Nanisivik Mine

Closure and Reclamation Plan

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CanZinco Ltd.
February 2002

Volume 2 of 2:
Supporting Documents

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Nanisivik Mine
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Volume 2 of 2
Supporting Documents

A. 2001 Environmental Site Assessment and Proposal for Phase 2 ESA, Gartner Lee Limited, February 28, 2002.
B. Reclamation Cover Design for Nanisivik Mine West Twin Disposal Area Surface Cell, Gartner Lee Limited, March 08, 2002.
C. Pseudostatic Analysis for Seismic Stability of West Twin Lake Dyke, Closure Planning for Nanisivik Mine, NU, BGC Engineering Inc., February 5, 2002.
D. Report on Hydrological Study Nanisivik Spillway Design, Golder Associates Ltd., February 2002.
E. Preliminary Design of the West Twin Dike Spillway for Closure, Nanisivik Mine, NU, BGC Engineering Inc., February 28, 2002.

Prepared for:

CanZinco Ltd.

Prepared by:

Gartner Lee Limited

February 2002

Nanisivik Mine

2001 Environmental Site Assessment and Proposal for Phase 2 ESA

Prepared for

Canzinco Ltd. Nanisivik Mine

Prepared by:

Gartner Lee Limited

GLL P21957

February 28, 2002

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1. Introduction

1.1 Overview of Nanisivik Mine

The Nanisivik Mine is located on the Borden Peninsula on northern Baffin Island in the Canadian Arctic at a latitude of approximately 73 degrees north (Figure 1). The mine site is on the south side of Strathcona Sound approximately 30 km from the inlet to the Sound. The community of Arctic Bay is located approximately 25 km to the west of Nanisivik. The two communities are linked by a 33 km all-weather road.

A jet airport that is owned and operated by the Government of Nunavut is located approximately 10 km south of the town. Commercial flight service is provided via Ottawa, Iqaluit and Resolute.

Mineral exploration activities were carried out primarily from 1958 to 1968. Construction of the mine commenced in 1974 and operation/processing commenced in 1976, making it the first operating metal mine in the Canadian Arctic. Mine employees live in the town of Nanisivik, built approximately 1 km from the mine/mill area specifically to house mine workers. The town includes a church, recreation centre, school, housing, post office, store, diesel electric power plant and other amenities to provide comfortable living for employees and their families. Construction of the town was partially funded by the Government of the Northwest Territories and some of the town facilities are currently owned by the Government of Nunavut.

The mill and mine are located approximately 3 km from Strathcona Sound, the town is located approximately 4 km from the Sound and the tailings storage facility is located approximately 7 km from the Sound as illustrated on Figure 2. A concentrate storage shed, ship loading facility, dock, fuel tank farm and reagent storage area are located at the Sound. The dock is used by the Canadian Coast Guard as a storage facility for marine environmental emergency response equipment and also as a fueling station.

The mine is primarily an underground operation with smaller contributions of ore from four open pits. Underground mining has been primarily room and pillar method and will focus largely on pillar recovery during the last months of operation in 2002. The underground mine is very “dry” due to the permafrost conditions to the extent where specialized dust collection apparatus is installed on drilling equipment. Ground temperatures in the underground mine are constantly below freezing (typically $-13^{o}C$) and permafrost conditions are known to extend to at least 600 metres below surface. The underground workings extend in an approximate east-west alignment and daylight on either side of a topographic ridge (approximately 3 km long X 100 metres wide X 10 metres thick). Vehicle access into the underground mine is via several adits that allow passage of both heavy and light equipment. There is one ventilation raise to surface from the primary underground workings.

The processing plant involves dense media separation (2001) and conventional grinding, flotation and dewatering circuits. Zinc and lead mineral concentrates are produced that are hauled in open gravel trucks from the mill to the concentrate storage shed, which is located at the dock. Mineral concentrates are loaded onto ocean going ships during the ice free season. The ship loading conveyor system was enclosed in the early 1980's. On average, 790,000 tonnes/year of ore containing 8 to 14% zinc are processed per year to produce 110,000 tonnes/year of mineral concentrates.

Process tailings are pumped approximately 4 km from the mill to the tailings storage facility, West Twin Disposal Area (WTDA), formerly known as West Twin Lake. The WTDA storage capacity was increased in 1990 with construction of an internal dyke across the lake that created upper and lower storage areas. The upper portion of the lake became a surface tailings deposition area and has been the primary storage area since 1990. The lower portion of the lake has remained a subaqueous tailings storage cell and reservoir for water decanted from the upper area via a series of syphon pipes and pumps. A large portion of the water in the WTDA is returned to the mill via an overland pump/piping system for reuse in the concentrator. Surplus water is released seasonally through a polishing/retention system.

A tailings reclamation test area ("Test Cell") was constructed in the lower portion of the WTDA. The test cell is separated from the remainder of the lower storage facility by a second internal dyke. Test pads were constructed as a means of testing various reclamation measures. Thermocouples and frost gauges were installed within the tailings and the cover materials to allow monitoring of ground freezing.

The two WTDA internal dykes were constructed using frozen tailings core construction. The upper storage area dyke has been raised on an incremental basis since 1990 using upstream construction with tailings and shale.

1.2 Land and Water Authorizations

CanZinco Ltd. holds three land leases that were issued under the Commissioner's Land Act and are subject to the Commissioner's Land Regulations. The leases require that, upon termination of the lease, the leaseholder shall deliver the land in a restored condition as prescribed by the latest approved plan of restoration.

Water License NWB1NAN9702 was issued by the Nunavut Water Board in 1997 to CanZinco Ltd. The initially stated License expiry date was July 2002. The expiry date was extended in December 2001 to correspond to the recently announced date of mine closure (September 2002). Additionally, the Water Board has extended the schedule for submission of a Final Abandonment and Reclamation Plan from December 31, 2001 (60 days following the announcement of permanent closure) to February 28, 2002.

It is understood that Nanisivik Mine also holds federal mine leases and mineral claims.

1.3 Related Government Owned Facilities

The construction of some facilities and infrastructure related to the Town of Nanisivik were funded by the Government of the Northwest Territories during construction of the mine and town. Ownership of these facilities was subsequently passed to the Government of Nunavut.

These facilities include:

- Sewage treatment system.
- Town centre (including: school, RCMP, fire hall, daycare, store, post office).
- Town fresh water supply and distribution system.
- Road from town to East Twin Lake freshwater supply.
- Jet airport.
- Road to airport.
- Road to Arctic Bay.
- Some housing in the town of Nanisivik.

Construction of the dock was partially funded by the Government of Canada and is used routinely by the Canadian Coast Guard as a storage facility for marine environmental response equipment and for refueling.

1.4 Project Objectives and Approach

The objectives for this project are to provide a Phase 1 Closure Assessment for the Nanisivik Mine and provide recommendations for completion of a Phase 2 Environmental Site Assessment (ESA) to identify and quantify specific remediation requirements. Completion of a Phase 2 ESA will utilize relevant information that has been collected by mine personnel.

The approach that has been taken to achieve the project objectives involved:

- Preliminary document review and information gathering.
- Site visit and interviews with management personnel.
- On-site review and documentation of available information.
- Descriptive report of proposed reclamation plans and available information.
- Development of a recommended Phase 2 ESA.

2. Overview of Environmental Setting

2.1 Biophysical Environment

The climate is typical of the Canadian Arctic with relatively low precipitation and cold temperatures. The average annual precipitation and air temperature measurements at the jet airport from 1981 to 2001 were 242 mm and -15 degrees C, respectively. The depth of the active layer in the mine area is observed to vary in the order of 1.0 metres dependent on air temperature, slope attitude, ground cover, snow thickness and other factors.

The surface topography is moderately steep rising from sea level to a local high of 650 metres immediately west of the mine area ("Mount Fuji"). The approximate elevations of several areas around the minesite (Figure 2) are listed in Table 1.

Table 1: Approximate Elevations of Mine Facilities

Location	Approximate Elevation (masl)
mill site	260
town site	325
freshwater storage tank	375
lower portion of West Twin Disposal Area (West Twin Lake)	370
freshwater supply (East Twin lake)	372
Adit No. 1 (main entrance to underground mine)	300
Oceanview Open Pit	260
Area 14 mining area	450
landfill/STOL airport	360

Vegetation cover in the mine area prior to construction of the mine and town was sparse with 96% of the mine area was classified as "dry ridge". Wildlife utilization of the mine area is low and baseline studies reported indications of lemming, Arctic hare and Arctic fox. Several species of terrestrial birds were observed in limited numbers in the baseline studies.

The local marine environment is documented as supporting aquatic resources typical of Canadian Arctic coastal areas. Marine sediments in the immediate area of the dock have been documented as displaying increased concentrations of heavy metals subsequent to the start of mine activities.

2.2 Surface Geology and Natural Mineralization

The mine area is characterized by the Society Cliffs Formation. This formation is a gently dipping homogeneous dolostone of Neoproterozoic age, estimated to be 1200 million years of age. This formation is underlain by shale of the Arctic Bay Formation, and by dolomitic shale of the Victor Bay Formation. Massive sulphide deposits occur in the upper part of the Society Cliffs Formation. Ice lenses were found in the dolostone beneath the plantsite and in the mine workings.

Virtually no soil formation has occurred. The little soil has developed is located primarily in alluvial plains where eroded and wind blown material have settled.

Naturally occurring sulphide mineralization at surface is well documented throughout the mine area. As a result, the concentrations of heavy metals in surface water run off prior to mine development were high in some locations in the West Twin Lake area, townsite area, and other mine areas. Sands in the area including the bottom of West Twin Lake can be stained red due to oxidation.

Surface soil sampling for metal concentrations has conducted extensively in the mine area as part of exploration activities and this data documents the range of metal concentrations that were present in surface soils due to natural conditions.

2.3 Surface Water Drainage

The primary surface drainage in the mine area is Twin Lakes Creek, which drains the East and West Twin Lakes, town area and west adit area watersheds into Strathcona Sound as illustrated on Figure 2.

The release of decant water from West Twin Lake is manually controlled as appropriate to maximize water cover over subaqueous tailings. Water flow exiting East Twin Lake is not artificially controlled except to the extent that a relatively small volume of water is extracted from the lake for freshwater use in the town and the mill.

Twin Lakes Creek flows directly below the 01, 02 and 09 adits, the 09 and 02 rock piles, the West Open Pit, an exposed natural mineral outcrop and the millsite. Untreated effluent from the government sewage treatment plant enters Twin Lakes Creek near the mill. Twin Lakes Creek enters Strathcona Sound west of the dock area.

Water quality in Twin Lakes Creek is significantly affected by runoff from the areas listed above and contains seasonally variable loadings of heavy metals. The potential sources of metals in Twin Lakes Creek have been extensively investigated by Nanisivik Mine and others and are considered to include both naturally occurring exposures of sulphides and mine activities. The compliance record at the decant from the West Twin Disposal Area is excellent.

Chris Creek is a smaller creek that drains surface water into Strathcona Sound from the watershed on the north side of the mine area. Specifically, surface run off from the East Adit area, waste rock piles, K-Baseline area and discharge from the east adit water treatment system enters Strathcona Sound via Chris Creek where water quality is also monitored.

Baseline studies indicated that neither Twin Lakes Creek nor Chris Creek supported fish populations prior to mine development due to steep gradients, waterfalls and generally unsuitable habitat. Baseline studies also indicated that neither East nor West Twin Lakes supported fish populations prior to mine development.

3. Site Description and Remedial Concepts

3.1 General Layout

The general layout of the mine and related facilities is illustrated on Figure 1.

3.2 Town and Related Facilities

The town consists of approximately 50 small houses, several apartment/bunkhouse buildings, a recreation centre complete with swimming pool, a cook/mess building, a church, a school, an arena, a fire hall, a library, a post office and various garages and shops for maintenance equipment (Figure 3).

The town facilities are primarily owned by the mine. Several houses and some public infrastructure buildings are owned by the Government of Nunavut such as the school and various maintenance garages and maintenance equipment. The freshwater and sewage systems are also owned by the government of Nunavut.

The buildings are heated by oil fired furnaces with each building served by an individual supply tank. The typical arrangement is one 100 gallon above ground tank per house. Buildings are typically wood frame construction and are generally in the order of 25 years old. Maintenance garages are sheet metal construction or quonset hut construction.

There are two closure concepts for the town facilities. The primary concept is the demolition of all facilities with disposal of non-hazardous materials into the permafrost environment in the underground mine. Hazardous materials will be managed appropriately with packaging, transport and disposal off site, if necessary. This concept provides for secure disposal of all materials and allows for compete reclamation of the land. Demolition and reclamation of government owned facilities within the town would be included in the project on behalf of the Government of Nunavut.

The alternate closure concept is for ownership of some or all of the town facilities to be transferred to other organizations for on-going use. This could include moving some buildings to Arctic Bay, the transfer of ownership of the entire town to Defence Canada for use as a military training facility or the transfer of some buildings to the Government of Nunavut for use as a trades training facility. This concept would provide for the on-going use of existing facilities for the benefit of Northern residents or the Government of Canada. Under this scenario, contaminated soil in the town area would be remediated as deemed appropriate for the on-going use of the facilities.

Although discussions have been held regarding the alternate closure concept, the primary closure concept is being advanced until such time as an alternate concept comes into effect. That is, demolition of the town facilities will take place if formal agreement regarding an alternate concept has not been achieved by that time.

3.3 Mill and Related Facilities

The concentrator plant is a conventional grind/flotation plant that produces two mineral concentrates from sulphide ore. A dense media separator plant, constructed in 2000/2001, is a pre-concentration process step that removes gangue material from the ore before it enters the mill circuit. Other major mill equipment includes: flotation cells, pumps, piping, cyclones, grinding mills, thickeners, dewatering filters, air compressors, blowers, vacuum pumps, controllers/instrumentation and electrical wiring.

The mill/administration building includes: all offices for property management and administration, mine operations, mill operations and maintenance personnel. A dry/shower facility, lunch room, first aid facility and assay laboratory are also included in the building.

The mill facilities also include the outdoor storage and laydown yards, miscellaneous small buildings/sheds and the diesel fuel delivery system for the diesel electric power plant and other ancillary uses. A detail of the outdoor warehouse yard is illustrated on Figure 3.

