PWGSC, Environmental Services Western Region

ISSUED FOR USE

# EUREKA HIGH ARCTIC WEATHER STATION
# GEOPHYSICAL INVESTIGATION
# EUREKA, NU

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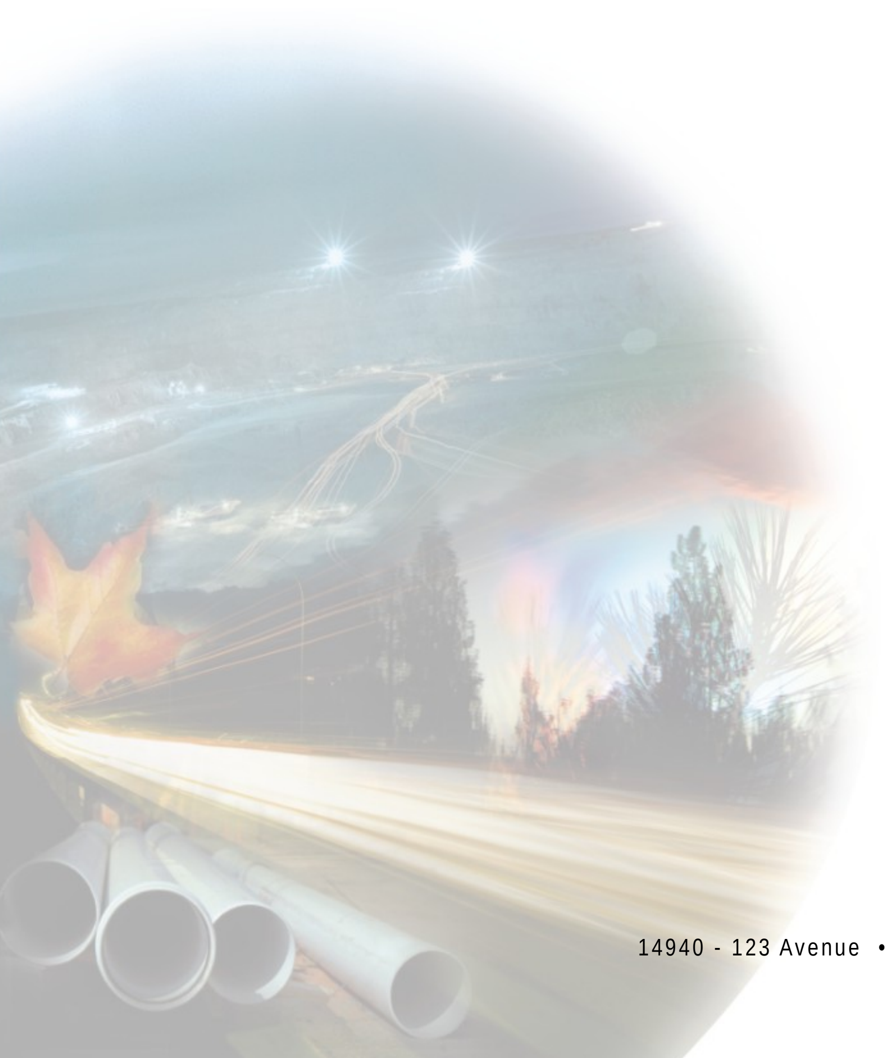

EBA Engineering Consultants Ltd.
p. 780.451.2121 • f. 780.454.5688
14940 - 123 Avenue • Edmonton, Alberta T5V 1B4 • CANADA

# EXECUTIVE SUMMARY

The Eureka High Arctic Weather Station (HAWS) is located on the north side of Slidre Fjord, at the northwestern tip of the Fosheim Peninsula, Ellesmere Island, Nunavut. To assist the Phase II/III ESA, EBA Engineering Consultants Ltd. (EBA) was retained by Public Works & Government Services Canada (PWGSC) on behalf of Environment Canada's Meteorological Services Canada department, to provide geophysical services at Eureka.

The primary objective was to design and complete a geophysical investigation to identify, map, and define the limits and, if possible, the thickness of any buried or partially buried landfills and buried fuel drums. A secondary objective was to identify and map potential petroleum hydrocarbon plumes in three known areas of hydrocarbon contamination in the vicinity of the Old Tank Farm.

Magnetic gradiometer surveys were employed to fully cover and delimit the boundaries of each landfill/buried debris area. Four Ground Penetrating Radar (GPR) profiles were collected to better characterize the limits of and, if possible, the thickness of buried material. Two OhmMapper Resistivity profiles were collected to assess the potential of characterizing contaminated hydrocarbon areas in the Old Tank Farm. Figures 1 to 10 and photographs are included in the back of this report.

A total of eight areas were investigated, with a total of 17 anomalous locations identified. Table A is provided as a summary chart of the geophysical anomaly locations and the associated investigated area.

TABLE A: LIST OF INVESTIGATE AREAS AND GEOPHYSICAL ANOMALIES

| Area | Area Name | Lobe/Profile | Approximate Easting (m) | Approximate Northing (m) |
|---|---|---|---|---|
| 1 | West Landfill | A | 522240 | 8881518 |
| | | B | 522275 | 8881510 |
| 2 | Barrel Storage | A | 522030 | 8880890 |
| | | B | 522070 | 8880920 |
| | | C | 522110 | 8880885 |
| 3 | Barrel Landfill | A | 522520 to 522620 | 8881170 to 8881240 |
| 4 | Barrel Crushing Area | A | 522765 | 8881165 |
| | | B | 522820 | 8881170 |
| | | C | 522860 | 8881150 |
| | | D | 522755 | 8881110 |
| | | E | 522816 | 8881105 |
| 5 | South and East Landfill | A | 523720 to 523840 | 8880780 to 8880950 |
| | | B | 523690 | 8880850 |

| TABLE A: LIST OF INVESTIGATE AREAS AND GEOPHYSICAL ANOMALIES | | | | |
|---|---|---|---|---|
| Area | Area Name | Lobe/Profile | Approximate Easting (m) | Approximate Northing (m) |
| 6 | Ash and Asbestos Landfill | A | 523645 | 8880965 |
| 7 | Battery Landfill | A | 524058 | 8881195 |
| 8 | Old Tank Farm | Profile 01 (Chainage -25 to 0) | 520530 to 520540 | 8880600 to 8880620 |
| | | Profile 02 (Chainage 70 to 120) | 520595 to 520625 | 8880635 to 8880675 |
| | | Profile 02 (Chainage 220 – 250) | 520675 to 520705 | 8880525 to 8880545 |

It is recommended that all anomalous locations be sampled if further information is required to fully characterize the environmental impact and risk of each anomaly.

It is also recommended that a reconnaissance geophysical investigation be carried out covering a much larger area that reflects total historical usage of the Eureka station. Magnetic gradient surveys would be the recommended method for this type of investigation.

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# 1.0 INTRODUCTION

## 1.1 GENERAL

The Eureka High Arctic Weather Station (HAWS) is located on the north side of Slidre Fjord, at the north-western tip of the Fosheim Peninsula, Ellesmere Island, Nunavut. To assist the Phase II/III ESA, EBA Engineering Consultants Ltd. (EBA) was retained by Public Works & Government Services Canada (PWGSC) on behalf of Environment Canada's (EC's) Meteorological Services Canada department to provide geophysical services at Eureka.

The primary objective was to design and complete a geophysical investigation to identify and map by defining the extent and, if possible, the thickness of any buried or partially buried landfills and buried fuel drums. A secondary objective was to identify and map potential petroleum hydrocarbon plumes in three known areas of hydrocarbon contamination in the vicinity of the Old Tank Farm.

Three geophysical techniques were employed for this project: a magnetic gradiometer survey using a Geometrics G-858 and G-856; a Ground Penetrating Radar (GPR) survey using Sensor and Software's PulseEKKO IV; and a resistivity survey using a Geometrics TR1 OhmMapper Resistivity system. The magnetic gradiometer was used to fully cover and delimit the boundaries of each known landfill/buried debris area. The GPR was used to confirm the limits and, if possible, the thickness of buried material. The OhmMapper Resistivity system was used to characterize the contaminated hydrocarbon areas.

## 1.2 SITE VISIT

Eureka is located at approximately 79º 59' 41" N latitude and 85º 48' 48" W longitude. A location map is provided in Figure 1. The geophysical investigation was carried out between September 10 and September 17, 2007 by Mr. Patrick Finlay, Geoph.I.T., of EBA's Edmonton office and Mr. James Mickle, Geoph.I.T., of EBA's Riverbend (Calgary) office under the direction of Mr. Neil Parry, P.Geoph.

At the time of the survey, there was at least 3 cm of fresh snow, which formed deep drifts in some locations (see Photo 2). Daytime temperatures were between -6°C and +2°C. The geophysical data collection took place in eight areas. An overall site map of Eureka showing all the areas surveyed is provided in Figure 2. A photos section for each area is provided in the back of this report. The eight areas surveyed are as follows:

- Area 1: The West Landfill. The West Landfill is located at the west end of the air strip. It is a closed landfill and its surface is partially capped.
- Area 2: Barrel Storage. The Barrel Storage is an abandoned site 100 m east of the main access road.

- Area 3: Barrel Landfill. This landfill is located south of the airstrip between the new DND buildings and the Bradley Air Services facilities.
- Area 4: Barrel Crushing Area. This site is south of the airstrip and around the barrel crushing machines and barrel stockpile.
- Area 5: South and East Landfill. This site combines the old east landfill with the active south landfill. The landfill is situated over an in-filled valley. It is partially capped, but waste materials are still exposed on the slope.
- Area 6: Ash and Asbestos Landfill. The Ash and Asbestos Landfill are two adjoining landfills. They are south of the airstrip and slightly west of the South and East Landfill and roughly within a fenced boundary marked with a sign.
- Area 7: Battery Landfill. This landfill is a raised and capped area north of the east end of the runway. There is an unused access road going to it, and it has a sign marking the location.
- Area 8: Old Tank Farm. The Old Tank Farm is located just west of the New Tank Farm, northwest of the main site (offices, accommodation complex). There is a building where the Old Tank Farm was, which is now being used by the Polar Environment Atmospheric Research Laboratory (PEARL).

## 2.0 BACKGROUND

The Eureka HAWS is operated by and is under the jurisdiction of the Meteorological Services of Canada, a section within EC. It has been in operation since April 7, 1947 and has a year-round staff of approximately 12 people. The main portion of the site occupies an area immediately east of Station Creek and consists of approximately 17 buildings with associated infrastructure. An airstrip is located approximately 1.5 km northeast of the main site. The current limits of the Eureka station area is approximately 2.23 hectares, although some historic activity has taken place outside of those limits.

