REVIEW OF AQUATIC STUDIES RELATED TO

NANISIVIK MINE, BAFFIN ISLAND

by

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1998

PREFACE

This report was prepared under contract for the Department of Fisheries and Oceans, Iqaluit, NT. The Scientific Authority for this contract was Gary Weber of the Department of Fisheries and Oceans, Iqaluit, NWT, Canada, XOA OHO.

Correct citation for this report is:

Stewart, D.B. 1998. Review of aquatic studies related to Nanisivik Mine, Baffin Island. Arctic Biological Consultants, Winnipeg, MB for Department of Fisheries and Oceans, Iqaluit. vi + 77 p. + disk. (Executive Summary available in Inuktitut).

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tailings disposal area from the rest of the lake which serves as a reservoir from which the mill reuses the tailings water. To maintain the water balance within the system, the dyke structure has been raised about 2 m annually since on-land disposal was begun (1994 excepted) (Nanisivik Mines Ltd. 1997c).

Contaminated water from the tailings is contained in West Twin Lake. On-land deposition results in crude separation of water from the tailings solids. This water remains in the tailings disposal area until it is pumped over the dyke into the reservoir side. Particles in the water settle to the bottom. This settling process is aided by the relatively high pH of the tailings, which causes metals in the water to form compounds that fall to the bottom, and by the dyke which has increased the residence time of water in both areas of the lake. Water from the reservoir flows into a retention pond before being released (decanted) periodically into Twin Lakes Creek during the open water season. If metal concentrations in the decant water are greater than what is permitted under its Water License, the Mine must stop the flow until they are reduced.

When the mine was established, tailings disposal under water in West Twin Lake was considered to be a cost effective method of environmental protection (Asmund et al. 1991). It had the advantage of keeping the tailings physically contained over the life of the mine and following abandonment. The protection this affords the environment was considered to outweigh the increased cost associated with pumping the tailings slurry over the hill to West Twin Lake, instead of having it flow by gravity downhill to be discharged at depth into Strathcona Sound (Asmund et al. 1991). Disposal on land was not considered to be environmentally advantageous (B. Fallis, pers. comm.). However, the mine has lasted much longer than was initially predicted and generated more tailings than could be stored under the water of West Twin Lake. Since 1991, most of the tailings have been deposited on land to preserve the lake's ability to clarify water from the tailings. To reduce dust emissions, the exposed tailings have been saturated in summer and ice-capped in winter. This exposure to weathering, and another factor not originally considered--climatic warming, mean that the tailings may have to be relocated prior to abandonment of the mine to stabilize metals that might otherwise be leached into the environment.

Nanisivik Mine also operates a water treatment plant, the East Adit Treatment Facility, at the east end of the ore deposit (Grey 1989; Nanisivik Mines Ltd. 1997b+c). At this facility, metal-rich acid drainage from the area's waste rock stockpiles and the East Open Pit are collected and treated with hydrated lime in a treatment pond. By raising the pH, the lime causes metals in the water to form compounds that fall to the bottom so that they do not enter East Portal Creek. Before treated water is released into the Creek it must meet water quality standards specified under the Water Licence.

FRESHWATER ENVIRONMENT

Pre-development studies were conducted on three lakes in the vicinity of the ore body, East Twin (Quasaqtoq), West Twin (Kuviku), and Kuhulu (B.C. Research 1975b; Bohn and Fallis 1978). East Twin Lake, the Nanisivik water supply, drains into West Twin Lake, the mine tailings pond which decants water into Strathcona Sound via Twin Lakes Creek (Figure 3). These lakes are elevated about 370 m above sea level, and prior to tailings disposal West Twin Lake was over 20 m deep. Kuhulu is a deep lake (>60 m) located in another watershed 2 km south of Strathcona Sound at an elevation of 264 m. It has a surface area of 3.2 km^2 and drains directly into the Sound via a seasonal stream.

The lakes are oligotrophic and cold monomictic. They were not thermally or chemically stratified in late July or August of 1974, and had low ion concentrations, nutrient levels and productivity, and near neutral pH (B.C. Research 1975b). Metal concentrations are shown in Table 1. Coliform counts from Kuhulu and West Twin Lakes in July and September 1974 were zero coliform organisms per 100 ml. A non-anadromous population of Arctic charr inhabits Kuhulu Lake, but fish not have been reported from the other lakes (B.C. Research 1975b; Bohn and Fallis 1978).

Creeks in the area of the ore body are small, with steep gradients and seasonal or ephemeral flow. Twin Lakes Creek is the largest of the creeks and receives most of the runoff from the area of the ore body. Annelid worms, tipulids, and chironomids have been collected from some of the creeks (B.C. Research 1975b).

The annual flow of Twin Lakes Creek has

been estimated at 7.5-8.6 x 10^6 m^3 (Thomas et al. 1983; Nanisivik Mines Limited 1997a). The creek begins to flow with local snowmelt in mid-May, passing through areas of exposed mineralization and over several waterfalls on its way to Strathcona Sound (Figure 4). Flow rates increase dramatically in early June when East Twin Lake discharges, and continue to increase slightly with spring runoff until early July, they then decrease gradually as average temperatures decline until freeze-up in late September. Short term peaks in flow are caused by rain or unusually warm temperatures. In 1993, the flow rate in the creek at station 159-10 (mid-basin) averaged 0.4 m^3/s, and ranged up to 1.6 m^3/s in July; in 1994, the average flow was 0.5 m^3/s and the maximum flow was 3.2 m^3/s (Nanisivik Mines Limited 1994).

Pre-development metals data from the Twin Lakes and Twin Lakes Creek are limited. Data from 1974 and 1976 both show higher zinc concentrations at the creek outlet to Strathcona Sound than in the headwaters (Fallis 1982). In 1976, the mid-basin zinc concentrations (total and dissolved) were about 25X greater than those of the headwaters and 2X greater than those at the outlet to Strathcona Sound. The degree to which this metal loading pattern had already been altered by mine-related exposure of mid-basin metal deposits to weathering is unknown. Cadmium and lead concentrations (total and dissolved) measured in 1974-76, were typically below 1.0 μg/L along the length of Twin Lakes Creek (Tables 1 + 2)

In 1974, high levels of zinc and cadmium were found at some tributaries of Twin Lakes Creek and Strathcona Sound (B.C. Research 1975b). The highest concentrations were found in coloured drainage from exposed metal sulphide deposits.

Freshwater metals data from 1974-76 must be interpreted with care given the high variability in metal concentrations associated with rainfall events and annual precipitation, and the fact that exploratory work had already exposed surface metal deposits in several of the basins (Grey 1989; DINA 1991). These data do not provide an adequate basis for the establishment of a "natural baseline" for metal concentrations in Twin Lakes Creek.

MARINE ENVIRONMENT

Strathcona Sound is a narrow, deep fiord which extends over 50 km into Borden Peninsula from Admiralty Inlet. It is bounded on both sides by precipitous cliffs, over 300 m in height, and divided into two basins (Bornhold 1976). The upper basin occupies 23 km at the head of the Sound and the main basin occupies the central portion of the Sound. Maximum water depths exceed 175 m in the upper basin and 320 m in the main basin. Tides can vary the water level in Strathcona Sound by at least 2.74 m in a single day (B.C. Research 1975a). Currents in the Sound are not well known.

