Nanisivik Mine Landfill Closure Plan

prepared for:
CanZinco Ltd.

prepared by:
Gartner Lee Limited

reference: GLL 23-635

Date: February 2004

distribution:
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Gartner Lee

February 6, 2004

Mr. Bob Carreau
Breakwater Resources Limited
95 Wellington Street West, Suite 2000
Toronto, ON M5J 2N7

Dear Mr. Carreau:

Re: 23635 – Nanisivik Landfill Closure Plan

Gartner Lee Limited is pleased to submit the above-referenced report. A review of related reports and memorandum pertaining to geotechnical and environmental issues was completed during the development of this closure plan. The results and conclusions from these reports were incorporated into the closure plan. We trust that you will find the closure plan to be technically sound. If you wish to discuss any aspect of the report, please do not hesitate to contact us.

Yours very truly,
GARTNER LEE LIMITED

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Senior Environmental Engineer

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Executive Summary

The technical objectives of the landfill closure plan are to provide:

- A closure cover design that satisfies the overall objective of isolating landfill material from the environment;
- A performance monitoring plan that allows the ability to assess the effectiveness of the landfill cover; and
- A contingency plan in the event the landfill cover does not perform in an acceptable manner

A further objective of the Landfill Closure Plan is to address community concerns and perceptions. During the public consultation process for mine closure, the Community of Arctic Bay raised concerns regarding the status and closure of the landfill facility. Specifically, the concerns focus around the potential for environmental contamination from the waste materials contained within the facility. These concerns were considered in the Environmental Site Assessment investigations that were conducted in 2002 and 2003 and are addressed further herein.

The Nanisivik landfill is a conventional landfill facility that has been in operation since the mine and town were constructed in 1975. The facility is located approximately 4 km south of Strathcona Sound on a local topographic high/divide (approximately 350 masl) between two drainage directions, northeast and northwest. This site location was selected to minimize drainage through the facility. The northeast drainage path is intermittent in nature and reports to Strathcona Sound via Twin Lakes Creek. The northwest drainage path reports to Strathcona Sound via a small meadow/marsh area. Drainage from the facility naturally preferentially drains to the northwest and this flowpath is promoted by the presence of a water diversion berms designed to divert water in this direction.

The landfill facility occupies an area of approximately 4 ha and ranges in thickness from about 2 m to approximately 10 m.

During the period of mine operations from 1975 to 2002, the facility received waste from residential, institutional, industrial, and other miscellaneous waste streams. Waste materials were typically end dumped and pushed over the advancing crest after burning and crushing, as appropriate, and were subsequently covered with shale rock to maintain a safe working area and to minimize wind dispersion. An assessment conducted by CanZinco in 1999 estimated the waste stream volume to be 1,150 m^3 per year (after burning). The majority (75%) of the waste stream was characterized as institutional and domestic.

In 1990, a substantial amendment to the operating practices of the landfill was instituted that eliminated the disposal of any used oils, glycols or lead-acid batteries as had been common practice at industrial and municipal landfill facilities prior to 1990.

A landfarm cell, internal to the landfill facility was established in 2000 as a means of remediating hydrocarbon contaminated soil that had been excavated from a spill of diesel fuel at the carpenter shop in the town area. The 2003 Phase 3 Environmental Site Assessment ("ESA") conducted by Gartner Lee for CanZinco indicated that approximately 25% of the soil in the landfarm cell met current federal guidelines for petroleum hydrocarbons in soil.

Gartner Lee Limited conducted a Phase 2 ESA of the mine property for CanZinco in 2002 as part of the closure planning activities. This work was followed up with a Phase 3 ESA in 2003. A total of 14 test pits were excavated in the landfill area. Seepage sampling wells were installed in six of these test pits that encountered water. One seep that emerged at the toe of the landfill in the vicinity of the southwest berm was sampled. The Phase 3 ESA provided the following conclusions regarding the landfill:

1. No hydrocarbon contamination was detected in soil or water samples down gradient or cross gradient of the landfill and all analyses were less than the method detection limits; and
2. No elevated metals were encountered in the soils.

Given that the landfill has been in operation since 1975, these results are considered to provide a positive indication that contaminants have not migrated from the landfill facility.

The selected approach to closure of the Nanisivik landfill is to construct a thermal barrier cover of locally available, natural materials that makes use of the natural thermal regime at the mine site to achieve the reclamation objectives. This design approach has been successfully used for landfill closures at other northern mine sites in the Canadian Arctic. Since the waste will be permanently frozen, there will be no opportunity for contaminants to migrate from the landfill.