Eureka is also used by other groups, namely, DND, the Polar Continental Shelf Project (PCSP), and PEARL. DND occupies an area south of the airstrip and has been more or less present at that location since the Eureka site began operation. They have used some of the landfills in conjunction with EC and have also developed their own landfill sites. PEARL operates a building at the site of the Old Tank Farm and has equipment (antennas, cables, telescope) set up around this building. PEARL and PCSP dispose of their waste under the guidance of the Eureka Station Manager.

Soils in the site area consist primarily of sand/gravel fill underlain by silty, sandy clays. Permafrost is present with an active layer ranging between 0.5 and 1.2 m in thickness, depending on the soil type and exposure.

## 2.1 PREVIOUS WORK

Eureka has been the subject of many environmental investigations. However, none of these investigations, to the best of our knowledge, have included any geophysics. Any geophysics collected on the site prior to this study has not been documented or reported in an accessible way. The following reports listed below have been reviewed in order to identify areas to focus on during the current geophysical investigation. Due to the size and history of the Eureka HAWS site, this geophysical study was not expected to provide 100% mapping coverage of all buried debris areas. The intent was to map the primary known areas and provide an assessment of successful geophysical methodologies with recommendations for future studies.

### 2.1.1 Previous Works Summary

The following reports were reviewed to identify primary geophysical study areas. The major findings for each are summarized below.

- **February 1998. Detailed Environmental Site Characterization and Remediation of the Eureka High Arctic Weather Station**

  Following the release of 37,000 L of diesel fuel into the north tank farm in July 1990, an investigation was conducted by O'Connor Associates in the tank farm area. 5,000 L of diesel liquid product were recovered and 200 $m^3$ of contaminated soils were removed and stockpiled at the main landfill. It was found that neither the potable water reservoir nor Slidre Fjord was impacted by spill.

  Three areas showed Total Petroleum Hydrocarbons (TPH) concentration greater than Government of Northwest Territories (GNWT) criteria: Area 1 (east side of the drainage pond); Area 2 (adjacent to old south tank farm and the fuel bladders); and Area 3 (within the north tank farm).

- **April 1999. Eureka: An Environmental Study of DND Facilities (Environmental Science Group of the Royal Military College of Kingston)**

  This report looked at a number of locations used by DND at Eureka.

  The report found that the East Airstrip Landfill is a primary concern because it is unstable and subject to erosion, and contains hazardous and non-hazardous materials. Therefore, the potential for contaminant migration is high. The drainage from the landfill leads ultimately to Slidre Fjord, approximately 1 km to the south. At the time of the ESG investigation in 1998, there was little evidence of the cap on the landfill. Most of the fine sand and silt used to cap the top was no longer present. A great deal of debris was exposed in the drainage channel below the main part of the landfill.

  There is also mention of a barrel disposal area east of the accommodations buildings at DND's Camp Eureka where the contents of used barrels are burnt, the barrels crushed and then buried under a small amount of fill. The barrels are primarily generated by

DND, PCSP, Bradley First Air and Kenn Borek Air Ltd. TPH was the only contaminant of concern in the soil from the barrel dump. It was recommended that the current method of disposing of waste liquid hydrocarbons at the barrel dump should be abandoned in favour of one that reduces the amount of fuel spilled and also increases incineration efficiency. It was also recommended that a new incinerator be under consideration by Environment Canada to replace the current unit to be capable of handling liquid hydrocarbon wastes that also meet the requirements for fuels permitted to be burned in the north.

The West Airstrip Landfill is located west and north of the airstrip, west of the Bradley Air Services building that is located on the north airstrip apron. The landfill is completely re-vegetated; however, in some areas, debris is apparent. Sampling showed no evidence that the west airstrip landfill is leaching contaminants. This landfill is located in a relatively stable location with limited receptors. However, it was recommended that additional fill should be placed over the entire area.

- **July 2000. In Situ Remediation of Eureka HAWS, EBA Engineering Consultants Ltd. (EBA File: 0201-00-14507)**

  This report gave a good overview of soil, groundwater and contamination conditions at Eureka, but did not identify any additional survey locations. Contaminated areas shown on the figures in the report are used in Figure 10a.

Other previous activities occurring in Eureka from August 23 to 26, 2006 included a Phase I ESA of the entire HAWS completed by PWGSC, and two Phase II ESAs for the Former Fuel Storage Area and the Ex-Situ Bioremediation Cell completed by Nunami Jacques Whitford, Ltd.

# 3.0 METHODOLOGY

The following section describes the survey methodology used at the Eureka HAWS facility for each geophysical system used. A detailed technical explanation of the systems operation and procedures is included in Appendix A.

## 3.1 MAGNETIC GRADIOMETER

The magnetics survey at the Eureka site was performed using a Geometrics G-856 and G-858 magnetometer/gradiometer systems.

The G-856 proton free-precession magnetometer was used as a base station to record diurnal variations in the background magnetic field intensity. This permitted the accurate calculation of the total magnetic field intensity during the course of the field program. The base station was set up approximately 50 m north of the runway at 522766E, 8881357N (shown in Figure 2), an undisturbed location with limited cultural magnetic interference (vehicles, people, surface debris).

The G-858 portable cesium vapour magnetometer was used as a roving field gradiometer. Two sensors were employed and were vertically separated by 1 m. Each measured the total magnetic field intensity at its respective location. The difference between the readings of the two sensors divided by the separation is a measure of the vertical magnetic gradient at that location. This value is proportional to the quantity of ferrous objects. Locations with high magnetic gradients will correspond to areas with large quantities of ferrous debris and, therefore, potential landfill locations or debris piles.

The gradient data set is plotted as colour contours on a mapping grid and provides a visual representation of the location and distribution of magnetic gradient anomalies. On the colour contour map, a transparent background indicates a limited or nil response. High magnetic gradients are represented by either red at approximately +200 nanoTeslas per metre (nT/m) and above or blue at -200 nT/m and below. There is no significance between a positive or negative anomaly, except to provide an indication of the polarity and, therefore, direction of the magnetic gradient at that location.

The gradiometer data set was collected by walking parallel lines approximately 5 to 10 m apart. In areas known to contain significant buried debris, a 5 m line spacing was used to increase sampling density and, therefore, mapping resolution. In other areas, a 10 m line spacing was used due to time constraints.

Once mapped, any anomalous region was re-visited and the edges were then more carefully mapped by temporarily using a smaller grid spacing, in "search mode" (data points not stored). The edges were then pin-flagged and surveyed by PWSGC staff.

A real-time differentially-corrected GPS system was used for survey collection, then mapped with the G-858 roving field unit to provide integrated sub-meter positioning accuracy. A second GPS (Trimble ProXRS) was used as the main GPS base station, with known coordinates as surveyed by PWGSC staff. This base station was configured with a Pacific Crest modem transmitter and used to radio RTCM GPS corrections to the Pacific Crest receiver antenna attached to a roving GPS unit. The RTCM corrections were used to differential correct in real-time the roving Trimble AG132 GPS receiver. The GPS positioning data was then output as a NMEA GPS string and logged internally into the G-858. Positions were recorded at one-second intervals concurrently with the gradiometer data. The resulting accuracy of the system is ±0.5 m horizontally and 2 m vertically.

All magnetic gradiometer geophysical survey lines are identified by small black cross-marks on the attached figures.

All positioning data has been reported in UTM coordinates using the NAD83 datum. Eureka, NU falls within UTM Zone 16X.

## 3.2 GROUND PENETRATING RADAR

GPR is a non-destructive geophysical technique capable of delineating materials that have contrasting bulk electrical properties. The GPR technique images shallow soil and rock structure at a high resolution. The resolution and depth of penetration is a combined function of the soil electrical properties, the antenna frequency and the transmitted power. Higher antenna frequencies provide higher resolution but lower depth penetration. Generally, although not always, changes in the bulk electrical properties correspond to changes in stratigraphy within the ground profile. Therefore, the net result is a cross-section profile of the stratigraphy showing considerable detail.

The GPR system transmits a short duration electromagnetic (EM) pulse into the ground, and a downward propagating wave front is generated. The velocity at which the wave front propagates is controlled by the dielectric constant (or charge capacity) of the material it is travelling through. The dielectric constant is a ratio of the electric-field storage capacity of a material to that of free space. Different dielectric constants between two material layers will create an echo at the material boundary, which can be seen within the GPR trace. An abrupt change in dielectric properties will be more detectable than a gradual change. The second controlling electrical property is the material's electrical conductivity. In conductive material, such as clayey soils and metal, the radar signals can become attenuated. This will prevent the signal from penetrating through the material.

The GPR system used at Eureka was the Sensor and Software's PulseEKKO IV, with 400 V and 1000 V transmitters. Two antenna frequencies were used at Eureka: the 100 MHz and 200 MHz antennas. Table 1 summarizes the GPR parameters used for each radar profile, and is provided in the Tables section at the back of this report.

Data positioning was based on surveyed coordinates of profile start and end points. The intermediate trace coordinates were then interpolated to provide positioning mapping. All GPR data was collected in step mode. Step mode is when the antennas are placed in a stationary location and a reading or trace is recorded. The antennas are then "stepped" a known distance to the next reading along the line and the process is repeated, making a profile of multiple traces.

## 3.3 OHMMAPPER

Resistivity data is collected as a series of discrete apparent resistivity measurements with varying collection parameters that are then combined and inverted as a data set. The result is a true resistivity profile cross-section of the subsurface along the survey line. Depending on the site characteristics and history, the resistivity data provides information on variations in soil and geologic strata, subsurface boundaries and variations in moisture conditions.

The Geometrics TR1 OhmMapper Resistivity system is a capacitively coupled towed dipole-dipole array system. The towed cable array has a transmitter and receiver that can be operated with dipoles of varying lengths and separations to control the effective sounding depth. The data collected is processed to create a vertical two-dimensional cross-section by surveying a single geophysical profile with different dipole lengths and separations. For this project, dipole lengths of both 5 m and 10 m were used, with dipole separations varying between 5 m and 20 m. OhmMapper parameters used for each profile are provided in Table 2, located in the Tables section of this report.

Similar to the G-858 data collection, all data was logged with an internal data logger with real-time differentially-corrected global positioning system (DGPS) locations being integrated into the same file. The resistivity data was collected at a rate of 2 readings per second for the OhmMapper, and 1 reading per second for the GPS system.

The raw resistivity data was then processed and filtered using custom built Matlab routines that preserve the elevation data. The commercial program RES2DINV was used to reduce and convert the apparent resistivity data with positional and elevation information at each data point, generating a true vertical resistivity profile. This was achieved by an iterative least squares correlation between the measured and modelled (inverted) apparent resistivity values yielding a resistive model.

