- the lake was found to be well oxygenated and not thermally stratified to 50 m depth;
- Kuhulu Lake was found to exhibit higher values for conductivity, hardness and dissolved solids than West Twin Lake;
- metal concentrations in Kuhulu Lake were found to be similar to those in East and West Twin Lakes except that iron was found to be lower;
- Kuhulu Lake was found by Fisheries and Marine Service (as reported in BCRI 1975a) to support a resident population of Arctic char; and
- The concentration of total zinc at the mouth of Kuhulu Creek entering Strathcona Sound 4.5 km from the lake was 0.040 mg/L and alkalinity was 80 mg/L $CaCO_3$.

Water Quality of Inflow Seeps

Two small surface seepages into Kuhulu Lake from the west side were sampled during mine operations as sample stations NML-12 and NML-13.

Water quality at these locations for select parameters is tabulated in Appendix F. The maximum and average reported concentrations of total zinc were 0.226 mg/L and 0.078 mg/L, respectively, with pH in a range from 5.8 to 8.2 pH units.

2003 Water Quality and Fisheries Study

A study was undertaken in 2003 by JWEL for CanZinco that included water quality sampling and fish sampling at two locations in Kuhulu Lake. A report on this study, as prepared by JWEL, is provided herein in Appendix G. The general conclusions and observations of that study (JWEL 2003b) are repeated here as follows:

None of the above results [concentrations of arsenic, cadmium, lead, mercury, copper and zinc in fish muscle tissues] *indicates that there should be any concern regarding consumption of properly cooked Arctic char from Kuhulu Lake.*

Water and fish collected from the western end of Kuhulu Lake during the summer, 2003, contained low concentrations of trace elements, including lead. Water quality was excellent overall, both at the western inflow, and at the outflow of the lake. Arctic char tissue metals (arsenic, lead and mercury) concentrations were within Canadian guidelines for fish and fish products.

There is some evidence to suggest that recent sediments in the western bay of Kuhulu Lake are chemically distinct from older sediments. The presence of a sediment layer having lower water content (typically associated with coarser sediments) at a depth of 3 cm in both cores suggests that there was a recent disturbance in the watershed, leading to increased erosion of coarse silt to fine sand sized particles. This would be consistent with shale quarrying and road construction in the area starting approximately 30 years ago. Minor changes in trace element composition of the recent (surface) sediments, accompanied *by a dramatic increase in the calcium concentration suggests that weathering of a new source of calcium-rich minerals began in the recent past. It is hypothesized that shale quarrying and use as road construction materials may have caused these changes.*

3.4 Marine Sediment Quality

3.4.1 Overview of Studies

A number of studies of metal concentrations in marine sediments in Strathcona Sound have been conducted beginning with a baseline study in 1974 (BCRI 1975b) and up to a 2003 study conducted for CanZinco by JWEL (JWEL 2003c).

An overview of the studies conducted from 1974 to 2000 was provided in the Phase 2 ESA, of which excerpts are repeated below. The most recent, 2003 study, provides a comparison to the 1974 background data and some additional detail regarding the nature of the sediments in the near shore area proximal to Twin Lakes Creek.

The 2003 study concludes that some metal concentrations in the near shore area exceed the federal probable effects levels. A comparison between metal concentrations obtained in 2003 and those reported for 1974 is difficult because it has been shown that metal concentrations vary significantly over small differences in sampling locations. The report further concludes that bottom sediments in the near shore area proximal to Twin Lakes Creek are likely to be relatively coarse and subject to tidal erosion and underwater slumping. This would prevent the accumulation of a fine fraction in the near shore sediment, since finer material is likely to be dispersed over a wide area before being deposited to bottom.

3.4.2 1974 to 1992 Studies

The following is excerpted from the Phase 2 ESA Report, Section 3.1.1.

The concentrations of heavy metals in marine sediments in Strathcona Sound have been recorded in:
1. August 1974;
2. September 1975;
3. August 1979, August 1980 and August 1981;
4. June 1982;
5. June 1985; and
6. August 1992.

The studies of marine sediments confirmed that heavy metals are concentrated in the fine fraction of the sediment. Concentrations of zinc, lead and cadmium have been elevated in the near-field area as compared to areas more distant from Twin Lakes Creek in all of the studies (i.e., including the pre-operational studies). The reference areas are illustrated on Figure B.1 in Appendix B (*of the Phase 2 ESA Report*).

Metal concentrations have increased in the near-field area from the pre-operational studies to 1992.

3.4.3 2000 Study

Overview

The following is excerpted from the Phase 2 ESA Report, Section 3.1.2.

Six locations in Strathcona Sound were sampled for sediment metal concentrations in September and October 2000 by Dr. Bo Elberling of the University of Copenhagen. The sample locations included two samples in each of the near-field, mid-field and far-field areas. Sediment was collected in intervals of 0.5 cm or 1.0 cm to depths ranging from 20.5 cm to 37.5 cm. The depth of water at the sample locations ranged from 42.8 m to 177 m. The sampling locations are illustrated on Figure B.1 and summarized on Tables B.1 to B.6 in Appendix B (*of the Phase 2 ESA Report*).

Sedimentation Rate

Lead isotope dating of sediment cores was used to estimate the depth at which sediments representative of the year 1970 were located (i.e., as an approximation of the pre-mining/post-development timeframes).

The results indicate that the depth of sediment representative of post-1970 deposition for station 1.3, located 82 m from the mouth of Twin Lakes Creek was 7.5 cm or 0.25 cm per year. The depth of sediments representative of post-1970 deposition for the remaining five stations, located further from Twin Lakes Creek in deeper water, ranged from 1.75 to 3.75 cm or an average of 0.1 cm per year.

