A Novel Case Study on Achieving Site Closure - EM31 and Pseudo-3D OhmMapper Surveys, Calibrated with Physical Analytical Soil Data, to Create Impacted Soil Volume Estimates before Remediation

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EXTENDED ABSTRACT

1.0 INTRODUCTION

Volume estimation and three-dimensional mapping of salt-impacted soils is an integral part of both remediation and risk management activities in order to create accurate project budgets, alternative remedial options, and to properly characterize the site for risk management. This extended abstract reviews a case study documenting the process and final results after the combined acquisition and interpretation of novel geophysical survey data using innovative techniques for mapping chloride contaminated soils in the vicinity of a historical pipeline release. The integration of geophysical data from the OhmMapper and EM31 systems with borehole measured concentrations and conductivities enables quantifiable constraints for the geophysical data to be used. For this case study, a start to finish methodology can be recognized, highlighting impacted soil volume estimates compared to actual impacted soil volumes removed from site during a remedial excavation to achieve site closure.

2.0 SITE HISTORY

Contamination of the site occurred due to a pipeline break that released approximate volumes of 29 m^3 of crude oil and 75 m^3 of produced water. Immediate cleanup efforts resulted in the excavation of 1793.95 tons of impacted soil which was disposed of at an off-site facility.

The results of a previously conducted Phase 2 Environmental Site Assessment (ESA) showed that the spill area had elevated electrical conductivity (EC) and that the Sodium Absorption Ratio (SAR), Benzene, Toluene, Ethylbenzene, Xylenes (BTEX), and Petroleum Hydrocarbon (PHC) fraction F3 concentrations exceeded the regulatory guidelines. Analyses of soil samples were compared to the Alberta Environment and Parks (AEP) Tier 1 Soil and Groundwater Remediation Guidelines (SGRG). It was determined that 5775 m^3 of impacted soil may exist in the former spill area. The final extent of impact was not determined as part of this Phase 2 ESA.

The Site was re-assessed by the Owner in order to characterise the background and on-site soil chemistry. The results would be used to develop site-specific Tier 2A guidelines using the Subsoil Salinity Tool (SST). Additional boreholes were drilled and soil samples collected at specific depth intervals for the analysis of salinity parameters. A more traditional frequency domain electromagnetics (EM31) survey was conducted to target the drilling assessment. The volume of salinity impacted soil, as determined by this Phase 2 ESA, SST assessment, and EM31 survey was estimated 13600 m^3.

DMT Geosciences Ltd. and Pinchin Ltd. were then involved by the Owner to create a better model of the impacted plume. DMT Geosciences used EM31 and advanced pseudo-3D capacitively coupled resistivity (OhmMapper) surveys to create a better model.

3.0 GEOPHYSICAL INVESTIGATION METHODS

3.1 EM31 - Fixed Frequency Electromagnetic Method

The Geonics EM31 MKII conductivity meter was used to map variations in ground conductivity, which can be indicative of variations in Total Dissolved Solids (TDS). The system is a self-contained portable instrument that consists of a transmitter dipole that produces a primary field and a receiver dipole that measures secondary fields dependent on subsurface conditions. The ratio of the primary and secondary fields is related to ground conductivity. Apparent conductivity varies due to many factors including mineral composition (clays are of high electrical conductivity for example), variations in volume and concentration of TDS, presence of buried metal, and thermal state. The depth of exploration for the instrument is approximately 6 metres when the instrument is held near ground level. This depth will vary with ground conductivity, and will be reduced with increasing conductivity. The conductivity values obtained are bulk averages of conductivity from the surface to the depth of exploration, and sensitivity decreases with increased depth.

3.2 OhmMapper – Capacitively Coupled Resistivity

The OhmMapper, manufactured by Geometrics Inc., is a resistivity measurement system that generates electrical current flow in the subsurface through capacitive coupling rather than by direct current injection (i.e. galvanic coupling). The system consists of a transmitter, up to five receivers, a fibre optic isolator, and a data-logging console. Each receiver has a cable on either end creating a dipole to which the size equals the combined cable length on either side. The dipole lengths and transmitter-receiver separations can be varied in order to assess apparent resistivities at different depths. For this survey, 16 lines were acquired using 10 metre dipoles, each with two passes to increase vertical data density, which can provide a depth of investigation up to approximately 8 metres. The 16 lines were gridded together to create a pseudo-3D block of conductivity.

The system functions by imparting current to the subsurface by using the soils as the dielectric in a capacitive 'circuit' between the system and the subsurface. Voltages generated by the current flow in the sub-surface are sensed by the receiver dipoles and recorded by the data logger. While conventional electrical imaging systems (i.e. Electrical Resistivity Imaging, ERI) require the insertion of multiple stationary electrodes into the ground, the capacitively-coupled system is towed along the surface, which enables rapid data collection. Since 16 lines with two passes each were acquired, it equates to 32 lines acquired in a single day.

4.0 ADDITIONAL PHASE II ESA

EM31 and pseudo-3D OhmMapper data are first used to image the contaminated area and target for another intrusive Phase II Environmental Site Assessment (ESA). It was performed to fully delineate impacts vertically and horizontally and add groundwater data for a Tier 2B SGRG model. The Phase II ESA would create a vertical distribution profile of laboratory measured chloride and EC measurements at each borehole while also using additional data from previous assessments characterize the impact plume. Groundwater data included measurements of the chemical and physical characteristics of the shallow aquifer.

