Naturally Elevated Concentrations of Trace Metals (Cu, Ni, Co and As) at the FOX-2 DEW Line Site, Longstaff Bluff, Nunavut

Prepared by

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ACKNOWLEDGEMENTS

The 2005 background sampling program at FOX-2 was conducted as part of the overall environmental investigation commissioned by the Defence Construction Canada Distant Early Warning (DEW) Line Cleanup Project Management Office, on behalf of the Department of National Defence (DND). The investigation was performed by the Environmental Sciences Group (ESG), Royal Military College of Canada, directed by Dr. Ken Reimer. ESG would like to thank UMA Engineering Ltd. and Defence Construction Ltd. (DCC) for providing technical assistance and consultation throughout this project.

ESG developed the background sampling program; sampling was directed by Nick Battye (ESG) with assistance from Andrew Passalis (UMA). Logistical support from Kingston, ON, was provided by Leslie Carman, Karen Edmunds, Kathleen Francis, Mary MacGregor and Geoff Dawson. Darren White and Dr. Daniela Loock were the project managers, while Deborah Reimer and Nancy Langevin were in charge of financial administration.

The analytical work was carried out by the Analytical Services Unit (ASU) of Queen's University. Special thanks to Paula Whitley and staff for their hard work and high standards.

This report was written and compiled by Nick Battye based on the internal technical reports prepared by Dr. David Love (technical support). The technical review and editing were performed by Darren White and Dr. Daniela Loock.

EXECUTIVE SUMMARY

Previous investigations at the FOX-2, Longstaff Bluff, DEW Line site, as well as a geological and geochemical literature review of the surrounding area, indicated the potential for naturally occurring, elevated concentrations of Cu, Ni, Co and As in the soil. Bedrock at the site consists of interbedded psammite, semipelite, pelite, arkosic- and lithic-wacke with minor calc-silicate beds. Surficial geological mapping was performed by EBA Engineering Consultants Ltd., which identified nine separate terrain units. These units, along with their respective soil types are generally well defined and easy to distinguish. However, construction of building pads and roads, as well as management of landfills, has disturbed large areas and caused local mixing of surficial materials, as well as the redistribution of large quantities of material from several borrow areas and geological units to other areas of the site. A similar situation at DYE-M led to the conclusion that it would be more appropriate to establish global background limits than unit-specific ones.

A geology-based sampling program, similar to those conducted at DYE-M and PIN-2, was carried out during the site investigation in 2005. It was based on a uniform random sampling approach because this best eliminates bias, and useful statistical inferences can be confidently drawn from such a dataset. A total of 113 background samples were collected and analyzed for copper (Cu), nickel (Ni), cobalt (Co), cadmium (Cd), lead (Pb), zinc (Zn), chromium (Cr) and arsenic (As). A secondary program, the baseline program, sampled borrow material in support of the landfill assessment and monitoring programs and produced an additional 59 samples. Between the two programs, Cu, Ni, Co and As were found to exceed the DEW Line Cleanup Criteria (DLCC) on a regular basis.

Background mean concentrations for all elements except Cd and Pb were conservatively calculated as the 95-percent upper confidence limit (UCL) of the geometric mean, where sufficient data were available. The mean background concentration of Pb was estimated using maximum likelihood estimations because of the large proportions of non-detects. Estimates of mean background concentration could not be made for Cd because there were no data above detection limits.

The geometrically transformed data were tested for mild (more than 1.5 times the interquartile range above the third quartile) and extreme outliers (more than three times the interquartile range above the third quartile). The extreme outlier limits exceed the DLCC for Cu, Ni, Co and As, and are proposed as environmentally suitable local

alternatives to the standard cleanup criteria for these elements. These values, coupled with the generic DLCC for Cd, Pb, Zn and Cr, were combined to form the recommended site-specific criteria for the cleanup of the FOX-2 DEW Line site.

The global criteria levels for Cu and Ni are occasionally exceeded naturally, and have been linked to groundwater flow through the RLg (steeply sloped exposed bedrock) terrain unit. Groundwater travelling through the bedrock dissolves metals and carries them in solution. At the lower boundary of the RLg terrain unit, the steeply sloped bedrock transitions into a relatively flat, coastal area of marine-washed sand and gravel deposits. This sudden topographical shift leads to local resurgences of groundwater to atmospheric conditions, which favours mineral precipitation. Distinctive iron oxide and/or carbonate precipitates, high in inorganic metal concentrations, could often be traced back to these discharge points following the stream bed. The airstrip and west landfill were the two main areas where visual evidence clearly indicated this kind of natural geochemical accumulation of elements. Both areas were located at the base of the RLg terrain unit.

An evaluation matrix was created to help standardize the process of determining whether concentrations that exceeded the site-specific criteria were anthropogenic or isolated occurrences of naturally elevated hot spots. Several samples fall into the latter category, and it is recommended that these locations be considered exempt from cleanup activities.

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I. INTRODUCTION

FOX-2, Longstaff Bluff, is located on the southwest coast of Baffin Island near the tip of the Baird Peninsula overlooking Nauja Bay (68^{o} 54’N, 75^{o} 10’W). Hall Beach is located 245 kilometres to the west. The nearest community with a full range of charter aircraft and commercial and public services available is Iqaluit, 640 km away.

FOX-2 was an auxiliary site within the original DEW Line system and consisted of a module train, garage, warehouse, radar facilities, POL facilities, a sewage outfall, pallet storage areas, landfills, east beach landing area, water lake road, an airstrip and associated hangar before it was decommissioned in the early 1990s. A North Warning System (NWS) short-range radar station occupies a site just south of the former DEW Line station. In 2005, on behalf of the DEW Line Cleanup Project Management Office, the Environmental Sciences Group (ESG) of the Royal Military College of Canada completed an environmental investigation of the site.

From earlier ESG studies across the North Warning System (ESG, 1991) it was apparent that contamination at these sites presented some environmental risk and it was equally clear that existing southern cleanup strategies would not be appropriate for the Arctic without some modification. From this followed the development of a general site assessment and cleanup approach suitable for the unique Arctic environment. This approach, the DEW Line Cleanup Protocol (ESG, 1992), was designed to restore the sites to an environmentally safe condition and to prevent migration of contaminants into the Arctic food chain. It has formed the basis for cleanup recommendations for DEW Line sites and other Arctic and northern installations. The protocol includes recommendations for dealing with contamination (primarily PCBs and inorganic elements) in soil, and for handling landfills and debris.

The protocol also provides a set of numerical guidelines for contaminant tolerances in soil, the DEW Line Cleanup Criteria (DLCC), which were developed in the course of the 1989 and 1990 site investigations described above (ESG, 1991). Two tiers of soil contamination were established: Tier I soil contains contaminants at concentrations that are considered high enough to have the potential to migrate via aerial transport; and Tier II soil contains contaminants at concentrations that have the potential to be transferred to the food chain via plant uptake. The protocol recommends that Tier I soil be placed in an on-site engineered landfill or, if in a stable location, backfilled or capped in place under a minimum of 0.3 m of clean fill. It recommends that Tier II soil be excavated and placed in an on-site engineered disposal facility.

Detailed background characterization is not generally required for site investigation and remediation where contaminant sources are clearly anthropogenic and there are applicable generic soil quality guidelines. However, geologic units such as some of those found in the Longstaff Bluff region have naturally high concentrations of various trace metallic elements. High concentrations of inorganic elements in the soil at FOX-2, in particular arsenic, were identified in earlier DEW Line Cleanup site assessments (UMA, 1991b; ESG, 1993). A till deposit geochemical study conducted by the Geological Survey of Canada (GSC) (Dredge, 2004) over most of south-central Baffin Island confirmed the presence of high concentrations (albeit in sieved fine-grained fractions only) both near the site and in distant isolated areas that are free from site impacts. Specifically, the study showed high natural arsenic (0.3 ppm to 412 ppm), nickel (20 ppm to 341 ppm) and cobalt (0.5 ppm to 94 ppm) in the silt and clay fraction (<0.063 mm). Copper values were only determined for the clay-size fraction (<0.002 mm) and ranged from 16 ppm to 578 ppm.

Based on this information, a detailed background sampling program was deemed necessary and was conducted during the 2005 site investigation at FOX-2. The goal of the program was to establish local inorganic element levels in the soil to: a) differentiate natural and anthropogenic concentrations; b) define boundaries for excavations; and c) calculate acceptable levels for confirmatory testing. A thorough understanding of the geology of the area, as well as the geochemistry of the soil, is important to correctly assess inorganic element migration patterns for the assessment of landfills and the continuing, long-term landfill monitoring program.

To that end, all background soil samples were analyzed for all the inorganic elements to which the DLCC apply: copper (Cu), nickel (Ni), cobalt (Co), cadmium (Cd), lead (Pb), zinc (Zn), chromium (Cr) and arsenic (As). The results of the background program, which appear in Appendix A, indicated that natural levels of Cu, Ni, Co and As exceeded the DLCC on a regular basis, over a large proportion of the site. Use of the DLCC would therefore have a significant impact on remediation of the site and would lead to the unnecessary excavation and destruction of large portions of natural tundra. Consequently, detailed characterization was warranted and site-specific cleanup criteria and appropriate remediation options had to be considered.

II. GEOLOGY AND GEOCHEMISTRY OF THE SOIL

A. Bedrock Geology

The Longstaff Bluff area is underlain by the Longstaff Bluff Formation of the Piling Group. The rocks of the Piling Group were deposited in middle Paleo-Proterozoic time (2.0-1.9 billion years ago) on a continental margin that was evolving from a continental shelf (quartzites and marbles of the underlying Dewar Lakes and Flint Lake Formations) to a foredeep environment (Longstaff Bluff Fm.). They were deformed and metamorphosed in the Trans-Hudson Orogeny (folding, faulting and mountain-building event 1.8 billion years ago) and now constitute part of the Foxe Fold Belt. Just to the west of Longstaff Bluff, on Baird Peninsula, the Proterozoic rocks are overlain unconformably by much younger, undeformed lower Paleozoic limestones.

The Longstaff Bluff Formation is described as interbedded psammite, semipelite, pelite, arkosic- and lithic-wacke with minor calc-silicate beds (St. Onge *et al.*, 2004). Thus these rocks originally varied in grain size from sandstone to shale and mudstone, and in composition from relatively pure quartz, through feldspar-rich, to very dirty with mixed mineralogy and sand-sized rock fragments, and locally contained minor muddy limestones. At Longstaff Bluff, these rocks have been tightly folded into isoclinal folds (fold limbs nearly parallel). The axial planes of the folds, the rocks on the fold limbs and the cleavage developed in the rocks all strike east-northeast. The fold axes plunge gently to moderately, to the east-northeast. The metamorphism that accompanied deformation produced coarser biotite, muscovite and locally garnets in the more impure rocks (less quartz-rich). There is a mappable increase in metamorphic grade northward in the Longstaff Bluffs area, with the south tip of the peninsula containing only the above-mentioned minerals, and the rest of the peninsula being higher grade and also containing cordierite with or without andalusite. This change in metamorphic mineralogy is demarcated on the peninsula by an isograd. Near the south tip of Longstaff Bluff peninsula, this mineral isograd is offset in a right-lateral sense by a later northwest-striking fault.

The Longstaff Bluffs Formation is stratigraphically underlain by the Astarte River Formation. The latter varies in grain size from slate to schist with increasing metamorphic grade. It is rich in iron sulphides throughout and is locally graphite-rich. The Astarte River Formation is locally infolded and also structurally repeated by thrust faulting in areas of predominantly Longstaff Bluff Formation. This is only apparent in areas of detailed bedrock mapping (Allan and Pattison, 2003), yet likely in other areas also, such as the Longstaff Bluff region. The regional metamorphism has redistributed sulphide minerals (primary mineral sources of trace metals) in the Astarte River Formation and concentrated them into seams parallel to the cleavage and axial planes of the folds.

B. Surficial Geology

With the retreat of the Laurentide ice sheet approximately 6,000 years ago (Fulton, 1989), global sea levels began to rise along with the earth's crust through isostatic rebound. The marine water transgression within the project area reached an elevation as high as 99 m (Dredge, 2003). Therefore, at elevations higher than 99 m asl, till is the prevalent deposit type and is characterized as a well graded, clayey, silty and sandy matrix with a gravelly, cobbly and bouldery content. It typically occurs as thin veneer over top of bedrock. Below 99 m asl, marine-washed deposits dominate the present-day landscape and locally form discontinuous veneers and continuous blankets of predominantly coarse (cobbly and gravelly) marine and glaciomarine deposits.

Much of the topographic relief on site is made up of steeply sloped, rugged, exposed bedrock. Felsenmeer deposits (frost shattered bedrock), consisting of angular cobble-, gravel- and sand-sized weathered material, form an extensive, thin, discontinuous cover over much of the exposed bedrock.

Glaciolacustrine sediments composed of saturated silt and sand underlie portions of the terrain around the perimeter of two major unnamed lakes in the area. The sediments are likely ice-rich as indicated by polygonal ground (EBA, 1994). Other permafrost-related landforms include thermokarst lakes, patterned ground and some solifluction forms (EBA, 2005).

Soil was sampled at surface and at depth(s), where possible, to capture any changes in soil characteristics over the vertical soil profile. Some vertical variations in grain size and colour were observed in select test pits; however, statistical tests to determine variability with depth were conducted on each individual element, as well as for correlations between elements, resulted in patterns that were not consistent, systematic or significant.

C. Terrain Units

Air photo review was conducted by EBA Engineering Consultants Ltd. (EBA, 2005) prior to the actual site investigation. Nine terrain units were identified at FOX-2 and are detailed below.

- Mr – Beach sediments: cobble, gravel and sand.
- Mv – Marine veneer deposits: sand, gravel and cobble in varying proportions, trace silt, a discontinuous cover of littoral and off-shore sediment, including raised beach ridges and sea-ice rafted debris, mimicking the surface of underlying till or bedrock with patches of exposed bedrock.
- Mb – Marine blanket deposits: thick deposits of sand, gravel and cobble in varying proportions, trace silt, with some sea-ice rafted debris, forming a continuous cover of littoral and off-shore sediment.
- GM – Glaciomarine deposits: diamictic stony sand and mud with ice-rafted dropstones, forming undulating terraces.
- GL – Glaciolacustrine deposits: sand, silt and mud with ice-rafted dropstones, forming flat to undulating plains with patches of exposed bedrock.
- Tv – Till veneer: glacial diamicton (silt, clay, gravel, and cobble in varying proportions, bouldery), discontinuous cover mimicking topography of underlying bedrock with patches of exposed bedrock.
- RL – Exposed metasedimentary bedrock: psammite, pelite, wacke and quartzite of the Longstaff Bluff Formation.
- RLg – Exposed metasedimentary bedrock with patches of felsenmeer or till veneer or marine veneer.
- RLs – Steep bedrock slope.

Three of these units, marine blanket deposits (Mb), exposed metasedimentary bedrock with patches of felsenmeer, till veneer, or marine veneer (RLg), and till veneer deposits (Tv) cover approximately 72% of the site (31%, 21% and 20%, respectively). The remainder of the site is made up of marine veneer deposits (Mv – 13%), exposed metasedimentary bedrock (RL – 5%), glaciolacustrine (GL – 5%) deposits, glaciomarine deposits (GM – 4%), beach sediments (Mr – 1%) and steep bedrock slopes (RLs – <1%). Despite the potential correlation between bedrock and soil compositions in undisturbed areas, most of the areas investigated as part of the site investigation program are disturbed, such that contamination does not occur in unit-specific material of distinguishable composition. This is because building pads, roads and landfill cover are made of mixed material from more than one borrow area and geological unit, and even away from these features, construction and other work disturbed large areas and caused local mixing of surficial materials.

III. 2005 SAMPLING PROGRAM

A. Approach and Rationale

Characterization of background concentrations of inorganics for contaminated-site investigation and remediation has been addressed by many environmental regulators (BCMWLAP, 2000; CCME, 1999; USEPA, 1995). Typically, a soil sampling program is conducted in areas of background units comparable to on-site areas but free from anthropogenic inputs. Significant differences between the population distributions for the inorganic elements of concern from the background units and the potentially contaminated areas are interpreted as indicating that an area in question has been affected by an anthropogenic point-source of contamination.

In 2005, a geologically based program to further investigate the background concentrations of inorganic elements at FOX-2 was conducted. The goal of this program was to establish local background levels and thresholds above which contamination may be indicated. Similar programs have been conducted at other DEW Line sites, including DYE-M and PIN-2. The approach used for DYE-M was presented to the Environmental Working Group (EWG) which accepted it, in addition to the conclusions that were drawn in the report (ESG, 2003; EWG minutes, 2004). The methodology for FOX-2 was also presented to EWG prior to the investigation, which accepted it as well. It is based on a uniform random sampling approach because this best eliminates bias and useful statistical inferences can be confidently made from such a data set (Swan and Sandilands, 1995). The details of the sampling program appear below.

B. The 2005 Sampling Program

1. Background Sampling Program

For the purposes of the background sampling program, the FOX-2 site was defined as the area encompassed by the DEW Line reserve boundary. During the pre-field planning stages, this area was divided into 250 x 250 m square cells using digital maps within AutoCAD. Sample sites were then generated inside each square cell using a random number generator, which produced a uniform, random data set. This sampling methodology originally produced 173 potential sample locations, which were plotted on the property maps and considered for inclusion in the survey. This design is illustrated in Figure 1.

These sample locations were then inspected on underlying air photos and rejected if the sample location fell offshore, outside the designated boundary (DEW Line reserve), within 50 m of another sample location, and/or within 50 m of a known contaminated area. These rules are necessary from a practical sense and must be followed if the goals of the background program are to be fulfilled; namely, to determine accurate background inorganic element concentration levels. If a sample were to be included in the background data set that was not representative of background conditions (e.g. has been anthropogenically affected), a bias in the calculated background levels, resulting in an erroneous decision to augment the cleanup criteria, would be introduced. Following the above-listed rules for sample exclusion, 82 of the original 173 sampling sites were eliminated. This yielded the final set of 91 sample sites.