The closure concept for the mill facilities is to salvage equipment for use at other Breakwater Resources Ltd. operations or public sale and to demolish the remaining facilities and buildings for permanent disposal in the permafrost environment in the underground mine. Contaminated soil (per the site remediation objectives) will be either excavated and disposed in the permafrost environment of the underground mine or covered in place with clean soil/overburden. This concept provides for on-going use of some equipment and the secure disposal of unwanted equipment and materials. Remediation of the land in the mill area will be enabled by the complete demolition of the facilities. Concrete floor slabs and equipment foundations will be covered with soil/overburden such that they are not exposed.

3.4 Dock and Related Facilities

The dock facilities that are owned by Nanisivik Mine include: the concentrate storage shed, the ship loading conveyor, the fuel tank farm and the reagent storage/laydown yard (Figure 4). The concentrate storage shed is approximately 100 metres X 50 metres. The tank farm consists of 15 tanks varying in capacity from 100,000 litres to 10,000,000 litres.

The concentrate handling system consists of truck haulage of concentrates from the mill to the storage shed. Front end loaders may rehandle and repile concentrates within the shed and, ultimately, load the concentrates onto the ship loading conveyors. The ship loading conveyor was enclosed in 1982 to minimize concentrate losses to the environment.

The tank farm is used to store diesel fuel for use in mine activities and home heating, jet fuel and gasoline. Jet fuel is stored and delivered to the jet airport by mine personnel on a contract basis for the Government of Nunavut. Diesel fuel is stored and provided to the Canadian Coast Guard for refueling of ships.

The dock itself is owned by the Government of Canada. The dock and dock area are used by the Canadian Coast Guard as a storage depot for marine environmental emergency response equipment.

The closure concept for the mine-owned facilities in the dock area is dismantling and disposal of the ship loading conveyor, the concentrate storage shed and the tank farm in the permafrost environment in the underground mine. The tank farm and related piping would be cleaned of residual hydrocarbons and purged of vapours as part of dismantling. Contaminated soils would be remediated either by disposal in the underground mine or by covering in place with clean overburden/soil. The slab floor of the concentrate storage shed would be covered with overburden/soil. An alternate closure concept would allow for the transfer of ownership of some of the mine-owned facilities (such as the tank farm and the concentrate storage shed) to other organizations. This alternate concept would allow for the continued use of existing infrastructure for the benefit of Northern residents but would not alter the current concept (complete remediation of mine-owned facilities) until formal agreements are in place.

3.5 Tailings Storage Facility: West Twin Disposal Area (WTDA)

Process tailings are pumped from the mill to the WTDA. Tailings were deposited under a water cover in West Twin Lake until 1990, at which time a frozen core dyke was constructed of tailings and shale that divided the lake into two approximately equal sections. The dyke was built in annual upstream lifts of approximately 2 metres each to ensure permafrost aggradation. The dyke is currently 18 metres high and 800 metres in length. Tailings deposition at the toe of the dyke provides increased physical stability for the structure. Tailings have been confirmed to possess the potential to produce acid rock drainage under certain environmental conditions.

Tailings are currently deposited subaerially (exposed) in the upper containment area (the “surface cell”) according to a strategic plan that ensures the maximum utilization of the available storage capacity. Water is decanted from the upper surface cell to the lower “reservoir” via syphon pipes and pumping. The water is largely clear due to rapid settlement of solids.

The lower containment area (the “reservoir”) contains subaqueous tailings that are covered with water and a relatively small amount of tailings that are exposed in a reclamation test cell area and around the littoral area of the reservoir. Water is pumped from the reservoir to the mill for reuse in the concentrator process. The water elevation in the reservoir is manually controlled at a valved discharge structure where water is released to Twin Lakes Creek. The water elevation is managed in such a way to maintain adequate water supply for the reclaim pumping system and to maintain at least one metre over the subaqueous tailings. The water level is also managed to remain below the water elevation in East Twin Lake as a means of reducing the possibility for subsurface flow from the WTDA to East Twin Lake

The reclamation test area (the “test cell”) is located within the lower containment area separated from the wet reservoir by a small (approximately 4 metres high) dyke constructed of tailings and shale. The test cell area has been used to evaluate the efficiency of various materials and methods of placement as the reclamation soil cover on exposed tailings.

Wind dispersion of tailings particles has been an issue of environmental concern in recent years. Wind dispersion has typically been observed during the winter when the surface of the upper containment area might be windswept clear of snow cover exposing dry tailings particles. The wind direction is predominantly from the SSE and dispersion of particles has been observed to the lee side of the surface cell. Dust control methods have been implemented to mitigate wind dispersion including: induced ice cover (through flooding and water cannons), natural and induced snow cover (through fencing), shale cover, and water saturation during periods of thaw.

The closure concept for the WTDA combines two appropriate remedial methods (illustrated on Figure 5):

1. water cover in the reservoir.
2. soil cover to induce freezing in the surface cell.

The decant control structure at the outflow of WTDA will be removed, which will return the lake water level to the pre-mining condition. An overflow spillway will be constructed that will safely pass runoff water from the upper surface cell to the lower reservoir.

A minimum 1 metre water cover will be provided over subaqueous tailings in the WTDA lower reservoir that will minimize oxygen availability and, thereby, minimize oxidation rates within the upper zone of subaqueous tailings. A layered soil cover comprised of shale and gravel will be placed over exposed tailings in the surface cell, the test cell dyke and in littoral areas of the reservoir. The shale and gravel cover will be of sufficient thickness to ensure that the underlying tailings remain frozen with the seasonal active layer restricted to the cover materials. The cover will also enable the formation of an ice zone within the lower portion of the cover. The soil cover will minimize oxidation rates in two ways: by maintaining low temperatures (below 0^0C) and by reducing oxygen availability through lower oxygen diffusivity (in ice versus air or water). The soil cover will also minimize the transport of any contaminants to surface water by preventing contact between tailings and water.

3.6 Freshwater Supply (East Twin Lake)

Water is pumped from East Twin Lake to a freshwater supply tank located on a hill above the town and subsequently distributed to the town and the mill. A relatively small quantity of fresh water is required for the processing system in the mill (less than 10% of the water usage).

Outflow from the lake is not manually controlled but is passed through a short diversion channel (the East Twin Diversion Channel) prior to mixing with water from the WTDA. The diversion channel ensures that mixing of water from East Twin Lake with water from the WTDA reservoir takes place below the WTDA decant control structure.

A hydrogeological assessment that was completed in 2000 confirmed that there is no subsurface hydraulic connection that would allow subsurface water flow from the tailings storage facility (West Twin Lake) into East Twin Lake. The study also verified that the permafrost is intact between the two lakes. The water elevation in West Twin Lake is manually maintained below that in East Twin Lake to provide increased environmental protection.

The closure concept for East Twin Lake involves removal of the pumping system and long term stabilization of the outlet diversion channel.

3.7 Roadways and Pipelines

There are approximately 30 km of roadways around the mine site and the town of Nanisivik that will be remediated. There is a possibility of surficial contamination of road material by tracking or spillage of concentrates in haulage areas. A suite of acid-base accounting analyses (reported by Lorax Environmental) has indicated that the roadfill from the main portal to the mill contains rock with a positive "net neutralization potential" and is not classified as potentially acid generating.

Pipelines run on surface between the mill and the East/West Twin Lakes area for transport of tailings, reclaim water and fresh water. Two small sediment ponds are located along the tailings pipeline route between the mill and the West Twin Lake tailings storage area. These ponds can provide some retention of solids and water in the event of a pipeline break or a planned draining. The ponds are lined with impermeable plastic liners and have been cleaned, as required to maintain storage capacity. Fuel supply pipelines run from the tank farm at the dock to the mill yard day tanks and dispensing facilities.

The closure and reclamation plan includes the decommissioning of some facilities owned by the Government of Nunavut including the road from the town of Nanisivik to East Twin Lake and the above ground freshwater and sewage pipelines. Reclamation would be performed by Nanisivik Mine on behalf of the Government of Nunavut.

The closure concept for roadways is to remove the roadfill where surface flow may be impeded and to scarify and contour the road surface in other locations to remove the hard packed driving surface. The surface of roads will be sampled and remediated, as appropriate for the intended land use. The exception will be the road from the airport/Arctic Bay to the dock, owned by the Government of Nunavut, which may undergo remediation of surface soils, as appropriate for the continued use, but will not be further decommissioned. The closure concept for pipelines is that all above ground pipelines will be dismantled and disposed of in the permafrost environment in the underground mine. The two tailings pipeline "retention ponds" will be cleaned of the plastic liners and any contaminated soils and then backfilled/contoured. These closure concepts provide for secure permanent disposal of materials and also provide for emergency or contingency driving access to and from the dock to inland areas.

3.8 Landfill

The landfill is located approximately 1 km west of the town near the STOL airstrip. The landfill has been used for disposal of waste materials from the Town of Nanisivik, the jet airport and the mine throughout the life of the mine. Paper/wood and foodstuff materials are routinely burned to reduce volume. Waste materials are routinely compacted and covered with local shale.

The primary environmental concern regarding the landfill is the potential for transport of contaminants (esp. hydrocarbons) from the landfill. Hydrocarbons in the landfill originated from historical operating practices and the disposal of spill clean up materials. Environmental protection measures include a soil berm at the toe of the landfill that directs run off water to a hydrocarbon absorbent boom.

A landfarming cell was constructed in the landfill area as a means of treating hydrocarbon contaminated soil that was recovered from small spills. The cell was constructed with a bentofix geotextile liner to prevent the transport of hydrocarbons into the soil.

An internal Phase1/2 site assessment was completed for the landfill in 2000/01 by Nanisivik Mine that included water and soil sampling downslope from the toe of the landfill. The report indicates that an average annual volume of 1,150 m^3 of solid waste (post burning) is added to the landfill with the majority of this volume originating from “institutional sources” such as the mill kitchen, the “dome” kitchen and the jet airport.

The closure concept for the landfill consists of covering waste materials with a shale cover of sufficient thickness to induce permafrost freezing within the waste and cover materials. This concept provides for secure long term containment of the landfilled waste.

3.9 Open Pits

There are four small open pits on the property: Oceanview, East Open Pit, East Trench and West Open Pit.

The Oceanview pit is located north and east of the East Adit area and contains mineable reserves that may be extracted during the summer season of 2002. Drainage from this pit passes into Strathcona Sound via poorly defined local channels east of Chris Creek.

The East Open Pit is located immediately west of the East Adit entry and includes a portal entry that connects with the primary underground workings.

The East Trench is located immediately east of the East Adit entry into the underground mine. This is a relatively small mined-out trench with minor underground mining into the trench wall. This underground mining did not connect with the primary underground mine workings.

The West Open Pit is located between the 00/01 portals and Twin Lakes Creek. This relatively small pit is mined-out and currently serves as a water collection pond for the adit area. Water that is collected in this pond is routinely pumped to the mill for subsequent pumping to the tailings storage facility.

The closure concept for the open pits is to backfill, where necessary, to prevent ponding of water and to provide a soil/rock cover over mineralized areas to induce permafrost aggradation into the backfill. This may include placing shale over pit slopes and waste rock used for backfilling. This concept provides for secure reclamation of the pits by providing land use and ground cover similar to the pre-mining condition (i.e. predominantly shale ground cover).

3.10 Underground Mines

The primary underground mine workings are located immediately east of the mill. The workings extend in an approximate northeast-southwest direction. Mining is currently proceeding in these workings and is focussed on the removal of support pillars. There are eight openings to surface:

- 00 portal: west adit area – ventilation.
- 01 portal: west adit area – primary vehicle access west side.
- 09 south portal: west adit area – alternate (summer) vehicle access.
- lower adit: west adit area – ore conveyor.
- 17N portal: currently unused vehicle access.
- shale hill raise: east adit area – ventilation.
- 39 portal: east adit area – no longer accessible (crown pillar mined).
- 88 portal: east adit area – primary vehicle access east side.

The mining method is drill and blast in ore using standard trackless equipment (jumbo drills, remote scoop trams, and haulage trucks). Ore is hauled to an underground pass that controls ore flow to the primary and secondary crushers. All crushing takes place in the underground mine and the crushed ore is moved to surface via a conveyor system.

Three small underground mines were developed at the K-Baseline, Oceanview and Area 14 sites. There is no additional mining scheduled for these workings during the remaining mine life. There is one entrance to each of these workings and the Oceanview workings has one ventilation raise to surface.

The closure concept for the primary underground mine is to utilize the permafrost environment for disposal of contaminated soils, demolition debris, equipment with no salvage value and other non-hazardous solid waste. All equipment would be drained of fluids (oil, grease, etc.) prior to disposal. The openings to surface will then be sealed with rockfill. The K-Baseline, Oceanview and Area 14 underground mines will not be used for disposal but the openings to surface will be securely sealed with rock fill. This concept provides an environmentally secure disposal location for contaminated soils and non-hazardous materials with no salvage value and also provides safety measures that prevent access into the mine.

3.11 Waste Rock Piles

Waste rock piles are located at each of the open pits and underground mine adits. The waste rock contains, in some areas, sulphide mineralization. The current mining method is employing waste rock underground as fill material necessary to facilitate pillar removal. This process is effectively relocating a large portion of waste rock from the east adit area and the west adit area waste rock piles into the underground mine.

The closure concept for the waste rock piles is to relocate mineralized waste rock into open pits or the underground mine. Material placed into the open pits will be contoured and covered as prescribed for reclamation of open pits for the aggradation of permafrost into the waste rock. Material placed underground will become part of the continuous permafrost zone. This concept provides a secure disposal environment.

3.12 Lime Treatment System

A lime treatment system is operated on an as-required basis in the East Adit area. The influent is runoff from the adit area that is collected in a constructed holding pond. Influent is mixed directly with dry lime in a conditioning tank and pumped to a settlement pond where treatment sediments are deposited. Two small dykes form the treatment pond and the settlement pond. The system is typically operated on an intermittent basis through the summer season during freshet or a rainfall event.

The remediation work planned for the east adit area is anticipated to eliminate the need for operation of the lime treatment system. The system will remain in place and will be operated on an as required basis until surface runoff water quality demonstrates that the system can be safely decommissioned. At that time, treatment sediments will be excavated from the settlement pond and placed in the permafrost environment in the underground mine. The two small dykes will be excavated such that natural surface runoff flow is restored without risk of sedimentation.

4. Available Information

4.1 Background Environmental Studies

A series of three progress reports were prepared by B.C. Research Inc. in March 1975 that describe baseline environmental conditions in the mine area.

Progress Report No. 1 describes the marine environment in Strathcona Sound. This includes (among other topics):

- Bathymetry.
- Shallow and deep current patterns.
- Metal concentrations in Sea Water.
- Numeration and metal concentrations in aquatic organisms.
- Metal concentrations in Twin and Chris Creeks.
- Metal concentrations in marine sediments.