## 3.4 POSITIONING SURVEY CONTROL

Positioning control was obtained by using two GPS systems, a base station and a roving unit, in conjunction with a Pacific Crest radio modem. As a quality control, the four corners of each magnetic gradiometer survey area were surveyed by PWGSC staff and then used in matching the survey corners recorded during data collection, if any discrepancies were observed.

The Trimble ProXRS was used as the main GPS base station, with known coordinates as surveyed by PWGSC staff. Two locations were utilized. The first location, set up near the west end of the runway, was located at 79º 59' 45.94197" N, 85º 51' 11.18395 W and used in Areas 1, 2, 3, 4, and 8. The second location, set up by the East Landfill, was located at 79º 59' 29.30649" N, 85º 46' 25.56407" W and used in Areas 5, 6, and 7. Base station locations are shown in Figure 2.

The base station was configured with a Pacific Crest modem transmitter and used to radio RTCM GPS corrections to the Pacific Crest receiver antenna attached to a roving GPS unit. The RTCM corrections were used to differential correct in real-time the roving Trimble AG132 GPS receiver. The GPS positioning data was then output as a NMEA GPS string and logged internally into the geophysical system's data console.

Positions were recorded at one-second intervals concurrently with the magnetic gradient and OhmMapper geophysical data. The resulting accuracy of the system is ±0.5 m horizontally and 2 m vertically.

All positioning data has been reported in UTM coordinates using the NAD83 datum. Eureka, NU falls within UTM Zone 16X.

## 4.0 FINDINGS AND DISCUSSION

Figure 2 presents an overall plan map showing the relative location of the eight survey areas.

Within areas where a gradiometer survey was performed (Area 1 to Area 7), anomalous lobes have been identified. The larger lobes are indicative of either larger objects, or several objects situated in the same area. Smaller anomalies are the result of individual, localized ferrous surface debris and are not necessarily labelled. Along with the magnetic gradient contour maps, separate top and bottom sensor contours of diurnally corrected total magnetic field intensity are also plotted and provided. The total magnetic field intensity is useful in that the largest values will correlate with where the greatest concentration of ferrous debris and potentially buried material is situated.

The background magnetic field strength value for Eureka, NU, was approximately 56725 nT at the time of the survey. Diurnal fluctuations were in the order of 8 nT per hour, with micropulsations of 5 nT.

Geophysical profiles are also presented in areas where GPR (Areas 2, 3 and 6) and OhmMapper (Area 8) data were collected.

Results for each area are discussed in the following sub-sections. Table 3 (see attached Tables section) further summarizes the size and likely source of each anomaly, as well as any observations made. Also included in Table 3 are approximated surface area and volume calculations.

### 4.1 AREA 1: THE WEST LANDFILL (FIGURES 3A, 3B, 3C, 3D)

The West Landfill is a located at the west end of the air strip. It is an abandoned (closed) landfill and its surface is partially capped. The approximate extent and location of the landfill was unknown prior to surveying. For this reason, a large area was covered to make sure that all the landfill was surveyed. Figure 3a shows the location of the area surveyed. There was, however, a ridge and mound that corresponded to the anomalies, which can be used as a rough visual guide of the landfill's perimeter. Photos 1 and 2 (in the Photos section) are of the West Landfill survey area.

Figure 3b shows the vertical magnetic gradient results and Figure 3c and 3d show the top and bottom sensor total magnetic field strength results, respectively. Two anomalous locations, Lobe A and Lobe B, were identified in Area 1. Lobe A is the main part of the landfill, centred at approximately 522240 E, 8881518 N. Judging from the surface debris (cans, kitchen garbage), the total magnetic field response, and past documentation, Lobe A most likely contains domestic waste. Lobe B is a smaller lobe 20 m east of Lobe A consisting of partially buried fuel drums. There are also smaller anomalies scattered throughout the survey area that are not encompassed in the lobes. These are most likely surface debris, but not all could be visually confirmed at the time of the survey due to the presence of snow.

## 4.2 AREA 2: BARREL STORAGE (FIGURES 4A, 4B, 4C, 4D, 4E)

The Barrel Storage is an abandoned site approximately 100 m east from the main access road. Figure 4a shows the location of the area surveyed. Little is known or documented about this area. The presence of some surface debris and crushed fuel drums indicated the potential for buried debris. Photo 3 is an aerial photograph showing the approximate location of the survey area. Photos 4 and 5 are of the survey area and Lobe A, respectively.

Figure 4b shows the vertical magnetic gradient results and Figure 4c and 4d show the top and bottom sensor total magnetic field strength results, respectively.

Lobe A is centred at approximately 522030 E, 8880890N, and Lobe B is centred on 522070 E, 8880920N. Both of these lobes are beneath level terrain and have a similar magnetic response, and therefore, it is assumed that they consist of similar debris. Based on the name description of the area form previous reports (particularly, Environmental Science Group of the Royal Military College of Kingston, April 1999) and the presence of partially buried crushed drums on the surface, Lobe A and B are most likely buried metal drums. However, this does not preclude the possibility that other material has been buried at this location.

Figure 4e is the radar profile (100 Mhz) running overtop of Lobes A and B. The radar was used to try and detect the edges, and possibly the depth, of the anomalies. The ground has been disturbed where the lobes are located. The active layer reflector is visible and there is ringing in the data where metallic anomalies are present. This ringing in the radar signal is indicative of the presence of metal (or very conductive material). However, the soil is either sufficiently clayey or homogenous enough that the radar signal cannot resolve any stratigraphic features that might provide an indication of the burial depth of the material in these lobes. Therefore, no interpretative depth of Lobes A and B was derived from the GPR data at this site.

Lobe C is located at around 522110 E, 8880885 N and consists of partially buried and buried metal drums based on visual observation.

## 4.3 AREA 3: BARREL LANDFILL (FIGURES 5A, 5B, 5C, 5D, 5E)

The Barrel Landfill is located south of the airstrip between the new DND camp and the Bradley Air Services Buildings. Figure 5a shows the location of the area surveyed. Photo 6 is a photo of the survey area.

Figure 5b shows the vertical magnetic gradient results and Figure 5c and 5d show the top and bottom sensor total magnetic field strength results, respectively.

Lobe A is the Barrel Landfill. The edges of the landfill are clearly defined to the south and east. The northwest edge of the survey was bordered by the current fuel drum storage area and DND facility buildings; therefore, due to interference from these features, the northeastern extent of the landfill is unknown.

Figure 5e is the radar profile (100Mhz) starting at approximately 522583E, 881185N and running west from the anomaly to about 522612 E, 8881176 W. There is ringing present in the radar signal from chainage 0 m to 15 m, where metallic anomalies are present. This ringing is indicative of the presence of metal (or very conductive material). However, the soil is either sufficiently clayey or homogenous enough that the radar signal cannot resolve any stratigraphic features that might provide an indication of the burial depth of the material in these lobes. Therefore, no interpretative depth of Lobe A was derived from the GPR data at this site.

A test pit was dug to an approximate depth of 1 m at 522592 E, 8881183 N, near chainage 10 m in the GPR profile (see Photos 7 to 10). A crushed metal fuel drum was encountered approximately 0.5 m from the surface, with more fuel drums found beneath the first one, to the depth of the test pit. Soil composition was found to be of clayey substrate. Permafrost was found below approximately 0.30 m but was not present around the drums. Liquid leaked out of a drum once it was removed from the test pit. The liquid had no odour and was presumed to be water, but was not sampled.

Lobe A likely consists of buried crushed fuel drums down to a depth of at least 0.5 m to 1 m below grade.

## 4.4 AREA 4: BARREL CRUSHING AREA (FIGURES 6A, 6B, 6C, 6D)

The Barrel Crushing Area is south of the airstrip and east of the Bradley Air Services Buildings. Figure 6a shows the area surveyed. The survey location included a fenced area directly south of the airstrip, in the northwest corner of the survey area, marked by a sign with skull and crossbones reading: “Barrels 2005.” Also present within the survey area was a barrel crushing facility, a stockpile of empty fuel drums (presumably waiting to be crushed), and an abandoned steel storage tank. Photo 11 is an aerial view of the survey area.

Figure 6b shows the vertical magnetic gradient results and Figure 6c and 6d show the top and bottom sensor total magnetic field strength results, respectively.

Lobe A is centred at around 522765 E, 8881165 N, just northwest of the storage tank (see Photo 13), and is thought to be buried metal debris. Lobe B (522820 E, 8881170N) and Lobe C (522860 E, 8881150 N) are within the fenced area and are assumed to be buried crushed drums (see Photo 12).

Lobe D is centred at 522755 E, 8881110 N, west of the crushing facility, and is thought to be buried metal debris. The northwestern extent of Lobe D could not be surveyed due to interference from the crushing facility. Lobe E, centred at 522816 E, 8881105 N, could be a buried crushed drum landfill in use before 2005 (see Photo 14).

No data was collected within a 2 m perimeter of the barrel crushing facility and barrel stockpile.

## 4.5 AREA 5: SOUTH AND EAST LANDFILL (FIGURES 7A, 7B, 7C, 7D)

Area 5 combines the closed East Landfill with the active South Landfill. The South Landfill has a large metal container used for incinerating waste. The landfills are more or less joined. The East Landfill consists of two in-filled valleys that are partially capped, with waste materials being exposed on the slope (see Photos 16 to 20). The South Landfill is the buried and partially buried active landfill area 20 m north of the valley's edge. Figure 7a shows the area surveyed. Photo 15 is an aerial view of the two landfills.

Data was not collected on the valley slopes or ridges where the terrain was steep and therefore unsafe for surveying.

Figure 7b shows the vertical magnetic gradient results and Figure 7c and 7d show the top and bottom sensor total magnetic field strength results, respectively.

Lobe A is the main landfill lobe (both South and East). It extends along the valley's edge from 523720 E to 523840 E and from 8880780 N to 8880950 N. Most of the material present is partially buried debris and surface debris (drums, vehicles, metal scrap, tires) that could not be incinerated. The north area of the lobe (South Landfill) is below the access road to the incinerator. The anomalies here are more dispersed and relatively lower in magnetic gradient strength, and may have been used to bury domestic debris and non-metal waste.

Lobe B is centred at 523690 E, 8880850 N and is most likely buried metal debris. It is unknown why this lobe was separated from the rest of the landfill material.

The small anomalies located to the west and south are visually identified pieces of surface debris, possibly sourced from the exposed East Landfill.

## 4.6 AREA 6: ASH AND ASBESTOS LANDFILLS (FIGURES 8A, 8B, 8C, 8D)

The Ash and Asbestos Landfills are two relatively small adjacent landfills that were surveyed at the same time. They are south of the airstrip and slightly west of the South and East Landfill. Figure 8a shows the surveyed area. There is an unused access road leading to them from the South and East Landfill access road. They consist of two areas surrounded by a fence, made with braided metal cable with metal posts and are marked with a sign. The location of the Ash and Asbestos Landfill can be seen in relation to the South and East Landfill in Photo 15.