During the field season, samples could only be collected from 63 of the 91 randomly drawn sampling sites. The majority of the sites that could not be sampled were not safely accessible either by ATV or on foot. These sites also tended to be in the terrain unit Tv (till veneer), which consisted of steeply dipping, jagged bedrock outcrops. A total of 113 samples were collected, consisting of both surface and depth samples, as well as 12 field duplicates for QA/QC purposes. Depth sample collection was subject to the amount of overburden present and therefore tends to be biased to the terrain units that had a thicker surficial cover. The actual sampling that was done appears in Figure III-2. The results appear in Appendix A.

2. Baseline Sampling Program

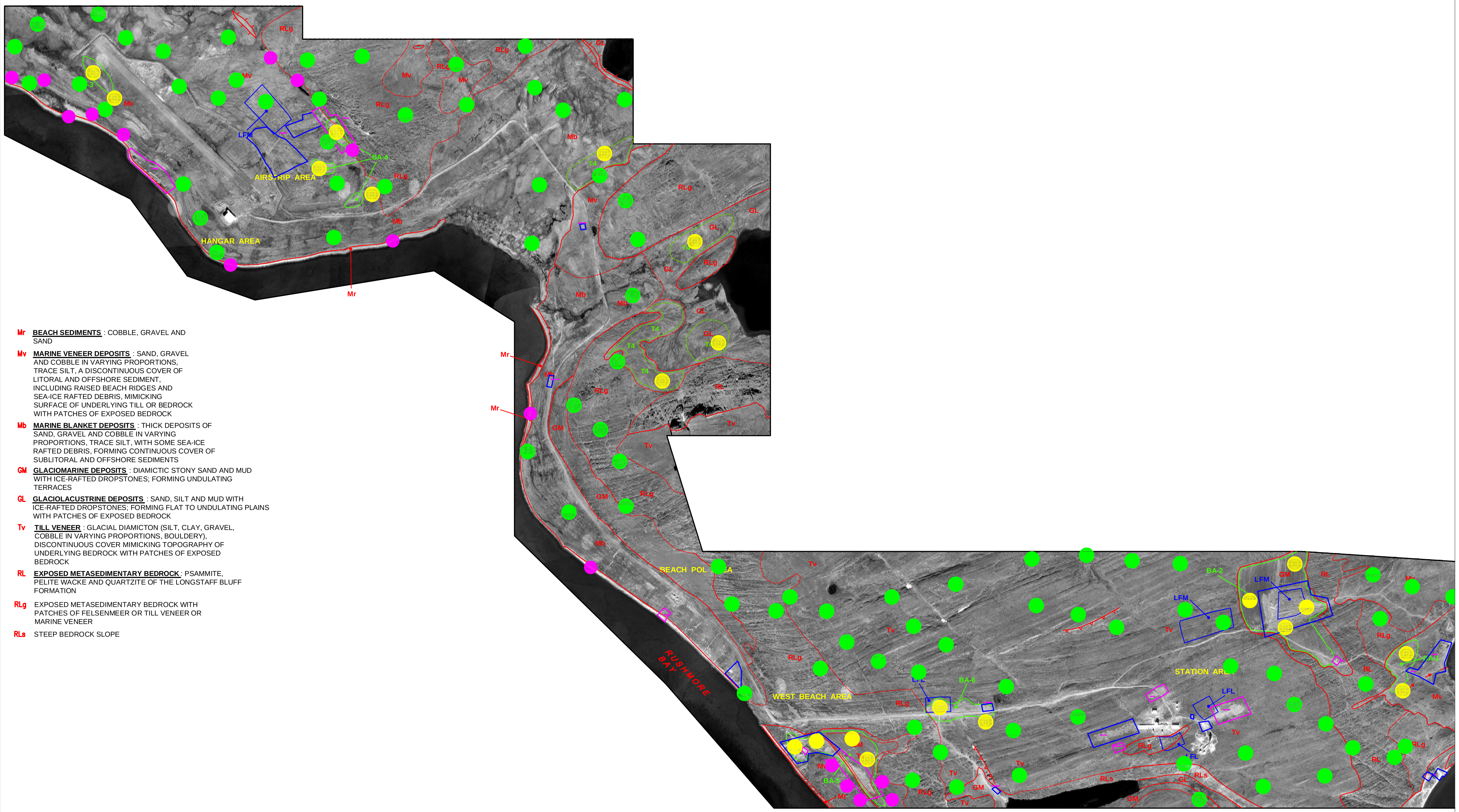
The baseline program was conducted concurrently with the background program. The purpose of this program was to provide information specifically for the landfill assessment and landfill monitoring programs by targeting areas such as existing and proposed borrow sources because of their influence on the geochemistry of infrastructure pads, landfill remediation and new landfill construction. Anthropogenic influences within the baseline data can be determined by either the presence of non-naturally-occurring contaminants (e.g. polychlorinated biphenyls – PCBs – or total petroleum hydrocarbons – TPH), or by variations in the suite of inorganic elements present, and/or the concentration ratios between those elements from those of the background program. In addition, an unbiased statistical test between the background and baseline program data sets can be performed to determine whether inorganic element concentrations are consistent between the program data sets (i.e. whether they are from the same “population”). If the data set can be proven not to have been anthropogenically affected, then the background and baseline data sets can be combined into one larger data set in order to achieve greater accuracy and precision when calculating criteria levels.

An additional 59 samples were collected from 24 sites as part of the baseline program. The sites targeted include six separate borrow areas on site (Borrow Areas 2, 3, 4, 7, 8 and 9) that reflect the geochemistry of two different terrain units (Mb and GM). The analytical results of the baseline program are found in Appendix A.

C. Analytical Methods, Accuracy and Precision

The trace metal geochemistry of the soils was performed at the Analytical Services Unit (ASU) at Queen’s University using standard methods that are accepted industry-wide. These are described in detail in Appendix B. The accuracy and precision of the trace metal analyses are also described in detail in Appendix B, and summarized below. The accuracy is acceptable and the analytical blank analyses are acceptably low. The measured duplicates of the lab standard indicate very good analytical precision. The majority of the lab duplicates analytical precision showed good to very good precision with only one unacceptable result (related to arsenic). The majority of field duplicates showed good to very good precision although four duplicate pairs had unacceptable relative standard deviations (RSDs) (three of four related to arsenic).

The increased occurrence of unacceptable duplicate pairs related to arsenic in the laboratory and field duplicates is likely related to mineralogical heterogeneity in the sampled material. Arsenic is known to preferentially concentrate within iron oxide minerals, which were observed as distinct layers and mottles within the soil in certain areas on-site. Even if a few such mineral grains get sequestered in one of the two samples of a duplicate pair that are not a part of such visually distinct formation, this can still cause major differences in the two sample As concentrations.



Mr **BEACH SEDIMENTS** : COBBLE, GRAVEL AND SAND

Mv **MARINE VENEER DEPOSITS** : SAND, GRAVEL AND COBBLE IN VARYING PROPORTIONS, TRACE SILT, A DISCONTINUOUS COVER OF LITORAL AND OFFSHORE SEDIMENT, INCLUDING RAISED BEACH RIDGES AND SEA-ICE RAFTED DEBRIS, MIMICKING SURFACE OF UNDERLYING TILL OR BEDROCK WITH PATCHES OF EXPOSED BEDROCK

Mb **MARINE BLANKET DEPOSITS** : THICK DEPOSITS OF SAND, GRAVEL AND COBBLE IN VARYING PROPORTIONS, TRACE SILT, WITH SOME SEA-ICE RAFTED DEBRIS, FORMING CONTINUOUS COVER OF SUBLITORAL AND OFFSHORE SEDIMENTS

GM **GLACIOMARINE DEPOSITS** : DIAMICTIC STONY SAND AND MUD WITH ICE-RAFTED DROPSTONES; FORMING UNDULATING TERRACES

GL **GLACIOLACUSTRINE DEPOSITS** : SAND, SILT AND MUD WITH ICE-RAFTED DROPSTONES; FORMING FLAT TO UNDULATING PLAINS WITH PATCHES OF EXPOSED BEDROCK

Tv **TILL VENEER** : GLACIAL DIAMICTON (SILT, CLAY, GRAVEL, COBBLE IN VARYING PROPORTIONS, BOULDERY), DISCONTINUOUS COVER MIMICKING TOPOGRAPHY OF UNDERLYING BEDROCK WITH PATCHES OF EXPOSED BEDROCK

RL **EXPOSED METASEDIMENTARY BEDROCK** : PSAMMITE, PELITE WACKE AND QUARTZITE OF THE LONGSTAFF BLUFF FORMATION

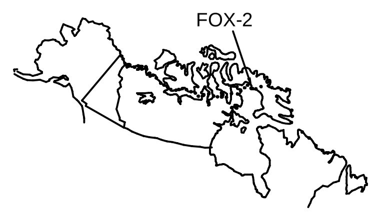
RLg EXPOSED METASEDIMENTARY BEDROCK WITH PATCHES OF FELSENMEER OR TILL VENEER OR MARINE VENEER

RLs STEEP BEDROCK SLOPE

National Defence **Défense nationale**

Headquarters
Quartier général

LOCATION



LEGEND:

- CLIFF FACE IN BEDROCK

- MORAINE RIDGES

a b - GEOLOGICAL BOUNDARY (a - defined; b - assumed)

T4 - POTENTIAL SOURCE OF TYPE 4 GRANULAR FILL

BA-1 - BORROW AREA (1994)

LFL - PROPOSED LANDFILL

LFM - PROPOSED LANDFARM

FOX-2 BACKGROUND SAMPLE PLAN

● BACKGROUND
● BASELINE
● LANDFILL ASSESSMENT

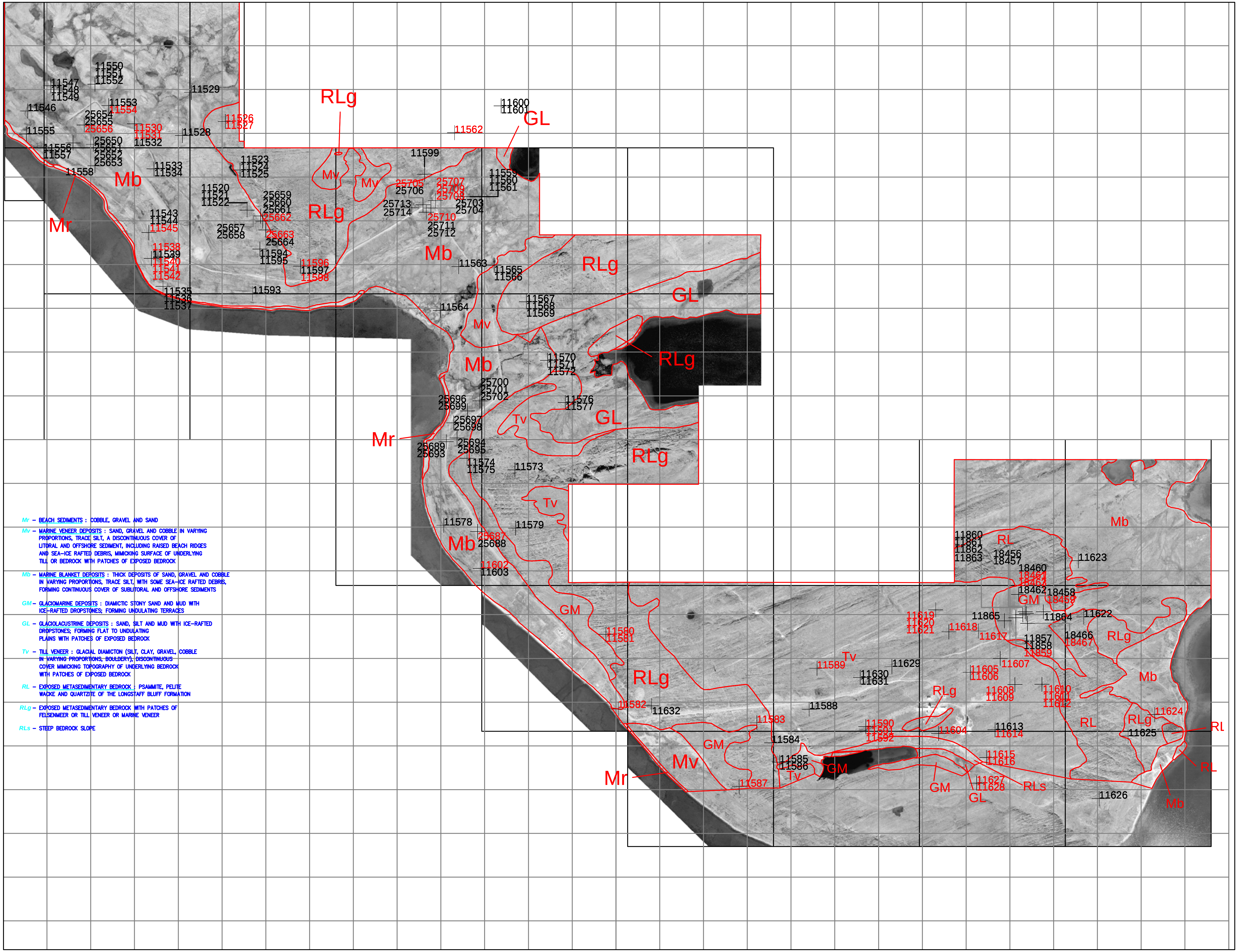
SCALE	AERIAL PHOTOGRAPHY (1994) NAPL (NRCan) - A28112 (42-130)

SITE
FOX-2 - LONGSTAFF BLUFF NU

PROJECT	DATE
Dew Line Clean Up (DLCU)	2005 APR 22

SUBJECT

Figure III-1: Planned Background & Baseline Soil Sample Locations



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Tv – TILL VENEER : GLACIAL DIAMICTON (SILT, CLAY, GRAVEL, COBBLE IN VARYING PROPORTIONS, BOULDERY), DISCONTINUOUS COVER MIMICKING TOPOGRAPHY OF UNDERLYING BEDROCK WITH PATCHES OF EXPOSED BEDROCK

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National Defence **Défense nationale**

Headquarters
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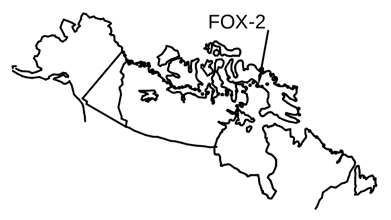
LOCATION



LEGEND:

\+ Sample Location
720 Sample Number
– – Property Boundary
Geophysical Anomaly Boundary
Proposed Landfill

Contaminant Levels - DLCU Criteria

Sample & Area Definitions	Tag Number	Area
Background Clean	⬛	
Not Analyzed	■	
CEPA	🟪	▨
Tier II	🟥	▨
Tier II & TPH Type A	🟨	▨
Tier II & TPH Type B	🟧	▨
Tier I	🟩	▨
Tier I & TPH Type A	🟩	▨
Tier I & TPH Type B	🟩	▨
TPH Type A	🟦	▨
TPH Type B	🟦	▨
Leachable Inorganic Elements	🟪	🟪

NOTES

NO.	DATE	REVISION	APPR.

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GRID SCALE
200m

PROJECT
FOX-2 LONGSTAFF BLUFF NU

GIS Technician
Laura Stewart

DATE
2006/09/29

SUBJECT
FIGURE III-2: Background Samples, Baseline Samples, and Terrain Units

Canada

X:\Maps\FOX-2-inv-DLCU\Background\FOX2_BkGrnd_Figure 3-2.dwg

IV. DATA EXPLORATION

The sampling programs conducted in 2005 yielded a data set of 113 background samples and 59 baseline samples, which include 12 and six duplicates, respectively, for QA/QC purposes. Field duplicates were averaged to produce a dataset with one value per sampling location. Table IV-1 provides a summary of the background data set collected by terrain unit. The sample distribution in the various terrain units for the background program shows good representation for the three most spatially extensive units on-site (Mb, RLg and Tv). Those terrain units are followed by GL, GM and RL, which each cover approximately 5% of the site. GL is only located in isolated pockets, usually at a distance from any work areas, and RL represents bedrock with no soil covering. Soil from the GM units has been historically used for borrow material; background samples that randomly fell within these areas had to be eliminated because they are considered disturbed areas. However, information on these locations was bolstered by samples taken as part of the baseline program.

The baseline data set of 59 samples adds 40 samples to the terrain unit Mb and 19 samples to terrain unit GM. Table IV-1 summarizes the aerial extent of each terrain unit as well as the number of samples that were taken within them.

Table IV-1. Summary of terrain unit and sample coverage for both background and baseline sampling programs at FOX-2.

Terrain Unit	Area (km)	Area (%)	Samples (background)	Samples (baseline)
GL	0.7528	5.12%		
GM	0.6146	4.18%	3	19
Mb	6.0908	41.45%	56	40
Mr	0.0792	0.54%		
Mv	0.4009	2.73%		
RL	0.7209	4.91%	1	
RLg	3.0665	20.87%	23	
RLs	0.0651	0.44%		
Tv	2.9033	19.76%	30	
	14.6941	100.00%	113	59

A. Data Ranges and Detection Limits

The proportion of samples that returned analyses above detection limits (DL) in both the background and baseline surveys varied from 100% for Cu, Ni, Zn, Cr and As, to zero for Cd (Table IV-2). Copper, nickel, cobalt, zinc, chromium and arsenic were above their DLs in all samples. Two of the samples were below DL for cobalt in the background survey, but they were all above DL in the baseline survey. Lead was above its DL in 23 samples in the background survey and in 13 of 59 samples in the baseline survey. Cadmium was not above its DL in any samples in either survey.

Table IV-2 outlines some of the summary statistics tabulated for each element in question from both soil sampling programs.

Table IV-2. Summary statistics for all soil samples from FOX-2.

Background	Cu	Ni	Co	Cd	Pb	Zn	Cr	As
DL	1	5	5	1	10	15	20	1
n>DL	101	101	99	0	23	101	101	101
Min.	14	7	5.2		10	28	25	1.3
Max.	700	210	85		59	280	120	78
DLCC	100	100	50	5	500	500	250	30
n>DLCC	5	6	2	0	0	0	0	27

Baseline	Cu	Ni	Co	Cd	Pb	Zn	Cr	As
DL	1	5	5	1	10	15	20	1
n>DL	59	59	59	0	13	59	59	59
Min.	16	11	6.1		10	31	26	12
Max.	120	150	34		16	190	130	110
DLCC	100	100	50	5	500	500	250	30
n>DLCC	2	1	0	0	0	0	0	11

DL = detection limit (in ppm); n>DL indicates the actual number of values recorded above the DL; Min. = minimum value above the DL (in ppm); Max. = maximum value above the DL (in ppm); and DLCC = Dew Line Cleanup Criteria Tier II contamination thresholds, followed by the number of times they were exceeded (n>DLCC).