4.1 Tier 2B SGRG using the SST

The Tier 1 SGRG represents the most conservative guidelines which assume generic scenarios for a site with the presence of all receptors and exposure pathways relevant to its land use taken into consideration. Tier 2 SGRG are developed to consider site-specific conditions that allow for the adjustment of receptor and exposure pathways and model parameters if different from the Tier 1 SGRG assumptions. The Tier 2B guidelines for the Site were developed in accordance with the SST for salinity impacts at depths greater than 1.5 mbgs. These guidelines are developed on an ion-specific basis (primarily chloride), in the subsoil (>1.5 mbgs).

Examination of the analytical results from the borehole investigations in conjunction with the SST analysis identified significant differences in the magnitude and vertical distribution of chloride impacts across the salt-impacted area and as a result, the affected area was subdivided into four sub-areas, each with its own criteria.

5.0 GEOPHYSICAL RESULTS

Both ground conductivity datasets (EM31 and OhmMapper) agree when identifying the lateral extent of anomalous conductivity except the pseudo-3-D OhmMapper data additionally shows that the anomaly extends further to the northwest in the subsurface than the EM31 indicates.

To correlate the SST criteria to the OhmMapper survey results, the gridded OhmMapper data was first extracted at the borehole locations to enable comparison with the measured borehole values. The OhmMapper values were then split into depth increments equal to the intervals of the borehole measurements (50 centimetres) and averaged over the range to get a single conductivity value for each interval. EC have been assumed to be dominantly due to chlorides and so a relation between EC and chloride concentration from the borehole measurements can be made. The OhmMapper EC data has been split into similar ranges as the borehole data so that they can be more appropriately correlated to each other.

A pseudo 3-D block volume was created to construct iso-surfaces of conductivity values in the subsurface (Figure 1). Volumes were then calculated within 4 iso-surface values and depth ranges that were dictated by criteria from the SST used in the Tier 2A SGRG.

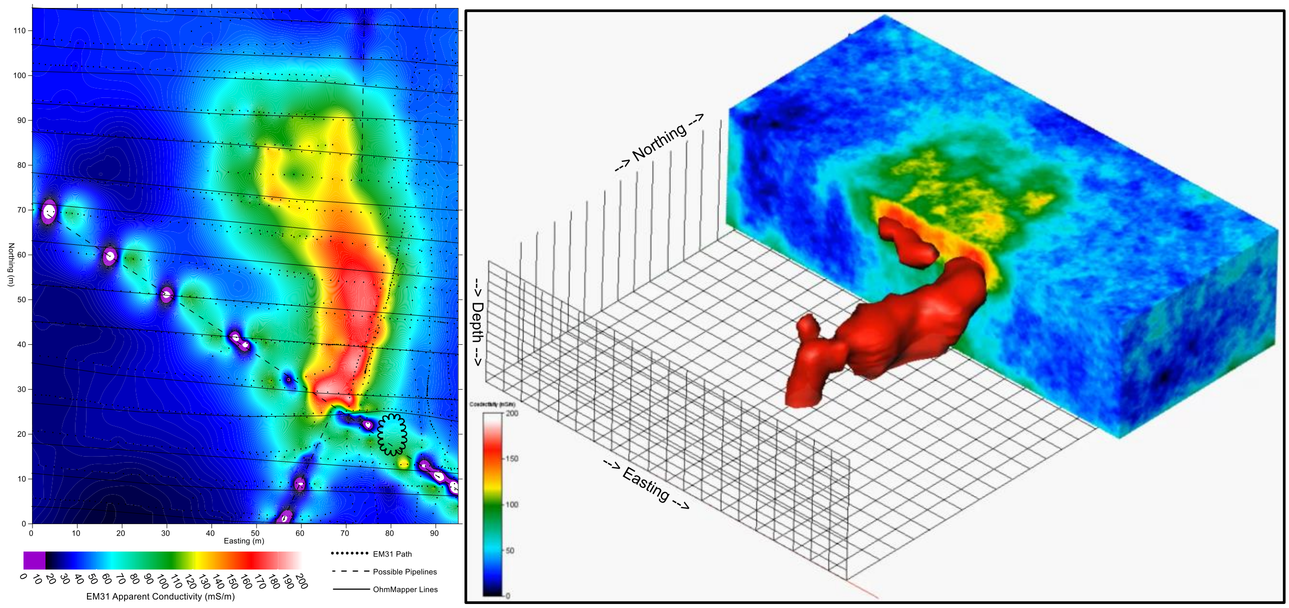

Figure 1: DMT Geosciences EM31 Survey (Left) and 3D Conductivity block created from OhmMapper lines (Right). Iso-surface of High conductivity shown in Red.

The total amount of material exceeding criteria values initially defined by the SST from the Tier 2A SGRG that was correlated to the OhmMapper was estimated at approximately 6170 m^3 but is likely overestimated due to the effect of the pipelines at the southern end of the anomaly on the OhmMapper data.

6.0 CONCLUSION

The remedial excavation targeted areas with analytical results that contained elevated EC and SAR measurements in excess of the Tier 1 SGRG and sub-area specific Tier 2B guidelines. An approximate volume of 5926 m^3 of affected soil was excavated as a result of the remediation program. Of that volume, approximately 5707 m^3 of impacted soil was transported to an approved disposal facility while 219 m^3 were deep buried at the Site in areas and at burial depths compliant to the Tier 2B guidelines.