Figure 8b shows the vertical magnetic gradient results and Figure 8c and 8d show the top and bottom sensor total magnetic field strength results, respectively.

The concentrated anomaly values of Lobe A are centred at approximately 523645 E, 8880965N. This is considered to be the Ash Landfill, and the high magnetic gradient anomaly is thought to be from the ash being buried in metal drums, as previous documents and anecdotal information suggests. The other part of the lobe is either from part of the Ash or the Asbestos Landfill, since the area to the east is not as clearly labelled.

High magnetic gradients found just outside of Lobe A and in the northern part of the survey is interference from the metal part of the fence.

## 4.7 AREA 7: BATTERY LANDFILL (FIGURES 9A, 9B, 9C, 9D, 9E, 9F)

The Battery Landfill is a raised capped mound of at least 1.5 m above ground. It is north of the east end of the runway. There is an unused access road leading up to it, and a sign labels the area (see Photo 21). Figure 9a shows the area surveyed.

Figure 9b shows the vertical magnetic gradient results and Figure 9c and 9d show the top and bottom sensor total magnetic field strength results, respectively.

Lobe A is in the middle of the southern end of the mound, centred at 524058 E, 8881195 N. The magnetic gradients are lower and less pronounced compared to the other landfills, indicating that there is less ferrous debris (i.e., no fuel drums). The anomaly seen is likely due to ferrous mounting debris associated with buried batteries.

Two radar lines where performed over the lobe with the 200 MHz antennae (see Photo 22). Profile 01 runs south-north (Figure 9e); Profile 02 runs east-west (Figure 9f). The soil, however, is either sufficiently clayey or homogenous enough that the radar signal cannot resolve any stratigraphic features that might provide an indication of the burial depth of the material in these lobes. Therefore, no interpretative depth was obtained at this site from the radar, although the raised area suggests a likely burial depth of 1.5 m from on top of the landfill. .

## 4.8 AREA 8: OLD TANK FARM (FIGURES 10A, 10B, 10C)

The Old Tank Farm is located just west of the New Tank Farm, in the northwest corner of the main site. The New Tank Farm was installed in 1992 but consists mainly of restored older tanks. A new building is at the site of the Old Tank Farm, which is currently used by PEARL. This area has been the subject of previous environmental investigations, due to a history of hydrocarbon spills in the vicinity. Photo 23 is an aerial view of the main camp showing the PEARL lab and the currently existing New Tank Farm.

Two OhmMapper profiles were collected to assess resistivity variations in the soil and determine if there is any possible correlation between resistivity and hydrocarbon contaminated soils. Figure 10a shows the location of the two profiles as well as the location of contaminated areas, as obtained from EBA's In Situ Remediation of Eureka HAWS report (July, 2000). Profile 01 (Figure 10b) runs from the in situ bioremediation area (approximately from chainage -25 to 50) northbound, just west of the PEARL lab and onto a gravel road (sees Photos 24 and 25). Profile 02, Figure 10c, runs from the edge of the valley, southwest of the PEARL lab and followed the north edge of the road, passing just south of the New Tank Farm and ending at the main access road.

It is expected that any hydrocarbon contamination present along these resistivity profiles will show up as being more resistive than the surrounding conductive silty material, in unfrozen ground.

In Profile 01, between chainages -20 to 0, there is a resistive zone at the surface, which corresponds to an area within the in situ biotreatment area. The soils here are being treated for hydrocarbon contamination, although only this section shows up as being more resistive. Only two different dipole parameters were performed in this area, due to layback orientations, and the higher resistivity could also be an artefact of the modelling software.

Profile 02 has two areas of higher resistivity: from chainage 70 to 120 and from 220 to 250. The first one could be a potential area of hydrocarbon contamination, just south of the New Tank Farm. It also partially overlaps to southeast corner of one of the contaminated areas as mapped in EBA's 2000 report (see Figure 10a). The second one corresponds to the where the profile is next to a main access road intersection and may just be the result of the road fill gravel (as part of the road maintenance/construction). It could also still be a potential area of hydrocarbon contamination.

Both profiles show the ground being fairly conductive, indicating that the underlying material may consist of marine soils and therefore may be higher in salts. The presence of salts could depress the freezing point of water and result in the ground having taliks, or unfrozen areas. These areas could act as a conduit or reservoir for contaminated fluids within otherwise ice barrier soils.

Available time on site prevented any further resistivity measurements. The results do show some indication of more resistive surficial materials being detected in areas where hydrocarbon contaminated soils may be present. Nevertheless, the results do not cover a large enough area, nor is there sufficient ground truthing to consider them conclusive.

Use of resistivity measurements to map hydrocarbon contamination may be worth pursing at Eureka and likely offer the best available geophysical technique, but it must be done in conjunction with soil sampling. The soil sampling must be carried out in an area with hydrocarbon contamination to determine actual contamination levels. These results will then be correlated with the results from a more detailed resistivity survey with close line spacings, giving 3D coverage. Once a known problem area has been characterized, these results can be used to then further characterize resistivity data collected in other identified potential problem areas.

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the geophysical data collected by EBA during the September 2007 field investigation.

Magnetic gradiometer surveys were carried out in Areas 1 to 7. GPR profiles were employed at Areas 2, 3 and 6 and OhmMapper profiles were collected in Area 8 (The Old Tank Farm.) Within these areas, a total of 17 anomalous locations were identified. Table 3 summarizes the geophysical anomalies. All geophysical anomalies identified have been located and the perimeters mapped (except as noted) to an accuracy of ±0.5 m.

It is recommended that all anomalous locations be sampled if further information is required, to fully characterize each anomaly.

The majority of the anomalies identified are most likely due to buried metal fuel drums and other assorted ferrous debris, with the exception of the Battery Landfill (Area 7, batteries) and the Old Tank Farm (Area 8, hydrocarbons). There is little evidence of metallic/non-metallic sorting having taken place at any of the landfill locations. With that in mind, metallic and non-metallic debris could be recovered from the same location and searching only for metallic debris could be an efficient way of finding buried waste in general.

The geophysical investigation was focused on select areas of known disturbance or known landfills within EC's lease, and did not cover the entire Eureka site. Several areas of known disturbance exist that were not within the scope of this investigation, for example, along the beach, areas west of the main camp across Station Creek, and the original airport location to the north. There may also be buried debris areas within the vicinity/perimeter of the main station near the communication facility at Skull Point and areas used during the initial construction of the station.

It is therefore recommended that a reconnaissance geophysical investigation be carried out covering a much larger area. A careful review of previous site activity would identify suspect areas, which would then be cleared by geophysical methods. Magnetic gradient surveys would be the recommended method for this type of investigation.

## 6.0 CLOSURE

This report summarizes the results of the geophysical data collection at Eureka, NU, in September 2007 and we trust that the information provided satisfies your present requirements. Please do not hesitate to contact the undersigned if you have any comments or questions regarding this report.

Respectfully submitted,
EBA Engineering Consultants Ltd.

REGISTERED PROFESSIONAL GEOPHYSICIST
N.S. PARRY
LICENSEE
NWT/NU
May 27, 2008

Patrick Finlay, Geoph.I.T.
Jr. Geophysicist
Engineering & Environmental Geophysics
Direct Line: 780.451.2130 x527
pfinlay@eba.ca

Neil Parry, MBA, P.Geoph.
Project Director
Engineering & Environmental Geophysics
Direct Line: 780.451.2130 x274
nparry@eba.ca

/jnc

THE ASSOCIATION OF
PROFESSIONAL ENGINEERS,
GEOLOGISTS and GEOPHYSICISTS
OF THE NORTHWEST TERRITORIES
**PERMIT NUMBER**
**P 018**
EBA ENGINEERING
CONSULTANTS LTD.
May 27, 2008

# TABLES

| TABLE 1: GPR PARAMETERS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Area | Profile | Antennae Frequency | Transmitter Pulse Voltage | Receiver - Transmitter Spacing | Step Size | Sampling Interval | Window Length | Approximate Depth of Penetration | Vertical Resolution |
| 2 – Barrel Storage | 1 | 100 MHz | 400 V | 1 m | 0.20 m | 0.8 ns | 512 ns | 1.5-2.5 m | 0.75 m |
| 3 – Barrel Landfill | 1 | 100 MHz | 1000 V | 1 m | 0.10 m | 0.8 ns | 512 ns | 1.5-2.5 m | 0.75 m |
| 7- Battery Landfill | 1 | 200 MHz | 400 V | 0.50 m | 0.10 m | 0.8 ns | 512 ns | 1.5-2 m | 1.5 m |
| 7 -Battery Landfill | 2 | 200 MHz | 400 V | 0.50 m | 0.10 m | 0.8 ns | 512 ns | 1.5-2 m | 1.5 m |

| TABLE 2: OHMMAPPER PARAMETERS | | | | |
|---|---|---|---|---|
| Area | Profile | Dipole Separations (m) | Dipole Lengths (m) | Approximate Sounding Depth (m) |
| Area 8 – Old Tank Farm | 1 | 5 | 5 | 2.5 |
| | | 5 | 10 | 3.3 |
| | | 5 | 15 | 4.2 |
| | | 10 | 10 | 5 |
| | | 10 | 20 | 6.7 |
| Area 8- Old Tank Farm | 2 | 5 | 5 | 2.5 |
| | | 5 | 10 | 3.3 |
| | | 5 | 15 | 4.2 |
| | | 10 | 10 | 5 |
| | | 10 | 20 | 6.7 |