B. Arsenic Locations

Arsenic was the predominant element that exceeded the DLCC. The majority of these sample site locations (12) were found at the upper site associated within the terrain unit Tv. Of the six sites in terrain unit Tv that did not exceed 30 ppm, three of them (11588, 11629 and 11630/31) had a coarser texture than was typical of the majority of other Tv soils, and the fourth (11613) was found to contain 29 ppm As, just below the criterion of 30 ppm. Although classified as Tv in the EBA geological map, TP 11576 did not have the same soil characteristics as other samples in this unit and more closely resembles the soil associated with terrain unit Mb. Samples in other terrain units that exceeded the arsenic criterion were divided into terrain units Mb (seven) and RLg (two).

Of the seven sites within the Mb terrain unit that had >30 ppm As, four of them (11530/31, 11553, 11627 and 25654) exhibited finer-grained particles than was normal for the Mb terrain unit. In particular, sites 11530/31 and 11553 were taken from an outwash plane that originated from upgradient till veneer deposits and exhibited the finer-grained soils typical of the Tv terrain unit.

All the samples in terrain unit GM with concentrations greater than the generic DLCC criteria are associated with Borrow Area 2. It is likely that this area would also have been influenced by the Tv terrain unit, which lies immediately upgradient of the borrow area.

Terrain unit RLg is characterized by having exposed bedrock with patches of either Tv or Mb. Both locations that have As over the generic DLCC have soil that is more characteristic of Tv.

C. Copper, Nickel and Cobalt Locations

From the background and baseline data sets, Cu, Ni and Co were found to be in excess of the DLCC, although at a lesser extent (eight sites, six sites and three sites, respectively). Copper values over the criteria were found in terrain units Mb (five), RLg (two) and GM (one); nickel and cobalt values over the criteria were found in Mb (three and two sites, respectively) and RLg (two and one sites, respectively). Sample 11582 in terrain unit Mb exhibited the highest concentrations of Cu, Ni and Co measured in any background sample (700 ppm, 210 ppm and 85 ppm, respectively). It was collected in an area dominated by cobble-sized rock with virtually no gravel, sand or fines; there was, however, an organic matrix that made up approximately 10% of the overall content. The unusually high inorganic element concentrations can likely be explained by the presence of the organics particles, to which inorganic elements preferentially bind.

All of the sites that were in excess of the generic DLCC for Cu, Ni and Co in the RLg terrain unit had surficial soil that was more characteristic of Mb soils (11583 was an exception and showed characteristics of both Mb and Tv). Because the RLg terrain types are characterized by only having a thin veneer of material overtop the bedrock, the localized spikes in metal concentrations in the associated soils may be reflecting a local bedrock signature; sulphide minerals were observed in certain areas on-site. In addition, the sharp gradient change between the steeply sloped fractured bedrock unit of RLg and the relatively flat lower marine-washed units allows for some unique hydrology and geochemistry to occur (discussed in detail in Section VII).

Acid rock drainage (ARD) effects related to the presence of sulphide minerals are not considered to be an issue at this site. The surficial bedrock and sediments have been extensively weathered over an extended period of time (since the retreat of the Laurentide ice sheet thousands of years ago). Borrow material used during the cleanup phase will only include surface weathered material and will not involve the excavation or extraction of unweathered material (please refer to memorandum ESG-FOX-2-005 (ESG)/FOX-2 1.4.8 (UMA)).

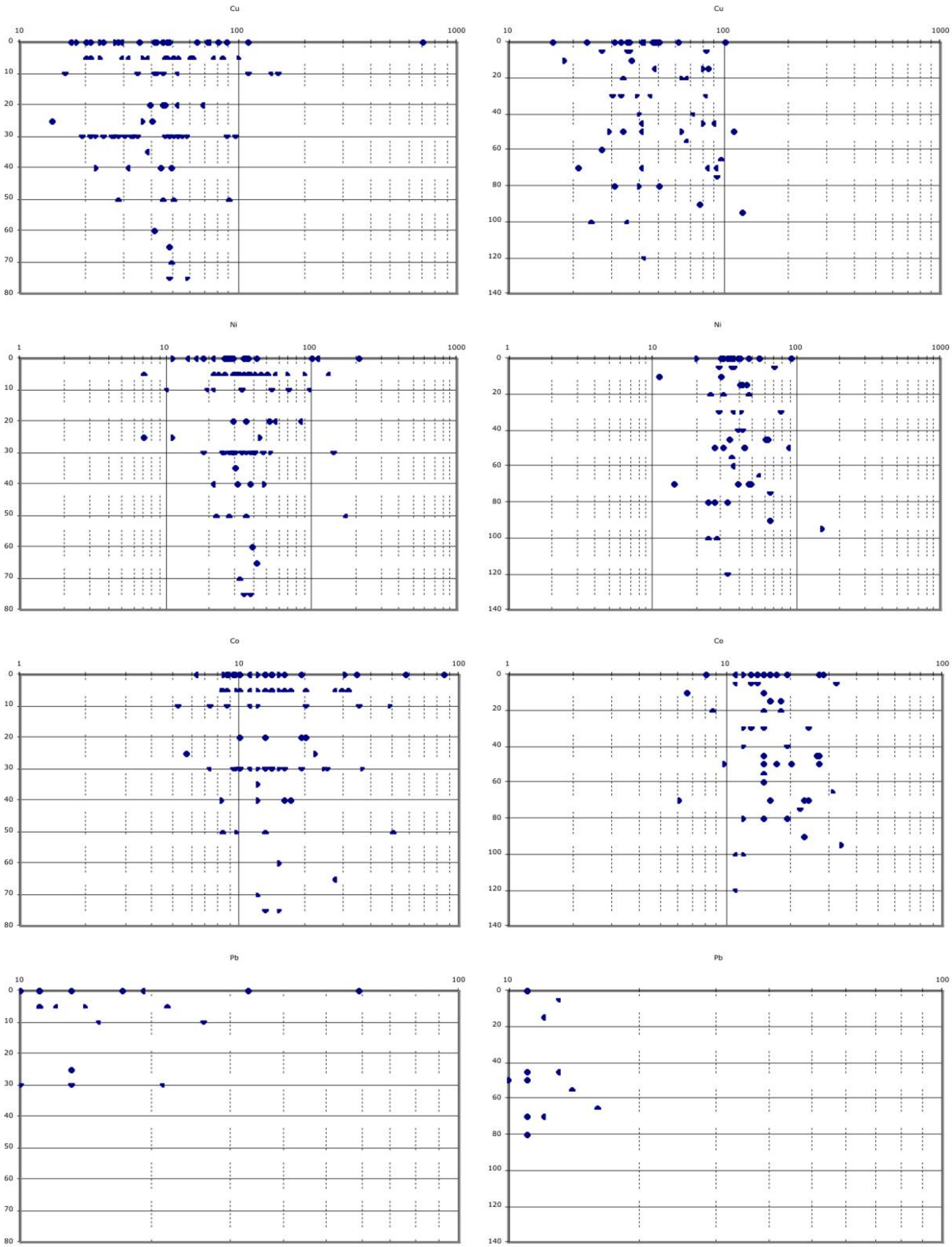
D. Variations with Depth

The Cu, Ni, Co, Pb, Zn, Cr and As data were tested for variations with depth to refusal (usually bedrock or permafrost). There was insufficient Cd data to test for variations with depth.

The variations with depth in the background and baseline surveys are plotted in Figure III-1. The highest values for each element in the background survey occur near surface, although there is otherwise poor correlation of concentrations with depth: the variations with depth are neither consistent, nor systematic, nor significant. The results are more variable in the baseline survey; the highest values of Cu, Ni, Pb and Zn occur at depth, there is no pattern for Co, the highest Cr value occurs at surface, and the highest As value occurs at moderate depth. Similarly, there are very poor correlations of concentrations with depth: the variations with depth are not consistent, systematic or significant.

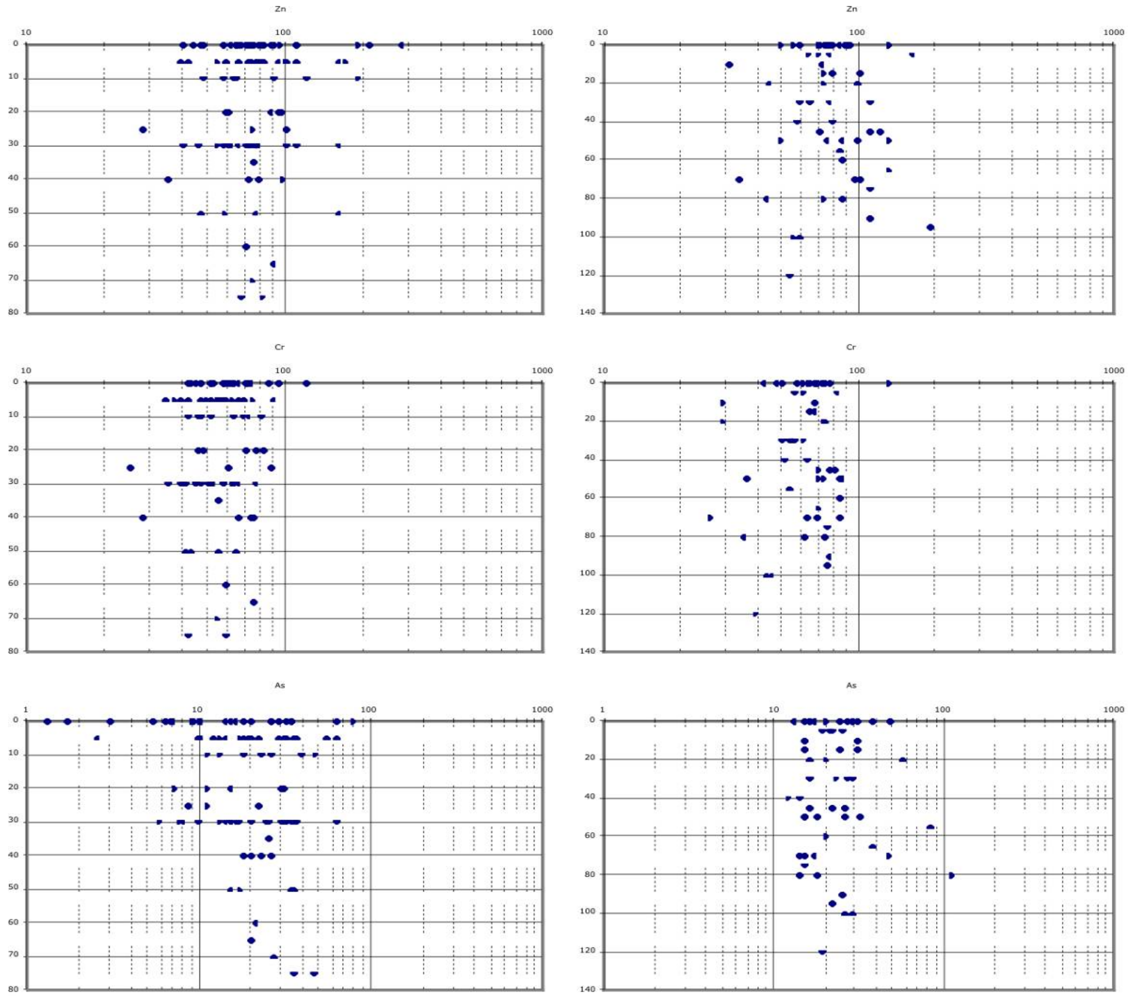
Correlation coefficients were calculated against absolute and relative depth. No significant correlations were found between any element and depth.

Figure IV-1. Variations in Cu, Ni, Co, Pb, Zn, Cr and As (in ppm) with depth (in cm).



The results of the background survey in the left column and those of the baseline survey on the right. No significant, systemic or consistent variations are present with depth.

Figure IV-I (cont'd). Variations in Cu, Ni, Co, Pb, Zn, Cr and As (in ppm) with depth (in cm).



The results of the background survey in the left column and those of the baseline survey on the right. No significant, systemic or consistent variations are present with depth.

V. DISTRIBUTIONAL TESTING

This section deals with the statistical analyses that were performed on the datasets. In summary to each of the following sections:

- The majority of the data are better modelled by log-normal distributions; however, the results are ambiguous for Cr and As in the background data and for Cu, Zn and As in the baseline data. The data distributions for Cd could not be determined and for Pb are not easily estimated with confidence because of the large proportion of non-detects.
- Although some minor inconsistencies occur in the statistical tests to determine whether the background and baseline data sets come from one underlying population, the concentration ranges for each inorganic element are considered sufficient evidence to treat them as one population.
- The 95% upper confidence limits (UCL95) of the mean were calculated for each inorganic element as a conservative estimate of the average concentration at the site. They are: 57.8 ppm for Cu, 47.4 ppm for Ni, 35.4 ppm for Co, 89.0 ppm for Zn, 64.2 ppm for Cr, and 33.5 ppm for As. Because of the limited amount of data above the detection limit, the mean background level for Pb was calculated using the adjusted log-normal maximum likelihood method; it was calculated as 6.76 ppm.
- The data were tested for mild and extreme outliers. Mild high outliers are more than 1.5 times the interquartile range above the third quartile (the 75th percentile) and extreme outliers are more than three times the interquartile range above the third quartile. These values are: 155 and 407 ppm for Cu, 77 and 142 ppm for Ni, 42 and 93 ppm for Co, 19 and 27 for Pb, 168 and 311 ppm for Zn, 113 and 184 ppm for Cr, and 82 and 228 ppm for As.
- Correlation coefficients reveal two distinct groups of elements that are related: Cu, Ni, Co, Zn and Cr correlate well with each other, Pb and As do not correlate with any of the first group, nor with each other.

A. Data Distributions

The Cu, Ni, Co, Pb, Zn, Cr and As data were tested to determine if they were normally or log-normally distributed. There was insufficient Cd data to test for the type of data distribution.

Probability plots and curve fitting were done using the program KaleidaGraph. Cumulative frequency distributions illustrate the shape of the data distribution by plotting the percent of analyses from the data set below a given level. With the y-axis as a linear scale, cumulative frequencies plot as a straight line if the data is normally distributed, whereas with the y-axis as a logarithmic scale, a log-normal data distribution plots as a straight line.

The FOX-2 background and baseline data sets (excluding the non-detects) plot closer to straight-line relationships on the log-scale plots than on the linear-scale ones. Best-fit equations for each line and corresponding regression coefficients were calculated. The regression coefficients measure goodness of fit and are also shown (Figure IV-1). For each element except Cr in the baseline data, the regression coefficients are higher (better) for the log-scale graphs and exponential curve fitting than the linear ones, indicating the data distributions are more closely modelled by log-normal distributions.

Statistical analysis of the likelihood that the data come from a particular model data distribution, normal or log-normal, was done with JMP software (SAS Institute, Cary, NC).

The Shapiro-Wilk's w-test is a rigorous test of goodness of fit to a normal population distribution. The equivalent rigorous test for log-normally distributed data is the Kolmogorov-Smirnov-Lilliefor's D-test (Sall et al., 2001). The results of these two tests for the background and baseline surveys are documented in Table V-1. The p values indicate the probability that the data could have come from normal or log-normal distributions. The data distributions for Cd could not be determined and for Pb are not easily estimated with confidence because of the large proportion of non-detects. The Shapiro-Wilk's w-tests for normal distributions for all the elements in both surveys, except Cr in the background survey, fail to be significant indicating that those data are not normally distributed. The KSL D-tests for log-normal distribution are significant for Cr and As in the background survey and for Cu, Zn and As in the baseline survey. In the case of Cr, the background data are better modelled by a log-normal distribution. For every element in each survey, except Cr in the baseline survey, the data are better modelled by log-normal distributions.

Table V-1. Tests for normality of data distribution for the available data without substitutions.

Background		Cu	Ni	Co	Pb	Zn	Cr	As
SW w-test	p	0.000	0.0001	0.000	<0.0001	0.000	0.0587	<0.0001
KSL D-test	p	<0.010	<0.010	<0.010	<0.010	<0.010	>0.150	0.115

Baseline		Cu	Ni	Co	Pb	Zn	Cr	As
SW w-test	p	<0.0001	<0.0001	0.0004	0.0225	0.0060	0.015	0.000
KSL D-test	p	0.110	0.045	0.034	0.0103	>0.150	<0.010	0.094

SW: Shapiro-Wilk test for normal data distribution. KSL: Kolmogorov-Smirnov-Lilliefor test for log-normally distributed data. p: probability that the data came from the assumed distribution model. If p >0.05 we can be 95% confident the data come from the assumed distribution model.

B. Two Surveys, One Population

The data for each element from both surveys were tested to determine if they belong to one population or two using analysis of variance (ANOVA) and other non-parametric methods (Table V-2). The raw data were tested and because the data are better modelled by log-normal distributions, the logs of the data were also tested by one-way ANOVA. Since the distributions of many of the elements in each survey were not well matched with log-normal distributions (at a statistically significant level) the two sample sets were also compared non-parametrically using Wilcoxon Rank Sums and Chi-squared calculations, which do not require an assumption of any particular population distribution.

The distributions of the two data sets are compared in log-scale box and whisker plots in Figure IV-2. The parametric tests indicate that for all elements the data from the two surveys belong to the same underlying populations, although the results for arsenic are inconclusive. One could conclude with 95% confidence that the As data belong to two separate populations, but not with 97% confidence. The non-parametric tests suggest that the data for Co and Cr belong to two separate populations. Another non-parametric test, the Van der Waerden test (not tabulated) showed only borderline significance at a 95% confidence level for the Co and Cr data. The Cr data have the same ranges for the two surveys, although they do have different means and medians. The maximum Cr value in either survey is 130 ppm, approximately half of the DLCC. It was therefore felt that it was not essential to establish with the utmost confidence whether the Cr data belong to one or two populations. The similar ranges of data for the two surveys and the fact that tests for two populations are only borderline significant are considered sufficient evidence to treat them as one population. On the other hand, Co exceeds the DLCC in two samples in the background survey. The Co data from the two surveys have similar means and medians; however, their ranges are very different. These different ranges of data are caused by two samples in excess of the DLCC that distort the statistical tests and it is therefore considered safe to treat the Co data as one population also.