Progress Report No. 1 reports concentrations of zinc in upstream reaches of Twin and Chris Creeks of 54 mg/L and 15 mg/L, respectively.

Progress Report No. 2 describes the terrestrial environment in the mine area. This included (among other topics) vegetation/ground cover mapping. Approximately 96% of the mine area was classified as "dry ridge" characterized by low productivity, sparse cover and low wildlife utilization. The generally sparse and rocky ground cover was interspersed with small areas of denser vegetation coverage typically in small isolated areas where moisture was retained in surface soils.

Progress Report No. 3 describes bioassay testing on tailings supernatant that was obtained from metallurgical test work. The bioassay test results appear to have been acceptable when the pH of the supernatant was modified (reduced) although additional review of the document will be required to confirm this observation.

4.2 Environmental Studies

The following is a chronological listing of environmental studies that have been performed at or that involved the mine area and a brief comment highlighting contents of particular interest. This list may not be exhaustive but is thought to represent a substantial compilation of available information.

1. Hatfield Consulting Ltd. (for DIAND), 1976, A Summary of Possible Environmental Effects of Disposing Mine Tailings into Strathcona Sound.
   - comments on direct deposit of tailings into Strathcona Sound, which was an alternate mine plan at start up

- uses existing environmental information (i.e. no new information generated)

2. DFO (B. Fallis), May 1982, Trace Metals in Sediments and Biota from Strathcona Sound, NWT, 1974-1979
   - presents data collected from 1974 to 1979
   - also related to background environmental conditions

3. DIAND (Thomas & Erickson) (per Arctic Environmental Laboratories Ltd.), March 1983, The Concentrations of Zn, Cd & Pb in Sediment Cores from Strathcona Sound, NWT

4. DIAND (via Arctic Environmental Laboratories Ltd.), May 1983, The Concentrations of Zn, Cd & Pb in Sediment Cores from Strathcona Sound.
   - analysis of core samples collected in 1982
   - greatest metal concentrations generally identified near sediment surface and in proximity to Twin Lakes Creek

5. DIAND (via Arctic Environmental Laboratories Ltd.), December 1983, Chemical and Biological Studies at Strathcona Sound.

6. INAC (D. Thomas) (via Arctic Environmental Laboratories Ltd.), 1983, Final Report.
   - identifies greatest metal concentrations in sediment and water in proximity to Twin Lakes Creek
   - suggests that concentrate dust from storage/loading facility is related to observed trends in metal concentrations in sediment and water

7. DIAND (via Arctic Environmental Laboratories Ltd.), June 1986, Cd, Pb & Zn Particulate Fluxes and Sea Water Concentrations.
   - additional water sampling in Strathcona Sound
   - estimates sedimentation rate
   - expands on reference in 1983 report to suggested relation between concentrate storage/loading activities and observed metal concentrations in sediment and water

8. INAC/DFO, September 1986, Heavy Metals and Organic Contaminants in Arctic Marine Fishes.
   - fisheries study that included Arctic Bay as well as other northern communities

9. Boojum Research Ltd., October 1987, Ecological Engineering for Gold and Base Metal Mining Operations in the NWT.
   - presents new and existing surface water quality data
   - identifies naturally occurring high metal concentrations

10. INAC (B. Grey), December 1989, Summary Report on Surface Water Quality at Nanisivik 1977-1988.
    - includes a water quality interpretation of Twin Lakes Creek

- suggests relationship between higher zinc concentrations and high precipitation events
- refers to possible effects of dustfall from the tailings area

11. Asmund, Johansen and Fallis, May 1990, Disposal of Mine Wastes Containing Pb & Zn Near the Ocean … in the Arctic.

12. DFO (B. Fallis), September 1990, A Further Evaluation of Trace Metals in Sediment and Biota from Strathcona Sound.
    - collects and analyses available metal concentrations in sediments, seaweed, urchins and molluscs
    - metal concentrations suggested to have increased prior to ~1982 and to have stabilize since that time

13. North/South Consultants Inc., 1992 or 1993(?), Draft Report An Assessment of the Environmental Impacts on Strathcona Sound from the Nanisivik Mine
    - presents and discusses 1992 data

14. AQUAMIN Report, April 1995, Draft Case Study for Nanisivik Mine, NWT.
    - presents and summarizes existing environmental information

15. UMA Engineering Ltd. (for GNWT), June 1998, Nanisivik Mine Operations Literature Review.
    - provides compilation and summary of existing information

16. Lorax Environmental (for Nanisivik Mine), October 2000, Chronic Toxicity Testing Mouth of Twin Lakes Creek in Strathcona Sound.
    - conducted testing on marine sand dollars, Microtox testing and sea water sampling on samples from the Twin Lakes Creek estuarine mixing zone and an upstream control sample in Strathcona Sound
    - samples in the Twin Lakes Creek mixing zone were collected from surface 30 metres off shore and at surface and 5 metres depth (mid-depth), 75 metres from shore
    - samples from the control station were collected at surface and at 5 metres depth at a distance of 25 metres from shore at the mouth of Kuhulu Creek, which is located approximately 8 km upstream from Twin Lakes Creek
    - the concentration of zinc in sea water was greatest in closest proximity (30 metres off shore) to the inflow from Twin Lakes Creek; the concentrations of zinc in sea water 75 metres off shore from the inflow of Twin Lakes Creek were similar to those at the inflow of Kuhulu Creek
    - sand dollar fertilization was slightly inhibited in the sample proximal to the inflow of Twin Lakes Creek as compared to the other samples; microtox test results did not clearly repeat this observation

17. A water quality and metal loading study in Twin Lakes Creek has been conducted and reported on by Nanisivik Mine in the early 1990's and in 2000/2001. This has involved rigorous sampling and flow

monitoring in the creek through the ice free season with the intent of identifying source areas for metals and seasonal trends. The primary observations are as follows:

- zinc concentrations and loadings exiting the West Twin Lake tailings containment area are a very minor contributor to metal loadings in Twin Lakes Creek
- zinc concentrations and loadings generally increase from the East/West Twin Lakes area to Strathcona Sound with the greatest concentrations observed at various times in proximity to certain rock dumps and natural outcrops of massive sulphides
- an early season (spring) spike in zinc concentrations occurs in proximity to rock dumps, which is considered to be related to melting and flushing of rock dumps
- a second spike in zinc concentrations occurs in proximity to a natural sulphide outcrop, which is considered to be related to slower (as compared to rock dumps containing very coarse material) melting and runoff from natural soils
- the late season spike in zinc concentrations is accompanied by high iron concentration, which is also considered to be related to natural runoff and melting of surface soils
- the high late season iron concentrations result in a visible orange discolouration of the creek water and staining of creek sediments in Twin Lakes Creek and other local creeks

4.3 Mine Reclamation Studies

4.3.1 Tailings Soil Cover Research Studies

A great deal of original research work and engineering studies have been conducted at the Nanisivik mine regarding optimizing the closure concept for the tailings containment area.

A multi-year research program focussed on investigating optimum design criteria for a soil cover over dry tailings has been jointly funded by Nanisivik Mine, the University of Copenhagen and the Danish Environmental Agency. This work was led by Dr. Bo Elberling of the University of Copenhagen and followed two general topic areas:

1. Development and calibration of a site specific geothermal model for the prediction of ground temperatures at various depths under various climatic and cover conditions.
2. Estimation of sulphide oxidation rates at various ground temperatures.

Both of these topic areas included field work for the installation and monitoring of instrumentation in upper West Twin Lake containment area and in the lower West Twin Lake tailings cover test facility.

A brief summary of the research findings is as follows:

- A commercially available geothermal model was calibrated to site specific conditions based on: field measurements of ground temperatures and climatic conditions, laboratory determined physical properties of tailings and various cover materials, and generally used thermal properties for snow.
- The calibrated model was demonstrated to reasonably reproduce the observed conditions.

- The geothermal model indicates that the thickness of soil/rock cover over tailings is the most critical factor for controlling ground temperatures within the upper tailings.
- The geothermal model indicates that ground temperatures in the upper tailings is sensitive to the thickness of snow cover with a late and/or thin snow cover resulting in colder ground temperatures.
- The model predictions of ground temperatures indicate that a 1.25 metre thick cover would maintain the ground temperature at the cover/tailings interface below zero in unsaturated conditions in the test cell area (i.e. not completely analogous to the closure concept).
- Sulphide oxidation declines with declining ground temperature.
- Sulphide oxidation rates at 4 degrees C are approximately 20% of oxidation rates at 20 degrees C.
- The testing procedures that were utilized were not considered accurate for assessing ground temperatures below about 4 degrees C; nonetheless, sulphide oxidation was observed to occur at very low rates at a ground temperature of 0 degrees C and oxidation was projected to continue to occur at increasingly lower rates to ground temperatures as low as –4 degrees C (shallow ground temperatures exceed these low temperatures for only a short seasonal period each year).

A series reports and presentations have been prepared by Mr. Elberling (singly or in concert with associates) that describe the research methodologies that include the following:

1. Kyhn and Elberling, 2002, An Evaluation of the Thermal Response of Covered Tailings at Nanisivik Mine
2. Kyhn and Elberling, 2001, Thermal cover requirements for reactive mine tailings deposited on land in the Arctic
3. Kyhn and Elberling, 2001, Frozen cover actions limiting AMD from mine waste deposited on land in Arctic Canada
4. Elberling, 2001, Environmental Controls of the Seasonal Variation in Oxygen Uptake in Sulphidic Tailings Deposited in a Permafrost Affected Area
5. Elberling and Damgaard, 2000, Microscale measurements of oxygen diffusion and consumption in subaqueous sulphide tailings
6. Elberling, Shippers and Sand, 2000, Bacterial Activity and Oxygen Uptake in Pyritic Tailings Deposited in the Canadian Arctic
7. Elberling, Shippers and Sand, 2000, Bacterial and Chemical Oxidation of Tailings at Low Temperatures
8. Elberling, 1999, Seasonal Trends in Pyrite Oxidation of Tailings Deposited in a Permafrost Affected Area
9. Elberling, 1998, Processes Controlling Oxygen Uptake Rates in Frozen Mine Tailings in the Arctic

4.3.2 Other Studies Related to the Tailings Containment Area

In addition to the research studies described above, numerous engineering reports have been developed that are focussed on reclamation of the Tailings Containment Area.

A study report was prepared by Senes Consultants Ltd. dated December 1992 that describes the anticipated oxidation of tailings and release of contaminants for tailings deposited underwater as is the case in the lower West Twin Lakes containment area. The study confirms that sulphide oxidation is reduced to very low rates beneath the water cover and that the release of contaminants is expected to be at very low concentrations.

A soil cover test cell was developed in 1991 in the lower West Twin Lake area and has been utilized since that time to test the effectiveness of various construction methods and cover types. The area contains several individual pads that are instrumented with thermistors, frost gauges and piezometers. A construction report for the test pads was prepared by SNC Lavalin in 1993. Annual monitoring of test pad behaviour has been conducted by Nanisivik Mine since 1991.

A test program was conducted and reported on in 1999 by Golder Associates regarding the physical durability of various cover materials.

An investigation of the potential for acid rock drainage from tailings and from the proposed shale rock cover material was conducted by Lorax Environmental and reported on in “Acid Generation Potential of Tailings and Shale Cover Material” dated September 1999. This study confirmed that the tailings are potentially acid generating and that zinc is the metal of primary concern. The study indicated that the shale rock that was used for construction of the dyke and that is proposed for the tailings cover is geochemically benign or acid consuming. A follow up study by Lorax Environmental reported on in “Acid Generation Potential of Soil, Waste Rock and Shale” dated April 2001 included static and kinetic testing of additional samples of tailings and shale rock and provided the same conclusions.

A Failure Modes and Effects Analysis (FMEA) for the surface cell area was conducted by BGC Engineering 2000. The FMEA concluded that the highest risk for the West Twin Dyke was possible seepage through or under the dyke and that the most likely cause of such seepage would be ineffective freezing or thawing of the tailings or dyke core. A follow up analysis of the physical stability of the WTDA Dyke was also performed by BGC Engineering in 2000. This study indicated the dyke currently meets all of the appropriate operational guidelines for static and seismic stability for the material parameters used. This analysis also included an assessment of the susceptibility of various materials to frost heave.

Two studies are currently underway (2001) regarding design of a closure spillway for the upper West Twin Lake tailings containment area. The first study (Golder Associates) is a hydrological study that will define appropriate flood flows for sizing of the spillway. The second study (BGC Engineering Inc.) is the geotechnical design for the spillway that includes sizing for passage of flood flows, location selection and investigation, and protection for physical stability.

Annual inspections of the physical stability of the dykes are conducted by a professional geotechnical engineer. The most recent inspection (summer 2001) was conducted and reported on by BGC Engineering Inc.

4.3.3 Other Mine Reclamation Studies

An Interim Closure Plan report has been prepared by Nanisivik Mine on an annual basis since 1994. These reports describes the conceptual reclamation measures that are anticipated for various reclamation areas.

A Waste Rock Management Plan is prepared annually by Nanisivik Mine. This report details the volumes and locations of waste rock on the mine site and describes the management plan for relocation of waste rock during the next year. The preparation of these reports recognizes the need for efficient management of waste rock during mine operations as a means of progressive reclamation that will minimize the work required after mine closure (i.e. relocation of mineralized waste rock into the permafrost environment of the underground mine).

An Annual Environmental Report is prepared Nanisivik Mine that documents activities and studies that are relevant to protection of the environment. Many of these activities are relevant to reclamation planning such as water monitoring, soil/snow/air monitoring, clean up of spills, landfill operation, etc. Some of this information is also documented as separate discreet reports. Some environmental monitoring studies that are reported in the annual environmental reports and, on occasion, in stand alone reports and that are of particular interest for reclamation planning are:

- Sampling of snow for metals concentrations.
- Sampling of air particulates for metal concentrations.
- Clean up of a hydrocarbon spill near the carpenter shop.

A study was completed in 2000 by Nanisivik Mine that investigated the potential for a subsurface hydraulic connection from West Twin Lake to East Twin Lake that might allow for the passage of water from the tailings containment area into East Twin Lake (potable water source). The study included water sampling, measurement of ground temperatures and monitoring of lake elevations. The study results indicated that there was no hydraulic connection due to stable permafrost within the ground that separates the two lakes and due to the relative elevations of the lakes. As an additional safeguard against this possibility, the mine environmental management plan includes monitoring and management of the two lake levels such that the water elevation in West Twin Lake is maintained lower than the elevation in East Twin Lake.