During mid-winter Strathcona Sound is covered by landfast ice where first year forms predominate (Dirschl 1980; Markham 1981; Marko 1982). Break-up, clearing, and ice formation dates for the Sound can vary by a month depending on the severity of the winter. Break-up (<9/10 ths cover) occurs between 3 July and 4 August and open water generally predominates by mid-August, while ice formation normally begins in late September and is completed by late October. Thickness of the first year ice at Arctic Bay can range from 1.3 to 1.5 m, with maximum thickness occurring between March and June.

Surface water temperature of Strathcona Sound in mid-August varies from 0.4° to 9.2°C depending on the warming effects of freshwater runoff and rainfall (B.C. Research 1975a). Temperature below the surface decreases with increasing depth above 100 m and then begins to increase. At the 100 m level it reaches a minimum of -1.5°C, and then increases to -0.5°C at 300 m. Below the 100 m level there is relatively little temperature variation between stations or seasons. In September, surface water temperatures are generally low, -0.9° to 0.0°C, at the mouth and higher, 1.0°C, near the head of the Sound (Bornhold 1976). There are also temperature discontinuities between the depths of 15 and 20 m.

Waters in Strathcona Sound are relatively clear with August secchi disc readings of 6 to 13 m--the lower readings and therefore light transmission tending to be closer to shore (B.C. Research 1975a; Walker 1977). They range near neutral pH, from 7.6 to 8.2, with measurements at a deep water station decreasing gradually with depth from the surface measurement of 8.1 to 7.6 at 300 m.

In under-ice samples taken from Strathcona

Sound in late May and early June 1982, salinity, nitrate, and silicate concentrations all increased with increasing depth (Thomas et al. 1983). Water column stratification is stable below 50 m and subject to summer wind mixing and winter convection currents above 50 m (B.C. Research 1975a; Walker 1977). The early summer salinity profile of Strathcona Sound is characterized by a steep halocline to about the 10 m level with a more gradual increase in salinity thereafter. During break-up, when it is depressed by runoff and meltwaters, salinity at the surface ranges from 15 to 20 ppt (parts per thousand). It increases rapidly to 31 ppt by 10 m, and then gradually thereafter, increasing to 33.5 ppt at 300 m.

Later in the season when storms have mixed the upper water column, the surface salinity ranges from 27.6 to 29.4 ppt, and there is a halocline between 15 and 20 m (Bornhold 1976). In September 1975, a tongue of high salinity (up to 28.7 ppt) entered the south side of the Sound and extended towards the north coast (Figure 5). The central part of the Sound was characterized by salinities of about 28.0 ppt. Beyond the narrow constriction, towards the head of the Sound, the salinities increased steadily to >29.4 ppt, suggesting that there is little interchange of water between the upper and lower parts of the Sound.

DISCUSSION OF CONTAMINANTS

TWIN LAKES CREEK

Twin Lakes Creek is the main drainage basin affected by the mining operation and community. It receives decant water from the West Twin Lake Tailings Disposal Area, surface runoff from the vicinity of the mine, mill, and community; and raw sewage from the mine and community. It also receives much of the natural runoff from the ore body (Figure 3).

Effluent from the West Twin Lake Tailings Disposal Area

The quality of clarified water discharged from the Tailings Disposal Area into Twin Lakes Creek is regulated by a water license. This license was issued under the Northern Inland Waters Act (Northwest Territories Water Board 1976, 1978, 1983, 1987, 1991), and is now issued under the NWT Waters Act (Nunavut Water Board 1997). The license also limits the quantity of water that can be withdrawn from East Twin Lake for use in the mine and community to 180,000 m^3/ yr. Wastewater discharged from West Twin Lake must have a pH greater than 6.0, and must not exceed 9.5 (Nunavut Water Board 1997). The maximum allowable concentrations of contaminants in the decant from West Twin Lake are as follows:

PARAMETER	MAXIMUM AVERAGE CONCENTRATION (mg/L)	MAXIMUM CONCENTRATION OF ANY GRAB SAMPLE (mg/L)
Total Arsenic	0.25	0.5
Total Cadmium	0.005	0.1
Total Copper	0.1	0.2
Total Lead	0.1	0.2
Total Zinc	0.25	0.5
Oil and Grease	15	30
Suspended solids	15	30

There have been a number of amendments to the water licence over the life of the mine. In November 1991, the requirement for mercury monitoring was removed because mercury levels had consistently been below the detection limits of the sampling program (P. Smith, pers. comm.). The maximum allowable Total Zinc concentrations were lowered in May 1978 from 0.4 mg/L average and 0.8 mg/L grab to 0.2 mg/L average and 0.4 mg/L grab. In November 1991, they were increased to the levels shown above. The maximum allowable Total Lead concentrations were lowered in May 1978 from 0.2 mg/L average and 0.4 mg/L grab to 0.1 mg/L average and 0.2 mg/L grab. The concentration of metals in the decant has been controlled within licensed limits and monitored on a regular basis at the decant and at stations downstream (Figure 6). Since 1977, there have been a number of instances of non-compliance for lead, cadmium, and/or zinc in the decant from West Twin Lake (Stephens 1989; Jessiman 1990; AQUAMIN Working Group 5 1996; Smith 1996). Since the dyke was constructed across West Twin Lake in 1991, there have been fewer instances of non-compliance with respect to metals levels (P. Smith, pers. comm.).

The decant contributes to elevated zinc levels in the creek and to zinc inputs to the Sound but, since 1980, its contribution has been small relative to mid-basin inputs to the creek from surface drainage (Grey 1989; DINA 1991; Nanisivik Mines Ltd. 1994; Vista Engineering Ltd. 1996). In 1982, a year of very high runoff, Grey (1989) estimated that about 40 kg of zinc passed through the decant structure, but that this represented only 0.033% of the total zinc loading that passed into Strathcona Sound at the creek outfall. The 2.4 kg of cadmium decanted made up only 14% of the total cadmium loading that passed into the sea from the creek. In contrast, 227% more lead passed through the decant than entered the sea--indicating a settling out of lead in the creek downstream of the decant. Asmund et al. (1991) estimated the quantities of metals released from tailings deposited to West Twin Lake at 78.7 kg/yr zinc, 3.88 kg/yr *cadmium, and 70.2 kg/yr lead.*

Surface drainage

Erosion of surface metal sulphide deposits is a major source of iron, lead, and zinc entering aquatic systems in the Strathcona Sound area (Grey 1989). Newly exposed surfaces which have a high metal sulphide content are susceptible to oxidation of the sulphur and acid leaching when moisture from precipitation or permafrost melting reacts with the pyrite, galena, and sphalerite to form sulphuric acid and water soluble metal sulphates (Grey 1989;CCME 1995). The resulting iron, lead, zinc, and cadmium sulphates erode into aquatic systems. Strong positive correlations have been observed between zinc concentrations in Twin Lakes Creek, which vary widely from year to year (Figure 7), and annual precipitation (Figure 8) (Grey 1989; DINA 1991). Iron and zinc are soluble and can be carried long distances unless increases in pH cause them to precipitate. The transport of cadmium is not well understood. Lead is not carried as far, either because suspended lead particles settle out or dissolved lead is precipitated from solution.

