2008
Environmental Investigation and Remediation of Contamination at Quttinirpaaq National Park, Ellesmere Island, Nunavut

Prepared by

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EXECUTIVE SUMMARY

In 2008, at the request of Parks Canada Agency (PCA), the Environmental Sciences Group (ESG) performed an environmental investigation at Tanquary Fiord, Lake Hazen and Ward Hunt Island in Quttinirpaaq National Park (QNP), northern Ellesmere Island. This work is the continuation of a multiyear project started in 2004 to investigate the extent of hydrocarbon and other contamination at QNP sites, and to identify management and remediation options for these sites. The main objectives of the 2008 work were to determine the degree and extent of contamination at Lake Hazen and Ward Hunt Island, and to carry out remediation of the Tanquary Fiord and Lake Hazen sites.

Since 2005, ESG has conducted field and laboratory experiments investigating the use of bioremediation as a treatment technology for hydrocarbon contamination at QNP sites. Samples collected from the experimental test plots at both sites in 2007 indicated that soil petroleum hydrocarbon (PHC) concentrations were below criteria and that the experiment could be decommissioned in 2008. Samples collected from the Tanquary Fiord test plots in 2008 indicated little change in the PHC content from 2007 to 2008. Three previous years of experimental results show continued success in removing hydrocarbons from Tanquary Fiord and Lake Hazen soils, particularly by use of landfarms amended with surfactants and fertilizers. The findings from this experiment were the basis of the design for the field-scale landfarms used to remediate hydrocarbon-contaminated soil at both Lake Hazen and at Tanquary Fiord.

At Tanquary Fiord, samples were collected from the landfarm that was constructed in 2007 to remediate hydrocarbon-contaminated soil excavated from areas around the site. According to ESG protocol, the landfarm may be decommissioned when the 95 percent upper confidence limit (95% UCL) of the total PHC concentrations in the samples is below 2500 ppm (*i.e.* there is a 95% chance that the true mean value for the PHC concentrations in the samples is below 2500 ppm). Samples collected from the landfarm indicated that the 95% UCL of the 19 samples analyzed was 2,400 ppm, below the remediation criteria of 2,500 ppm. Since no further remediation is required, the soil can be removed from the landfarm; it is recommended that the landfarm structure be used for the remediation of any soil contaminated by new fuel spills. While this landfarm soil is below criteria, it still contains trace amounts of hydrocarbons and may have a noticeable odour; therefore, this soil should not be disposed of in any areas used regularly

by PCA staff or visitors. ESG recommends that the soil be spread thinly in the incinerator area, where the soil may not be pristine.

The horizontal and vertical extents of hydrocarbon-contaminated areas at Lake Hazen were delineated. Soil samples from these test pits were analyzed for total petroleum hydrocarbons (TPH) using PetroFLAG™ test kits. ESG used a risk-based evaluation matrix to define areas with hydrocarbon-contaminated soils requiring remediation. A landfarm similar to the one established in 2007 at Tanquary Fiord was established at Lake Hazen in 2008. Approximately 27 m^3 of contaminated soil was excavated from both contaminated sites and placed in the on-site landfarm for treatment. Following confirmatory sampling, the excavations were backfilled using clean soil from the site. A monitoring program was undertaken to verify the decrease in hydrocarbon concentrations in the landfarm soils over time. PHC results from the first set of samples collected from the landfarm in 2008 indicated a UCL of 4,800 ppm. The landfarm is to be maintained by PCA staff in 2009, following the instructions in Appendix D. It may be decommissioned when the UCL of the PHC concentrations in the samples collected from the landfarm is below 2,500 ppm.

At Ward Hunt Island, previous site investigations have indicated areas of inorganic contamination in the soil, and the presence of full and partly full fuel barrels located around the site. Three areas of inorganic contamination were delineated using a tight grid (1 m x 1 m). Based on the soil sample analysis, ESG recommends that 0.3 m^3 of soil be excavated from each of the three areas during the 2009 field season. Samples were also taken from the contents of each of the fuel barrels located on site, according to the ESG barrel sampling protocol. The results from the barrel sample analysis have been used by a research group at the Royal Military College (RMC) in Kingston, ON, to design a waste fuel burner that can be used to dispose of the barrel contents. The incineration of the waste fuel present at Ward Hunt Island shall be conducted by researchers and technicians from RMC during the 2009 field season.

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LIST OF ABBREVIATIONS

Abbreviation	Full Name
As	arsenic
BTEX	benzene, toluene, ethylbenzene and xylenes
CCME	Canadian Council of Ministers of the Environment
Cd	cadmium
CFU	colony-forming units
Co	cobalt
Cr	chromium
Cu	copper
DEW	Distant Early Warning
DLCU	DEW Line Cleanup
DLCC	DEW Line Cleanup Criteria
EC	Environment Canada
ESG	Environmental Sciences Group (RMC)
GPS	global positioning system
HAPT	hydrocarbon absorbent polymer technology
HDPE	high-density polyethylene
Hg	mercury
INAC	Indian and Northern Affairs Canada
N	nitrogen
Ni	nickel
P	phosphorus
ppm	parts per million; equivalent to µg/g (microgram of substance per gram of soil or sediment sample) and mg/L (milligrams of substance per litre of aqueous solution)
ppb	parts per billion; equivalent to ηg/g (nanograms of substance per gram of soil or sediment sample) and µg/L (micrograms of substance per litre of aqueous solution)
PAH	polycyclic aromatic hydrocarbon
Pb	lead
PHC	petroleum hydrocarbon
PHC CWS	CCME Canada-Wide Standard for Petroleum Hydrocarbons
QAQC	quality assurance/quality control
QNP	Quttinirpaaq National Park

LIST OF ABBREVIATIONS (CONT'D)

RMC	Royal Military College
TDGA	Transportation of Dangerous Goods Act
TKN	total Kjeldahl nitrogen
TPH	total petroleum hydrocarbons
UCL	upper confidence limit
USEPA	United States Environmental Protection Agency
UXO	unexploded ordinance
XRF	X-ray fluorescence
Zn	zinc

I. INTRODUCTION

Quttinirpaaq National Park (QNP) is located on northern Ellesmere Island in the Canadian Arctic (Map I-1). Located within QNP are research, exploration and park operations camps, as well as historic and current fuel caches. Previous environmental site assessments at 17 locations within the park found petroleum hydrocarbon (PHC) concentrations in excess of the relevant environmental criteria at five locations (EBA, 2002; 2003). In 2004, the Environmental Sciences Group (ESG) completed an environmental investigation at the following sites in QNP: Tanquary Fiord, Ward Hunt Island, Fort Conger, Lake Hazen and Gilman River (ESG, 2005a). Results indicated that PHCs were the main contaminants of concern at these sites, with the exception of Fort Conger. Most contamination found to date has consisted of heavier hydrocarbons (F3 and F4 fractions). At the Fort Conger Historical Site, significant inorganic element (arsenic and metals) and polycyclic aromatic hydrocarbon (PAH) contamination was found. The extent of contamination at Tanquary Fiord, Ward Hunt Island, Lake Hazen and Gilman River was delineated in 2005 (ESG, 2006). Inorganic contamination was also found at Ward Hunt Island ESG, 2007b).

A research program was conducted to investigate the feasibility of using bioremediation to treat hydrocarbon-contaminated soils at QNP (ESG, 2005b). ESG has carried out treatability tests at laboratory (microcosms, miniature biopiles) and field scales using soil contaminated with both lighter hydrocarbons (*i.e.* diesel, mostly F2 fraction) and heavier hydrocarbons (*i.e.* lubricating oils, mostly F3 fraction) from several sites in QNP (Tanquary Fiord, Lake Hazen and Ward Hunt Island). The results to date indicate that bioremediation shows good potential as a treatment method for hydrocarbon-contaminated soils at the site (ESG, 2005b; 2007; ongoing studies).

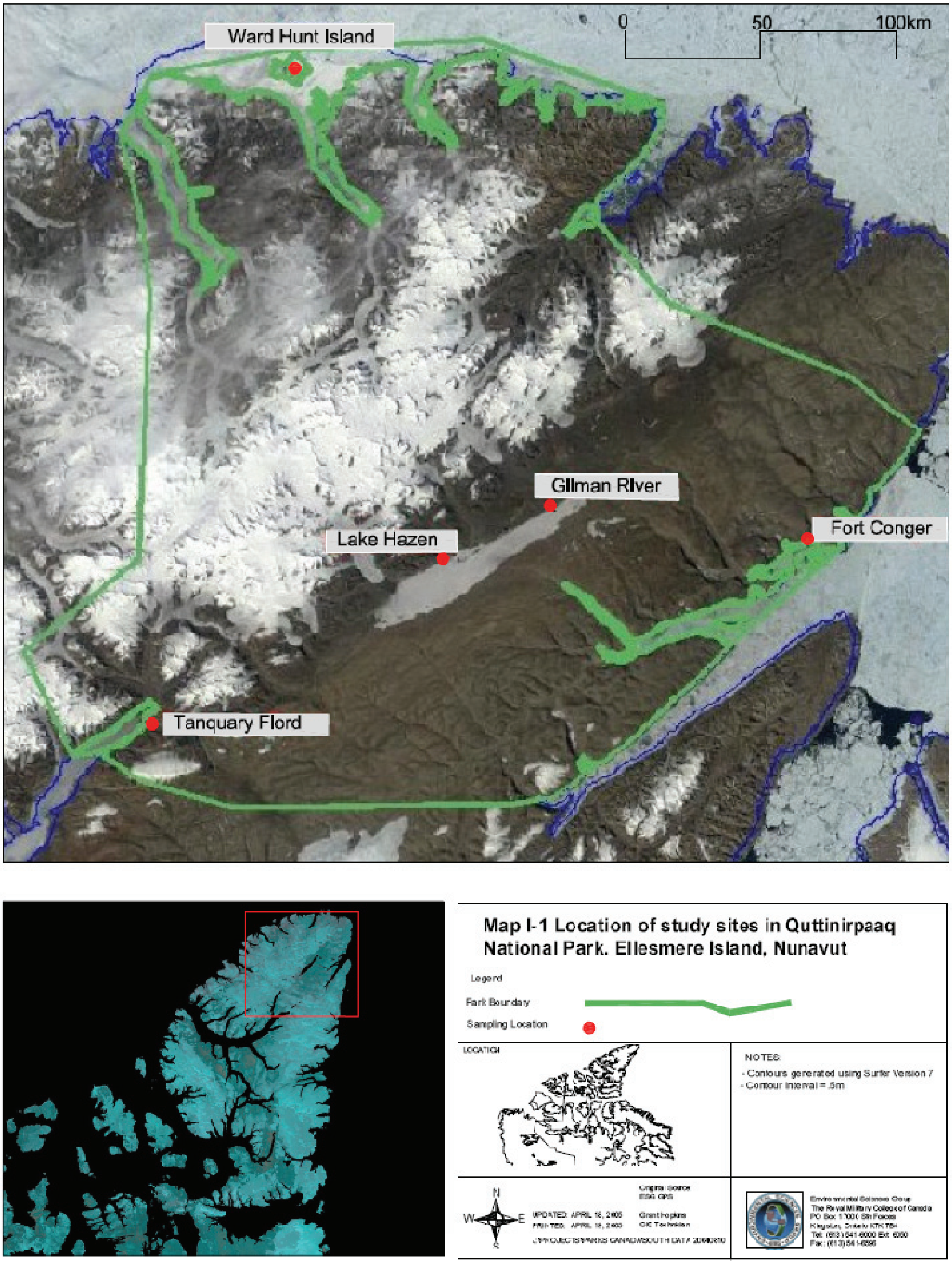
In the 2007 field season, the delineated areas of hydrocarbon contamination at Tanquary Fiord were excavated and the contaminated soil was remediated using landfarm technology. The landfarm was constructed in 2007 and monitoring samples were taken in 2007 and 2008.

The objectives of the 2008 investigation and remediation in Quttinirpaaq National Park were to:

- assess bioremediation effectiveness of the landfarm at Tanquary Fiord;
- complete remediation of the Lake Hazen site;
- delineate the extent of inorganic contamination at the Ward Hunt Island site; and

##################• assess the barrels in the historic fuel cache on Ward Hunt Island.

Map I-1: Location of study sites in Quttinirpaaq National Park, Ellesmere Island, Nunavut



II. BACKGROUND

A. Study Area Description and Physical Characteristics

1. Study Area Geographic Location and Description

QNP is located on the northeastern portion of Ellesmere Island (Map I-1). The park covers approximately 37,775 km^2 and is the second-largest park in Canada. Grise Fiord (population 148), located almost 800 km away on the southeastern tip of Ellesmere Island, is the community nearest to the park. Canadian Forces Station Alert (latitude 82° 30'N and longitude 62° 20' W) is situated approximately 40 km from the northeastern boundary of QNP.

QNP has a rich archaeological heritage, as sites within it have been used by Inuit for the past 4,000 years. During the late 1800s and early 1900s, several Arctic expeditions explored the northern Ellesmere region, using locations such as Fort Conger as overwintering and supply bases. From 1954 to 1973, the Defence Research Board (affiliated with the Department of National Defence) established field camps for scientific research at Ward Hunt Island, Lake Hazen, Tanquary Fiord and Gilman Glacier (Hattersley-Smith, 1974). Since then, these field stations have been used by various parties as research and expedition bases. In 1988, Ellesmere Island National Park Reserve (now known as QNP) was established, and ownership of the field stations was transferred from the Defence Research Board to PCA. The Tanquary Fiord camp is the main park headquarters and visitor reception area. In addition to the field stations, there are fuel caches and field research camps scattered throughout the park.

2. Physical geography

Detailed descriptions of the physical geography and biology of the study area are found in ESG (2005a). A brief summary is presented below.

The mountains of northern Ellesmere Island are the second highest in North America, after the Canadian Rockies. Bedrock geology is complex because of the uplift, folding and faulting of rock layers that occurred during several mountain-building events (Gray, 1997). The high elevations of the park are covered with an ice cap, with numerous glaciers flowing north toward the Arctic Ocean and south toward the Hazen Plateau. The ground surface is underlain by continuous permafrost. Permafrost studies at nearby Alert have shown that permanently frozen ground exists to a depth of at least 480 m (Gray, 1997). The active layer, which is the layer of surface soil that thaws each summer, is less than 1 m deep in most places.

QNP is classified as a polar desert, receiving an average of 60 mm of precipitation annually. Temperatures are very low year round. Average Canadian climate normals for the period 1971-2000 from the nearest Environment Canada weather station at Alert indicate that the mean daily temperature for January through March is -33 ˚C, with a record low of -50 ˚C (EC, 2005). In July, the mean daily maximum is 6 ˚C with a record high of 20 ˚C. Alert has only 20 to 30 frost-free days per year. There are 24 hours of daylight for six months of the year, from the beginning of April until the beginning of September. Darkness arrives in mid-October and remains until the middle of March.

3. Flora and Fauna

QNP has sparse plant cover because of low precipitation, low nitrogen and phosphorus availability, and rocky soils. Despite these conditions, there are at least 116 species of vascular plants in northern Ellesmere (Hattersley-Smith, 1968), not including mosses and lichens. Mountain avens (*Dryas integrifolia*), Arctic poppies (*Papaver radicutum*) and purple saxifrage (*Saxifraga oppositifolia*) are common flowering plants. Grass-sedge meadows, characterized by foxtail grass (*Alopecurus alpinus*) and sedges (*Carex bigelowii*), are found in areas that retain soil moisture from snowmelt. Thermal oases such as Lake Hazen support richer and more abundant vegetation than does the surrounding environment.

Seven species of terrestrial mammals are found within QNP: Arctic wolves (*Canis lupus arctos*), Arctic fox (*Alopex lagopus*), muskoxen (*Ovibos moschatus*), Peary caribou (*Rangifer tarandus Pearyi*), ermine (*Mustela erminea*), collared lemmings (*Dicrostonyx groenlandicus*) and Arctic hares (*Lepus arcticus*). Of these, Peary caribou are listed as an endangered species. About 30 species of birds use habitat in the park as breeding grounds. In coastal areas, ringed seals and walrus are frequent, while whales and polar bears are rarely seen.

4. Previous Environmental Assessments

In 2001, PCA asked EBA Engineering Consultants Ltd. to perform site assessments at various fuel caches and field stations throughout QNP (EBA, 2002). Seventeen sites were assessed over a three-day period: where hydrocarbon contamination was suspected, soil samples were collected and analyzed for total petroleum hydrocarbons (TPH). A detailed site assessment was carried out on the Ward Hunt Island area in 2002 (EBA, 2003). Results from these studies indicated that hydrocarbon contamination at Wrangel Bay, Fort Conger Runway, Lake Hazen, Ward Hunt Island and Tanquary Fiord exceeded the relevant Canadian Council of Ministers of the Environment

(CCME) criteria for soil samples in residential/parkland areas. In addition, environmental site assessments were recommended for Cape Aldrich, Gilman River and the Gilman Glacier camp.

In 2004, ESG carried out an environmental investigation at five QNP sites: Tanquary Fiord, Lake Hazen, Gilman River, Ward Hunt Island and Fort Conger (Map I-1). Detailed descriptions of the sites and the results of the investigation are presented in ESG (2005a). A total of 392 soil samples, two water samples and one paint sample were analyzed. With the exception of Fort Conger, the main contamination found at QNP sites consisted of heavier hydrocarbons (F3 and F4 fuel fractions). Some inorganic contamination (*e.g.* copper and lead) was found at Lake Hazen and Ward Hunt Island. The extent and depth of hydrocarbon and inorganic contamination at Tanquary Fiord, Lake Hazen, Gilman River and Ward Hunt Island was delineated in 2005 (ESG, 2006). Volumes of contaminated soil at each site appear to be low (tens to hundreds of cubic metres).

At Fort Conger, significant inorganic element (especially arsenic, copper, lead and zinc) and PAH contamination was found (ESG, 2005a; 2006). Evidence for migration of inorganic contamination to the adjacent ocean was mixed, but considered very likely in the future because the shoreline located beside the site appears to be slumping. Plant samples from the site indicated that plants growing on the site were either taking up inorganic contaminantsor being contaminated by contaminated dust particles. A preliminary ecological risk assessment indicated that arsenic and copper concentrations at the site pose a risk to collared lemmings, although higher-trophic-level organisms, such as long-tailed jaegers, snowy owls and Arctic fox, do not appear to be at risk (ESG, 2006). Given these results and the high future likelihood of contaminant transport to the ocean, remedial action will be necessary at the Fort Conger Historical Site.

At Ward Hunt Island, historic fuel caches are degrading and could release the contents into the surrounding environment. The PHCs could eventually make their way from the soil into the Arctic Ocean.

B. General Methodology

ESG performed its environmental investigation in QNP from July 3 to July 28, 2008. Work was completed at three sites: Tanquary Fiord, Lake Hazen and Ward Hunt Island (Map I-1).

Delineation and confirmatory soil samples were taken. Delineation sampling was used to determine the horizontal extent and depth of contamination in areas of known contamination. Confirmatory sampling was used in excavated areas to verify that the remaining soil met the remediation criteria.

Barrel samples were also taken from unused fuel caches at Ward Hunt Island. The sampling program was used to develop a remediation strategy that shall be implemented in the 2009 field season.

Detailed sampling and analytical methodologies are outlined in Appendix A. The results of sample analyses are presented in Appendix B. Quality assurance and quality control data for field and laboratory procedures are listed in Appendix C.

1. Delineation Sampling

Delineation samples are collected to determine the extent of contamination at a site. In 2008, ESG staff further delineated hydrocarbon contamination at Lake Hazen and inorganic contamination at Ward Hunt Island. Samples were collected on an approximate grid pattern, in which the grid spacing was based on the estimated size of the contaminated area: the larger the estimated area, the larger the grid spacing. For delineation of hydrocarbon-contaminated soil, test pits were excavated to permafrost (ground remaining below 0˚C through two or more consecutive winters and intervening summer, though not necessarily frozen), and soil samples were collected at surface (0-10 cm) and depth (*i.e.* permafrost). To delineate inorganic contamination, shallow test pits (maximum depth 30-50 cm) were excavated, as inorganic contaminants are typically not very mobile in soil. Samples were collected at surface (0-10 cm) and depth for each test pit. All sampling locations were marked with a steel nail and attached tag, and the location of each sample was collected using GPS equipment.

2. Confirmatory Sampling

All of the excavations from Lake Hazen were small (<100 m^2) and irregularly shaped. Soil samples were collected from the perimeter and bottom of the excavation, using an approximate 3m-x-3m spacing. All samples collected from each excavation were analyzed using field test kits. Approximately 10 percent of the confirmatory samples were subsequently analyzed in southern laboratories for quality control purposes.

3. Barrel Sampling

At Ward Hunt Island, 105 barrels identified at the Ward Hunt Island main camp are no longer in use but contain unidentified liquids. Barrel sampling was conducted to identify the contents of the barrels and determine the quantity of fluids for disposal. The results from the barrel samples were used to determine an appropriate method for on-site disposal and identify any barrel contents containing contaminants above the guideline, which could necessitate off-site disposal (see Section II.C.1: Cleanup Criteria).

4. Analysis

Because hydrocarbons are the main contaminant found in the park to date, most soil samples were analyzed for either TPH or CCME fuel fractions (see Section II.C.3: Soil criteria for PHCs) of petroleum hydrocarbons (PHCs). In the PHC analysis, hydrocarbons are categorized into four fuel fractions, based on their molecular weight (see Section II.C.3: Soil criteria for PHCs). The TPH and PHC analyses use different methods (summarized in Appendix A), but the results obtained are broadly comparable. Results from a subset of samples analyzed using both techniques indicate that the CCME Canada-wide standard for petroleum hydrocarbons (PHC CWS) method tends to give slightly higher values, because it uses a more aggressive extraction technique. However, for the purpose of evaluating hydrocarbon concentrations with regard to the cleanup criteria, the results obtained using both methods are almost always in agreement. A comparative investigation of techniques for analyzing hydrocarbons was presented in ESG (2005b).

At Ward Hunt Island, samples were collected for inorganic analysis, as well as barrel content identification. The detailed analytical methods are summarized in Appendix A.

5. Remediation

Remediation of hydrocarbon-contaminated soil in Arctic regions is challenging, because the sites are remote and there is a very short workable field season. Bioremediation is a promising treatment technology that uses native soil microorganisms to degrade PHCs into the harmless by-products carbon dioxide, water and biomass. Factors such as temperature, nutrient supply, aeration and bioavailability of contaminants can affect the efficiency of microbial treatment of hydrocarbon-contaminated soils. Treatability studies, which define optimal growth conditions for native microbes in soils from a particular region, must be undertaken before on-site bioremediation can be implemented.

Since 2004, ESG has carried out laboratory and field bioremediation research to investigate the potential for bioremediation of hydrocarbon-contaminated soils in QNP. The results from these projects are discussed in more detail as part of the research program results (ESG, 2005b; 2007). Overall, both laboratory and field treatability studies have indicated that bioremediation shows good potential to treat hydrocarbon-contaminated soils in QNP, with significant decreases noted in soil hydrocarbon concentrations. Given the success of these pilot experiments, bioremediation has been chosen as the technology to treat hydrocarbon-contaminated soils at Tanquary Fiord and Lake Hazen.

Barrel waste remediation at Ward Hunt Island also presents a unique challenge. Because of the remote location, ESG has recommended that the unused fuel stored at the Ward Hunt main camp be incinerated on site at high temperatures, to ensure a clean burn. It may be necessary to dispose of barrel contents containing contaminants above criteria at a southern treatment facility.

Inorganic contamination cannot be remediated on site. Soil at Ward Hunt Island that has been contaminated with inorganic contaminants will have to be packaged properly according to guidelines under the Transportation of Dangerous Goods Act (TDGA) and shipped to an off-site treatment facility.

C. Cleanup Criteria

1. Barrel protocol criteria

As part of the site cleanup, ESG staff sampled and analyzed the liquid contents of the unused barrel caches at Ward Hunt Island to determine total chlorine, cadmium, chromium, lead and PCB content. The Nunavut government has no specific regulations regarding the incineration of waste fuels; however, the analytical results from the barrel samples were compared with the Distant Early Warning (DEW) Line Clean Up (DLCU) barrel content incineration criteria (DGE, 1998), which were developed based on provincial guidelines. These criteria were reviewed and accepted by Indian and Northern Affairs Canada (INAC), the Department of National Defence and Environment Canada and were adopted by the government of the Northwest Territories. The criteria were developed to address contaminant concentrations in samples from large barrel caches found at DEW Line sites above which it is not recommended that contents be incinerated on site (Table II-1). In such cases, the contents may require special treatment or disposal in a southern facility.

Table II-1: DEW Line Cleanup Barrel Protocol Criteria

Contaminant	Criterion
Glycol	2.0%
PCBs	2.0 ppm
Cadmium	2.0 ppm
Chromium	10 ppm
Lead	100 ppm
Total Chlorine	1,000 ppm

2. Soil criteria for inorganic elements

Federal guidelines for the residential/parkland land use category specified by CCME (1999; updated 2007) were used as initial screening criteria to evaluate soil sample concentrations of inorganic elements at Ward Hunt Island. These guidelines are summarized in Table II-2.

Table II-2: CCME Residential/Parkland Environmental Health Soil Quality Guidelines for Inorganic Elements

Contaminant	CCME residential/parkland guidelines [ppm]
Copper	63
Nickel	50
Cobalt	50
Cadmium	10
Lead	140
Zinc	200
Chromium	64
Arsenic	12
Mercury	12

3. Soil criteria for PHCs

A summary of the PHC CWS process has been discussed in ESG (2005a; 2008) as well as the complications that arise for sites located in arctic settings. Because of these complications, ESG – in consultation with PCA staff – decided to follow the INAC approach for evaluating PHC contamination in QNP soils.

In 2008 INAC released a draft guidance document outlining a risk-based approach for evaluating hydrocarbon-impacted areas at its northern military sites (INAC, 2009). The draft INAC document builds on 10 years of experience using a similar risk evaluation matrix for hydrocarbon contamination as part of the DLCU at Department of National Defence sites (EWG, 1998; 1999). However, the INAC document also reviews and incorporates the PHC CWS Tier 1 (2001) guidelines, the recently released (2007) Alberta Environment guidelines – which reflect proposed changes to PHC CWS 2001 and incorporate updated toxicological information – and several site-specific Arctic risk assessments. The steering committee for remediation of Stokes Point (BAR-B) in Ivvavik National Park, Yukon has recently adopted the INAC risk-evaluation framework for PHCs.

The primary objectives of the INAC risk evaluation approach are to mitigate potential environmental and human health impacts associated with hydrocarbon-contaminated soils, and minimize the impact of remediation activities on fragile tundra ecosystems. As part of the criteria derivation process, INAC considered the applicability of the eco-soil contact criteria for Arctic sites. Overall, the areal extent of hydrocarbon impacts relative to the surrounding local habitat and total area of the site is sufficiently minor. However, local physical disturbances associated with remediation, such as the excavation of borrow material for backfilling and development of a treatment area, leave a more significant physical footprint than the areal extent of the original hydrocarbon-impacted area. Given the desire to minimize remediation impacts on tundra environments, as well as uncertainties regarding the appropriateness of the PHC CWS eco-soil contact criteria for Arctic environments, the eco-soil contact criteria were not used to derive the INAC guidelines.

For QNP, ESG adopted the draft INAC protocol as the hydrocarbon risk evaluation matrix. Hydrocarbon contamination is categorized as Type A (non-mobile, F3/F4 fractions) or Type B (mobile, F1 to F3 fractions). Type A-contaminated soils are characterized by limited mobility and solubility. Remedial targets are based on criteria for non-aqueous-phase liquid formation (PHC concentration), and potential for movement by erosion (topography). Remedial options include excavation to a specific depth or scarifying the surface of contamination.

Diesel fuel is the predominant contaminant found in Type B-contaminated soils. As lighter-end hydrocarbons exhibit increased mobility and solubility, the primary evaluation criterion is the migration distance to water bodies supporting aquatic life. For Type B-contaminated areas within 30 m of a water body, remedial targets of 330 ppm (F2 fraction) and 1,290 ppm (F1 fraction) are specified. These criteria were derived through modification of the Tier 2 guidelines consistent with the PHC CWS and Alberta Environment approach, using Arctic-specific conditions for hydrogeological flow.

For other hydrocarbon-impacted areas well removed from water bodies, a remedial objective of 2,500 ppm PHC (as the sum of F1 to F3) is specified for surface soils to a depth of 0.5 m. This value is consistent with the site-specific target level generated through risk assessments for protection of avifauna and smaller terrestrial mammals at Arctic sites. For hydrocarbon contamination at depth, a 5,000 ppm remedial target is used. This is consistent with the intent of the Management Limits provided in the Alberta Government (2007) and the revised CCME (2008) guidelines. It is recommended that excavation activities for removal of hydrocarbon-impacted soil be confined to worked areas to minimize disturbance to tundra ecosystems.