A proposed landfarming design and procedure for remediation of hydrocarbon contaminated soils was prepared by Nanisivik Mine and submitted to the Water Board in 2000. The proposal described the design and operation of the landfarming cell that was subsequently constructed in the landfill area.

An investigation of the potential for acid rock drainage from soil, waste rock, roads, pit walls and shale quarries was conducted by Lorax Environmental and was reported in "Acid Generation Potential of Soil, Waste Rock and Shale" dated April 2001. This study conducted static tests on approximately 88 samples collected in 1997. The test results indicated that all samples, including tailings and waste rock, contained a relatively high neutralization potential due to the calcareous nature of the local country rock. The tailings, 00 rock dump and K-Baseline rock dump were indicated to be potentially acid generating. Most other rock dumps and pit walls were indicated to be possibly acid generating although acid generation from these locations was suggested to be unlikely given the relatively high neutralization potential and cold climate. All of the shale quarries, the shale rock used in construction of the tailings containment dyke and soil in the West Twin Lake area were indicated to have a positive net neutralization potential (i.e. acid consuming).

The water quality and metal loading studies in Twin Lakes Creek that are conducted and reported on by Nanisivik Mine are described above along with other Environmental Reports. These reports are also directly relevant to reclamation planning. These studies suggest that a portion of the observed metal loadings are related to rock dumps, which will be removed as part of the mine reclamation plan. The studies also suggest that a portion of the observed metal loadings are related to naturally occurring sulphide outcrops that were (likely) contributing sources of the observed elevated background metal concentrations.

Surface soil geochemistry and metal analyses were conducted for mine exploration purposes prior to mine development. This information is directly relevant to mine reclamation planning as it will provide some context for the interpretation of current and predicted post reclamation water quality.

An environmental site assessment of the landfill was conducted and reported on by Nanisivik Mine in 2000 and 2001. This assessment included documentation of waste streams, historical and current operating practices, estimation of waste volumes, collection of soil and water samples, and a proposed plan for reclamation of the landfill. Soil sampling results indicated the presence of low concentrations of hydrocarbons down gradient from the landfill but at concentrations less than regulatory guidelines.

4.4 Government Review Comments

Review comments have been provided by the Nunavut Water Board on the individual study reports that were submitted in response to requirements of the Water License. The most recent review comments (dated 2001) are as follows:

1. August 15, 2001, Re. Environmental Site Assessment of the Landfill, report by Nanisivik Mine.
2. August 20, 2001, Re. Proposed Soil Remediation (Landfarm) Cell, report by Nanisivik Mine.
3. October 23, 2001, Re. Hydraulic Confinement of the West Twin Lake Tailings Containment Area, report by Nanisivik Mine.
4. October 25, 2001, Re. 2000 Twin Lakes Creek Metal Loading Study, report by Nanisivik Mine.
5. October 25, 2001, Re. Waste Rock Disposal Plan for 2001, report by Nanisivik Mine.
6. October 25, 2001, Re. 2000 Tailings Test Cell Evaluation Study, report by Nanisivik Mine.

5. Comparison of Studies

5.1 Approach

The purpose of this report is to provide a brief description of the various reports under each topic. Where possible, a comparison over time is also provided. However, this was often difficult or impossible due to the following factors:

1. Sampling Locations: Slight differences in sampling locations can result in large variations in contaminant concentrations and this must be considered in comparisons between studies. This potentially difficult factor can be managed by defining areas in the receiving environment that encompass various sampling locations and this approach has been utilized here, where practical, using the approach described below for near-field. mid-field, far-field, far-far-field and reference areas.
2. Sampling Methodology: Slight differences in sampling methodologies can result in wide variations in data results that make inter-study comparisons invalid or difficult. For example, marine sediments sampling with a dredge sampler will provide different samples than would a core sampler.
3. Sample Preparation: Sample preparation is an important factor when considering comparisons between studies. For example, sea urchins for various studies may be purged, unpurged, washed unwashed, analysed whole or in parts.
4. Detection Limits: Analytical detection limits have generally decreased in recent years in response to advances in analytical technology. Data from older studies must be analysed in the context of the detection limits that were available and utilized at the time of the study.
5. Analytical Methodology: Various analytical methodologies for the determination of concentrations of metals and other parameters have been used between studies. On occasion, methodologies may have varied with the laboratory used and, in recent years, methodologies have advanced from those available at the time of some older studies.
6. Time of Sample Collection: Seasonal effects such as ice cover, precipitation and freshet can be significant factors regarding evaluation of study results. Additionally, the timing of sample collection with regards to mine activities can also be critical given the environmental interactions surrounding rock dump construction, release of treated effluent, etc.
7. Information Reported: Sampling and analytical methodologies may not be reported to equal detail in various study reports. Where details are not reported, assumptions must be made or the data can not be used in a cross study comparison.

In order to allow some comparisons over time to be made between studies in the marine environment, an assessment technique was employed that allows such comparisons to be made even where sample locations are not the same. This technique involves the definition of areas within the receiving environment which encompass the sample locations. In this case, the mouth of Twin Lakes Creek was defined to be the centre of the study area. From the mouth of Twin Lakes Creek, the following areas were defined and utilized for a comparison among studies:

- Near-Field: within a 1 km radius from the mouth of Twin Lakes Creek.
- Mid-Field: within a radius of 1 km to 5 km from the mouth of Twin Lakes Creek.
- Far-Field: within a radius of 5 km to 10 km to the west of Twin Lakes Creek.
- Far-Far-Field: greater than 10 km radius to the west of Twin Lakes Creek.
- Reference: greater than 5 km radius to the east of Twin Lakes Creek.

The area boundaries are illustrated on Figure 6.

Summaries have focussed on the concentrations of zinc, lead and cadmium as these are the contaminants of primary interest and the parameters most often measured in the studies.

5.2 Marine Environment

5.2.1 Metals in Sea Water

Summary of Metals in Sea Water

The concentrations of heavy metals in sea water in Strathcona Sound have been recorded in:

1. August 1974 (BCRI, 1975) (background information)
2. June 1982 (Thomas, 1983)
3. December 1984 and June 1985 (Arctic Laboratories Ltd., 1986)
4. August 2000 (Lorax, 2000) (also included toxicity testing)

The studies indicate that, since the first post operational study in 1982, metal concentrations have been elevated in the near-field area and to a lesser degree in the mid-field area. The greatest concentrations of metals have typically been observed near surface and decrease with depth in the water column although some studies suggested an enriched zone at depth in the near-field area. This is an expected change attributed to many years of mine activities as compared to the sole pre-operational study in which no spatial or depth trends were identified.

Zinc concentrations display the clearest trends. Lead concentrations have display a similar trend to zinc, although with a more restricted spatial distribution and lower concentrations. Cadmium concentrations have often followed the trend displayed by zinc and lead but to a lesser extent and not as consistently between studies.

August 1974 Study (BCRI, 1975)

The 1974 study (pre-operations) included sampling of sea water at various depths from surface to bottom at 8 locations that covered near-field (2), mid-field (3), far-field (2) and far-far-field (1) areas. Samples were filtered and preserved in the field.

The study did not identify any spatial or depth trends in metal concentrations in Strathcona Sound. Concentrations of dissolved lead and cadmium were consistently below the method detection limits of 5 ppb and 1 ppb, respectively. Concentrations of dissolved zinc ranged from 14 to 42 ppb.

June 1982 Study (Thomas, 1983)

Samples were collected at 8 locations representing near-field (1), mid-field (5), far-field (1) and reference (1) areas. There was no ice cover on the Sound at that time. Sample filtering and preservation with acid did not take place in the field but in the laboratory after transport. Subsequent to filtering and preservation, the samples were stored for up to 4 months prior to analysis for metals. This methodology introduces some uncertainty into an evaluation of the analytical results but is not considered to render the results unusable.

Samples were collected using a "Go-Flo" sampler that was subjected to comparative analysis in a follow up study (December 1984/June 1985 study). The comparative study found that the Go-Flo sampler returned greater concentrations of lead and zinc in near surface samples than did a pressure sampler due to interactions with sampling activities and poor rinsing in the shallow water column. Near surface (to 10 metres depth) lead concentrations in the December 1984 study were highlighted as "likely contaminated in collection" and this comment may also apply to lead and zinc concentrations reported for this (1982) study.

The June 1982 study identified spatial and depth trends for heavy metals with greater concentrations observed near surface and proximal to the inflow of Twin Lakes Creek. The concentrations of zinc near surface (1 metre depth) were as high as 52.8 umol/m^3 in the near field area and decreased in a northerly line across the Sound to 5.1 umol/m^3 near the north shore in the mid-field area. Zinc concentrations were less than 7 umol/m^3 at all locations below 10 metres depth except in the near field area where the concentration was 10.9 umol/m^3 at 10 metres depth. Elevated (i.e. >7 umol/m^3) were also observed at 1 metre depth at a far field location (station no. 8), which may have been indicative of dispersion of zinc in surface currents although this is unclear since the near surface concentration at the far field location (13.3 umol/m^3) was greater than at mid field locations (2.2 to 10.0 umol/m^3). Elevated concentrations of zinc were also observed at 1 metre and 10 metre depths (236 and 12.7 umol/m^3, respectively) at an upstream reference location (station no. 11) although a follow up study (December 1994) did not repeat the elevated concentrations. Similar spatial and depth trends were observed for lead and cadmium, although near surface cadmium concentrations were not elevated at the upstream location (station no. 11) as were zinc and lead.

December 1984 and June 1985 Study (Arctic Laboratories Ltd., 1986)

Sea water samples were collected in December 1984 and June 1985 during the setting and retrieving of sediment traps. The methodology and results of the sediment traps are described as part of the marine sediment studies. Water sampling took place through augered sampling holes and "considerable" meltwater was present on top of the ice in June 1985. Seawater sampling included 4 locations in

December 1984 (2-near-field, 1-mid-field and 1-reference) and three locations in June 1985 (excluding the reference area). There was no flow in Twin Lakes Creek at the time of the December 1984 sampling.

The methodology for sample filtering and preservation was not provided although both filtered and unfiltered metal concentrations were reported for select samples. The comparison of filtered and unfiltered metal concentrations indicated very similar concentrations with no consistent trend of one greater than the other. Most samples were not filtered to avoid potential contamination during the process.

Concern was expressed in the report regarding near surface samples collected with a "Go-Flo" sampler wherein artificially high concentrations of lead and zinc may have been obtained due to interactions with sampling activities on the ice. Other, deeper samples collected by the Go-Flo sampler did not appear to have any concerns. A pressure sampler was also tested and returned substantially lower metal concentrations in near surface samples in June 1985. The pressure sampler was unsuitable for use at depths greater than about 10 metres. The data set for December 1984 was collected using the Go-Flo sampler because cold temperatures prevented use of the pressure sampler and the near surface lead concentrations were highlighted as "likely contaminated in collection". All samples in June 1985 were collected with a pressure sampler (sampling was only conducted to 10 metres depth in June).

In December 1984, concentrations of zinc were elevated near surface in the near-field area to 10 metres depth and concentrations were slightly elevated at the mid-field location at 3 metres depth. Metal concentrations at and below 50 metres depth in the near-field area and at and below 10 metres depth in the mid-field area were within the range of the reference area. The maximum concentration of zinc measured was 9.6 $\mu mol/m^3$ at 3 metres depth at one of the near-field locations. A similar spatial and depth trend was observed for lead but no clear trend was observed for cadmium. Concerns regarding the accuracy of near surface concentrations of lead and zinc were expressed due to the sampling methodology (Go-Flo sampler) used, as described above.

In June 1985, a similar spatial and depth distribution was observed although the extent and depth of the elevated metal concentrations was less than was observed in December. However, the concentration of zinc near surface in the near-field area was greater than in December at 47 $\mu mol/m^3$ at 3 metres depth.

August 2000 Study (Lorax Environmental, 2000)

Seawater samples were collected in August 2000 at three locations representing shallow conditions (0.1 metres and 5 metres depth) in near-field (2) and reference (1) areas. Chemical analyses and toxicity tests were conducted on the samples. The samples were not filtered and, therefore, metal concentrations are total metals. Samples were collected using a "Go-Flo" sampler, which was identified in previous studies (Arctic Laboratories Ltd., 1996) as possibly allowing contamination (increased metal concentrations) of near surface samples due to interactions with sampling activities and poor rinsing in shallow water columns.

Concentrations of total zinc were elevated in the shallowest (0.1 metre) sample in the near-field area at 217 and 52 µg/L. The concentrations of lead and cadmium displayed a similar trend, although lead was elevated only at one of the near-field locations located closest to Twin Lakes Creek.

Toxicity testing with marine sand dollars and Microtox testing were also perfomed. Sand dollar fertilization was slightly inhibited in one of the near-field samples located closest to Twin Lakes Creek. Microtox test results indicated some response typical of low levels of metals but did not display clear spatial or depth trends.

5.2.2 Metals in Fish

Summary of Metals in Fish

The concentrations of heavy metals in fish in Strathcona Sound have been recorded in:

1. August 1974 (BCRI, 1975) (background information)
2. August 1979 (Fallis, 1982)

Neither study indicated a consistent spatial trend in the concentrations of zinc, lead and cadmium in liver or muscle. Metal concentrations in liver were nearly uniformly greater than in muscle. Metal concentrations in sculpins were similar in 1974 and 1979 and no increases were observed. Metal concentrations and other data are summarized in Table 1.

August 1974 Study (BCRI, 1975)

Concentrations of lead, zinc, arsenic, cadmium, copper, iron and nickel were determined for fillets and livers of 14 shorthorn sculpins caught in August 1974 by BCRI. The locations of sample collection were not explicitly stated.

Concentrations of lead, zinc, cadmium, copper, iron and nickel were determined for fillets and livers of 53 shorthorn sculpins, 2 Arctic sculpins, 8 fourhorn sculpins and 14 Arctic char caught in the summer of 1974 by Fisheries and Marine Service (FMS). The analyses were performed and reported by BCRI.

The concentrations of all metals in all fish were uniformly greater in liver than in fillets with only a few exceptions for copper and iron. The concentrations of lead, cadmium and nickel in fillets were uniformly (with only a few exceptions) less than the method detection limit and the concentrations of lead, cadmium and nickel in livers were primarily less than the method detection limit. The concentrations of metals did not appear, on a preliminary basis, to have varied between fish species or between studies except that copper and iron in char livers were greater than in sculpins (statistical analysis has not been performed to verify significance of trends). The concentrations of metals did not appear, on a preliminary basis, to be directly related to weight or length of fish (statistical analysis has not been performed to verify significance of trends).

