BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

# NANISIVIK MINE, A DIVISION OF CANZINCO LTD.

## NANISIVIK MINE CLOSURE STUDIES



# ENGINEERING DESIGN OF SURFACE RECLAMATION COVERS

**(WATER LICENSE Part G, Item 4)**

**FINAL**

PROJECT NO.: 0255-008-06
DATE: FEBRUARY 6, 2004

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Project No. 0255-008-06
Date: February 6, 2004

Mr. Bob Carreau
Manager, Environmental Affairs
CanZinco Ltd.
c/o Breakwater Resources Ltd.
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Toronto, Ontario M5J 2N7

**Re: Final Report: Engineering Design of Reclamation Covers**

Dear Bob:

Please find attached four copies of our above referenced report dated February 6, 2004.

Should you have any questions or comments regarding the final report, please contact BGC at your convenience.

Yours truly,
**BGC Engineering Inc.**
**per:**

James W. Cassie, M.Sc. P.Eng.
Specialist Geotechnical Engineer

encl. Final Report

JWC/sf

# EXECUTIVE SUMMARY

Under the terms of Water Licence NWB1NAN0208 issued by the Nunavut Water Board (NWB), CanZinco Ltd., the current owner of the Nanisivik Mine is responsible for continuation of on-site environmental protection activities and developing for submission and approval of a Final Closure and Reclamation Plan ("FCRP").

The Nanisivik Mine FCRP has been developed, as per the terms of the Water Licence as a series of stand-alone documents, each addressing in detail the information and proposed closure measures for one specific component or topic area. This document and the information presented herein are provided in response to the requirements for report Part G, Item 4, the Reclamation Cover Designs.

In accordance with Part G, Item 4, of the Water Licence, this report provides the following requirements for the Cover Design:

1. A description of the proposed materials.
2. The results of field-testing and thermal modelling for covers over tailings, waste rock and landfill debris.
3. Plans showing the pre- and post-cover topography using sufficiently detailed contour intervals.
4. An assessment of cover performance under 1 in 100 year return period (warm year) and global warming scenarios.
5. Confirmation of availability of materials for cover construction.
6. The bathymetry of sub-aqueous tailings in West Twin Lake Reservoir which shows the extent of tailings located within 1.0 m of the water surface, and plans for mitigation of wave action on these tailings.
7. Quality Assurance/Quality Control measures for short and long term maintenance.
8. A verification of cover thickness against extreme annual temperature variation (i.e., 1:100 year warm event) verified within the boundaries already provided by global warming estimates.
9. An evaluation of alternatives for increasing minimum water depth in the Reservoir with emphasis on possible effects of waves and winter ice cover on long term water quality.
10. An assessment of cover thickness with reference to cover result available for Area 14 as a case study.

The requirements Nos. 6 and 9 of Part G, Item 4, which apply to the water covered tailings in the Reservoir are addressed within the context of the West Twin Disposal Area Closure Plan Report (Water Licence Requirement Part G, Item 15). The detailed design and grading plans for the waste rock pile/open pit covers and landfill cover are included in the respective reports; Waste Rock and Open Pit Closure Plan (Water Licence Requirement Part G, Item 8) and the Landfill Closure Plan (Water License Requirement Part G, Item 17). A detailed development and reclamation plan for the shale and sand and gravel borrow areas is submitted as required by Water License Part G, Item 6 (Borrow Quarry Development and Reclamation Plan) under a separate cover.

In summary, this Cover Design Report provides details for the following components:

- Review of cover design options for various materials including tailings, waste rock, open pits and the landfill.
- The rationale for selecting the recommended cover materials and thicknesses.
- A detailed cover grading plan along with material quantities for the Surface Cell and Test Cell areas.
- A monitoring plan to assess the performance of the cover during closure.
- A series of contingency plans that may be implemented should the cover perform in an unacceptable manner.

The conceptual review of cover design considers the requirements of covers for potentially acid generating mine wastes and for landfills. In cold regions, the purpose of the cover is to allow permafrost to develop within the waste and to restrict the depth of thawing to within the cover thickness. A frozen, ice saturated zone develops within the cover that will limit infiltration of water and air into the underlying waste materials. This provides a reduction in oxygen diffusion and prevents the generation of leachate and movement of contaminants. Since the purpose of the cover is to provide a thermal barrier to maintain frozen ground conditions, granular materials, such as sand and gravel and crushed rock can be used. These materials are abundant at Nanisivik.