Surface drainage following rainfall events appears to be the main source of elevated zinc levels in Twin Lakes Creek (Grey 1989). While the maximum licensed concentration of zinc in the decant in 1983-90 was 250 μg/L, the average concentration of zinc at the creek outfall into Strathcona Sound was 612 μg/L (SD 381 μg/L) (Grey 1989) (Figure 9). The volume of flow at the decant was also much smaller than at the outfall. These elevated concentrations resulted mainly from the erosion of exposed metallo-sulphites.

In the early 1980's, the concentrations of cadmium and zinc in the creek increased by an order of magnitude downstream of the West Open Pit outfall, more after rainfall events. Nanisivik Mines Ltd. was required to terminate runoff from the pit into Twin Lakes Creek, in 1983, and to transfer this runoff into the mill for eventual transport to the Twin Lakes Creek Tailings Disposal Area (Figure 10; Grey 1989). Re-routing the open pit drainage into the tailings pond reduced lead and zinc inputs to the creek to previous levels.

Most of the high zinc and cadmium inputs to the mid-basin of Twin Lakes Creek have been related to mining operations which exposed mineralized surface areas. The mining company was able to mitigate some of these sites but periodic, dramatic increases continued during monitoring in 1984-90. These increases were strongly correlated with high rainfall events (Grey 1989; DINA 1991).

Water flowing through the canyon adjacent to the mine is affected by acid rock drainage generated from massive sulphide exposed in the western mine workings--mainly the West Pit, sulphide bodies in the 2 South and 9 South waste dumps, and sulphide bodies exposed in the creek banks or covered with overburden but subject to the annual freeze-thaw cycle (Figure 10). In 1991-94, the average zinc content in the water increased by a factor of more than 20, from 60 to 1500 μg/L, as it passed through the canyon. (Nanisivik Mines Ltd. 1994). Maximum loading occurs during the latter part of the summer when thaw of the surface layer is deepest. The total loading of zinc metal in Twin Lakes Creek in 1993 was 3,280 kg. In 1994, the total loading fell to 1,700 kg. The decrease is attributed to a shorter and cooler melt season and to less mining disturbance in the West Pit (Nanisivik Mines Limited 1994).

Other minor sources of metals in surface drainage to Twin Lakes Creek include: 1) runoff from the lower west portal, 2) water from periodic washing of mine vehicles contaminated with metal dust; and 3) natural acid seepage. While the metal concentrations in each of these can be extremely high, the flow volumes are very low, so the overall effect on the metal loading to the Creek is minor (Grey 1989). Deposits of waste rock containing galena and sphalerite along the east bank of Twin Lakes Creek had no detectable effect on metal concentrations in the Creek in the 1980's, but mitigative measures were undertaken with respect to waste rock deposition near creek banks (Grey 1989).

Metal loading to the creek from natural sources and from some mining disturbances, mainly unreclaimable dump remnants, will continue indefinitely. Remedial actions proposed in the Abandonment and Restoration Plan should substantially reduce the metal loading, either by removing the sulphides or by causing them to become permanently frozen. These actions include: 1) removal to underground or to the West Pit of the sulphidic waste in 2 South and 9 South dumps (Figure 10), 2) backfilling the pit to cover exposed sulphides, 3) covering the pit and the dump remnants with shale to ensure freezing, and 4) sealing the portals to prevent thawing of the exposed sulphides by warm air in summer (Nanisivik Mines Ltd. 1994).

Sewage disposal

During the early development of the mine at Nanisivik, an Aer-o-Flo extended aeration sewage treatment system was installed to service the camp. In 1977, during development of the townsite, a rotating biological contactor was built and this unit was incorporated as the sludge storage tank. The sewage treatment plant was abandoned ca. 1983 due to severe condensation and frosting inside the building. Since then, untreated sewage from the community and mine has been pumped into Twin Lakes Creek, just north of the treatment plant, to flow into Strathcona Sound (Vista Engineering Ltd. 1996).

An assessment of the domestic sewage disposal at Nanisivik was conducted in August 1996 by Vista Engineering Ltd. (1996). The filterable residue, biological oxygen requirement (BOD), fecal coliforms (1.7×10^6 CFU/dL), and total coliforms (4.0×10^6 CFU/dL) in samples taken at the sewage outfall into Twin Lakes Creek, exceeded the Guidelines for the Discharge of Treated Municipal Waste Water established by the NWT Water Board (1992). Downstream, at stations located 100 and 1000 m from Strathcona Sound, the fecal and total coliform counts exceeded the Canadian Guidelines for Drinking Water Quality (0 CFU/dL). It is not safe to drink water from Twin Lakes Creek downstream from the sewage outfall. Warning signs to that effect have been posted near the sewage treatment plant and the creek mouth. [Note: Fecal coliforms (<2 CFU/dL) were also present in a sample taken by Vista Engineering (1996) from Twin Lakes Creek above the sewage outfall. This result may be due to sample contamination or it may indicate that there is another source of human waste upstream.]

The continuation of current sewage disposal practices will require the approval of the regulatory authorities. Vista Engineering Ltd. (1996) assessed a number of other options, including: 1) construction of a sewage treatment lagoon with a small primary cell for solids removal and a larger secondary cell for treatment and storage, 2) construction of a smaller primary cell only, 3) refurbishing the existing treatment plant for primary and secondary treatment, and 4) refurbishing the plant for primary treatment only. The latter option was recommended as providing the lowest cost and most aesthetically pleasing option.

The impacts of these sewage inputs to Strathcona Sound are unknown. In general, the impacts of marine disposal of raw sewage are local, with the main biological effects being near the outfall where there is a decrease in benthic species diversity and increase in biomass (Stanley Associates Engineering Ltd. 1988). There is a potential for human health effects if raw sewage is discharged in an area where marine mammals are slaughtered for food and eaten raw. The potential for bacterial or viral contamination of marine mammals harvested from Strathcona Sound at the outlet of Twin Lakes Creek is unknown.

EAST PORTAL CREEK

East Portal Creek also drains the ore body area (Figure 6). High concentrations of zinc were found in the creek water prior to mine development (700 μg/L Zn; B.C. Research 1975b). These data probably do not represent the natural "baseline" as the creek likely received metal inputs from an adit sunk nearby in 1969, and may have been influenced by ongoing exploratory work (Grey 1989). Zinc concentrations in the creek water decreased to 200 μg/L by 1988, following the addition of a treatment pond, the East Adit Treatment Facility, on East Portal Creek in 1984. Cadmium and lead concentrations (<2 μg/L Cd, <20 μg/L Pb) in the creek water were low and steady between 1984-88, and the basin's contribution of these metals to Strathcona Sound was minor (Grey 1989). In 1993-94 the catchment area for the East Adit Treatment Facility was expanded to make it more effective (P. Smith, pers. comm.).

KUHULU LAKE

The area around Kuhulu Lake was the site of some exploration activities in the late 1960's (P. Smith, pers. comm.). At some point, a road was constructed which obstructed the lake drainage. This road was washed out the following spring, and the original outlet channel was deepened such that the lake established a new and much lower level.