Table V-2. Tests for determining if the two sample sets (background and baseline surveys) belong to one population.

ANOVA		Cu	Ni	Co	Pb	Zn	Cr	As
raw data	P	0.92	0.87	0.76	0.12	0.70	0.06	0.23
log data	P	0.24	0.20	0.14	0.079	0.43	0.092	0.031

Non-parametric methods		Cu	Ni	Co	Pb	Zn	Cr	As
WRS	P	0.203	0.0663	0.0113	0.160	0.180	0.0158	0.143
X^2	P	0.202	0.0660	0.0112	0.155	0.179	0.0157	0.143

ANOVA: One-way analysis of variance, calculated allowing for the possibility that the variances of the two sample sets are different. WRS: Wilcoxon Rank Sums test for non-parametrically comparing two sample sets. X: Chi square test for non-parametrically comparing two sample sets. p: probability that the data came from the assumed distribution model. If p <0.05, we can conclude that the two sample sets do not belong to the same population with 95% confidence.

C. Background Concentrations

The U.S. Environmental Protection Agency recommends calculating the 95% upper confidence limit (UCL95) of the mean as a conservative estimate of the average concentration at a site (this should not be confused with a 95th percentile of site concentration data); and takes into account uncertainties due to limited sampling (USEPA, 1992; Kesar and Asti, 1999). The UCL95s (Table V-3) were calculated for both sample sets combined because one can be reasonably confident they came from one underlying population. They were calculated on log-transformed data because the data are better modelled by log-normal distributions. The UCL95s were calculated for all elements except Cd. Calculations were performed on an Excel spreadsheet available on the Internet from the Louisiana Department of Environmental Quality (LDEQ, 2006). This spreadsheet uses the equations specified by the USEPA. The calculated average background levels for all elements except Pb can be viewed with high confidence (because of the lack of Pb data above detection limits).

UCL95s are not appropriate estimates of the average in highly censored data, i.e., data with a large proportion of non-detects, such as the Pb data from FOX-2. This is because neither the subset of data above DL nor the modified data after substituting 0.5 times the detection limit for all non-detects will be representative of the true population (Helsel 1990). Such substitution would introduce bias into the estimation of the means and variances.

For data with up to 80% non-detects, the United States Geological Survey (U.S. GS), Water Resources Division recommends the use of robust statistical calculations such as regression on order or maximum likelihood estimations (MLE) to determine the summary statistics (Helsel and Hirsch, 2002). However, the U.S. Department of Energy cautions that one can have very little confidence that a background distribution can be adequately characterized if the background frequency of detection is between zero and 50% (because more than half of the data points are reported as detection limits) (USDOE 1999). In the background samples from FOX-2, Pb had a frequency of detection of approximately 1/4, so the use of these statistical methods is appropriate. The mean background level for Pb was calculated using an adjusted log-normal maximum likelihood method with the program MDL (Helsel, 2006). The calculated average background level for Pb can be viewed with fair confidence.

For Cd, the background frequency of detection is zero; therefore, no estimate of the background concentration can be made and it is not appropriate to compare site data against background data (USDOE, 1999).

Table V-3. Average background levels (in ppm) for Arctic suite metals in FOX-2 soils.

	Cu	Ni	Co	Cd	Pb	Zn	Cr	As
DL	1	5	5	1	10	15	20	1
DLCC	100	100	50	5	500	500	250	30
UCL95	57.8	47.4	35.4		(23.9)	89	64.2	33.5
Mean (by MLE)					6.76			

Calculated by appropriate methods: for all elements except Cd and Pb as the 95% Upper Confidence Limit (UCL95) of the geometric mean, and for Pb by robust Maximum Likelihood Estimation (for highly censored data). DLCC = Dew Line Cleanup Criteria Tier II contamination threshold. Mean (MLE) = mean calculated by robust Maximum Likelihood Estimation.

D. Outliers

The background data for Cu, Ni, Co, Pb, Zn, Cr and As were tested for outliers. Mild outliers are more than 1.5 times the interquartile range above the third quartile (the

75th percentile) and extreme outliers are more than three times the interquartile range above the third quartile. The 75th percentile represents the level at which 75% of the data points fall below it. Likewise, the 25th percentile is the point at which 25% of the data points fall below it. The interquartile range is the difference between the two; the range that contains the middle 50% of the data (similar to the principle that one standard deviation about the mean contains 68% of the data in a normal distribution). Log-transformed data were used in the calculations because the sample sets are better modelled by log-normal distributions. The procedure was refined so that extreme outliers were not included in the calculation of quartiles or outliers. This eliminates their bias, which would otherwise be introduced. These tests for Cu, Ni, Co, Zn, Cr and As are valid because there are very few non-detects in the data.

Although seven Cu analyses were over DLCC, only one extreme outlier (>407 ppm) was detected in the background Cu data, and no mild outliers (155 <Cu <407). That one outlier (700 ppm) came from an area consisting of cobble-sized regolith with a high organic content, which is believed to be responsible for the unusually high concentration (discussed earlier in Section IV).

Whereas seven Ni analyses exceeded the DLCC, 10 mild outliers (77 <Ni <142 ppm) and three extreme outliers (>142 ppm) are present in the data. The three extreme outliers correspond to samples also high in Cu.

For cobalt, four mild but no extreme outliers were detected in the data, although two samples exceeded the DLCC.

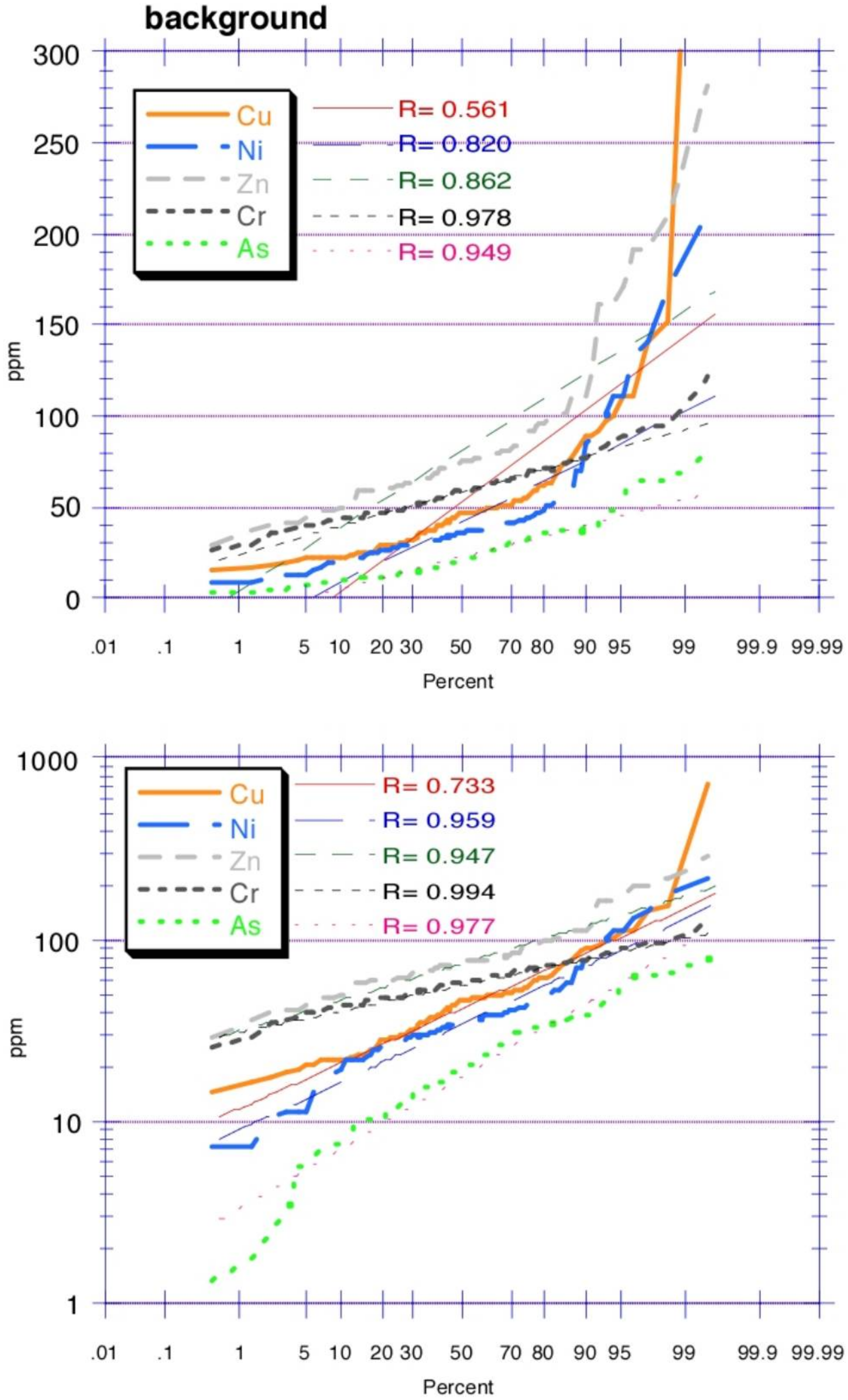
For Pb, Zn and Cr, the extreme outlier limit was lower than the DLCC Tier-II criteria; therefore no modification of background thresholds was deemed necessary for these elements.

Thirty-eight samples exceeded the DLCC for As, but there are only two mild and no extreme outliers in the data set. Since it is extremely unlikely that one quarter of the samples taken in the two surveys sampled As-contaminated soils when they were intended to sample uncontaminated soils, the absence of extreme outliers in the As data suggests that the data represent naturally high, log-normally-distributed background levels of arsenic.

E. Correlations

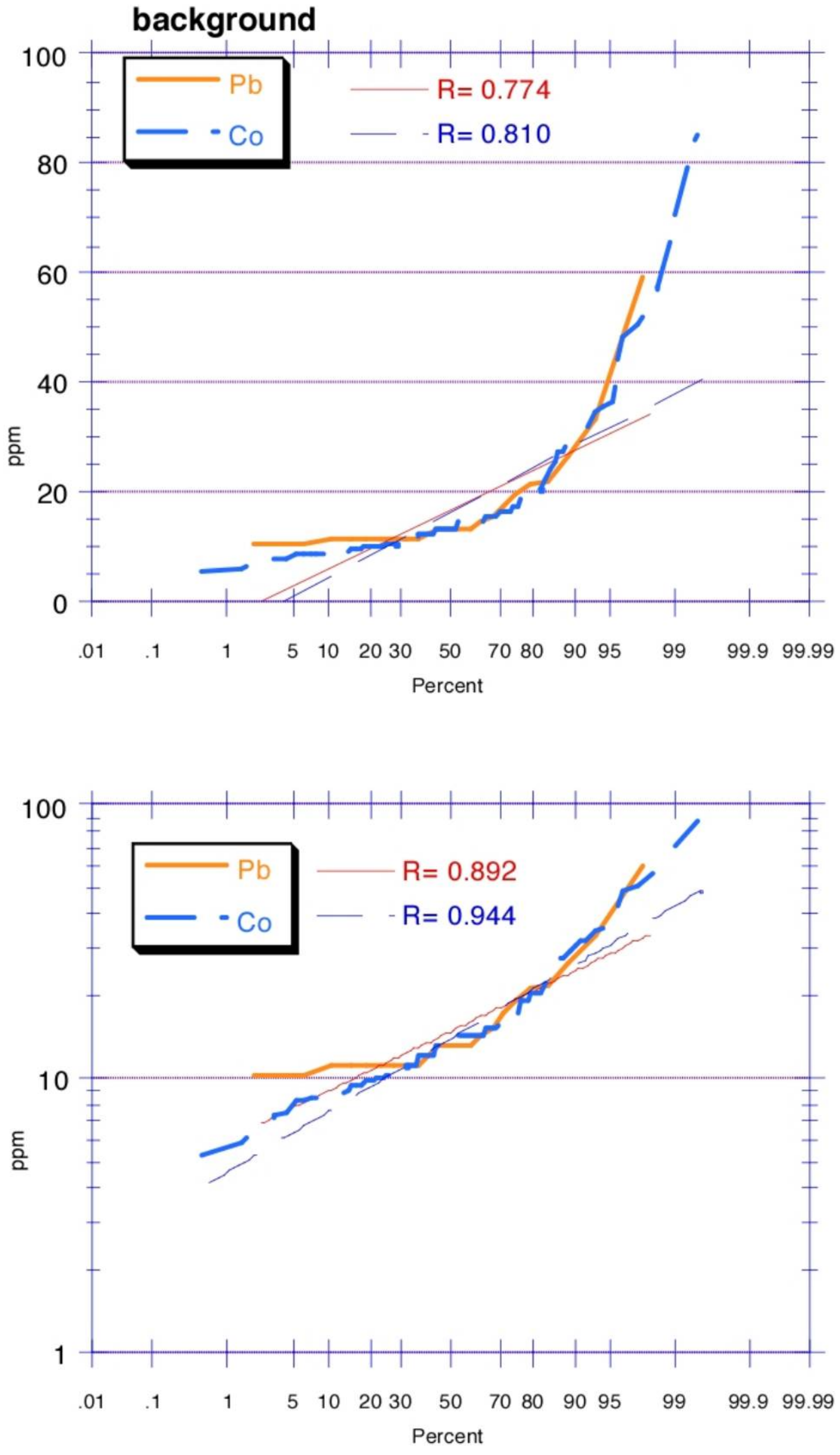
Correlation coefficients were calculated to investigate possible links between elements; because the data are not normally distributed, non-parametric ones were determined. Because the data can be considered to have come from one population, the background and baseline surveys were combined. All of the elements are plotted against each other and the resulting graphs are shown in Figure IV-3. The correlation coefficients (Spearman’s Rho) and their associated probabilities are given on Figure IV-3. Using only the data above detection limits without substitutions, two distinct groups of elements are apparent: those that correlate well with each other and those that do not. Cu, Ni, Co, Zn and Cr correlate well with each other. Pb and As do not correlate with any of the first group, nor with each other.

Figure V-1. Cumulative frequency plots of background and baseline soil samples, showing the best-fit lines, and the regression coefficients (R) for each line.



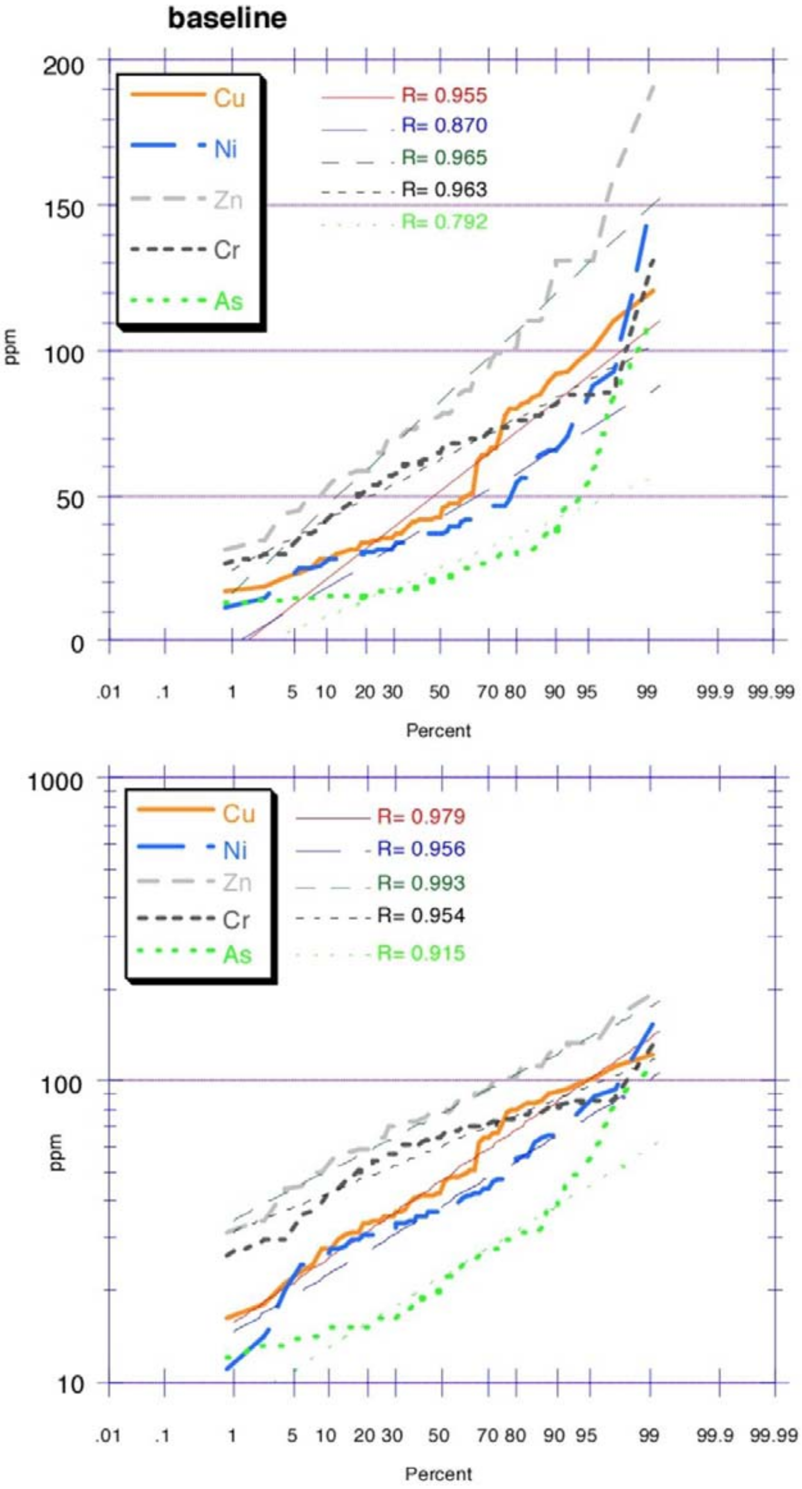
Upper plot: linear scale; straight lines represent normally distributed data. Lower plot: log-scale; straight lines represent log-normally distributed data.