The indications of the 2000 lead isotope dating are consistent with the suggestion of the June 1992 study that the rate of sedimentation in Strathcona Sound would be expected to range from 0.1 to 0.6 cm per year.

The indications of the 2000 lead isotope dating are also consistent with the observed concentrations of metals at some locations, as described below.

Metal Concentrations

The concentrations of some metals (especially lead and zinc) are elevated in the upper, post-1970 deposition sediment as compared to the lower, pre-1970 sediment at most stations. This trend is most pronounced for locations 1.3 and 10.2, located closest to Twin Lakes Creek, and the clarity of the trend diminishes with distance from Twin Lakes Creek. This trend is most pronounced for lead and zinc but is also apparent for iron, manganese and calcium. This trend is not apparent, even at stations 1.3 and 10.2, for copper, nickel and potassium.

Within the upper, pre-1970 deposition sediment, there is not a consistent trend with depth for the various stations. For example, at station 1.3 closest to Twin Lakes Creek, the maximum concentrations of lead and zinc occur at approximately ¾ depth within the upper sediment. At location 10.2, however, concentrations of lead and zinc generally decrease with depth within the upper sediment.

The concentrations of some metals within the upper, post-1970 deposition sediment decreased with distance away from Twin Lakes Creek. The average concentration of zinc, for example, in the upper sediment decreases from 1,478 mg/kg at station 1.3 closest to Twin Lakes Creek to 75 mg/kg at station 51.1, furthest from Twin Lakes Creek.

The concentrations of some metals also decreased in the lower, pre-1970 sediment with distance from Twin Lakes Creek. For example, the concentration of zinc ranged from 174 mg/kg to 345 mg/kg at station 1.3 closest to Twin Lakes Creek and from 50 mg/kg to 71 mg/kg at location 51.1 furthest removed from Twin Lakes Creek.

3.4.4 2003 Study

Overview

A study of metals in marine sediments was carried out in conjunction with a study of metals in fish tissue in July 2003 by JWEL for CanZinco. The following is excerpted from the study report, which is also provided in its entirety in Appendix H.

Methods

Sediment samples (2 cores) were collected on July 13 and 14, 2003, in the vicinity of the outlet of Twin Lakes Creek. The core sampler used was a Wildco KB gravity core sampler, with stainless steel barrel and nose cone, and polycarbonate core tube liners.

Core sampling proved to be difficult in the targeted area around the mouth of Twin Lakes Creek, due to a combination of factors. Although the bottom sediments could not be directly inspected, the majority of attempted core samples did not penetrate the sediments. Rather, the sampler appeared to strike the *sediments and then fall over, without significant penetration. Occasional short plugs of silty sediments were recovered, but these were only about 5 cm in length, and were disturbed.*

Based upon a subjective evaluation of the core sampler performance and the professional experience of the operator, it is suggested that the bottom of Strathcona Sound near Twin Lakes Creek is predominantly composed of gravel and sand, with only a patchy veneer of fine sediments. The bottom is steeply sloping in this area, and the Sound is relatively exposed to winds, currents, and tidal water movement in an east-west direction. These factors will tend to minimize the accumulation of sediments in shallow waters and in the sloping near-shore area, favouring periodic slumping and/or resuspension, with subsequent re-deposition in deeper and flatter areas of the Sound.

Results

Two short cores were successfully collected, and both "surface" and "deep" samples were segregated from each core. The cores were as follows:

- *Core S (samples S1 and S2) collected at position 73° 04 15.069 N, 84° 32 13.127 W in 56 m water depth. This core was collected some distance east of the wharf.*
- *Core F (samples F1 and F2) collected at position 73° 04 19.370 N, 84° 32 43.873 W in 80 m water depth. This core was collected between the outlet of Twin Lakes Creek and the wharf.*

Chemical analysis of the core samples reflects the local mineralogy. High concentrations of calcium (>60,000 mg/kg) and magnesium (>50,000 mg/kg) were recorded, in addition to relatively high concentrations of iron (>25,000 mg/kg). Aluminum, while still a major element, was present at relatively low concentrations (12,000 to 14,000 mg/kg). These results presumably reflect the locally dominant dolomitic and shale rock types.

Arsenic concentrations (9 to 14 mg/kg), while above the CCME (1999) interim marine sediment quality guideline (ISQG) of 7.24 mg/kg, were well below the probable effects level (PEL) of 41.6 mg/kg. Elevated arsenic is often found in association with high concentrations of iron, and high iron can reduce the bioavailability of arsenic. Arsenic was not notably enriched in the surface sediment layer at either location.

Cadmium concentrations (1.6 to 10.2 mg/kg) spanned the range of the PEL guideline (4.2 mg/kg). Cadmium has geochemistry similar to that of zinc, and is often found in association with zinc deposits. Cadmium concentrations were slightly elevated in the surface sediment layer of Core S when compared with the deeper layer (2.45 mg/kg compared to 1.6 mg/kg) but was present at a lower concentration in the surface of Core F than in the deeper layer (5.8 mg/kg compared with 10.2 mg/kg).

Chromium concentrations (23 to 27 mg/kg) were below the ISQG (52.3 mg/kg) in all cases.

Copper concentrations (26 to 40 mg/kg) were above the ISQG (18.7 mg/kg), but below the PEL (108 mg/kg) in all cases. Copper concentrations in the surface and deeper layers of both cores were comparable.

