responses tend to predominate in regions of mixed conductivity. For example, in buried pits containing chlorides (conductive) and hydrocarbons (resistive), chlorides tend to prevail and cause conductive responses over resistive hydrocarbons.

2.3 DGPS Positioning (Trimble Pathfinder Power)

Site feature data were differentially corrected using Hinton, Alberta base station data. Site feature data were post-processed using specialized software (Trimble Pathfinder Office). Positioning accuracies in the several decimeters range are generally possible. Site features, vertical conductivity stations and borehole locations have been surveyed on site and serve as reference markings for follow-up work.

2.4 SOIL CORING (GEOPROBE 6600)

The Geoprobe 6600 collects continuous or discrete soil core in 4 ft. clear PVC liners. The Geoprobe 6600 uses static weight of the carrier vehicle in combination with 34,000 lbs. of percussion force to achieve undisturbed penetration. The Geoprobe 6600 cannot bore through large rocks, but under normal soil conditions can achieve penetration depths of up to 30 m. In western Canadian soils effective core tube recovery is achieved to maximum depths of approximately 9 m.

In-field examination of continuous core is a valuable component of EI. Clean core enables correlation to geophysical results. Further, high-quality core may yield results in environments where geophysical techniques are not effective (e.g. for the delineation of geophysically unresponsive hydrocarbons). Core was gathered at one location (Bh1) to 4 m depth to coincide with vertical conductivity data.

3. ENVIRONMENTAL IMAGING (EI) - DATA PROCESSING AND PRESENTATION

EI data processing was initiated infield and completed at headquarters. Data processing was designed to enhance results by carefully applying specific mathematical algorithms. Such algorithms may filter unwanted data, enhance trend continuity or highlight otherwise unclear or invisible data.

EM34 data were processed to moderate responses from buried metals or powerline interference. Additional data processing enhanced trend continuity and amplified hidden anomalies. Key data processing parameters are tabulated to enable future data processing repeatability. An aerial photograph mosaic underlay is included on the maps to improve feature location during follow-up work. The photographic underlay is dated May 1998. As the underlay exhibits focal distortion and does not display current site features, the DGPS surveyed features should be used for referencing field locations.

Vertical conductivity data were checked for random noise spikes and combined to form a complete profile data set. The profiles target regions across EM-identified zones. Data were imaged and enhanced to reveal trace-to-trace trend continuity. Key data processing parameters are tabulated to enable future data processing repeatability.

Specialized processing software by Trimble Navigation incorporated Hinton, Alberta base

station data to differentially correct rover positions (correction for ionospheric effects). Due to the large site dimension and the large footprint of the EM34, EM data were not differentially corrected (since the EM34 measures a half-sphere of soil with an approximate 60 m diameter surface footprint, a positioning error of less than 5 m for that measurement is negligible).

PDOP (Positional Dilution of Precision) was consistently below 2.8. PDOP is a statistical measure of positional accuracy related to satellite geometry relative to the receiver. In general, PDOP values in excess of five suggest somewhat more inaccurate positioning. Map UTM coordinates were projected in NAD83.

4. ANALYSIS

Maps 1/3 and 2/3 are titled 'Lateral Conductivity Distribution (EM34 - 20/40 m Depth) and Regional Features'. The colour images represent the lateral conductivity distribution on site. Map 3/3 is titled 'Vertical Conductivity Profiles 1 & 2' and represents vertical conductivity distributions across EM-identified zones. Lab results from the posted borehole location (Bh1) should be correlated to all geophysical data. The combined interpretation of all data ensures a comprehensive understanding of site conditions.

Data are presented in UTM coordinates and projected in NAD83. The UTM grid coordinate system displays in units of metres (as opposed to degrees) and allows distance measurements to be read directly off the maps. UTM X and Y grid lines (the fine vertical and horizontal lines on the maps) are spaced 500 m apart. Site features, vertical conductivity stations and borehole locations have been DGPS surveyed and are included on the maps to provide reference control during follow-up work.

Lateral conductivity can also be referred to as apparent conductivity. Apparent conductivity approximates the bulk conductivity from surface to skindepth of the primary EM field. Generally speaking, frequency-domain EM techniques are poor at yielding conductivity depth information.