Figure V-1 (cont'd). Cumulative frequency plots of background and baseline soil samples, showing the best-fit lines, and the regression coefficients (R) for each line.



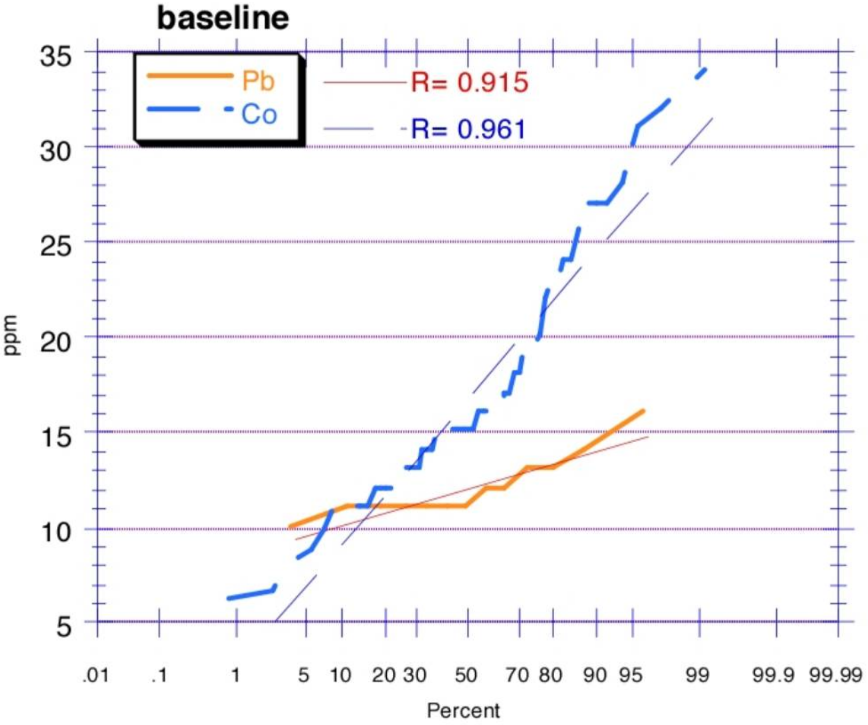
Upper plot: linear scale; straight lines represent normally distributed data. Lower plot: log-scale; straight lines represent log-normally distributed data.

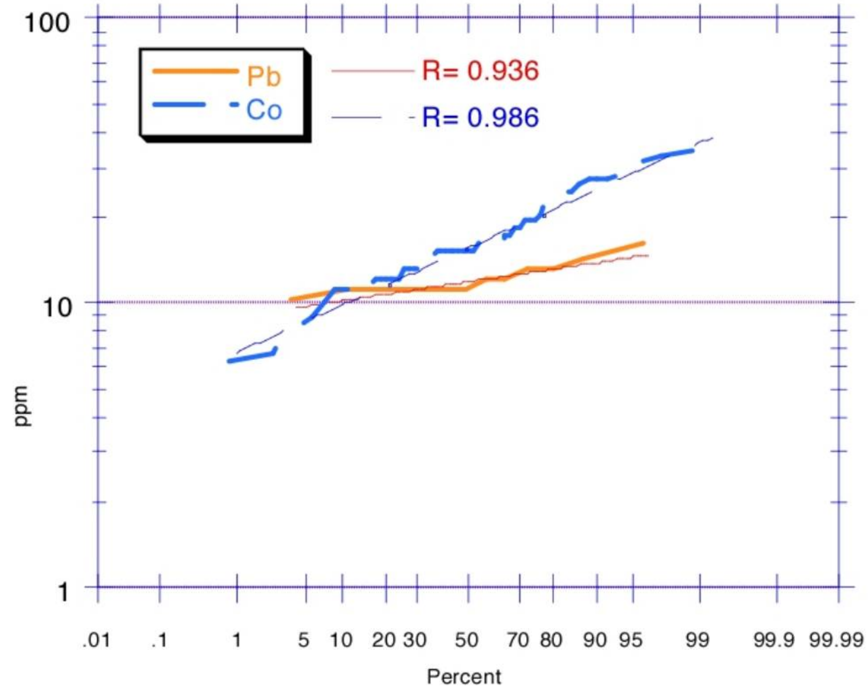
Figure V-1 (cont'd). Cumulative frequency plots of background and baseline soil samples, showing the best-fit lines, and the regression coefficients (R) for each line.



Upper plot: linear scale; straight lines represent normally distributed data. Lower plot: log-scale; straight lines represent log-normally distributed data.

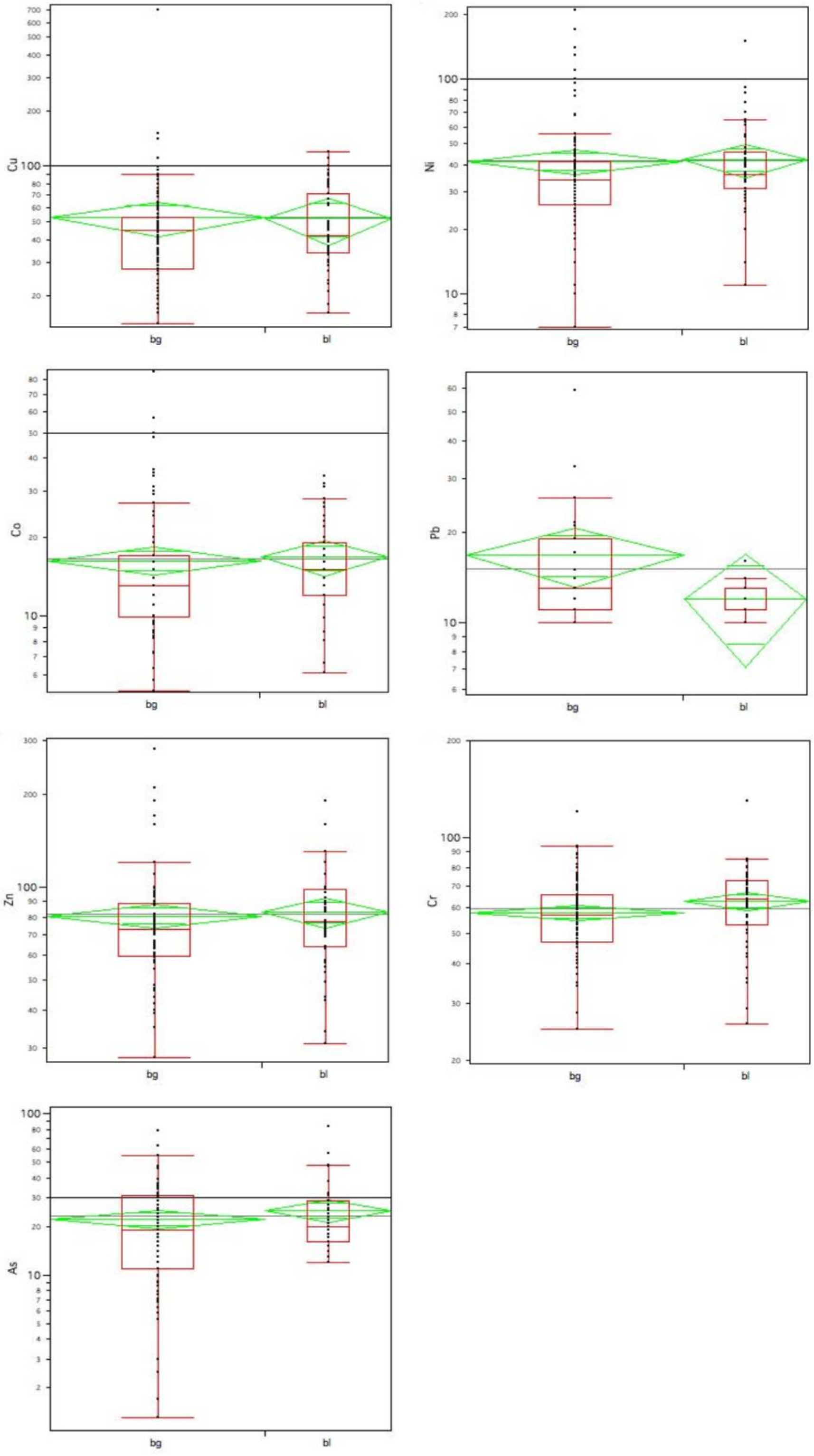
Figure V-1 (cont'd). Cumulative frequency plots of background and baseline soil samples, showing the best-fit lines, and the regression coefficients (R) for each line.





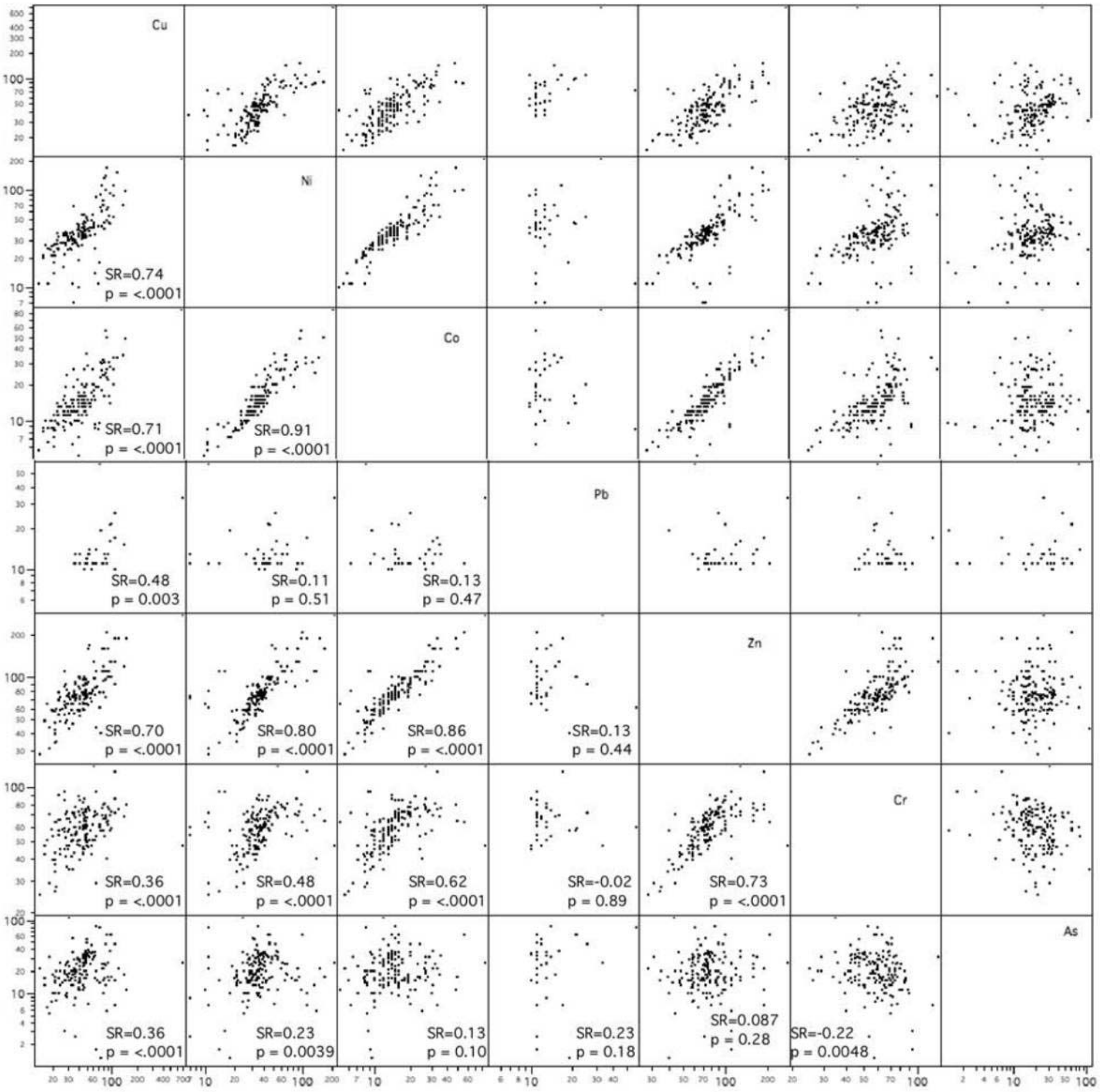
Upper plot: linear scale; straight lines represent normally distributed data. Lower plot: log-scale; straight lines represent log-normally distributed data.

Figure V-2. Log scale comparisons of the data distributions in the background survey (bg) and baseline survey (bl).



Grey horizontal line represents the grand mean for all the data and the 95% confidence limits on the estimates of the means for each sample set are shown by the top and bottom of the green diamonds. The middle of the green diamonds is the mean for each sample set. The red box and whisker plots show the 10, 25, 50 (median), 75 and 90 percentiles.

Figure V-3. Scatterplot matrix with nonparametric correlation coefficients.



SR: Spearman's Rho, calculated as the Pearson product-moment correlation coefficient of the ranks of the data. p: probability that SR could be the result of random, uncorrelated data. If $p < 0.05$ we can be 95% confident that the correlation is significant.

VI. DELINEATION OF CONTAMINATION AND THE DEVELOPMENT OF SITE-SPECIFIC CRITERIA

A. Delineation of Contamination

There are two general approaches to delineating contamination: development of unit-specific criteria, and development of global criteria. A third possible approach is to combine the two.

The first approach, development of different criteria for each terrain unit, was appealing because there are geologically distinct terrain units at FOX-2. If this approach could have been executed effectively, it would have had the lowest risk of overprotecting or underprotecting the environment. However, this approach would be very difficult to implement during the remediation phase, because the 2005 field program confirmed that while the geology of the different units may be visually distinguished, the soils originating from specific units have not remained static, but have been transported anthropogenically, in addition to wind and water movement, to become mingled with the soils of other terrain units. Therefore, assigning certain samples to specific terrain units would be challenging. Additionally, many of the areas with contaminated soil lie on pads or landfills where fill materials have been laid down upon, or mixed with, the underlying soil. Since it is not possible to know, and difficult and unreliable to calculate, the relative proportion of each terrain unit in the fill material, these areas would have to be addressed by adopting some sort of generic criteria.

Conversely, the second approach, to develop a set of global criteria, can be applied to all areas across the FOX-2 site because the uniform random background sampling conducted in 2005 provides a set of data that is representative and sufficiently large to allow the calculation of global statistics. The data can be grouped into one statistical population because they were collected from a grid laid down over the entire site (excluding contaminated areas) and are therefore spatially representative. The global criteria approach has the advantage of being simple to develop and implement. Its main disadvantage is that it ignores the presence of the different background units, which may cause the presence of unique characteristics specific to individual terrain units to be subdued when combined with all other terrain units. The calculated global criteria may therefore be higher or lower than if criteria values were calculated for each individual terrain unit, but can be viewed as a 'best fit' set of criteria values for the site as a whole.

The third possible approach, a combination of global criteria and unit-specific criteria, can address possible exceptions. Terrain unit Tv is the most spatially dominant geological unit at the Upper Site, third overall in terms of size, and contributes the second-highest number of samples to the global values (because the global values are spatially representative). However, this terrain unit has relatively low concentrations of most trace metallic elements, compared to some of the other units. Thus the equal weighting of all uniform random samples collected in 2005, which is the most reasonable global approach, could lead to significant overprotection in areas where the other units predominate. The process of identifying and developing area-specific plans for all the exceptions can make this approach challenging to implement.

B. Development of Site-Specific Criteria

Detailed analyses of the most commonly used statistical techniques for developing site-specific criteria can be found in Love and ESG (2004) and Loock *et al.* (2005). These statistical techniques vary widely in their application, technical merit, complexity, risk of error, degree of protection, and ease of implementation. They are: i) use of the maximum measured background concentration; or calculation of ii) a mean + n standard deviations (SD); iii) an upper tolerance limit (UTL); and iv) an upper prediction limit (UPL). Selection of the appropriate technique and the correct calculation method depends on the sample set size, its distribution characteristics (normal, log-normal, neither) and the frequency of detection for each background analyte (number and percentage of non-detects). All the statistical techniques were scrutinized for their advantages and disadvantages in those reports.

For DYE-M, though many different statistical options were selected and analyzed, it was determined that calculating background criteria using the mean + 3 SD (standard deviations) was the best option, both statistically and environmentally. At FOX-2, the same rationale could not be applied due to the greater uncertainty in the distribution of the data. In such cases where one is unsure of the type of data distribution (normal, log-normal, etc.), outlier calculations provide a more robust estimate than the mean + 3 SD method. The term robust, in this sense, refers to less sensitivity in the calculation to the distorting effects of outliers in the data, which in turn provides more accurate criteria.

Two sets of outlier calculations were performed on the combined FOX-2 datasets: mild and extreme. The mild outlier limits were judged too conservative because background concentrations for Cu, Ni, Co and As regularly exceeded them. Furthermore, the mild outlier limits for Ni and Co were calculated to be below their generic DLCC levels, which in turn were exceeded on numerous occasions. It is therefore recommended that the extreme outlier limits be used as the new site-specific cleanup levels for these four elements. It should be noted, however, that values of Cu and Ni exceeding this proposed upper limit of background have been found in both the background and baseline surveys. Therefore, even these levels should not be considered as absolute and automatic triggers for cleanup, but rather as cases requiring further careful consideration and investigation (discussed in detail in the following section). However, the recommended cleanup criteria consisting of extreme outlier limit values for Cu, Ni, Co and As combined with generic DLCC for Cd, Pb, Zn and Cr serves as a solid basis for assessment and is proposed as the new site-specific criteria for FOX-2.

A summary of the criteria levels calculated for each individual inorganic element appear in Table VI-1.

Table VI-1. Mild and extreme outlier limits calculated from the combined background and baseline surveys at FOX-2 and the numbers of samples exceeding those, using the geometric transformation of the data.