TABLE 3: SUMMARY OF GEOPHYSICAL ANOMALIES

| Area | Area Name | Lobe/Profile | Approximate Easting (m) | Approximate Northing (m) | Approximate Radius (m) | Type of Debris/Contamination | Approximate Surface Area (m²) | Approximate Volume (m³) at depth of 1.5 m |
|---|---|---|---|---|---|---|---|---|
| 1 | West Landfill | A | 522240 | 8881518 | 35 | Buried Metal/Debris (Domestic?) | 1871 | 2726 |
| | | B | 522275 | 8881510 | 10 | Buried Metal/Debris (Domestic?) | 480 | 720 |
| 2 | Barrel Storage | A | 522030 | 8880890 | 10 | Buried Metal Drums? | 586 | 879 |
| | | B | 522070 | 8880920 | 20 | Buried Metal Drums? | 1379 | 2069 |
| | | C | 522110 | 8880885 | 5 | Buried and Partially Buried Metal Drums. | 462 | 693 |
| 3 | Barrel Landfill | A | 522520 to 522620 | 8881170 to 8881240 | N/A | Buried Crushed Metal Drums | 5001 | 7502 |
| 4 | Barrel Crushing Area | A | 522765 | 8881165 | 10 | Buried Metal Debris | 552 | 828 |
| | | B | 522820 | 8881170 | 20 | Buried Crushed Metal Drums | 1203 | 1805 |
| | | C | 522860 | 8881150 | 5 | Buried Crushed Metal Drums | 400 | 600 |
| | | D | 522755 | 8881110 | 10 | Buried Metal Debris | 635 | 953 |
| | | E | 522816 | 8881105 | 20 | Buried Crushed Metal Drums? | 1278 | 1917 |
| 5 | South and East Landfill | A | 523720 to 523840 | 8880780 to 8880950 | n/a | Buried and Partially Buried Metal Debris (Fuel Drums, Vehicles, Scrap Metal, Tires, Domestic Garbage, Ashes) | 12, 591 | 18887 |
| | | B | 523690 | 8880850 | 10 | Buried Metal Debris | 687 | 1031 |
| 6 | Ash and Asbestos Landfill | A | 523645 | 8880965 | 10 | Buried Ashes in Drums? Buried Asbestos Piping? | 299 | 449 |
| 7 | Battery Landfill | A | 524058 | 8881195 | 10 | Buried Batteries? | 871 | 1307 |
| 8 | Old Tank Farm | Profile 01 (Chainage -25 to 0) | 520530 to 520540 | 8880600 to 8880620 | n/a | Hydrocarbon contamination? | N/A | N/A |
| | | Profile 02 (Chainage 70 to 120) | 520595 to 520625 | 8880635 to 8880675 | n/a | Hydrocarbon contamination? | N/A | N/A |
| | | Profile 02 (Chainage 220 – 250) | 520675 to 520705 | 8880525 to 8880545 | n/a | Gravelly Fill? Hydrocarbon contamination? | N/A | N/A |

# FIGURES

# PHOTOGRAPHS

**Photo 1**
Area 1, West Landfill - looking east over the survey area towards the fuel tank storage on the north side of the runway.


**Photo 2**
Area 1, West Landfill - looking west, James Mickle with the G-858 magnetic gradiometer in a snow drift. An example of terrain conditions at the time of the survey.

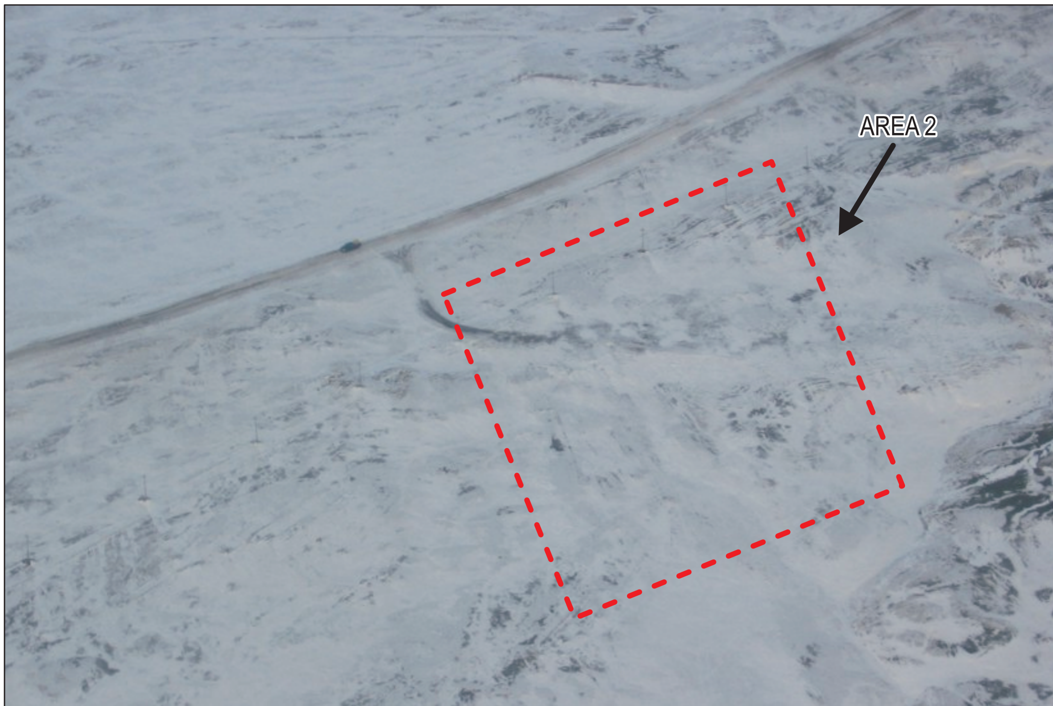


**Photo 3**
Area 2, Barrel Storage - Aerial view of the Barrel Storage area, just off the main access road.


**Photo 4**
Area 2, Barrel Storage - looking northeast towards DND camp.


**Photo 5**
Area 2, Barrel Storage - looking southeast towards Lobe A.

**Photo 6**
Area 3, DND Barrel Landfill - looking east at survey area.


**Photo 7**
Area 3, DND Barrel Landfill - looking east at excavation test pit.

**Photo 8**
Area 3, DND Barrel Landfill - test pit encounter with crushed fuel drum.

**Photo 9**
Area 3, DND Barrel Landfill - test pit showing depth to fuel drum (approximately 0.5 m).

**Photo 10**
Area 3, DND Barrel Landfill - fuel drum from the test pit.

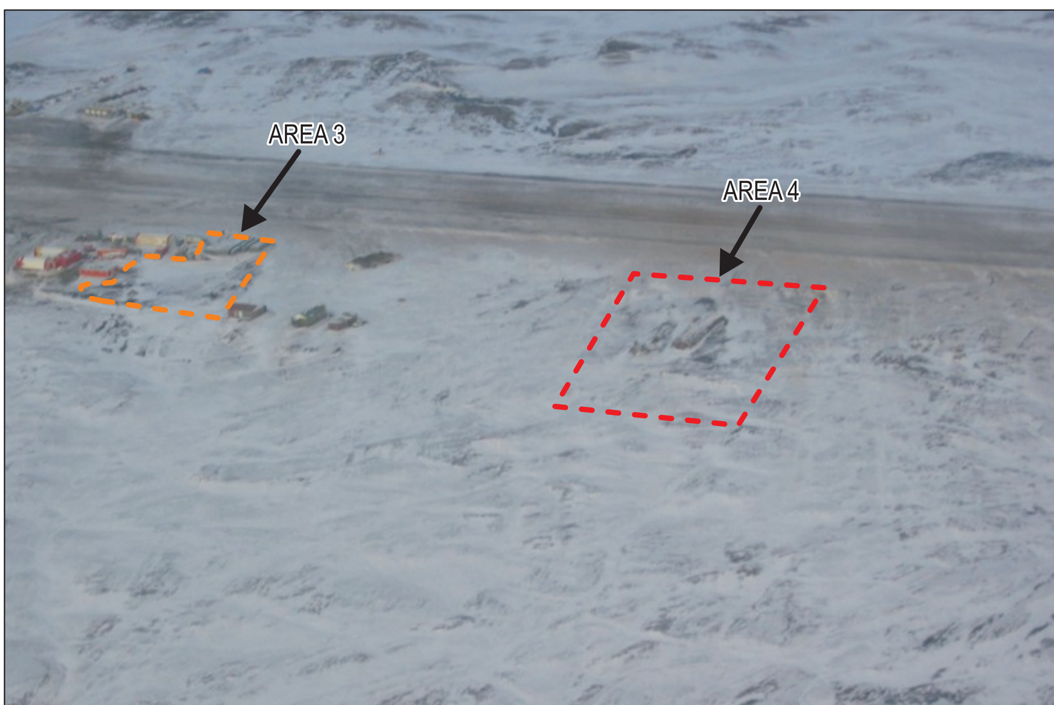


**Photo 11**
Area 4, DND Barrel Crushing Area - Aerial view of DND Barrel Landfill and Crushing Area.

**Photo 12**
Area 4, DND Barrel Crushing Area - looking northeast at buried drums just south of the airstrip, Lobe B and C.