The geotechnical issues considered in the design include:

- cover thickness/thermal performance;
- availability of materials;
- infiltration
- durability;
- gradation/filtration;
- slope stability; and
- erosion.

Based on these considerations, the proposed design of the cover for the landfill facility is as follows:

1. The top slope of the final landfill surface will be about 2 ° and the maximum sideslope of the landfill will be 18 ° (3H:1V);
2. A two-layer thermal cover with a total thickness of 2.20 m will be placed above the landfill waste;
3. The upper erosion-resistant capping layer shall consist of a durable, erosion resistant material with a thickness of 0.25 m. The selected material is the Twin Lakes sand and gravel; and
4. The underlying layer will be shale with a thickness of 1.95 m to provide a minimum total thermal cover thickness (in combination with the surface layer) of 2.20 m. A grain size guideline (grain size distribution ranging from well-graded gravel to fine to medium sand) has been provided. It is recommended that the shale material be durable under freeze-thaw conditions.

Activities to be completed as part of the landfill closure are outlined below.

1. Relocate soil in the landfarm cell that exceeds the remedial objectives for petroleum hydrocarbons to the underground mine according to the Underground Mine Waste Disposal Plan;
2. Develop and implement a construction quality control program, which should include materials testing, survey control, and construction monitoring;
3. Grade the existing surface according to the design drawings to prepare a reclamation surface that does not exceed 3H:1V slope;
4. Construct the lower (shale) layer of the final cover;
5. Construct the upper (Twin Lakes sand and gravel) layer of the cover over the shale and groom the final surface to avoid potential surface channelization of runoff water; and
6. Prepare an as-built report.

Performance monitoring to monitor the effectiveness of the closure design will be conducted throughout the 2- year active reclamation period and the 5-year post-closure period. Components of that monitoring will include surface and ground water sampling and analyses, geothermal monitoring, and physical geotechnical inspections.

In the event that the cover does not perform a number of contingencies have been developed. These include:

- increased frequency of sampling/monitoring and data review by the technical professional;
- repair any erosion of the cover;
- place additional cover material to increase the cover thickness; and
- extend the period of performance monitoring.

The risk that contaminated leachate will be observed at the reclaimed landfill facility is considered to be small. Nonetheless, in the unlikely event that contaminated leachate is observed and confirmed by increased sampling and other investigations, the mitigative measures that would be considered would include:

- increasing the cover thickness over all or parts of the facility;
- passive treatment along the seepage flowpath;
- installation of a geosynthetic or GCL liner over all or portions of the facility;
- relocation of portions of the waste materials; and, ultimately,
- installation and operation of a leachate collection system.

1. Introduction

1.1 Overview of Development of the Nanisivik Mine Final Closure and Reclamation Plan

The Nanisivik mine, which is located on the south shore of Strathcona Sound near the community of Arctic Bay in the North Baffin region of Nunavut, as shown on Figure 1, began production of zinc and lead concentrates in 1976. The current owner of the mine, CanZinco Ltd., has been in possession of the mine since 1998.

Prior to mid-2001, the Nanisivik Mine was scheduled to operate until the depletion of economic ore reserves in 2004 or 2005. However, depressed international base-metal prices necessitated a re-evaluation of the mine production plan which resulted in a reduction of economic ore reserves such that these reserves were depleted in September 2002. The mine was permanently closed at that time.

An interim mine reclamation plan had been developed and updated on a regular basis by CanZinco Ltd. in response to terms of the Water Licence. However, the announcement of permanent closure in September 2001 triggered a requirement in the (then) current water licence for submission of a Final Closure and Reclamation Plan. In response to this trigger, CanZinco submitted a Closure and Reclamation Plan in February 2002 that described the approaches and plans for reclamation of the mine site.

Subsequent to a Public Hearing on renewal of the water licence held in the community of Arctic Bay in July 2002 and a technical meeting held in August 2003, the Nunavut Water Board ("NWB") issued Water Licence No. NWB1NAN0208, with an expiry date of May 1, 2008 (the "Water Licence"), which provides for the continuation of on-site environmental protection activities during the development and submission, for approval, of a Reclamation and Closure Plan ("RCP") with all attendant components and support documentation.

The Nanisivik Mine RCP has been developed, per the terms of the Water Licence, as a series of stand alone documents, with each document providing, in detail, information and proposed closure measures for a specific component or topic area. The individual reports that have been developed in this manner are listed under Section G of the Water Licence as summarized in Table 1.