Landlocked Arctic charr caught in Kuhulu Lake in 1974 ranged in fork length from 200 to 629 mm and in weight from 50 to 2480 g (Figure 1; Fallis pers. comm.). The major food items in their stomachs were chironomid pupae and Arctic charr, and 46% of the charr caught (n = 24) were host to heavy parasite encystations (Diphyllobothrium sp.). The lake is not subject to drainage from the vicinity of the ore body, being separated from it by a steep valley. Concentrations of arsenic, cadmium, and lead in the charr were similar to those reported from other fish in the NWT (Falk et al. 1973), while copper and zinc were higher (Bohn and Fallis 1978).

No post development studies of Kuhulu Lake have been conducted.

STRATHCONA SOUND

Metal contamination in Strathcona Sound appears to originate primarily from: 1) the erosion of surface metal sulphide deposits on Borden Peninsula, 2) spillage of concentrate during ship loading, and 3) natural sources within the Sound. The metal distributions and relative contributions of these sources to the marine environment are discussed below.

Seawater

Studies in June 1982 (Thomas et al. 1983), and in December 1984 and June 1985 (Arctic Laboratories Ltd. 1986) have provided most of the comparative data available on metal concentrations in the seawater of Strathcona Sound. These data are not readily comparable to pre-operational data from B.C. Research (1975a), due to improvements in sampling and analytical techniques.

The concentrations of lead and zinc in Strathcona Sound seawater ranged from levels that are comparable with open-ocean concentrations to levels that are more typical of contaminated coastal water (Table 3; Thomas et al. 1983). Iron concentrations also ranged over almost two orders of magnitude, but the lowest iron concentrations were many times greater than open-ocean levels. Cadmium concentrations (0.03 to 0.1 μg/L) showed little variation with depth, season, or location. They were lower than levels found in spring runoff from Twin Lakes Creek (Table 3), and within the range reported from marine waters in the Canadian eastern Arctic (Macdonald and Sprague 1988).

Twin Lakes Creek is a significant source of lead, zinc, and cadmium for Strathcona Sound during the spring and summer. Metal loading of the Creek water in summer is sufficient to create a build up of metals in the receiving waters, the duration and extent of which depends upon the effectiveness of natural oceanographic processes in dispersing these inputs (Thomas et al. 1983). Indeed, under-ice sampling in December 1984, did not find a surface concentration gradient of zinc with distance from the loading dock, so these elevated concentrations do not persist year-round (Arctic Laboratories Ltd. 1986). The relative enrichment of surface water with lead is, however, persistent and does not appear to result from a single localized source.

In June 1982, the concentrations of lead, zinc, and iron were elevated in Strathcona Sound in the vicinity of the mouth of Twin Lakes Creek and the ore concentrate loading dock; and in the shallow region of the inner sill (Thomas et al. 1983). Enrichment factors of 100 for lead, 25 for zinc, and 2 for iron were observed in surface water adjacent to the Creek mouth and loading dock compared to surface metal concentrations at mid-inlet stations. The concentrations of zinc and lead in the seawater were typically highest near the surface and decreased with increasing depth (Figures 11-13).

In June 1985, the zinc concentrations were similar to those observed in June 1982, and about 5 times higher near the loading dock than in the middle of the Sound (Thomas et al. 1983; Arctic Laboratories Ltd. 1986). June lead concentrations were also greater near the loading dock than in the middle of the Sound, but less so in 1985 (2x) than in 1982 (5x). Lower levels of iron in samples near the loading dock in 1985, and lack of a strong surface gradient from shore are similar to the lead results. This suggests that the metals may have a similar source. The elevated spring zinc concentrations near shore can be accounted for by zinc rich (104x that of seawater) spring runoff from Twin Lakes Creek. The levels of cadmium, lead, and iron were not elevated in the runoff to the same extent as zinc, so their concentrations in sea water should have remained relatively constant as they did in 1985. The higher levels observed in 1982, suggest that there must have been some contribution of lead and zinc from ore concentrate dust, which was visible on the ice near the loading dock in 1982 (Table 3).

Bottom sediments

The interpretation of sediment metals data from Strathcona Sound is complicated by the fact that researchers have analyzed different fractions of the sediment cores. These fractions can vary widely in their metal content (Fallis 1982; unpubl. data.).

Sediments in the upper basin of Strathcona Sound consist of a soft brown clay overlying intensely mottled, compact grey clay with abundant black streaks throughout (Bornhold 1976). Sediments in the main basin and at the entrance to the Sound are similar, but lighter brown in color. Samples taken on the sills between the basins and in the mouth of the Sound contain more sand and pebbles than those from within the basins. Black streaks in the cores appear to be associated with organic matter (Thomas et al. 1983).

Elevated lead and zinc levels were present in some areas of the bottom sediments of Strathcona Sound before the mine began producing in 1976. This has been demonstrated by metal analyses of samples taken prior to October 1976, and by the analysis of sub-surface sections of core samples collected since then. In 1982, the concentration ranges of zinc, cadmium and lead in the sediments of Strathcona Sound were 38.6-1641 μg/g dry wt. (0.59-25.1 mmol/kg dry wt.), 0.09-5.2 μg/g dry wt. (0.84-46.6 μmol/kg dry wt.), and 8.9-100 μg/g dry wt. (43-483 μmol/kg dry wt) respectively. Values were usually highest at the surface and decreased with depth along the cores (Figure 14). The metal concentrations are generally higher than those reported for uncontaminated coastal marine sediments (Thomas et al. 1983).

The spatial and vertical distribution of metals in the sediments of Strathcona Sound suggests a source of metals adjacent to the mouth of Twin Lakes Creek (Figure 15). Elevated zinc levels in bottom sediments near the creek mouth in 1974, indicate that there was zinc-enriched drainage from the area of the ore body into Strathcona Sound before Nanisivik Mine began to operate (B.C. Research 1975a; Fallis 1982). Relatively high lead and zinc concentrations have been observed in bottom sediments of Strathcona Sound downstream from the ore body since then (Fallis 1982, unpubl. data; Thomas et al. 1983; *Arctic Laboratories* Ltd. 1986). By 1979, the lead, cadmium, and arsenic concentrations of sediments in the Twin Lakes Creek mouth/Nanisivik marine terminal area had increased 3.8, 6, and 2.4 times, respectively, from pre-operational levels (Figure 16; Table 2; Fallis 1982). They remained at these levels until at least 1984 (B.W. Fallis, unpubl. data). The results of Environment Canada's 1992 sediment sampling program in Strathcona Sound were not available at writing.

The mainstream of zinc and lead drainage appears to fan offshore into the Sound rather than following the shallows along the southern shore. In the early 1980's, the zone of influence of anthropogenic inputs of trace metals appeared to extend to stations 2 and 4 situated 4.5 and 5.8 km towards the mouth and head of the Sound respectively (B.W. Fallis, unpubl. data).

Blowing surface dust is common in the Nanisivik area. It includes natural surface materials, tailings, and ore concentrate. At times snow and ice can be covered with dust--to the point where flashlights have to be used to examine the interiors of seal breeding lairs because dust in the snow prevents light penetration (e.g. winter 1990-91; S. Innes, pers. comm.). The relative contributions of these sources of metals to the marine sediments and food chains have not been documented. However, past problems with concentrate dust during ship loading have largely been corrected (P. Smith, pers. comm.).