**Photo 13**
Area 4, DND Barrel Crushing Area - looking south at Lobe A.


**Photo 14**
Area 4, DND Barrel Crushing Area - looking north over Lobe E.

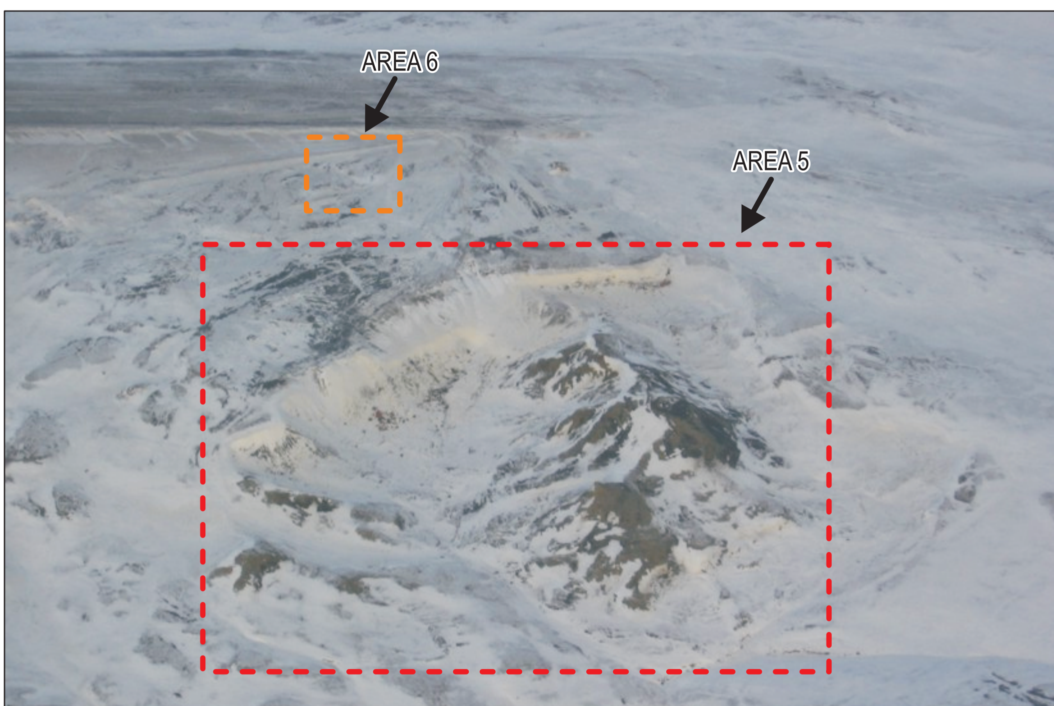


**Photo 15**
Area 5, South and East Landfill - Aerial view of the South, East, Ash, and Asbestos Landfills.

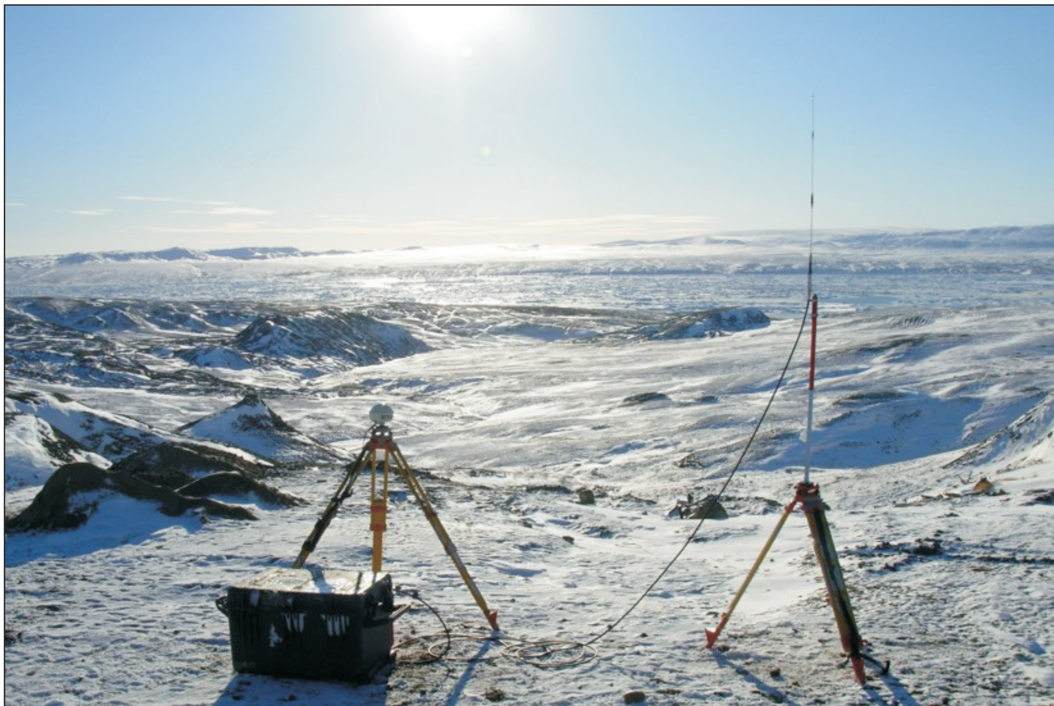

**Photo 16**
Area 5, South and East Landfill - looking south over the East Landfill, GPS base station set-up.


**Photo 17**
Area 5, South and East Landfill - looking southeast over the eastern valley of the East Landfill.


**Photo 18**
Area 5, South and East Landfill - looking south over the ridge separating the two valleys in the East Landfill.


**Photo 19**
Area 5, South East Landfill - looking south over the west valley of the East Landfill.

**Photo 20**
Area 5, South and East Landfill - looking west at the East Landfill survey area. Debris is exposed on the southern bank.


**Photo 21**
Area 7, DND Battery Landfill - looking northeast towards the survey area.

**Photo 22**
Area 7, DND Battery Landfill - looking southwest at GPR Profile 2.

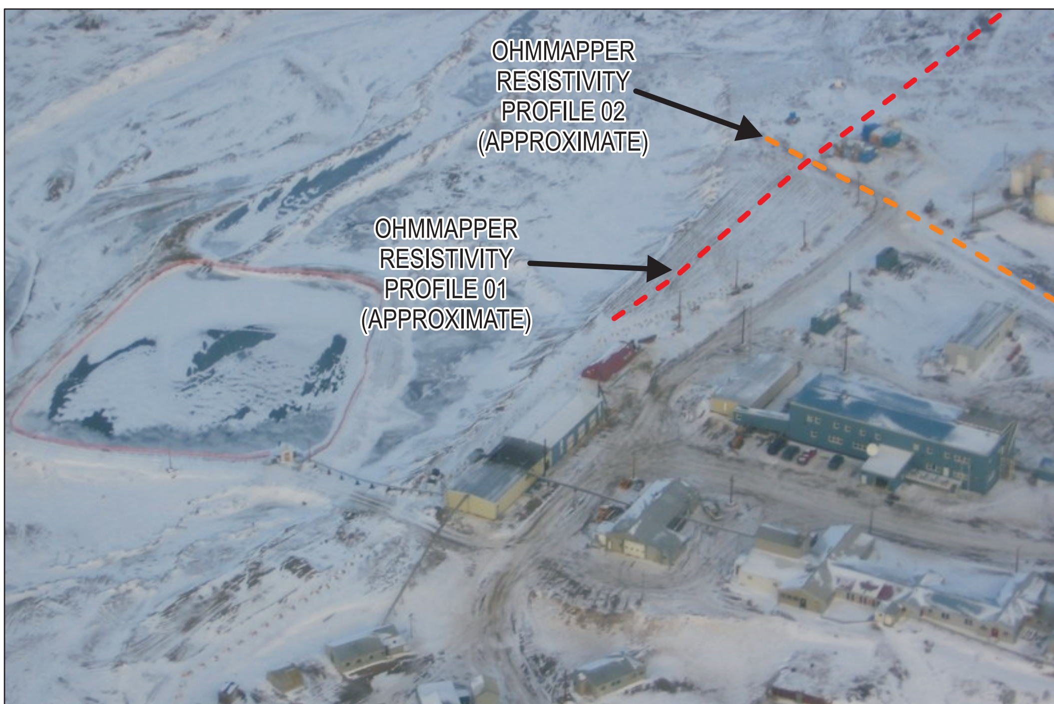


**Photo 23**
Area 8, Old Tank Farm - aerial view of the main camp and tank farms.

**Photo 24**
Area 8, Old Tank Farm - looking north towards the PEARL lab at OhmMapper Resistivity Profile 01.

**Photo 25**
Area 8, Old Tank Farm - looking north at the north end of OhmMapper Resistivity Profile 01.

**Photo 26**
Area 8, Old Tank Farm - Looking west towards the New Tank Farm at OhmMapper Resistivity Profile 02.

# APPENDIX

## APPENDIX A GEOPHYSICAL SURVEY PROCEDURES

# GEOPHYSICAL SURVEY PROCEDURES

## A.1 Magnetic Survey Procedure

Two separate systems were used to collect the magnetic data. A Geometric G-858 cesium magnetometer was used to collect the field data at each landfill site or debris area and a Geometric G-856 proton precession magnetometer was used as a magnetic base station to collect background total magnetic field readings during the course of the survey.

The G-858 unit was configured using two vertically displaced sensors with a 1 m separation and was programmed to read every 0.1 seconds. This translated to a horizontal sampling resolution of approximately one reading every 8 cm along each profile line. All data collected was logged to an internal data logger with the GPS data being integrated into the same file. Each landfill site was walked along parallel lines spaced at approximately 5 m intervals.

The magnetic base station readings were collected at a location 60 m west of the Landfill, approximately 593420E, 6813080N. The area was isolated from traffic and had no undesirable metallic debris that might influence the readings. The G856 was installed with a single sensor and then programmed to take a reading every 10 seconds. This data was logged automatically and later used to correct the total field data collected over the survey area and provide a measure of quality control.

## A.2 Magnetic Theory

The theory behind magnetic or gradiometer data at its simplest level involves taking a point measurement of the earth's total magnetic field strength at a specific location at an instant in time. The earth is surrounded by a magnetic field. The field strength varies with time (diurnal variations) primarily caused by the influence of solar activity, which is highest during periods of intense solar flaring (sunspot activity) and conversely lowest level when the sun is quiet. Usually these variations are less than a few hundred gammas (nanoTesla, nT) in magnitude. Variations due to location on the earth's surface are solely a function of relative position with respect to the earth's magnetic poles. As the magnetic poles drift, so do the location readings. The earth's magnetic field varies by approximately 35,000 gammas from the magnetic poles to the equator.

Magnetic data is useful in locating objects such as buried steel and other ferrous objects since the earth's background magnetic field can be distorted by the presence of magnetized rocks, soils and ferrous (iron) objects. This is because these objects also possess an induced field in the presence of the background field and the background and induced fields will combine to produce a resultant total field strength that is a summation of the two magnetic field vectors. Objects can be detected by subtracting the earth's background magnetic field from field data and contouring the remainder. In general, the effect from natural materials such as rocks and soils is small over small areas and is usually less than 1 gamma/m.

Concentrated ferrous debris, however, can cause magnetic field distortions of up to 30,000 gammas/m.

A gradiometer differs from a magnetometer only in that two readings of the total magnetic field strength are taken at a specific location and time. The two readings are taken at slightly different positions; therefore, the difference between the two readings is a reflection of the magnetic gradient at that location. This reading is sensitive to near surface ferrous objects and gradient anomalies can, therefore, be interpreted as an indicator of potential targets. This difference is plotted as contours on a grid system and provides a visual representation of the location and distribution of magnetic gradient anomalies.

The G-856 proton precession magnetometer takes advantage of the fact that molecules of hydrocarbon fluids behave as small magnets (dipoles) and, therefore, will align or polarize themselves with the lines of magnetic flux when exposed to a uniform magnetic field. In the sensor head this is achieved in a controlled fashion by means of an energized electric coil. When the uniform magnetic field is removed, the molecules will rotate (precess) from their polarized orientation in a circular fashion around the direction of the ambient or local magnetic field lines (similar to the way a spinning top will wobble in a circular fashion in the presence of a gravitation field). The rate at which this precession occurs is proportional to the intensity of the ambient field. By measuring the rate (frequency) of precession and applying a well known atomic constant (the gyromagnetic ratio of the proton), one can calculate the total magnetic field strength at a specific point in time.

By using this technique to measure total magnetic field strength, measurements can be made utilizing an instrument with no moving parts to an accuracy of 0.1 nT (gammas). The disadvantage of this method is that adequate time has to be allowed for the sensor system to energize (polarize the molecules) and then relax the field and take the reading. This requires a minimum reading rate of no faster than one reading every three seconds. As the sensor has to be stationary during this period it is difficult to collect data at a high enough rate for real-time evaluation of the data. In addition, the system stability and accuracy degrades in the presence of high magnetic gradients and background noise. If correctly tuned and setup, however, proton precession magnetometers are ideal for monitoring background magnetic readings at a static location.

A G858 cesium vapour magnetometer offers several advantages over the more traditional proton precession or flux-gate magnetometers, particularly for collecting field readings over large survey areas. These advantages include more stable readings in high field gradients, increased resolution, (0.01 nT) and high sampling rates. This means that it is possible to use these devices as "real-time" detectors when seeking magnetic anomalies and it also allows data to be collected rapidly with high horizontal data resolutions while walking a site without having to stop at each reading location.