ESG evaluated each occurrence of hydrocarbon contamination in QNP using the risk-management approach described above based on the following factors: type of hydrocarbon (fuel or lubricating oil and grease); maximum concentration of the hydrocarbons (measured as TPH or as CCME PHC); and location and potential for migration to sensitive receptors. Flowcharts outlining the decision-making protocol are shown in Figure II-1 and Figure II-2 for Type A and Type B contamination, respectively (INAC, 2009).

The boundaries of the areas contaminated with Type B hydrocarbon concentrations above 2,500 ppm were estimated using analytical data and interpolation software, followed by ground-truthing based on field observations, surveyed topography, soil types and previous experience. Because Type A hydrocarbons do not readily migrate and are commonly associated with visible stains, the surface area of the stain was generally used as an estimated boundary for this contamination. Where there was no distinct stain, the boundaries of contamination were calculated arithmetically, assuming a constant rate of decrease in contamination between a contaminated area and a clean sample point. Small Type B-hydrocarbon-impacted areas were calculated in a similar manner.

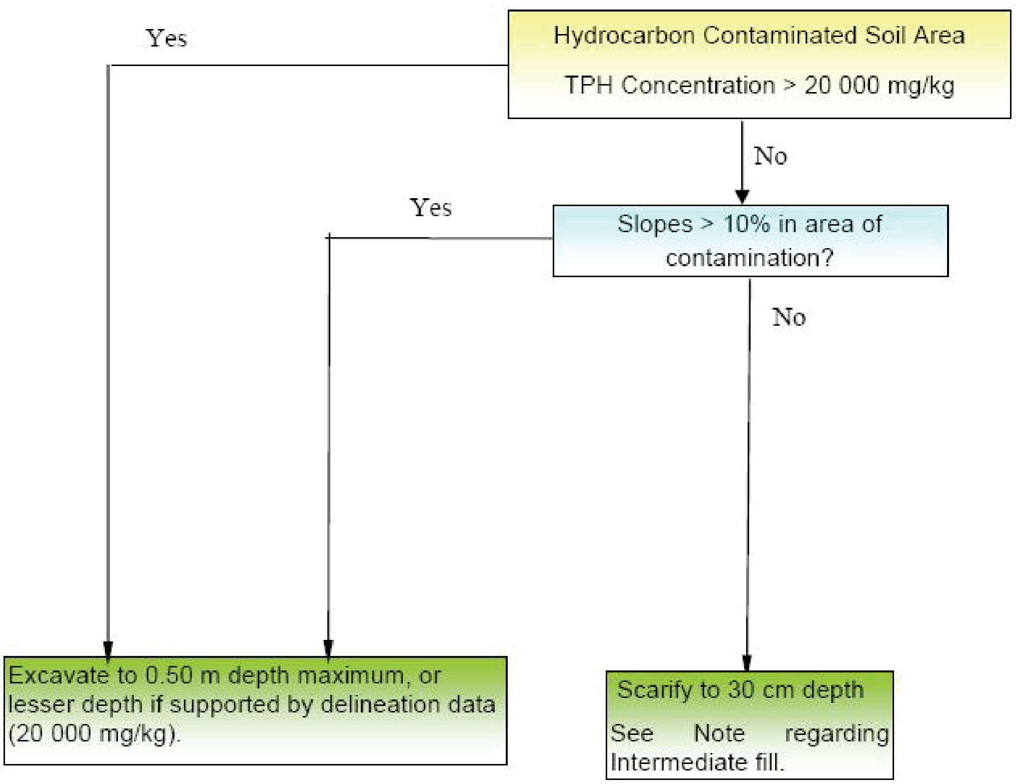


Figure II-1: Updated hydrocarbon risk evaluation matrix (Type A hydrocarbons) (INAC, 2009).

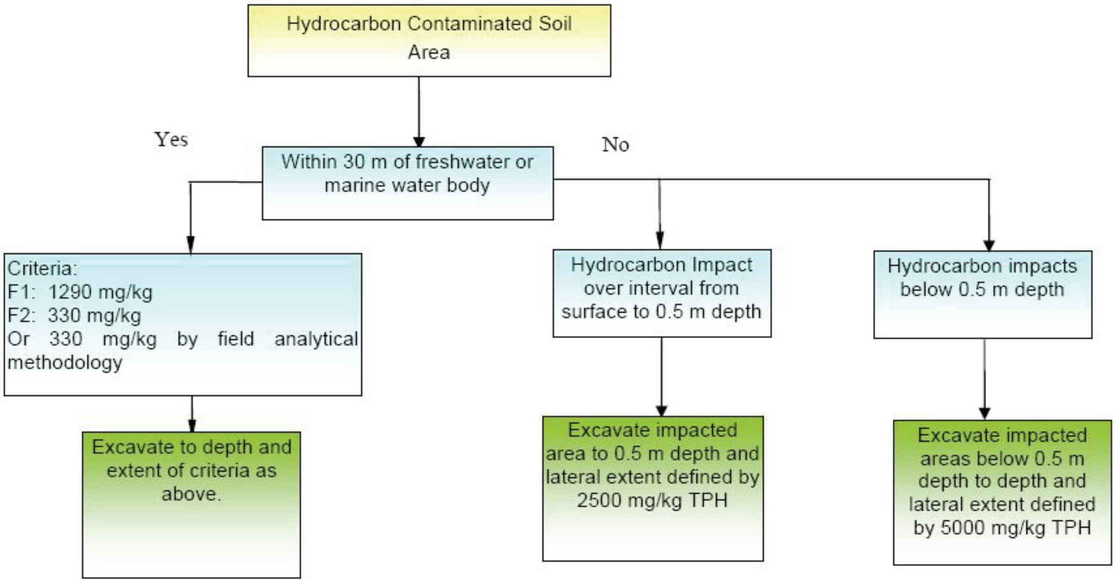


Figure II-2: Updated hydrocarbon risk evaluation matrix (Type B hydrocarbons) (INAC, 2009).

III. TANQUARY FIORD

A. Site Location and History

Tanquary Fiord camp is located near the shore of Tanquary Fiord at latitude N 81° 24’ and longitude W 76° 53’ (Map I-1). The camp was established in 1963 as a field station with the Defence Research Board, and has been used since that time as a staging point for operations throughout northern Ellesmere Island because of its airstrip and accessibility by sea. At the time of publication, Tanquary Fiord is the main QNP base camp and visitor centre for PCA. The site is divided into three areas: the Old Camp and Beach Area, New Camp Area and Runway Area.

B. Summary of Site Assessments and Remediation

In the 2004 site investigation ESG staff analyzed one water sample and 153 soil samples (ESG, 2005a). The results indicated limited hydrocarbon contamination at the Old Camp and Beach Area and Runway Area, while the New Camp appears to be relatively free of contamination. Both diesel fuels (F2 fuel fraction) and lubricating oils and greases (F3 and F4 fractions) were found at this site; however, there was little to no evidence of other contaminants (*e.g.* inorganic elements, BTEX). A hydrocarbon remediation project was initiated in 2007 using suspected and known hydrocarbon-contaminated soil excavated from the Tanquary Fiord site.

Work in 2005 focused on delineating the extent of hydrocarbon contamination previously identified in the site investigation in 2004, assessing new stains and continuing the hydrocarbon remediation research project. Using the hydrocarbon risk evaluation matrix, the volume of hydrocarbon-contaminated soil requiring treatment was identified to be approximately 48 m^3. In 2007, further delineation reduced that volume of soil to 36 m^3, which was excavated and placed in an on-site landfarm, to facilitate bioremediation. In the same field season, the hydrocarbon-contaminated soil was excavated and a landfarm was constructed to facilitate bioremediation. The landfarm is maintained by PCA and can be used to remediate soil contaminated by future fuel spills. Details of the 2007 delineation, excavation, confirmatory sampling and landfarm establishment at Tanquary Fiord are presented in ESG (2007a).

1. Landfarm monitoring program

ESG collected baseline samples from the landfarm in 2007, immediately following landfarm construction. A random number generator was used to select 30 co-ordinates for sample locations at the landfarm. Of the 33 samples collected, including three duplicate pairs, 16 were analyzed for total PHCs, which ranged in concentration from 930 ppm to 7,700 ppm with a 95% UCL of 4,300 ppm (ESG, 2008). Four samples were used for nutrient analysis and plate count to analyze for hydrocarbon-degrading microbes. Three of these contained sufficient numbers of hydrocarbon degraders for biodegradation of the contaminants (ESG, 2008).

ESG collected 36 more soil samples (08-11880 to 08-11915), including three scoop blanks and three duplicate pairs, from the landfarm in 2008 for PHC analysis (Table B-1) and another set of samples for nutrient analysis (Table B-4) and plate count of HC degraders (Table B-2), using the same procedure used in 2007. At each location, samples were collected at a depth of 15-25 cm. The collected samples and their locations are shown in Photograph III-1. The PHC results for the 19 samples analyzed from the landfarm indicated a 95% UCL of 2,400 ppm, which is below the cleanup criteria of 2,500 ppm. This indicates that the landfarm may be decommissioned in 2009. The soil in the landfarm may be removed and disposed of, as it no longer requires remediation.

The remediated soil should be removed from the landfarm and disposed of with consideration to the following recommendations. The geotextile liner is fragile and should be handled with care. A 10-cm layer of clean fill separates the liner from the previously contaminated soil in the landfarm. Shovels should be used to remove the soil and the layer of clean fill – which does not need to be removed from the landfarm – can be used to protect the liner. The soil should be disposed of only in areas with minimal human exposure. Although the soil is below criteria, it may still contain low levels of hydrocarbons and have a noticeable odour. ESG recommends that the soil be spread as thinly as possible over the soil surrounding the incinerator, since this area is not likely to be pristine.

The landfarm liner and berms should be left in place for future use. In the event that additional soil on site becomes contaminated by a fuel spill, it can be immediately placed within the landfarm to begin remediation of the soil. A 5- to 10-cm layer of clean silt from the camp area should be placed directly on the fragile geotextile liner before adding any contaminated soil on top. This will protect the liner from coarse gravel in the soil and if landfarm remediation is not necessary in the immediate future, the layer of clean fill will protect the liner from UV damage. The remediated soil in the landfarm could be left in place until more room is required. Landfarm maintenance instructions are provided in Appendix D.

At the time of establishment of the landfarm in 2007, four signs were posted around its perimeter to warn people of the presence of contaminated soil. In 2008, ESG staff noticed that all but one of the signs had either fallen down or been damaged by the wind or snow during the winter (see Photograph III-2). Since the soil in the landfarm has been remediated, the signs are no longer needed. If, however, the landfarm is used in the future to remediate soil contaminated by new fuel spills, additional signs should be posted to warn bystanders to stay away from the contaminated soil.

2. *Field experimental treatment plots*

ESG conducted field experiments using experimental landfarm test plots at Tanquary Fiord. Six test plots were established in 2004 and redesigned in 2005 using hydrocarbon-contaminated soil from the site. The six experimental test plots are shown on either side of the six plots being used in the hydrocarbon absorbent polymer technology (HAPT) experiment (ESG, 2008) in Photograph III-3, with the greenhouse cover over three of the test plots. The experiment was designed to examine the potential for surfactant and fertilizer treatments, as well as an extended summer season simulated by use of a greenhouse to enhance bioremediation. Further details from this work are presented in two reports summarizing results of the research program on remediation of hydrocarbon contamination in QNP (ESG, 2005b; 2007). Samples from the test plots were collected in 2005, 2006, 2007 and 2008. Soil PHC concentrations for all of the landfarm plots are now below the remediation criteria of 2,500 ppm, indicating that the soil may be removed from the landfarm treatment plots and disposed of on site. ESG recommends that the soil be spread in a thin layer over the soil around the incinerator with the soil from the field-scale landfarm. The liner can be used in the future to line the trailer used for transportation of fuel-contaminated soil, but should not be used for recreation activities, such as camping, and should be stored away from recreational areas on site.

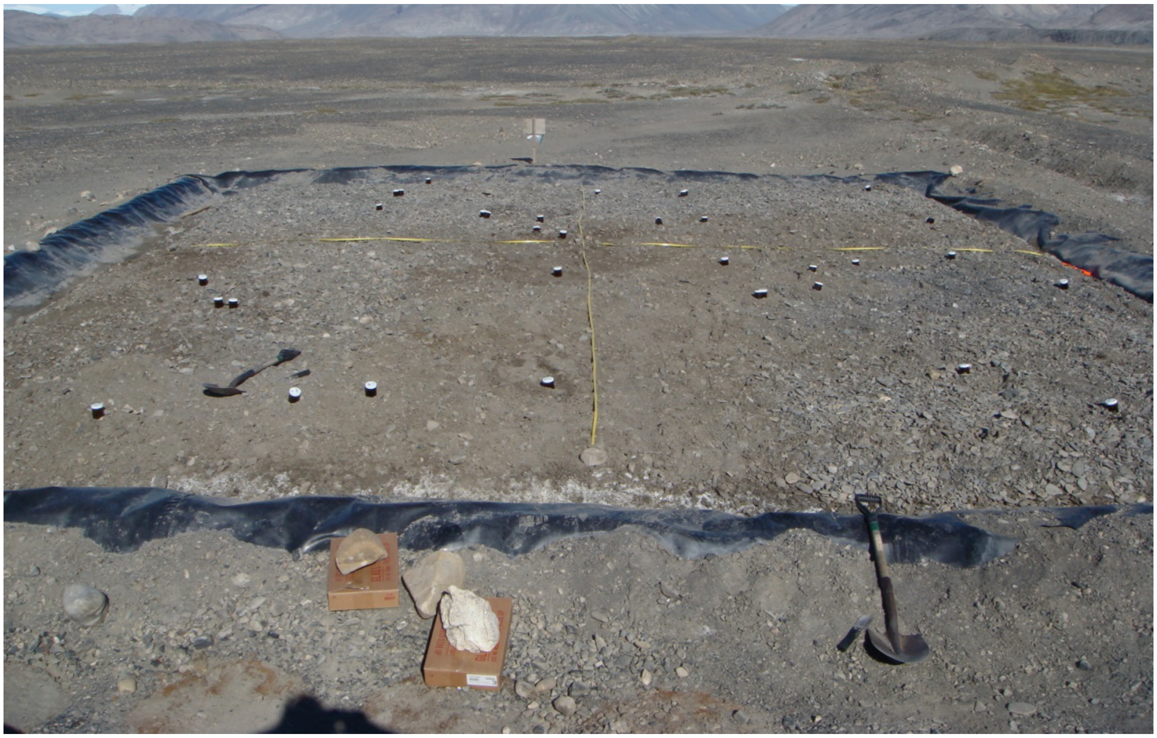
Overall, these results indicate that landfarms with minimal treatment are an effective remediation option for soil contaminated with Type B compounds (<nC16), but the removal of Type A compounds (nC16-nC34) was only observed in experimental plots treated with nutrients and surfactant. It should be noted that while the test plots at Tanquary Fiord were effective, TPH reduction rates were one third of those observed in similar laboratory experiments. It has been suggested that biodegradation of compounds >nC16 in the test plots was affected by the climate (low temperature and low moisture content). In the laboratory, little volatilization was measured but it is possible that this is the predominant PHC removal process in the test plots at Tanquary Fiord (ESG, 2007).

In the 2008 field season, the last set of samples was collected from the experimental test plots. The samples were analyzed for PHCs and the results are presented with the results from previous years in Table B-3. Samples were also analyzed for hydrocarbon degraders (Table B-2) and nutrients (Table B-4). Results from 2008 indicate a significant decrease of TPH and F2 from 2007, but only in the test plots treated with surfactant and fertilizer. Throughout the three years of this experiment, the addition of surfactant alone did not result in lower concentrations of PHCs than in the control plots, indicating that fertilizer plays a key role in the bioremediation process.

C. Site summary and recommendations

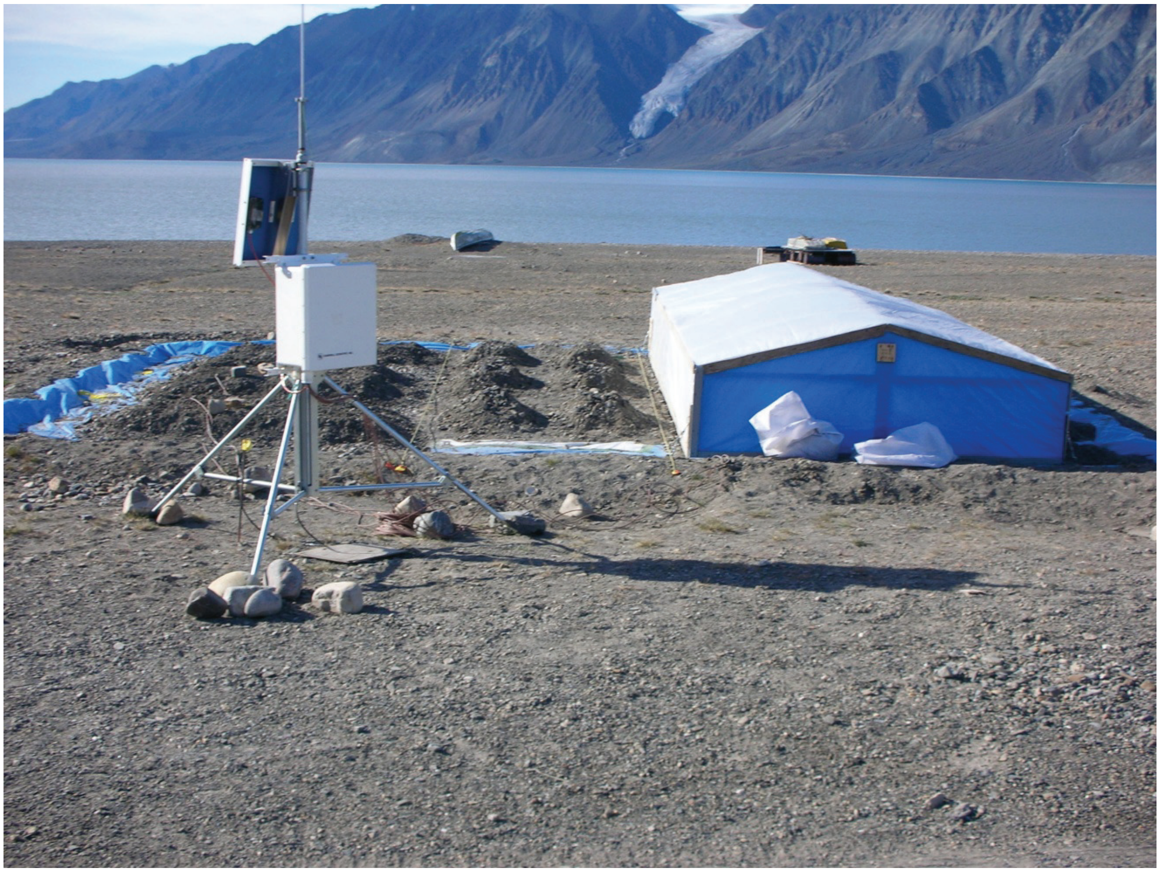
Results from the 2008 monitoring samples indicate that the soil in the landfarm has been successfully remediated and the landfarm no longer needs to be maintained. It is recommended that the soil be removed from the landfarm carefully, to prevent damage to the fragile geotextile liner. The landfarm structure may be reused for future remediation of soil contaminated by new fuel spills. The remediated soil should be spread in a thin layer around the incinerator for disposal. While the soil is below criteria, it may still contain hydrocarbons and have a noticeable odour. The soil should not be placed in areas used for recreational activities and personnel handling the soil should be aware of the hazards of hydrocarbon contamination and wear long pants, boots, gloves and protective glasses when disposing of the soil.

Proposed work at Tanquary Fiord in 2009 includes dismantling the experimental test plots and decommissioning the Tanquary Fiord landfarm.



Photograph III-1: Location of Tanquary Fiord landfarm samples collected in the 2008 field season as part of the long-term monitoring plan.

Photograph III-2: Warning sign posted at the landfarm at Tanquary Fiord a) in 2007 and b) in 2008.



Photograph III-3: The six test plots of the ESG landfarm experiment and six test plots of the HAPT experiment at Tanquary Fiord with the greenhouse cover on.

IV. LAKE HAZEN

A. Site Location and History

Lake Hazen camp is located on the northern shore of Lake Hazen at latitude N 81° 49.70’ and longitude W 71° 19.61’ (Map I-1). The camp was established in 1957 by the Defence Research Board, and is situated on a raised sandy pad approximately 100 m from the shore of the lake (Photograph IV-1). It is currently used as a base camp and visitor centre for PCA, and is also used by researchers as well as military personnel from the nearby stations of Eureka and Alert. The site may be divided into three areas (Map IV-1): the main camp, an adjacent tundra storage area, and a fuel storage area at the north end of one of the three runways.

During the 2004 site investigation ESG analyzed a total of 144 samples from this site (ESG, 2005a). Although the tundra storage and runway areas appear to be relatively free of contamination, significant hydrocarbon contamination was found at the Lake Hazen main camp and was composed of a mixture of diesel fuels (F2 fraction) and lubricating oils and greases (F3 and F4 fractions). Some inorganic contamination (Cu, Pb, Zn) was also found in the Lake Hazen main camp (sample tags 04-352, 383, 356, 358, 598; ESG, 2005a; Map IV-2). Although five samples were above the CCME guidelines for inorganic contaminants, all but one sample (tag 04-352: 151 ppb Cu; 1,100 ppm Pb; 540 ppm Zn) were only slightly above the guidelines; thus no further work was carried out for these areas in 2005.

Further work at Lake Hazen in 2006/2007 focused mainly on delineation of hydrocarbon and inorganic contamination in the main camp with. Given logistical constraints (*i.e.* no heavy equipment for excavation), a close spatial delineation of hydrocarbon-contaminated soils at Lake Hazen was carried out in 2007. This allowed the horizontal and vertical extent of hydrocarbon contamination in each area to be precisely defined to minimize the volume of soil to be excavated. ESG staff analyzed delineation samples in the field using test kits. The results were used to refine the boundaries around hydrocarbon-contaminated areas for excavation. A maximum volume of approximately 37 m^3 of hydrocarbon-contaminated soil from eight locations on site was identified as requiring treatment; however, it was anticipated that this volume would likely decrease following further delineation.

To evaluate the usefulness of a landfarm as a remediation option, ESG undertook a hydrocarbon remediation experiment beginning in 2005, using contaminated soil from the site (excavation 04-412; Map IV-3), similar to the experiment at Tanquary Fiord (see

Section III.B.2). Results from the experimental treatment plots at Lake Hazen and Tanquary Fiord indicated that landfarm remediation of hydrocarbon-contaminated soil is a realistic option for this site and that the remediation may be enhanced by amending the landfarm with fertilizers and surfactants (ESG, 2005b).

B. Summary of Sampling Activities and Results

1. Delineation samples

An important goal of the 2008 field season was to complete the close spatial delineation of hydrocarbon-contaminated soils in the main camp area (Map IV-1). This differs from regular delineation sampling in that samples are collected on a tighter grid (approximately 1 m x 1 m). This allowed the horizontal and vertical extent of hydrocarbon contamination in each area to be precisely defined, to minimize the volumes of soil excavated. Delineation samples were analyzed in the field using PetroFLAG test kits and the results were used to define boundaries around hydrocarbon-contaminated areas for subsequent excavation.

A total of 23 delineation soil samples were collected from four contaminated areas on site and analyzed for TPH using PetroFLAG test kits (Map IV-2, Map IV-3 and Map IV-5). Most of the samples analyzed were below the relevant guidelines for hydrocarbons (Table B-1), indicating that in most areas proposed for excavation, the hydrocarbon contamination was restricted to small areas. In cases in which delineation samples had PHC concentrations above the criteria, boundaries for excavation were adjusted accordingly.

2. Excavation and confirmatory sampling

The location and extent of excavations of hydrocarbon-contaminated soil, as well as associated confirmatory samples, are shown in Map IV-4 and Map IV-6.

Excavation 04-352: This area is located near the antenna on the northwest camp pad (Map IV-3). Contamination at this location was formed predominantly of Type A hydrocarbons (F3 and F4 fractions). Surface soil at this location has also been identified as containing leachable lead contamination in excess of the relevant guidelines (04-352; Table B-4, ESG 2005a). This area was excavated to 30 cm (Photograph IV-2). Confirmatory samples were below applicable criteria. Because of the leachable Pb contamination associated with this soil, it will be shipped south for disposal following

TDGA guidelines. It is being stored in a separate cell within the landfarm until the 2009 field season.

Excavation 04-376: This stained area, north of the barrel shed, south of the grey water discharge area and west of the kitchen shelter (Map IV-4), was contaminated with Type A hydrocarbons (F3 and F4 fractions), with a maximum TPH concentration of 30,000 ppm at surface (sample 04-376; Table B-1, ESG 2005a). Delineation samples from the 2008 field season and prior field seasons were used to determine the horizontal extent of contamination and, following the hydrocarbon risk assessment framework, the area was excavated to 0.5 m (Photograph IV-3). Three confirmatory samples were taken around the perimeter at the bottom of the excavation and all were below criteria.

Excavation 05-15367: Located on the south side of the barrel shed on the west camp pad (Map IV-4), soils at this location were contaminated with Type A hydrocarbons (4,600 ppm). This area was excavated to 0.3 m (Photograph IV-4). A confirmatory sample (08-11986; TPH=3,500 ppm) indicated that the guideline had been met.

Excavation 04-415: This small stained area is adjacent to the east side of the kitchen shelter (Map IV-6). One contaminated surface soil sample at this location, taken directly on the stain, contained predominantly Type A hydrocarbons. This area was excavated to 0.3 m and a confirmatory sample indicated that removal of contamination was complete.

Excavation 04-472: This was the largest excavation area on site, located south of the snowmobile trailer on the main camp pad (Map IV-6). It had one large stain at its centre (Photograph IV-5). Soils at surface and depth were contaminated with Type B hydrocarbons (fractions F2 and F3), with a maximum total PHC of 12,000 ppm (ESG, 2008). Based on delineation results, the area was excavated to 1.10 m on the east side and to 0.5 m on the west side. Confirmatory samples (08-12007 to 08-12014; Table B-1) taken from around the bottom of the excavation area were all below criteria.

Excavation 04-429: This area is located immediately south of excavation 04-425 on the main camp pad (Map IV-6) and was the second largest excavation on site, with two stains within it. Contaminated surface soils at this location contain predominantly Type A hydrocarbons (F3 and F4 fractions), with a maximum total PHC of 25,000 ppm (04-430, ESG 2005a). This area was excavated to a depth of 50 cm (Photograph IV-6). Confirmatory samples (08-12003 to 08-12005; Table B-1) indicated that the contamination had been removed after excavation.

Excavation 04-441: This smaller stained area is located southwest of the office shelter on the main camp pad (Map IV-6). Soils at this location were contaminated with Type A hydrocarbons. This area was excavated to 50 cm and backfilled with clean fill.

Excavation 04-445: This stained area is located southwest of the office shelter on the main camp pad (Map IV-6). Contaminated soils contained predominantly Type B hydrocarbons, with a maximum PHC of 9,500 ppm (07-23491; ESG 2008; Table B-1). This area was excavated to 1 m. The five confirmatory samples, including one duplicate pair, (08-11997-12001) indicated that the remediation objectives were completed.

Following confirmatory sampling, all excavated areas were backfilled using clean fill from the surrounding areas. In total, an estimated 27 m^3 of contaminated soil was excavated and placed in the landfarm. In addition, a small amount (~0.1 m^3) of soil from on top of the ski of the sled on the north side of the kitchen was placed in the landfarm because previous surface samples (04-419/20) indicated that the soil was contaminated above guideline with Type A hydrocarbons (ESG, 2005a).

3. Establishment of a landfarm treatment area

ESG has demonstrated through laboratory and field treatability studies that bioremediation (*i.e.* the degradation of hydrocarbon contamination by soil microbes into carbon dioxide and water) is a feasible option for the treatment of hydrocarbon-contaminated soils in QNP (ESG, 2005b; 2007). Based on the demonstrated field and laboratory success, ESG staff decided to establish a landfarm to treat hydrocarbon contamination at Lake Hazen. Landfarms are used extensively to treat hydrocarbon-contaminated soils at other Arctic sites (*e.g.* Rutter *et al.*, 2005), and are especially attractive for use at remote sites such as QNP, where cost and logistics limit the options for remediation.

The landfarm at Lake Hazen was designed and constructed in accordance with Environment Canada's Federal Guidelines for Landfarming Petroleum Hydrocarbon Contaminated Soils (SAIC Canada, 2005). It was constructed on a flat area a safe distance from the main camp and the shoreline (Map IV-7). The chosen area contained little vegetation and was not close to any drainage pathways. Before its construction, seven surface soil samples, including one duplicate pair (08-11956 to 08-11962; Table B-1), were collected from the area underlying the proposed landfarm. These samples provide a baseline for ensuring the integrity of the landfarm.