Conductivities vary in response to differing soil types. Dry accumulations of sand or gravel typically yield low responses while naturally occurring ions, fertilized, fine-grained and/or saturated soils yield elevated backgrounds. Elevated backgrounds can match magnitudes typical of ion-contaminated regions. In such scenarios, trend behaviour of the anomalous zone may suggest the cause of anomalous conductivities (for example, if an anomalous conductivity trend appears migrating from an old flare pit, this trend most likely corresponds to salt contamination). Lab results of targeted core from within anomalous regions (hot colours) should reveal the cause of anomalous responses. Similarly, lab results of core from outside anomalous regions (cold colours) should reveal the nature of background responses.

Metallic and ionic responses can often be distinguished by interpreting their characteristic behaviour. Such behaviour is a function of geometric coupling between the instrument and buried metal. Buried metal is easily identified when geometric coupling is maximized (for example, when surveying perpendicularly across pipelines). Consequently, buried metal is not always

identified when coupling is minimized (for example, when surveying parallel to pipelines). Please note that while the EM 34 responds to buried metal, this tool is not specifically designed to map buried metals.

The possibility of ionic contamination increases from dark blue (cold colours) to dark red (hot colours). Regions that have been surveyed (as revealed by the presence of geophysical measurement stations, dark crosses) and are not coloured (but appear clear) can also be presumed background. Colour (blue) was omitted to ease viewing of black site features and the aerial photo underlay.

In general, Maps 1/3 and 2/3 reveal similar conductivity responses. Typically, the different EM coil orientations yield similar responses primarily due to skindepth principles. A shallow conductor (contaminant) will reduce the depth to which an EM signal can penetrate; practically, a deeper-imaging tool may not be imaging as deep as initially thought. Further, as apparent conductivities are summed responses from surface to various skindepths, a shallow conductor tends to be visible by shallower and deeper-imaging coil orientations. EM tools with different depth-imaging capabilities should be used to determine the depth onset of conductors rather than the depth extent. A knowledgeable field operator is usually capable of choosing the appropriate tool for different site conditions.

When comparing EM surveys to previously conducted surveys, it should be noted that seasonal changes (e.g. frozen ground conditions) have effects on measurement magnitudes. It is common, but not necessary, for comparison surveys to be executed during the same season.

Map 1/3 exhibits higher conductivities than Map 2/3, suggesting ionic contamination in the surface to 20 m range rather than the surface to 40 m range. Due to the inherent sensitivity of the EM34 in the vertical dipole mode (Map 2/3) to 60 Hz noise and the need for very good coplanar alignment of the receiver and transmitter coils, data can be somewhat unreliable. If possible, Map 1/3 should be used over Map 2/3 during the interpretation.

Map 1/3 reveals conductivities exceeding 250 mS/m within the brine pond. An anomalous conductivity trend appears migrating from the pond towards the southeast for approximately 2.5 km. This trend ends by the Bonavista Amisk Battery (near 5814500N, 504250E). Vertical conductivity data were obtained along this trend and support the possibility of ionic contamination. Attempts to better define the southeastern end of this trend with the EM34 were unsuccessful due to significant powerline interference from nearby oilfield facilities. A 'region of excessive noise interference' is outlined on Maps 1/3 and 2/3, which unluckily coincides with the end of the high conductivity trend.

A second anomalous conductivity zone appears trending from the brine pond toward the northeast. This trend is approximately 1 km long crossing Highway 13 and ending near the pond at approximately (5817200N, 502750E). Vertical conductivity data were obtained along this trend and suggest ionic contamination.

A third anomalous conductivity trend suggests migration from the brine pond northwest into

the nearby lake. Conductivity readings between the brine pond and lake reached approximately 70 mS/m, an amplitude easily matched by natural soil salinity. Vertical conductivity Trace VC2 has been positioned to help identify the cause of elevated conductivity in this region.

Hughenden Lake appears highly elevated in conductivity. Readings as high as 308 mS/m were recorded, an EM34 amplitude rarely matched by natural salinity. Trace VC13 and targeted borehole Bh1 were positioned to identify the cause of elevated conductivities in Hughenden Lake. Lab results from Bh1 could play a key role in any future groundwater work. Should results indicate the occurrence of unusually high sulfates (probably in the order of 10000 ppm to match an equivalent EM34 reading of above 300 mS/m) then natural salinity must be factored into the interpretation of the geophysical findings. Lab results indicating the absence of sulfates, but presence of chlorides, would suggest chloride migration from the brine pond to the northwest at great depths (below EM34 reach).