The site is located within the continuous permafrost zone, with a Mean Annual Air Temperature (MAAT) of –15.1° C. The long-term temperature trends from several weather stations in the vicinity of Nanisivik were used to estimate the 1:100 year warm annual temperature for Nanisivik of –13.3° C. Climate change due to global warming is expected to increase the MAAT at Nanisivik by 2.8° C by 2100 for the "Best Estimate" case and 5.0° C for the "High sensitivity" case, as provided by Environment Canada.

Various cover types were reviewed, including wet cover and dry cover options. Dry cover options included geosynthetics and natural materials. Natural materials on site include marine silty clay, Airport sand, till, Twin Lakes sand and gravel and shale. A dry cover option using shale was selected as the main component of the cover for the following reasons:

- Availability: shale is available in sufficient quantities at locations proximal to the areas requiring covering.
- Workability: shale has been used for various purposes throughout the life of the mine and the site staff have a valuable knowledge base of quarrying and handling the material.
- Carbonate content: may provide buffering capacity should acidic leachate be produced by the underlying tailings.
- Grain size characteristics the quarried grain size characteristics of the shale do not require additional mechanical breakdown to be used as cover material.

The Twin Lakes sand and gravel was selected as an armouring material to be placed above the shale to limit erosion from both wind and water. This material was selected as the armouring material based on the following factors:

- Durability: the material is composed of re-crystallized quartzite, which is characteristically highly durable and resistant to weathering.
- Availability: the material is available in sufficient quantity in an area proximal to the West Twin Disposal Area.
- Light colour: the light colour of the material (tan to reddish) will reflect sunlight and provide less heat absorption than darker materials.

The report provides details of the geotechnical properties of the preferred cover materials, which included grain size distribution, compacted density, natural and saturated moisture content, durability and permeability. Samples of shale were tested to assess the acid generation and acid consumption potentials. As expected, the acid-base accounting analyses confirmed the general expectation that the shale is acid consuming. A humidity cell test was conducted for 37 weeks, which indicated that leachate remained neutral (pH > 7.5) throughout the test.

The design of the covers was based on an assessment of the ongoing Test Cell cover study, geothermal modelling and thermal assessment of the Area 14 waste rock cover. The Test Cell covers have been studied by CanZinco since 1989. Five test covers were constructed using various tailings materials and varying degrees of compaction and saturation with thicknesses of about 2 m. Monitoring of the depth of annual thaw in the covers indicated that the maximum depth of thaw decreased each year to a range of 0.73 m to 1.4 m. This trend indicated that the permafrost was developing within the base of the covers. In addition, examination of the covers in test pits indicated that a zone of ice had developed within the base of the cover due to seasonal infiltration and freezing of water. This ice saturated zone will form an effective barrier to the diffusion of oxygen and water between the tailings and the rest of the cover.

Geothermal modelling of the cover was carried out to evaluate the potential variations in the depth of the active layer thaw within the shale cover due to extreme temperature events. The thermal model was calibrated to the site test cover data and then extended for extreme warm years and for global warming scenarios over the next century. Based on this assessment, the design cover system for the tailings is comprised of 1.0 m of quarried shale fill, covered by 0.25 m of Twin Lakes sand and gravel. This proposed thickness appears adequate to resist both the 1 in 100 year warm event and the High Sensitivity estimate of global warming over the next 100 years.

Assessment of the Area 14 rock cover was done to compare the cover requirements for the tailings, which is saturated and waste rock, which is unsaturated. Since the underlying waste is not saturated, water that percolates through the cover may drain through the waste rock and not form an ice zone barrier whereupon the depth of the active zone will be greater than in the tailings covers. An additional thickness of cover is required to ensure freezing of the waste. Based on the actual field trial in Area 14 and results of thermal modelling, the total cover thickness was determined to be 2.2 m of shale or 1.95 m of shale and 0.25 m of Twin Lakes Sand and Gravel.

Regrading of the tailings surface will be done before any shale is placed. The proposed Surface Cell cover results in the placement of approximately 400,000 $m^3$ of shale and 95,000 $m^3$ of Twin Lakes sand and gravel. The proposed Test Cell cover requires approximately 151,000 $m^3$ of shale and 27,500 $m^3$ of Twin Lakes sand and gravel.

Material specifications, construction considerations, fill placement and quality control/quality assurance procedures are detailed for the shale and Twin Lakes sand and gravel cover materials. During construction, detailed information will be collected concerning cover thickness, grades and elevations, level of compaction, grain size analysis and moisture content. Upon completion of construction, performance monitoring will include collection of ground temperature, piezometric pressures and water quality information, as well as observing the physical condition of the covers. A monitoring schedule for the Reclamation and Closure Period (7 years) has been provided.