Lead concentrations (88.4 to 568 mg/kg) spanned the range of the PEL guideline (112 mg/kg). Lead concentrations were higher in the surface layer of Core S than in the deeper layer (143 mg/kg compared to 88.4 mg/kg). However, the lead concentration was lower in the surface layer of Core F than in the deeper layer (359 mg/kg compared with 568 mg/kg).

Mercury concentrations 0.03 to 0.1 mg/kg) were below the ISQG (0.13 mg/kg) in all cases.

Zinc concentrations (481 to 2,740 mg/kg) were above the PEL (271 mg/kg) in all cases. Zinc concentrations were higher in the surface layer of Core S than in the deeper layer (825 mg/kg compared to 481 mg/kg). However, the zinc concentration was lower in the surface layer of Core F than in the deeper layer (1,890 mg/kg compared to 2,740 mg/kg).

The results reported above can be compared with data collected by BC Research (1974). They reported metal concentrations in 14 core samples collected throughout Strathcona Sound. Most if not all of the BC Research sediment samples were collected using a Shipek dredge (taking roughly the surface 10 cm of sediments) from "deepwater" portions of the Sound, where sediments would be accumulating. In particular, the two stations located closest to the mouth of Twin Lakes Creek were at depths of 247 m (Station 9) and 304 m (Station 10), and appear to represent sediments from beyond the "toe" of the shoreline slope.

BC Research (1974) reported the following ranges of metal concentrations:

- *arsenic, 1.0 to 7.9 mg/kg;*
- *cadmium, <0.4 mg/kg;*
- *copper, 3.7 to 27.9 mg/kg;*
- *iron, 2,820 to 34,000 mg/kg;*
- *lead, 3.9 to 19.3 mg/kg;*
- *nickel, 3.9 to 27.3 mg/kg; and*
- *zinc, 3.9 to 171 mg/kg.*

Notably, the comparison with BC Research data shows that while arsenic, copper, iron and nickel concentrations occupy similar ranges, the concentrations of cadmium, lead and zinc appear to be much higher in the near-shore sediments sampled during 2003. JWEL believes that the reason for this difference is that the near-shore sediments sampled during 2003 contain larger quantities of relatively coarse, dense mineral particles that would have been eroded from the exposed ore body, and been deposited in the alluvial fan at the mouth of Twin Lakes Creek. The samples collected by BC Research, *coming from farther out in the Sound, would not contain these particles, and would therefore show less enrichment of the ore body metals, zinc, lead and cadmium.*

Additional Observations

Twin Lakes Creek has a high flow rate in the springtime, and at the same time, the sea ice on Strathcona Sound is melting. The combined freshwater inputs from these two sources lead to the formation of a thin surface freshwater lens (1 to 2 parts per thousand total salinity) on top of more strongly marine influenced water (a halocline exists so that the salinity increases from about 4 ppt to 25 ppt at a depth of about 2 m. The halocline was strong enough to provide a reflecting surface for sonar, so that a hand-held sonar unit periodically gave depth readings of 2 m or less in waters that were substantially deeper.

As a result of the halocline, freshwater discharged from Twin Lakes Creek does not mix rapidly with the marine waters of Strathcona Sound. Instead, the freshwater lens extends some distance (perhaps several kilometres) away from the mouth of Twin Lakes Creek, and will be advected east-west by tidal action. Only the heaviest sediment particles will be deposited near the mouth of Twin Lakes Creek. These can be expected to include coarse particles including gravels and sands, and the denser fine-grained particles in the silt size range. Silt-sized particles with less dense mineralogy, and clay-sized particles will have low-enough settling rates to be advected a considerable distance away from the mouth of Twin Lakes Creek before settling. Likewise, dissolved trace metals can also be expected to be transported a considerable distance from the mouth of Twin Lakes Creek before mixing with the full water column. Therefore, it is not likely that substantial accumulations of fine-grained sediments will occur at the mouth of Twin Lakes Creek. However, most of the input of coarse material transported by the creek will deposit near the mouth.

In addition to the behaviour of suspended solids and dissolved trace metals discharged from Twin Lakes Creek, the sedimentary environment along the south shore of Strathcona Sound is worthy of discussion. There is a rapid drop off in depth from the mouth of Twin Lakes Creek, so that depths of 50 m or more are reached within approximately 200 m of the shoreline. The bottom is also exposed to erosional forces from tidal water movements in an east-west direction. As a result of these factors, it is expected that any fine-grained (silty) sediment that does accumulate near the shoreline will be susceptible to periodic slumping into deeper waters, or re-suspension by currents or wave action. As a result of the slumping process, it is likely that sediments at the toe of the slope in Strathcona Sound are highly disturbed.

The core sampling efforts that were conducted at water depths of 3 m to 80 m in front of Twin Lakes Creek during July, 2003, support this interpretation. At the 3 m water depth, the core sampler was observed to strike the sand and gravel bottom without significant penetration, and subsequently to fall over on its side. These coarse-grained materials resist penetration using a gravity core sampler, and are too loose to be retained in such a device. Although not directly observed, the core sampler could be felt as it hit the sediments in deeper water, without an audible "click" as would be heard if the sampler was striking bedrock or a substantial boulder. The core sampler could subsequently be felt as it fell over, *indicating that there had been minimal penetration of sediments. Based upon these observations, it is believed that sand and gravel sediments predominate on the slope of Strathcona Sound at Twin Lakes Creek. There appear to be thin veneers of fine-grained (silty) sediments in some areas, and short plugs (approximately 10 cm in length) of these sediments were occasionally brought to the surface, although it was very difficult to recover them undisturbed from the core sampler. As noted above, thicker deposits of fine-grained sediments are not likely to be stable on the slope of the Sound.*

Conclusions

Concentrations of cadmium, lead and zinc regularly exceeded the CCME PEL guideline in sediments collected in the vicinity of the mouth of Twin Lakes Creek and the wharf. Concentrations of these elements exceeded concentrations measured in sediments by BC Research (1974). However, the historical samples were not collected in close proximity to the mouth of Twin Lakes Creek, and may not have properly reflected the natural background condition in this area. A comparison of surface (0-5 cm) to deeper (5-10 cm) sediments was ambiguous, in that higher concentrations of cadmium, lead and zinc were present in the deeper sediments of Core F than in the surface sediments.