The theory behind how cesium vapour magnetometers work is based on quantum physics. Briefly, the sensor head measures the total magnetic field at a point in space at a reading interval of up to 10 times a second. It does this by shining circularly polarized light through a glass chamber (called an absorption cell) containing a small amount of cesium vapour in a partial vacuum. Cesium vapour is used because it only has one electron present in the atom's outermost electron shell and this simplifies the excitation effect being measured. This electron can exist in nine different energy states in the presence of an external magnetic field. This effect is called Zeeman splitting. The energy differences from one Zeeman level to the next are approximately equal and are proportional to the strength of the ambient external magnetic field. By shining circularly polarized light generated by a cesium lamp through the absorption cell and measuring the Larmor frequency of an injected RF signal (called the H1 drive) required to reset photons within the absorption cell (so that they can absorb that light), one can measure their changes in energy and hence the ambient magnetic field strength. The constant of proportionality between the Larmor frequency and the ambient magnetic field strength is 3.498572 Hz/nT. This value is valid for the full range of typically encountered magnetic field values (20K nT to 90K nT).

## A.3 Magnetic Survey Procedure

A GPS unit attached to the G-858 magnetometer was used to record the location of the magnetometer survey. A real time differentially corrected GPS was used with the G-858 roving field unit to provide integrated sub-meter positioning accuracy. A Trimble AG132 GPS unit was used as the main GPS receiver collecting GPS positioning data and transmitting NMEA GPS strings to the G-858. Recordings were at one second intervals with the gradiometer data. The GPS data collected by the Trimble AG132 GPS receiver was corrected in real time by a CDGPS RTCM correction box that uses satellite relayed correction data from an MSAT satellite in geo-synchronous orbit. The RTCM corrections were calculated using the GPS correction data generated by the Canadian GPS base station grid (CACS) and location of the field roving unit. If the differential signal lock was lost, the data automatically is tagged as uncorrected and can be reviewed for quality control during the post-processing. The resulting accuracy of the system is less than ±0.5 metres horizontally and 2 metres vertically. All geophysical survey lines are identified by small black cross-marks on the attached figures.

The Liard Highway Checkpoint Road Maintenance Camp is found within UTM Zone 10 West with Longitude 123°W as the central meridian.

The survey procedure while collecting geophysical survey data was as follows:

- The perimeter of the Landfill Survey Area (Zone 5) was located based on previous site maps and environmental investigations. Minor adjustments were made to this location in the field due to the presence of visible debris and/or severe terrain. Data profiles were then collected by walking parallel lines at intervals of 2.5 to 3 m for the landfill area. Pinflags placed at survey line ends at 10 m intervals were used as visual references for walking straight and consistent lines.

- Outside the landfill area, the Magnetometer was put in "search" mode to help locate other suspected buried debris. If an area were located, the data would then be logged.

## A.4 Magnetic Data Processing

The magnetic gradient data collected during the main geophysical survey was processed on site to provide plots indicating the distribution of buried debris. These plots were then used as guides to relocate the anomalous areas using the G-858 in detection mode and to place pin flags to outline these locations to facilitate sampling.

The following analysis steps were carried out on all data sets.

- the data was reviewed and all bad magnetic readings removed;
- the GPS UTM data was reviewed and edited as necessary; and
- the magnetic data for each sensor was corrected for diurnal drift and micro-pulsations using the magnetic base station data yielding top and bottom total magnetic field plots.

The final results are summarized in figures comprising gradient and top and bottom total magnetic field plots for all areas surveyed.

## A.5 Magnetic Data Interpretation

Variations in the total magnetic field (anomalies) are indicative of buried metallic debris. In gradiometer mode, two sensors are used and magnetic readings are taken at both sensors and compared. The difference between the two readings provides the magnetic gradient, which is proportional to the quantity of buried ferrous metal. The magnetometer data is processed and plotted as a colour contour map with UTM coordinates. Site plan information is integrated as a layer on the drawing.

On the colour contour map, anomalies appear as areas of high magnetic gradients either red (positive) or blue (negative), on a clear background of limited or no response. There is no significance to whether the anomaly is red or blue. The red/blue colours simply represent the positive/negative gradient. Locations with high magnetic gradients will correspond to locations with ferrous debris and, therefore, the landfill or debris piles. The extent and intensity of the total magnetic field readings usually indicates whether one is looking at a small highly magnetic surface object or conversely a more massive, deeply buried object.

Interpreting the data is done by grouping the magnetic gradient anomalies (red or blue areas) into anomaly areas. Anomaly areas are groupings of individual magnetic responses that may be related based on knowledge of site conditions (buried concrete rubble with rebar, buried barrels, wood with nails, tin cans etc.). These anomaly groupings are then compared against the total magnetic field readings for those locations in order to gauge their potential significance.

The anomalies perimeters are marked on the geophysical figures. This is an estimate of the extent of buried debris as indicated by the presence of ferrous debris. Buried debris that has no ferrous content will not be detected by the magnetometer.

## A.6 Ground Penetration Radar (GPR)

Ground penetrating radar is a non-destructive geophysical technique capable of delineating materials that have contrasting bulk electrical properties. Operationally, GPR systems transmit a short duration electromagnetic (EM) pulse into the ground generating a downward propagating wave front. At each interface, a portion of the wave front energy is reflected back to the surface. A radar receiver, located at the surface, detects (and typically digitally samples and records) the reflected EM pulse. The detected pulse amplitude and delay time are a function of the subsurface electrical properties. The strength of the reflected signal is approximately proportional to the difference in dielectric contrasts at the reflecting interface. The pulse transmit/receive delay time is inversely proportional to the EM propagation velocity (determined by the bulk electrical properties), and proportional to the distance from the receiver at the surface to the reflecting stratigraphic interface (Davis and Annan, 1989).

Changes in dielectric constants and electrical conductivity also affect signal attenuation. High conductivities, as found in fine-grained materials such as silts and clays, can increase signal attenuation and limit signal propagation to a few metres or less. Saline (salt water) pore water in otherwise resistive sediments can result in the same effect. Conversely, in areas not affected by excessive signal attenuation, interfaces deeper than 50 m can be detected.

Table A1 shows typical electrical properties of various materials. However, it should be noted that these properties of the materials do vary from site to site. The properties can be approximated site-specifically using ground truth information or by using techniques such as Wide Angle Reflection Refraction (WARR) Sounding.

TABLE A1: ELECTRICAL PROPERTIES OF MATERIALS (MISC. SOURCES)

| Material Type | Dielectric Constant | Velocity (m/ns) | Conductivity (mS/m) | Attenuation (dB/m) |
|---|---|---|---|---|
| Wet Sand | 10-30 | 0.05-0.09 | 0.2-10 | 0.03-0.3 |
| Sand | 3-5 | 0.13-0.17 | 0.01-1 | 0.01 |
| Silts | 5-30 | 0.05-0.13 | 0.5-100 | 1-100 |
| Clay | 5-40 | 0.05-0.13 | 5-1000 | 1-300 |
| Ice | 3-5 | 0.13-0.17 | 0.01-1 | 0.01-1 |
| Granite | 4-6 | 0.12-0.15 | 0.001-3 | 0.01-1 |
| Fresh Water | 80 | 0.033 | 0.5-2 | 0.1 |
| Salt Water | 80 | 0.033 | $5 \times 10^3$-$3 \times 10^4$ | 1000 |

By exploiting the sensitivity to variations in bulk material electrical properties, GPR is an established method for detecting subsurface anomalies and voids, profiling complex geological stratigraphic components, and mapping natural phenomena.

## A.7 Resistivity Fundamentals

The physics of mapping permafrost and arctic soils have not changed a great deal over the past 50 years. Many of the geophysical techniques which have been successfully employed in permafrost terrain have been available for some time. Electrical resistivity methods were used in the early 1970's, but suffered due to contact resistance problems due to the frozen ground. The instrumentation has undergone some improvements since then, but methods such as electrical resistivity are still hampered by contact resistance problems, particularly during winter exploration programs. Newly available systems such as the capacitively coupled resistivity systems (VCHEP and OhmMapper) offer a means to collect resistivity data without the contact resistance problems encountered by other resistivity systems.

For any geophysical technique to be successfully employed, there must be a mappable contrast in physical properties. For permafrost, the physical properties of interest include: electrical, acoustic, and dielectric constant. Previous research has provided good evidence of the contrasts in these properties with variations in temperature and ice content (Hoekstra et al, 1975, Rennie et al 1978, Rosenburg et al, 1984). In the case of the electrical properties, as the temperature of the subsurface decreases below 0 Centigrade (C), and/or as the ice content increases, the resistivity of subsurface materials increases substantially as illustrated in Figures 1a and 1b.

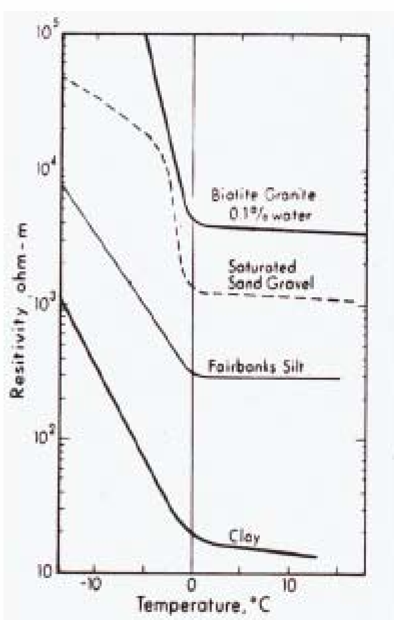


FIGURE 1a Relationship between

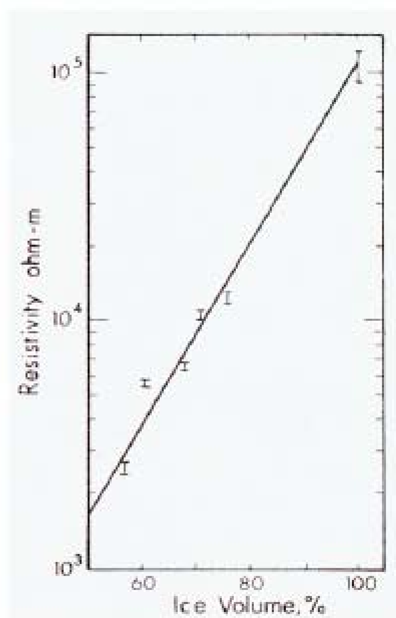


FIGURE 1b Relationship between

Figure 2 illustrates ranges of resistivity for both frozen and unfrozen soil types in the vicinity of Fort Simpson, NT. It should be noted that there is considerable overlap of resistivity values for the various soil types.