Phytoplankton and Aquatic Macrophytes

Tidal ice scouring prevents the establishment of flora in the 3 m tidal zone (Ellis and Wilce 1961; B.C. Research 1975a). Below the ice scour zone the sea bottom sustains an intermittent growth of seaweed (brown algae), including Fucus vesiculosus and Laminaria solidungula, down to the limits of visibility (Fallis 1982).

Concentrations of lead, iron, and zinc are highest in seaweed near the mine property and decrease with increasing distance from the ore body (B.C. Research 1975a; Bohn 1979). This trend was apparent before the mine began operating in 1976. By 1979, the lead, zinc, cadmium, and arsenic concentrations in Fucus vesiculosus in the vicinity of the Nansivik marine terminal had increased 28, 5.6, 2.6, and 1.4 times, respectively, from pre-operational levels (Figure 16; Table 2; Fallis 1982). Trace metal concentrations in the vicinity of the marine terminal (station 3) were monitored in 1980, 1981, and 1984. Cadmium, lead and zinc concentrations in seaweed remained fairly constant at about the 1979 level. The zone of influence of anthropogenic inputs of trace metals appears to extend to stations 2 and 4 situated 4.5 and 5.8 km towards the mouth and head of the Sound respectively (B.W. Fallis, unpubl. data).

Invertebrates

In August 1974, scraper dredge sampling of benthic habitats in Strathcona Sound found sea urchin to be numerous at depths less than 10 m, coelenterate medusae between 35 and 120 m, and brittlestars between 35 and 250 m (B.C. Research 1975a). Other invertebrates included sea anemones, clams, scallops, whelks, snails, limpets, shrimp, barnacles, sea spiders, starfish, sunstars, sea feathers, sea cucumber, and polychaete worms. The infauna collected by bottom grab sampling with a Shipek dredge included many polychaete species, sipunculid worms, ostracods, copepods, clams, and foraminiferans. The benthic fauna may be more diverse in the main basin than the upper basin (Bornhold 1976).

Zooplankton collected from Strathcona Sound include copepods, amphipods, decapods, chaetognaths, coelenterate medusae, pteropods, and arrow worms (B.C. Research 1975a; Bohn and McElroy 1976). Planktonic copepods tested for heavy metals were found to have higher concentrations of cadmium and lower concentrations of arsenic, copper, iron, and zinc than Arctic cod which feed upon them (Table 1; Bohn and McElroy 1976). Concentrations of zinc in urchin gonads and iron in whole urchins are greatest near the ore body and greater than those observed in Fucus tips, one step lower in the food chain (Figure 17; Bohn 1979). The concentrations of arsenic, cadmium, copper, iron, lead, and nickel in marine tissues resembled those from other non-industrial locations (B.C. Research 1975a).

Studies conducted by DFO between 1974 and August 1979, found that the concentrations of lead, zinc, cadmium, and arsenic in molluscs (Mya truncata; Serripes groenlandicus; Cardium ciliatum) in the vicinity of the marine terminal (station 3) had increased following the start of mine production in October 1976, as had the concentrations of lead, zinc, and arsenic in sea urchins (Strongylocentrotus droebachiensis), and mercury in S. groenlandicus and C. ciliatum (Figure 16; Fallis 1982)

Trace metal concentrations in the clams were monitored in 1980, 1981, and 1984. In the vicinity of the marine terminal (station 3), zinc levels in Mya remained unchanged until at least 1984, but lead increased sharply in 1980 to plateau at a higher level (Figure 16; B.W. Fallis, unpubl. data). Most of the lead and zinc in Mya tissue was found in the siphon sheath. Metal concentrations in Strongylocentrotus more than doubled in 1980, but declined to 1979 levels in 1981. High metal concentrations were reflected in Mya tissues one year later than they appeared in sediments. The zone of influence of anthropogenic inputs of trace metals was similar to that observed for seaweed.

Thomas et al. (1983) did not find a relationship between the health of Mya truncata examined in Strathcona Sound and their proximity to the area of the Nanisivik ore concentrate loading dock and the mouth of Twin Lakes Creek.

Clams taken from the stomachs of harvested walrus are considered a delicacy by many Inuit who have little access to fresh clams. In the summers of 1989 and 1990, small exploratory fisheries were undertaken, using a dredge, to assess clam resources in the Arctic Bay area (DFO 1992a+b). The quantities of clams were small, 170 and 50 kg in the respective years. They were marketed locally and a commecial fishery has not developed. The most promising test areas for edible clams like Mya truncata may be in Moffett Inlet, well south of Strathcona Sound, where there are shallow nearshore areas with sandy bottoms (H. Welch, pers. comm.)

Fishes

Arctic cod (Boreogadus saida), shorthorn sculpin (Myoxocephalus scorpius), and fourhorn sculpin (M. quadricornis) are very important links in the Arctic marine food chain between invertebrates and the larger anadromous Arctic charr, seabirds, and marine mammals (Figure 17). Schools of the pelagic cod have been observed in Strathcona Sound, where the species is common below 100 m (B.C. Research 1975a; Bohn and McElroy 1976). The sculpin are benthic omnivores, abundant in shallow coastal waters, from 20 m to the intertidal zone, on rocky and sand-mud substrates. While cod and sculpin are occasionally jigged for sport or taken as a by-catch during the charr harvest by residents of Arctic Bay and Nanisivik, they are seldom eaten (Table 4).

Pre-operational studies of Arctic cod from Strathcona Sound found that they bioaccumulate zinc and arsenic from their diet (Bohn and McElroy 1976), generally at a lower level than sculpin (Table 1). Studies of the heavy metals in shorthorn sculpin found elevated arsenic levels in muscle and liver tissues prior to mine operation (Table 1; B.C. Research 1975a; Bohn and Fallis 1978). Concentrations of heavy metals in closely related fourhorn sculpin collected from Strathcona Sound in 1979 were within the ranges reported for marine fishes from more southern latitudes (Fallis 1982).

Marine Mammals

Ringed (Phoca hispida), bearded (Erignathus barbatus), and harp seal (Phoca groenlandica), walrus (Odobenus rosmarus), narwhal (Monodon monoceros), beluga (Delphinapterus leucas), killer whales (Orcinus orca) and bowhead (Balaena mysticetus) all occur in the Admiralty Inlet area, and all but the killer whale and bowhead are harvested for food by area residents (Table 4). Of these species, only the ringed seal is a year round resident of Strathcona Sound, and even it is quite mobile. Of the summer visitors, only narwhal occur commonly in Strathcona Sound and are harvested in quantity.

Ringed Seal (Phoca hispida) are the seals most commonly harvested by residents of Nanisivik and Arctic Bay, and the only marine mammal species they harvest year round (Table 4; Donaldson 1983, 1984; Pattimore 1985, pers. comm.). The main harvests occur on the ice at the floe edge across the inlet's mouth in June and early July and in open water during August and September (Dirschl 1982). Ringed seals are an important link in the marine food chain between pelagic amphipods and Arctic cod and humans, polar bears and killer whale (Figure 17). Seal meat is one of the most important and sought after food resources in the region. Seals harvested near Nanisivik are used primarily for dog food (S. Innes, pers. comm.).