The landfarm was constructed in mid-July, 2008. A 30-mm HDPE-equivalent geomembrane (Enviroliner 6030) was first laid down to prevent contact between the hydrocarbon-contaminated soils in the landfarm and the underlying soils. A layer of clean silt approximately 5-10 cm deep was placed on the liner to help prevent liner damage during tilling (Photograph IV-7). The 27 m^3 of hydrocarbon-contaminated soil excavated from the site were placed on top of the silt base of the landfarm in a layer approximately 30 cm deep (Photograph IV-8). The contaminated soil is mostly fine to coarse sand with some gravel. This layer of contaminated soil covered only 3/4 of the landfarm area, which was approximately 10 m x 12 m. One corner of the geotextile liner was left uncovered and was used for storage of the leachable-lead-contaminated soil from excavation 04-352 (Photograph IV-9). This soil could not be treated on site and was covered with a tarp to prevent exposure to rainwater, which may enhance leaching, until it could be removed from the site. Four berms (each 30 cm high) were constructed around the sides of the geotextile liner and then covered with the liner to prevent potential migration of hydrocarbon-contaminated soil through surface runoff, although this is expected to be minimal because of QNP's desert climate (Photograph IV-9). The clean soil used to cover the liner and build berms was collected from the beach. A caution sign was placed on a box next to the landfarm, indicating that the area is a PHC-contaminated soil treatment facility.

Previous laboratory and field treatability experiments have investigated the optimal amendment regime for maximizing bioremediation efficiency in QNP soils (ESG, 2005b; 2007). Based on these studies, hydrocarbon-contaminated soils in the landfarm were amended with agricultural fertilizers (Photograph IV-10), including nitrogen (N) and phosphate (P), using 90 percent of the average TPH concentrations from samples collected during the years 2005 to 2007 as a reference for the carbon concentration (7,100 mg/kg). The optimum C:N:P ratio of 100:3.75:0.25 was attained in the landfarm by adding 14 kg of urea as a nitrogen source and 1 kg diammonium phosphate as a phosphate source. Following application of the amendments evenly across the landfarm surface, the landfarm was tilled manually using shovels and rakes to mix the soils and promote aeration (Photograph IV-11). The surfactant Biosolve™ was added to the landfarm at half of the manufacturer recommended concentration to enhance bioremediation; 2 L of Biosolve™ was mixed with about 200 L of water and sprayed evenly over the soil using a sump pump and garden hose. A total of 3,500 L of water was pumped evenly from Lake Hazen onto the soil to adjust the soil moisture to 60 percent water-holding capacity. On July 16, the landfarm was watered again with 1,500 L of water and turned manually with shovels.

PCA staff have agreed to perform the required ongoing maintenance of the landfarm to ensure that treatment occurs effectively. This consists of regular tilling, ideally every two weeks during the summer season, to promote aeration. Also, the landfarm should be watered regularly to maintain bioremediation efficacy. Instructions for landfarm maintenance were left with PCA staff at Tanquary Fiord in 2007 and are appended in Appendix D. This landfarm has additional space available and may be used by PCA for future treatment of any hydrocarbon-contaminated soils resulting from accidental spills.

4. Landfarm monitoring program

ESG staff sampled the landfarm immediately after construction and placement of contaminated soil (08-12015 to 12051; Table B-1) to assess hydrocarbon contamination, nutrients and hydrocarbon degrading bacteria. ESG staff collected a total of 33 soil samples, including three duplicate pairs, as baseline samples for the landfarm monitoring program. A random number generator was used to select 30 co-ordinates for sample collection. At each location, samples were collected at a depth of 15 to 25 cm. Total PHC concentrations in the 19 samples analyzed (08-12015 to 08-12051; Table B-1) ranged from below detection to 17,000 ppm; the 95% UCL was 4,800 ppm.

A plate count of hydrocarbon-degrading microbes was carried out for three of the six landfarm samples collected for the microbial analysis (Table B-2). All three samples contained sufficient numbers of hydrocarbon degraders for biodegradation of the contaminants (average ~ 1.28×10^4 CFU/g dry soil).

Three out of six samples taken from the landfarm at random locations were analyzed for nitrogen and phosphorous content, and all three samples were below detection for both analytes (08-12041, 12043 and 12045; Table B-4). This may mean that the soil in the landfarm was not homogenized enough; however, nutrient and fertilizer concentrations may be sufficient to facilitate bioremediation and further homogenization will occur through tilling.

As part of the monitoring program, samples from the landfarm will be collected annually to ensure that hydrocarbon concentrations are decreasing. Sample collection should follow the same procedure used to collect the baseline samples: *i.e.* at least 30 samples (plus three duplicate pairs) should be collected from the base of the landfarm (depth = 15-25 cm) at randomly chosen co-ordinates. The landfarm may be closed and decommissioned when the 95% UCL of the measured total PHC is less than the cleanup criteria (2,500 ppm). Until the landfarm is decommissioned, it must be maintained, following the landfarm maintenance instructions provided in Appendix D, and sampled each field season. Samples are to be analyzed for PHC, nutrients and hydrocarbon degraders.

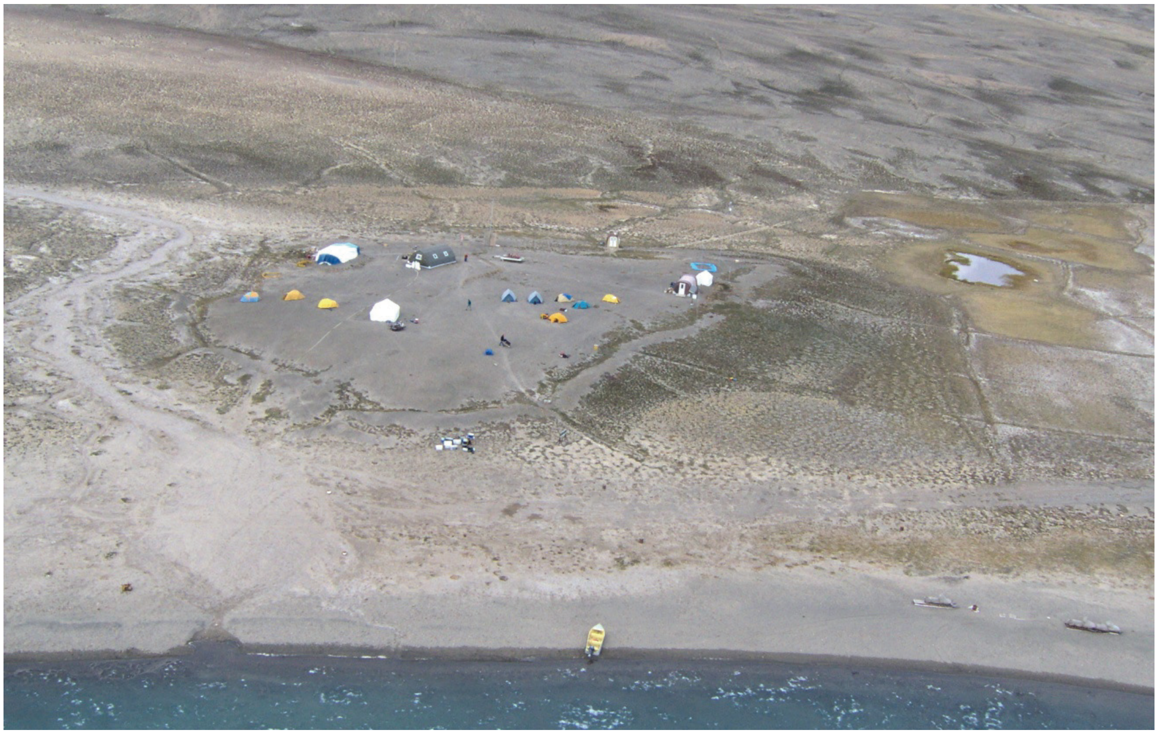
5. Hydrocarbon remediation experiment

The landfarm feasibility experiment initiated in 2005, similar to that at Tanquary Fiord (see Section III.B.2), was dismantled (Map IV-5). The remediated soil was used to backfill one excavated contaminated area on site. Three soil samples were collected from underneath the liner of the experimental landfarms and all three soil samples were below detection for PHC (08-12052/53/54; Table B-1).

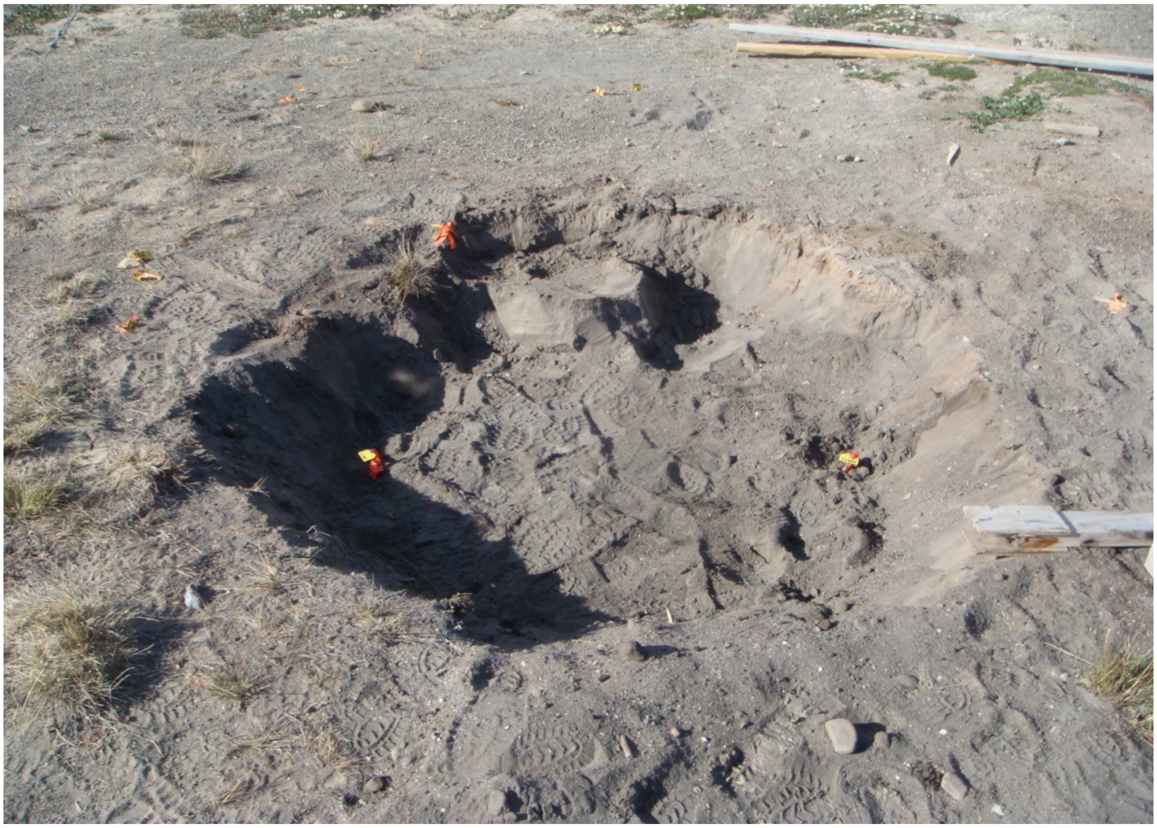
C. Site Summary and Recommendations

The extent of hydrocarbon and inorganic contamination at Lake Hazen was closely delineated and excavated in 2008. A landfarm was established for the remediation of the hydrocarbon-contaminated soil. The hydrocarbon-contaminated soil was placed in the landfarm, sampled and treated with water, fertilizer and Biosolve™. The landfarm was aerated by manual tilling using shovels and rakes. It is recommended that PCA staff continue to till and water the landfarm in accordance with the landfarm maintenance instructions, described in detail in Appendix D. In addition, it will be necessary to collect samples from the landfarm each year until the PHC concentrations of the samples are below the criteria required to decommission the landfarm. The sampling protocol is also outlined in Appendix D.

One location on site near the antenna on the northwest pad contained leachable lead. This area was excavated in 2008 and the contents (~1 m^3) have been temporarily stored in a separate cell within the landfarm. This soil was covered with a tarp to prevent exposure to rainwater, which could enhance leaching into the rest of the landfarm. This soil shall be containerized for off-site disposal, following TDGA guidelines, in 2009.



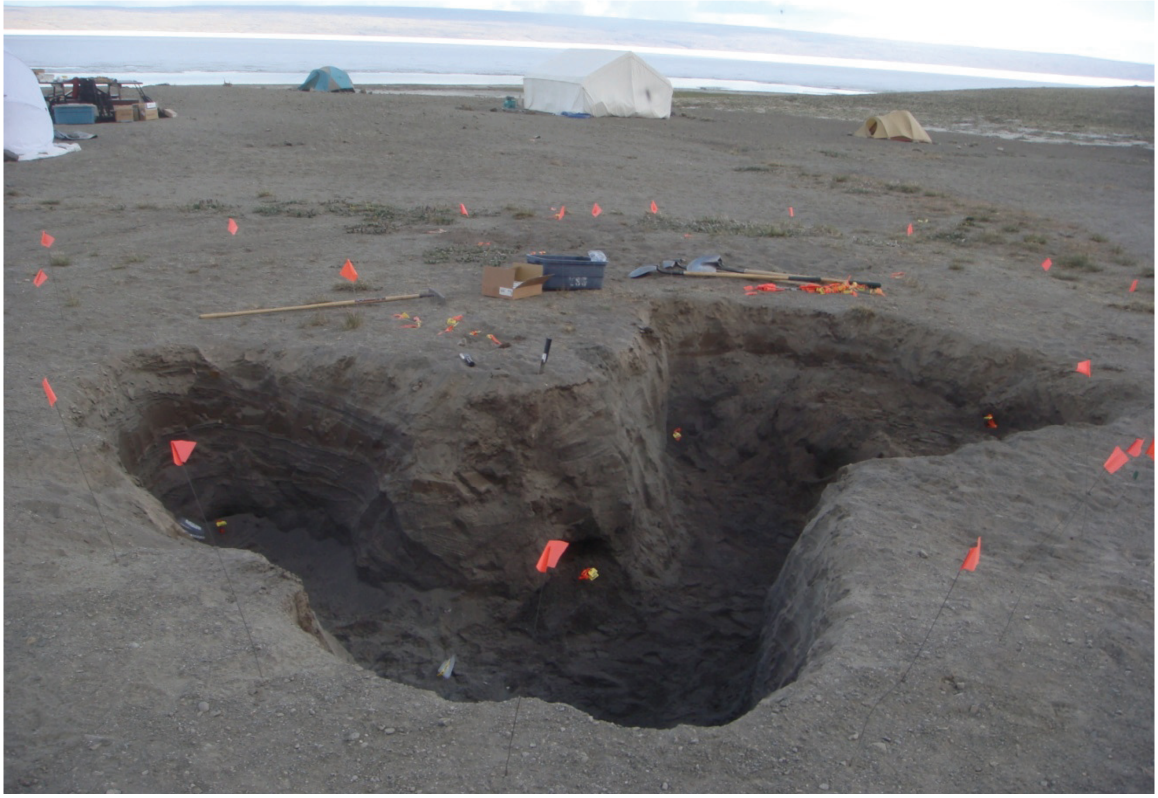
Photograph IV-1: Lake Hazen main camp pad.

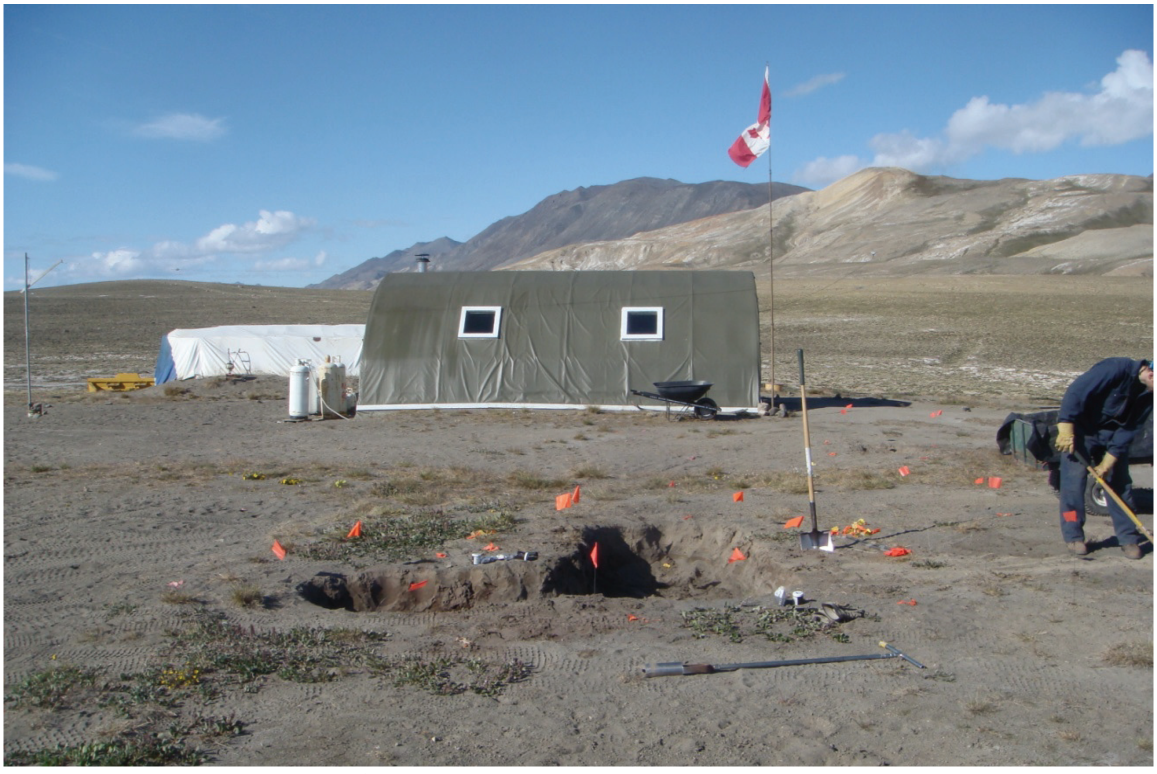


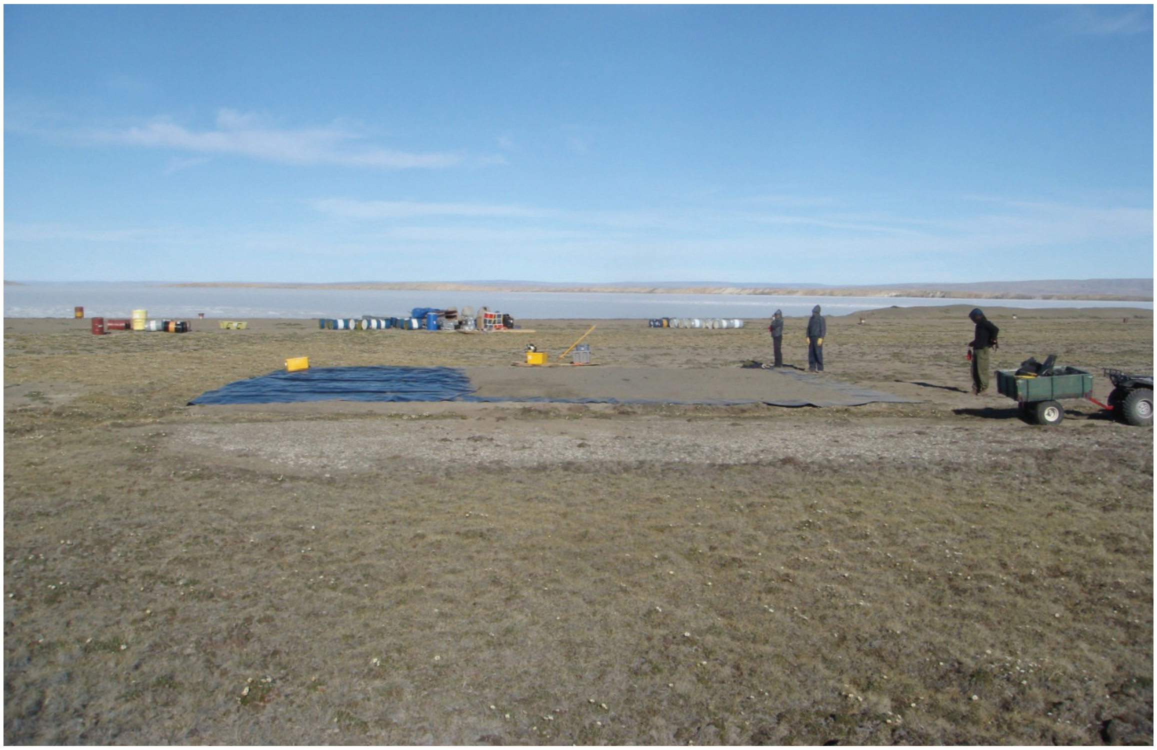
Photograph IV-2: Excavation 04-352.

Photograph IV-3: Excavation 04-376.

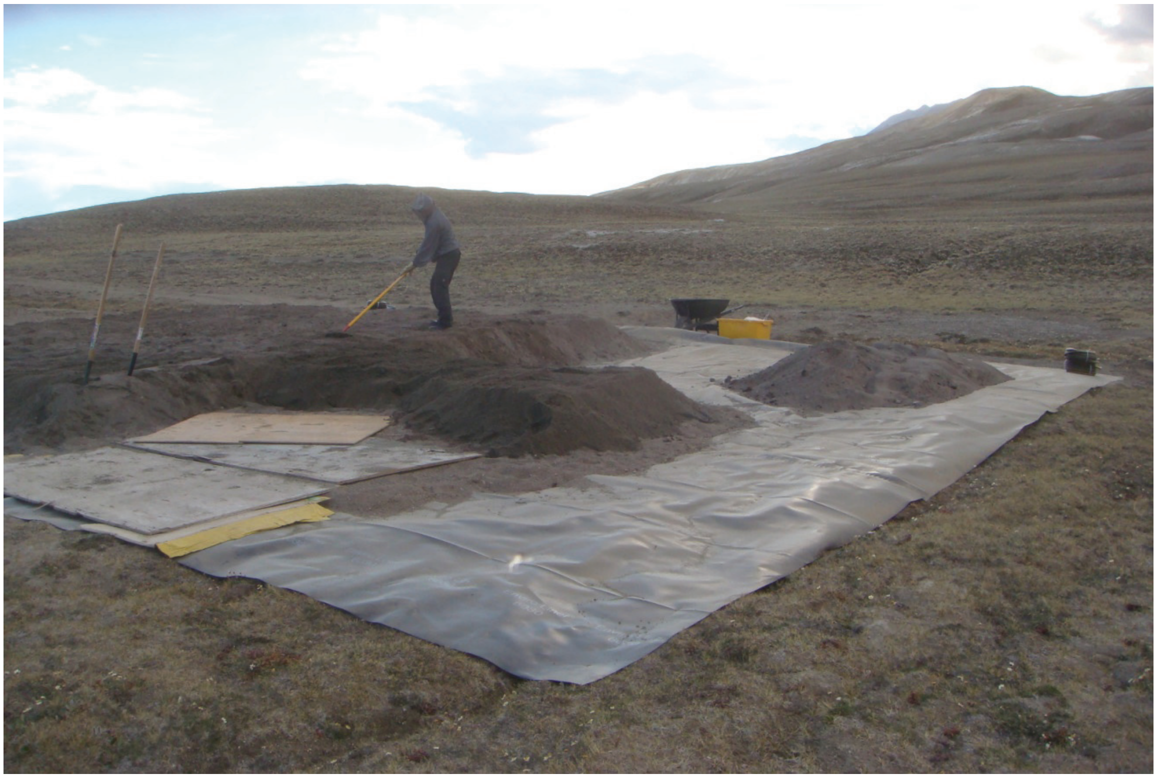
Photograph IV-4: Excavation 15367.


Photograph IV-5: Excavated area 04-472.

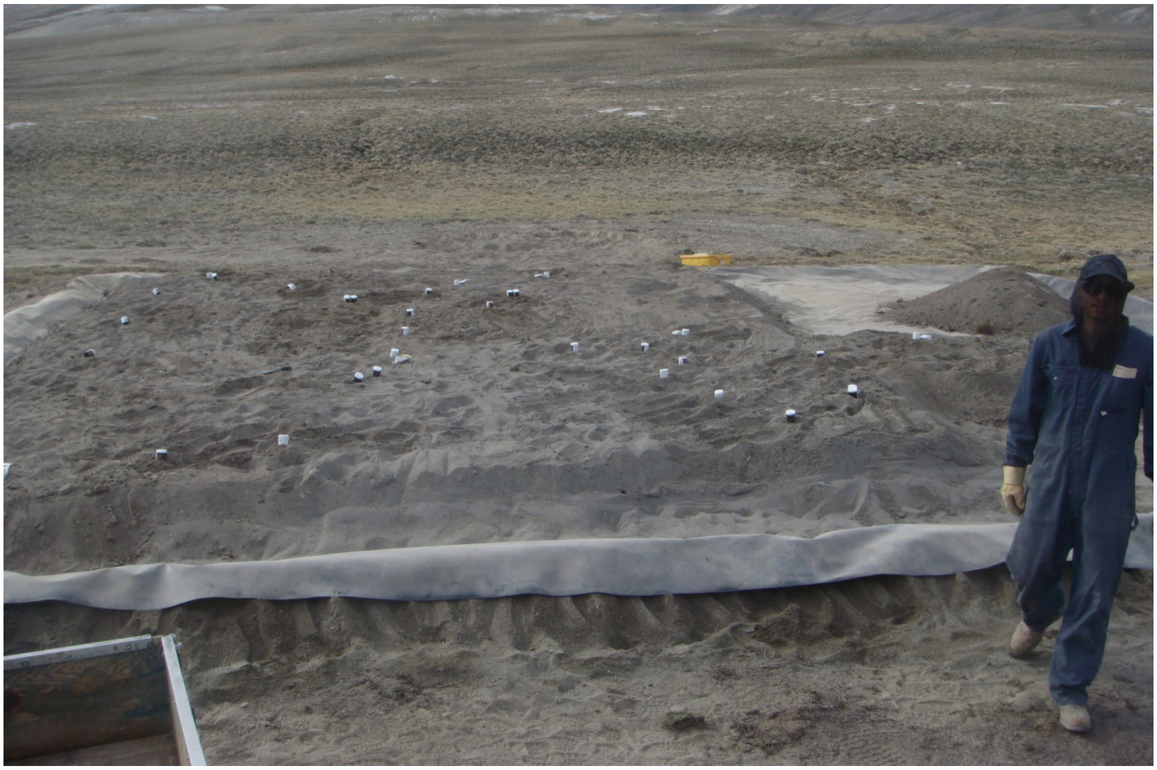

Photograph IV-6: Excavation area 04-429.



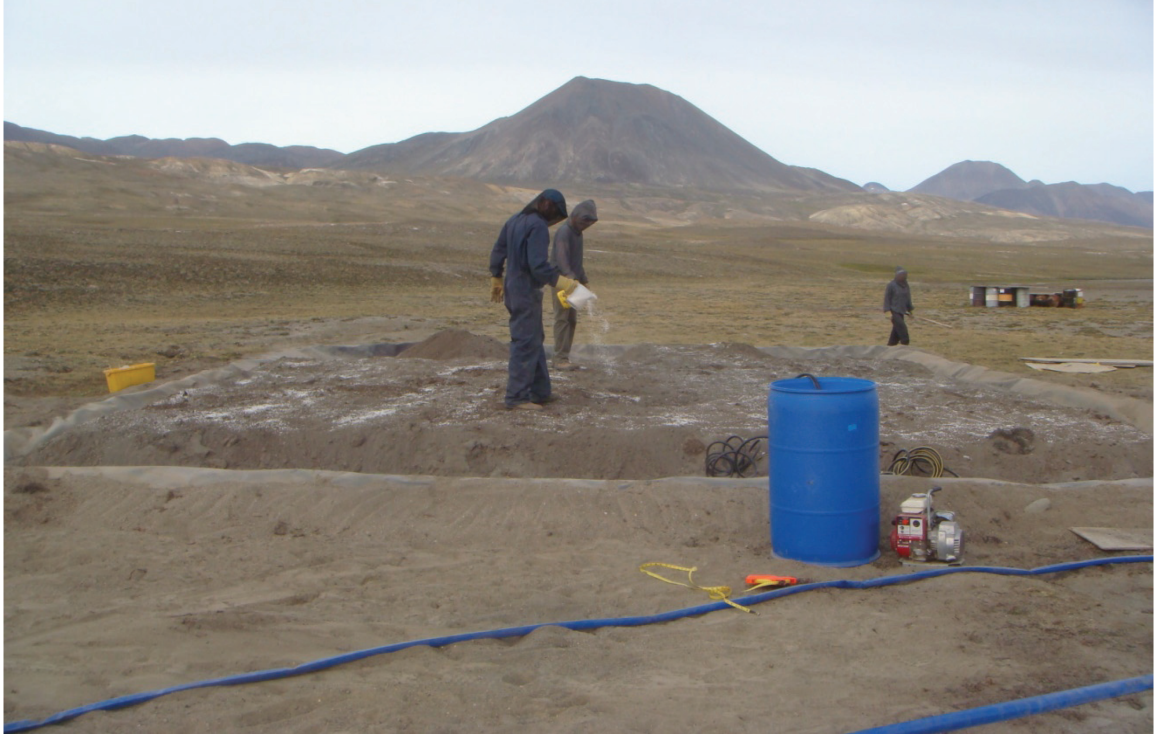
Photograph IV-7: Construction of the Lake Hazen landfarm: geotextile liner with silt and gravel layer being constructed.