Sediment deposition in the alluvial fan of Twin Lakes Creek is likely to be restricted to coarser grained sediments, or those fine-grained sediment particles that are composed of denser minerals. The physical aspects of the marine environment during spring runoff are such that fine-grained particles and dissolved metals are likely to be widely dispersed in Strathcona Sound before they are deposited to sediments.

4. 2003 Phase 3 ESA Program

4.1 Introduction

4.1.1 Program Design

The design of the 2003 Phase 3 ESA field investigations was initiated immediately following completion of the Phase 2 ESA Report. At that time, the Phase 3 follow up program was focussed strictly on addressing information needs as assessed by the ESA team, such that a detailed remedial plan could be developed.

Prior to conducting the work in August 2003, the program design was modified to address the comments, suggestions and requests that were brought forward through the NWB review of the Phase 2 ESA Report.

The final project design took the form of a Phase 3 investigation and included the 12 components listed below. Note that the road from the industrial complex to the fork near 09 portal was not recommended for investigation because of the drill sampling previously conducted for an acid rock drainage assessment as reported in Lorax (2001) and submitted to the NWB.

1. Dock Area, Tank Farm, Concentrate Shed:
    - to delineate hydrocarbon and metals impacted soil as a follow up to the 2002 results;
    - test pits to be excavated to investigate the hydrocarbon impacted areas downgradient of the fuel tank farm and the area surrounding the day tank;
    - soil samples to be submitted for analysis of petroleum hydrocarbons;
    - test pits to be excavated to delineate the metals impacted area; and
    - soil samples to be submitted for metals analysis.

2. Road from Industrial Complex to Dock:
    - to follow up on the NWB review comments;
    - test pits to be excavated at 500 to 1,000 m intervals; and
    - soil samples to be visually logged and analysed for metals.

3. Mill Yard and Warehouse Yard:
    - to provide additional detail in these areas in response to the NWB review and the 2002 results;
    - test pits to be excavated to delineate the metals and hydrocarbon impacted areas, including the fuel storage and dispensing areas;
    - soil samples to be submitted for analysis of metals and petroleum hydrocarbons; and
    - seepage water samples to be submitted for analysis of metals and petroleum hydrocarbons.

4. K-Baseline:
    - to delineate the hydrocarbon impacted area identified in the 2002 results;
    - test pits to be excavated; and
    - soil samples to be submitted for analysis of petroleum hydrocarbons.

5. STOL Airstip:
    - to follow up on the high contaminant concentrations in the 2002 results;
    - test pits to be excavated to delineate the metals and hydrocarbon impacted areas; and
    - soil samples to be submitted for analysis of metals and petroleum hydrocarbons.

6. Land Fill Area:
    - to expand upon the 2002 results and generally increase the level of detail regarding the landfill, in response to the high priority placed on this area in the regulatory and community review;
    - additional test pits to be excavated between the 2002 test pit locations at the toe of the landfill and in the Land Farm Cell;
    - soil samples to be collected and, where feasible, seepage sampling wells (standpipes) to be installed to collect groundwater;
    - soil samples to be submitted for analysis of petroleum hydrocarbons and metals;
    - seepage sampling wells to be sampled, if possible, including those wells installed in 2002;
    - surface water seeps from the landfill to be sampled; and
    - water samples to be submitted for analysis of petroleum hydrocarbons.

7. Carpenter Shop:
    - to delineate residual hydrocarbons in soil in the spill area as a follow up to the 2002 results;
    - test pits to be excavated to investigate the area downgradient of the past fuel spill;
    - soil samples with high hydrocarbon vapour concentrations to be submitted for petroleum hydrocarbon analysis;
    - seepage sampling wells to be installed, if possible, to collect groundwater; and
    - water samples to be submitted for analysis of petroleum hydrocarbons.

8. Road from Town to Industrial Complex:
    - to follow up on the NWB review comments;
    - test pits to be excavated at 500 to 1,000 m intervals; and
    - soil samples to be visually logged and analysed for metals.

9. South of WTDA:
    - to investigate for contaminant distribution to the south of the WTDA in response to the NWB review;
    - test pits to be excavated south of the WTDA; and
    - soil samples to be submitted for metals analysis.

10. Road from WT Dyke to Fork near 09 Portal:
    - to follow up on the NWB review;
    - test pits to be excavated at 500 to 1,000 m intervals; and
    - soil samples submitted for metals analyses.

11. Road from Fork near 09 Portal to Area14:
    - to follow up on the 2002 results and to follow up on the NWB review;
    - test pits to be excavated at 500 to 1,000 m intervals; and
    - soil samples to be submitted for metals analyses.

12. Road from OceanView to Fork near 09 Portal:
    - to follow up on the NWB review;
    - test pits to be excavated at 500 to 1,000 m intervals; and
    - soil samples to be submitted for metals analyses.