Map 3/3 reveals the vertical conductivity distribution across EM identified trends. Measurements are made at 1.5 cm increment with a vertical resolution of approximately 5 cm. Absolute conductivities on Map 3/3 are more 'reliable' than those exhibited on Maps 1/3 and 2/3. Differences in absolute conductivity arise since, generally speaking, data are derived from different geophysical methods (EM induction versus AC current injection). The two tools differ in EM footprint (the technical term for the volume of soil measured with each reading) and exhibit different system linearity responses. Interpretation should reflect on relative conductivity trends rather than absolute magnitudes.

The map is horizontally scaled at (1:4000) and vertically at (1:200), presenting a vertical exaggeration of (20:1). Distances and depths are posted in metres. Station-to-station separations have been accurately calculated and are direct (straight-line) distances between each station pair. As DGPS systems in standard operating mode typically yield poor vertical accuracy, conductivity station locations are posted only with field-estimated vertical control.

The possibility of ion occurrence increases in dark red regions. Dense hydrocarbon accumulations or dry sand often cause very low readings ranging from 0 to 50 mS/m. In general, dry and coarse-grained soils (gravel, sand, etc.) yield low conductivities. Saturated and fine-grained soils (clay, silt, etc.) cause elevated conductivities. Ion enriched soils usually yield very high conductivities.

Zero-depth of each vertical conductivity trace coincides with the soil-probe electrodes being halfway submerged into soil; two electrodes make soil contact, while the other two remain above ground. Initial conductivity readings gradually increase from zero at surface to the actual soil conductivity value at approximately 10 cm depth. The resulting vertical conductivity images appear blue (or white, depending on processing parameters) for the initial 10 cm, unless measurements were initiated with full-submersion of the soil conductivity probe (e.g. probing in muskeg conditions). Frozen ground will also reduce conductivity responses, typically affecting readings in the initial half-meter of soil.

Profile 1 runs northwest-southeast across the EM-identified conductivity trend from the brine pond toward the Bonavista Amisk Battery. Profile 2 runs south-northeast perpendicularly across Profile 1 targeting the conductivity trend from the brine pond toward the northeast. Profiles 1 and 2 are 4.9 km and 2.1 km long respectively.

Traces VC13 and VC12 were not incorporated into any profiles but are posted as standalone traces in Figures 1a and 1b. Targeted borehole Bh1 was strategically located to ground-truth anomalous responses for Trace VC13.

Profile 1 comprises seven vertical conductivity traces. Trace VC3 was located at the northern edge of the brine pond. Vertical closure was achieved at approximately 20 m depth. Conductivities reached 2800 mS/m, an amplitude strongly suggestive of ionic contamination. Pushing the conductivity probe through salt-sludge of the lake surface caused the initial conductivity spike near 2500 mS/m.

Trace VC6 continues the vertical conductivity trend from Trace VC3 toward the southeast. Anomalous conductivities start at approximately 7.5 m depth reaching amplitudes near 700 mS/m. An abrupt increase in conductivity appears near 16 m depth to 2500 mS/m. This boundary might indicate the start of the groundwater table (saturated salts are more conductive than dry ones) or perhaps an increase in conductivity caused by gravitational effects increasing ionic concentrations at depth. In any case, Trace VC6 continues the extreme vertical conductivity trend initiated by Trace VC3.

Trace VC9 reveals an anomalous conductivity zone from approximately 7 to 14 m. Amplitudes reach 2500 mS/m. Trace VC9 continues the vertical conductivity trend of Traces VC3 and VC6. Closure is achieved at approximately 14 m depth. Trace VC10 reveals the anomalous conductivity zone of 2500 mS/m at greater depth from approximately 17 to 28 m. Weaknesses in the interpolation routine cause the anomalous conductivity trend from Trace VC9 to VC10 to appear discontinuous. It should be noted that although vertical conductivity stations were not precisely level-surveyed for vertical control, Traces VC10 and VC9 did not appear to exhibit a 10 m elevation difference (the difference between the depth-onset of anomalous conductivity between Traces VC9 and VC10). Consequently, the rapid change in depth of anomalous response from VC9 to VC10 could indicate highly varying soil types (flowpaths) and hydraulic heads. Trace VC11 serves as background trace to the anomalous conductivity trend identified by Traces VC3, VC6, VC9 and VC10. Data were acquired to approximately 27 m depth to ensure vertical closure of the anomalous response (it is possible for ionic material to have seeped underneath Trace VC11).