Several contingency plans have been developed that address potential performance issues, such as erosion of the armouring layer or underlying shale, deformation of the cover, excessive depth of thaw and poor quality of surface water runoff. The consequences of each issue and suggested mitigative approach are summarized in table format. Common to all suggested mitigation measures is identification of the root cause and appropriate reaction to limit environmental consequences of each concern.

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# LIMITATIONS OF REPORT

This report was prepared by BGC Engineering Inc. (BGC) for the account of Nanisivik Mine, a division of CanZinco Ltd. The material in it reflects the judgement of BGC staff in light of the information available to BGC at the time of report preparation. Any use which a Third Party makes of this report, or any reliance on decisions to be based on it are the responsibility of such Third Parties. BGC Engineering Inc. accepts no responsibility for damages, if any, suffered by any Third Party as a result of decisions made or actions based on this report.

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# 1.0 INTRODUCTION

## 1.1 Overview of Development of the Nanisivik Mine Final Closure & Reclamation Plan

The Nanisivik Mine 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 1996.

Prior to mid-2002, the Nanisivik Mine was scheduled to operate until the depletion of economic ore reserves in at least 2004 or 2005. However, depressed international base-metal prices necessitated a re-evaluation of the mine production plan in fall 2001. This assessment 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 an annual basis by CanZinco Ltd. in response to the terms of the Water License. However, the announcement of permanent closure in October 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 (C&R 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 2002, the Nunavut Water Board ("NWB") issued Water Licence No. NWB1NAN0208 (the "Water Licence"). The license provides for the continuation of on-site environmental protection activities during the development and submission, for approval, of a Reclamation and Closure Plan ("RCP").

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

This document and the information presented herein are provided in response to the requirements for Part G, Item 4, the Reclamation Cover Designs.

## 1.2 Specific Requirements for the Reclamation and Closure Plan

The specific requirements for the Reclamation Cover Design (the "Cover Design") come from two sources: Part G, Item 4 of the Water Licence and the requirements of CanZinco with respect to long term monitoring of the site.

Part G, Item 4 of the Water Licence, as excerpted below, provides the following requirements for the Cover Design.

*The Licensee shall submit to the Board for approval a report assessing the proposed covers which shall include, but not be limited to the following:*

1. *A description of the proposed materials;*
2. *The results of field testing and thermal modeling for covers over tailings, waste rock and landfill debris;*
3. *Plans showing the pre- and post-cover topography using sufficiently detailed contour intervals;*
4. *An assessment of cover performance under 1 in 100 year return period (warm year) and global warming scenarios.*
5. *Confirmation of availability of materials for cover construction;*
6. *The bathymetry of sub-aqueous tailings in West Twin Lake Reservoir which shows the extent of tailings located within 1.0 m of the water surface, and plans for mitigation of wave action on these tailings;*
7. *Quality Assurance/ Quality Control measures for short and long term maintenance;*
8. *A verification of cover thickness against extreme annual temperature variation (i.e., 1:100 yr warm event) verified within the boundaries already provided by global warming estimates;*
9. *An evaluation of alternatives for increasing minimum water depth in the Reservoir with emphasis on possible effects of waves and winter ice cover on long term water quality; and*
10. *An assessment of cover thickness with reference to cover result available for Area 14 as a case study.*

It is CanZinco's objective to develop all of the closure component reports in a comprehensive and logical manner while satisfying all of the requirements set forth in the water license. In such instances where the presentation and clarity of the reports is improved by addressing specific components in a different closure report than is designated within the water license, that measure has been taken. As such, upon reviewing the requirements of the cover report, as shown above, it has been determined that requirements Nos. 6 and 9 of Part G, Item 4, which apply to the water covered tailings in the Reservoir, are most logically addressed within the context of the West Twin Disposal Area Closure Plan Report (Water License Requirement Part G, Item 15). Similarly, the detailed design and grading plans for the landfill cover and waste rock pile/open pit covers are included in the respective reports; Landfill Closure Plan (Water License Requirement Part G, Item 17) and Waste Rock and Open Pit Closure Plan (Water License Requirement Part G, Item 8).

Therefore, in summary, the cover design report will provide the following:

1. Rationale for recommended cover material and thickness over tailings, waste rock, open pits and the landfill;
2. A detailed cover grading plan along with material quantities for the Surface Cell and Test Cell;

3. A monitoring plan to assess the performance of the tailings cover during closure;
4. A series of contingency plans that may be implemented should the cover perform in an unforeseen manner.