4.1.2 Overview of the 2003 Program

The Phase 3 field investigation program was conducted at the Nanisivik mine site from August 8 to August 20, 2003. The field staff consisted of a professional geologist experienced in conducting ESAs at northern mine sites assisted by two field assistants from Arctic Bay who aided with sample collection and sample management.

The field investigations included a test pit excavation and soil sampling program using judgmental and systematic grid sampling techniques. It also included installation of wells in tests pits and the sampling of existing wells to test the meltwater or seepage that collects within the active layer. The field investigation program resulted in:

- excavation of 90 test pits and the installation of a seepage sampling well in one of the test pits;
- collection of 267 soil samples, including field duplicates;
- sampling of groundwater from one surface seep, one open test pit and 11 seepage sampling wells;
- collection of two surface water samples from an intermittent stream;
- measuring the organic vapour concentrations in soil; and
- submission of soil and water samples to an off-site laboratory for petroleum hydrocarbon ("PHC") and metals analysis.

Table C provides the areas investigated, how many sample locations were examined, the number of samples collected from these locations and an indication of the analyses completed, including Quality Assurance/Quality Control ("QA/QC") duplicate sampling.

Table C. Phase 3 ESA Sample Summary

Area	New Sample Sites	Samples Collected	Sample Analysis to date
Dock and Related Facilities	17	62 soil	14 for PHC in soil, 14 for metals in soil.
Industrial Complex and Related Facilities	11	36 soil, 2 water	15 for PHC in soil (including 1 QA/QC duplicate), 2 for PHC in water, 15 for metals in soil and 2 for metals in water.
Town and Related Facilities	4	14 soil, 2 surface water	5 for PHC in soil (including 1 QA/QC duplicate), 2 for PHC in water.
K-Baseline	7	27 soil	12 for PHC in soil (including 2 QA/QC duplicates), 1 for metals in soil.
STOL air strip	9	29 soil, 1 water	9 for PHC in soil, 1 for PHC in water, 9 for metals in soil (including 2 QA/QC duplicates).
Solid Waste Facility (Landfarm Cell and Landfill)	9	13 soil, 8 water	10 for PHC in soil, 8 for PHC in water, 1 for metals in soil.
Mine Access Roads	28	77 soil	28 for metals in soil (including 2 QA/QC duplicates).
WTDA	5	9 soil, 2 water	3 for metals in soil, 2 for metals in water.
TOTALS	**90**	**267 soil** **15 water**	

4.2 Remedial Guidelines

4.2.1 Soil Quality

Site Specific Soil Quality Remediation Objectives

The CCME has established federal guidelines to address the protection of atmospheric, aquatic, and terrestrial resources. These guidelines were developed using conservative, risk-based procedures selecting the most stringent receptors and tests to provide equal protection to human and ecological receptors.

A three-tiered approach for the assessment and remediation of contaminated sites has been established by the CCME. Generic guidelines represent the first tier, while a second tier allows limited modification of the guidelines to establish site-specific remedial objectives[1,2]. The third tier uses risk assessment

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[1] CCME. 1996a. Guidance Manual for Developing Site-Specific Soil Quality Remediation Objectives for Contaminated Sites in Canada. The National Contaminated Sites Remediation Program. En 108-4/9-1996e.

[2] *Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil - User Guidance*" submitted to CCME by O'Connor Associates Environmental Inc. and Meridian Environmental Inc., dated April 2001.

procedures to establish remediation objectives at contaminated sites on a site-specific basis. The first tier guidelines represent generic recommendations that are based on a conservative application of the most current scientific information without consideration of possible site-specific, special considerations.

The NWB approved an HHERA for the Nanisivik Mine (JWEL 2003a) in November 2003, including the resultant soil quality remediation objectives ("SQRO"s) for cadmium, copper, lead, silver and zinc. The CCME provides for the use of site-specific remediation objectives, which "allows the proponent to ensure that the assumptions used in the [soil] protocol apply to the site-specific conditions". These SQROs were not available for preparation of the Phase 2 ESA Report and, therefore, all of the soil quality results (i.e., from both the 2002 and 2003 investigations) are assessed in the text and figures of the current report against the Nanisivik Mine site-specific SQROs.

Generic Federal CCME Guidelines and Standards

The soil analytical results were compared to SQROs for cadmium, copper, lead, arsenic and zinc (JWEL 2003a) as described above. For other parameters, first tier generic Industrial Land (IL) use and/or Residential / Parkland (RL/PL) land use standards and guidelines in the following documents were used:

- *Canadian Environmental Quality Guidelines ("CEQG"),* Canadian Council of Ministers of the Environment (CCME), Winnipeg MB, 1999; and
- *Canada Wide Standards for Petroleum Hydrocarbons in Soil ("PHC CWS")*, Canadian Council of Ministers of the Environment (CCME), Winnipeg, MB, 2001 05 01.

Additionally, both the CEQG and PHC CWS provide criteria for various receptors and exposure pathways such that the user may select those that are applicable to the site under investigation. The exposure pathways that are provided are listed in Table D. Those receptors/pathways that are considered appropriate for application at the Nanisivik mine site, and that have been used in this report, are also identified on Table D.