Photograph IV-8: Construction of the Lake Hazen landfarm: addition of the 30 cm layer of hydrocarbon-contaminated soil.

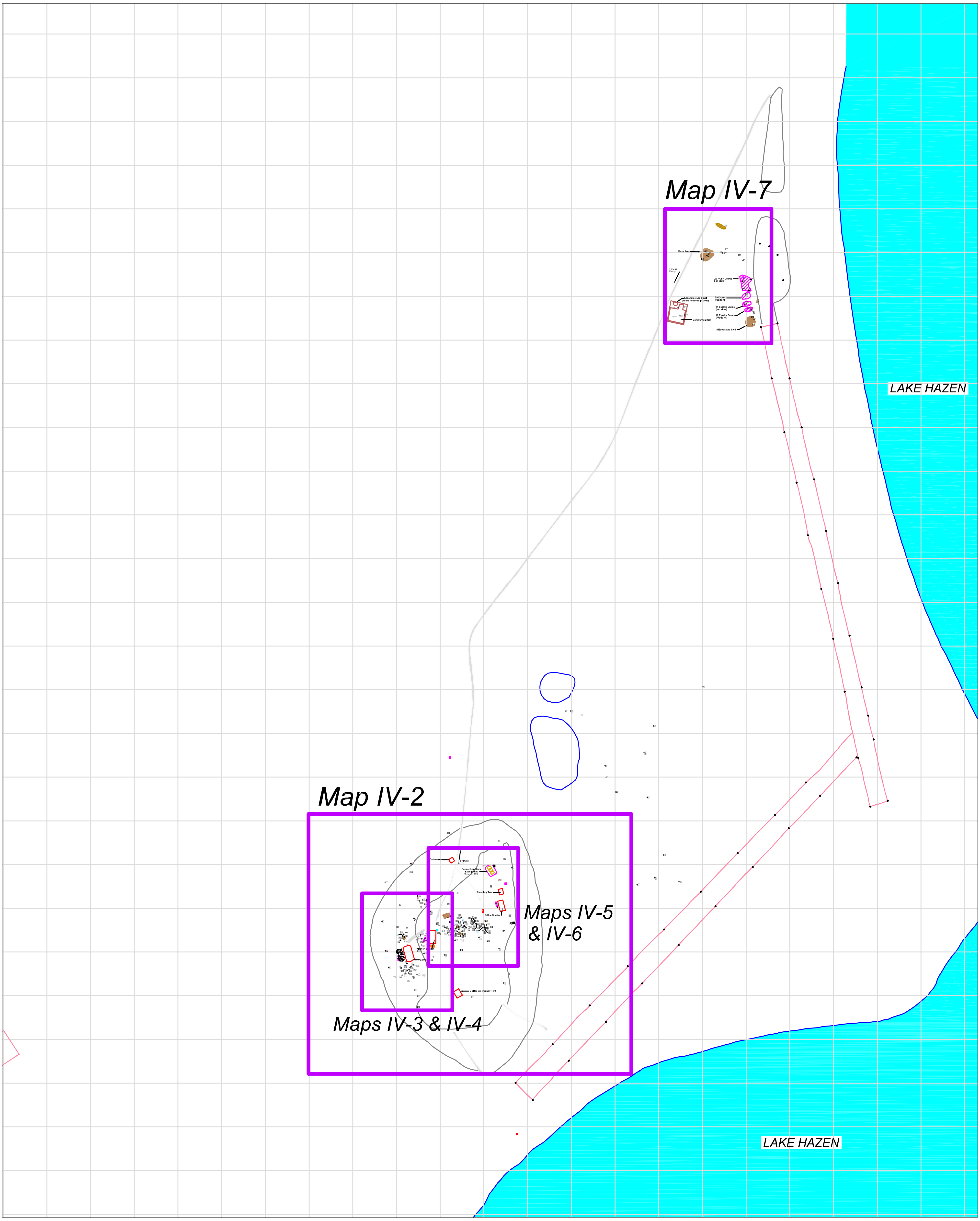


Photograph IV-9: A berm was constructed around the entire geotextile liner to prevent leaching of contaminants into the surrounding soil. Soil containing leachable lead was stored separately in one corner of the landfarm (top right).



Photograph IV-10: Fertilizer was added evenly across the landfarm.

Photograph IV-11: Landfarm treatment: fertilizer and Biosolve™ were mixed into the soil, which was homogenized using a shovel.



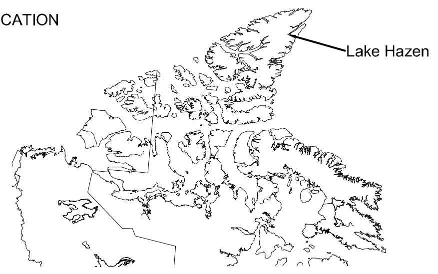
Legend

Antenna	☒	Solar Panel	☒
Barrel	●	Stain	▰
Barrel Area	▨	Survey Base Station	⟂
Barrel on its side	▮	Water Supply Line	—
Building	□	Weather Sensor	☒
Debris	▩	Winch	×
Drainage	—	Windsock	⚑
Emergency Cache	●		
Excavated Area 2005	▨		
Excavated Area 2008	▨		
Flag Pole	◎		
Foundation	□		
Gravel Pad Extent	—		
Grey Water Well	●		
Path	▬		
Propane Cylinder	●		
Propane Cylinder Area	—		
Runway	—		
Runway Marker	●		
Sample Tag	+11964		
Shoreline, Rivers, Lakes	—		
Snowmobile Storage	▨		

Sample & Area Definitions	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	■	▦
DLCC TPH Type B	■	▨
CCME Inorganics	■	▥

Map IV-1: Lake Hazen (Overview)

LOCATION



NOTES:

Grid Scale: 25m Original Source: ESG GPS

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UPDATED: MARCH 11, 2009
PRINTED: MARCH 11, 2009

Sam Soja
GIS Technician

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Base Map\Lake Hazen\LakeHazen_04_05_07_08.DWG

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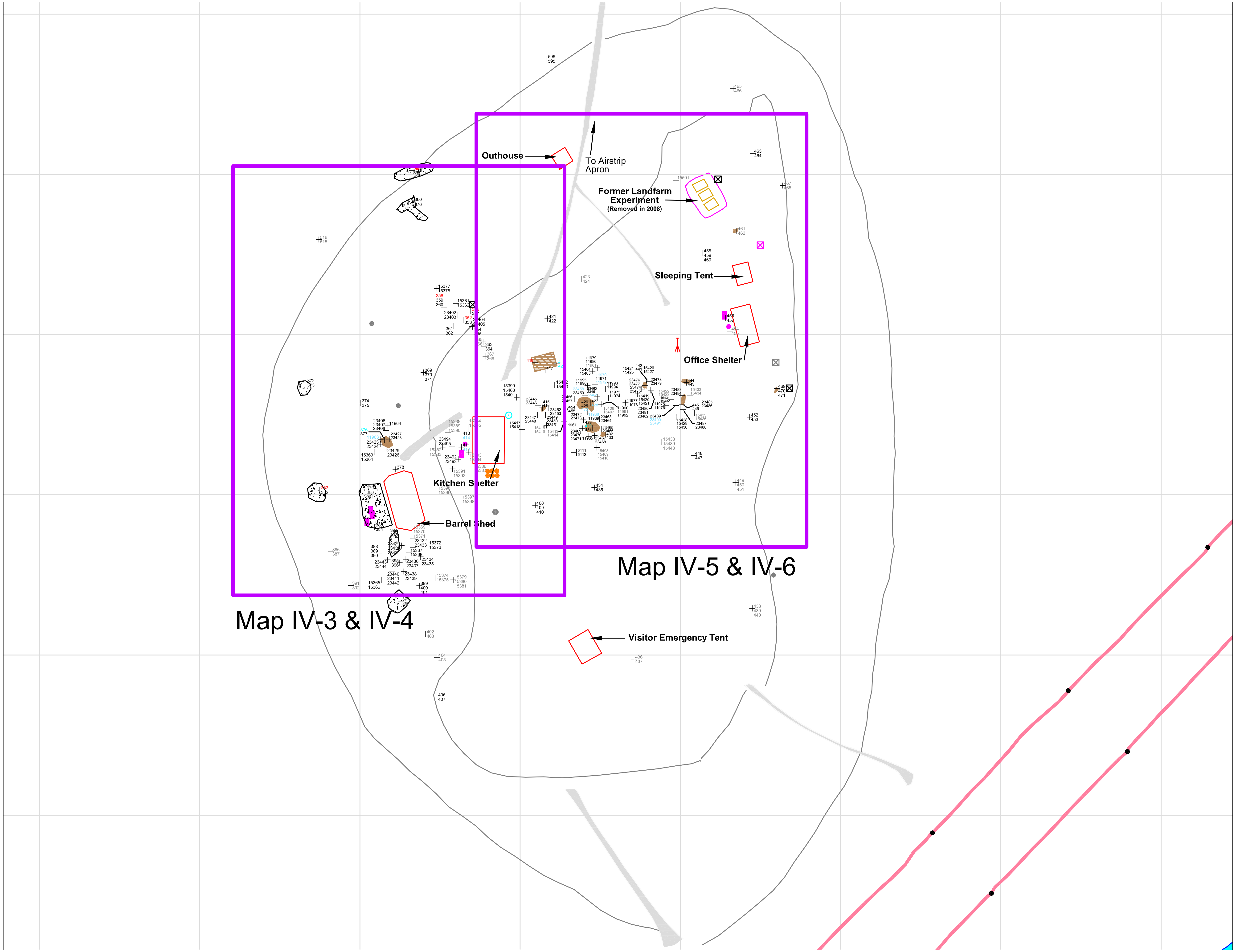
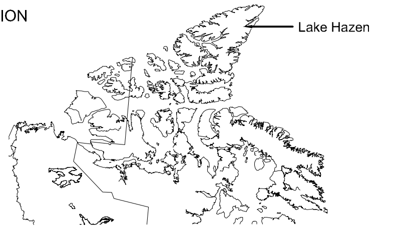
Tel: (613) 541-6000 Ext: 6050
Fax: (613) 541-6596

Map IV-2: Lake Hazen Main Camp (Overview)



LOCATION



Grid Scale: 25m

Original Source:
ESG GPS

Legend

Antenna	☒
Barrel	●
Barrel Area	▨
Barrel on its side	▮
Building	☐
Debris	▨
Drainage	—
Emergency Cache	●
Excavated Area 2005	▨
Excavated Area 2008	▨
Flag Pole	⊙
Foundation	☐
Gravel Pad Extent	—
Grey Water Well	●
Path	▬
Propane Cylinder	●
Propane Cylinder Area	—
Runway	—
Runway Marker	●
Sample Tag	+ 11964
Shoreline, Rivers, Lakes	—
Snowmobile Storage	▨
Solar Panel	☒
Stain	▰
Survey Base Station	⊥
Water Supply Line	—
Weather Sensor	☒
Winch	✕
Windsock	⚑

Sample & Area Definitions

	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	■	▦
DLCC TPH Type B	■	▨
CCME Inorganics	■	▥

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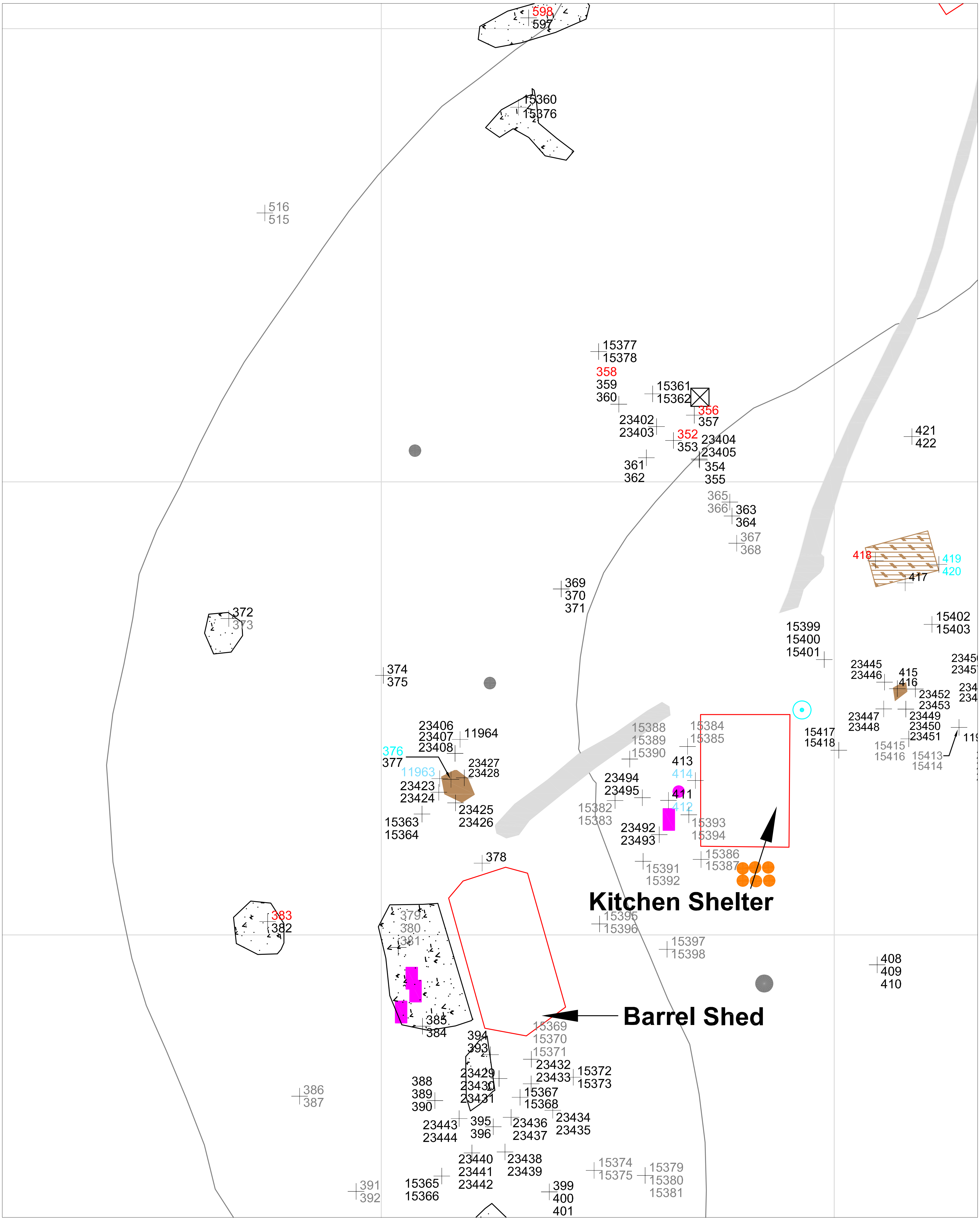

Legend

Antenna	☒	Solar Panel	☒
Barrel	●	Stain	▰
Barrel Area	▨	Survey Base Station	⊥
Barrel on its side	▮	Water Supply Line	—
Building	☐	Weather Sensor	☒
Debris	▨	Winch	✕
Drainage	—	Windsock	⚑
Emergency Cache	●		
Excavated Area 2005	▨		
Excavated Area 2008	▨		
Flag Pole	⊙		
Foundation	☐		
Gravel Pad Extent	—		
Grey Water Well	●		
Path	▬		
Propane Cylinder	●		
Propane Cylinder Area	—		
Runway	—		
Runway Marker	●		
Sample Tag	+11964		
Shoreline, Rivers, Lakes	—		
Snowmobile Storage	▨		

Sample & Area Definitions	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	■	▦
DLCC TPH Type B	■	▩
CCME Inorganics	🟥	▥

Map IV-3: Lake Hazen Main Camp, West Camp Pad

LOCATION

NOTES:

Grid Scale: 25m Original Source: ESG GPS

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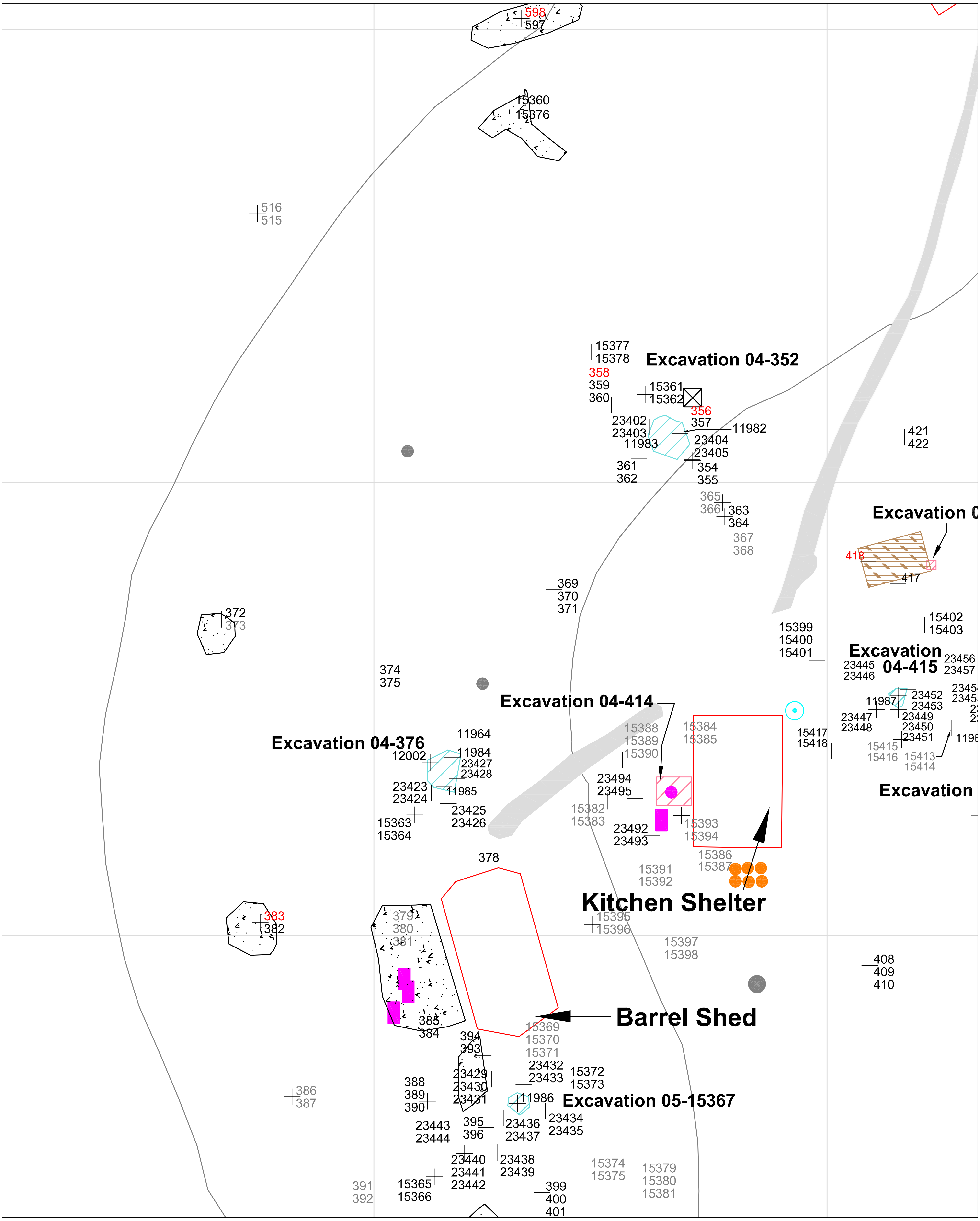


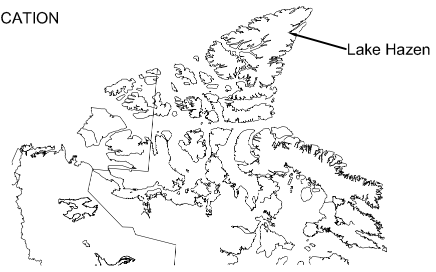
Legend

Antenna	☒	Solar Panel	☒
Barrel	●	Stain	
Barrel Area	▨	Survey Base Station	⊥
Barrel on its side	▮	Water Supply Line	—
Building	□	Weather Sensor	☒
Debris	▨	Winch	×
Drainage	—	Windsock	⚑
Emergency Cache	●		
Excavated Area 2005	▨		
Excavated Area 2008	▨		
Flag Pole	⊙		
Foundation	□		
Gravel Pad Extent	—		
Grey Water Well	●		
Path	▬		
Propane Cylinder	●		
Propane Cylinder Area	—		
Runway	—		
Runway Marker	●		
Sample Tag	+11964		
Shoreline, Rivers, Lakes	—		
Snowmobile Storage	▨		

Sample & Area Definitions	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	■	▦
DLCC TPH Type B	■	▨
CCME Inorganics	■	▥

Map IV-4: Lake Hazen Main Camp, West Camp Pad (Excavated Areas)

LOCATION



NOTES:

Grid Scale: 25m Original Source: ESG GPS

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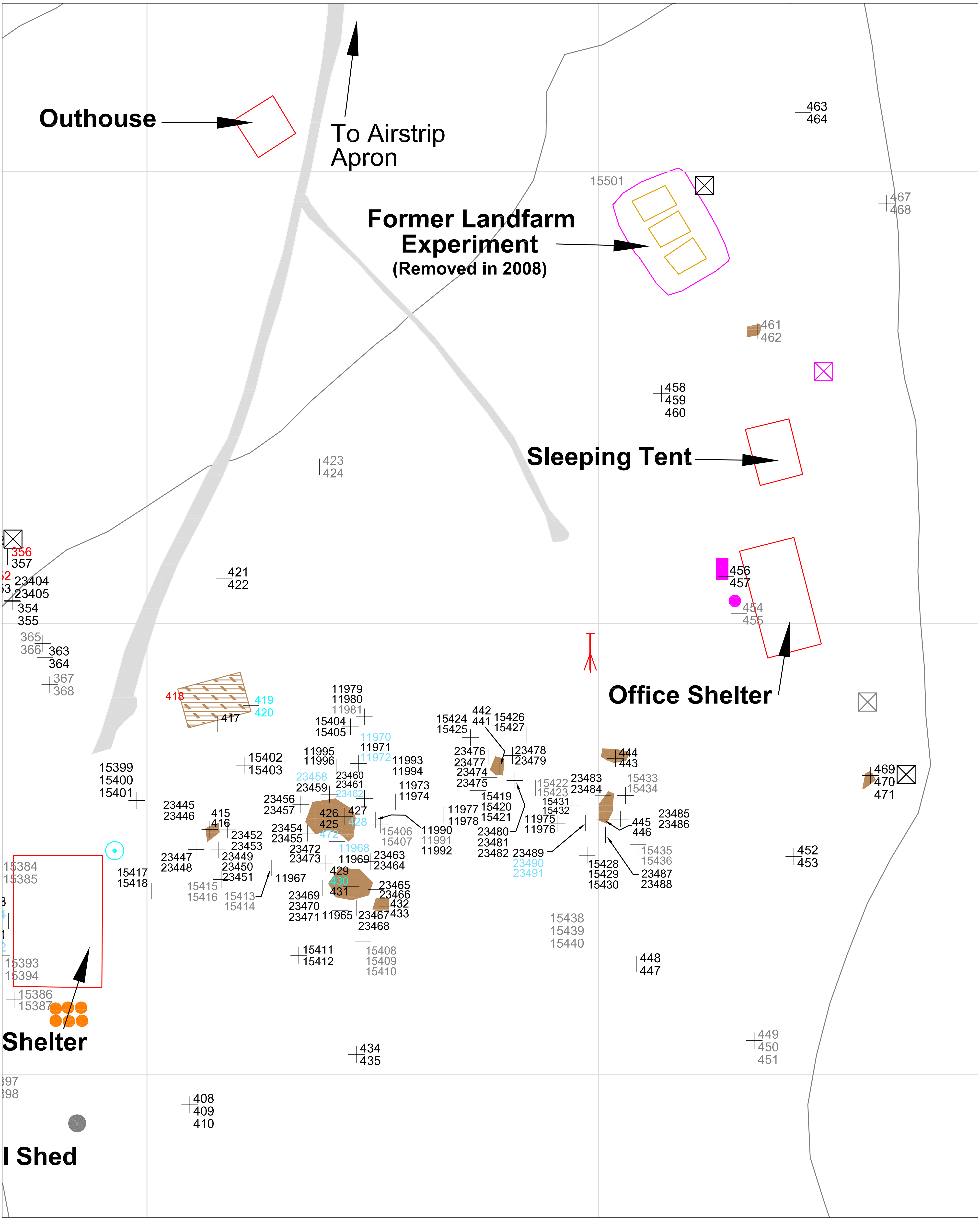


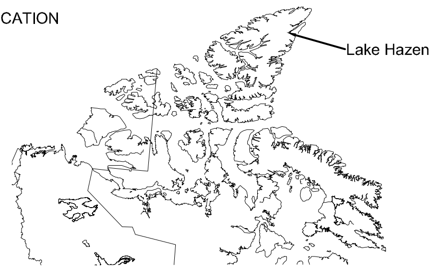
Legend	
Antenna	☒
Barrel	●
Barrel Area	▨
Barrel on its side	▮
Building	☐
Debris	▩
Drainage	—
Emergency Cache	●
Excavated Area 2005	▨
Excavated Area 2008	▨
Flag Pole	⊙
Foundation	☐
Gravel Pad Extent	—
Grey Water Well	●
Path	▬
Propane Cylinder	●
Propane Cylinder Area	—
Runway	—
Runway Marker	●
Sample Tag	+ 11964
Shoreline, Rivers, Lakes	—
Snowmobile Storage	▨

Solar Panel	☒
Stain	▰
Survey Base Station	⊥
Water Supply Line	—
Weather Sensor	☒
Winch	✕
Windsock	⚑

Sample & Area Definitions	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	🟦	▦
DLCC TPH Type B	🟦	▨
CCME Inorganics	🟥	▥

Map IV-5: Lake Hazen Main Camp, East Camp Pad

LOCATION



NOTES:

Grid Scale: 25m Original Source: ESG GPS

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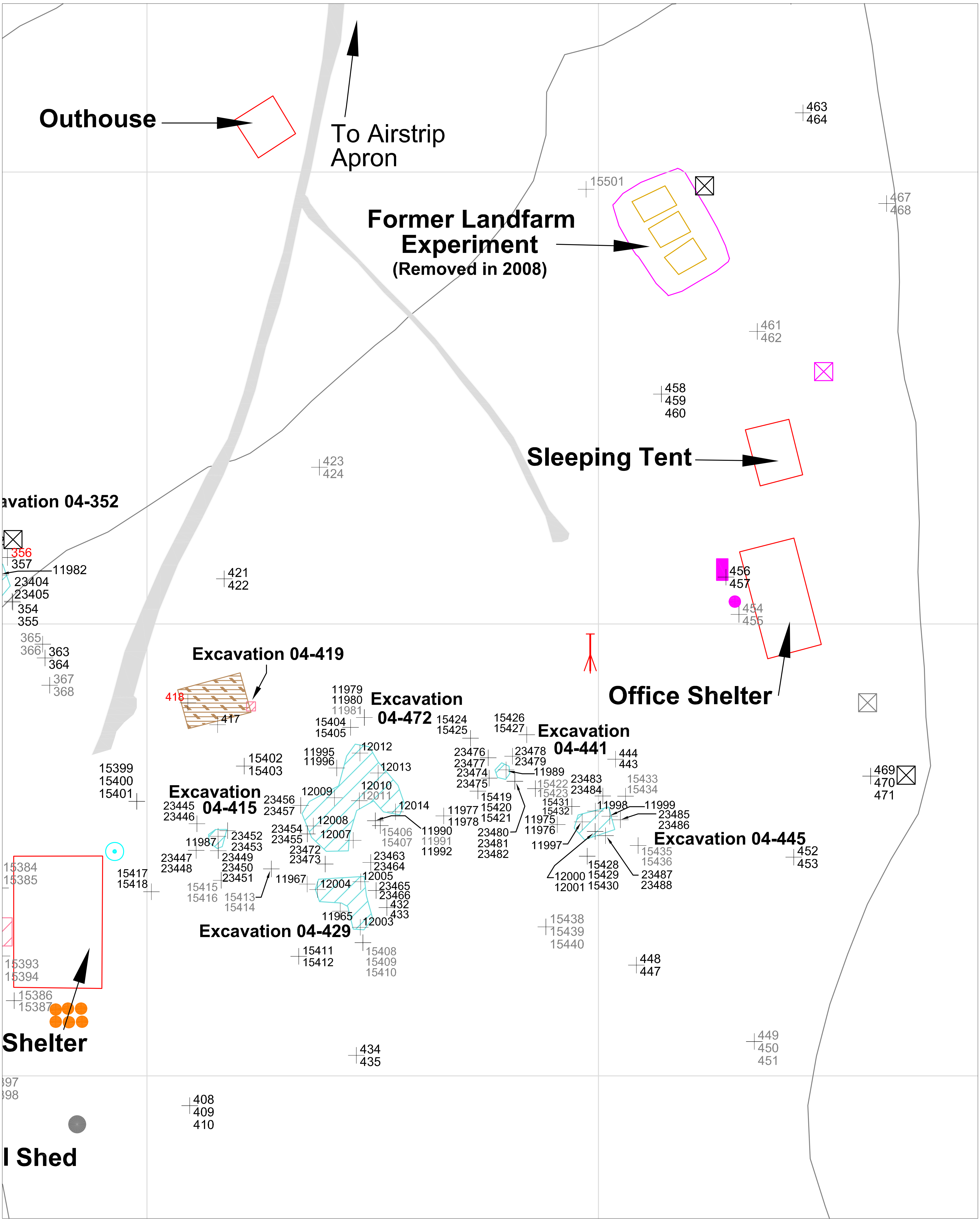