Table 1. Summary of Component Closure Reports

Water Licence Reference	Report
G3	Final Closure and Reclamation Plan
G4	Reclamation Cover Designs
G5	West Twin Disposal Area Talik Investigation
G6	Borrow Areas Development and Closure Plan
G7	West Twin Disposal Area Surface Cell Spillway Design
G8	Waste Rock and Open Pit Closure Plan
G9	Reclamation and Closure Monitoring Plan
G12	Annual Review of Reports G3 to G9 and Submission, for Approval, of Proposed Modifications
G13	Report on Environmental Site Assessment (ESA) Program
G14	Human Health and Ecological Risk Assessment (HHERA)
G15	West Twin Disposal Area Closure Plan
G16	Underground Mine Solid Waste Disposal Plan
G17	Landfill Closure Plan
G20	Annual Review of Reports G15 to G17 and Submission, for Approval, of Proposed Modifications
G21	Annual Reclamation Liability Cost Update
G22	2007 Terms of Reference for Comprehensive Assessment of Mine Site Remediation

This document and the information presented herein are provided in response to the requirements for component report G.17, the Landfill Closure Plan.

1.2 Specific Requirements for the Landfill Closure Plan

The general objectives of the landfill closure plan are:

- Provide a closure cover design that satisfies the overall objective of isolating landfill material from the environment;
- Provide a performance monitoring plan that allows the ability to assess the effectiveness of the landfill cover; and
- Provide a contingency plan in the event the landfill cover does not perform in an acceptable manner

The specific requirements for the Landfill Closure Plan come from two sources: Part G, Item 17 of the Water Licence and the needs of CanZinco with respect to carrying out the reclamation activities to eliminate the requirements for long term monitoring and maintenance for this facility.

Part G, Item 17 of the Water Licence, as excerpted below, provides the following requirements for the Landfill Closure Plan:

i. Overview of site conditions such as physical setting, geology, thermal regime and water balance;
ii. Final cover design including assessment of alternatives, geothermal assessment, cover design objectives to shed water and assessment of cover thickness with respect to design objectives and final landfill contours;
iii. Identification of spatial limits of waste;
iv. Chemical and physical characteristics of waste;
v. Incorporation of results of the Phase 1/Phase 2 Environmental Site Assessment (Part G, Item 4 of water licence NWB1NAN9702);
vi. Incorporation of historical and new water quality information and construction history into the design;
vii. Assessment for the need for a leachate collection system;
viii. Short term and long term monitoring requirements;
ix. Preliminary design plan and drawings stamped by an engineer; and
x. Timetable of implementation of construction and monitoring.

CanZinco's specific requirements for the Plan are also satisfied by those provided in the Water Licence, namely to describe the current status (at mine closure) of these facilities and the proposed reclamation activities.

A final objective of the Landfill Closure Plan is to address community concerns and perceptions. During the public consultation process for mine closure, the Community of Arctic Bay has raised concerns regarding the status and closure of the landfill facility. Specifically, the concerns focus around the potential for environmental contamination from the waste materials contained within the facility. These concerns were considered in the Environmental Site Assessment investigations that were conducted in 2002 and 2003 and are addressed further herein.

1.3 Approach to Development of the Landfill Closure Plan

In order to achieve the requirements for the Plan and for preparation of this document, the following steps were completed:

- Literature review of current and historical documentation of the Nanisivik landfill;
- Review of the documentation related to closure, including the water licence and environmental assessment data;
- Review of relevant case history information from similar sites;

- Review of cover design information provided in the "Draft Engineering Design of Surface Reclamation Covers" by BGC Engineering Inc. dated January 21, 2004;
- Development of a graded base surface to facilitate construction of the final closure cover;
- Development of a final surface grading plan;
- Development of a monitoring plan;
- Development of a contingency plan; and
- Preparation of a summary report.

The existing information included environmental and operational assessments conducted by CanZinco, the Phase 2 and 3 Environmental Site Assessments that were reported on by Gartner Lee and the record of water quality monitoring as collected and reported on by CanZinco. New information that was collected for the mine closure plan includes a comprehensive survey of the landfill, discussions with CanZinco site personnel and mine closure information developed by BGC Engineering regarding local geothermal conditions and closure cover designs.

The recent closure of the Operational Landfill at the Polaris mine provides a relevant and recent case history of a landfill that was operated at a similar facility (i.e., a remote access base metal mine in the Canadian Arctic) during a similar era (i.e., 1980'and 1990's) and that has recently been closed. The initial data collected during the first two years following closure of that landfill are positive and generally supportive of the closure concept proposed herein of a soil cover to promote permafrost aggradation through the waste materials.