Table D. PHC CWS Receptors/Pathways

Exposure Pathway	Applied at Nanisivik
Soil Ingestion	Yes
Dermal Soil Contact	Yes
Vapour Inhalation (indoor)	No
Protection of Potable groundwater	No
Protection of groundwater for Aquatic Life	Yes, if surface water body at 10 m from site
Nutrient Cycling	Yes
Ecological Soil Contact	Yes
Produce	No

The PHC CWS is a CCME remedial guideline for petroleum-hydrocarbons impacted soil and has been used to assess soil quality for hydrocarbons at the Nanisivik mine. In this guideline, petroleum hydrocarbons are subdivided according to specified ranges of equivalent carbon number as follows:

- PHC CWS fraction F1 encompasses the range of equivalent carbon number from C_6 to C_{10}. Constituents of fraction F1 include the volatile fraction of most hydrocarbons mixtures (including gasoline) such as benzene, ethylbenzene, toluene and xylene (BETX);
- PHC CWS fraction F2 encompasses the range of equivalent carbon number from C_{11} through C_{16}. Constituents of fraction F2 are semi-volatile petroleum hydrocarbons and include constituents of gasoline and diesel fuels;
- PHC CWS fraction F3 encompasses the range of equivalent carbon number from C_{17} through C_{34}. Constituents of fraction F3 include typical lubricating oils and greases, heavy fuel oils, road oils and asphalts; and
- PHC CWS fraction F4 encompasses ranges of equivalent carbon number from C_{35} through C_{50+}. PHC within this fraction often make up a significant proportion of crude oils.

The PHC CWS also includes consideration of fine grained versus coarse grained soils in the determination of guideline values.

4.2.2 Water Quality

The CCME CEQG also provides drinking water and surface water quality guidelines. Guidelines for surface water quality are based on usage (community water supplies, recreational use and aesthetics, aquatic life [freshwater and marine] and agricultural water uses).

In order to provide a reference for the water quality data gathered at the Nanisivik Mine site, the CEQG generic water quality guidelines established for the protection of fresh water aquatic life are included with the results. The CEQG freshwater aquatic life ("FWAL") guidelines apply to total concentrations in surface water bodies that host aquatic life and are provided for comparative purposes only.

The CEQG FWAL guidelines are not, however, applicable to the evaluation of groundwater quality. Modifying factors for chemical limits in groundwater due to factors such as natural attenuation and dilution are not considered in the CEQG FWAL guidelines. Groundwater quality standards for the protection of freshwater aquatic life that have been developed for other jurisdictions, such as in BC *Contaminated Sites Regulation*[3] and Yukon *Contaminated Sites Regulation*[4], generally apply a 10-fold

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[3] BC Waste Management Act, *Contaminated Sites Regulation*, BC Reg. 375/96, deposited 1996 12 16, O.C. 1480/96, effective 1997 04 01 (includes amendments BC Reg. 244/99, deposited 1999 07 19 and BC Reg. 17/2002, deposited 2002 02 04).

[4] Yukon Environment Act, *Contaminated Sites Regulation*, O.I.C 1996/192 (includes: amendments 2002)

dilution factor to dissolved metal concentrations of the regulated chemical parameters. These criteria have also been presented with the analytical data for discussion purposes only to provide a comparison for the site groundwater water quality data.

4.3 Methodologies

4.3.1 Test Pit Excavation

Test pitting was conducted to observe the subsurface soil conditions for the presence of fill zones, soil horizons, permafrost, discoloration, oil sheens, hydrocarbon or other unusual odours, and seepage zones. Test pitting also permitted the collection of subsurface soil samples and the installation of seepage sampling wells. A total of 90 test pits were excavated in areas of potential environmental concern using a tracked excavator. Consideration was given to obtaining adequate sampling coverage over the site and to define the extent of areas of environmental concern previously identified. Further, accessible sample locations were controlled by the presence of buildings, concrete pads and topography.

The test pits from the 2003 Phase 3 ESA are identified as TP03-301 to TP03-393 on Figure 3. The 2003 test pit locations were tied into the sample stations established during the Phase 2 ESA by locating survey stakes and referring to the key reference points previously surveyed by the Nanisivik Mine Surveyors.

4.3.2 Field Observations and Soil Sampling

Soil samples were taken during excavation of the test pits based on stratigraphy, visual observations and olfactory observations. Up to five soil samples were obtained from each test pit. Soil samples were collected directly from the walls of the test pit up to a depth of 1.2 m and directly from the excavator bucket at deeper depths for safety reasons. Test pits were generally excavated to expose frozen ground. The depths of the test pits ranged from 0.3 m (TP03-380 in the Landfarm Cell at the solid waste facility) to 2.8 m (TP03-333 at the industrial complex) and were measured by tape and are considered accurate to an estimated +/-0.1 m.

Soil samples were collected as follows:

- 62 soil samples were collected in the dock area from 17 test pits, of which 26 samples were analyzed for hydrocarbon and/or metal content;
- 14 soil samples were collected in the town area (including one duplicate) from four test pits of which five samples (including the duplicate) were analyzed for hydrocarbon content; and

- 191 soil samples (including seven duplicates) were collected in the "general mine area" (i.e., the remainder of the mine area) from 69 test pits of which 88 samples were analysed for hydrocarbon and/or metal content.

Samples were selected for chemical analysis based on the same guiding objectives and methods employed during the 2002 Phase 2 ESA as described in section 2.3.9 and can be summarized as follows:

- typically, samples with the highest portable photoionization detector (PID) measurements and/or greatest visible or olfactory indications of hydrocarbon contamination in each test pit were analyzed;
- samples collected at surface adjacent areas of metal contamination as determined during the Phase 2 ESA were analyzed;
- all duplicate QA/QC samples were analyzed; and
- consideration was also given to analyzing soil samples collected from adjacent intervals in the test pits in order to aid in establishing the vertical and lateral extent of the contamination.