		Cu	Ni	Co	Cd	Pb	Zn	Cr	As
	DL	1	5	5	1	10	15	20	1
	DLCC	100	100	50	5	500	500	250	30
	n>DLCC	7	7	2	0	0	0	0	38
Outliers									
	mild	155	77	42	-	19	168	113	82
	extreme	407	142	93	-	27	311	184	228
	n mild	0	10	4	0	3	6	2	2
	n extreme	1	3	0	0	2	0	0	0

DLCC = DEW Line Cleanup Criteria Tier II contamination threshold. Mild outliers: greater than the 75th percentile plus 1.5 times the interquartile range. Extreme outliers: greater than the 75th percentile plus 3.0 times the interquartile range.

VII. APPLICATION OF THE SITE-SPECIFIC CRITERIA

A. Approach and Rationale

Applying the site-specific criteria (Table VII-1), which consists of extreme outlier limits for Cu, Ni, Co and As, and generic DLCC for Cd, Pb, Zn and Cr, to the overall delineation data set for those elements reduces the number of samples that potentially could require remediation under the generic DLCC. This is because the analysis has shown that the samples contain naturally elevated concentrations of these parameters above the generic DLCC. As discussed previously, natural levels of the elements Cu, Ni, Co and As that exceed their respective global criterion are still expected to be found at several locations at FOX-2. It is proposed herein that despite these higher levels, certain areas can be exempted from remediation through the consideration of site-specific factors. The decision process used to identify and exclude these areas of naturally elevated elements in excess of the global criteria was based on additional statistical studies as well as geological and geochemical observations made in the field. This decision process is illustrated in Figure VII-1.

Based on the evaluation matrix, each contaminated sample within an area will be evaluated according to the site-specific criteria for inorganic elements listed in Table VII-1 (in addition to PCBs and TPH) as a first step in discriminating potentially contaminated areas. The second step will involve a more detailed assessment of the individual inorganic parameters present at that location. The calculated outlier limits for Cd, Pb, Zn and Cr (in addition to PCBs and TPH) were all well below the standard DLCC and will therefore be considered representative of anthropogenic contaminants if they occur in concentrations that exceed those levels. If the contamination does not include any of the indicator elements, the next step is to investigate for a possible anthropogenic source that may explain the presence of the Cu, Ni, Co and/or As, which might otherwise be considered natural. Examples could include copper wire or nickel-plated batteries.

In the absence of any physical evidence, the proximity and/or topographic location of the sample to the infrastructure on site should be considered. If the origin of the elevated concentration(s) is still in doubt, the next step in differentiating natural and anthropogenic contamination addresses the terrain unit in which the problem is found. If the sample was taken from soil characteristic of the Tv terrain unit, any concentration exceeding the site-specific criteria should be treated as anthropogenic, since natural inorganic element concentrations were generally significantly lower in this terrain unit; Cu, Ni and Co never exceeded the DLCC in terrain unit Tv, yet were present in other terrain units. However, because greater concentrations of all these elements occurred in the coastal marine-washed deposits of the lower site and those materials were brought to the upper site for use in gravel pads, roads and landfill cover, it is conceivable that elevated concentrations of these elements could be found in close proximity to such borrow material. Therefore, when making decisions regarding concentrations of metals in the Tv unit, the proximity to pad and road material should be taken into consideration.

In any other terrain unit at the lower site, foremost consideration should be given to the proximity of the samples to the base of the RLg terrain unit. Precipitation and runoff from the upper site percolates down into the underlying bedrock through fractures and shear zones. Groundwater is able to dissolve metals in the surrounding rock wall and carry them away in solution. Because sulphide minerals are known to be present in the bedrock at FOX-2, Cu, Ni, Co and Fe (iron) are all candidates for dissolution in the groundwater.

Across the site, the steeply sloped, exposed bedrock unit of RLg transitions into the relatively flat, coastal marine-washed sand and gravel deposits. This sudden topographical shift causes local resurgences of groundwater in the form of springs and seeps, which then become overland surface flow. The sudden shift in pressure gradient and dissolved oxygen content from re-exposure to atmospheric conditions causes the iron and other metals to precipitate out of solution. Distinctive iron oxide and/or carbonate precipitates could often be linked with these discharge points and caused rust-coloured surface staining along their flow paths. This discoloration through mineral precipitation is a natural occurrence despite the magnified inorganic element concentrations caused by the sudden mineral precipitation from the dissolved metal load. Some of these natural discharge areas are more pronounced than others, but such occurrences have been clearly recognized at both the airstrip and west landfills, which share similar geological settings. This kind of mass precipitation also leads to the congregation of all metals that were present in solution, which is partly responsible for the high calculated correlation coefficients of Cu, Ni and Co described earlier.

The significance of the RLg terrain unit was also tested objectively on a select data set for Cu, Ni, Co, Zn, Cr and As, where concentrations were plotted against distance from the toe of the RLg outcrop. Results indicated significantly more concentration "spikes" in the data for Cu, Ni, Co, Zn and Cr close to the toe of the outcrop (<200 m) than farther away, with the exception of As (Figure VII-2).

Thus, when working at the lower site, several factors can be responsible for the occurrence of natural accumulations of inorganic elements, most of which usually occur in areas close to the RLg lower boundary. Naturally elevated areas may be distinguished by the presence of surface drainage or groundwater flow, originating as springs or seeps, and may show signs of discoloration through secondary mineral precipitation (rusty-red in the case where iron oxides precipitate). Boulders or other bedrock-derived regolith may contain metallic sulphide minerals that include the trace metals for which soil samples are analyzed. Finally, it has been well documented both at FOX-2 and elsewhere that Cu, Ni and Co appear together in natural settings. Therefore, the presence of all three of these elements, without any of the other anthropogenic indicators, suggests that the concentrations may be natural.

Table VII-1. Proposed site-specific criteria for the cleanup at FOX-2.

Cu	Ni	Co	Cd	Pb	Zn	Cr	As
407	142	93	5	500	500	250	228

B. Application to the 2005 Site Investigation Results

Of the four elements that had an increase in criteria levels from the DLCC to global criteria (Cu, Ni, Co and As), As was the most common element in excess of the DLCC, with 229 samples greater than 30 ppm from all sampling programs. Of particular note is that As concentrations exceeded the DLCC fairly uniformly across the entire site, regardless of terrain unit. Only one sample collected exceeds the global criterion for As; sample 18338 was collected from the beach POL area in an upgradient debris area assessment test pit and was found to contain 230 ppm. This sample does not contain any other contaminant typically found on the DEW Line (PCBs and TPH included), has no obvious upgradient anthropogenic source and is within 100 m of the base of the steeply sloped RLg outcrop, which brings significant surficial runoff during the spring melting season that originates from the upper site; because of these factors, there is a high likelihood that this As concentration is natural. It is recommended that this sample be omitted from remediation designs.

Of the 1,106 samples analyzed for Cu during the site investigation, 140 samples exceeded the DLCC. When the global criterion for Cu is applied, 24 samples exceed the new criterion of 407 ppm. Of these 24 samples, 18 are co-contaminated with either inorganic elements whose concentrations did not exceed the DLCC during the calculation of global background criteria (mostly Pb and Zn) and whose presence is judged to be anthropogenic in origin. Several samples also had concentrations of PCBs and/or TPH that are known to be anthropogenic. These areas will require remediation. In the other six samples, Cu appears in excess of its global criterion by itself in two samples and in conjunction with Ni (in excess of its global criterion) in the other four samples. Co also appears as a co-contaminant, based on its global criterion value of 93 ppm, in one of those four samples. It is recommended that the two samples containing only Cu undergo remediation because of the nearby presence of obvious sources of anthropogenic contamination; debris, including copper mesh, surrounded the location at which sample 17886 was taken and copper wiring, located at the location for sample 19009, is the likely source of Cu influencing that result. The four samples with co-contamination occur in a background sample (11582), as well as at two separate landfills; sample 25488 was collected from the airstrip landfill and samples 25683 and 25684 were taken from the west landfill. All of these areas are subject to the unique hydrogeology and geochemistry that comes from being in close proximity to the RLg terrain unit, discussed earlier. Therefore, the location of these four samples, the clustering of Cu, Ni and Co and the lack of any other distinctively anthropogenic contaminant, suggests that they are all areas with naturally high inorganic element concentrations. It is proposed that the locations represented by these samples be excluded from the cleanup program.

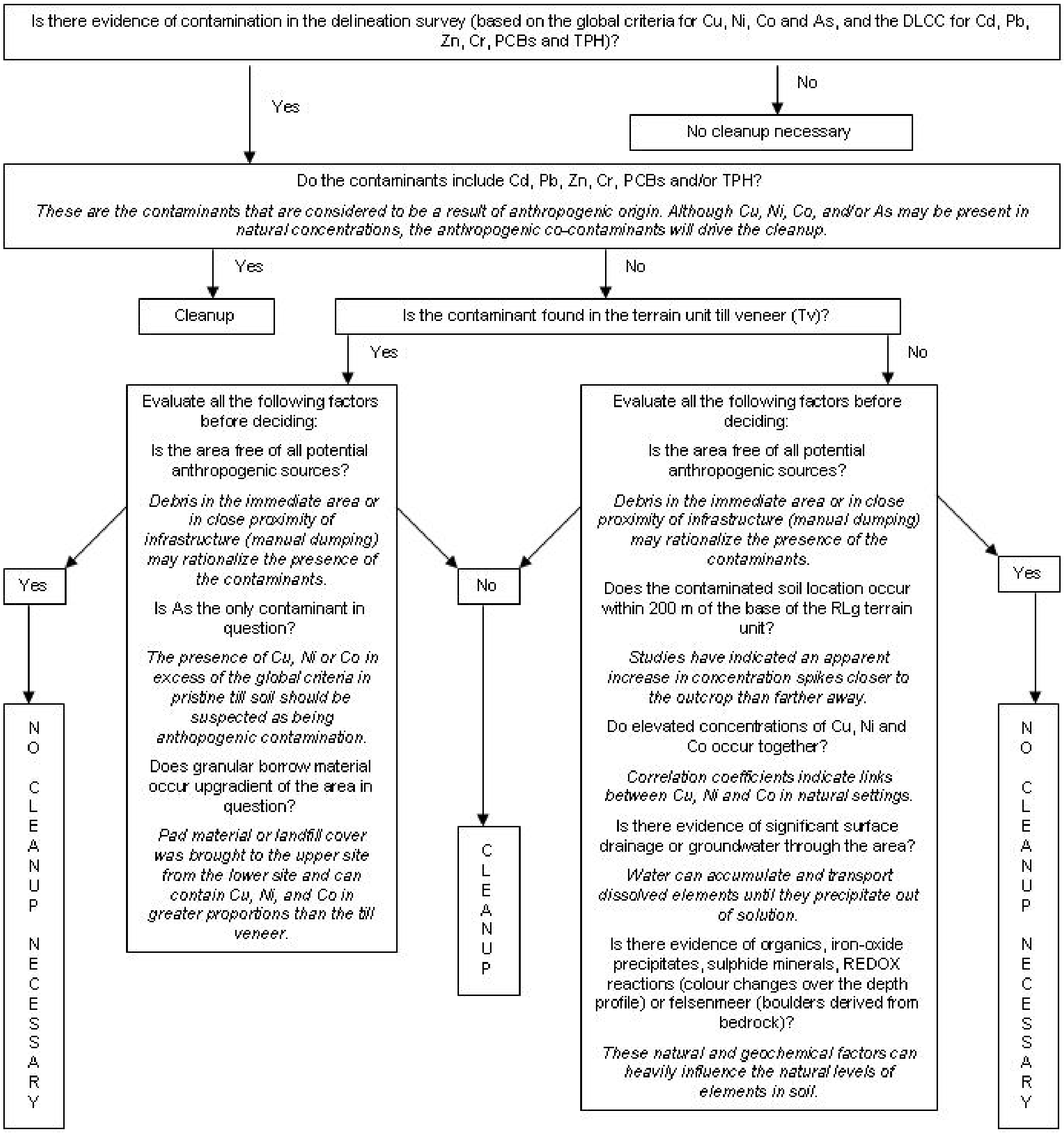
Nickel is in excess of the DLCC in 47 site investigation samples. With respect to the global criterion for Ni, 19 samples are above criteria. Only one sample is co-contaminated with an element that can be considered to be indicative of anthropogenic contamination; sample 18297 also contained Zn with a concentration equal to the DLCC (500 ppm). Five of these samples fall in areas that were determined to be clear of anthropogenic impacts both judgmentally and statistically: two samples from the background program (one of them also exceeds the site specific criteria for Cu and has already been discussed) and three samples from the baseline program (one sample from Borrow Area 4 and two samples from Borrow Area 8, from the same test pit). The other 14 samples originate from the west landfill (nine samples from six test pits), the airstrip landfill (four samples from three test pits) and the east beach (one), which are, again, in close proximity to the base of the RLg terrain unit, of which, the significance has been discussed above. One of the samples from both the airstrip landfill and west landfill are co-contaminated with Cu in excess of the site specific criteria. Using the flow chart for these samples leads to the conclusion that they are natural concentrations and do not warrant excavation. It is recommended that these areas be exempt from remediation.

Cobalt concentrations exceed the DLCC in 25 samples and are in excess of the global criterion for Co in seven of these. All of the samples also show elevated levels of Cu and Ni with respect to the DLCC, although only three of the samples also exceed their respective global criteria for these elements. The location of these samples are divided into three areas: the west landfill (three samples), the airstrip landfill (three samples from two test pits, one location shared with Cu, the other, Ni) and Borrow Area 8 (one sample, shared with Ni). Like the individual samples discussed above for Cu and Ni excesses, the close correlation to both these elements, in addition to the lack of any other contaminant as well as the close proximity to the base of the RLg terrain unit, suggests that these samples are simply showing significantly elevated natural levels. It is recommended that these areas be treated as exceptions rather than as contaminated areas for cleanup.

To summarize, there are two main settings, in addition to several smaller areas, of DEW Line-related work activity that coincide with sites of naturally elevated metals. The two most recurring places are the airstrip landfill and the west landfill. The levels of inorganic elements do not change the overall remedial recommendations for either of these landfills; however, several areas of surface contamination occur in proximity that are assumed to be natural, derived from the dissolution/precipitation reactions of minerals in and out of the groundwater medium. It is recommended that only those samples that show strong evidence of a natural origin, as determined through the step-by-step decision making process of the inorganic evaluation matrix, be considered exempt from cleanup design in an effort to reduce unnecessary disturbance to natural tundra. Aside from the samples currently in the vicinity of the landfills (five samples from three test pits at the airstrip landfill and 13 samples from eight test pits at the west landfill), other areas include: one sample in excess of the As global criterion southwest of the beach POL; background samples 11582, 650 m northwest of the west landfill, and 11598, 860 m east of the airstrip area; baseline samples from Borrow Area 4 (25662) and Borrow Area 8 (25716 and 25717, same test pit); and one sample location at the east beach, represented by sample 19005.

It is also proposed that when FOX-2 enters the cleanup phase of the project, this evaluation matrix be used by personnel on-site during confirmatory sampling to gauge subsequent analytical results as either natural or anthropogenic in the same manner that it was used herein for the investigation.

Figure VII-1. Illustration of the evaluation matrix used in identifying contamination.



Is there evidence of contamination in the delineation survey (based on the global criteria for Cu, Ni, Co and As, and the DLCC for Cd, Pb, Zn, Cr, PCBs and TPH)?

No cleanup necessary

Do the contaminants include Cd, Pb, Zn, Cr, PCBs and/or TPH?

These are the contaminants that are considered to be a result of anthropogenic origin. Although Cu, Ni, Co, and/or As may be present in natural concentrations, the anthropogenic co-contaminants will drive the cleanup.

Cleanup

Is the contaminant found in the terrain unit till veneer (Tv)?

Evaluate all the following factors before deciding:

Is the area free of all potential anthropogenic sources?

Debris in the immediate area or in close proximity of infrastructure (manual dumping) may rationalize the presence of the contaminants.

Is As the only contaminant in question?

The presence of Cu, Ni or Co in excess of the global criteria in pristine till soil should be suspected as being anthopogenic contamination.

Does granular borrow material occur upgradient of the area in question?

Pad material or landfill cover was brought to the upper site from the lower site and can contain Cu, Ni, and Co in greater proportions than the till veneer.

Evaluate all the following factors before deciding:

Is the area free of all potential anthropogenic sources?

Debris in the immediate area or in close proximity of infrastructure (manual dumping) may rationalize the presence of the contaminants.

Does the contaminated soil location occur within 200 m of the base of the RLg terrain unit?

Studies have indicated an apparent increase in concentration spikes closer to the outcrop than farther away.

Do elevated concentrations of Cu, Ni and Co occur together?

Correlation coefficients indicate links between Cu, Ni and Co in natural settings.

Is there evidence of significant surface drainage or groundwater through the area?

Water can accumulate and transport dissolved elements until they precipitate out of solution.

Is there evidence of organics, iron-oxide precipitates, sulphide minerals, REDOX reactions (colour changes over the depth profile) or felsenmeer (boulders derived from bedrock)?

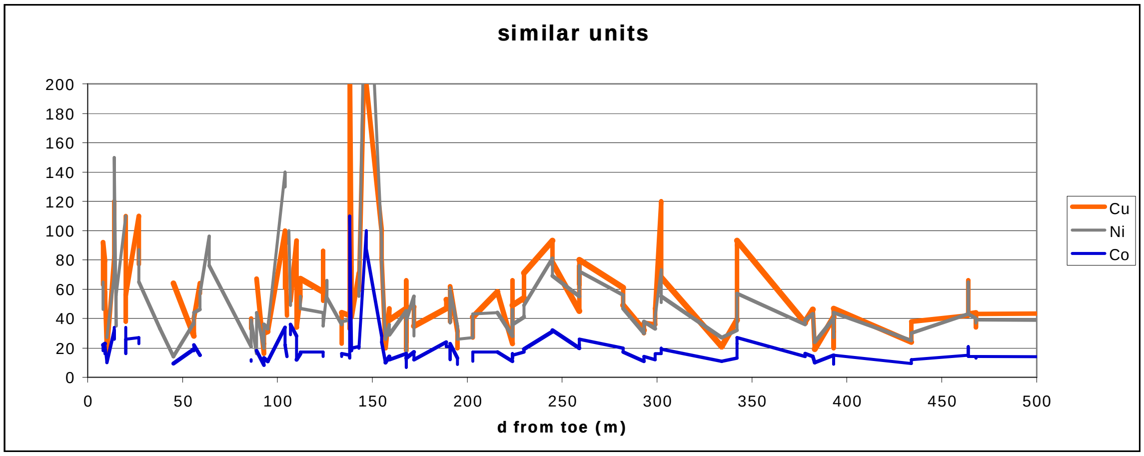
These natural and geochemical factors can heavily influence the natural levels of elements in soil.