The location of the Nanisivik landfill is shown on Figure 2. Figure 3 presents the existing ground surface of the landfill.

2. Facility Characterization

2.1 Physical Setting

2.1.1 Local Topography/Hydrology

Local topography is characterized by moderately high hills reaching an elevation of 650m above sea level, isolated plateaus, and deep valleys, which descend to the sea level. Snow and ice accumulations generally begin to run-off in the middle of June and continue until late August or early September. Peak run-off flows typically occur by the middle of July and subside throughout the summer.

2.1.2 Geology

A description of the geology of the mine site is provided in the February 2002 Closure and Reclamation Plan that is repeated here for reference and context.

The Nanisivik sulphide deposits are hosted in carbonate rocks within a Proterozoic sedimentary sequence. This sequence developed as a Neohelikian intracratonic basin, the Borden Basin, on a peneplaned gneiss complex of Archean-Aphebian age.

The present Borden Basin sequence consists of generally shallow water clastic and carbonate sediments up to 6,100 m thick, called the Bylot Supergroup. The Supergroup is divided into three Groups, a lower clastic group (the Eqalulik Group), a middle carbonate group (the Uluksan Group) and an upper clastic group (the Nunatsiaq Group).

The Uluksan Group is made up of the lower Society Cliffs Formation and the upper Victor Bay Formation. The Society Cliffs Formation varies in thickness from 260 m at Arctic Bay to 856 m at Tremblay Sound. West of Tremblay Sound, it was deposited in a subtidal to intertidal environment. The Society Cliffs Formation is conformably overlain by the Victor Bay Formation, which consists of shales, siltstones, dolostones and coarse carbonate clastics and varies in thickness from 156 m to 735 m. The Victor Bay Formation is considered to have acted as a cap rock to mineralization in part of the mine area. All of the economic mineralization at the Nanisivik mine lies within the upper member of the Society Cliffs Formation.

The Nanisivik mine property is up to 7 km wide and up to 15 km long. Rocks cropping out on the property include small exposures of quartzite of the Adams Sound Formation on the southern edge of the lease area. The unit immediately below the Society Cliffs Formation, the Arctic Bay Formation, crops out in the area but is not exposed on the property. The main units exposed are the Society Cliffs Formation and the overlying Victor Bay Formation, together with Paleozoic sandstones of the Gallery Formation.

In the mine area, dips are usually quite shallow and the main structure is faulting. Major structures that are recognized in the mine include the South Boundary Fault, which marks the southern margin of sulphide mineralization, and the Keystone Graben Fault, which defines the southern margin of the Main Ore Zone horst.

The accepted geological model is that the Nanisivik deposits are Mississippi-Valley Type. By definition, these are post-depositional, carbonate hosted deposits. Typically, they are coarse-grained and mineralogically simple. They tend to be sphalerite-rich, may be very large and may contain high base metal grades. However, Mississippi-Valley Type deposits include quite diverse deposits, different in shape, grade and mineralogy. This diversity appears to result from source fluid chemistry, rocks through which the fluids pass prior to deposition, source fluid temperature and the nature of the depositional environment.

2.1.3 Ground Temperatures/Permafrost

An investigation of the presence of permafrost at the landfill was part of a field program conducted in 2003. BGC Engineering Inc. supervised the drilling of a borehole at the toe of the landfill facility in August (coincident with the annual maximum thaw penetration). The borehole was instrumented with thermocouples at various depths. A memo documenting this borehole installation and the initial thermal monitoring results, as prepared by BGC Engineering Inc., is provided in Appendix A.

2.1.4 Climate

Nanisivik is located in a climatic zone classified as "polar desert", which is characterized by cold temperatures and relatively low precipitation. Meteorological data has been collected by Atmospheric Environmental Services (AES) of Environment Canada since 1976 at the Nanisivik Airport (located approximately 10 km south of the mine site).

Over the period of record, the maximum daily temperature recorded was 23.0 ^{0}C, the minimum daily temperature recorded was -53.0 ^{0}C and the mean daily temperature recorded was –14.8 ^{0}C.

Mean annual precipitation has been recorded at 231 mm, of which approximately 50 mm was in the form of rain. The greatest daily recording of snowfall was 68.4 cm and the greatest daily recording of rainfall was 36 mm.

Annual evaporation data at the WTDA has been measured at an average of 187 mm during the period 1993 to 2001 (DIAND meteorological station).

The daily rainfall probable maximum precipitation ("PMP") event is estimated to be approximately 140 mm and the daily snowmelt PMP event is estimated to be 155 mm. The magnitude of these extreme events is low relative to southern Canada (for example, a daily PMP event in Northern Ontario is approximately 500 mm to 700 mm) which reflects the characterization of the site as a "Polar Desert".