Table 2: Summary of Metals in Fish Data

Species	sculpin	shorthorn sculpin	Arctic sculpin	fourhorn sculpin	Arctic char	fourhorn sculpin	Arctic sculpin
Caught	Aug/74 BCRI	summer 1974 FMS	summer 1974 FMS	summer 1974 FMS	summer 1974 FMS	Aug/79 DFO	Aug/79 DFO
Number	14	53	2	8	14	15	2
Length	16.5-30.8	21.7-39.3	23.9 (both)	25.6-35.5	21.0-64.4	nr	nr
Weight	0.08-0.51	0.155-0.920	0.200-0.220	0.240-0.720	0.078-2.480	nr	nr
Zinc – Fillet	28.1-100	28.9-85.7	42.9-46.9	32.9-67.5	13.7-37.0	49.3-116	34.3-82.7
Zinc – Liver	57.6-144	47.4-162	135-166	84.9-129	35.3-177	66.6-120	127
Lead – Fillet	<5-<16	<3.27-<8.01	<4.01-<4.20	<3.17-<7.07	<2.17-<8.13	0.09-1.13	0.22-0.45
Lead – Liver	4.6-<46	<2.82-<13.5	<6.42-<8.97	<3.64-<15.3	<3.61-<37.8	0.23-0.86	0.98
Arsenic – Fillet	10.1-37.4	nr	nr	nr	nr	8.39-40.2	12.6
Arsenic – Liver	14.2-64.8	nr	nr	nr	nr	5.72-36.7	11.9-19.2
Cadmium – Fillet	<0.5-1.6	<0.33-<0.80	<0.40-<0.42	<0.32-<0.71	<0.22-<0.81	0.08-0.68	0.18-0.24
Cadmium – Liver	<1.1-16.0	0.87-15.7	7.98-17.5	1.41-5.37	<0.36-2.30	0.68-6.05	2.61
Copper – Fillet	4.2-9.9	1.55-9.10	2.61-3.15	1.74-4.44	1.14-2.46	nr	nr
Copper – Liver	5.3-26.3	1.80-20.1	5.94-6.42	3.64-5.26	30.5-221	nr	nr
Iron – Fillet	27.3-176	26.4-347	87.8-131	31.3-82.7	16.1-34.3	nr	nr
Iron – Liver	39.4-312	33.6-196	117-225	75.6-167	639-6473	nr	nr
Nickel – Fillet	<3-<8	<1.63-<4.00	<2.00-<2.10	<1.58-<3.53	<1.08-<4.06	nr	nr
Nickel – Liver	<2-<19	<1.41-<6.75	<1.85-<3.21	<1.82-<7.65	<1.80-<18.9	nr	nr

BCRI = B.C. Research Inc.; DFO = Department of Fisheries and Oceans; FMS = Fisheries and Marine Service
All concentrations mg/kg dry weight; nr = not reported

Analysis for zinc, lead, arsenic, cadmium, copper, iron and nickel was performed for samples of muscle, liver and kidney from one Greenland shark that was caught by BCRI in August 1974 at 110 to 120 metres depth. The concentrations of zinc, arsenic and nickel were greatest in the kidney at 56.0, 113 and 2.7 mg/kg, respectively. The concentrations of cadmium, copper and iron were greatest in the liver at 23.1, 12.3 and 385 mg/kg, respectively. The concentrations of lead were all below the method detection limits. The concentrations of metals in the shark muscle and liver appear to be generally similar to the ranges observed in fish with the exception of arsenic in shark muscle (102 mg/kg), which was greater than the range observed for sculpins.

August 1979 Study (Fallis, 1982)

Samples of muscle and liver of two type of sculpins (fourhorn sculpin and Arctic sculpin) were analysed for fish caught in August 1979 in Strathcona Sound by the Department of Fisheries and Oceans. Six sample locations included near-field (1), mid-field (1), far-far-field (2) and reference (3) areas. Measurement of fish weights and lengths were part of the study methodology but the results were not reported.

Concentrations of zinc, lead and cadmium were generally greater in liver than in muscle, with only a few exceptions for lead and cadmium. There was no clear variation in metal concentrations between Arctic sculpin and fourhorn sculpin. There was no clear spatial trend in concentrations of zinc, lead and cadmium with respect to near-field and other areas although concentrations of arsenic in Fourhorn sculpins was slightly greater in the near-field area than in other locations.

5.2.3 Metals in Seaweed

Summary of Metals in Seaweed

The concentrations of heavy metals in seaweed in Strathcona Sound have been recorded in:

1. August 1974 (BCRI)
2. August 1976 (Fallis, 1982)
3. August 1979 (Fallis, 1982)
4. August 1980 and August 1981 (Fallis, 1990)

Zinc and lead concentrations in the near-field area were elevated in all of the studies (i.e. pre and post mine operations). Cadmium did not display this trend. However, zinc and lead concentrations did not display any clear trend over time (i.e. neither increasing nor decreasing). Cadmium did not follow these trends.

August 1974 Study (BCRI, 1975)

Six seaweed samples representing three varieties were collected by BCRI in 1974 and analysed for heavy metals. Samples were collected from four locations, one near-field and three mid-field, in a transect across the Sound just east of the mine area.

The concentrations of zinc and lead were greatest at the near-field location (386 and 35.5 mg/kg, respectively) and decreased across the Sound to the north. The concentrations of arsenic, cadmium, copper, iron and nickel did not display any clear spatial trends (statistical analysis was not performed to identify significant trends). The concentrations of metals were generally greater in the seaweed *Fucus* sp as compared to *Agarum* sp and *Laminaria* sp. The identification of *Agarum* sp was not confirmed.

August 1976 Study (Fallis, 1982)

Plants of three species were collected at one near-field location. Analyses were conducted on plants washed and with the stipe removed plus one species also analysed unwashed with stipe removed. Samples were collected using a dredge sampler and from gill net sets.

Zinc concentrations varied from 36 to 88 µg/g for the washed whole samples of the three species. The unwashed sample returned a greater concentration of zinc than the corresponding washed sample at 105 µg/g versus 88 µg/g, respectively. Species *Fucus vesiculosus* returned a slightly greater concentration of zinc than did *Palmaria palmata* or *Laminaria solidungula* although this was not the case for lead or cadmium.

August 1979, August 1980 and August 1981 Studies (Fallis, 1982 and 1990)

Samples were collected at 11 locations representing near-field, mid-field, far-field, far-far-field and reference areas. Three species were represented (*Fucus vesiculosus, Laminaria solidungula* and *Agarum cribrosum)* and analyses were performed for a variety of sample preparations including combinations of whole, stipes, washed, unwashed, with stipe, without stipe, new growth, old growth. The most common sample preparation was washed without stipe and the most common species sampled was *Fucus vesiculosus*. Samples were collected by Scuba diver.

Analyses of washed, whole plant less stipe indicated a spatial trend in zinc concentrations wherein slightly elevated concentrations were observed in the near-field area for *Fucus vesiculosus* (493 µg/g) and *Agarum cribrosum* (76 to 141 µg/g). All other zinc concentrations were in a range from 36 to 141 µg/g for *Fucus vesiculosus* and from 30 to 88 µg/g for *Agarum cribrosum.* A similar spatial trend was observed for lead but not for cadmium.

Multiple analyses of *Fucus vesiculosus* indicated that zinc was slightly concentrated in slimes as compared to the other sample preparations. Zinc was found to be slightly more concentrated in washed old growth than in washed new growth. There was no clear trend in zinc concentrations between washed stipes and unwashed stipes.

5.2.4 Metals in Sea Urchins

Summary of Metals in Sea Urchins

The concentrations of heavy metals in sea urchins (*Strongylocentrosus droebachiensis*) in Strathcona Sound have been recorded in:

1. August 1975 and May/August 1976 (Fallis, 1982)

2. August 1979 (Fallis, 1982)
3. August 1980 and August 1981 (Fallis, 1990)
4. June 1982 (Thomas, 1983)

The pre-operational studies did not include multiple sample locations and, therefore, did not provide indications of spatial trends in metal concentrations. The post-operational studies indicated that concentrations of zinc and lead were elevated in the near-field area. Cadmium did not display this spatial trend.

The known differences in sampling methodologies and sample preparations make cross study comparisons of metal concentrations uncertain. Nonetheless, in a gross sense the data suggests that concentrations of zinc and lead increased subsequent to the commencement of mine operations in the near-field area (i.e. from 1975/76 to 1979). The apparent increase did not continue from 1979 through 1982 suggesting that the increase, if present, was not additive but singular through that timeframe. A possible exception may be a slight increasing trend from 1979 to 1992 in soft tissues of *Mya truncata*. Concentrations of cadmium did not display a similar trend.

August 1975 and May/August 1976 Studies (Fallis, 1982)

Samples were collected in August 1975 at one near-field location. *Mya truncata* was sampled as were several other species. Samples were collected using a dredge and individual organisms were pooled together for analysis. The concentration of zinc in *Mya truncata* was 105 µg/g and the range in zinc in other species sampled was from 51 to 480 µg/g. The nature of the sample preparation was not reported (i.e. total body versus soft tissues, etc.).

Sea Urchin (*Strongylocentrotus droebachiensis*) was sampled in each of May and August 1976 at one near-field location. Multiple analyses were performed on variations of group and population sizes. The concentrations of zinc in May and August ranged from 33 to 50 µg/g and from 48 to 65 µg/g, respectively.

August 1979, August 1980 and August 1981 Studies (Fallis, 1982 and 1990)

Samples were collected over three years by the Department of Fisheries and Oceans at a variety of locations. The sample locations included near-field (1), mid-field (3), far-field (1), far-far-field (2) and reference (4) areas. Samples focussed on species *Mya truncata* and *Strongylocentrotus droebachiensis* although samples of several other species were collected in 1979. The most common sample preparation was total soft tissue analysis but sample preparation for *Strongylocentrotus droebachiensis* also included total body analysis. For samples in which sample preparation was not specified (esp. 1979), total body analysis was assumed based on the range of metal concentrations reported. Samples were collected by scuba diver with a goal of collecting 25 individuals of each of the two primary species.

In 1980 and 1981, *Mya truncata* samples were collected in duplicate with one set of samples allowed to purge in clean water prior to freezing and analysis. Duplicate analyses indicated that there was no significant difference between the purged and unpurged samples and that, therefore, comparisons with previous data (unpurged) were possible.

In 1980 and 1981, sample preparation for *Mya truncata* was modified to include removal of the syphon sheath (part of the soft tissues) for separate analysis. It was found that metal concentrations were not consistently concentrated in either syphon sheaths or other soft tissues. In order to allow comparison with previous data, a concentration for total soft tissues was calculated in 1980 and 1981 from individual measurements.

Concentrations of zinc in total soft tissues from 1979 to 1981 were similar for the two primary species sampled and zinc concentrations were greater in soft tissues of *Strongylocentrotus droebachiensis* as compared to total body analyses.

Concentrations of zinc displayed a spatial trend in which greater concentrations were observed in the near-field area for both species. All other concentrations of zinc were within the range of the reference area samples. The concentrations of zinc in soft tissues in the near-field and mid-field areas for the two primary species sampled ranged from 388 to 455 µg/g and from 118 to 184 µg/g, respectively. The concentrations of zinc for all other samples ranged from 74 to 228 µg/g. A similar spatial trend was observed for lead but not for cadmium.

Possible correlations of body dimension and weight with metal concentrations were evaluated. It was found that some correlations existed but that they were inconsistent in nature and location.

June 1982 Study (Thomas, 1983)

Samples of species *Mya truncata* were collected by scuba diving at five locations in June 1982 in open water conditions. Approximately 50 individuals were collected at each location. The sample locations covered near-field (2) and mid-field (3) areas. Samples were purged in clean water for 24 hours prior to preservation. Analyses were performed on soft tissue parts less the syphon sheaths.

The biochemistry and reproductive capacity of the samples was evaluated to test for sub lethal effects related to mining activities. The study concluded that, although the sample size was smaller than ideal, there were no apparent correlations between size or health of samples and metal concentrations. An analysis of kidney stones indicated that these were enriched with heavy metals and, therefore, may have been removing the metals from bioavailability.

Calculated Condition Indices were suggested as representative of the general health of the samples. The indices were interpreted in the context of recent spawning as this natural activity causes stress in the organisms. No significant trends in Condition Indices were identified with respect to near-field and other areas.

Concentrations of zinc and lead were slightly elevated in the near-field locations but the concentration of cadmium did not display a clear spatial trend. The concentrations of zinc in the near field locations were 388 and 584 µg/g. The concentrations of zinc at the mid-field locations ranged from 180 to 408 µg/g.

5.2.5 Metals in Marine Sediments

Summary of Metals in Marine Sediments

The concentrations of heavy metals in marine sediments in Strathcona Sound have been recorded in:

1. August 1974 (BCRI, 1975)
2. September 1975 (Fallis, 1982)
3. August 1979 (Fallis, 1982)
4. August 1980 and August 1981 (Fallis, 1990)
5. June 1982 (Thomas, 1983)
6. June 1985 (Arctic Laboratories Ltd., 1986)
7. August 1992 (North South Consultants Inc., 1992)
8. 1999/2000 Study (Elberling, unpublished)

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).

Metal concentrations have increased in the near field area from the pre-operational studies to 1992. The pending results of the 1999/200 study will indicate whether metal concentrations continued an increasing trend or remained relatively constant from 1992 to 2000.

August 1974 Study (BCRI, 1975)

Sediment samples were collected at 14 locations in Strathcona Sound in August 1974 by BCRI representing near-field (2), mid-field (4), far-field (2), far-far-field (3) and reference (3) areas. Samples were collected using a dredge designed to collect sediment to a depth of 10 cm. Pebbles and visible organic fragments were removed from the samples prior to analysis.

Concentrations of zinc and lead were greatest in the near-field area at 171 and 19.3 mg/kg, respectively. Concentrations of arsenic, copper, iron and nickel were greatest, however, in various other areas (mid, far, far-far, reference) at 7.9, 27.9, 34,000 and 25.7 mg/kg, respectively. Concentrations of cadmium were all less than the method detection limit of 0.4 mg/kg. Metal concentrations were uniformly least at one far-far-field location near the south shore of the Sound. The bottom sediments at this location were described to be sandy, which may relate to the lower metal concentrations as compared to clayey (i.e. finer grained) soils described for most other areas.