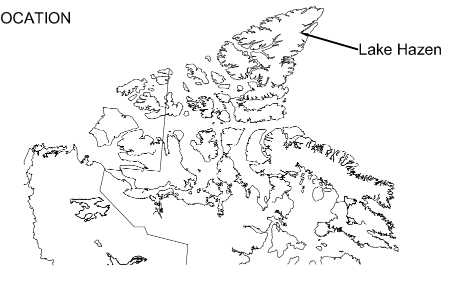
Legend

Antenna	☒	Solar Panel	☒
Barrel	●	Stain	▰
Barrel Area	▨	Survey Base Station	⊥
Barrel on its side	▮	Water Supply Line	—
Building	☐	Weather Sensor	☒
Debris	▩	Winch	✕
Drainage	—	Windsock	⚑
Emergency Cache	●		
Excavated Area 2005	▨		
Excavated Area 2008	▨		
Flag Pole	⊙		
Foundation	☐		
Gravel Pad Extent	—		
Grey Water Well	●		
Path	▬		
Propane Cylinder	●		
Propane Cylinder Area	—		
Runway	—		
Runway Marker	●		
Sample Tag	+11964		
Shoreline, Rivers, Lakes	—		
Snowmobile Storage	▨		

Sample & Area Definitions	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	■	▦
DLCC TPH Type B	■	▨
CCME Inorganics	■	▥

Map IV-6: Lake Hazen Main Camp, East Camp Pad (Excavated Areas)

LOCATION



NOTES:

Grid Scale: 25m Original Source: ESG GPS

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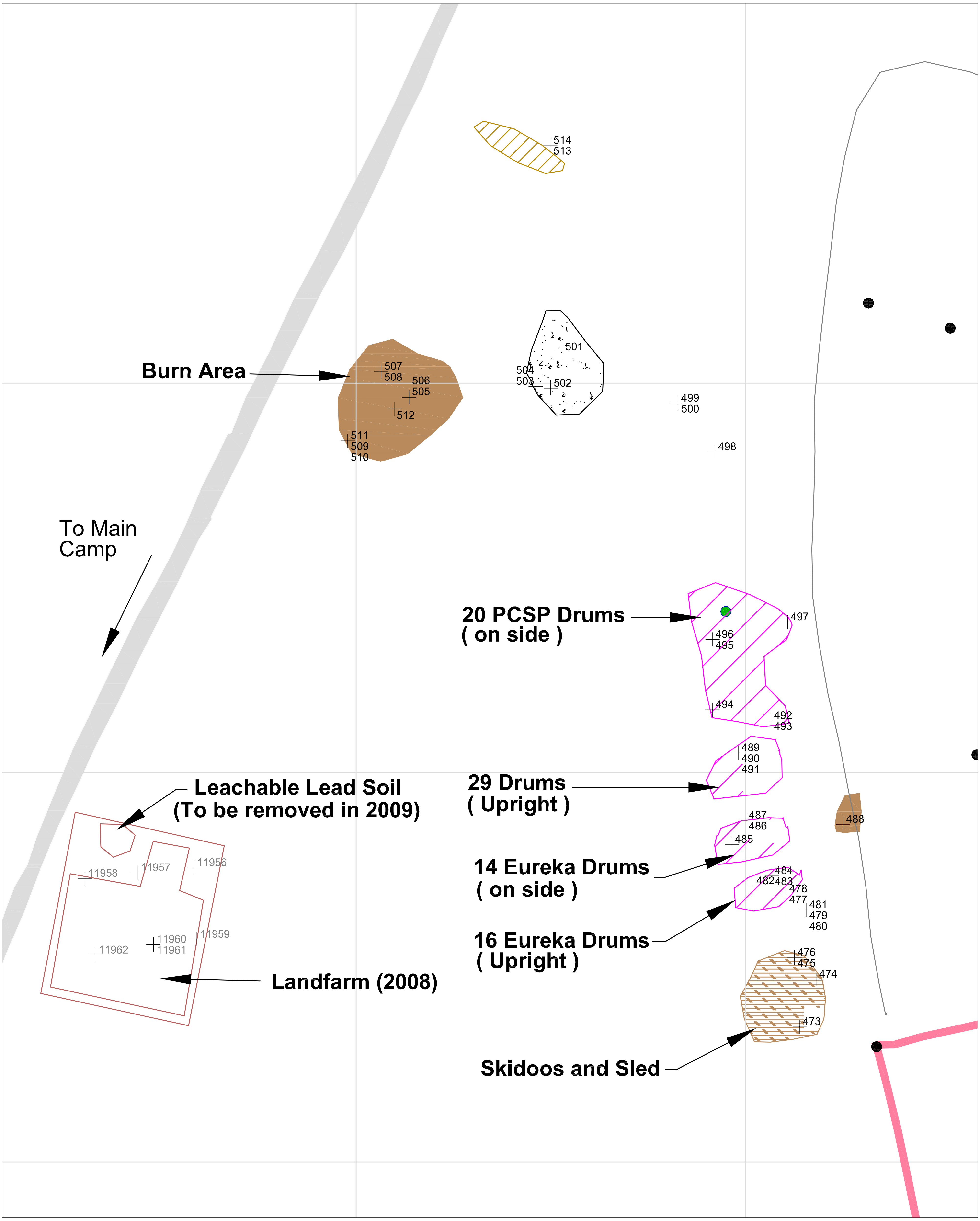


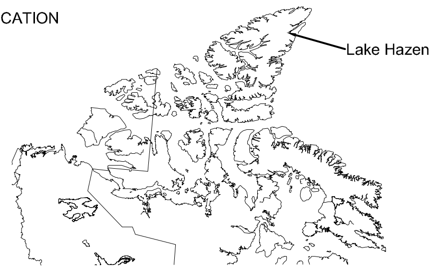
Legend

Antenna	☒	Solar Panel	☒
Barrel	●	Stain	
Barrel Area	▨	Survey Base Station	
Barrel on its side	▮	Water Supply Line	—
Building	☐	Weather Sensor	☒
Debris	▒	Winch	×
Drainage	—	Windsock	
Emergency Cache	●		
Excavated Area 2005	▨		
Excavated Area 2008	▨		
Flag Pole	◎		
Foundation	☐		
Gravel Pad Extent	—		
Grey Water Well	●		
Path	▬		
Propane Cylinder	●		
Propane Cylinder Area	—		
Runway	—		
Runway Marker	●		
Sample Tag	+11964		
Shoreline, Rivers, Lakes	—		
Snowmobile Storage	▨		

Sample & Area Definitions	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	■	▦
DLCC TPH Type B	■	▩
CCME Inorganics	■	▥

Map IV-7: Landfarm & Airstrip Fuel Cache Site

LOCATION



NOTES:

The barrel cache at the north end of the runway was surveyed and inventoried in 2004. Barrel quantities and cache extents may have changed since then.

Grid Scale: 25m Original Source: ESG GPS

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V. WARD HUNT ISLAND

A. Site Location and History

Ward Hunt Island is located off the north coast of Ellesmere Island at latitude N 83˚ 5.3' and longitude W 74˚ 8.55' (Map I-1). The Ward Hunt camp is located on the north side of the island adjacent to the Ward Hunt ice shelf. The ground slopes gradually toward a meltwater lake located about 100 m from camp at the base of the ice rise. The main camp on Ward Hunt Island was established in 1959, and used by the Defence Research Board (DRB) as a research station between 1961 and 1973. Since its establishment, the Ward Hunt Island camp has also been used as a base for numerous North Pole expeditions. PCA staff conducted an extensive cleanup of the area during the 1990s, including the completion of an inventory of historical artifacts, removal of hazardous materials, and sorting and burning consolidated wastes (EBA, 2003). The site currently serves as a base for scientific research, polar expeditions, and for national park operations with PCA. Ward Hunt camp (Map V-1) may be divided into two areas: the main camp and the runway area. Detailed descriptions of the site layout and history are found in EBA (2003) and ESG (2005a). Previous site investigations have indicated areas of hydrocarbon and inorganic contamination, but no evidence of other contaminants (PCBs, BTEX) was found.

During a 2002 site assessment, hydrocarbon contamination was noted at several locations including next to the Tucker snow machine, near the empty hut frame in camp, and near leaking barrels at the airstrip apron area (EBA, 2003). The 2004 ESG site investigation also found significant hydrocarbon contamination in the form of lubricating oils and greases (F3 and F4 fuel fractions) at the main camp (Map V-2), mostly located in a large stain next to the Tucker snow machine (ESG, 2005a). Limited hydrocarbon contamination (both F2 and F3 fractions) was found at the runway.

Inorganic contamination (Cr, Ni, Cu, Pb, Zn) was also identified in several areas in the 2004 and 2005 site investigations. One sample was collected and analyzed from each area suspected to contain elevated concentrations of inorganics (ESG, 2005a; 2006).

B. Summary of Sampling Activities and Results

Previous site investigations at Ward Hunt Island in 2004 and 2005 indicated four areas of inorganic contamination above the relevant CCME criteria, described in Section II.C.2. It has been recommended that three of these areas (296, 274 and 267; Map V-3) be excavated and that the excavated soil be shipped to an off-site treatment facility (ESG, 2006). The site's remoteness makes shipping contaminated soil off site for treatment challenging and costly. Each contaminated area was carefully delineated in 2008 to determine the minimum amount of soil requiring excavation. Delineation excavation was not recommended for the fourth area because the sample contains Cu and Ni concentrations only slightly above the CCME guideline (05-15724; Map V-2; ESG, 2006)

Numerous areas of hydrocarbon contamination have been noted on site (ESG, 2005a; EBA, 2003), some of which are a result of leaking fuel barrels on site (ESG, 2006). Numerous fuel caches of full and partly full barrels are present on site and are no longer in use. Some of the barrels appear to be weathered and possibly leaking. If the contents of the barrels are not disposed of, the barrels will eventually weather and leak, causing more hydrocarbon contamination. For this reason, ESG conducted a barrel sampling program in 2008 to determine the contents of the barrels such that the unused fuel could be burned off in an incinerator in 2009.

1. Delineation

The three areas recommended for excavation were delineated using a 1 m x 1 m grid along with one depth sample. The samples were analyzed for copper, nickel, cobalt, cadmium, lead, zinc, chromium and arsenic.

Area 296: This area is the remains of a burn pit, and contains a large pile of ash, approximately 1 m in diameter (Map V-3a). To prevent disturbing the ash pile and further dispersing the contamination, no depth samples were taken. Instead five surface samples, including one duplicate pair, were collected adjacent to the ash edge (08-12187 to 121911; Table B-5; Photograph V-1). The duplicate depth samples were above criteria for chromium, but all other samples were below criteria for all inorganic elements analyzed. Another four surface samples (08-12192/3/4/5) were taken in a ring 1 m out from the first set of samples, and the one that was analyzed (08-12195) was below criteria.

Area 267: This area was also a burn pit and contains wood, metal, plastic and battery debris (Photograph V-2). Ten samples were collected from this area, including one duplicate pair. At surface and at depth, all samples were below criteria (08-12176/7/8/9; Map V-3b; Table B-5).

Area 274: This area is located in a moss-covered drainage channel (Photograph V-3). The soil is silt and clay with high organic content and is covered with a 15-cm layer of moss. All surface samples taken from the drainage channel were taken at 0-10 cm under the moss layer (*i.e.* 15-25 cm below the actual surface). A total of 10 samples were taken from this area, including one duplicate pair. A duplicate pair of depth samples (12170/171), taken at 30-40 cm, indicated that inorganic contamination does not extend to this depth. Four surface delineation samples were collected 1 m from the depth sample (08-12165/67/68/69; Map V-3c), three of which are located in the moss-covered drainage channel. All four samples were below the CCME criteria (Table B-5).

Approximately 0.3 m^3 of soil from each of the three areas requires excavation and off-site disposal.

2. Barrel sampling

At the Ward Hunt Island main camp, 101 barrels were identified as waste fuel that is no longer in use. Most barrels were found in groups around the main camp and runway areas (Map V-2, Map V-4 and Map V-5). Six barrels were not sampled: four of these were bulging and not considered safe to open; one was almost empty and there was not enough liquid to collect a sample; and one barrel was rusted and could not be opened. All are assumed to have similar contents to the surrounding barrels. Of the 95 remaining barrels, 105 samples were collected in total, including 10 duplicate pairs. The samples were analyzed for polychlorinated biphenyls (PCBs), chlorine, chromium, lead and cadmium and results are shown in Table B-6. For samples containing two phases, the bottom phase was aqueous and the top phase (organic phase) was analyzed.

Approximately 67 of the barrels contained gasoline, 45 of which had lead concentrations above the DLCC (Table B-6). Because the DLCC was developed based on provincial guidelines they were created for permanent, licensed facilities. Since the application at Ward Hunt is for a one-time burn event, ESG has submitted an application for a permit with the intention to proceed with the burning of the leaded-gasoline on site, given that the alternative, to remove all barrels that exceed the DLCC, would be virtually impossible in a meaningful time-frame because of transport logistics, as well as being cost-prohibitive. None of the remaining barrels, which were identified as lubricating oil or ethylene glycol, contain any inorganics or PCBs above criteria, with two exceptions. The sample from barrel number 58 (08-12115; Table B-6) contained 458 ppm PCBs, which exceeds the DLCC of 2 ppm. This barrel must be shipped off site for disposal, as it falls under Canadian Environmental Protection Agency (CEPA) regulations. Another barrel contained Cl above the DLCC of 1,000 ppm (08-12132; 173,000 ppm; Table B-6). It has been proposed to burn this barrel on-site.

3. Other site observations

The meltwater lake between the island and the ice rise was previously used as a drinking water lake for the main camp. Over the course of the 2008 field season, this lake became increasingly saline and undrinkable. In recent years, large cracks in the Ward Hunt ice shelf have been observed and large pieces of it have broken off (England, 2008). On July 22, 2008, a large piece of the ice shelf broke off and drifted into the Arctic Ocean (Mueller, 2008). Previous changes in the ice shelf may have caused ocean water to flow into the freshwater lake. For the remainder of the field season, the freshwater lake located in the middle of the island (south of the camp) was used as a drinking water source.

A box labelled T.N.T. is located east of the kitchen shelter. TNT was used during seismic studies conducted in 1959 and may still present a safety concern. Because the box may still contain explosive material, it is highly recommended that it be examined by an unexploded ordinance (UXO) specialist. In addition, at the east end of the runway, two metal containers, both labelled “explosive bomb”, have been placed marking the end of the airstrip (Photograph V-4). It is not known whether these boxes contain explosives and therefore, it would also be beneficial to have a UXO specialist look at them.

C. Site Summary and Recommendations

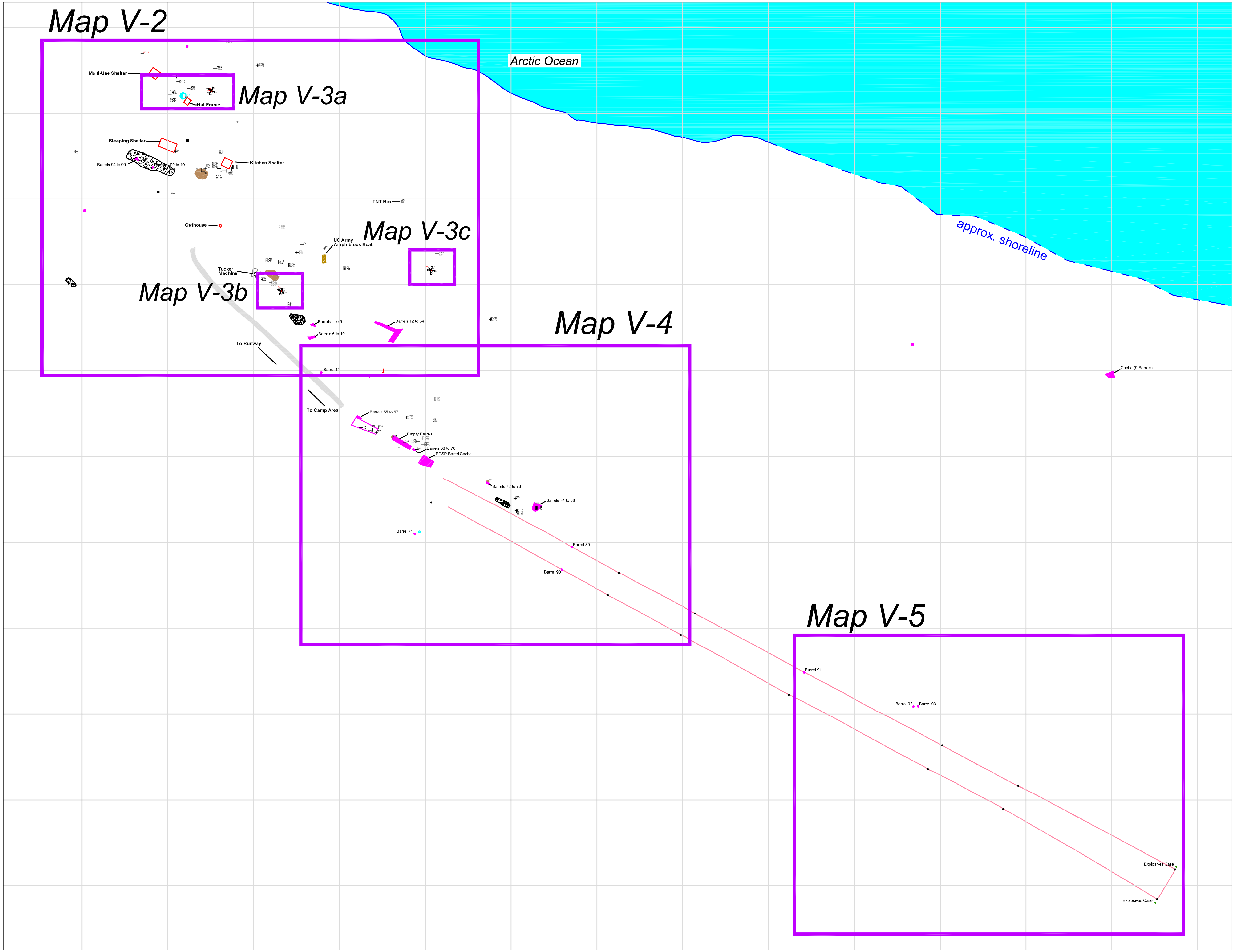
The extent of inorganic contamination in three areas was delineated. Approximately 1 m^3 of soil must be excavated and shipped to an off-site disposal facility. The soil will be excavated and prepared for shipment in 2009. The contents of the waste fuel barrels were identified: most are full of leaded gasoline or lube oil, but some are only partly full. It has been proposed in the research application permit to burn these barrels on site in 2009. One barrel is contaminated with PCBs in excess of CEPA regulations and will be shipped off site for proper disposal.


Photograph V-1: Delineation sampling in area 296.


Photograph V-2: Delineation sampling in area 267.

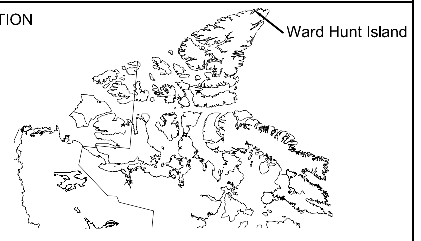
Photograph V-3: Delineation area 274, located in a drainage pathway covered in moss, with sample tags.

Photograph V-4: Two boxes labelled "explosive bomb" are used at Ward Hunt Island to mark the east end of the airstrip.



Map V-1: Ward Hunt Island, Overview

LOCATION



Grid Scale: 50m

Original Source:
ESG GPS

Legend

Antenna	☒
Boat	▨
Building	☐
Debris	▨
Emergency Cache	●
Flag Pole	◉
Foundation	☐
Barrel	●
Barrel Area	▨
Barrel on its side	▮
Grey Water Well	●
Path	▬
Propane Cylinder	●
Propane Cylinder Area	—
Runway	—
Runway Marker	●
Sample Tag	+11964
Shoreline, Rivers, Lakes	—
Stain	▬
Survey Base Station	⊥
Water Supply Line	—
Weather Sensor	☒
Winch	✕
Windsock	⊥

Sample & Area Definitions	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	■	▦
DLCC TPH Type B	■	▦
CCME Inorganics	■	▥

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Map V-2: Ward Hunt Island, Camp Area

LOCATION

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Grid Scale: 25m

Original Source:
ESG GPS

Legend

Antenna	⊠
Boat	▨
Building	☐
Debris	▩
Emergency Cache	●
Flag Pole	◎
Foundation	☐
Barrel	●
Barrel Area	▨
Barrel on its side	▮
Grey Water Well	●
Path	▬
Propane Cylinder	●
Propane Cylinder Area	—
Runway	—
Runway Marker	●
Sample Tag	+11964
Shoreline, Rivers, Lakes	—
Stain	▰
Survey Base Station	⏉
Water Supply Line	—
Weather Sensor	⊠
Winch	✕
Windsock	⚑

Sample & Area Definitions	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	■	▦
DLCC TPH Type B	■	▩
CCME Inorganics	■	▥

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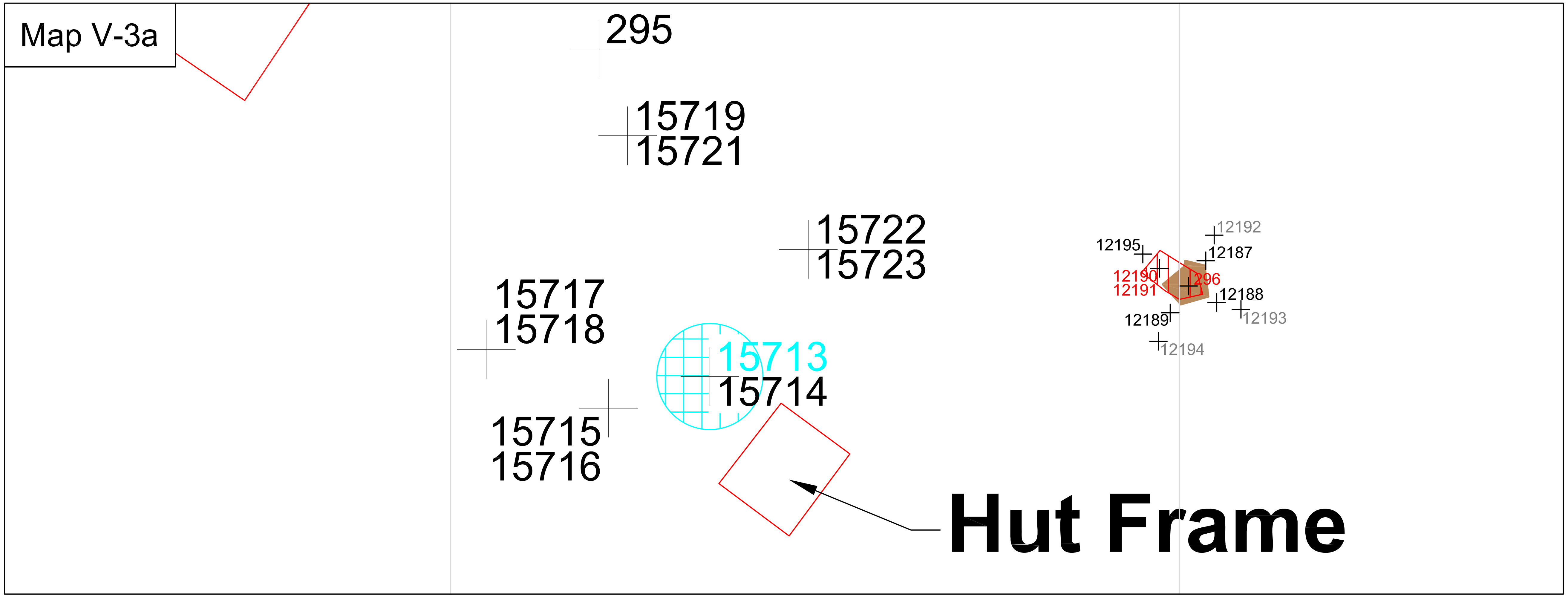
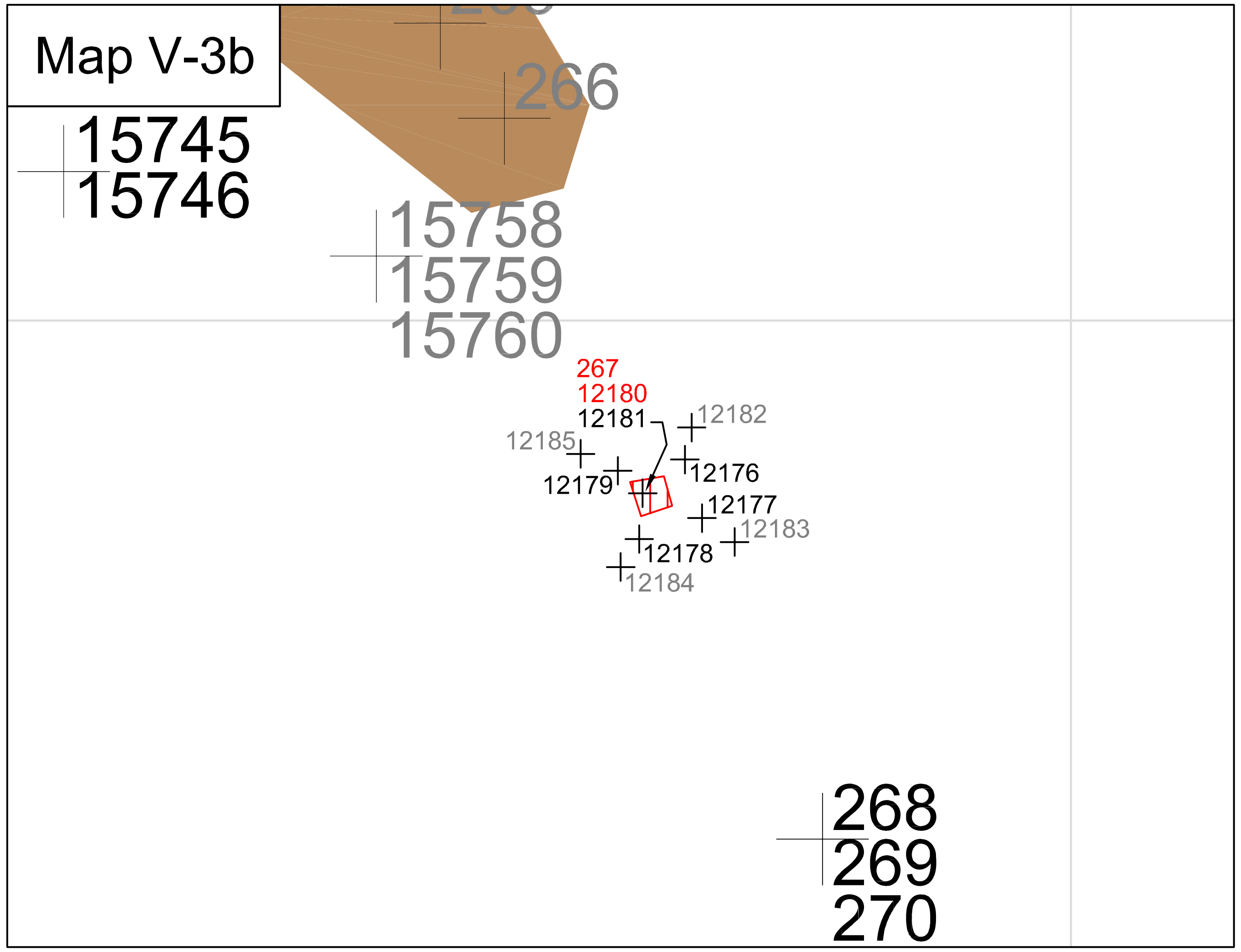
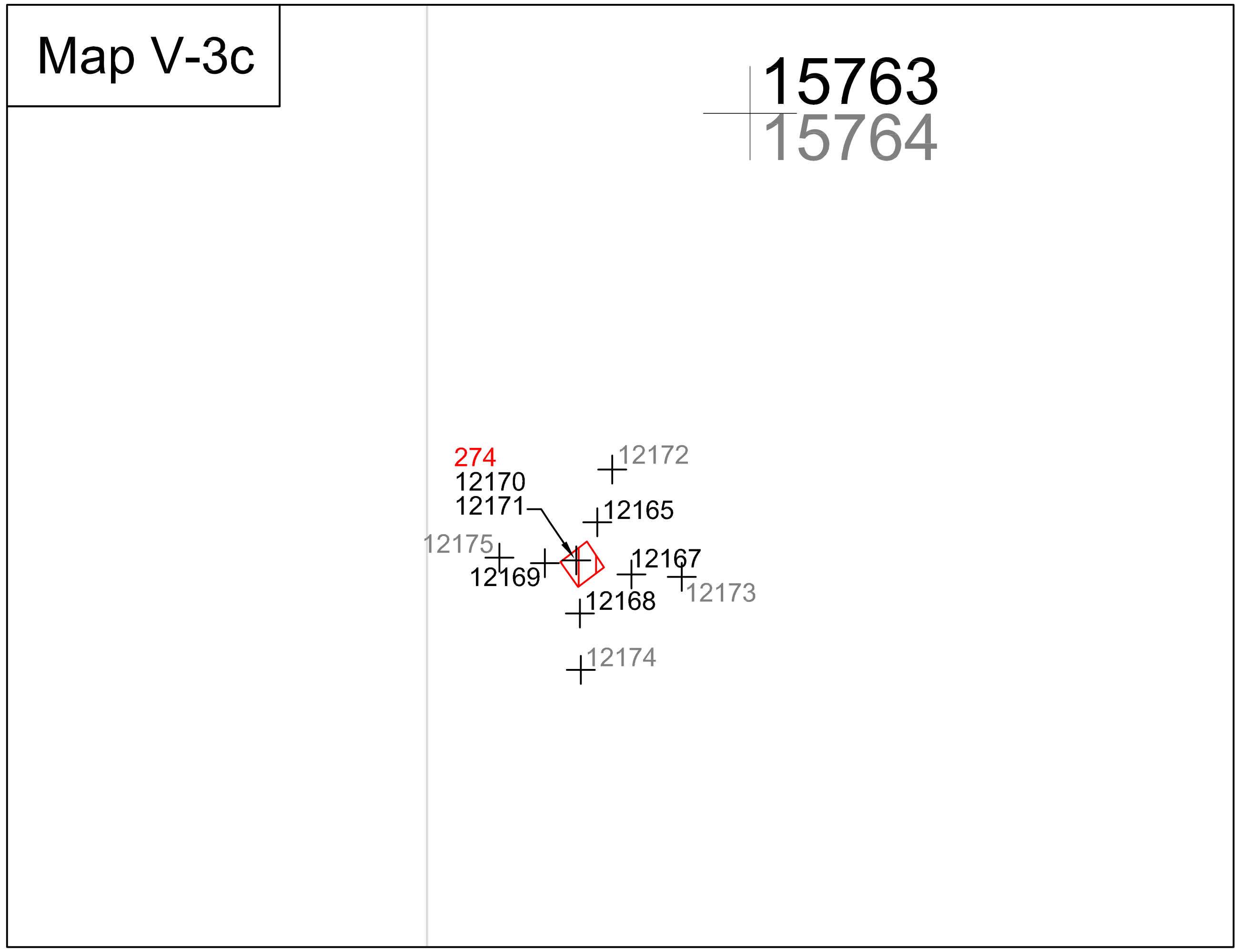
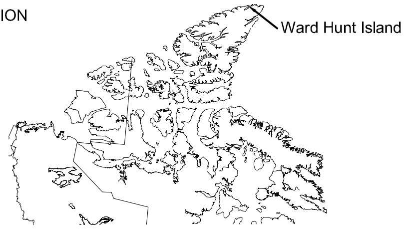
Map V-3: 2008 Soil Delineations