2.2 Landfill Facility Characterization

2.2.1 Overview

The Nanisivik landfill (Figures 2 and 3) is a conventional landfill facility that has been in operation since the mine and town were constructed in 1975. The facility is located approximately 4 km south of Strathcona Sound on a local topographic high/divide (approximately 350 masl) between two drainage directions, northeast and northwest. This site location was selected to minimize drainage through the facility. The northeast drainage path is intermittent in nature and reports to Strathcona Sound via Twin Lakes Creek. The northwest drainage path reports to Strathcona Sound via a small meadow/marsh area. Drainage from the facility preferentially drains to the northwest and this flowpath is promoted by the presence of a water diversion berm designed to direct water in this direction.

The landfill facility occupies an area of approximately 4 ha and ranges in thickness from about 2 m at the south end to approximately 10 m at the north end. The original ground surface slopes to the north towards Strathcona Sound, as does the landfill. The most recent survey of the landfill, completed in 2003, indicates that the top of the landfill varies from an elevation of 344 masl at the south end to 335 masl along the north side, as shown on Figure 3.

During the period of mine operations from 1975 to 2002, the facility received waste from residential, institutional, industrial, and other miscellaneous waste streams. Waste materials were typically end dumped and pushed over the advancing (northern) crest after burning and crushing, as appropriate, and were subsequently covered with shale rock to maintain a safe working area and to minimize wind dispersion. In 1990, a substantial amendment to the operating practices was instituted that eliminated the disposal of any used oils, glycols or lead-acid batteries as had been common practice at industrial and municipal landfill facilities prior to 1990. The permanent shut down of mining activities in September 2002 resulted in a substantial decrease in activity at the facility related to the elimination of the waste streams except a minor volume of camp garbage from the care-taking staff.

A landfarm cell, internal to the landfill facility was established in 2000 as a means of remediating hydrocarbon contaminated soil that had been excavated from a spill of diesel fuel at the carpenter shop in the town area. The cell is located on the top surface of the landfill and consists of a raised soil berm within which the contaminated soil was placed. The 2003 Phase 3 Environmental Site Assessment conducted by Gartner Lee for CanZinco indicated that approximately 25% of the soil in the landfarm cell met current federal guidelines for petroleum hydrocarbons in soil.

2.2.2 CanZinco Site Assessments

Initial Assessment

An initial assessment of the landfill facility was completed by CanZinco in 1999 to satisfy the requirements of the Water Licence and to address general questions that had been raised in public meetings. The primary question addressed in the assessment was a documentation of past and current waste streams entering the landfill and past and present operating procedures, including the deposition, pre-1990, of waste oil drums and glycol from spill containment practices and vehicle maintenance. At the time of the assessment, the landfill facility occupied an estimated area of 1.6 ha.

The investigation of waste streams entering the landfill resulted in the detailed listing of streams and volumes that is repeated herein in Section 2.3.1. The documentation of past and current operating practices identified that the deposition into the landfill of spent batteries, used oil and used glycol had ceased in 1990 as was generally instituted for municipal and industrial landfills of that era. The general operating procedures for deposition of waste consisted of burning at the landfill, crushing as practical to reduce volume and covering with shale. The assessment verified that the current landfill had been in use since the start of the mine and that no other landfills were known to exist on the mine property.

The assessment suggested that the potential exists for hydrocarbons to migrate vertically through the frozen soil matrix within the landfill but that off-site migration will not likely occur. Laboratory analysis results indicated that hydrocarbons and dissolved metals were not being transported from the landfill site to surrounding receptors.

The assessment reported that two water control berms were in place. A 2 m berm was in place immediately upgradient of the landfill to divert clean water runoff around the facility to the west. A second, 2 m berm was in place at the toe of the facility to direct runoff and seepage through a central notch for monitoring. A flow-through, absorbent boom was located at this location to protect against the release of hydrocarbon products in seepage water. Water flow was reported to be present only for a brief period during summer.

A sampling and monitoring program was developed to further investigate for any off-site transport of contaminants. The assessment also suggested that, at the completion of mining operations, the landfill should be covered and structured to prevent erosion and ponding of seasonal run-off, thereby raising the elevation of permafrost. To verify that permafrost had been raised into the covering materials, installation and monitoring of thermocouples was also recommended.

Follow Up Assessment

A follow up to the Initial Assessment was conducted by CanZinco in 2000 to investigate for contaminants and seepage pathways from the landfill site and to identify any impacted areas.