September 1975 Study (Fallis, 1982)

Sediment samples were collected at seven locations using an Ekman dredge covering near-field (1), mid-field (1), far-field (1), far-far-field (2) and reference (2) areas. The depth of sediment collected is unknown with this methodology but is representative of the upper sediment layer at the water/soil interface. The samples were collected by the Geological Survey of Canada (GSC). A study-specific report was not available but the results were described in Fallis, 1982. The size fraction analysed was alternately <2μm, <180μm or whole sample.

The results confirmed the general expectation that heavy metals are concentrated in the fine fraction of the sediment. The results did not indicate any clear spatial trend with respect to near-field, mid-field and far-field areas. All results were generally within or close to the range in the reference area. The concentrations of zinc for all of the samples ranged from 50 μg/g (mid-field, whole sample) to 175 μg/g (near-field, <180μm).

August 1979, August 1980 and August 1981 Studies (Fallis, 1982 and 1990)

Sediment samples were collected over three years by the Department of Fisheries and Oceans at a variety of locations. The sample locations covered near field (1), mid-field (3), far-field (1), far-far-field (2) and reference (4) areas. Samples were collected using a corer but the reported methodology does not specify whether the cores were extruded and cut at discreet intervals or whether the same depth of sediment was analysed at each location. The size fraction analysed was <1.00mm.

The results indicated that concentrations of zinc were elevated in the near-field area at 379 to 750 μg/g. The remainder of the zinc concentrations (including the mid-field area) ranged from 20 μg/g (far-far-field) to 135 μg/g (reference area). A similar spatial trend was also observed for lead and cadmium. No apparent consistent temporal trends from 1979 to 1981 were apparent.

June 1982 Study (Thomas, 1983)

The June 1982 study included sampling at 26 locations that covered near-field (6), mid-field (16), far-field (1), far-far-field (1) and reference (2) areas. Samples were collected using a corer and the samples were extruded and cut (in the field) into discreet intervals for analysis. Analysis was performed on the size fraction less than 75 um (#200 mesh sieve). The samples were collected by sampling through a continuous ice cover.

The sample results identified spatial and depth trends with greater concentrations of zinc, lead and cadmium observed near surface and proximal to Twin Lakes Creek. The interface (0-1 cm) concentrations of zinc in the near-field, mid-field, far-field and far-far-field areas were 1.81 to 25.09 mmol/kg, 1.30-3.93 mmol/kg, 1.52 mmol/kg and 1.34 mmol/kg, respectively. Two reference area samples contained 1.00 and 1.56 mmol/kg zinc in the 0-1 cm interval. Zinc concentrations were all less than 2.5 mmol/kg below 5 cm depth except at some of the near field locations. Nonetheless, the same spatial distribution was also observed for the 5-10 cm sample interval, although at lower concentrations than for the surface interval.

The 1992 study estimated sedimentation rates using three methods: Pb-210 dating, sedimentation trap data and hydrometric analysis. The estimates suggested that the annual sedimentation rate in Strathcona Sound would be expected to range from <1 mm to 6 mm. This range of sedimentation rates suggests that the spatial trend in metals observed in the 5-10 cm interval is indicative of the deposition of heavy metals prior to the commencement of mine activities (i.e. related to natural sources).

Electron microscopy of sediment particles indicated that sulphide particles were present but the methodology was unable to distinguish whether the particles originated as ore concentrates or as sulphide minerals eroded from surface exposures and transported into the Sound.

June 1985 Study (Arctic Laboratories Ltd., 1986)

Sediment traps were set out at five locations in Strathcona Sound from December 1984 to June 1985. The locations covered near-field (2) and mid-field (2) areas. Two sediment traps were hung at two depths (approximately 20 metres below surface and approximately 20 metres above bottom) at each location.

Sedimentation rates were measured to average 8.3 $\mu g/cm^2/day$ with no significant variance between stations or with depth. The amount of sediment collected over the period of the study was suggested to represent approximately 2% of the minimal annual sedimentation load (0.5 mm/yr) that was estimated by a previous study (Thomas, 1983). However, sedimentation rates vary seasonally and annually due to a wide variety of factors and the single set of measurements from 1985 are representative only of the controlling factors present at that time.

Particles were analysed for concentrations of zinc, lead and cadmium. Concentrations of zinc were greater in the upper trap than in the lower trap at all locations but concentrations of lead and cadmium did not display a consistent trend with depth. Concentrations of lead and zinc were slightly elevated in the near-field area, when taking into account the suggestion that the upper sample from one of the mid-field locations was suspected to be contaminated. Concentrations of cadmium did not display a clear spatial trend.

Microscopic examination of particulate matter indicated that there was there was “very little, if any” presence of particulates of lead and zinc concentrates in the sediment traps.

August 1992 Study (North South Consultants Inc., 1992)

Sediment core samples were collected from 19 locations in August 1992 covering near-field, mid-field, far-field, far-far-field and reference areas. Sample cores were extruded and cut into discreet intervals in the field. Chemical analysis was conducted on the size fraction less than 75 µm. The complete report including data tables and appendices was not available but the synopsis text was used for this summary.

Average concentrations of zinc, lead and cadmium were elevated in the near-field and mid-field areas at 2,911 μg/g and 141-214 μg/g, respectively. Concentrations of zinc in other samples in Strathcona Sound ranged from 58-111 μg/g. The concentration of lead in the near-field area was 695 μg/g and was 36 μg/g at one mid-field locations. Other lead concentrations were generally below the detection limit of 3.0 μg/g.

Concentrations of zinc, lead and cadmium were relatively consistent with depth in the near-field area, indicating that sedimentation with metal rich particles had been occurring over the period represented by the sediment core. Concentrations of zinc and lead decreased with depth in the mid-field area. The report suggested that these trends may be related to a greater rate of sedimentation in the near-field area combined with increased contaminant load in the near-field area.

Sediment toxicity for select sample sites was tested using three standard tests described by Environment Canada:

1. 10-day acute lethality test using the amphipod Rheopoxinius abronius.
2. acute/chronic toxicity test using the bacterium *Photobacterium phosphoreum* (luminescence).
3. fertilization inhibition using the white sea urchin *Lytechinus pictus*.

Test results were compared to an artificial control sample and to a regional reference sample that was collected from the head of Strathcona Sound. Amphipod toxicity was the same for the reference sample and the test samples although toxicity was greater than in the artificial control sample. Some effects on bacterium bioluminescence were observed but these effects did not follow a clear spatial trend and were not greatest in the near-field or mid-field areas but the effects did not result in a "fail" of the test per Environment Canada requirements. Some variations in sea urchin fertilization rates were observed but confidence in the test was low because the results for the control sample were below the minimum recommended by Environment Canada for a useful test.

1999/2000 Study (Elberling, unpublished)

A sediment sampling program was undertaken by Dr. Bo Elberling in 1999/2000. Sample results are pending.

5.3 Terrestrial Environment

5.3.1 Metals in Surface Water

Summary of Metals in Surface Water

A great deal of surface water quality data is available. Initial baseline studies were conducted in 1974 by B.C. Research Inc. (BCRI). Sampling per the terms of the Water License has been undertaken throughout the mine life by Nanisivik Mine. Additionally, discreet comprehensive studies have also been undertaken at times that collected detailed information in one area or over one time period.

The most important of the studies carried out in excess of the Surveillance Network Program are a series of metal loading studies in Twin Lakes Creek. The first of these studies was conducted by Indian and Northern Affairs Canada (INAC) in 1987 and 1988(Grey, 1989). Nanisivik Mine has conducted an annual metal loading study since 1995 and has reported these to the Nunavut Water Board. The most recent of these studies (for the year 2000) (Nanisivik Mine, 2001) provides observations and conclusions of recent years and is a recommended accompaniment to this summary document.

The general observations provided by the water quality studies is that metal loadings entering Strathcona Sound from Twin Lakes Creek increased as a result of mine activities, even in light of the elevated concentrations of metals that pre-existed the mine. The studies show that the dominant source of the metals is run off in the west adit area, which includes both naturally occurring and anthropogenic sulphide exposures. Concentrations of zinc and cadmium generally follow similar trends with maximum concentrations typically observed in the west adit/mill area that are greater than the concentrations at the mouth of the creek. The record of compliance with the Water License maximum allowable discharge limits at the decant from West Twin Lake has been excellent over the life of the mine.

The most recent (year 2000) metal loading study in Twin Lakes Creek indicates that there are typically two peaks in metal loadings in Twin Lakes Creek. An early summer peak may be related to early season thawing and release of stored water from rock dumps comprised of coarse materials. A late summer peak may be related to the release of stored water from natural soils and natural exposures of sulphides. The late summer peak includes peak iron loadings and is typically accompanied by orange staining in many local creeks (including Twin Lakes Creek and Strathcona Creek) due to the release of iron stored in surface soils.

July 1974 Study (BCRI, 1975)

A suite of surface water samples was collected by BCRI in late July 1974 from 12 locations that included Twin Lakes Creek, Chris Creek and other streams in the area on both the north and south shores of Strathcona Sound. Samples were also collected at 2 depths (surface and bottom) in Kuhulu Lake and at 3 depths (surface, middle and bottom) in East Twin Lake and West Twin Lake (2 locations). The samples were analysed for dissolved concentrations of zinc, lead, arsenic, cadmium and iron.

The metal concentration data generally indicates that metal concentrations in Twin Lakes Creek and Chris Creek were elevated above reference locations and that the metal concentrations in Chris Creek were generally greater than in Twin Lakes Creek. The greatest concentrations of zinc, arsenic and cadmium were alternately measured in a tributary to Twin Lakes Creek north of the (future) townsite and a tributary to Chris Creek near the (future) east adit area. The metal concentrations in Kuhulu Lake, East Twin Lake and West Twin Lake were similar to the reference locations.

Zinc concentrations at all reference locations (i.e. excluding Twin Lakes Creek and Chris Creek and their tributaries) ranged from 9.0 to 40 µg/L. This includes all of the samples from Kuhulu Lake, East Twin Lake and West Twin Lake. Strathcona Creek located on the north side of Strathcona Sound approximately opposite the mine area contained 90 µg/L zinc. One tributary to West Twin Lake on the northwest side contained 80 µg/L zinc.

The water samples from Twin Lakes Creek and Chris Creek and their tributaries contained greater concentrations of zinc than other locations. The highest concentration was measured in a tributary to Twin Lakes Creek north of the (future) town site and was 54,000 µg/L. The second greatest concentration of zinc measured was a tributary to Chris Creek near the (future) east adit area and was 15,000 µg/L. The concentrations of zinc at the mouths of Chris and Twin Lakes Creeks were 700 µg/L and 150 µg/L, respectively.

The spatial variability of lead concentrations was generally similar to that for zinc. The exception was that the concentration of lead at the mouth of Twin Lakes Creek was the same as observed at the reference locations (range from 0.7 µg/L to 1.0 µg/L). The greatest concentration of lead measured was in the northwest tributary to West Twin Lake at 110 µg/L. Lead in Strathcona Creek was slightly elevated at 2.0 µg/L. The concentration of lead at the mouth if Chris Creek was slightly elevated at 1.6 µg/L.

The spatial variability of cadmium was generally similar to that for zinc and lead. The exception was that the concentration of cadmium in the northwest tributary to West Twin Lake was the same as at the reference locations (range from 0.1 to 0.3 µg/L). The greatest concentration of cadmium measured was in the tributary to Twin Lakes Creek north of the (future) townsite at 140 µg/L. The concentrations of cadmium at the mouths of Chris and Twin Lake Creeks were slightly elevated at 2.2 and 0.4 µg/L, respectively.

The spatial variability of iron was different than that for zinc, lead and cadmium in that all of the sample locations save two were within the range from 3.4 to 49.0 µg/L including all of the lake samples. The highest concentration was measured in the tributary to Twin Lakes Creek north of the (future) townsite at 3,350 µg/L. Strathcona Creek was also slightly elevated at 100 µg/L.

Samples were also collected at the mouth of Twin Lakes Creek by FMS in 1974, 1975 and 1976 (one sample per year reported that are assumed to have been collected in summer in conjunction with other environmental studies). These samples contained dissolved zinc concentrations of 223, 236 and 47 µg/L in 1974, 1975 and 1976, respectively. These concentrations are in general agreement with the sampling by BCRI as described above wherein the concentration of dissolved zinc at the mouth of Twin Lakes Creek was measured to be 150 µg/L in July 1974.

1982 Study (Thomas, 1983)

Surface water samples in East Twin Lake, West Twin Lake and Twin Lakes Creek were collected on 4 occasions in June, July and August 1982. The samples included Twin Lakes Creek at the outflow from the West Twin Disposal Area, on Twin Lakes Creek upstream of the west adit area, approximate mid-point on Twin Lakes Creek downstream of the mill and at the mouth of Twin Lakes Creek. It is assumed that the samples were filtered and preserved in the laboratory and subsequently analysed within 4 months, although this is not explicitly stated. In this case, the metal concentrations reported are dissolved concentrations although the timeframes between sampling and filtering/preservation and subsequent analysis introduces some uncertainty into the evaluation of results.

The sample results illustrated that the dominant source of metals entering Twin Lakes Creek was from the west adit area. However, sampling was not detailed to the degree of differentiating between individual sources (rock dumps, outcrops, etc.) in the west adit area. The greatest concentrations of metals were commonly observed at the sample location located immediately downstream of the mill. The concentrations of zinc at the mouth of Twin Lakes Creek ranged from 3.63 mmol/m^3 to 135 mmol/m^3.

June 1985 Study (Arctic Laboratories Ltd., 1986)

One sample was collected at the mouth of Twin Lakes Creek in June 1985 as part of a seawater quality assessment. This sample returned a zinc concentration of 12 mmol/m^3 zinc and 0.012 mmol/m^3 lead.

Report on Water Quality 1977 to 1988 (Grey, 1989)

This report summarized the water quality information that had been gathered from 1977 to 1988. The available data was primarily gathered as part of the Surveillance Network Program but also included special detailed sampling that was conducted from 1981 to 1984 in the west adit area.

The data indicated that decant (outflow) from West Twin Lake represented a minor percentage of zinc (<1% in 1982) and cadmium (14% in 1982) entering Strathcona Sound. The majority of the loadings of zinc and cadmium entered Twin Lakes Creek in the mid-creek/west adit area where maximum concentrations were observed. The concentration of lead in Twin Lakes Creek water progressively decreases with distance downstream, which suggests that lead may be bound to suspended particles that settle out along the length of the creek.