Trace VC2 confirms the region of subtle elevated EM34 conductivity between the brine pond and the nearby small lake to the northwest. Slightly elevated conductivities (300 mS/m) from 4 m to 7 m depth could have caused the EM34 to respond slightly at that location (see Map 1/3). It is not clear if this slight increase in conductivity was of natural or man-made origin.

Profile 2 is made up of five vertical conductivity traces. Profiles 1 and 2 share Trace VC3 (profile intersection). At the southern edge of the brine pond, Trace VC4 yields vertical closure

of the anomalous conductivity zone identified by Trace VC3 at a comparatively shallow 10 m depth. Trace VC5 reaches deeper than Trace VC4 to approximately 11 m depth. Revealing background conductivities to 11 m depth, Trace VC5 provides vertical closure of the anomalous response south of the brine pond.

Trace VC7 was positioned to vertically delineate the conductivity trend northeast across Highway 13 from the brine pond. VC7 exhibits typical chloride behaviour and reaches maximum conductivity responses near 1400 mS/m from 2.5 to 11 m depth. Trace VC8 was positioned to close the anomalous response northeast of the brine pond. Conductivities remain within background range to a final depth of approximately 7.5 m.

Trace VC13 (Figure 1a) targets unusually high conductivities within Hughenden Lake. EM34 conductivities exceeding 200 mS/m are typically not caused by natural salinity. Similarly, Trace VC13 reveals maximum response amplitudes of approximately 1100 mS/m. Such magnitudes are equally unlikely to have been caused by natural salinity (as a rough guide, based on past experience, sulfates would have to be in the tens of thousands range to yield vertical conductivities near 1100 mS/m). Borehole Bh1 was located to coincide with Trace VC13 to 4 m depth. Lab results from Bh1 are very important in identifying the cause of high anomalous conductivities in this region.

Trace VC12 (Figure 1b) targets the subtle elevated EM34 conductivity trend (Map 1/3) from near the Bonavista Amisk Battery toward Shomcliffe Lake. Trace VC12 reveals background conductivities to a depth of approximately 11 m. A higher conductivity zone begins at 11 m depth reaching amplitudes of approximately 350 mS/m. It is possible for this slight increase in conductivity to have caused the slightly elevated EM34 response in this region (Map1/3). The 'blocky' or layered nature of this response suggests natural soil influences rather than chlorides.

5. CONCLUSIONS AND RECOMMENDATIONS

Lateral conductivity surveying (EM34) revealed numerous anomalous conductivity zones in the region. Possible ionic migration from the brine pond was identified toward the southeast, northeast and northwest. The most apparent conductivity trend extended from the brine pond toward the southeast for approximately 2.5 km. Lateral closure of all possible conductivity trends was achieved.