Soil samples for hydrocarbon analyses were collected into clean, laboratory certified 250 mL glass jars, which were sealed with a Teflon®-lined lid. All soil for potential hydrocarbon analyses was kept cool until delivery to the analytical laboratory. The jarred soil samples were placed in a cooler and delivered to Maxxam Analytics Inc. for analysis of the petroleum hydrocarbon fractions in soil, and benzene, ethylbenzene, toluene and xylene (BETX) in accordance with the Canada-wide CCME procedures and protocols.

As a field-screening method, concentrations of organic vapours in the soil at sampling locations suspected of having the potential to be impacted by hydrocarbons were measured using a bag-headspace method. The bag headspace method involves placing soil in a sealable polyethylene bag, sealing the soil in the bag, disaggregating the soil in the bag, allowing organic vapours in the soil to accumulate in the bag's headspace, and then monitoring the concentration of organic vapour in the bag headspace. The concentrations of organic vapours were measured using a PID. The results of the PID measurements along with the visual appearance and olfactory indicators were used to determine which samples warranted laboratory testing.

Soil samples collected for metals analyses were collected in polyethylene bags using a clean pick and shovel and nitrile gloves. Soil conditions, as indicated by walls of the test pits, were logged with respect to soil type, colour, density, and apparent metal oxidation products. Discrete samples were collected based on the stratigraphy observed or the standard established depth intervals. The bags were sealed and either shipped to the laboratory or placed in file boxes for storage in the mine warehouse pending possible future analysis.

4.3.3 Installation of Seepage Sampling Wells and Water Sampling

One sampling well was installed in 2003, in test pit TP03-373, where seepage water was observed. The seepage sampling well consisted of a 25 mm diameter PVC screen pipe set to the base of the test pit. The annulus surrounding the well screen section was backfilled with coarse rock excavated from the test pit and the surface was compacted with the bucket of the excavator. Developing involved the agitation and evacuation of a minimum of 50 L of water from the well to remove installation-induced disturbances. A large volume of water was removed because the method used to install the wells into test pits and securing the pipe with backfill soils involves the disturbance of a considerably larger volume of soil than if a drill hole were used to install the wells.

The 2003 seepage sampling well was subsequently purged and a water sample collected. All of the groundwater seepage sampling wells that had been installed in 2002 were purged and sampled, if water was present. Dedicated sampling equipment consisting of disposable polyethylene bailers were used at each well for the purpose of developing, purging and sampling the seepage water. The wells were purged by removing approximately 15 L of water one day before sampling to allow for the stabilization of subsurface conditions.

Surface water samples were collected in areas that had not been disturbed during the site assessment program. The collection of water samples was timed to coincide with a "flight-day" in order to minimize the travel time to the analytical laboratory.

All water samples were collected into precleaned, laboratory certified containers and filtered and preserved with acid as required, specific for the chemical parameters to be analyzed. Immediately after collection, each water sample was placed in a cooler and stored at approximately 4°C until delivered to the analytical laboratory.

4.3.4 Sample Management and Shipping

Standard chain-of-custody forms were completed for each sample and the forms accompanied the samples to the external analytical laboratory. A logbook was kept of the sample numbers collected and the samples shipped off site. The logbook was also used to maintain a listing of the samples that remained in storage at the mine site. The logbook is available on site to facilitate locating samples for future analysis.

4.3.5 Analytical Laboratory

Chemical analyses were carried out by Maxxam Analytics Inc. ("Maxxam") of Mississauga, ON. Maxxam is accredited by the Canadian Association for Environmental Analytical Laboratories.

Soil samples were analyzed for metals and petroleum hydrocarbons. Metals were analyzed by Inductively-Coupled Plasmaspectrometer Atomic Emission Spectrometry ("ICP-AES") and/or graphite Furnace Atomic Absorption ("FAA") methods. The ICP-AES method provides results for 33 elements, while the FAA method is element specific and provides a higher degree of accuracy. Also, while the ICP-AES method provides results for a large variety of elements is can be biased-high for hydride metals (arsenic, thallium, antimony and selenium). In areas where arsenic is a potential concern, the results obtained by the FAA or the ICP-MS methods are recommended.

Water samples were analyzed for a variety of parameters including metals, extractable hydrocarbons, sulfates, sulphide, chloride, ammonia, alkalinity, acidity, pH, and total dissolved solids.

The specific analytical methodologies and internal quality control measures utilized by Maxxam are documented in the raw data sheets that are provided, as received from Maxxam, in Appendix I.

4.4 Results

4.4.1 Introduction

The results of analysis for the samples collected at the Nanisivik Mine during the 2003 Phase 3 field program are provided in Appendix I and summarized on Figure 6: *2003 Phase 3 ESA Results – Petroleum Hydrocarbons* and Figure 7: *2003 Phase 3 ESA Results – Metals.* Only the highest result obtained in a given test pit is illustrated on the figures, regardless of the depth at which the sample was collected. A complete listing of all results obtained is provided in the following tables:

Table 1.	Dock and Related Facilities, Summary of Analytical Results for Hydrocarbons in Soil
Table 2.	General Mine Area, Summary of Analytical Results for Hydrocarbons in Soil
Table 3.	Town Site, Summary of Analytical Results for Hydrocarbons in Soil
Table 4.	Dock and Related Facilities, Summary of Analytical Results for Metals in Soil
Table 5.	General Mine Area, Summary of Analytical Results for Metals in Soil
Table 6.	Summary of Analytical Results for Metals in Groundwater
Table 7.	Summary of Analytical Results for Hydrocarbons in Groundwater and Surface Water
Table 8.	Quality Assurance/ Quality Control Results for Metals in Soil
Table 9.	Quality Assurance/ Quality Control Results for Hydrocarbons in Soil

Results obtained during the Phase 2 ESA program are also summarized on Figures 6 and 7. The analytical results for soil obtained during the Phase 2 ESA are compared to the SQROs established in 2003 on tables provided in Appendix J. Photographs taken during the 2003 Phase 3 ESA are provided in Appendix K.