Specific detailed investigations of sources of metal were undertaken in 1982. A naturally occurring outcrop of massive sulphides in the west adit area resulted in a small flow of extremely poor quality drainage with pH around 2 and zinc around 15,000 mg/L. A gossan zone near the townsite on the south side of Twin Lakes Creek resulted in a small flow of drainage with pH around 5 and "high" metal values (not reported). Flow through the west open pit that entered Twin Lakes Creek until 1982 (then diverted to the mill) was measured to have pH around 2 and zinc as high as 1,000 mg/L. A reduction in zinc and cadmium concentrations in Twin Lakes Creek from 1982 to 1984 was attributed to this diversion. The report recognizes that this flow would include seepage and runoff passing over both naturally mineralized areas and mining disturbed areas. Waste rock piles, vehicle wash area and drainage from the lower west portal were also investigated and concluded to have a negligible effect in Twin Lakes Creek.

2000 Twin Lakes Creek Metal Loading Study (Nanisivik Mine)

An annual study of metal loadings in Twin Lakes Creek has been undertaken since 1995. The studies have involved detailed sampling along the length of Twin Lakes Creek and flow monitoring at the mouth. The 2000 metal loading study as prepared by Nanisivik Mine was submitted to the Nunavut Water Board in early 2001 and contained the following observations:

1. Zinc concentrations and loadings exiting the West Twin Lake tailings containment area are a very minor contributor to metal loadings in Twin Lakes Creek.
2. Zinc concentrations and loadings generally increase from the East/West Twin Lakes area to Strathcona Sound with the greatest concentrations observed at various times in proximity to certain rock dumps and natural outcrops of massive sulphides.
3. An early season (spring) spike in zinc concentrations occurs in proximity to rock dumps, which is considered to be related to the melting of snow and ice and subsequent flushing of rock dumps.
4. A second spike in zinc concentrations occurs in proximity to a natural sulphide outcrop, which is considered to be related to slower (as compared to rock dumps containing very coarse material) melting of snow and ice and subsequent runoff from natural soils.
5. The late season spike in zinc concentrations is accompanied by high iron concentration, which is also considered to be related to natural runoff and the thawing of surface soils.
6. The high late season iron concentrations result in a visible orange discolouration of the creek water and staining of creek sediments in Twin Lakes Creek and other local creeks.

6. Fundamental Mine Reclamation Issues

6.1 West Twin Lake Tailings Containment Area

6.1.1 Chemical Stability

The long term chemical stability of the tailings containment area is important to ensure that the concentrations of metals or other contaminants exiting the containment area are low and do not pose an environmental risk to the downstream environment. The mine tailings have been confirmed to be potentially acid generating. Long term chemical stability is proposed to be provided by combining two reclamation methods: water cover to minimize oxygen availability and soil cover to induce freezing of the tailings and, thereby, reduce oxygen availability and transport of contaminants.

In the upper containment area (i.e. above the dyke) and in the test cell area of the lower containment area, a layered cover of shale and gravel will be applied of sufficient thickness to maintain the tailings and the cover interface below zero degrees C. This approach is intended to minimize the release of contaminants in two ways. Sulphide oxidation rates are significantly reduced at lower temperatures and, therefore, the generation of contaminants will be significantly reduced (as demonstrated in the reclamation research studies that are described in Section 4.3). The formation of an ice layer at the base of the soil cover will further reduce oxidation rates via the lower diffusivity of oxygen in ice as compared to air or water. Additionally, the transport of any small amounts of contaminants generated in the tailings will be inhibited by an ice layer at the base of the soil cover which will prevent contact between surface runoff and tailings.

Research studies described in Section 4.3 resulted in the development and calibration of a 2-dimensional geothermal model that predicts ground temperatures in well drained, unsaturated conditions for various cover thickness and climatic conditions. The model indicates that a 1.25 metre cover will maintain the ground temperature at the cover/ tailings interface below zero for unsaturated conditions in the test cell area. This modeled indication of cover thickness is not directly transferable to reclamation of the tailings surface cell in that the test cell area was initially in a raised and drained condition and was later flooded by deposition of new tailings. Focussed research into appropriate cover thickness for the closure concept is continuing by Nanisivik Mine.

Global warming is an environmental issue that has the potential to effect the long term performance of remedial measures. Increases in long term air temperatures would generally promote deeper ground thawing and a thicker active layer than is currently observed. Long term global warming predictions for the Canadian Arctic are developed by Environment Canada and available for general use. A preliminary reference may be made to the Panel on Energy Research and Development for Environment Canada in 1998 (PERD). PERD used a “best estimate” scenario and a pessimistic “high sensitivity” scenario that corresponded to average global temperature increases of 2°C and 3.5°C respectively between the years

1990 and 2100. Additionally, temperature changes are expected to be attenuated by a factor of 0.35 times during the summer at N74º latitude.

The exothermic chemical reactions that occur as part of the acid generation process generate heat. Even in the sub zero temperatures that will exist in the tailings (post reclamation), the reactions may continue at slow rates and may generate a small amount of heat on a local or even microscopic level. It is likely that this heat of reaction will be relatively small and will dissipate quickly with respect to the energy required to melt pore ice. An overview quantitative examination of the possible effects of the exothermic heat of reaction is planned to be incorporated into the Closure and Reclamation Plan.

6.1.2 Physical Stability

The long term physical stability of the dyke that separates the upper and lower portions of the West Twin Disposal Area is important. A physical failure of this dyke could compromise the integrity of the tailings rock cover and could expose tailings to the atmosphere where oxidation and release of contaminants could occur. An annual inspection of the dyke is conducted by a professional geotechnical engineer that includes recommendations for operation, maintenance and upkeep of the dyke.

Ground temperatures within and below the dyke confirm that the dyke and foundation are in a frozen state, which enhances the static and dynamic stability of the dyke. Issues that have the potential to affect the long term physical stability of the West Twin dyke include:

1. overtopping of the crest by flood flows
   An overflow spillway that would safely pass flood flows from the upper surface cell to the lower containment area is planned. Two studies (hydrology and geotechnical design) are underway in 2002. The spillway is conceptually located at the south abutment of the dyke.
2. seismic events
   Stability modeling conducted by BGC Engineering Inc. indicates that the frozen dyke has an acceptable factor of safety for a seismic event of more than 1,000 year return period as defined by the Geologic Survey of Canada.
3. thawing of the frozen core
   The possibility for effects from global warming and heat generated by AMD reactions in the tailings are described in Section 5.1.1 above.
4. physical durability of the shale rock
   Physical protection for exposed shale rock will be provided by a cover (approximately 0.25 metres thick) of sand and gravel, which is more durable than the shale.

6.2 Contamination of Surface Soil

Surface soils around the mine site may be contaminated with metals and hydrocarbons that originated from mine activities. Some mining related sources of metals in surface soils may be: tracking of concentrates in vehicle tires, air dispersion of concentrates, air dispersion of tailings dust, spillage of concentrates at the ship loading dock, or tailings pipeline breaks or drainage. Some mining related sources of hydrocarbons in surface soils may be: spillage during offloading of ships, pipeline breaks, spillage during filling of small mobile tanks, or spillage from stationary tanks

The primary areas where metal contamination related to mining activities might be expected to be identified are:

1. Mill yard.
2. Warehouse yard (Figure 3).
3. Road from mill to concentrate storage shed.
4. Dock/ship loading area.
5. Downwind of the tailings impoundment.
6. Tailings pipeline route including “dump” ponds.

The primary areas where hydrocarbon contamination related to mining activities might be expected to be identified are:

1. tank farm at dock.
2. fuel supply pipeline route.
3. various fuel storage tanks.

Two examples of known contamination of surface soils due to mine activities are a hydrocarbon spill at the carpenter’s shop area and loss of concentrate dust at the ship loading area. The hydrocarbon spill occurred in 2001 due to the failure of a valve housing when the tank settled or shifted putting the weight of the tank onto the valve. The spill was cleaned up appropriately and was documented in the annual environmental report for that year. Loss of concentrate dust onto the ground in the ship loading area is known to have occurred prior to enclosing of the conveyors in 1982. Most of the concentrate dust was reclaimed at the time but it is likely that some residual contamination remains.

6.3 Acid Rock Drainage/Metal Leaching

Acid rock drainage (ARD) is an important environmental issue at sulphide mines. This issue as it applies to the West Twin Lake tailings containment area is described above. This issue also applies to the reclamation of waste rock piles and open pits.

An ARD study reported on by Lorax Environmental described the ARD potential of various rocks in various locations of the mine site. In general, most waste rock piles and open pit walls have potential to generate ARD because of the presence of sulphide mineralization. The reclamation measures that are planned for mineralized rock piles are to excavate and return material back to the open pits or underground or to cover in place with shale. Open pits are to be covered with locally available shale rock to a thickness that will promote freezing of the mineralized rock. Open pits may be partially backfilled with both mineralized rock and shale rock to prevent ponding of water within the pit bottoms.

6.4 Landfill

The prevention of contaminated seepage from the landfill is an important reclamation issue. The proposed reclamation measures are to cover the landfill with a cover of shale rock that is contoured to promote surface run off and that is designed to be thick enough to maintain permafrost within the landfill material and the base of the cover. Additionally, surface runoff diversion ditches will be upgraded such that the diversion of water around the landfill area will be maximized.

6.5 Dismantling and Disposal of Buildings and Equipment

Buildings and Equipment will fall into one of three broad categories: those with economical salvage value, those with no economical salvage value and special or hazardous materials. The determination of economical salvage value will vary over time and for various appraisers but is generally defined as equipment for which a positive economic return can be realized inclusive of dismantling, cleaning, packaging, transportation and permitting. Scrap steel is assumed, at this time, to have no economic value due, primarily, to high transportation costs to southern recycling facilities.

On a conceptual level for illustrative purposes only, the following might be determined to have a positive economic return for reuse or salvage:

- Dense media separation plant.
- Mobile underground mining equipment (trucks, scoops, drills, etc.).
- Crushers.
- On stream analyser.
- Grinding mills.
- Certain pumps.
- Mobile surface equipment (grader, dump trucks, loaders, etc.).
- Diesel-electric generators.
- Personal computers/office furniture.
- Shop tools.
- Some small metal sheds.
- Ventilation equipment.
- Residual reagents and chemicals.

Any buildings or equipment that is being shipped off the mine site for reuse or salvage must be cleaned to be in compliance with environmental regulations, must be packaged in compliance with the Transportation of Dangerous Goods Act (where applicable) and must be shipped in accordance with relevant regulations. There is a potential for some facilities to be left in place or relocated locally for reuse. This possibility is described below and is considered separate from the description of "economic salvage value" as described here.

Any buildings or equipment that are determined to have no salvage value will be disposed into the permafrost environment of the underground mine. Dismantled fuel handling equipment such as fuel storage tanks and fuel pipelines should be cleaned prior to placement in the underground mine. Free hydrocarbons that are produced during the cleaning should be burned on site in an incinerator.

Special or hazardous materials might include residual laboratory chemicals, residual lubricants or other hydrocarbons or PCB's. An asbestos survey was conducted by Nanisivik Mine which indicated that no asbestos was on the property. These materials should be identified and handled in accordance with relevant regulations for packaging, transportation and destruction. It is likely, that these materials will be shipped to an off-site disposal facility and that contracting of the packaging and transportation will be incorporated into a disposal contract.

6.6 Third Party Owned Facilities

The buildings and facilities in the town that are owned by the Government of Nunavut are to be included in the reclamation plan with the work being performed by Nanisivik Mine on behalf of the Government of Nunavut. This would include:

- Sewage treatment plant.
- Town sewer system.
- Town water supply system.
- Road maintenance garage/shop.
- Town centre.
- Road from town to East Twin Lake.

Any other buildings or facilities that are owned by a third party such as the Government of Nunavut are not included in the mine reclamation work plan, at this time. This includes, but is not restricted to:

- Dock.
- Road from town of Nanisivik to airport.
- Road from town of Nanisivik to Arctic Bay.
- Airport.
- Road from town of Nanisivik to dock (although clean up of surface soils contaminated due to mine activities is planned by Nanisivik Mine).

6.7 Possible Transfer of Ownership of Certain Facilities

The possibility of transfer of ownership for the on-going use of some facilities has been discussed on a preliminary level with the Government of Nunavut, DIAND and other interested parties.

An illustrative list of some of the facilities and options that have been discussed in this context is as follows:

- Occupation of the town.
- Relocation of housing to Arctic Bay.
- Use of town as DND training camp.
- Use of the fuel tank farm and, possibly, concentrate storage shed by Coast Guard as fueling depot.
- Use of housing and mill maintenance shops as a trades training facility.

These opportunities remain possibilities only at this time and are not included in the current reclamation plan. That is, the current reclamation plan assumes that the facilities discussed here are to be dismantled and otherwise reclaimed.

7. Proposed 2002 Site Assessment Program

7.1 Overview

The purpose of the 2002 Environmental Site Assessment will be to complete the data collection and interpretation that has been initiated by Nanisivik Mine. The 2002 ESA program will attempt to take full advantage of previous work in order to avoid duplication of time and effort. The data collection is intended to be appropriate for an ecological and human health risk assessment that would result in the development of site specific soil quality remediation objectives.

The 2002 program that is proposed here is based on an on-site preliminary review of available information (including some raw data not yet reported on) and may include some reasonable assumptions. Therefore, a more complete review of all of the available information will be necessary at the outset of the 2002 program to finalize the scope of work. Nonetheless, the 2002 program that is described here is considered to be reasonable and the detailed review of existing information is anticipated to result in only minor changes that can be implemented in the field.

The project objective will be to identify and delineate areas of environmental contamination related to mine activities. The 2002 ESA program will include the town, all mining areas, tailings area, mill site, dock site and landfill. This includes some facilities related to the Town of Nanisivik that are owned by the Government of Nunavut: housing, mobile equipment storage garage, sewage treatment system, freshwater supply system, road to East Twin Lake, town centre and school. It is assumed, at this time, that the inclusion of GN owned facilities will be undertaken by Nanisivik Mine on behalf of the GN on a contract basis.

7.2 Approach

7.2.1 Utilization of On-Site Facilities and Personnel

The presence of environmental personnel and analytical facilities at the mine site will be of benefit to the environmental site assessment program. The involvement of mine environmental staff will ensure that the work is conducted with the benefit of site specific knowledge and experience. The use of on-site analytical facilities will allow analyses to be completed at reduced cost (as compared to an external laboratory).