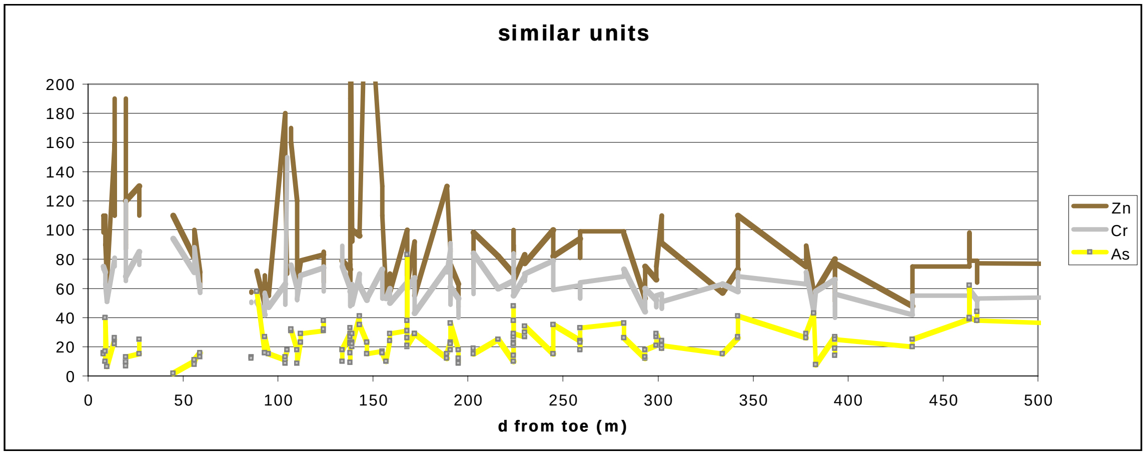
NO CLEANUP NECESSARY

CLEANUP

NO CLEANUP NECESSARY

Figure VII-2. Plots of concentration of Cu, Ni, Co, Zn, Cr and As versus distance from the toe of terrain unit RLg.





VIII. CONCLUSIONS

In the context of the DEW Line Cleanup, background concentrations of inorganic elements are evaluated at each site during the investigation phase, with the intent that naturally high areas above the DLCC be considered exempt from remediation. The data collected at FOX-2 during the 2005 background and baseline sampling programs not only confirmed the presence of naturally high levels of some elements, but also indicated that a remarkably large area of the site is affected by various combinations of these naturally high levels.

A total of 113 samples were collected during the 2005 field season. The baseline program collected an additional 59 samples. The extreme-value tests used to calculate the site specific criteria levels were based on three times the inter-quartile range above the third quartile for the combined background and baseline data sets. This method indicated that site-specific criteria were needed for Cu, Ni, Co and As since these criteria frequently exceeded the DLCC.

Samples from the delineation survey that exceed the global background criteria for Cu, Ni, Co and As are generally considered to indicate a need for remediation. However, certain natural hot spots are still expected to exist that will exceed even these new criteria levels, primarily the airstrip and west landfill. An inorganic evaluation matrix flow chart was created to standardize the decision-making process of determining which areas represent natural versus anthropogenic sources. For those that are judged through this process to be natural, it is recommended that they be excluded from remediation and remain in place, based on the hydrogeological and geochemical evidence. The standard DLCC would still apply to all other contaminants and would immediately be considered for cleanup where the respective concentrations are exceeded.

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APPENDIX A: DATA

Table A-1: Background and Baseline Soil Sample Analytical Results

Sample #	Surface/ Reference Tag	Depth [cm]	Refusal*	Cu [ppm]	Ni [ppm]	Co [ppm]	Cd [ppm]	Pb [ppm]	Zn [ppm]	Cr [ppm]	As [ppm]	Terrain Unit**
Tier I Criterion								*200*				
Tier II Criterion				***100***	***100***	***50***	***5***	***500***	***500***	***250***	***30***	
1. Background Samples												
05-11520/21		0		29	37	19	<1.0	<10	82	73	9	
05-11522	11520	25	B-35	40	44	22	<1.0	<10	100	88	11	
05-11523		0		47	34	14	<1.0	<10	88	86	16	RLg
05-11524	11523	30		48	40	19	<1.0	<10	74	62	16	
05-11525	11523	65		48	42	27	<1.0	<10	89	75	20	
05-11526		0		80	***110***	30	<1.0	<10	95	57	10	RLg
05-11527	11526	30	F-40	88	***140***	25	<1.0	<10	110	40	5.8	
05-11528		0		20	26	10	<1.0	<10	57	53	9.9	Mb
05-11529		0		29	29	11	<1.0	<10	64	47	18	Mb
05-11530/31		0		88	***100***	***57***	<1.0	11	215	63	***63***	Mb
05-11532	11530	30		30	35	24	<1.0	<10	76	45	17	
05-11533		0		24	25	9.3	<1.0	<10	48	42	20	Mb
05-11534	11533	35		38	30	12	<1.0	<10	75	55	25	
05-11535		0		27	34	12	<1.0	<10	67	59	15	Mb
05-11536	11535	30		32	30	11	<1.0	<10	70	63	15	
05-11537	11535	70		49	32	12	<1.0	<10	74	54	27	
05-11538		0		45	37	14	<1.0	<10	79	61	***32***	Mb
05-11539	11538	30		55	38	14	<1.0	<10	71	57	25	
05-11540/41	11538	50		50	35	13	<1.0	<10	76	55	***35***	
05-11542	11538	75	B-85	48	38	15	<1.0	<10	81	59	***35***	
05-11543		0		45	37	13	<1.0	<10	75	58	26	Mb
05-11544	11543	30		28	29	12	<1.0	<10	61	52	24	
05-11545	11543	75	B-85	58	34	13	<1.0	<10	67	42	***46***	
05-11546		5		38	29	9.9	<1.0	<10	71	56	20	Mb
05-11547		10		34	33	12	<1.0	<10	64	51	13	Mb
05-11548	11547	30		33	25	9.6	<1.0	<10	58	41	20	
05-11549	11547	50	F-60	28	22	8.3	<1.0	<10	47	41	15	
05-11550/51		5		20	21	8.7	<1.0	<10	59	39	18	Mb
05-11552	11550	30		27	29	10	<1.0	<10	54	45	15	
05-11553		5		36	68	27	<1.0	<10	93	55	19	Mb
05-11554	11553	30		34	24	9.3	<1.0	<10	46	35	***36***	
05-11555		5		31	30	13	<1.0	<10	77	58	19	Mb
05-11556		5		21	21	8.2	<1.0	<10	39	34	17	Mb
05-11557	11556	40		22	21	8.2	<1.0	<10	35	28	20	
05-11558		0		21	21	8.7	<1.0	<10	47	43	14	Mb
05-11559		0		23	28	11	<1.0	<10	70	65	10	Mb
05-11560/61	11559	40		31	31	12	<1.0	<10	72	66	23	
05-11562		10		***140***	69	35	<1.0	15	120	68	18	RLg
05-11563		25		14	11	5.7	<1.0	<10	28	25	22	Mb
05-11564		5		21	23	8.3	<1.0	<10	42	37	14	Mb
05-11565		5		23	25	9.6	<1.0	<10	54	54	9.8	Mb
05-11566	11565	30		21	18	7.2	<1.0	<10	40	39	9.8	
05-11567		5		60	49	17	<1.0	<10	82	62	29	RLg
05-11568	11567	30		26	29	13	<1.0	<10	60	58	14	
05-11569	11567	60		41	39	15	<1.0	<10	70	59	21	
05-11570/71		10		16	21	8.7	<1.0	<10	48	47	13	Mb
05-11572	11570	30		22	28	10	<1.0	<10	60	63	7.9	
05-11573		0		35	11	6.3	<1.0	11	80	71	6.9	RLg
05-11574		0		28	35	16	<1.0	<10	90	70	9.1	GM
05-11575	11574	20		45	56	20	<1.0	<10	96	82	11	
05-11576		5		29	34	14	<1.0	<10	74	66	10	Tv
05-11577	11576	30		24	33	13	<1.0	<10	72	65	13	
05-11578		30		21	27	11	<1.0	<10	57	63	15	Mb
05-11579		10		42	10	5.2	<1.0	<10	64	63	11	RLg
05-11580/81		0		71	11	8.4	<1.0	59	61	60	***78***	RLg
05-11582		0		***700***	***210***	***85***	<1.0	33	280	47	26	Mb
05-11583		10		***110***	53	20	<1.0	26	90	71	***47***	RLg

Table A-1: Background and Baseline Soil Sample Analytical Results, cont'd

Sample #	**Surface/ Reference Tag**	**Depth**	**Refusal**	**Cu**	**Ni**	**Co**	**Cd**	**Pb**	**Zn**	**Cr**	**As**	**Terrain Unit****
		[cm]		**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	
Tier I Criterion								*200*				
Tier II Criterion				***100***	***100***	***50***	***5***	***500***	***500***	***250***	***30***	
1. Background Samples cont'd												
05-11584		0		73	18	9.5	<1.0	19	40	57	1.3	RLg
05-11585		5		36	7	<5.0	<1.0	11	71	54	2.5	Tv
05-11586	11585	25		36	7	<5.0	<1.0	13	74	60	8.6	
05-11587		10		***150***	96	48	<1.0	<10	190	80	11	GM
05-11588		0		18	25	8.6	<1.0	<10	44	70	5.3	Tv
05-11589		20		46	35	13	<1.0	<10	60	46	***31***	Tv
05-11590/91		10		52	33	11	<1.0	<10	63	46	***39***	Tv
05-11592	11590	50		45	27	9.6	<1.0	<10	58	43	***34***	
05-11593		30	B-40	19	24	9.9	<1.0	<10	58	58	7.6	Mb
05-11594		5		23	36	14	<1.0	<10	78	89	10	Mb
05-11595	11594	40	B-50	44	38	16	<1.0	<10	79	75	18	
05-11596		5		84	***130***	31	<1.0	<10	110	69	13	RLg
05-11597	11596	20		68	84	19	<1.0	<10	87	70	15	
05-11598	11596	50		90	***170***	***50***	<1.0	<10	160	64	17	
05-11599		5		76	89	31	<1.0	11	160	69	22	RLg
05-11600/01		20		52	51	20	<1.0	<10	94	77	7.1	RLg
05-11602		5		61	56	20	<1.0	<10	99	68	***36***	Mb
05-11603	11602	40		49	47	17	<1.0	<10	97	73	26	
05-11604		20		39	29	10	<1.0	<10	59	48	***30***	Tv
05-11605		5		60	41	15	<1.0	11	80	51	***37***	Tv
05-11606	11605	30		58	41	14	<1.0	10	77	47	***35***	
05-11607		5		46	31	11	<1.0	<10	66	42	***32***	Tv
05-11608		5		50	38	14	<1.0	<10	73	49	***35***	Tv
05-11609	11608	30		50	39	14	<1.0	<10	75	50	***34***	
05-11610/11		5		99	45	14	<1.0	21	100	59	***63***	Tv
05-11612	11610	30		96	46	16	<1.0	21	100	57	***63***	
05-11613		0		41	36	14	<1.0	<10	74	51	29	Tv
05-11614	11613	30		48	40	14	<1.0	<10	78	52	***31***	
05-11615		5		62	41	16	<1.0	11	76	51	***36***	Tv
05-11616	11615	30		46	33	13	<1.0	<10	65	45	***30***	
05-11617		5		50	32	12	<1.0	12	65	47	***55***	Tv
05-11618		0		47	36	13	<1.0	10	65	45	***34***	Tv
05-11619		0		48	42	15	<1.0	<10	71	51	***34***	Tv
05-11620/21	11619	30		53	40	15	<1.0	13	77	51	***37***	
05-11622		0		27	16	8.8	<1.0	<10	110	93	3	RL
05-11623		0		64	14	9.3	<1.0	11	110	94	1.7	Mb
05-11624		0	B-10	***110***	***110***	34	<1.0	17	190	120	6.8	Mb
05-11625		0		42	26	10	<1.0	13	58	63	16	RLg
05-11626		0		17	27	9.9	<1.0	<10	64	51	6.3	Mb
05-11627		5		53	49	29	<1.0	14	170	74	***31***	Mb
05-11628	11627	30		52	52	36	<1.0	13	160	76	***32***	
05-11629		10		45	33	11	<1.0	<10	58	42	26	Tv
05-11630/31		10		41	19	7.3	<1.0	<10	57	47	23	Tv
05-11632		5		47	37	16	<1.0	<10	59	66	12	RLg
2. Baseline Samples												
05-11857		10		37	30	15	<1.0	<10	71	67	15	GM
05-11858	11857	45		41	34	15	<1.0	<10	70	69	16	
05-11859	11857	70	F-80	83	46	24	<1.0	12	96	68	***47***	
05-11860/61		15		81	41	17	<1.0	<10	75	66	19	GM
05-11862	11860	40		71	42	19	<1.0	<10	78	62	14	
05-11863	11860	70	F-80	91	48	23	<1.0	<10	100	62	17	
05-11864		80	F-90	40	27	15	<1.0	<10	86	73	14	GM
05-11865		80	F-90	50	33	19	<1.0	11	72	61	18	GM
05-18456		0		46	31	16	<1.0	<10	88	71	13	GM
05-18457	18456	60	F-70	27	36	15	<1.0	<10	86	84	20	
05-18458		0		36	31	19	<1.0	<10	89	77	17	GM

Table A-1: Background and Baseline Soil Sample Analytical Results, cont'd

Sample #	**Surface/ Reference Tag**	**Depth**	**Refusal**	**Cu**	**Ni**	**Co**	**Cd**	**Pb**	**Zn**	**Cr**	**As**	**Terrain Unit****
		[cm]		**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	**[ppm]**	
Tier I Criterion								*200*				
Tier II Criterion				***100***	***100***	***50***	***5***	***500***	***500***	***250***	***30***	
2. Baseline Samples cont'd												
05-18459	18458	65	F-75	96	54	31	<1.0	16	130	69	***38***	
05-18460/61		0		48	43	21	<1.0	<10	103	99	25	GM
05-18462	18460	50	F-60	34	31	15	<1.0	<10	74	72	18	
05-18463	18460	20		34	31	15	<1.0	<10	72	72	***57***	
05-18466		0		47	34	16	<1.0	<10	78	69	20	GM
05-18467	18466	50	F-60	63	43	20	<1.0	11	85	69	***32***	
05-25650/51		5		35	36	13	<1.0	<10	73	60	21	Mv
05-25652	25650	70		21	14	6.1	<1.0	<10	34	26	15	
05-25653	25650	120	F-130	42	33	11	<1.0	<10	53	39	19	
05-25654		20		66	25	8.7	<1.0	<10	44	29	20	Mv
05-25655	25654	50		29	27	9.8	<1.0	<10	49	36	26	
05-25656	25654	80	B-90	31	24	12	<1.0	<10	43	35	***110***	
05-25657		20		63	46	18	<1.0	<10	98	73	16	Mv
05-25658	25657	75	F-85	92	65	22	<1.0	<10	110	75	15	
05-25659		5		82	70	32	<1.0	13	160	81	25	Mv
05-25660/61	25659	45		84	62	27	<1.0	12	115	79	24	
05-25662	25659	95	B-105	***120***	***150***	34	<1.0	<10	190	75	22	
05-25663		50		***110***	87	27	<1.0	10	130	85	15	Mv
05-25664	25663	90	F-100	77	65	23	<1.0	<10	110	76	25	
05-25687		0		***100***	92	28	<1.0	<10	130	73	17	Mb
05-25688	25687	30		81	78	24	<1.0	<10	110	53	16	
05-25689		0		47	36	14	<1.0	<10	70	60	24	Mb
05-25693	25689	30		39	29	12	<1.0	<10	58	50	29	
05-25694		0		33	36	11	<1.0	<10	58	50	13	Mb
05-25695	25694	40		40	39	12	<1.0	<10	57	51	12	
05-25696		0		31	33	11	<1.0	<10	55	47	15	Mb
05-25697		0		42	39	15	<1.0	<10	73	60	29	Mb
05-25698	25697	30		45	41	15	<1.0	<10	76	60	23	
05-25699	25696	30		33	36	13	<1.0	<10	64	54	16	
05-25700/01		0		19	25	10	<1.0	<10	59	49	16	Mb
05-25702	25700	30		30	36	13	<1.0	<10	64	56	27	
05-25703		5		27	29	11	<1.0	<10	63	56	19	Mb
05-25704	25703	50	F-60	41	43	17	<1.0	<10	98	84	15	
05-25705		15		47	45	16	<1.0	<10	100	64	***31***	Mb
05-25706	25705	100	F-110	24	24	11	<1.0	<10	58	45	26	
05-25707		0		49	35	14	<1.0	<10	75	64	***38***	Mb
05-25708	25707	55		66	35	15	<1.0	14	84	53	***83***	
05-25709	25707	100	F-110	18	11	6.6	<1.0	<10	31	29	***31***	
05-25710/11		0		45	43	15	<1.0	<10	87	65	***37***	Mb
05-25712	25710	70	F-80	41	39	16	<1.0	11	100	84	14	
05-25713		0		48	55	17	<1.0	11	92	67	29	Mb
05-25714	25713	100		35	28	12	<1.0	<10	55	43	29	

*F = frozen ground, B = bedrock

For terrain unit descriptions, see **Section II.C Terrain Units.

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

An internal quality assurance/quality control program was implemented to allow data quality to be monitored on an ongoing basis. All samples were given sequential, numerical codes before being submitted to the analytical firms; these codes masked any information concerning location on site, sample type or possible concentration of the sample. Aspects of the QA/QC program for the 2005 background sampling program at FOX-2, Longstaff Bluff, and the results are discussed below.