LOCATION



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Grid Scale: 25m

Original Source:
ESG GPS

Legend

Antenna	☒
Boat	▨
Building	☐
Debris	▨
Emergency Cache	●
Flag Pole	◎
Foundation	☐
Barrel	●
Barrel Area	▨
Barrel on its side	▮
Grey Water Well	●
Path	▬
Propane Cylinder	●
Propane Cylinder Area	—
Runway	—
Runway Marker	●
Sample Tag	+11964
Shoreline, Rivers, Lakes	—
Stain	▲
Survey Base Station	⊥
Water Supply Line	—
Weather Sensor	☒
Winch	✕
Windsock	⚑

Sample & Area Definitions	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	■	▦
DLCC TPH Type B	■	▦
CCME Inorganics	🟥	▥

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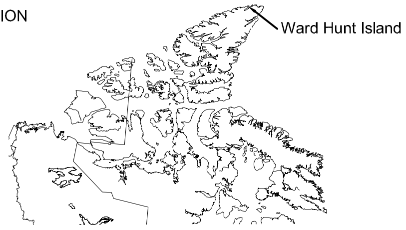
Map V-4: Ward Hunt Island, Runway West

LOCATION



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Grid Scale: 25m

Original Source:
ESG GPS

Legend

Antenna	☒
Boat	▨
Building	☐
Debris	▨
Emergency Cache	●
Flag Pole	◎
Foundation	☐
Barrel	●
Barrel Area	▨
Barrel on its side	▮
Grey Water Well	●
Path	▬
Propane Cylinder	●
Propane Cylinder Area	—
Runway	—
Runway Marker	●
Sample Tag	+11964
Shoreline, Rivers, Lakes	—
Stain	▬
Survey Base Station	⊥
Water Supply Line	—
Weather Sensor	☒
Winch	×
Windsock	⚑

Sample & Area Definitions	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	■	▦
DLCC TPH Type B	■	▨
CCME Inorganics	■	▥

NOTES:

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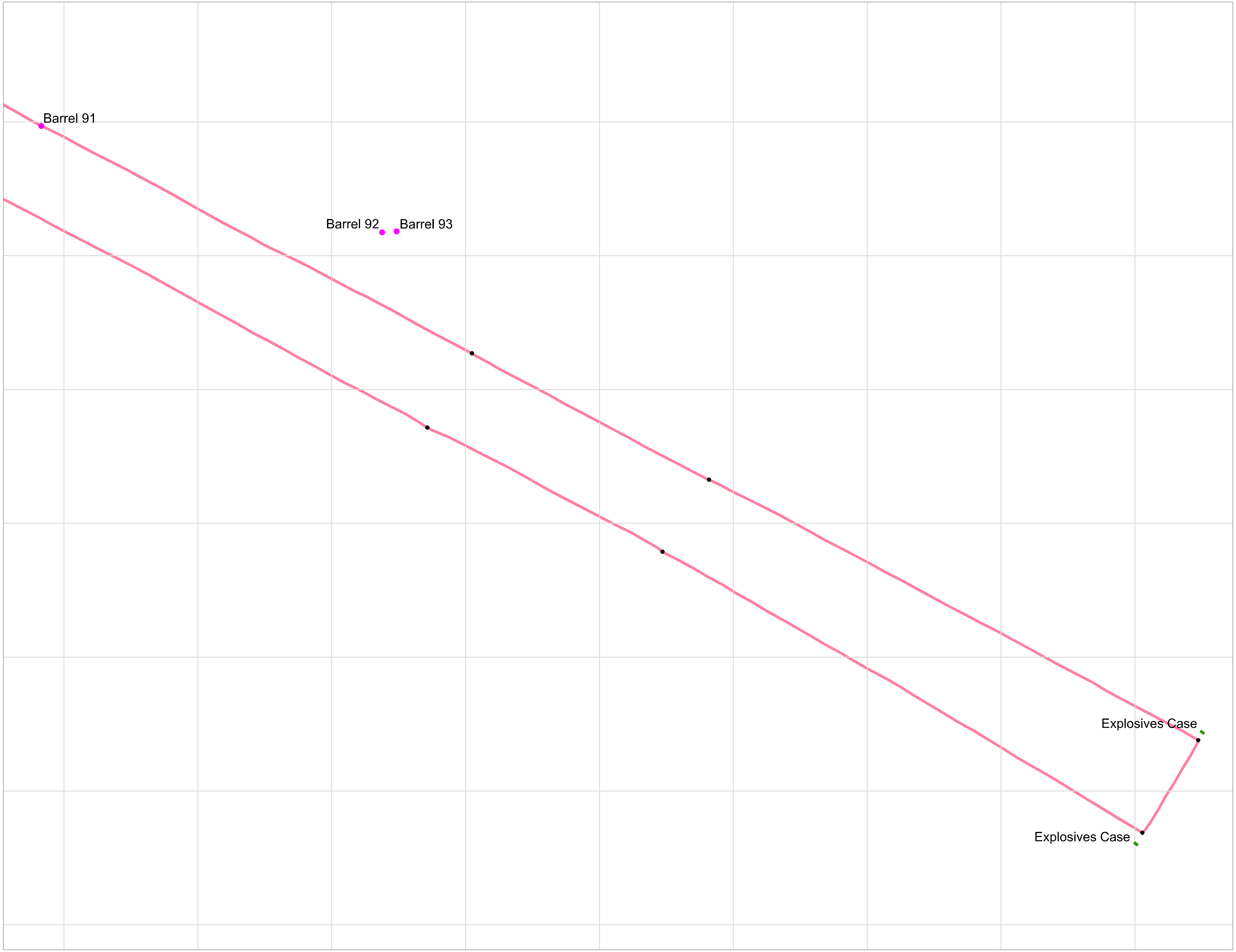

Map V-5: Ward Hunt Island, Runway East

LOCATION

N
W E
S

Grid Scale: 25m

Original Source:
ESG GPS

Legend

Antenna	☒
Boat	▨
Building	□
Debris	▩
Emergency Cache	●
Flag Pole	◎
Foundation	□
Barrel	●
Barrel Area	▨
Barrel on its side	▮
Grey Water Well	●
Path	▬
Propane Cylinder	●
Propane Cylinder Area	—
Runway	—
Runway Marker	●
Sample Tag	+11964
Shoreline, Rivers, Lakes	—
Stain	
Survey Base Station	
Water Supply Line	—
Weather Sensor	☒
Winch	✕
Windsock	⚑

Sample & Area Definitions	Tag Number	Area
Below Criteria	■	
Not Analyzed	■	
DLCC TPH Type A	■	▦
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VI. SUMMARY

In the summer of 2008, ESG continued the environmental investigation and remediation of hydrocarbon contamination and inorganic contamination at three sites in Quttinirpaaq National Park (QNP): Tanquary Fiord, Lake Hazen and Ward Hunt Island. The first year of the long-term monitoring program was completed at the Tanquary Fiord landfarm. The final year of sampling was completed for the test plots at Tanquary Fiord and Lake Hazen, which were decommissioned. Construction of the Lake Hazen landfarm was completed to remediate soil contaminated with hydrocarbons. At Ward Hunt Island, delineation samples were collected to determine the lateral extent and depth of inorganic contamination. Also at Ward Hunt Island, barrel samples were collected to provide the information required to start the on-site incineration of the barrel contents in 2009.

The general findings are as follows:

- The first-year sampling program at the Tanquary Fiord landfarm indicated a 95% UCL of 2,400 ppm for PHCs which is below the cleanup criteria of 2,500 ppm. This indicates that the soil has been remediated and can be removed.
- A similar landfarm was established at Lake Hazen in 2008. Following the landfarm maintenance protocol outlined in Appendix D, PCA staff will have to regularly water and till the landfarm to ensure effective treatment. Annual monitoring programs, similar to the one at Tanquary Fiord, will be established for the Lake Hazen landfarm to confirm that PHC concentrations are decreasing. The baseline sampling program indicated a 95% UCL of 4,800 ppm, and the landfarm may be decommissioned when the PHC concentrations of the samples have a 95% UCL below 2,500 ppm.
- At Ward Hunt Island, delineation samples collected in 2008 indicated inorganic contamination requiring the excavation of approximately 0.3 m^3 of soil from each of three locations around the main camp.
- Also at Ward Hunt Island, 101 barrels were investigated, all containing fuel and other substances no longer in use. The barrel contents have been proposed to be incinerated during the 2009 field season.

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APPENDIX A: METHODS

A. Sampling

Soil Sampling – Spatial

Two standard techniques for sampling large areas are available. This investigation employed a combination of the two, as described below.

The preferred technique, the geostatistical (or random) field approach, involves sampling at the randomly chosen co-ordinates of a gridded area. This approach was used for delineation sampling, but was not always sufficient when localized areas of contamination were suspected. In such cases, the deterministic random approach, which focuses on areas likely to be contaminated, was used. In these areas, samples were collected near the contamination sources and in drainage pathways leading away from them. Every sample location was marked with an implanted 150-mm stainless steel nail, to which was attached a plastic disk stamped with the sample number and a long strip of brightly coloured flagging tape (a “sample tag”).

Soil Sampling-Collection

Reusable stainless steel scoops were employed for sampling soil. The clean scoop was used for soil sampling at each site. No visible soil particles remained on the scoop from one sampling event to the next. Scoops were decontaminated between sampling events as follows:

a. If the sampled soil was sandy and relatively dry the scoop was first knocked vigorously to dislodge any soil, and then used to homogenize the soil immediately adjacent to the next sampling location (*i.e.* given a soil “rinse”).

b. If the sampled soil was wet or clayey, the scoop was vigorously knocked to dislodge as much soil as possible. The scoop was then rinsed thoroughly with clean tap water. When the scoop was clean by visual inspection, it was dried with a clean Kim towel. The scoop was then given a soil rinse in the next sampling location before the sample was collected.

When samples were collected with a reusable stainless steel scoop, a field rinsate blank (scoop blank) was taken every 20 samples or once per day, whichever was more frequent. If scoop blanks had detectable results, corrective action was implemented, such as more rigorous decontamination procedures.

Soil samples designated for inorganic analyses were stored in WhirlPak™ bags. Samples designated for petroleum hydrocarbon analyses, BTEX (benzene, toluene, ethylbenzene and xylenes), and polycyclic aromatic hydrocarbons (PAHs) were stored in 125-mL amber glass jars fitted with Teflon-lined lids certified to be free of organic materials.

Field duplicate samples were taken at a rate of 10 percent and submitted blind to the laboratories to monitor precision of sampling techniques and analytical methods. These samples were well homogenized in the field before being split between two separate containers.

All soil samples were kept at ambient temperatures. Each sample was given a blind number that was the only number provided on the labels of samples submitted for analysis. This number matched the one stamped on the sample tag left at the sample location. Sample locations and descriptions were recorded in note pads and/or on field maps, and a photographic record was made of each general area that was to be delineated.

a) Assessment

Sample collection initially focused on areas of contamination found in previous site assessments, and any other areas in which contamination was suspected based on the presence of debris or staining. The number of samples collected from each area was dependent on the topography and former land use.

b) Delineation

Where contamination was discovered or confirmed to be in excess of applicable criteria, additional samples were collected in a grid pattern surrounding the contaminated area or known contaminant source, to determine its lateral extent. The extent of the grid (and expected extent of contamination) was estimated according to the initial assessment, as well as the topography of the area. The grid size was determined according to the guide in Table A-1. A closer grid spacing (approximately 1 m x 1 m) was used for areas in which a precise delineation of soil contamination was required (*i.e.* Tanquary Fiord and Lake Hazen).

Table A-1: Delineation Grid Sizes

Size of Area	Grid Size
<100 m^2	3 m x 3 m
>100 m^2, <2,500 m^2	6 m x 6 m
>2,500 m^2	12 m x 12 m

Generally, soil was sampled from the upper 10 cm and collected so as to obtain representative material. Depth samples were also collected just above refusal (*e.g.* frozen ground or bedrock) in test pits to determine the depth of contamination

c) Confirmatory Testing

Because the contaminated areas for excavation were small (less than 100 m^2), samples were collected on a 3 m x 3 m grid and all samples were analyzed. Where the excavation had an irregular shape, samples from the perimeter of the excavated area were collected following the shape of the excavation, rather than the grid if the grid points did not fall on the edge of the excavation. The samples were analyzed for TPH in the field using field test kits. A selected number of samples (approximately 10 percent) were shipped to the Analytical Services Group at RMC in Kingston, ON, for quality-control analysis.

Subsurface Hydrocarbon Investigation

Within areas of suspected subsurface hydrocarbon contamination, depth sampling was undertaken with two goals: to determine the maximum depth of contamination, and to delineate the lateral extent of contamination.

The depth samples were collected from test pits, with one sample targeted immediately above refusal (*e.g.* frozen ground or bedrock) in each test pit. Other samples were targeted to the depth of the water table, where there was a stained layer present, or at stratigraphic boundaries, in an attempt to space samples evenly throughout.

The test pits were excavated by hand with picks and shovels. To avoid cross-contamination, the shovels and picks were wiped (or rinsed in nearby surface water) to remove any adhered soil before the next test pit was dug. A log was recorded to provide a permanent record of the test pit.

Depth samples were initially collected in the vicinity of the contaminant source. If contamination was detected, the next round of sampling targeted the outer edge of the estimated affected area (assuming a worst-case scenario) with the goal of immediately establishing an edge to the contaminated area. Once the edge was established, further samples were collected when time permitted, radiating inward according to a rough grid pattern to refine the volume of contaminated soil.

Landfarm Sampling

Discrete samples were collected randomly in the landfarm from 30 co-ordinates determined by a random number generator. Samples were collected at depths between 15 and 25 cm. The samples were containerized in 125-mL amber glass jars with Teflon-lined lids. Analyses were performed in a southern laboratory for total PHC using the CCME analytical method. Reusable stainless steel scoops were used for landfarm sampling. Scoop blanks and field duplicates were collected as described in the *Soil Sampling - Collection* section of this report.

The results of the analyses were used to determine the 95% upper confidence limit (UCL) on the sample mean. If the 95% UCL is below 2,500 ppm (*i.e.* the true mean of the samples has a 95% probability of being below 2,500 ppm) and no individual sample results are greater than 5,000 ppm, then the landfarm may be closed.

Barrel Sampling

Barrel sampling was conducted in accordance with ESG protocol (ESG, 2008a). Each barrel was assessed for rust, dents, bulging and other damage. If the barrel was safe to open, a sample was extracted using a drum thief and stored in a 30-mL Quorpak® glass vial. The depth of each phase was measured and notes were taken on such traits as colour and viscosity. Viscosity measurements were taken for some of the barrel samples using a Gilmont® falling ball viscometer. At least one viscosity measurement was taken for each grouping of barrels that appeared to have the same contents. Samples were labelled and packed in Rubbermaid™ containers, with the extra space filled with vermiculite for shipping.

Chain of Custody

ESG staff filled out chain-of-custody forms for each sample that were checked before shipment from the North, and the contents of the shipments were verified upon receipt in the southern laboratory. The relevant documentation is available on request.

B. Analyses Conducted at Analytical Services Unit (ASU), Queen's University, and Analytical Services Group (ASG), RMC

Digestion of Various Matrices for Inorganic Elements

Analyses were conducted by the Analytical Services Unit, Queen's University, Kingston, ON. Each sample was clearly labelled and stored in a secured area (before and after analysis) at a temperature appropriate for the analytical method.

Soil and sediment samples were air-dried and ground to a fine powder with a mortar and pestle. Large stones were removed, as they would not be expected to contain any anthropogenic environmental contaminants. Approximately 0.5 g of powdered sample was heated with 2 mL of nitric acid and 6 mL of hydrochloric acid overnight so that the volume was reduced to 1-2 mL. This solution was then made up to 25 mL with distilled deionized water and analyzed by atomic absorption spectrometry. Although not all metals may be brought into solution by this procedure (some may be locked in silicate minerals), metals that are released are considered to be of greater environmental significance than are true total metals because they are more readily mobilized and may be available for uptake by plants and animals.

Inorganic Elements by Inductively Coupled Plasma Atomic Emission Spectroscopy

Analyses were conducted by ASU. Each sample was clearly labelled and stored in a secured area before and after analysis at a temperature appropriate for the analytical method. Concentrations of the following eight elements were measured: arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn). Samples were analyzed in batches of up to 36, which comprised up to 28 samples, two blanks, four duplicates and two samples of standard reference materials (NRC MESS-3 or SS-2).

Extractable Phosphorus in Soil and Sediment

Analyses were conducted by ASG. Each sample was clearly labelled and stored at low temperatures in a secured area before and after analysis.

A 1-g air-dried sample was extracted using 10 mL of Bray solution (ammonium fluoride in diluted HCl). Samples were agitated on a shaker for 30 min and allowed to stand overnight. Carbon black was added to coloured solutions. A 10-mL aliquot was removed and filtered through a 0.45-micron filter. Nine millilitres of this solution were analyzed by ascorbic acid phosphorus determination.

A solution was prepared with 20 g ammonium molybdate dissolved in 500 mL water. A second solution was prepared with 01.3715 g antimony potassium tartrate in 500 mL water. A third solution was prepared using 1.76 g ascorbic acid in 100 mL water. This solution was held for a maximum of one week at 4 ˚C. Solutions were mixed in the proportions of 15 mL, 5 mL and 30 mL with 50 mL 5N sulfuric acid. Two millilitres of the combined sulfuric acid solution were added to the acidified extract and analyzed by visible spectrometry at the 880-ηm wavelength. Standard were prepared in a similar extractant solution and analyzed by the same method. All data were reported on a dry-weight basis in μg/g (ppm).

KCl-extractable Nitrite, Nitrate and Ammonia in Soil Samples

Stock standards are prepared using potassium nitrate, sodium nitrite and ammonium chloride. Dilute working standards are prepared on the day of analysis, and quality control is maintained through the analysis of a sample with a known concentration.

Soil samples are extracted using a 2N KCl solution. If only analyzing for NO_2 and NO_3, 5 g of dried soil is used. If the analysis requires NH_3, all three parameters are sampled from wet soils and a wet/dry ratio is calculated in order to estimate a 5-g dry sample. Each sample is weighed into a plastic vial and 25 mL of KCl is added. The vials are put on a rotating shaker for 30 min at 200 rpm. Samples are then filtered through P5 filter paper and analyzed on a Technicon Autoanalyzer.

CCME Method of Measuring Petroleum Hydrocarbons in Soil

Analyses were conducted by ASG. Each sample was stored in an appropriate, clearly labelled container and kept at low temperatures in a secured area before and after analysis. Soil analysis was performed as prescribed in the CCME Reference Method for Canada Wide Standard for Petroleum Hydrocarbons in Soil, 2001.

Soil Fraction F1

Accurately weighed samples of wet soil (5 g) were extracted on a shaker for one hour with 10 mL of methanol. The methanol layer was then transferred into a vial and refrigerated until analysis. A 50-μL aliquot of the extract, made up to 5 mL with water, was directly syringed into a Tekmar autosampler/purge-and-trap apparatus. The sample was purged with high-purity helium gas for 11 minutes. The trapped components were desorbed from the trap in the unit by heating to 225 °C and holding for four minutes. A Hewlett Packard 6890 GC-FID system was used for analysis in conjunction with an SPB-

1 fused silica capillary column (30 m, 0.25 mm i.d. x 0.25 μm film thickness). The retention time was marked using nC6 and nC10 hydrocarbons, and calibration was performed with toluene. Blanks, control samples and duplicates were run at a frequency of approximately 20 percent. A wet/dry ratio for the sample was determined using a sub-sample. The final result was calculated using the dry weight of the sample (μg/g). When analyses for benzene, toluene, ethylbenzene and xylenes (BTEX) were requested, the BTEX results were subtracted from the F1 fraction results.

Soil Fraction F2 to F4

Soil samples were homogenized and subsamples dried for moisture determination. Accurately weighed samples of wet soil (10 g) were extracted by Soxhlet for six hours at four to six cycles per hour with 250 mL of hexane/acetone (1:1). The extract was filtered through sodium sulphate and 3 mL of toluene were added. The extract was then concentrated by rotoevaporation. A 15-mm-diameter column containing 5.0 g activated silica below 1 cm of sodium sulphate was prepared and eluted with 10 mL 50:50 dichloromethane:hexane. The concentrate extracted was added to the head of the column and eluted with 20 mL 50:50 dichloromethane:hexane. Toluene (1 mL) was added and the collected eluent was concentrated to approximately 1 mL using rotary evaporation.

Analysis was performed by GC-FID using an Agilent 6890 instrument fitted with a cool on-column injection system. A DB-1 capillary column (15 m, 0.53 mm diameter, 0.15 μm film) was used to achieve separation. Blanks, control samples and duplicates were run at a frequency of approximately 20 percent. Calibrations were performed and the retention time was marked using nC10, nC16, and nC34 hydrocarbons. NC50 was analyzed as the performance standard, with a required response of less than 70 percent of that obtained using nC10, nC16 and nC34 response factors. The final result was reported as mg/kg for each fraction. In any samples that underwent analysis for polycyclic aromatic hydrocarbons (PAH), naphthalene was subtracted from fraction F2, and the other 15 priority pollutant PAHs were subtracted from fraction F3.

C. Analyses Conducted at IG MicroMed Environmental Inc.

Hydrocarbon degrader analyses were conducted by IG MicroMed Environmental Inc., Richmond, BC. At least 1 g of soil was weighed into a sterile stomacher bag and buffered water (3.125×10^{-4} M KH_2PO_4, 0.002 M $MgCl_2$, pH 7.2 adjusted with 1 N NaOH) was added to yield an initial dilution of 1:100 (10^{-2}). The soil sample was extracted with the stomacher for 30 seconds. The extract was then diluted to 10^{-3}, 10^{-4}, 10^{-5} and 10^{-6}. A 0.1 mL aliquot of each dilution was placed on plates with minimal media containing the hydrocarbon source of interest and spread to dryness with a bent glass rod. The plates were incubated in desiccator jars with reservoirs of the hydrocarbon source for 96 hours to one week at 20 °C. All colonies appearing after incubation were counted. The numbers of colonies on higher concentration plates was expected to increase by the reciprocal of the dilution interval, otherwise contamination was suspected. The bacterial density was calculated as:

CFU/mL = (mean number of bacteria counted) x
(reciprocal of dilution of sample) x (reciprocal of sample volume)

Minimal medium:

MnSO4.H2O	0.2 g
MgSO4.7H2O	2.0 g
NH4Cl	10.0 g
K2HPO4	6.0 g
KH2PO4	4.0 g
Agar	15.0 g
CaCl2.2H2O	0.1 g
FeSO4.7H2O	0.05 g
Reagent-grade water	1 L

A volume (10 mL) of the hydrocarbon source (contaminant of interest) was added to 1 L of the minimal medium as solution for plate preparation. The precision of duplicate counts was determined by making 10 duplicate counts on a single source of bacteria, grown and diluted to the appropriate range of counts. Each count was converted to log-10 value and the range of log-10 values was summed. The precision criterion is 3.27 times the sum of the range of log-10 values divided by the number of values.

D. Field Analyses

Total Petroleum Hydrocarbon Analysis using PetroFLAG Test Kit

Analysis of total petroleum hydrocarbon (TPH) was performed in the field with PetroFLAG™ TPH in soil test kits from Dexsil Corp., using simple turbidimetric analysis. The analysis works on the principle that TPH molecules in the sample become dispersed as tiny hydrocarbon micelles in the aqueous solution. The turbidity of the resulting mixture is directly proportional to the concentration of TPH in the sample. The analysis was carried out according to the manufacturer’s instructions, with a few minor modifications. TPH results were reported on a dry-weight basis by correcting the results for the soil moisture content. A separate subsample of each soil tested was analyzed for percent moisture.

A 5-g subsample of wet soil was weighed and extracted with 10 mL of methanol. Using a syringe that contained a silica cleanup column, the soil-solvent mixture was filtered through a 0.2-μm filter directly into a premeasured vial of aqueous developing solution and mixed thoroughly. The turbidity of the sample was measured using a portable turbidimeter. Turbidity was measured with the analyzer provided by the supplier, and TPH concentration calculated from an internal calibration curve.

E. References

Environmental Sciences Group (ESG, 2008a) DLCU sampling protocols.