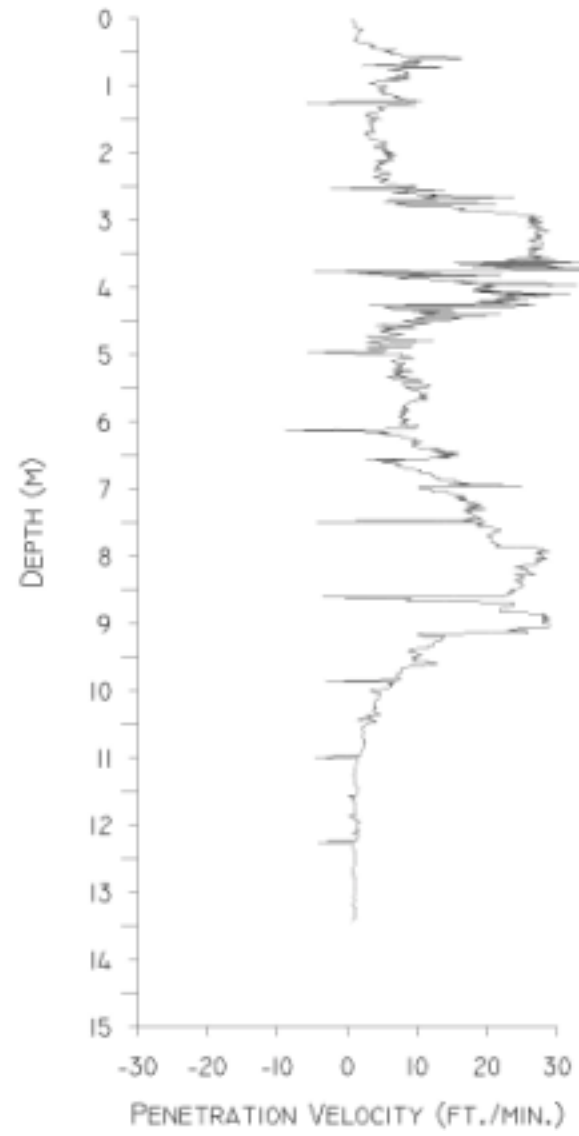
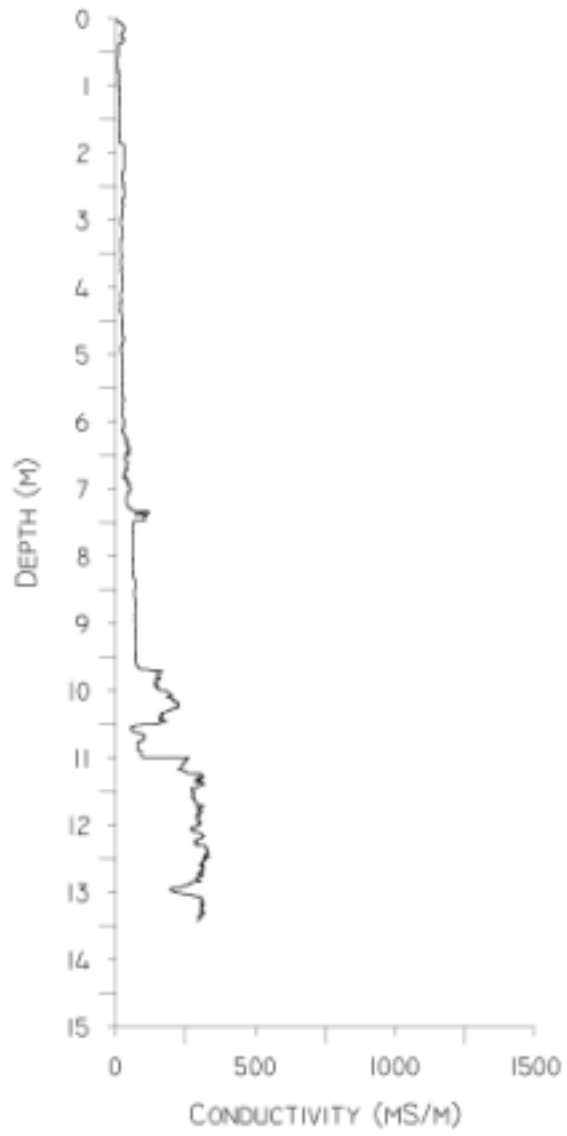
Vertical conductivity data were obtained to depths up to 30 m. Vertical conductivity responses correlated well to lateral conductivity responses (EM34) supporting the existence of and yielding accurate depth information on the three possible plume migrations from the brine pond. Vertical closure was achieved on all traces.

Vertical conductivity and penetration velocity data indicated deep anomalous responses, steep vertical flowpath gradients (based on trace to trace trend continuity) and highly varying soil types. These findings describe an environment that could support a multitude of complexly varying flowpaths. A danger exists that smaller conductive channels at greater depth (contaminant flowing through small, deep flowpaths) were not detected with the large footprint EM34.