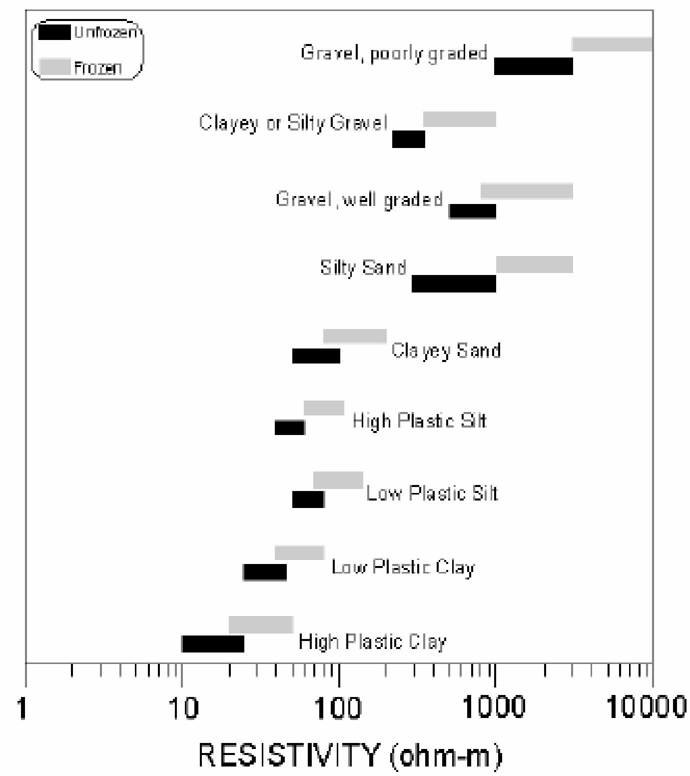


FIGURE 2 Range of resistivity values for frozen and unfrozen soils types in the Ft. Simpson, NT region (J.A. Rennie, D.E. Reid & J. Henderson; 1978)

This can make it difficult to distinguish between variations in soil/bedrock type and variations in ice content. Conversely, if one knows the nature of the soil/bedrock type, the resistivity measured can be used to determine whether it is frozen or not. Given a known soil/bedrock type, the areas showing higher resistivity values would be expected to be frozen.

## A.8 OhmMapper Resistivity System

For the field investigation at Eureka, the Geometrics OhmMapper Resistivity system was utilized. The resistivity data is collected as a series of discrete apparent resistivity measurements with varying collection parameters that are then combined and inverted as a data set. The result is a true resistivity profile cross-section of the subsurface. Depending on the site characteristics and history, the resistivity data provides information on variations in soil and geologic strata, subsurface boundaries and variations in moisture conditions.

The Geometrics TR1 OhmMapper Resistivity system is a capacitively coupled towed dipole-dipole array system. The towed coaxial cable array has a transmitter and receiver that can be operated with dipoles of varying lengths and separations to control the effective sounding depth. The data collected is processed to create a vertical two-dimensional cross-section by surveying a single geophysical profile with different dipole lengths and separations. For this project, dipole lengths of both 5 and 10 m were used, with dipole separations varying between 5 and 20 m.

The OhmMapper induces electric currents that are injected into the ground creating a regulated AC (16.5 kHz) current loop over the entire length of the transmitting dipole. The resulting voltage potential difference is measured across the entire length of the receiver dipole. Eight regulated current levels with 1% variation or less are transmitted to the receiver and communicate which current level it is using by encoding a 3 bit binary number. This code is superimposed on the AC current signal that the transmitter generates. To synchronize the receiver with the transmitter and to ensure that the receiver measurements are in phase, a one-second 2 Hz timing pulse is superimposed on the AC current signal. Once the receiver has locked onto the transmitter signal and has determined that the signal level is within range and stable, the voltage reading is sampled. The pseudo resistivity is calculated using the induced current values at the transmitter, the measured voltage drop at the receiver, and Ohm's Law. By applying an appropriate geometric factor (which is a function of the dipole length and dipole separation) and calculating the effective voltage drop at a unit current of 1 mA, the apparent resistivity value for that point is calculated.

All data was logged with an internal data logger with real-time differentially corrected global positioning system (DGPS) locations being integrated into the same file. The resistivity data was collected at a rate of 2 readings per second for the OhmMapper, and 1 reading per second for the GPS system.

The raw resistivity data is then processed and filtered using custom build Matlab routines that preserve the elevation data. The commercial program RES2DINV is used to reduce and convert the apparent resistivity data with positional and elevation information of each data point into a true vertical resistivity profile. This is completed by an iterative least squares correlation between the measured and modelled (inverted) apparent resistivity values based on a defined resistive model.

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Rozenberg, G., Henderson, J. and MacDonald, J. C., 1985, The use of transient electromagnetic data on permafrost distribution for CDP static correction, 55th Ann. Internat. Mtg: Soc. of Expl. Geophys., Session:AG.9.

# APPENDIX

## APPENDIX B EBA GEOPHYSICAL TERMS AND CONDITIONS

## GEOPHYSICAL REPORT – GENERAL CONDITIONS

This report incorporates and is subject to these "General Conditions".

### 1.0 USE OF REPORT

This geophysical report pertains to a specific site, a specific development, and a specific scope of work. It is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site or proposed development would necessitate a supplementary investigation and assessment.

This report and the assessments and recommendations contained in it are intended for the sole use of EBA's client. EBA does not accept any responsibility for the accuracy of any of the data, the analysis or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than EBA's client unless otherwise authorized in writing by EBA. Any unauthorized use of the report is at the sole risk of the user.

This report contains figures, maps, drawings and sketches that represent processed geophysical data collected at a specific site. This processed data will have inherent interpretation assumptions and accuracies that are discussed in the report. Consequentially the report can only be considered in its entirety and individual figures, maps, drawings and sketches shall not be distributed without the text of the report unless authorized in writing by EBA.

This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of EBA. Additional copies of the report, if required, may be obtained upon request.

### 2.0 LIMITATIONS OF REPORT

This report is based solely on the conditions which existed on site at the time of EBA's investigation. The client, and any other parties using this report with the express written consent of the client and EBA, acknowledge that conditions affecting the geophysical assessment of the site can vary with time and that the conclusions and recommendations set out in this report are time sensitive.

The client, and any other party using this report with the express written consent of the client and EBA, also acknowledge that the conclusions and recommendations set out in this report are based on limited observations and testing on the subject site and that conditions may vary across the site which, in turn, could affect the conclusions and recommendations made.

The client acknowledges that EBA is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the client.

### 3.0 INFORMATION PROVIDED TO EBA BY OTHERS

During the performance of the work and the preparation of this report, EBA may have relied on information provided by persons other than the client. While EBA endeavours to verify the accuracy of such information when instructed to do so by the client, EBA accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

### 4.0 LIMITATION OF LIABILITY

The client recognizes that property containing contaminants and hazardous wastes creates a high risk of claims brought by third parties arising out of the presence of those materials. In consideration of these risks, and in consideration of EBA providing the services requested, the client agrees that EBA's liability to the client, with respect to any issues relating to contaminants or other hazardous wastes located on the subject site shall be limited as follows:

1. With respect to any claims brought against EBA by the client arising out of the provision or failure to provide services hereunder shall be limited to the amount of fees paid by the client to EBA under this Agreement, whether the action is based on breach of contract or tort.
2. With respect to claims brought by third parties arising out of the presence of contaminants or hazardous wastes on the subject site, the client agrees to indemnify, defend and hold harmless EBA from and against any and all claim or claims, action or actions, demands, damages, penalties, fines, losses, costs and expenses of every nature and kind whatsoever, including solicitor-client costs, arising or alleged to arise either in whole or part out of services provided by EBA, whether the claim be brought against EBA for breach of contract or tort.

### 5.0 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. EBA does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

### 6.0 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

## 7.0 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. EBA does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

## 8.0 SURFACE WATER AND GROUNDWATER CONDITIONS

Surface and groundwater conditions mentioned in this report are those observed at the times recorded in the report. These conditions vary with geological detail between observation sites; annual, seasonal and special meteorologic conditions; and with development activity. Interpretation of water conditions from observations and records is judgmental and constitutes an evaluation of circumstances as influenced by geology, meteorology and development activity. Deviations from these observations may occur during the course of development activities.

## 9.0 JOB SITE SAFETY

EBA is only responsible for the activities of its employees on the job site and is not responsible for the supervision of any other persons whatsoever. The presence of EBA personnel on site shall not be construed in any way to relieve the client or any other persons on site from their responsibility for job site safety.

## 10.0 DISCLOSURE OF INFORMATION BY CLIENT

The client agrees to fully cooperate with EBA with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The client acknowledges that in order for EBA to properly provide the service, EBA is relying upon the full disclosure and accuracy of any such information.

## 11.0 STANDARD OF CARE

Services performed by EBA for this report have been conducted in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Geophysical interpretations have been applied in developing the conclusions and/or recommendations provided in this report. No warranty or guarantee, express or implied, is made concerning the interpretations, comments, recommendations, or any other portion of this report.

## 12.0 EMERGENCY PROCEDURES

The client undertakes to inform EBA of all hazardous conditions, or possible hazardous conditions which are known to it. The client recognizes that the activities of EBA may uncover previously unknown hazardous materials or conditions and that such discovery may result in the necessity to undertake emergency procedures to protect EBA employees, other persons and the environment. These procedures may involve additional costs outside of any budgets previously agreed upon. The client agrees to pay EBA for any expenses incurred as a result of such discoveries and to compensate EBA through payment of additional fees and expenses for time spent by EBA to deal with the consequences of such discoveries.

## 13.0 NOTIFICATION OF AUTHORITIES

The client acknowledges that in certain instances the discovery of hazardous substances or conditions and materials may require that regulatory agencies and other persons be informed and the client agrees that notification to such bodies or persons as required may be done by EBA in its reasonably exercised discretion.

## 14.0 OWNERSHIP OF INSTRUMENTS OF SERVICE

The client acknowledges that all reports, plans, and data generated by EBA during the performance of the work and other documents prepared by EBA are considered its professional work product and shall remain the copyright property of EBA.

## 15.0 ALTERNATE REPORT FORMAT

Where EBA submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed EBA's instruments of professional service), the Client agrees that only the signed and sealed hard copy versions shall be considered final and legally binding. The hard copy versions submitted by EBA shall be the original documents for record and working purposes, and, in the event of a dispute or discrepancies, the hard copy versions shall govern over the electronic versions. Furthermore, the Client agrees and waives all future right of dispute that the original hard copy signed version archived by EBA shall be deemed to be the overall original for the Project.

The Client agrees that both electronic file and hard copy versions of EBA's instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except EBA. The Client warrants that EBA's instruments of professional service will be used only and exactly as submitted by EBA.

The Client recognizes and agrees that electronic files submitted by EBA have been prepared and submitted using specific software and hardware systems. EBA makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.