4.4.2 Dock Area, Tank Farm, Concentrate Shed

Hydrocarbons

A total of 14 test pits were excavated in the area of the dock and related facilities, from which samples from ten test pits were analyzed for petroleum hydrocarbons in soil. This is in addition to the samples collected and analyzed during the Phase 2 ESA. Petroleum hydrocarbon concentrations in soil greater than generic PWC CWS standards for Industrial (IL) land use were exceeded at three locations, test pits TP03-301, TP03-308 and TP03-310. The analytical results are summarized on Table 1 and shown on Figure 6.

Concentrations of Fraction 2 (C_{10}-C_{16}) were greater than generic PHC CWS IL criterion near surface (0.5 to 0.6 m below surface) in sample TP03-301-2 and sample TP03-301-3 collected at 0.9 m below surface was less than the PHC CWS criterion for Fraction 2. PID field screening results for these two samples were 125 ppm and 40 ppm, respectively.

Concentrations of Fraction 2 (C_{10}-C_{16}) were greater than generic PHC CWS IL criteria near the high tide elevation (at 2.0 m below surface) in TP03-310-4. The PHC CWS criterion for Fraction 2 is lower at this location because a surface water body is within 10 m of the test pit, as shown in Photograph 1. PID field screening results for this sample was 105 ppm.

Concentrations of Fraction 3 (C_{16}-C_{34}) in sample TP03-308-1 exceeded generic PHC CWS IL criterion. The PID field screening result for this sample was 20 ppm.

All samples analyzed for volatile petroleum hydrocarbons, parameters benzene, ethylebenzene, toluene, xylene, and Fraction 1 (C_6-C_{10}), met the generic PHC CWS and CEQG IL criteria.

Each of the 14 samples that were analysed for hydrocarbons were field screened based on the 'dry headspace' method using a combustible gas meter calibrated to a hexane standard. The results ranged from 15 ppm to 330 ppm, and there is a loose correlation between elevated field screening results and elevated levels of Fraction 2 (C_{10}-C_{16}). No correlation was evident with elevated field screening results and elevation concentrations of Fraction 3 (C_{16}-C_{34}).

Metals

Metal concentrations for soil samples analyzed from the dock area are listed in Table 4 and illustrated on Figure 7. Eight samples were analyzed for 33 elements by ICP-AES, and six samples were analyzed for cadmium, lead, and zinc only. Two of the samples analyzed for 33 elements by ICP-AES were also analyzed for arsenic and thallium by graphite FAA methods. Twelve of the fourteen samples analyzed were collected from surface (0 to 0.15 m), surface samples.

Cadmium concentrations ranged from 4.6 µg/g to 513 µg/g in the fourteen samples analyzed. All of the samples analysed meet the Nanisivik Mine site-specific SQRO for cadmium, 2,800 µg/g.

Copper concentrations ranged from 33.7 µg/g to 339 µg/g in the eight samples analyzed. All of the samples analyzed meet the site-specific SQRO for copper, 5,900 µg/g.

Lead concentrations ranged from 87.8 µg/g to 13,800 µg/g in the fourteen samples analyzed. One sample, TP03-312-1, collected from surface, exceeded the site-specific SQRO for lead, 4,500 µg/g. The remaining sample results meet the site-specific SQRO, including results for sample TP03-312-2, collected from 0.4 to 0.5m depth in the same test pit as TP03-312-1.

Silver concentrations ranged from <0.7 µg/g to 63.5 µg/g in the eight samples analyzed for 33 elements by ICP-AES. Results for two samples, TP03-310-2 and TP03-312-1, exceed the generic CEQG IL criteria, 40 µg/g. Both samples had other parameters that were greater than two times the site-specific SQROs (Photographs 1 and 2).

Zinc concentrations ranged from 11.4 µg/g to 180,000 µg/g (indicating zinc concentrate) in the fourteen samples analyzed. Three surface samples, TP03-301-1, TP03-310-1 and TP03-312-1, exceeded the SQRO for zinc, 44,000 µg/g. Samples collected from 0.4 to 0.5 m in test pits TP03-310 and TP03-312 met the SQRO for zinc.

4.4.3 STOL Airstrip

Hydrocarbons

A total of nine samples were analysed for extractable hydrocarbons at east end of the STOL Airstrip (Table 2, Figure 6, Photograph 3). Hydrocarbon concentrations greater than the generic PHC CWS standards for Residential/Parkland (RL) land use was detected in one of the nine test pits. Fraction 2 (C_{10}-C_{16}) concentrations in sample TP03-371-3 (630 µg/g) exceeded the generic criteria of 450 µg/g. The PID field screening result for this sample was 8,000 ppm.

A sample of seepage water was collected from a well, installed in a test pit downgradient of TP03-371, where petroleum contaminated soil was detected. Total Petroleum Hydrocarbon concentrations of 1,100 µg/g were returned from a sample collected from test pit TP03-373, which is indicative of hydrocarbon contamination. There are no generic federal CCME guidelines for Total Petroleum Hydrocarbons.

Each of the nine soil samples analysed was field screened based on the 'dry headspace' method using a combustible gas meter calibrated to a hexane standard. The results ranged from 10 ppm to 10,000 ppm,