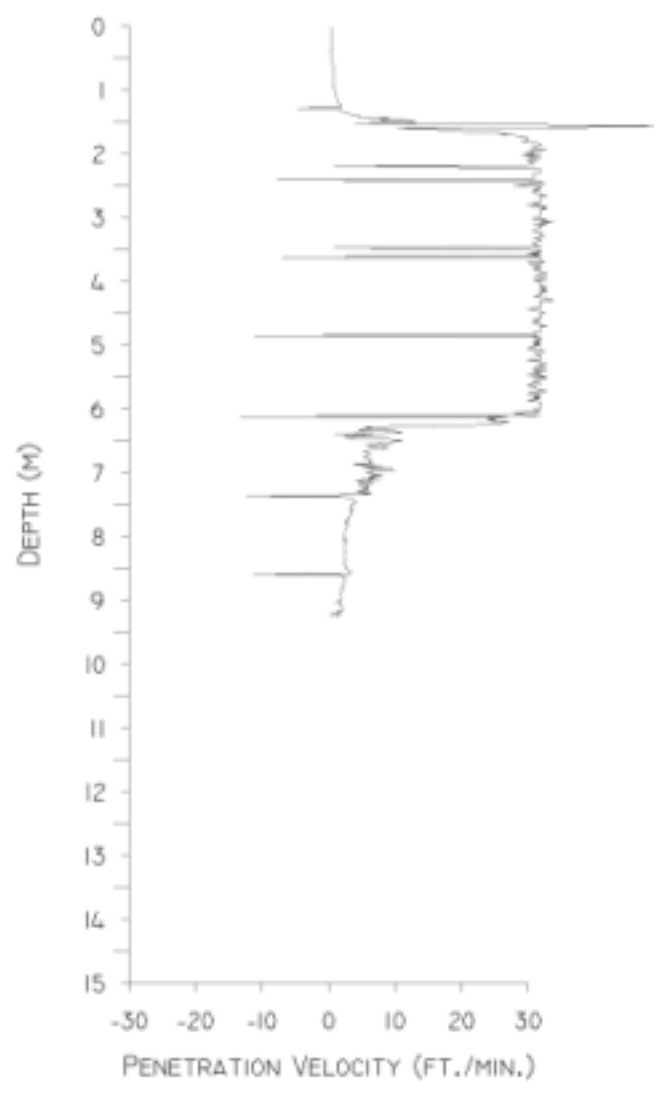
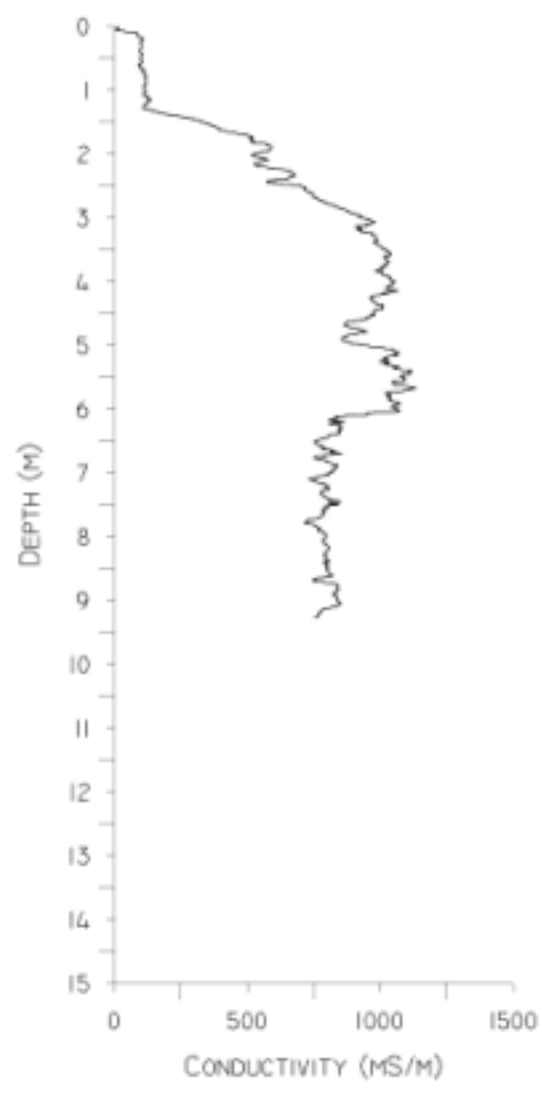
Hughenden Lake revealed unusually high conductivity responses. Vertical conductivity data and corresponding core was obtained from within Hughenden Lake to assist in determining the cause of unusually high anomalous conductivities in this region. All surrounding lakes and ponds (including Shomcliffe Lake) yielded elevated conductivities, further suggesting the possibility of natural salinity in the region.