Appendix B: DATA TABLES

LIST OF TABLES

Table B-1: Total Petroleum Hydrocarbon (TPH) and Canadian Council of Ministers of the Environment (CCME) Petroleum Hydrocarbon (PHC) Results for Soil Samples

Sample #	Site	Sample Depth	TPH	Fraction 1	Fraction 2	Fraction 3	Fraction 4	Total PHC	Moisture Content
		[cm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[%]
08-11880/81	Tanquary landfarm	15			34	2000	2800	4800	
08-11882	Tanquary landfarm	15		52	1500	410	140	2100	
08-11883	Tanquary landfarm	15			270	780	320	1400	
08-11884	Tanquary landfarm	15			<4.0	<9.0	26	32	
08-11885	Tanquary landfarm	15			490	220	26	740	
08-11889	Tanquary landfarm	15			760	340	20	1100	
08-11892	Tanquary landfarm	15			2800	530	130	3500	
08-11894	Tanquary landfarm	15			250	2600	1700	4600	
08-11896	Tanquary landfarm	15			17	1500	1400	2900	
08-11898	Tanquary landfarm	15			6.3	91	160	260	
08-11900/01	Tanquary landfarm	15			140	270	28	840	
08-11903	Tanquary landfarm	15			100	720	250	1100	
08-11905	Tanquary landfarm	15		<10	290	200	63	560	
08-11907	Tanquary landfarm	15			1200	360	32	1600	
08-11909	Tanquary landfarm	15			440	230	30	700	
08-11912	Tanquary landfarm	15			37	13	8.8	59	
08-11914	Tanquary landfarm	15			140	97	25	260	
08-11916	Tanquary Fiord experiment	10			92	680	290	1100	
08-11917	Tanquary Fiord experiment	10			96	570	280	950	
08-11918	Tanquary Fiord experiment	10			92	740	350	1200	
08-11919	Tanquary Fiord experiment	10			150	1100	420	1700	
08-11920/21	Tanquary Fiord experiment	10		<10	110	620	230	940	
08-11922	Tanquary Fiord experiment	10			41	380	170	590	
08-11923	Tanquary Fiord experiment	10			36	500	210	750	
08-11924	Tanquary Fiord experiment	10			22	320	130	470	
08-11925	Tanquary Fiord experiment	10			58	690	200	950	
08-11926	Tanquary Fiord experiment	10			180	650	220	1000	
08-11927	Tanquary Fiord experiment	10		<10	190	940	340	1500	
08-11928	Tanquary Fiord experiment	10			190	1400	380	2000	
08-11929	Tanquary Fiord experiment	10			170	830	280	1300	
08-11930/31	Tanquary Fiord experiment	10		<10	240	800	280	1400	
08-11932	Tanquary Fiord experiment	10			230	760	290	1300	
08-11933	Tanquary Fiord experiment	10			170	620	240	1000	
08-11934	Tanquary Fiord experiment	10			36	270	110	420	
08-11935	Tanquary Fiord experiment	10			45	420	170	640	
08-11936	Tanquary Fiord experiment	10			9.3	40	27	76	
08-11938	Tanquary Fiord experiment	10			<4.0	11	<8.0	11	
08-11940	Tanquary Fiord experiment	10			12	58	15	85	
08-11944	Lake Hazen experimental plots	10			75	62	14	150	
08-11945	Lake Hazen experimental plots	10		<10	90	56	8.5	160	
08-11946	Lake Hazen experimental plots	10			62	45	<8.0	110	
08-11947	Lake Hazen experimental plots	10			160	83	<8.0	250	
08-11948	Lake Hazen experimental plots	10			160	92	<8.0	260	4.4
08-11949	Lake Hazen experimental plots	10			130	73	<8.0	210	4.4
08-	Lake Hazen experimental plots	10		<10	160	230	9	120	6.6
08-11952	Lake Hazen experimental plots	10			270	120	<8.0	390	5.5
08-11953	Lake Hazen experimental plots	10			220	64	<8.0	290	6.2
08-11954	Lake Hazen experimental plots	10			<4.0	<9.0	<8.0	11	2.5
08-12052	Lake Hazen experimental plots	10			<4.0	<9.0	<8.0	11	0.3
08-12053	Lake Hazen experimental plots	10			<4.0	<9.0	<8.0	11	3.6
08-12054	Lake Hazen experimental plots	10			<4.0	<9.0	<8.0	11	2.7
08-11963	Lake Hazen	0	6400						
08-11964	Lake Hazen	0	60						
08-11965	Lake Hazen	0	470						
08-11966	Lake Hazen	0							
08-11967	Lake Hazen	0	<26						
08-11968	Lake Hazen	0	>8000						
08-11969	Lake Hazen	100	160						
08-11970/71	Lake Hazen	0	2600						

Table B-1: Total Petroleum Hydrocarbon (TPH) and Canadian Council of Ministers of the Environment (CCME) Petroleum Hydrocarbon (PHC) Results for Soil Samples cont'd

Sample #	Site	Sample Depth	TPH	Fraction 1	Fraction 2	Fraction 3	Fraction 4	Total PHC	Moisture Content
		[cm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[%]
08-11972	Lake Hazen	100	6200						
08-11973	Lake Hazen	0	<26						
08-11974	Lake Hazen	100	2900						
08-11975	Lake Hazen	1	<26						
08-11976	Lake Hazen	90	<26						
08-11977	Lake Hazen	0	<26						
08-11978	Lake Hazen	100	<26						
08-11979	Lake Hazen	0	<26						
08-11980/81	Lake Hazen	80	<26						
08-11982	Lake Hazen	30	64						
08-11983	Lake Hazen	30	55						
08-11984	Lake Hazen	50	71						
08-11985	Lake Hazen	50	1400		<4.0	85	68	160	
08-11986	Lake Hazen	30	3500						
08-11987	Lake Hazen	30	1100	<10	14	1100	76	1200	4.5
08-11988	Lake Hazen	30			<4.0	<9.0	<8.0	11	
08-11989	Lake Hazen	50	>8000		190	23000	970	24000	2.7
08-11990/91	Lake Hazen	0	340						
08-11992	Lake Hazen	100	720						
08-11993	Lake Hazen	0	81						
08-11994	Lake Hazen	100	4100						
08-11995	Lake Hazen	0	53						
08-11996	Lake Hazen	100	280						
08-11997	Lake Hazen	100	2600		2500	27	18	2500	2.8
08-11998	Lake Hazen	100	2600						
08-11999	Lake Hazen	100	4600						
08-12000/01	Lake Hazen	100	2900		1900	74	10	2000	
08-12002	Lake Hazen	50	3600						
08-12003	Lake Hazen	50	310		<4.0	37	27	66	
08-12004	Lake Hazen	50	76						
08-12005	Lake Hazen	50	90		<4.0	17	<8.0	23	2.5
08-12006	Lake Hazen	0			<4.0	<9.0	<8.0	11	0.0
08-12007	Lake Hazen	50	<26						
08-12008	Lake Hazen	50	4500						
08-12009	Lake Hazen	50	3900						
08-12010/11	Lake Hazen	100	3500						
08-12012	Lake Hazen	100	150						
08-12013	Lake Hazen	100	2000		1300	190	<8.0	1500	
08-12014	Lake Hazen	100	900						
08-12015	Lake Hazen landfarm	15			280	760	230	1300	
08-12017	Lake Hazen landfarm	15		<10	340	170	32	550	1.8
08-12019	Lake Hazen landfarm	15			1400	950	400	2800	3.8
08-12022	Lake Hazen landfarm	15			450	31	11	490	1.5
08-12024	Lake Hazen landfarm	15			<4.0	<9.0	<8.0	11	1.8
08-12026	Lake Hazen landfarm	15			<4.0	<9.0	<8.0	11	0.0
08-12028	Lake Hazen landfarm	15			7.4	300	69	380	1.3
08-12030/31	Lake Hazen landfarm	15			1600	10000	3000	14000	1.6
08-12033	Lake Hazen landfarm	15			200	110	64	370	3.1
08-12035	Lake Hazen landfarm	15			1300	210	22	1500	1.8
08-12037	Lake Hazen landfarm	15			1500	330	28	1900	2.1
08-12039	Lake Hazen landfarm	15			720	190	22	930	3.1
08-12042	Lake Hazen landfarm	15			620	940	520	2100	2.9
08-12044	Lake Hazen landfarm	15		52	2300	420	45	2800	2.2
08-12046	Lake Hazen landfarm	15			<4.0	<9.0	9.1	18	0.0
08-12048	Lake Hazen landfarm	15			2900	990	330	4200	3.4
08-12050/51	Lake Hazen landfarm	15			1700	560	160	2400	2.2

Table B-2: Hydrocarbon-Degrader Plate Counts in Tanquary Fiord (TF) and Lake Hazen (LH) Field Treatment Plots and Landfarms

Location	Sample #	HC-Degrader Plate Count [CFU*/g dry soil]
LH landfarm	08-12040	3.8E+03
LH landfarm	08-12042	5.0E+02
LH landfarm	08-12044	3.4E+04
TF landfarm	08-11882	1.4E+05
TF landfarm	08-11884	6.2E+04
TF landfarm	08-11886	1.3E+05
TF control	08-11916	1.2E+05
TF control	08-11917	1.3E+05
TF control	08-11918	3.0E+05
TF Biosolve	08-11919	1.5E+05
TF Biosolve	08-11920	3.4E+06
TF Biosolve	08-11922	2.2E+06
TF Biosolve + fertilizer	08-11923	7.3E+05
TF Biosolve + fertilizer	08-11924	2.8E+05
TF Biosolve + fertilizer	08-11925	2.8E+06
TF control G	08-11926	5.6E+05
TF control G	08-11927	5.0E+04
TF control G	08-11928	8.4E+04
TF Biosolve G	08-11929	2.8E+05
TF Biosolve G	08-11930	9.0E+04
TF Biosolve G	08-11932	4.7E+05
TF Biosolve + fertilizer G	08-11933	2.2E+06
TF Biosolve + fertilizer G	08-11934	6.1E+05
TF Biosolve + fertilizer G	08-11935	3.7E+05
LH control	08-11950	2.1E+03
LH control	08-11952	2.2E+04
LH control	08-11953	5.9E+03
LH Biosolve	08-11947	3.2E+04
LH Biosolve	08-11948	3.4E+04
LH Biosolve	08-11949	3.9E+04
LH Biosolve + fertilizer	08-11944	6.5E+05
LH Biosolve + fertilizer	08-11945	2.8E+06
LH Biosolve + fertilizer	08-11946	4.5E+06

*CFU: Colony Forming Unit
G = Greenhouse

Table B-3: CCME Petroleum Hydrocarbon (PHC) Results for Tanquary Fiord 2005-2008 Field Treatment Plots

Location	Sample #	CCME Petroleum Fractions				Moisture Content	Total PHC
		F1	F2	F3	F4		
		[ppm]	[ppm]	[ppm]	[ppm]	%	[ppm]
Control	05-15689*	NA	890	1200	550	4.6	2600
Control	05-15690*	NA	920	1200	410	4.6	2500
Control	05-15691	52	1600	1200	440	4.2	3300
Control	05-15692	NA	1500	640	240	3.5	2400
Biosolve	05-15693	NA	800	1700	590	3.4	3100
Biosolve	05-15693d	NA	730	1700	630	NA	3100
Biosolve	05-15694	NA	1500	890	300	4.7	2700
Biosolve	05-15695	NA	1200	810	280	4.9	2300
Biosolve + fertilizer	05-15696	NA	650	1300	510	3.9	2500
Biosolve + fertilizer	05-15697	53	1500	830	230	5.3	2600
Biosolve + fertilizer	05-15698	NA	1300	870	310	4.6	2500
Control G	05-15686	NA	1400	860	290	3.4	2600
Control G	05-15687	100	2000	710	230	4.2	3000
Control G	05-15688	NA	670	860	270	3.9	1800
Biosolve G	05-15683	NA	660	770	310	4.7	1700
Biosolve G	05-15684	NA	2000	460	160	4.3	2600
Biosolve G	05-15685	NA	1000	890	300	4.7	2200
Biosolve + fertilizer G	05-15679*	NA	1300	1100	410	3.7	2800
Biosolve + fertilizer G	05-15680*	NA	1300	1100	380	3.6	2800
Biosolve + fertilizer G	05-15681	89	1700	740	240	3.9	2800
Biosolve + fertilizer G	05-15682	NA	890	600	200	4.9	1700
Control	06-18398	NA	480	1000	340	4.0	1800
Control	06-18399	<10	340	530	180	4.5	1000
Control	06-18400	NA	880	890	320	4.1	2100
Biosolve	06-18402	NA	530	1300	500	4.9	2400
Biosolve	06-18403	NA	820	970	320	5.4	2100
Biosolve	06-18404	NA	810	160	<8	5.9	1000
Biosolve + fertilizer	06-18405	NA	160	760	300	7.1	1200
Biosolve + fertilizer	06-18406	NA	280	900	330	4.3	1500
Biosolve + fertilizer	06-18407	NA	340	720	290	5.1	1400
Control G	06-18408	NA	1100	790	260	0.5	2200
Control G	06-18409	NA	1100	1200	420	0.7	2700
Control G	06-18410	NA	660	1000	340	0.4	2000
Biosolve G	06-18412	NA	960	1000	350	0.6	2300
Biosolve G	06-18413	NA	1200	70	230	0.5	1500
Biosolve G	06-18414	NA	600	1200	450	0.6	2200
Biosolve + fertilizer G	06-18415	NA	420	910	360	1.0	1700
Biosolve + fertilizer G	06-18416	<10	540	720	250	2.1	1500
Biosolve + fertilizer G	06-18416d	<10	660	720	240	NA	1600
Biosolve + fertilizer G	06-18417	NA	370	1000	370	2.8	1700
Control	07-23086	NA	180	770	300	3.4	1200
Control	07-23087	<10	220	950	350	4.4	1500
Control	07-23087d	<10	NA	NA	NA	NA	0.0
Control	07-23088	NA	250	660	250	4.5	1200
Biosolve	07-23089	NA	210	1100	420	3.7	1700
Biosolve	07-23090*	NA	220	1000	400	5.9	1600
Biosolve	07-23091*	NA	210	1100	430	5.3	1700
Biosolve	07-23092	NA	84	600	29	4.2	710
Biosolve + fertilizer	07-23093	NA	59	710	310	4.2	1100
Biosolve + fertilizer	07-23094	NA	71	630	280	4.7	980
Biosolve + fertilizer	07-23095	<10	95	600	270	4.8	960
Control G	07-23096	NA	380	780	300	3.8	1500
Control G	07-23097	NA	250	660	260	3.6	1200
Control G	07-23098	NA	230	930	370	3.2	1500
Biosolve G	07-23099	NA	210	630	250	2.4	1100
Biosolve G	07-23100*	NA	370	820	300	3.3	1500
Biosolve G	07-23101*	NA	400	880	330	3.5	1600
Biosolve G	07-23102	NA	210	800	330	4.0	1300
Biosolve + fertilizer G	07-23103	NA	90	550	240	6.2	880
Biosolve + fertilizer G	07-23104	<10	130	620	270	4.8	1000

Table B-3: CCME Petroleum Hydrocarbon (PHC) Results for Tanquary Fiord 2005-2008 Field Treatment Plots cont'd

Location	Sample #	CCME Petroleum Fractions				Moisture Content	Total PHC
		F1	F2	F3	F4		
		[ppm]	[ppm]	[ppm]	[ppm]	%	[ppm]
Biosolve + fertilizer G	07-23105	NA	69	620	250	4.8	940
drainage	07-23106	NA	6.0	23	24	1.7	53
drainage	07-23108	NA	6.0	10	15	2.4	31
drainage	07-23109	NA	<4	<9	<8	2.9	0.0
Control	08-11916	NA	88	620	240	4.4	950
Control	08-11916	NA	96	740	330	0.0	1200
Control	08-11917	NA	96	570	280	2.3	950
Control	08-11918	NA	92	740	350	4.1	1200
Biosolve	08-11919	NA	150	1100	420	5.0	1700
Biosolve	08-11920*	<10	96	500	180	4.6	780
Biosolve	08-11920d	<10	NA	NA	NA	NA	0.0
Biosolve	08-11921*	NA	130	730	280	4.1	1100
Biosolve	08-11922	NA	41	380	170	3.4	590
Biosolve + fertilizer	08-11923	NA	36	500	210	1.9	750
Biosolve + fertilizer	08-11924	NA	22	320	130	3.6	470
Biosolve + fertilizer	08-11925	NA	58	690	200	4.1	950
Control G	08-11926	NA	180	650	220	5.2	1000
Control G	08-11927	<10	190	940	340	3.7	1500
Control G	08-11928	NA	190	1400	380	5.2	2000
Biosolve G	08-11929	NA	170	830	280	1.5	1300
Biosolve G	08-11930*	<10	200	730	250	4.5	1200
Biosolve G	08-11931*	NA	270	900	300	3.9	1500
Biosolve G	08-11932	NA	230	760	290	6.6	1300
Biosolve + fertilizer G	08-11933	NA	170	620	240	5.0	1000
Biosolve + fertilizer G	08-11934	NA	36	270	110	9.6	420
Biosolve + fertilizer G	08-11935	NA	45	420	170	4.9	640
drainage	08-11936	NA	9.0	40	27	1.9	76
drainage	08-11938	NA	<4	11	<8	1.2	11
drainage	08-11940	NA	12	58	15	1.4	85

G=greenhouse

* = field duplicates (within each treatment and sampling event)

d = analytical duplicate

NA = Not available

Table B-4: Available Nitrogen and Phosphorus in TF and LH Field Treatment Plots and Landfarms

Location	Sample #	NH_3 (ammonia)	$NO_3^-+NO_2^-$ (as N)	PO_4^{3-} (as P)	TOC
		[mg/kg]	[mg/kg]	[mg/kg]	[%]
TF Biosolve + fertilizers	08-11923	<2.0	83	<0.10	NA
TF Biosolve + fertilizers	08-11924	<2.0	91	<0.10	NA
TF Biosolve + fertilizers	08-11924d	<2.0	110	NA	NA
TF Biosolve + fertilizers	08-11925	<2.0	32	<0.10	NA
TF Biosolve + fertilizers G	08-11933	<2.0	77	0.050	NA
TF Biosolve + fertilizers G	08-11934	<2.0	41	0.16	NA
TF Biosolve + fertilizers G	08-11935	<2.0	22	0.16	NA
TF Drainage hole	08-11936	<2.0	<2.0	0.22	NA
TF Drainage hole	08-11938	<2.0	2.4	0.18	NA
TF Drainage hole	08-11940	<2.0	<2.0	0.11	NA
TF landfarm	08-11883	170	3.5	<0.10	NA
TF landfarm	08-11885	140	66	<0.10	NA
TF landfarm	08-11887	140	39	<0.10	NA
LH landfarm	08-12041	<2.0	<2.0	<0.10	NA
LH landfarm	08-12043	<2.0	<2.0	<0.10	NA
LH landfarm	08-12045	<2.0	<2.0	<0.10	NA

G=greenhouse
d = analytical duplicate
NA = Not available

Table B-5: Inorganic Element Results for Ward Hunt Island Soil Samples

Sample #	**Depth**	**Cu**	**Ni**	**Co**	**Cd**	**Pb**	**Zn**	**Cr**	**As**
	[cm]	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**
CCME*		***63***	***50***	***50***	***10***	***140***	***200***	***64***	***12***
08-12165	0	9.1	16.8	7.4	<1.0	<10	41	26	4.2
08-12166	0	<5.0	<5.0	<5.0	<1.0	<10	<15	<20	<1.0
08-12167	0	8.6	19.3	8.3	<1.0	<10	44	31	4.0
08-12168	0	14.6	22.3	9.2	<1.0	11	53	34	6.0
08-12169	0	14.9	29.2	11.9	<1.0	13	71	46	6.7
08-12170	40	11.8	26.9	9.9	<1.0	11	60	38	6.1
08-12171	40	13.1	27.5	10.3	<1.0	12	63	39	6.4
08-12176	0	5.3	13.7	<5.0	<1.0	<10	33	21	2.8
08-12177	0	24.2	15.4	5.8	<1.0	16	63	22	3.5
08-12178	0	5.4	13.1	5.2	<1.0	<10	30	20	3.0
08-12179	0	<5.0	12.6	<5.0	<1.0	<10	30	<20	2.8
08-12180	50	<5.0	12.7	<5.0	<1.0	**214**	29	<20	2.6
08-12181	50	5.3	13.3	<5.0	<1.0	73	33	<20	3.3
08-12187	0	9.1	12.0	<5.0	<1.0	18	33	30	3.7
08-12188	0	20.9	18.4	7.2	<1.0	36	51	35	3.8
08-12189	0	7.0	15.0	5.9	<1.0	<10	33	22	3.2
08-12190	0	49.3	25.0	8.5	5.2	**255**	127	82	5.3
08-12191	0	45.8	23.6	8.1	3.4	**241**	138	80	6.0
08-12195	0	11.4	22.6	7.6	1.1	37	79	37	3.4

*CCME Environmental Soil Quality Guidelines (SQGE) for Residential/Parkland land use (CCME, 2001)

Table B-6: Barrel Sample Analytical Results

Barrel #	Sample #	Depth (Total)	Depth (aqueous phase)	Organic Phase					
		[cm]	[cm]	PCB [ppm]	Cl [ppm]	Cr [ppm]	Pb [ppm]	Cd [ppm]	Identity
DLCC*				***2.0***	***1000***	***10***	***100***	***2.0***	
1	08-12055	77	**	<2.0	<1000	<10	<100	<2.0	50-100% ethylene glycol
2	08-12056	51	**	<2.0	<1000	<10	<100	<2.0	50-100% ethylene glycol
5	08-12057	23	**	<2.0	<1000	<10	<100	<2.0	20-50% ethylene glycol
4	08-12058	32	**	<2.0	<1000	<10	<100	<2.0	50-100% ethylene glycol
6	08-12059	76	4	<2.0	<1000	<10	<100	<2.0	lubricating oil & grease
7	08-12060/61	75	**	<2.0	<1000	<10	<100	<2.0	lubricating oil & grease
8	08-12062	80	**	<2.0	<1000	<10	<100	<2.0	lubricating oil & grease
10	08-12063	80	**	<2.0	<1000	<10	<100	<2.0	lubricating oil & grease
9	08-12064	88	8	<2.0	<1000	<10	<100	<2.0	lubricating oil & grease
11	08-12065	64	**	<2.0	<1000	<10	***180***	<2.0	gasoline
12	08-12066	16	16						water
13	08-12067	13	13						water
14	08-12068	65	**	<2.0	<1000	<10	***570***	<2.0	gasoline
15	08-12069	78	**	<2.0	<1000	<10	***570***	<2.0	gasoline
16	08-12070/71	75	**	<2.0	<1000	<10	***540***	<2.0	gasoline
17	08-12072	75	**	<2.0	<1000	<10	***480***	<2.0	gasoline
18	08-12073	85	**	<2.0	<1000	<10	***520***	<2.0	gasoline
19	08-12074	75	**	<2.0	<1000	<10	***520***	<2.0	gasoline
20	08-12075	80	**	<2.0	<1000	<10	***520***	<2.0	gasoline
21	08-12076	80	**	<2.0	<1000	<10	***580***	<2.0	gasoline
23	08-12077	75	**	<2.0	<1000	<10	***540***	<2.0	gasoline
25	08-12078	80	**	<2.0	<1000	<10	***580***	<2.0	gasoline
26	08-12079	75	**	<2.0	<1000	<10	***600***	<2.0	gasoline
27	08-12080/81	75	**	<2.0	<1000	<10	***540***	<2.0	gasoline
28	08-12082	70	5	<2.0	<1000	<10	***750***	<2.0	gasoline
29	08-12083	63	**	<2.0	<1000	<10	***730***	<2.0	gasoline
30	08-12084	80	**	<2.0	<1000	<10	***690***	<2.0	gasoline
31	08-12085	71	**	<2.0	<1000	<10	***750***	<2.0	gasoline
32	08-12086	75	**	<2.0	<1000	<10	***540***	<2.0	gasoline
33	08-12087	75	**	<2.0	<1000	<10	***500***	<2.0	gasoline
34	08-12088	75	**	<2.0	<1000	<10	***790***	<2.0	gasoline
35	08-12089	43	**	<2.0	<1000	<10	***570***	<2.0	gasoline
36	08-12090/91	75	**	<2.0	<1000	<10	***650***	<2.0	gasoline
37	08-12092	75	**	<2.0	<1000	<10	***520***	<2.0	gasoline
38	08-12093	80	**	<2.0	<1000	<10	***460***	<2.0	gasoline
39	08-12094	75	**	<2.0	<1000	<10	***460***	<2.0	gasoline
40	08-12095	80	80						water
41	08-12096	75	**	<2.0	<1000	<10	***490***	<2.0	gasoline
42	08-12097	75	**	<2.0	<1000	<10	***580***	<2.0	gasoline
43	08-12098	70	**	<2.0	<1000	<10	***500***	<2.0	gasoline
44	08-12099	70	**	<2.0	<1000	<10	***480***	<2.0	gasoline
45	08-12100/01	75	**	<2.0	<1000	<10	***620***	<2.0	gasoline
46	08-12102	75	**	<2.0	<1000	<10	***600***	<2.0	gasoline
47	08-12103	80	**	<2.0	<1000	<10	<100	<2.0	lubricating oil & grease
48	08-12104	70	**	<2.0	<1000	<10	***690***	<2.0	gasoline
49	08-12105	54	**	<2.0	<1000	<10	***690***	<2.0	gasoline
50	08-12106	80	**	<2.0	<1000	<10	***650***	<2.0	gasoline
51	08-12107	55	4	<2.0	<1000	<10	***820***	<2.0	gasoline
52	08-12108	75	<1	<2.0	ne	<10	***3400***	<2.0	gasoline and fuel oil
53	08-12109	70	**	<2.0	<1000	<10	***580***	<2.0	gasoline
54	08-12110/11	80	**	<2.0	<1000	<10	***620***	<2.0	gasoline
55	08-12112	40	3	<2.0	<1000	<10	<100	<2.0	lubricating oil & grease
56	08-12113	1	2	<2.0	<1000	<10	***660***	<2.0	gasoline
57	08-12114	7	7						water
58	08-12115	20	2	***460***	<1000	<10	<100	<2.0	lubricating oil & grease
59	08-12116	5	4	<2.0	<1000	<10	<100	<2.0	lubricating oil & grease

Table B-6: Barrel Sample Analytical Results cont'd

Barrel #	**Sample #**	**Depth (Total)**	**Depth (aqueous phase)**	**Organic Phase**					
				PCB	**Cl**	**Cr**	**Pb**	**Cd**	**Organic Identity**
		[cm]	**[cm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	
DLCU criteria				***2.0***	***1000***	***10***	***100***	***2.0***	
61	08-12117	20	**	<2.0	<1000	<10	<100	<2.0	gasoline and fuel oil
62	08-12118	1	**	<2.0	<1000	<10	<100	<2.0	fuel oil
64	08-12119	2	2						water
65	08-12120/21	12	12						water
66	08-12122	10	10						water
67	08-12123	10	10						water
68	08-12124	20	5	<2.0	<1000	<10	<100	<2.0	gasoline and fuel oil
69	08-12125	20	20						water
70	08-12126	6	6						water
71	08-12127	10	10						water
72	08-12128	40	**	<2.0	<1000	<10	<100	<2.0	fuel oil
73	08-12129	80	**	<2.0	<1000	<10	***1100***	<2.0	gasoline
74	08-12130/31	67	**	<2.0	<1000	<10	<100	<2.0	gasoline
76	08-12132	70	**	<2.0	***17000***	<10	<100	<2.0	lubricating oil & grease
77	08-12133	80	**	<2.0	<1000	<10	<100	<2.0	gasoline and fuel oil
78	08-12134	25	**	<2.0	<1000	<10	***400***	<2.0	gasoline
79	08-12135	50	**	<2.0	<1000	<10	***680***	<2.0	gasoline
80	08-12136	50	**	<2.0	<1000	<10	***370***	<2.0	gasoline
81	08-12137	20	**	<2.0	<1000	<10	<100	<2.0	gasoline
82	08-12138	70	**	<2.0	<1000	<10	<100	<2.0	gasoline and fuel oil
83	08-12139	70	**	<2.0	<1000	<10	<100	<2.0	fuel oil
84	08-12140/41	25	**	<2.0	<1000	<10	<100	<2.0	fuel oil
85	08-12142	75	**	<2.0	<1000	<10	<100	<2.0	gasoline
86	08-12143	75	**	<2.0	<1000	<10	<100	<2.0	gasoline
87	08-12144	75	**	<2.0	<1000	<10	<100	<2.0	gasoline
88	08-12145	37	**	<2.0	<1000	<10	***830***	<2.0	gasoline
89	08-12146	45	**	<2.0	<1000	<10	***510***	<2.0	gasoline
90	08-12147	45	**	<2.0	<1000	<10	<100	<2.0	fuel oil
91	08-12148	45	**	<2.0	<1000	<10	<100	<2.0	fuel oil
92	08-12149	75	**	<2.0	<1000	<10	<100	<2.0	gasoline
93	08-12150/51	75	**	<2.0	<1000	<10	<100	<2.0	gasoline
94	08-12152	43	43						water with a trace of fuel oil
95	08-12153	75	**	<2.0	<1000	<10	<100	<2.0	fuel oil
96	08-12154	75	**	<2.0	<1000	<10	<100	<2.0	fuel oil
97	08-12155	30	<1	<2.0	ne	<10	<100	<2.0	fuel oil
98	08-12156	15	15						water
99	08-12157	70	**	<2.0	<1000	<10	<100	<2.0	fuel oil
100	08-12158	30	**	<2.0	<1000	<10	<100	<2.0	20-50% ethylene glycol
101	08-12159	10	10						water

*DEW Line Cleanup Criteria (DLCC)

**One phase only

ne = not enough sample

APPENDIX C: QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

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APPENDIX C: QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

ESG follows an internal quality assurance/quality control program that was implemented to allow data quality to be monitored on an ongoing basis. This program is completely described in the Quality Assurance Project Plan (QAPP) (ESG, 2008). The points relevant to the discussion of QA/QC sample collection and analysis at Ellesmere Island in 2008 are summarized here for completeness.