# 2.0 CONCEPTUAL REVIEW OF COVER DESIGN

## 2.1 Cover for Potentially Acid Generating Mine Waste

Acid generation from sulphide-bearing mine waste is a recognized environmental problem in the mining industry. Acid Rock Drainage (ARD) may be generated when sulphide minerals present in mine waste, such as pyrite, oxidize upon exposure to air and water. The resulting solution may be acidic, if the waste does not contain sufficient buffering capacity. Cover systems are generally placed on the tailings or waste rock to limit or minimize ARD generation. This is accomplished through minimization of water infiltration and oxygen uptake. Generally, the cover is constructed of a low permeability soil, and may include a geosynthetic liner or layers of different materials to provide capillary break. Alternatively, a water cover is sometimes used to provide isolation of mine waste due to its ability to act as an oxygen diffusive barrier.

## 2.2 Landfill Cover Design

Leachate may be generated in landfills when water percolates through the waste materials, potentially resulting in a transfer of contaminants. An engineered cover is generally placed on a landfill during closure to prevent or limit leachate generation. The cover is usually designed to promote surface run-off and limit infiltration. In order to limit infiltration, the cover is generally constructed using a low permeability material.

In addition, landfills are usually constructed overlying natural, low permeability materials or synthetic liners, if required. When water quality impacts are expected, a leachate collection system will typically be installed as well.

## 2.3 Cover Design in Cold Regions

Design of mine waste and landfill covers is different in cold regions, as compared to southern locations, due to the colder environment and existence of permafrost. The geothermal regime at northern locations provides the opportunity to use a natural cover constructed of granular material. A properly designed cover limits the depth of active layer thaw and keeps the waste in a frozen state. A frozen, ice saturated zone within the cover can limit infiltration of water and air into the underlying waste material. As a result, the cover provides a reduction in oxygen diffusion and mitigates the generation of leachate and the exfiltration of contaminants.

The concept of incorporating permafrost aggradation into cover design of landfills and tailings deposits has been successfully implemented at northern locations in the past. Grozic et al. (2003) states that natural permafrost is being utilized in the design of containment systems for contaminated soil and landfill waste materials at several Distant Early Warning (DEW) Line sites across the Canadian Arctic. The cover design for the DEW line landfills generally involves encapsulating the landfill with a saturated granular fill and geosynthetic liner that is keyed into the underlying permafrost. The concept is based on the cover thickness being sufficient to maintain frozen conditions throughout the year. When frozen, the saturated granular material acts as a low-permeability containment barrier to moisture migration and solute transport. A geo-synthetic liner is incorporated into the design for short term containment until permafrost aggrades into the landfill and cover. Grozic et al. (2003) goes on to state that, performance monitoring to-date has been accomplished utilizing ground temperature measurements, visual assessment and measurements of chemical indicators in the soil and groundwater around the landfills. The performance monitoring indicates that the constructed landfills are performing as intended.

Gartner Lee (2001) describes the cover design for the landfill at the Polaris Mine in Nunavut. The principle of the design involves construction of a cover made of coarse grained material (coarse shale or a comparable material). The cover is designed to provide sufficient insulation to keep the underlying waste (industrial waste and construction debris) in a perpetual frozen state. The cover thickness was selected based on the results of geothermal modelling which considered global warming. The global warming scenarios considered were the Best Estimate case (2.9°C/100 years) and High Estimate case (5.0°C/100 years). After the assessment, a 1.8 m thick cover of weathered shale was recommended; no liner was included in this design. The initial data collected during the first two years following closure of that landfill are positive and generally supportive of the concept of permafrost aggradation through the waste materials.

Holubec and Hohnstein (2003) describe the cover design for tailings at the Lupin Mine in Nunavut. Lupin Mine has proposed a partially saturated cover design for reclamation of the tailings. The design principle involves covering the tailings with approximately 1.0 m of esker sand and saturating the bottom 0.3 m of the cover to provide an oxygen barrier. The cover is designed to maintain frozen conditions within the tailings for much of the year with active layer thaw penetrating the tailings during the summer months. The design is undergoing field trials by constructing the cover on one of the cells and monitoring ground temperatures and water quality. Geothermal monitoring indicates that active layer thaw penetrates a maximum of 0.3 m into the tailings and ground temperatures above 0°C remain within the tailings for about 2.5 months of the year.