The concentrations of mercury, zinc, copper, lead, and cadmium measured in ringed seal from Admiralty Inlet are similar to those found in ringed seal from Greenland (Wagemann and Muir 1984)--both groups have high cadmium levels relative to seals in the north Atlantic. They also contain trace amounts of a variety of organochloride compounds in their blubber and liver tissues, including chlordane, PCB, and DDT isomers (Muir et al. 1988).

Wagemann (1989) found higher concentrations of lead, mercury, or cadmium in the tissues of ringed seals from Strathcona Sound than in a reference group from Admiralty Inlet. The seals sampled from Strathcona Sound were younger on average than those from Admiralty Inlet. He attributed the difference to local lead pollution, but did not find a correlation between tissue metal concentrations and distance from the marine terminal.

The fact that young seals had higher metals levels than the older seals suggest two things, 1) that they are eating different foods, and 2) that the bioaccumulations resulted from short exposure. Since the seals are mobile, the bioaccumulations may represent only a years residence in an area with higher metals. Feeding studies (S. Innes, pers. comm.) have found that the young seals only dive 100-180 m while the adults will dive to depths of 300 m. The younger seals then may be primarily pelagic feeders while the older seals may be benthic feeders. The Department of Fisheries and Oceans repeated the 1983 studies in 1993, but at writing, had not yet analysed the samples for metals.

Residents of Arctic Bay and Nanisivik value narwhal for their long ivory tusks and tasty muktuk. They hunt them at the floe edge across the mouth of Admiralty Inlet and in ice leads nearby in the spring, and to a lesser extent in open water during the summer (Table 4; Brody 1976; Fallis et al.

1983; Stewart et al. 1995). Narwhal are seen in Strathcona Sound from early July through November, but most often in late August and early September as they move northward out of Admiralty Inlet to avoid entrapment in the ice. Their brief residence time in these areas may be related to hunting by residents of Arctic Bay and Nanisivik.

The concentrations of lead, zinc, and cadmium measured in narwhal from Admiralty Inlet in 1975 are similar to those found in narwhal at Pond Inlet and in dolphins from the north Atlantic (Wagemann and Muir 1984). Post-operational measurements have not been conducted, although samples of narwhal have been collected by DFO for analysis.

IMPLICATIONS OF THESE FINDINGS FOR HUMANS

Metal levels in the environment in the vicinity of the Nanisivik ore body are naturally elevated. This only stands to reason given the presence and richness (7.4-14% zinc, 0.2-1.4% lead) of the ore body. It was also evident from samples taken before the mine began its operations in 1976, particularly in marine sediments and biota near the mouth of Twin Lakes Creek (B.C. Research 1975a; Fallis 1982), and in sediment core samples taken after mine production began (Thomas et al. 1983; Arctic Laboratories Ltd. 1986; B.W. Fallis, unpubl. data).

These natural metal levels have been further elevated by mine-related activities, beginning with mineral exploration in the 1960's and continuing to the present day. Indeed, researchers have questioned whether some of the pre-operational metals data from fresh water creeks accurately reflects the natural background level or whether they are artificially high as a result of surface disturbances caused by early mineral exploration activities (Thomas 1989).

The magnitude of change in metal concentrations in the freshwater and marine environments is very difficult to quantify. First, the pre-operational sampling programs were not designed for long-term effects monitoring. Second, sampling and analytical techniques have improved substantially since the mid-1970's, so some earlier marine samples are now considered to have been contaminated (e.g. lead and cadmium in seawater) (Thomas 1989). Third, results are often not directly comparable between studies as researchers have used different sampling and analytical techniques, not described their methods in sufficient detail to permit replication, grouped organisms without adequately describing the age/sex/size/species composition of the group, or have analysed different portions of sediments or biota. The notable exception to these problems are the studies by Fallis which provide detailed descriptions of the methods and comparable data from 1974 to 1984 (Bohn and Fallis 1978; Fallis 1982, Asmund et al. 1991; unpubl. data). A number of other studies, notably those by Arctic Laboratories Ltd. (Thomas et al. 1989; Arctic Laboratories Ltd. 1986), Grey (1989), and Nanisivik Mines Ltd. (1994) have provided very useful post-operational metals data.

The data show that mining operations have contributed to elevated metals levels in West Twin Lake which receives tailings from the mine, Twin Lakes Creek and East Portal Creek which drain areas of the ore body, and in Strathcona Sound which receives runoff from the ore body and spilled ore concentrate. The main mine-related sources of metals include decant from the West Twin Tailings Disposal Area, runoff from metal sulphides that have been exposed to oxidation, wind-blown tailings dust, and spilled ore concentrate.

The contribution of metals to the marine environment by decant from the tailings pond is small relative to the contribution from surface runoff. Metal concentrations in the decant water are specified under the mines' Water License, and must be carefully controlled and monitored.

A much greater source of metal loading to Twin Lakes Creek, which is the main watershed on the ore body, is from surface disturbances that have exposed sulphides to oxidation and thereby permitted metals to be leached from the minerals by acidic runoff water. The magnitude of the metal loading is strongly and positively correlated with rainfall. The extent of this natural year-to-year variability was not addressed by pre-operational studies, so it is impossible to separate the natural from the mine-related metal loading. However, mitigative measures undertaken by Nanisivik Mine, such as the re-routing of drainage from the open pit to West Twin Lake have reduced metal inputs to the creek (Grey 1989). The company has also begun removing waste rock. The disturbance of this material is expected to significantly increase the amount of metal loading in Twin Lakes Creek over the short term (P. Smith, pers. comm.), but should reduce it over the longer term.

Asmund et al. (1991) found lower concentrations of heavy metals in the water, sediments, seaweed, and molluscs in the vicinity of the Twin Lakes Creek outfall than did researchers at mines in Greenland where tailings are disposed of directly into the sea or on land close to the ocean shore. They concluded that in order to minimize environmental contamination, waste rock and tailings should be placed in areas which in so far as possible confine solids and restrict exposure to runoff and tidal action. The environmental effects were least at Nanisivik where tailings are deposited into a freshwater lake under controlled conditions and a minimum of waste rock is produced.

The contribution of metals from on-land tailings dust to the environment has not been documented, although in 1992-93, strong winds distributed substantial amounts of tailings in the vicinity of Nanisivik. Since then the Mine has tried to contain the tailings dust by keeping it wet in summer and ice-capped in winter, using snow fence to reduce wind speed and catch dust, and by covering areas of tailing with shale.

The contribution of metals from ore dust to the environment also has not been documented. In 1982, higher than expected levels of lead and zinc in seawater near the marine terminal may have been caused by ore concentrate dust, which was visible on the ice near the loading dock (Arctic Laboratories Ltd. 1986). At that time the conveyor carrying ore onto the M.V. Arctic was uncovered; it has since been covered. Under the terms of its current Water License Nanisivik Mines Ltd. has to study the airborne dispersal of tailings.

Lead, zinc and cadmium in water, sediments and biota within about 6 km of the mouth of Twin Lakes Creek, increased substantially between 1976 and 1979, and then stabilized at the higher level. While there was uptake by marine biota, there was little biomagnification of the metals up the food web. Dilution with sea water is a very effective means of eliminating the acute toxicity of the tailings to fish and invertebrates (B.C. Research 1975c), but the chronic effects of the elevated metal concentrations to the biota are unknown. Without this important information, it is impossible to separate out from other factors the effect that the metal rich water from Twin Lakes Creek has on the biota of Strathcona Sound (Thomas 1989).