The on-site laboratory facility has been used in the past for environmental analyses of water and soil. At those times, a quality assurance procedure was implemented that successfully demonstrated the validity of the results. For the proposed 2002 program, the on-site laboratory would be utilized for analysis of certain key heavy metals (for example: zinc, cadmium and lead) in soil and water samples with 10% of the samples also shipped to an external laboratory for duplicate analyses. In this way, the duplicate samples may also be analysed for additional metals or other parameters of concern that are not practical or possible in the on-site laboratory.

The remote location of the mine site can cause long transit times to an external laboratory, which could be a factor in the analysis of volatile parameters such as petroleum hydrocarbons in soil and water samples. Careful planning and management of samples, including field QA/QC procedures will be instituted such that travel time to the external laboratory is minimized. This will include scheduling the collection of samples for hydrocarbon analysis as close as practical to the date of shipment from the minesite. If necessary, a laboratory local to the Ottawa/Montreal area will be utilized in order to further minimize travel times.

Acid Base Accounting (ABA) analyses can be conducted at the Caribou mine site in New Brunswick according to the standard (Sobek) methodology and this facility will be utilized as practical.

7.2.2 Community Involvement

Experience from other similar projects has shown that involvement of the community in the site assessment program could provide two valuable benefits to the ESA program:

1. provide the ESA team with access to valuable knowledge about the local environment.
2. provide the community with first hand insight into ESA sampling program, which might increase confidence in the resulting interpretations.

We suggest that the Arctic Bay community liaison officer be contacted prior to the initiation of the site assessment to discuss the field work. The liaison could be invited to observe the work as it is underway in order to gain an understanding of field data collection and to enable the liaison officer to report first hand observations to the community. The liaison officer might also provide local traditional insights into environmental issues as the work is in progress. In addition to this possible involvement by the liaison officer, a community member could be employed as a field assistant. This would provide some employment and experience to a community member and would minimize costs by reducing the number of staff mobilized to Nanisivik. The individual would need to be physical fit and interested in taking part in an environmental sampling program.

7.2.3 Gartner Lee Team

Gartner Lee will provide the technical and field personnel required to complete the work in a professional and timely manner.

The project manager will be Mr. Eric Denholm of the Yellowknife office.

Technical staff will be utilized for backup regarding final planning for the field work, technical support during the field work (via telephone and email), and data interpretation and reporting. The technical staff will include both intermediate and senior level personnel.

The field team will include Mr. Denholm plus one or two environmental technicians. This is based on the following assumptions:

- A dedicated environmental assistant is available for the field work either from Nanisivik Mine or from Arctic Bay.
- An excavator/backhoe is available with operator from Nanisivik Mine.
- A surveyor is available at completion of the field work to survey selected sampling locations.

7.3 Proposed 2002 Site Assessment Program

7.3.1 Soil Sampling

Mine activities typically result in some localized contamination of surface soils, primarily with metals and hydrocarbons. At Nanisivik Mine, activities in the townsite may also have resulted in similar contamination of the surface soils within the town. Sampling of soil is required to determine the locations and extent of "contaminated" soil. The definition of "contamination" for various contaminants of interest can be taken from various generic regulatory guidelines or can be developed on a site specific basis using a risk-based approach.

Soil samples are proposed to be collected and analysed, primarily for metals and petroleum hydrocarbons. The primary target investigation areas will be the mill yard, the warehouse yard, the carpenter shop (location of 2000 hydrocarbon spill), the dock yard, the townsite, the tailings pipeline route and dump ponds, the ground surface downwind (north) of the tailings impoundment, the landfill, the road from the mill to the concentraet storage shed and the dock area. The results of previous surface soil sampling from the road between the mill and the concentrate storage shed wil be incorporated into the program.

Sampling of surface soils downwind of the tailings impoundments has been conducted by Nanisivik Mine. Additionally, air particulate fallout has been collected and analysed. This is an important issue for the ESA program because of the potential for air dispersion of tailings particles to increase the extent of the area of contamination and, thereby, the area requiring remediation. For this reason, additional sampling of surface soils is proposed that will further delineate the current metal concentrations. This will provide additional data for comparison to background soil quality as represented by historical mine exploration records.

Soil samples in work areas will be collected from test pits excavated by a hydraulic excavator or backhoe. It is anticipated that the test pits would be excavated to the bottom of the active layer, likely to be in the order of 1.0 metres below surface in various areas. Soil samples in unworked areas will be collected by hand. Samples will be collected at various depth intervals at the discretion of the ESA technician or as outlined below. Hydrocarbon samples will be collected where visual or olfatory observations indicate a high concentration.

A strategic analytical program will be defined subsequent to sample collection that will minimize the analytical work and cost while providing sufficient information. In this way, a subset of the total samples collected may undergo analysis with the remaning samples archived for possible future use. Test pit locations will be flagged by the ESA team and key locations will be surveyed for coordinates and elevations by mine personnel.

A brief description of the intent for each area is as follows:

- Mill yard: anticipate 20 test pits with an average four samples each including area at downslope toe of fill material.
- Warehouse yard: anticipate 10 test pits with an average four samples each including area at downslope toe of fill material.
- Carpenter shop: anticipate 10 test pits with an average four samples each.
- Dock yard: anticipate 10 test pits with an average four samples each.
- Townsite: anticipate 25 test pits with an average four samples each.
- Tailings pipeline route and dump ponds: anticipate 10 surface samples (collected by hand).
- Ground surface downwind from tailings facility: anticipate 25 surface samples (collected by hand).
- Landfill: anticipate 10 test pits with an average four samples each including area at downslope toe of fill material.

7.3.2 Water Sampling

Historic and recent studies show that local surface water contains elevated concentrations of certain heavy metals (primarily zinc) that are related to both mining activities and naturally occuring outcrops of mineralized rock.

No surface water sampling is anticipated for the 2002 ESA program based on the assumption that Nanisivik Mine will be repeating the detailed water sampling and flow monitoring program (metal loading study) in Twin Lakes Creek and will also be conducting water sampling required by the Water License. Any additional surface water samples that would be beneficial to the ESA program will be recommended to mine personnel for incorporation into these sampling programs.

Water that is present in the active soil layer during the summer season may become contaminated (primarily with metals or hydrocarbons) due to localized contamination of soils within the active layer. In this event, the water may serve as a transport mechanism for contaminants to the surface environment. Water that is encountered in test pits during the ESA program may be sampled at the discretion of the ESA technician. These samples would be filtered as appropriate, preserved as appropriate for metals analysis and analysed by the on-site laboratory.

7.3.3 Vegetation Sampling

Analysis of metals in local vegetation can help to determine the degree and extent of the dispersion of metals related to mine activities and is an important component of an ecological risk assessment. Vegetation can absorb metals from the soil via roots or from the air via the leaves and this can be determined to further identify the source(s) of metals.

We propose to sample vegetation in the general area downwind of the active mining areas (i.e. between the West Twin Lake tailings containment area and Strathcona Sound). The sample locations would be selected to correspond to soil sampling locations decribed in Section 6.3.1 such that surface soil samples are collected at the vegetation sampling sites. The combination of vegetation and soil sampling and the sampling of several types of vegetation will allow a determination of the pathways of any metals observed in the vegetation (i.e. from soil via roots or from air via leaves).

We anticipate 5 vegetation sampling locations generally located as follows:

1. Control station south of the WTDA.
2. South facing slope located immediately to the north of the tailings containment area.
3. Area initially mapped as “meadow” (BC Research) located at southwest side of townsite.
4. North facing slope betweeen East Adit area and Strathcona Sound and west of Chris Creek.
5. North facing slope near lower section of Twin Lakes Creek.

7.3.4 Marine Sediment Sampling

The marine environment is an important part of the local environment and may be part of the post closure monitoring plan. Marine sediments near the inflow of Twin Lakes Creek have been shown to contain elevated concentrations of heavy metals (esp. zinc).

The most recent sampling of marine sediments was conducted by Dr. Bo Elberling in 1999/2000 (results and reporting pending). This suite of samples can serve as a reference for assessing the future effects of mine reclamation activities on the marine environment and no additional sampling is considered to be required at this time.

7.3.5 Rock/Acid Mine Drainage Sampling

Geochemical studies of tailings, soil, waste rock, shale rocks and pit walls have been conducted and reported on by Lorax Environmental. The preliminary review of information indicated that these studies are adequate for site assessment purposes and no additional sampling or analysis of these materials is considered to be required with the exception of verification sampling of roadways.

The previous work included drill sampling of the roadway between 02 adit and the mill and showed that this road material was not acid generating. Random samples will be collected from other roadways on the minesite utilizing a backhoe to excavate test pits to the depth of permafrost or to the bottom of the roadfill.

The samples may undergo metals analysis and acid base accounting analysis at the Caribou mine laboratory to obtain the net neutralizing potential (NNP). Samples for which additional data is desired may undergo additional static AMD testing or metal leaching analyses at an external laboratory.

7.3.6 PCB's

A current inventory of equipment containing PCB's is available and appropriately registered with Environment Canada as is the on-site storage container.

The inventory was reviewed and no further inventorying or sampling is considered necessary at this time.

7.4 2002 Analytical Program

7.4.1 Soil and Water Metals Analyses

A strategic analytical program will be defined subsequent to sample collection that will minimize the analytical work and cost while providing sufficient information. In this way, a subset of the total samples collected may undergo analysis with the remaining samples archived for possible future use.

A large portion of the metals analyses for soil and water samples will be perfomed by the on-site laboratory. The on-site analytical procedures have been demonstrated to be valid and a quality contol procedure will also be implemented to further demonstrate the accuracy of the reuslts. The quality control procedure will involve the duplicate analysis of approximately 10% of samples at an accredited external laboratory.

The on-site analyses may be performed for paste pH, zinc, cadmium, copper, lead and iron. Water samples will be filtered either in the field or in the lab where the analysis of dissolved concentrations is desired.

A select group of the samples shipped to an external laboratory will also undergo a complete (30 element) ICP scan to provide a full suite of metal concentrations.

7.4.2 Soil Hydrocarbon Analyses

A select number of soil samples may undergo hydrocarbon analysis where visual and olfactory field observations indicate a strong presence. These samples will be collected into appropriate (glass) sampling containers and shipped to an external laboratory for analysis of light and heavy petroleum hydrocarbons (LEPH and HEPH).

Standard procedures for the analysis of petroleum hydrocarbons in soils and water recommends that the analysis be initiated within 7 days of sample collection. This timeframe is considered to be achievable provided that a laboratory within the Ottawa area is utilized.

7.4.3 Soil Acid Base Accounting Analyses

Select samples (anticipated to be primarily from roadways) may undergo acid base accounting analysis. These analyses will be conducted at the Caribou mine site according to the standard "Sobek" methodology.

If follow up testing is desired, this may involve additional static testing for breakdown of neutralization potential or acidity or metal leaching tests. These analyses would be performed at an accredited professional laboratory.

7.4.4 Vegetation Metals Analysis

At this time, samples are proposed to be collected of arctic willow (separated into roots and leaves) and lichen. This will be reviewed prior to commencement of the field work. The intent will be to obtain an indication of the source of any metals identified in vegetation as well as an indication of the bioavailability of any metals identified.

Analysis for key metals (copper, zinc, lead, iron and cadmium) is anticipated to be undertaken by the on-site laboratory pending final confirmation of methodology.

7.5 Schedule

The following items are assumed, at this time, to be provided by Nanisivik Mine for the ESA work:

1. Excavator/backhoe with operator for approximately 4 days.
2. Metal analysis (Zn, Cd, Cu, Pb, Fe) and pH of water, soil and vegetation samples within a timeframe of 4 weeks following sampling for an estimated 20 water samples, 315 soil samples and 15 vegetation samples.
3. ABA analyses at Caribou mine.
4. Direct payment of freight charges for samples shipped to an external laboratory and for supplies shipped to the mine site.
5. Airline tickets and overnight accommodations for Gartner Lee field personnel.
6. One dedicated environmental assistant from the community of Arctic Bay for an estimated 6 days who is paid directly by Nanisivik Mine.
7. Direct payment by Nanisivik Mine to the external analytical lab so that the 5% Gartner Lee admin. markup will not apply to the analytical lab cost.

The following schedule is anticipated for the project:

1. Field work: performed in mid to late June.
2. Analytical data: available by early August (from both the on-site and external labs).
3. Draft project report: end September (for review by Nanisivik Mine/Breakwater Resources).
4. Final report: four weeks after receipt of review comments.

8. Recommendations

The following are primary recommendations resulting from the Phase 1 Assessment. These recommendations are intended to provide a means of efficiently collecting the information that is considered to be necessary in the short term to technically support the proposed closure and reclamation measures.

1. Proceed with the proposed Phase 2 ESA in summer 2002.
   this will determine the extent, depth and levels of contamination in surface soils and other environmental media
2. Conduct a human health and ecological risk assessment immediately following the 2002 Phase 2 ESA that would develop site specific soil quality remediation objectives.
   this will determine site specific soil quality remediation objectives appropriate for the anticipated land use(s)
3. Develop an estimate of the practical disposal volume available in the mine for comparison to the estimated volume of materials to be placed in the underground mine from waste rock, building demolition, mobile equipment, contaminated soils, etc. and prepare a disposal location plan to verify space availability and scheduling.
   this will demonstrate that disposal volume is available and that a plan is in place for hauling and disposal underground
4. Install and monitor several strategically located thermistors in the underground mine to demonstrate and verify ground temperatures as suitable for long term disposal of waste materials.
   this will demonstrate the long term thermal stability of the underground mine
5. Develop an overview (i.e. as opposed to exhaustive) quantitative examination of the potential heat of oxidation that could be experienced in the context of anticipated heat dissipation and energy required to melt pore ice.
   this is underway for incorporation into the Closure Plan and will provide context and technical support for discussing the possible effects of heat of reaction on the closure freezing concept for tailings cover and dam stability
6. Research Environment Canada global warming predictions that are appropriate to the Nanisivik site and assess the sensitivity of the proposed tailings and landfill cover concepts to the predicted values.
   this will provide context and technical support for discussing the possible effects of global warming on the closure freezing concept
7. Review the current assessment of the physical stability of the West Twin dyke in the context of appropriate long term closure criteria such as the Canadian Dam Safety Guidelines.
   this would identify any additional work required to demonstrate the long term physical stability of the dyke