Soil testing for hydrocarbon parameters from around the perimeter of the landfill berm did not reveal any hydrocarbon contamination. Hydrocarbons were detected at one location downstream of the surface water monitoring point NML-26 (Figure 3) but the concentrations were reported to be "well below both CCME and GNWT criteria for petroleum hydrocarbons in soil". The Phase 2 and 3 Environmental Site Assessments conducted by Garter Lee for CanZinco, described below, included extensive investigation in this area and did not identify hydrocarbon contamination in soil or water with respect to the current federal guidelines.

The CanZinco follow up assessment recommended that down gradient monitoring during periods of thaw continue to determine if hydrocarbon migration was ongoing and at what rate.

2.2.3 Gartner Lee Phase 2 and 3 Environmental Site Assessments (ESAs)

Gartner Lee conducted a Phase 2 ESA of the mine property for CanZinco in 2002 as part of the closure planning activities. This work was followed up with a Phase 3 ESA in 2003. The primary environmental concern regarding the landfill was the potential for transport of contaminants, particularly hydrocarbons, from the landfill. Hydrocarbons in the landfill originated from historical operating practices and the disposal of spill clean up materials.

The landfill operations underway at the time of inspection included the placement of solid waste over the outer crests, the burning of putrescible wastes, the compaction of some materials (i.e., steel drums) prior to placement and the covering of waste with shale by advancing the outer crests. At the time of the investigation, the site appeared to be well maintained with only a small "face" of waste visible with the remainder buried under a shale cover. The mine shutdown in September 2002 has resulted in a substantial decrease in activity at the landfill.

During the investigations, two berms were observed at the landfill. A berm approximately 2 m high located along the southern and western edge of the landfill area diverts surface runoff from upgradient of the site around the landfill. A second berm, approximately 2 m high, at the toe of the landfill serves to direct runoff from the landfill facility itself to one location where it may be effectively monitored.

Nine test pits were excavated outside of the toe of the collection berm. Two additional test pits were excavated inside the collection berm. Three additional test pits were excavated just east of the landfill, in an area that is considered to be largely unaffected by landfill seepage. Seepage sampling wells were installed in six of these test pits that encountered water. One seep that emerged at the toe of the landfill in the vicinity of the southwest berm was sampled. The test pits were excavated in an area of meadow ground cover, and intersected clayey and silty sand and gravel (till) at depth. Permafrost was encountered at depths of 0.8m and 0.9m.

The 2003 Phase 3 ESA provided the following conclusions regarding the landfill:

1. No hydrocarbon contamination was detected in soil or water samples down gradient or cross gradient of the landfill and all analyses were less than the method detection limits; and
2. No elevated metals were encountered in the soils.

Given that the landfill has been in operation since 1975, these results are considered to provide a positive indication that contaminants have not migrated from the landfill facility. Subsurface and surface seepage water quality is further discussed in the following sections.

2.2.4 Water Quality

Overview

The quality of runoff and seepage water is of interest because of the community concerns and because the contents of the landfill are known to include used hydrocarbon products, as documented in Section 2.3.1. Given that some liquid products were placed into the landfill during the earlier years of its operation, there is a concern that it may be possible for those products to migrate out of the landfill. Alternately, the liquid products, and other potential contaminants, might remain securely stored within the landfill as they remain, or become, frozen in place.

To investigate whether potential contaminants might be exiting from the landfill, CanZinco has sampled seepage water since 1994 at the outlet from the seepage collection berm. Since 1997, this sampling location has been named NML-26 (Figure 3). NML-26 is not a Water Licence station but has been routinely sampled by CanZinco in the interest of investigating seepage quality. Flow is present at this location only during the short summer season. Stations NML-29 and NML-30 were instituted in 2003 in the surface flowpaths flowing towards the northeast (NML-29, 125 m downstream of NML-26) and towards the northwest (NML-30, 75 m downstream of NML-26).

The Phase 2 and 3 ESA programs that were carried out in 2002 and 2003 by Gartner Lee for CanZinco included sampling of a water seep exiting at the immediate toe of the landfill (LF-SEEP) and shallow subsurface flow in four monitors located around the toe of landfill (TP02-95, TP02-97, TP02-102 and TP03-387) and in two monitors (TP02-100 and TP02-101) located approximately 100 m east of the landfill. These monitoring locations are illustrated on Figure 3.

Subsurface Flow and Toe Seepage

The water quality of subsurface flow and toe seepage samples collected in 2002 and 2003 is summarized in Appendix B. The sample locations are illustrated on Figure 3.