Long-term exposure of marine biota to sub-lethal metal concentrations can inhibit growth and reproduction and alter species composition. Under the terms of its current Water License Nanisivik Mines Ltd. has to undertake a chronic toxicity study.

Dietary intake of metals by area residents should be at or very near natural background levels given that Arctic cod and sculpin are seldom eaten, seals harvested from the immediate area are generally fed to the dogs, and that metal levels in these animals are not necessarily elevated. Of perhaps greater concern is the potential for ingestion or inhalation of metal dust. Ingestion of dust was believed to be the cause of increases observed in blood lead levels of men working at Nanisivik in 1978 and 1980 (Eaton 1982). The ingestion of dust can be controlled with proper hygiene.

Other contaminants of concern to area residents include the raw sewage in Twin Lakes Creek that flows untreated to Strathcona Sound and waste oil buried in drums at the dump. Vista Engineering (1996) recommended options for treatment of the sewage, the preferred option was to refurbish the existing sewage treatment plant to provide primary treatment. At present, fecal coliforms make water in the Creek downstream from the outfall unfit for human consumption. Under the present Water License the Mine must assess the types and volumes of industrial waste disposed of and buried (e.g. used oil), evaluate the potential environmental impacts, and make recommendations for final abandonment and closure of the facility.

ACKNOWLEDGEMENTS

Paul Smith of DIAND in Iqaluit; Rob Eno of GNWT-RRWED, Iqaluit; Gary Weber of DFO Iqaluit; Ken Chang-Kue, Bruce Fallis, Stuart Innes, and Rudy Wagemann of DFO Winnipeg; Steve Harbicht and Jim Sparling of Environment Canada, Yellowknife; Tasha Stephenson of DFO, Yellowknife; and Dionne Filiatrault of the Nunavut Water Board, Gjoa Haven all gave freely of their time and expertise. Rob Eno, Bruce Fallis, Marg Keast, Paul Smith, and Cecile Stewart reviewed the manuscript. Thank-you all for your contributions.

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PERSONAL COMMUNICATIONS

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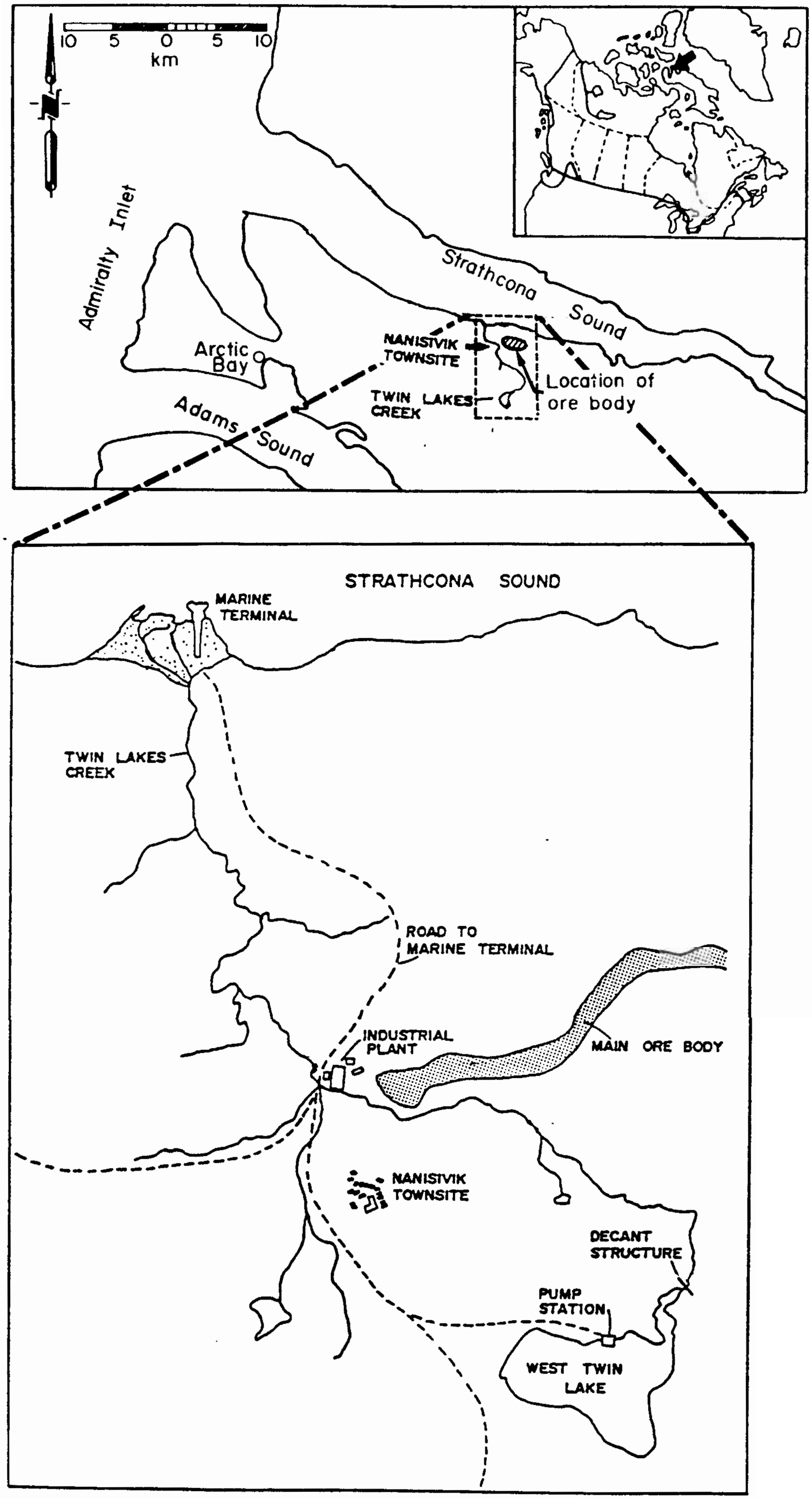
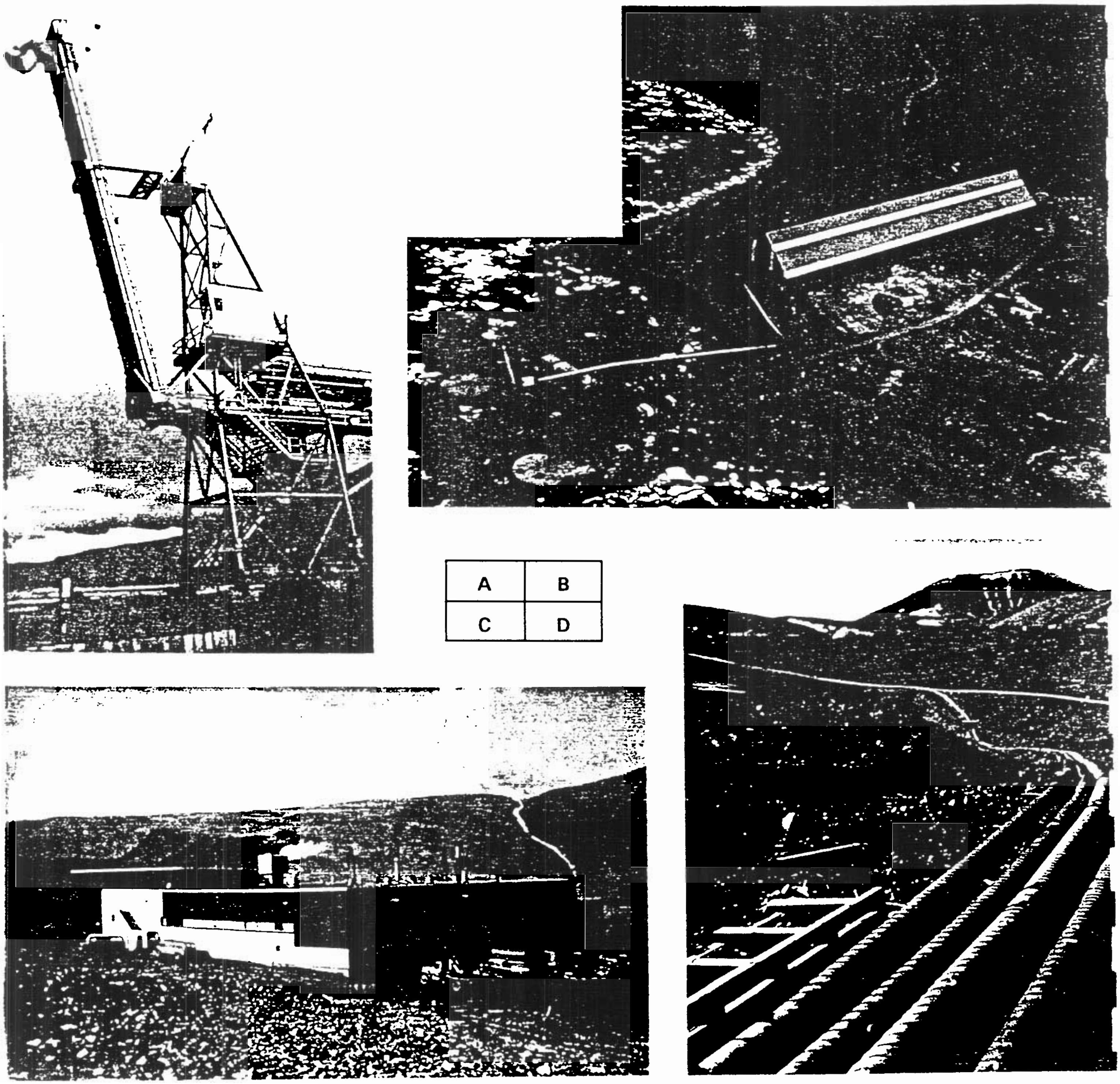