These three examples show some recent examples being used in the Canadian Arctic for the containment of various types of waste.

# 3.0 SITE CONDITIONS

## 3.1 Location and Topography

Nanisivik Mine is located at the northern end of Baffin Island at approximately 73° N latitude, as shown on Figure 1. The mine is approximately 5 km from Strathcona Sound, which is connected to the Arctic Ocean through Admiralty Inlet.

The mine area consists of a few intermittent planar areas predominantly surrounded by moderately steep, high-relief hills rising out of Strathcona Sound. The surface topography rises from sea level to a high point of approximately 650 m immediately west of the mine area (Mt. Fuji).

Figure 2 provides an outline of the main components of the West Twin Disposal Area (WTDA). Tailings solids are stored in the Surface Cell, Test Cell and Reservoir. The West Twin Dike and the Test Cell Dike provide retention of the solids above the water level of the Reservoir. Supernatant and runoff-water report to the Reservoir, which fluctuates at approximately 371 m elevation. When the water quality in the Polishing Pond meets licence criteria, the water is discharged into Twin Lakes Creek.

East Twin Lake (Figure 1 and 2) provides the potable water source for the mine and townsite. For that reason, the water level in the Reservoir is kept lower than the level of East Twin Lake to prevent seepage from the WTDA from entering East Twin Lake.

## 3.2 Climate

### 3.2.1 Climate Stations

The relevant baseline climatic data required for this study includes air temperature, precipitation, evaporation, wind speed and solar radiation. Atmospheric Environment Services (AES) of Environment Canada maintains a network of climate monitoring stations in Nunavut, which have systematically collected some of the required data. An AES station exists at the airport in Nanisivik and DIAND maintained a weather station at the WTDA between 1993 and 2001. However, not all required climate data is available from the Nanisivik weather station, therefore, some information had to be extrapolated from other weather stations. Table 2 identifies the different weather stations that are proximal to Nanisivik and Figure 3 displays the locations of these stations.

When available, and of sufficient quality, climatic data was used from the Nanisivik Airport AES Station. The airport is located 10 km from, and 270 m higher in elevation than the WTDA. Climate data that was used from this station includes maximum and minimum air temperature, maximum and minimum relative humidity values and precipitation. The DIAND station at the WTDA was installed to calculate the average annual evaporation rate between 1993 and 2001, but its data sets are incomplete in some years due to power supply limitations.

Despite the proximity of the Arctic Bay weather station, climate data comparisons with the Nanisivik AES Station are significantly different. Mean annual air temperatures for Nanisivik and Arctic Bay differ by approximately 1.3°C (with Arctic Bay being warmer), demonstrating the influence of elevation and proximity to the ocean. As a result, the Arctic Bay station was not considered representative for Nanisivik or the WTDA.

The average wind speed values and snow depth readings were derived from the Resolute Airport Station. Historically, wind speed values were not recorded from the Nanisivik Station. The Resolute weather station was chosen for snow depth readings since records have been kept at this location since 1955, whereas only partial snow depth data is available at Nanisivik since 1981. The Nanisivik Station contains insufficient data to develop appropriate snow depth monthly average values.

### 3.2.2 Air Temperature

The long-term daily air temperature data recorded at the Nanisivik Station were analyzed to determine the mean and extreme monthly temperature distributions for the project site. Table 3 summarizes the resulting statistics of mean monthly air temperatures. Figure 4 illustrates the distributions of the overall mean monthly temperatures, as well as the minimum mean and maximum mean monthly temperatures. The estimated long-term mean monthly air temperatures range from -30.3°C in February to +4.9°C in July. Based on the long term mean data (1977-2000), the mean annual air temperature (MAAT) for the site is -15.1°C. The highest MAAT occurred in 1977 and was recorded to be –13.9°C. The lowest recorded MAAT occurred in 1986 and was recorded to be –16.8°C.

Figure 5 illustrates yearly MAAT values versus time for the history of the climatic records (1977-2002) at the Nanisivik Station. A linear regression trend line has been added to the plot to help identify trends in the data. From the 20 years of available data (6 years missing), an apparent trend of 0.6°C/decade of warming can be seen in the Nanisivik weather data. The coefficient of determination, $r^2$, for the trend at Nanisivik was only 0.22, (or 22% correlation) a low value considering perfect correlation would result in a value of 1.0. The same plot, Figure 6, was developed for the Resolute data since a much larger database (1948-2000) was available. From the Resolute data, a warming trend of 0.12°C/decade was determined, based on an even lower correlation value of only 0.037.