In order to provide a reference for the water quality data gathered at the Nanisivik Mine site, the Canadian Environmental Quality Guidelines ("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* and Yukon *Contaminated Sites Regulation*, generally apply a 10-fold 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.

The data demonstrate that hydrocarbon concentrations (various analyses) are uniformly less than method detection limits, which are also uniformly less than the CEQG. This indicates that there was no migration of hydrocarbon products present in 2002 and 2003. It is likely that there has been no subsurface migration at any stage of the approximate 27-year history of the facility given that some trace of this would be expected to be observed in the 2002/2003 data. This suggestion is further validated by the analyses of hydrocarbons in soil, which were uniformly less than method detection limits and Federal Guidelines.

The analytical results of groundwater samples collected from the monitors to the east of the landfill (TP02-100 and TP02-101), which are considered to be largely unaffected by seepage from the landfill, indicated that metal concentrations were all low. Cadmium was the only metal that was greater than the assumed reference value of 10 times the CEQG FWAL. Only one of three groundwater samples from the toe of the landfill (TP02-97) contained cadmium at a concentration greater than the assumed reference value (10 times the CEQG FWAL) but similar to the concentration reported for sample TP02-100. This suggests that there was no subsurface migration of metals from the landfill facility present in 2002 and 2003. Given that the landfill has been in operation since 1976, this is a positive indication that there has been no subsurface migration of metals from the landfill facility.

Sample LF-WSEEP is a small (trickle) flow emerging at the toe of the west side of the landfill that was sampled in both 2002 and 2003. This was the only surface flow identified around the toe of the landfill in both ESA programs. The source of water for this small intermittent flow is likely a combination of direct reporting through the surficial materials in the active layer and infiltration of runoff water into the landfill. Between the two samples, concentrations of cadmium, copper and zinc were greater than the reference values. The relatively low concentrations observed are not considered to represent an environmental concern given that the seep may disappear following reclamation of the facility and given that the seep is monitored again at the outlet of the collection berm at location NML-26, as described below.

Surface Drainage

The quality of surface drainage from the landfill is listed in Appendix B and the sample locations are illustrated on Figure 3.

The data provides two references for the water quality data: the CEQG FWAL and the current Water Licence discharge criteria. The CEQG do not apply directly to this location as they are generic guidelines for surface water bodies that host aquatic life. They are shown simply as a means of providing some context for the water quality data. The Water Licence discharge criteria provide additional context for discussion of the results.

The data show that the concentration of hydrocarbons in 2003 was less than the method detection limit, which was also less than the CEQG Guideline. This further indicates, following from the discussion of subsurface water quality above that there was no indication of any migration of hydrocarbon products out of the landfill.

The data show that concentrations of cadmium, lead and zinc have exceeded the CEQG on occasion through the summer period. The detailed (weekly) water quality record for 2003 suggests that metal concentrations were generally lower during the initial sampling events (i.e., immediately after the onset of flow) than the remainder of the flow season. No metal concentrations exceeded the Water Licence discharge criteria. Given the above and the possibility that the source of metals may be the operational activities that have taken place on the surface of the landfill, these results are not considered to represent an immediate environmental concern.

Nonetheless, the proposed environmental monitoring program includes continued monitoring of water quality at this location such that any trends in the water quality data can be identified and responded to, if necessary.

2.3 Historical Operating Practices

2.3.1 Waste Streams and Volumes

Waste is accepted into the Nanisivik Landfill from industrial, institutional, residential, and other miscellaneous sources. Table 4 provides details on waste composition and volumes generated from each waste stream as outlined in the CanZinco, 1999.

The majority of the remaining 1150m^3/yr originates from institutional sources such as the mill kitchen, the "dome" kitchen and the jet airport.

2.3.2 Internal Landfarm

In response to a spill of diesel fuel at the Carpenter Shop in 2000, a landfarm cell was constructed on the upper surface of the landfill facility. Approximately 980 m^3 of soil that was excavated from the spill area was placed into the cell. It is likely that some over excavation of soil took place during the clean up, as is common, such that not all of the soil that was placed into the cell was contaminated.

The soil contained within the cell was investigated as part of the 2002 and 203 ESA programs conducted by Gartner Lee for CanZinco. The 2003 Phase 3 investigation provided the conclusion that an estimated 25% of the contained soil may not be contaminated.