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

1. Accuracy

Accuracy was monitored internally by ASU with the analysis of Standard Reference materials, specifically NRC Canada Marine Reference Sediment MESS-3 and contaminated soil reference material SS-2 (Table A-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 also biologically unavailable. The fact that numerical environmental criteria for metals are designed to be compared to potentially biologically available metal concentrations means that the level of accuracy reported above is acceptable. Analytical Services Unit (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. Average determined results for inorganic elements were all within control limits (Table A-1). Soil reference material SS-2 was also used to monitor accuracy and results were again within control limits.

2. Precision/Repeatability

Precision was monitored externally by ESG using 17 pairs of soil sample duplicates. These were homogenized in the field and submitted blind as separate samples to ASU for analysis. Average relative standard deviations (RSD %) or coefficients of variation (standard deviation divided by the mean) for sample pairs were expressed as percentages and used to evaluate laboratory precision. Acceptable limits are generally considered to be less than 40 percent relative standard deviation, with 20 percent or less considered good agreement. The average relative standard deviations for most inorganic elements in the FOX-2 soil samples were less than 10 percent, indicating very good precision for the method (Table A-2). Average results for copper, lead and arsenic were below 20 percent, indicating good agreement between replicates.

Some individual duplicate pairs showed higher RSDs. If another element in the sample reported results above the DLCC, or if duplicate results were well above or well below criteria, reanalysis was not performed. Occasionally, duplicate results straddled the DLCU criteria. When this occurred, if cleanup was not already indicated by other elements, the field notes were reviewed to look for indications of a heterogeneous sample matrix. If necessary, samples were reanalyzed to clarify differences.

One field duplicate sample (18460/61) was flagged with results straddling the DLCU criteria for arsenic. All other elements in the pair also duplicated poorly, resulting in elevated RSDs. The sample pair was reanalyzed and results for all elements with the exception of arsenic showed good agreement and low RSDs. Arsenic results were still variable, with one value on the criteria level (30 ppm) and the other below (Table A-2). This sample was collected in Borrow Area 2 (glaciomarine sediments), which lies immediately downgradient of arsenic-rich till deposits. Insufficient homogenization of the soil can sometimes result in the segregation of the arsenic-rich fines that originated from the till in one of the two samples, thereby off-balancing the arsenic concentrations between field duplicates.

In some cases, one duplicate result was above the detection limit while the other was below. For these duplicates, we have not calculated relative standard deviations. 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 leads to artificially inflated relative standard deviations, even when the concentration in the higher result is 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, we no longer include these duplicate calculations in the QA/QC analysis.

Internal precision was also monitored by ASU through the use of analytical duplicates. Soil samples (25) were analyzed in duplicate for inorganic elements (Table A-3). The average relative standard deviations (RSDs) for copper (6.8 percent), nickel (4.2

percent), cobalt (4.4 percent), lead (8.0 percent), zinc (4.5 percent) and chromium (2.9 percent) in the soil in the soil replicates were below 10 percent, indicating very good precision between analytical duplicates for these elements (Table A-3). The average RSD for arsenic was just over 10 percent, also indicating good agreement between replicates. All values for cadmium were below the detection limit so RSD calculations were not possible.

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

Element	MESS-3	Average (n=45)*	ASU Control Limits
	[ppm]		[ppm]
Cu	33.9 ± 1.6	33 ± 2.2	27.9-39.3
Ni	46.9 ± 2.2	38 ± 2.1	33.5-42.2
Co	14.4 ± 2.0	13 ± 0.6	10-14.4
Cd	0.24 ± 0.01	<1.0	
Pb	21.1 ± 0.7	17 ± 0.7	15.6-21.4
Zn	159 ± 8	134 ± 6.6	119.3-152.5
Cr	105 ± 4	42 ± 4.1	26.1-54.2
As	21.2 ± 1.1	17 ± 1.1	13.1-18.2

* n= 45 for most elements; n = 57 for copper, lead and zinc

Table B-1: Summary of Inorganic Element Results for Soil Internal Standards (MESS-3 and SS-2), cont'd

Element	SS-2	Average (n=26)**	ASU Control Limits
	[ppm]		[ppm]
Cu	191 ± 9.0	195 ± 7.2	158.1 – 225.4
Ni	54 ± 4.0	55 ± 2.5	49.2 – 60.8
Co	12 ± 1.0	14 ± 0.7	11.5 – 17.2
Cd	2.0	1.5 ± 0.2	0.1 – 3.0
Pb	126 ± 10	119 ± 4.2	99.4 – 130.3
Zn	467 ± 23	471 ± 27	391.7–544.1
Cr	34 ± 4.0	45 ± 2.7	43.0 – 48.7
As	75 ± 10	71 ± 5.4	54.8 –103.1

** n = 26 for most elements; n = 29 for copper, lead and zinc

Table B-2: Inorganic Element Results for Soil Sample Field Duplicates

Sample	Cu	Ni	Co	Cd	Pb	Zn	Cr	As
	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]
05-11520	28	37	19	<1.0	<10	81	71	10
05-11521	30	36	18	<1.0	<10	83	74	8.0
Average	29	36	18			82	73	9.1
Std Dev	1.8	0.7	0.6			0.9	2.2	1.4
RSD (%)	6.3	2.0	3.4			1.1	3.0	16
05-11530	88	100	58	<1.0	11	220	65	49
05-11531	88	100	55	<1.0	10	210	60	77
Average	88	100	56		11	210	63	63
Std Dev	0.4	0.1	1.9		0.3	11	4.0	20
RSD (%)	0.4	0.1	3.3		2.9	5.1	6.5	31
05-11540	49	35	14	<1.0	11	77	56	38
05-11541	51	34	13	<1.0	<10	75	55	32
Average	50	34	14			76	56	35
Std Dev	1.3	0.3	0.3			1.8	1.0	3.9
RSD (%)	2.6	0.7	2.5			2.3	1.8	11
05-11550	22	23	9.5	<1.0	<10	57	43	19
05-11551	18	18	7.8	<1.0	<10	61	36	17
Average	20	20	8.7			59	39	18
Std Dev	3.0	3.0	1.2			2.7	4.8	1.6
RSD (%)	15	15	14			4.6	12	9.0
05-11560	28	29	11	<1.0	<10	69	62	21
05-11561	33	34	13	<1.0	<10	75	70	25
Average	30	32	12			72	66	23
Std Dev	3.7	3.0	1.1			4.2	5.4	2.5
RSD (%)	12	9.5	9.1			5.9	8.1	11
05-11570	18	22	8.9	<1.0	<10	48	47	8.8
05-11571	14	20	8.5	<1.0	<10	48	46	17
Average	16	21	8.7			48	46	13
Std Dev	2.8	1.9	0.3			0.1	1.2	5.6
RSD (%)	18	9.1	3.2			0.2	2.5	44
05-11580	70	11	5.8	<1.0	58	62	61	80
05-11581	73	11	11	<1.0	61	61	59	76
Average	71	11	8.2		60	61	60	78
Std Dev	2.2	0.2	3.5		1.9	0.7	1.6	3.2
RSD (%)	3.1	1.4	42		3.2	1.2	2.7	4.1
05-11590	49	33	11	<1.0	<10	62	46	36
05-11591	55	34	11	<1.0	10	65	46	42
Average	52	33	11			64	46	39
Std Dev	3.8	0.6	0.1			2.1	0.6	4.0
RSD (%)	7.3	1.8	1.3			3.3	1.4	10
05-11600	42	47	19	<1.0	<10	91	77	6.7
05-11601	62	54	21	<1.0	<10	97	78	7.4
Average	52	51	20			94	77	7.1
Std Dev	14	4.8	1.5			4.5	0.7	0.5
RSD (%)	26	9.6	7.3			4.8	0.9	7.1
05-11610	100	45	14	<1.0	21	100	60	63
05-11611	99	45	14	<1.0	22	100	58	63
Average	99	45	14		21	100	59	63
Std Dev	0.8	0	0.3		0.2	1.0	1.4	0.4
RSD (%)	0.8	0	1.9		1.2	0.9	2.4	0.7

Table B-2: Inorganic Element Results for Soil Sample Field Duplicates, cont'd

05-11620	58	44	16	<1.0	13	82	53	40
05-11621	49	36	14	<1.0	12	73	50	34
Average	54	40	15		13	78	52	37
Std Dev	5.8	5.6	1.8		1.0	7.0	2.0	4.1
RSD (%)	11	14	12		7.7	9.0	3.9	11
05-11630	30	20	7.6	<1.0	<10	63	53	22
05-11631	52	17	6.9	<1.0	<10	51	40	25
Average	41	18	7.2			57	46	23
Std Dev	16	1.6	0.5			8.3	8.8	1.7
RSD (%)	39	8.8	7.1			15	19	7.4
05-18460	34	32	16	<1.0	<10	74	69	30
05-18461	33	32	15	<1.0	<10	71	71	15
Average	34	32	16			72	70	22
Std Dev	0.9	0	0.9			1.6	1.1	11
RSD (%)	2.7	0	6.1			2.3	1.6	48
05-25650	35	37	14	<1.0	<10	76	60	22
05-25651	36	35	13	<1.0	<10	69	60	21
Average	35	36	14			73	60	22
Std Dev	0.6	1.4	0.4			4.9	0	0.9
RSD (%)	1.6	3.9	3.1			6.8	0	4.2
05-25660	79	61	26	<1.0	11	120	80	22
05-25661	89	63	27	<1.0	13	110	77	26
Average	84	62	26		12	120	79	24
Std Dev	7.1	1.6	0.7		1.4	4.2	2.1	2.8
RSD (%)	8.4	2.5	2.7		12	3.7	2.7	12
05-25700	16	20	8.1	<1.0	<10	49	42	16
05-25701	23	30	12	<1.0	<10	69	57	16
Average	20	25	9.9			59	50	16
Std Dev	4.6	6.6	2.5			14	11	0.1
RSD (%)	24	27	26			24	21	0.9
05-25710	50	46	16	<1.0	11	90	67	48
05-25711	41	41	13	<1.0	<10	83	63	27
Average	46	43	15			87	65	37
Std Dev	6.6	3.5	2.2			4.9	2.8	15
RSD (%)	15	8.2	15			5.7	4.4	40

Table B-3: Inorganic Element Results for Soil Sample Analytical Duplicates

Sample	Cu	Ni	Co	Cd	Pb	Zn	Cr	As
	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]	[ppm]
05-11521	27	34	18	<1.0	<10	80	74	7.7
Duplicate	33	38	18	<1.0	<10	85	75	8.3
Average	30	36	18			83	74	8.0
Std Dev	3.7	2.3	0.2			4.0	0.3	0.5
RSD (%)	12	6.5	1.0			4.9	0.4	5.5
05-11528	21	27	11	<1.0	<10	58	54	10
Duplicate	19	25	9.9	<1.0	<10	55	53	9.5
Average	20	26	10			57	53	9.9
Std Dev	1.9	1.7	0.7			1.9	0.6	0.6
RSD (%)	9.6	6.6	6.6			3.3	1.2	5.8
05-11535	30	34	12	<1.0	<10	68	58	15
Duplicate	23	34	12	<1.0	<10	67	59	15
Average	27	34	12			67	59	15
Std Dev	4.4	0.3	0.2			0.4	0.4	0.04
RSD (%)	17	0.9	1.5			0.6	0.6	0.3
05-11542	50	38	16	<1.0	<10	81	58	37
Duplicate	46	38	14	<1.0	<10	82	60	34
Average	48	38	15			81	59	35
Std Dev	3.0	0.1	1.2			0.7	1.6	1.6
RSD (%)	6.2	0.3	7.8			0.8	2.7	4.6
05-11549	29	22	8.1	<1.0	<10	45	39	15
Duplicate	28	23	8.6	<1.0	<10	49	43	15
Average	28	22	8.3			47	41	15
Std Dev	0.9	0.9	0.4			2.7	2.4	0.6
RSD (%)	3.3	3.9	5.0			5.7	5.9	4.1
05-11556	16	20	7.9	<1.0	<10	38	34	17
Duplicate	23	22	8.5	<1.0	<10	40	35	18
Average	21	21	8.2			39	34	17
Std Dev	2.7	1.4	0.4			1.6	0.8	0.9
RSD (%)	13	6.5	5.4			4.1	2.2	5.3
05-11563	13	11	5.8	<1.0	<10	28	25	31
Duplicate	14	12	5.6	<1.0	<10	28	25	13
Average	14	11	5.7			28	25	22
Std Dev	0.7	0.7	0.2			0	0.5	13
RSD (%)	5.3	6.5	2.8			0.01	2.0	60
05-11572	21	27	10	<1.0	<10	57	63	7.8
Duplicate	24	28	11	<1.0	<10	63	64	7.9
Average	22	28	11			60	63	7.9
Std Dev	1.7	0.3	0.2			4.3	1.2	0.1
RSD (%)	7.7	1.1	1.6			7.2	1.9	1.5
05-11577	23	32	13	<1.0	<10	70	64	14
Duplicate	24	34	14	<1.0	<10	74	65	13
Average	24	33	13			72	65	13
Std Dev	0.7	0.9	0.2			2.7	0.4	0.8
RSD (%)	3.1	2.7	1.4			3.7	0.7	5.7
05-11584	74	19	9.7	<1.0	20	40	58	1.5
Duplicate	72	18	9.3	<1.0	19	41	57	1.2
Average	73	18	9.5		19	40	57	1.3
Std Dev	1.8	1.1	0.2		0.8	0.7	0.2	0.2
RSD (%)	2.5	5.9	2.4		4.3	1.7	0.3	16

Table B-3: Inorganic Element Results for Soil Sample Analytical Duplicates, cont'd

05-11589	46	34	13	<1.0	<10	60	46	32
Duplicate	46	35	13	<1.0	<10	61	45	30
Average	46	35	13			60	46	31
Std Dev	0.03	0.4	0.2			1.1	1.0	1.4
RSD (%)	0.07	1.2	1.7			1.8	2.1	4.3
05-11593	20	25	10	<1.0	<10	60	61	8.1
Duplicate	17	23	9.4	<1.0	<10	56	56	7
Average	19	24	9.9			58	58	7.6
Std Dev	2.2	1.5	0.6			3.2	3.3	0.8
RSD (%)	12	6.1	6.5			5.6	5.6	10
05-11600	42	47	19	<1.0	<10	89	76	6.7
Duplicate	43	48	19	<1.0	<10	93	78	6.7
Average	42	47	19			91	77	6.7
Std Dev	0.6	0.7	0.3			2.9	1.3	0.02
RSD (%)	1.5	1.6	1.5			3.2	1.7	0.2
05-11607	45	31	11	<1.0	<10	66	43	31
Duplicate	47	31	11	<1.0	<10	66	42	33
Average	46	31	11			66	42	32
Std Dev	1.1	0.1	0.07			0.01	0.8	1.8
RSD (%)	2.3	0.4	0.6			0.02	2.0	5.6
05-11614	46	39	14	<1.0	<10	75	52	29
Duplicate	50	41	15	<1.0	<10	81	52	32
Average	48	40	14			78	52	31
Std Dev	2.8	1.4	0.8			4.5	0.5	1.8
RSD (%)	5.8	3.6	5.4			5.7	1.0	5.9
05-11621	55	40	16	<1.0	13	83	53	39
Duplicate	44	31	12	<1.0	11	62	48	29
Average	49	36	14		12	73	50	34
Std Dev	7.3	6.0	2.6		2	15	3.6	7.2
RSD (%)	15	17	19		17	20	7.1	21
05-11860	81	39	16	<1.0	12	69	65	24
Duplicate	86	42	17	<1.0	11	75	66	24
Average	83	40	16		12	72	66	24
Std Dev	4.0	2.3	0.9		0.3	4	0.6	0.3
RSD (%)	4.8	5.7	5.5		2.6	5.6	0.8	1.1
05-18457	28	36	16	<1.0	<10	90	85	25
Duplicate	26	35	14	<1.0	<10	83	82	15
Average	27	35	15			86	84	20
Std Dev	1.6	0.5	1.0			5.3	2.0	6.8
RSD (%)	6.0	1.3	6.8			6.2	2.4	34
05-18462	33	30	15	<1.0	<10	72	69	22
Duplicate	36	32	15	<1.0	<10	76	75	15
Average	34	31	15			74	72	18
Std Dev	2.4	1.7	0.4			2.6	4.2	4.9
RSD (%)	7.0	5.5	2.3			3.4	5.8	27
05-25650	37	39	15	<1.0	<10	80	63	25
Duplicate	32	35	13	<1.0	<10	73	57	20
Average	35	37	14			76	60	22
Std Dev	3.5	3.3	1.6			4.9	4.3	3.6
RSD (%)	10	8.8	11			6.4	7.2	16
05-25657	66	48	19	<1.0	<10	105	77	15
Duplicate	60	44	17	<1.0	<10	92	68	17
Average	63	46	18			98	73	16
Std Dev	4.6	3.0	1.2			9.1	6.8	1.7
RSD (%)	7.4	6.4	6.7			9.3	9.3	11

Table B-3: Inorganic Element Results for Soil Sample Analytical Duplicates, cont'd

05-25664	77	64	23	<1.0	<10	109	74	29
Duplicate	77	66	23	<1.0	<10	113	77	21
Average	77	65	23			111	76	25
Std Dev	0.2	1.4	0.2			2.8	2.5	5.8
RSD (%)	0.3	2.2	0.9			2.5	3.3	24
05-25696	28	32	11	<1.0	<10	53	46	16
Duplicate	33	33	11	<1.0	<10	56	47	15
Average	31	33	11			55	47	15
Std Dev	3.4	0.6	0.1			2.2	0.4	0.6
RSD (%)	11	1.9	0.9			4.1	0.8	3.9
05-25703	26	29	11	<1.0	<10	62	56	23
Duplicate	27	29	10	<1.0	<10	64	56	15
Average	27	29	11			63	56	19
Std Dev	0.9	0.1	0.5			1.2	0.5	6
RSD (%)	3.4	0.4	4.4			1.8	1.0	32
05-25710	52	47	16	<1.0	11	93	69	45
Duplicate	49	44	16	<1.0	<10	88	65	51
Average	50	46	16			90	67	48
Std Dev	2.3	1.5	0.1			4.0	2.3	4.3
RSD (%)	4.7	3.2	0.8			4.4	3.4	9.0