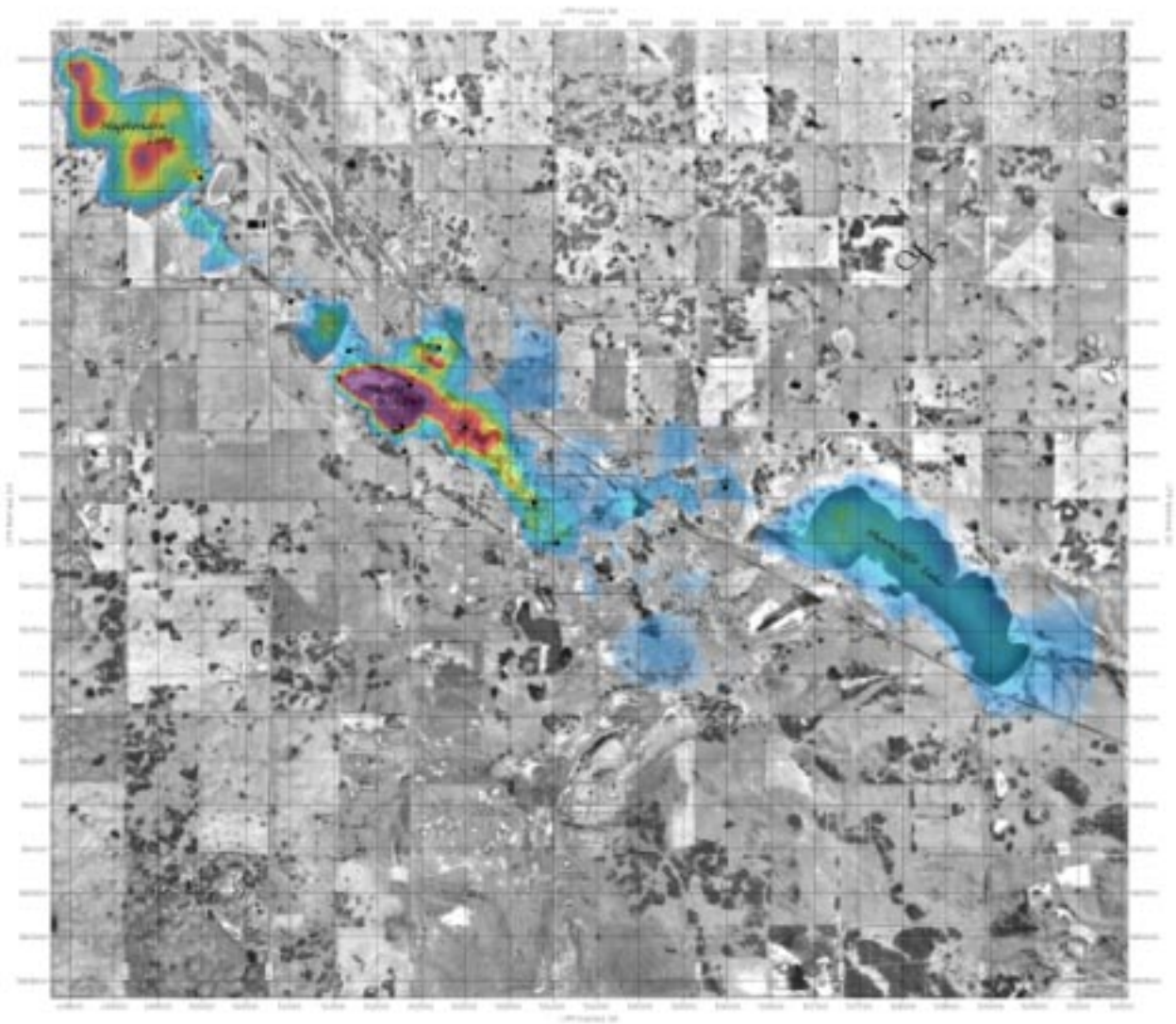
Future lab results should be correlated to all geophysical data. The combined interpretation of all data ensures a comprehensive understanding of site conditions.

TRACE VC12



TRACE VC13



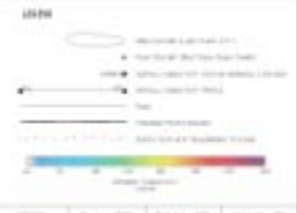


Summary

This report provides a summary of the lateral conductivity distribution (EMSL - 20m depth) and regional features. The data was collected using a ground-penetrating radar (GPR) system. The results show a complex pattern of conductivity, with high conductivity areas (red and purple) and lower conductivity areas (blue and green). The high conductivity areas are located in the north-west and south-east of the study area. The lower conductivity areas are located in the central and south-west of the study area.

Technical Details

Client:	Aberta
Project:	Aberta
Date:	2023-10-10
Scale:	1:1000
Author:	John Doe
Reviewer:	Jane Smith
Approved:	John Doe



LATERAL CONDUCTIVITY DISTRIBUTION (EMSL - 20m DEPTH) & REGIONAL FEATURES

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