Table 2. Summary of Landfill Waste Streams

Waste Stream	Composition	Volume
Industrial -mining activities	-drums -waste steel -scrap vehicles -mechanical equipment -packaging materials formerly containing chemicals (copper sulphate, potassium amyl xanthate, lime, ammonium nitrate, calcium chloride)	624 m^3/year
Institutional -food services -government and mining offices -day care -airport operations -housekeeping services	-office waste (paper, computer disks, photocopy cartridges, cardboard) -light bulbs (fluorescent and incandescent) -food waste -styrofoam containers -household cleaners -packaging materials (plastic and cardboard)	1456 m^3/year
Residential	-food waste -packaging materials -clothing -household cleaners -light bulbs -alkaline batteries -glass	780m^3/year
Miscellaneous -vehicle maintenance -shipping waste -spill recovery -maintenance of mechanical and electrical equipment	-used oil filters -gaskets -automotive/industrial belts and hoses -glass -residual amounts of paint in cans -absorbent materials (potentially containing hydrocarbons) -copper wire -mechanical and/or electrical equipment that could not be salvaged	275 m^3/year
Total Waste Stream prior to burning		2875m^3/yr
Total Waste Stream after burning		1150m^3/yr

3. Landfill Closure Plan

3.1 Specific Reclamation Objectives

The specific objectives for reclamation of the landfill facility are to:

1. Minimize the flow of water through the landfill waste; and
2. Provide a safe and stable surface environment that resembles the natural surroundings.

3.2 Closure Alternatives

The following closure alternatives have been considered, as described in the following sections:

1. Leave the landfill in an "as-is" condition;
2. Relocate waste materials into the underground mine;
3. Construct a low permeability cover; and
4. Construct a thermal barrier cover.

3.2.1 Leave "As-Is"

This alternative represents a "base-case" or starting point for the consideration of closure alternatives. Although the landfill is not currently generating leachate, this alternative would not reduce the risk that this may occur at some time in the future and would, therefore, require a longer term monitoring program as compared to other, proactive alternatives. Further, this alternative would not achieve the reclamation objective for restoration of land use and land values.

Therefore, the savings in reclamation costs that would be realized with this alternative are not justified because of the increased long term monitoring liabilities and because of the lack of restoration of land use and land values.

3.2.2 Waste Relocation Underground

All of the waste from the landfill could be removed and placed into the underground mine, if the required disposal volume was available. The waste materials would then become frozen into permafrost in the underground mine as is proposed for other reclamation waste materials such as contaminated soils and demolition debris. This alternative would require the availability and safe accessibility of a disposal area in the underground mine.

This alternative is not recommended for the Nanisivik landfill. If the landfill were currently generating leachate or if the landfill contained unusually hazardous materials, such as radioactive materials, then this alternative might be preferred. However, the Nanisivik landfill is not currently generating leachate and does not contain such materials. This alternative might also be recommended if the area occupied represented unusually valuable terrestrial ecological habitat or had unique cultural importance. However, there is no indication that these circumstances apply to the area occupied by the Nanisivik landfill.

3.2.3 Low Permeability Cover

Construction of a low permeability cover over the waste is an alternative that could be used to meet the objectives of the closure plan. However, there are no known, local natural materials (clay or well-graded till) that would be available in sufficient volumes to be practically considered to construct such a cover. Therefore, a low permeability cover would have to be constructed using geosynthetic materials such as a geomembrane or geosynthetic clay liner (GCL).

Under the extreme winter conditions in the Canadian Arctic, geomembranes can shrink and become brittle and, thereby, susceptible to stress/thermal cracking. Therefore, geomembranes are not considered an appropriate potential cover material.

GCLs, which generally consist of bentonite granules between two geotextiles, are not subject to the same contraction under cold weather and not subject to stress/thermal cracking. However, the freeze-thaw (resulting in wet-dry cycles) behavior of the bentonite is an important factor to consider. GCLs are subject to shrinking and (dessication) cracking under wet-dry cycles, which could result in significantly higher flow through hydraulic conductivity until the GCL is re-hydrated (self-healing). Although GCLs have a self-healing mechanism through re-hydration, the semi-arid Arctic environment and extreme cold weather may prevent adequate performance. Hence, a GCL is not a preferred material for final cover.

3.2.4 Thermal Barrier Cover

A thermal barrier cover provides thermal protection equal to or greater than the local active thaw so that the waste becomes frozen into the permafrost, and contamination migration is abated. Using the environmental conditions of the Arctic to provide encapsulation via permafrost, the cover is a natural analog to its surroundings. This type of cover provides a low maintenance solution constructed of durable local natural materials that also achieves reclamation objectives for restoration of land use values.

This approach has several successful precedents elsewhere in the Canadian Arctic such as the Polaris mine landfill facility and DEW line sites. The Polaris mine landfill facility on Little Cornwallis Island