All samples are given sequential, numerical codes before being submitted to the analytical firms. These codes mask any information concerning site location, sample type or possible concentration of the sample.

Accuracy is measured and controlled by instrument calibration, the use of control standards, control spikes and the collection and analysis of blanks: equipment rinsate ("scoop") blanks and analytical blanks.

Control standards and control spikes are reference materials with known concentrations. After analysis of a control standard or spike, the instrument calibration is evaluated based on comparison of the results with the target concentration.

The effectiveness of decontamination procedures between samples is monitored with the collection and analysis of equipment rinsate (scoop) blanks. In 2003, ESG implemented a new soil sampling protocol in which reusable stainless steel rather than disposable plastic scoops were used to collect soil samples. The primary reason for the change was to reduce waste. A scoop blank is collected from a known clean soil (*e.g.* Ottawa sand) using a cleaned scoop.

Analytical blanks are processed through extraction/digestion and analysis procedures. These blanks give a measure of the quantity of any contaminant (analyte) that may be added to the overall result during the analysis.

Precision is measured and controlled by the analysis of field and analytical duplicates.

Samples of the same material that are collected in the field and submitted blind as separate samples for analysis are field duplicates. Analytical duplicates are replicate preparations and analyses of the same sample. Comparison of the average relative standard deviations (RSD%) – also known as coefficients of variation, which are calculated as the standard deviation divided by the mean – are used to evaluate laboratory precision. Acceptable limits are generally considered to be less than 40 percent RSD for inorganics, 30 percent for other analyses, with 20 percent or less considered good agreement.

The results of the QA/QC program for the 2008 sampling program at Ellesmere Island (Lake Hazen, Tanquary Fiord and Ward Hunt Island) are discussed below in order of analysis type. The laboratory associated with each analysis type is also listed.

A. Inorganic Elements – Analytical Services Unit (ASU), Queen's University

1. Accuracy

ASU monitored accuracy internally with the analysis of standard reference materials, specifically NRC Canada Marine Reference Sediment MESS-3 and contaminated soil reference material SS-2 (Table C-1). The results for several elements were consistently lower than the certified value for MESS-3. This discrepancy is attributed to differences between the digestion methods used at ASU and those used to obtain the certified values. The reference values are established by a variety of techniques that analyze the total metal content of the standard substrate. By contrast, the method used in most laboratories, including the ASU lab (*aqua regia* digestion), extracts only the available metals in the sample substrate. This is because metals present within minerals forming part of the soil matrix are not released in the extraction process.

As these metals form part of the soil matrix, they are biologically unavailable. Because these elements are not extracted under the strongly oxidizing acid digestion procedure then generally they will not become mobilized by normal weathering and are therefore not environmentally significant. The fact that numerical environmental criteria for metals are designed to be compared with potentially biologically available metal concentrations means that the level of accuracy reported above is acceptable. ASU has developed a set of warning and control limits for MESS-3 sediment analyzed using *aqua regia* digestion, and results must be within these limits. The limits were created by compiling data from each MESS-3 sample over the last several years and checking for trends such as moving averages. The data compiled takes into account day to day variations in such factors as the weighing, acid digestion procedures and instrumentation. For the current MESS-3 limits, there were over 600 data points for the arctic suite elements (Cu, Ni, Co, Cd, Pb, Zn, Cr, As) used in the development of the control limits.

Determined results for inorganic elements in MESS-3 were all within control limits (Table C-1).

Soil reference material SS-2 was also used to monitor accuracy and determined results were again within control limits. Certified values provided in Table C-1 reflect results obtained by the supplier for total digest analysis, similar to MESS-3 certified values. While the supplier also lists EPA-3050 acid digestion values, the procedure is different from that used at ASU and digestion times are not provided by the supplier. Typically, digestion efficiencies for partial digestion methods have to be established on a lab-by-lab basis. As stated for MESS-3, the control limits established for SS-2 analysis at ASU are based on hundreds of digestions performed over several years and the tolerance intervals are much smaller than those listed by the SS-2 supplier for acid digestion.

All elements in the analytical blank were below detection limits (Table C-2).

2. Precision/Repeatability

ASU monitored precision internally through the use of analytical duplicates. One soil sample was analyzed in duplicate for inorganic elements and determined RSDs were all below 11 percent, indicating very good agreement (Table C-2).

B. Reactive (Extractable) Phosphorus Analysis of Soil Samples, Analytical Services Group (ASG), Royal Military College (RMC)

1. Accuracy

Soil samples were analyzed for reactive phosphorus and QA/QC results are listed in Table C-3. Three control spikes were analyzed for extractable phosphorus and the average recovery was 102 percent.

Results for phosphorus in the blank samples were below detection (Table C-3).

2. Precision

Two analytical duplicate samples were run and just one showed detectable phosphorus levels. Results for the pair were identical so the RSD was zero (Table C-3).

C. Ammonia, Nitrate/Nitrite (as N) in Soils, ASU, Queen's University

1. Accuracy and Precision

Soil samples were analyzed for ammonia, nitrate and nitrite (as N) at ASU, and QA/QC results are listed in Table C-4. Three control spikes were analyzed with average recoveries of 100 percent for ammonia, 107 percent for nitrate and 109 percent for the one nitrite control spike. Blank results were below detection for nitrogen.

One analytical duplicate was analyzed to monitor precision. Results for ammonia and nitrite were below detection in the duplicate. RSD for nitrate was 11 percent (Table C-4).

D. Analysis of Barrel Samples – ASU, Queen's University

Samples of barrel contents were analyzed to establish the identity of the contents (fuel oil or lubricating oil and grease) and to determine the concentrations of PCBs, chlorine, chromium, lead and cadmium.

1. Accuracy

One control-spiked sample was analyzed for PCBs, chlorine, chromium, lead and cadmium. The recoveries ranged from 90 percent to 104 percent (Table C-5). Three additional control spikes were run for PCBs with an overall average recovery of 84 percent. Laboratory control limits allow for a 30-percent variation in spike recovery.

All results were below detection in the sample blanks (Table C-5).

2. Precision

Seven field duplicates were analyzed and three duplicate pairs showed detectable levels of lead. The RSD for lead was 7.5 percent, indicating very good agreement between replicates (Table C-6). All other analytes were below detection in the field duplicates.

Thirteen analytical duplicates were run and again, lead was the only analyte with detectable concentrations. Five duplicate pairs reported detectable amounts of lead. The average RSD was 4.0 percent, indicating very good agreement (Table C-7).

E. Hydrocarbon Degrader Analysis at Research and Productivity Council (RPC), Fredericton, NB

1. Accuracy and Precision

Soil samples were analyzed for hydrocarbon degraders. Notes from RPC indicate that all positive and negative controls, media sterility and media performance checks were found to be satisfactory.

F. CCME Method of Measuring Petroleum Hydrocarbons in Soil Samples – ASG, RMC

Soil analysis was performed as prescribed in the CCME Reference Method for Canada-Wide Standard for Petroleum Hydrocarbons in Soil, 2001. Results were reported for F1 fraction, F2 to F4 fractions and, if extra cleanup was required, gravimetric F4G.

1. Accuracy

Four gasoline control spikes were analyzed for F1-fraction hydrocarbons and the average recovery was 97 percent (Table C-8). Five control diesel spikes and six control standards were also analyzed for total hydrocarbons, resulting in average recoveries of 102 percent and 105 percent, respectively (Table C-9).

Analytical soil blank and scoop blank results are listed in Table C-10. All results were below detection for hydrocarbons in the analytical blanks. Two scoop blanks showed low levels of F4 fraction hydrocarbons but not at concentrations that would have affected sample results.

2. Precision

Precision was monitored with the analysis of field and analytical replicates.

Five soil samples were analyzed in duplicate at ASU and the results are listed in Table C-12. Average RSDs ranged from 7.9 percent to 14 percent, indicating good agreement between replicates.

Eight field duplicates were submitted and the resulting average RSDs ranged from 4.1 percent (for one F4G result) to 35 percent for F3 fraction hydrocarbons (Table C-11). Three individual duplicates reported elevated RSDs (11900/01, 11950/51 and 12000/01) and since the analytical duplicate RSDs were acceptable, this indicates that the field duplicates may not have been properly homogenized. One of the duplicate pairs with an elevated RSD was collected as a confirmatory sample from excavation 445 at Lake Hazen (12000/01). The samples were collected near permafrost and were composed mostly of frozen sand and gravel, making it difficult to collect homogeneous samples. The other two duplicate pairs with elevated RSDs were taken from the Tanquary landfarm (11900/01) and the Lake Hazen experimental treatment plots (1950/01), which are both composed of mixtures of sand and gravel, making homogenization difficult.

In one case, one duplicate result was above the detection limit while the other was below. For these duplicates, we have not calculated RSDs. Previously in such cases, ESG calculated the relative standard deviation by a conventional method that takes the lower of the duplicate results as half of the detection limit. This method invariably led to artificially inflated RSDs, even when the concentration in the higher result was close to the detection limit. In our experience, in such cases the two results generally are, in fact, very close and do represent good precision. For these reasons, these duplicate calculations are no longer included in the QA/QC analysis.

G. Field Testing

1. TPH Analysis by Test Kit

a. Accuracy

Analysis of total petroleum hydrocarbons (TPH) was performed with PetroFLAG™ TPH in Soil test kits.

Five control standards were analyzed with the soil samples and the average result was 1959 ppm (Table C-13). Acceptable limits for controls are 1,700-2,300 ppm. Five analytical blanks were also run and results were below detection for all (Table C-13).

b. Precision

Precision was monitored through the use of analytical duplicates and by analyzing one pair of field duplicates (Table C-14). The RSD for the field duplicate was 15 percent, indicating good agreement between duplicates.

Five analytical duplicates were analyzed and the average RSD was 10 percent again indicating good agreement (Table C-14).

Table C-1: Summary of Inorganic Element Results for Soil Internal Standards (MESS-3 and SS-2)

Element	MESS-3 Certified Value	Determined	ASU Control Limits
	[ppm]	[ppm]	[ppm]
Cu	33.9 ± 1.6	29.8	28-39
Ni	46.9 ± 2.2	37.9	34-42
Co	14.4 ± 2.0	12.4	10-14
Cd	0.24 ± 0.01	<1.0	-
Pb	21.1 ± 0.7	17.2	15-21
Zn	159 ± 8	136.0	119-153
Cr	105 ± 4	43.9	26-54
As	21.2 ± 1.1	17.1	13-18

Element	SS-2 Certified Value	Determined	ASU Control Limits
	[ppm]	[ppm]	[ppm]
Cu	191 ± 9.0	204	158-225
Ni	54 ± 4.0	60.1	49-61
Co	12 ± 1.0	15.7	12 – 17
Cd	2.0*	2.3	0.1 – 3.0
Pb	126 ± 10	119	99-130
Zn	467 ± 23	511	392-544
Cr	34 ± 4.0	47	36-56
As	75 ± 10	81	55-103

* information only, not certified

Table C-2: Inorganic Element Results for Soil Analytical Blank and Duplicate

Sample	**Cu**	**Ni**	**Co**	**Cd**	**Pb**	**Zn**	**Cr**	**As**
	[ppm]	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**
Analytical Blank								
Blank	<5.0	<5.0	<5.0	<1.0	<10	<15	<20	<1.0
Analytical Duplicate								
08-12195	11.3	24	7.7	1.1	37	81	39	3.6
Duplicate	11.4	21	7.5	1.1	37	77	35	3.1
Average	11.4	23	7.6	1.1	37	79	37	3.4
Std Dev	0.07	1.8	0.1	0	0.2	2.8	3.3	0.4
RSD (%)	0.6	8.1	1.9	0	0.6	3.6	8.8	11

Table C-3: QAQC Results for Total and Extractable Phosphorus in Soil Samples

Sample	Extractable Phosphorus [ppm]
Control Spike	
Control Sample	1.02
Control Sample Target	1.0
Recovery (%)	102
Control Sample	1.01
Control Sample Target	1.0
Recovery (%)	101
Control Sample	1.02
Control Sample Target	1.0
Recovery (%)	102
Average Recovery (%)	**102**
Std Dev	**± 0.6**
Analytical Blank	
Blank	<0.10
Blank	<0.10
Blank	<0.10
Analytical Duplicates	
08-11945	0.13
Duplicate	0.13
Average	0.13
Std Dev	0
RSD (%)	0
08-12045	<0.10
Duplicate	<0.10

Table C-4: QAQC Results for Ammonia, Nitrate and Nitrite Analysis of Soil Samples

Sample	**Ammonia** **[ppm]**	**Nitrate** **[ppm]**	**Nitrite** **[ppm]**
Control Spikes			
Control	10	10.7	
Control Target	10	10	
Recovery (%)	100	107	
Control	10	10.7	
Control Target	10	10	
Recovery (%)	100	107	
Control	10	10.7	10.9
Control Target	10	10	10
Recovery (%)	100	107	109
Average Recovery (%)	**100**	**107**	**109**
Std Dev	**± 0**	**± 0**	**-**
Analytical Blank			
Blank	<2.0	<2.0	
Blank	<2.0	<2.0	
Blank	<2.0	<2.0	<2.0
Analytical Duplicates			
08-11924	<2.0	91	<2.0
Duplicate	<2.0	106	<2.0
Average		99	
Std Dev		11	
RSD (%)		11	

Table C-5: QAQC Results for Analysis of Barrel Contents: Controls and Blanks

Sample	PCBs [ppm]	Chlorine [ppm]	Chromium [ppm]	Lead [ppm]	Cadmium [ppm]
Control Spikes					
Control	45	1035	2.97	2.97	0.27
Control Target	50	997	3.0	3.0	0.3
Recovery (%)	90	104	99	99	90
Control	42				
Control Target	50				
Recovery (%)	83				
Control	42				
Control Target	50				
Recovery (%)	83				
Control	41				
Control Target	50				
Recovery (%)	81				
Average Recovery (%)	**84**	**104**	**99**	**99**	**90**
Std Dev	**± 3.8**	**-**	**-**	**-**	**-**
Analytical Blanks					
Blank	<2.0	<1000	<10	<100	<2.0
Blank	<2.0				

Table C-6: QAQC Results for Analysis of Barrel Contents

Sample	**PCBs**	**Chlorine**	**Chromium**	**Lead**	**Cadmium**
	[ppm]	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**
Field Duplicates					
08-12060	<2.0	<1000	<10	<100	<2
08-12061	<2.0	<1000	<10	<100	<2
08-12070	<2.0	<1000	<10	539	<2
08-12071	<2.0	<1000	<10	542	<2
Average				541	
Std Dev				2.1	
RSD (%)				0.4	
08-12090	<2.0	<1000	<10	589	<2
08-12091	<2.0	<1000	<10	718	<2
Average				654	
Std Dev				91	
RSD (%)				14	
08-12110	<2.0	<1000	<10	661	<2
08-12111	<2.0	<1000	<10	589	<2
Average				625	
Std Dev				51	
RSD (%)				8.1	
08-12120	water	water	water	water	water
08-12121	water	water	water	water	water
08-12130	<2.0	<1000	<10	<100	<2
08-12131	<2.0	<1000	<10	<100	<2
08-12140	<2.0	<1000	<10	<100	<2
08-12141	<2.0	<1000	<10	<100	<2
Average RSD (%)				**7.5**	
Std Dev				**± 6.8**	

Table C-7: QAQC Results for Analysis of Barrel Contents: Analytical Duplicates

Sample	**PCBs** **[ppm]**	**Chlorine** **[ppm]**	**Chromium** **[ppm]**	**Lead** **[ppm]**	**Cadmium** **[ppm]**
Analytical Duplicates					
08-12058	-	<1000	-	-	-
Duplicate		<1000			
08-12062	-	<1000	-	-	-
Duplicate		<1000			
08-12065	-	-	<10	180	<2.0
Duplicate			<10	189	<2.0
Average				185	
Std Dev				6.4	
RSD (%)				3.4	
08-12079	-	-	<10	623	<2.0
Duplicate			<10	572	<2.0
Average				598	
Std Dev				36	
RSD (%)				6.0	
08-12085	-	-	<10	774	<2.0
Duplicate			<10	724	<2.0
Average				749	
Std Dev				35	
RSD (%)				4.7	
08-12091	-	-	<10	715	<2.0
Duplicate			<10	721	<2.0
Average				718	
Std Dev				4.2	
RSD (%)				0.6	
08-12097	<2.0	-	-	-	-
Duplicate	<2.0				
08-12103	-	-	<10	<100	<2.0
Duplicate			<10	<100	<2.0
08-12124	<2.0	<1000	<10	<100	<2.0
Duplicate	<2.0	<1000	<10	<100	<2.0
08-12136	-	-	<10	384	<2.0
Duplicate			<10	357	<2.0
Average				371	
Std Dev				19	
RSD (%)				5.2	
08-12140	-	<1000	-	-	-
Duplicate		<1000			
08-12148	-	-	<10	<100	<2.0
Duplicate			<10	<100	<2.0
08-12154	-	<1000	-	-	-
Duplicate		<1000			
Average RSD (%)				**4.0**	
Std Dev				**± 2.1**	

Table C-8: Canadian Council of Ministers of the Environment (CCME) Hydrocarbon Control Spikes

Sample	**F1** **(C6-C10)** **[ppm]**
Control Sample F1	
Control F1	29
Control Target	29
Recovery (%)	100
Control F1	31
Control Target	29
Recovery (%)	107
Control F1	26
Control Target	29
Recovery (%)	90
Control F1	27
Control Target	29
Recovery (%)	93
Average Recovery (%)	**97**
Std Dev	**± 7.6**

Table C-9: Canadian Council of Ministers of the Environment (CCME) Hydrocarbon Control Spikes

Sample	Total Hydrocarbons
	[ppm]
Control Samples F2-F4	
Diesel Spike	59
Diesel Spike Target	50
Recovery (%)	118
Diesel Spike	58
Diesel Spike Target	50
Recovery (%)	116
Diesel Spike	56
Diesel Spike Target	50
Recovery (%)	112
Diesel Spike	42
Diesel Spike Target	50
Recovery (%)	84
Diesel Spike	40
Diesel Spike Target	50
Recovery (%)	80
Average Recovery (%)	**102**
Std Dev	**± 18**

Sample	Total Hydrocarbons
	[ppm]
Control	2600
Control Target	2500
Recovery (%)	104
Control	2600
Control Target	2500
Recovery (%)	104
Control	2900
Control Target	2500
Recovery (%)	116
Control	2600
Control Target	2500
Recovery (%)	104
Control	2600
Control Target	2500
Recovery (%)	104
Control	2400
Control Target	2500
Recovery (%)	96
Average Recovery (%)	**105**
Std Dev	**± 6.4**

Table C-10: Canadian Council of Ministers of the Environment (CCME) Hydrocarbon Control Spikes and Blanks

Sample	F1 (C6-C10) [ppm]	F2 (C10-C16) [ppm]	F3 (C16-C34) [ppm]	F4 (C34-C50) [ppm]
Analytical Blanks				
Blank	<10	<4.0	<9.0	<8.0
Blank	<10	<4.0	<9.0	<8.0
Blank	<10	<4.0	<9.0	<8.0
Blank	<10	<4.0	<9.0	<8.0
Blank		<4.0	<9.0	<8.0
Scoop Blanks				
08-11886		<4.0	<9.0	26
08-12006		<4.0	<9.0	<8.0
08-12026		<4.0	<9.0	<8.0
08-12046		<4.0	<9.0	9.1

Table C-11: CCME Hydrocarbon Analytical Duplicates

Sample	F1 (C6-C10) [ppm]	F2 (C10-C16) [ppm]	F3 (C16-C34) [ppm]	F4 (C34-C50) [ppm]
08-11914	130	99	26	N/A
Duplicate	140	95	24	
Average	135	97	25	
Std Dev	7.1	2.8	1.4	
RSD (%)	5.2	2.9	5.7	
08-11916	88	620	240	N/A
Duplicate	96	740	330	
Average	92	680	285	
Std Dev	5.7	85	64	
RSD (%)	6.1	13	22	
08-12005	<4.0	19	<8.0	N/A
Duplicate	<4.0	15	<8.0	
Average		17		
Std Dev		2.8		
RSD (%)		17		
08-12048	2600	920	300	N/A
Duplicate	3100	1100	370	
Average	2860	1020	335	
Std Dev	354	127	49	
RSD (%)	12	13	15	
08-12054	<4.0	<9.0	<8.0	N/A
Duplicate	<4.0	<9.0	<8.0	
Average RSD (%)	**7.9**	**11**	**14**	
Std Dev	**± 3.9**	**± 5.8**	**± 8.3**	

Table C-12: CCME Hydrocarbon Field Duplicates

Sample	F2	F3	F4	F4G
	(C10-C16)	(C16-C34)	(C34-C50)	
	[ppm]	[ppm]	[ppm]	[ppm]
08-11880	34	2200	3000	8780
08-11881	35	1800	2700	8280
Average	35	2000	2860	8540
Std Dev	0.7	283	212	353
RSD (%)	2.0	14	7.4	4.1
08-11900	200	130	36	N/A
08-11901	900	410	21	N/A
Average	540	270	29	
Std Dev	488	198	11	
RSD (%)	90	73	37	
08-11920	96	500	180	N/A
08-11921	130	740	280	N/A
Average	113	620	230	
Std Dev	24	163	71	
RSD (%)	21	26	31	
08-11930	200	740	250	N/A
08-11931	270	900	300	N/A
Average	235	820	275	
Std Dev	49	120	35	
RSD (%)	21	15	13	
08-11950	150	65	9.5	N/A
08-11951	170	400	8.8	N/A
Average	160	233	9.2	
Std Dev	14.1	237	0.49	
RSD (%)	8.8	102	5.4	
08-12000	1800	89	15	N/A
08-12001	2000	58	< 8.0	N/A
Average	1900	74		
Std Dev	141	22		
RSD (%)	7.4	30		
08-12030	1000	8900	1900	N/A
08-12031	2100	11000	4000	N/A
Average	1560	9960	2960	
Std Dev	780	1480	1480	
RSD (%)	50	15	50	
08-12050	1700	600	180	N/A
08-12051	1700	540	150	N/A
Average	1700	560	165	
Std Dev	0	35	21	
RSD (%)	0	6.3	13	
Average RSD (%)	**25**	**35**	**22**	**4.1**
Std Dev	**± 31**	**± 34**	**± 17**	**-**

Table C-13: Control Spike and Analytical Blank Results for Soil Samples Analyzed by TPH Test Kit

Sample	TPH Test Kit [ppm]
Control Spikes	
Control	1949
Control	1978
Control	1916
Control	1947
Control	2003
Average	**1959**
Std Dev	**± 33**
Target Range minimum	*1700*
Target Range maximum	*2300*

Sample	TPH Test Kit [ppm]
Analytical Blanks	
Analytical Blank	<26
Analytical Blank	<26
Analytical Blank	<26
Analytical Blank	<26
Analytical Blank	<26

Table C-14: Total Petroleum Hydrocarbon (TPH) Results for Soil Sample Duplicates Analyzed by TPH Test Kit

Sample	**TPH Test Kit**
	[ppm]
Field	
08-11970	2908
08-11971	2345
Average	2627
Std Dev	398
RSD (%)	15

Sample	**TPH Test Kit**
	[ppm]
Analytical Duplicates	
08-11973	<26
Duplicate	<26
08-11974	2870
Duplicate	2891
Average	2881
Std Dev	15
RSD (%)	0.5
08-11982	64
Duplicate	85
Average	75
Std Dev	15
RSD (%)	20
08-11993	81
Duplicate	70
Average	76
Std Dev	7.8
RSD (%)	10
08-12007	<26
Duplicate	<26
Average RSD (%)	**10**
Std Dev	**± 9.7**

Appendix D: LANDFARM MAINTENANCE INSTRUCTIONS

APPENDIX D: LANDFARM MAINTENANCE INSTRUCTIONS

I. INTRODUCTION

The Environmental Sciences Group (ESG) has conducted field studies on the remediation of petroleum hydrocarbon (PHC) contaminated soil at Tanquary Fiord and Lake Hazen in Quttinirpaaq National Park (QNP). In 2008, PHC-contaminated soils were excavated from Lake Hazen and placed in a landfarm for treatment. In order for the treatment to be effective, these studies have shown that on-going maintenance (i.e., watering, tilling) from Parks Canada Agency (PCA) staff is required. The following document outlines maintenance instructions for these areas.

A landfarm treatment facility was constructed in 2008 at the north end of the airstrip to remediate PHC-contaminated soil excavated from different locations at Lake Hazen. There is also an existing landfarm facility at Tanquary Fiord. Both facilities consist of a bermed and lined containment area. The geotechnical liners are covered with a layer of clean, porous material approximately 5 cm deep to promote aeration and prevent damage to the liner during tilling. PHC-contaminated soil was placed in the containment areas in a layer approximately 30 cm deep. The soil was amended with the surfactant Biosolve™, agricultural fertilizers, and water. Microorganism cultures were not added to the soil. A monitoring program has been established to confirm that hydrocarbon concentrations are decreasing with time, with complete remediation expected to take several years.

II. WATERING AND TILLING

Because ESG is in QNP for only a short period of time during the summer, we need help from PCA to water and till the soil in the landfarms. This will be essential for efficient remediation of the hydrocarbon-contaminated soil. Watering and tilling should be conducted biweekly or at least once if on site for less than 2 weeks. Watering and tilling events should be recorded in the log attached to this document. Another sheet can be added to the log if necessary. The following sections describe the procedure to be followed for these activities.

A. Equipment required

The equipment required (listed below) for these activities is located in the Quonset at Tanquary Fiord and should be placed back in the same area upon completion.

Orange garden watering can

20 L white pails with lids

Rototiller or shovel

Pump

50 ft blue hose

Yellow extension cord

Small Honda generator (Bezal's gasoline generator)

B. Watering

Watering must be done prior to tilling. Approximately three 3,500 L of freshwater from the lake should be applied evenly on the landfarm using the pump and 50 ft hose. The small Honda generator is used to power the pump.

C. Tilling

Tilling is carried out with the rototiller or shovel, in the event that the rototiller is not available. Before operating the rototiller for the first time, please refer to the rototiller operator manual and practice operating it in clean soil. For rototilling the soil, start from one end of the plots and work your way to the other end of the landfarm by walking forward slowly pushing the rototiller. Hold the rototiller at one spot for a few seconds to ensure the soil is mixed at depth. IMPORTANT: care must be taken not to damage the liners during tilling. To protect the liner, 30 cm of contaminated soil was laid over 5 cm of clean soil. The clean soil acts as a protection layer for the plastic liner. Once a row has been tilled, turn the rototiller around and shift to the side of the tilled row. Repeat this ''zig zagging'' until the whole landfarm has been tilled. SAFETY NOTE: gravel may get caught between the blades; if so, turn off the rototiller before removing any obstruction using a shovel or other tool.

D. Health and safety

Sturdy boots (preferably with steel toes), work gloves, goggles and pants must be worn when watering or operating the rototiller. Wearing a respirator with organic vapor filters (purple cartridges) is also recommended if there is a strong hydrocarbon odor during tilling. Respirator masks of various sizes and extra organic vapor cartridges can be found with the ESG equipment stored in the Quonset at Tanquary Fiord.

We would like to thank PCA for carrying out this maintenance – your help is important to ensure efficient remediation of the hydrocarbon-contaminated soil at Quttinirpaaq National Park sites.

III. CONTACT

If you have any questions or concerns regarding these procedures, please contact Catriona Jackson at 613-541-6000 ext. 3685 (catriona.jackson@rmc.ca) or David Sanscartier at 613-541-6000 ext. 6571 (david.sanscartier@rmc.ca).