Figure 1. Map of Strathcona Sound, northern Baffin Island, NT showing Nanisivik Project infrastructure (after Bohn 1979 and Thomas et al. 1983).

Figure 2. Photos of the Nanisivik Project infrastructure (from Fish 1979). Concentrate ship loader at Nanisivik's dock (A); concentrate storage building (> 200 m long) and dock on the shore of Strathcona Sound (B); industrial complex which houses the mill and almost all of the mine's other surface facilites under one roof (C); and insulated, heat-traced pipes that carry tailings, process water, drinking water, and sewage (D).



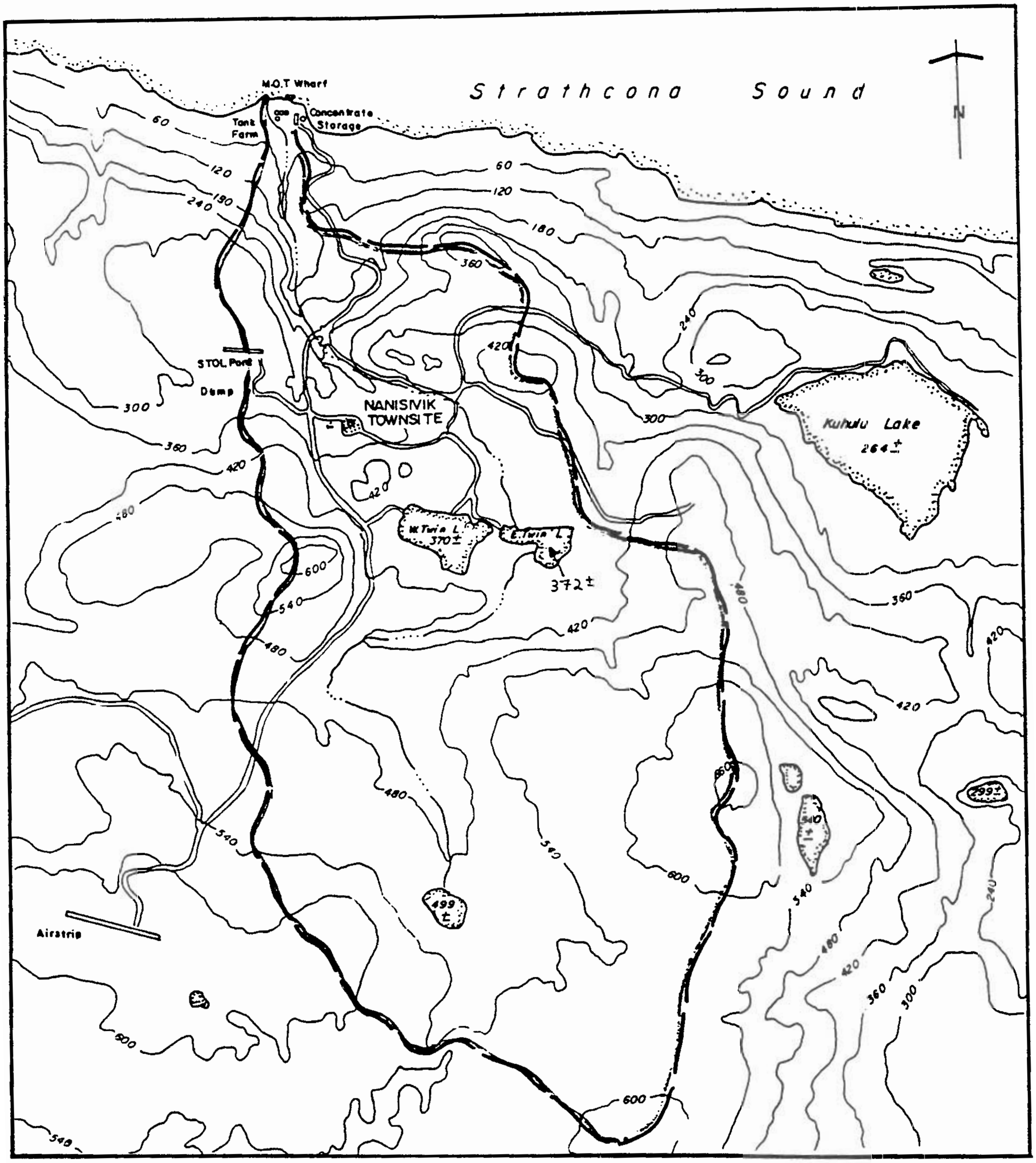
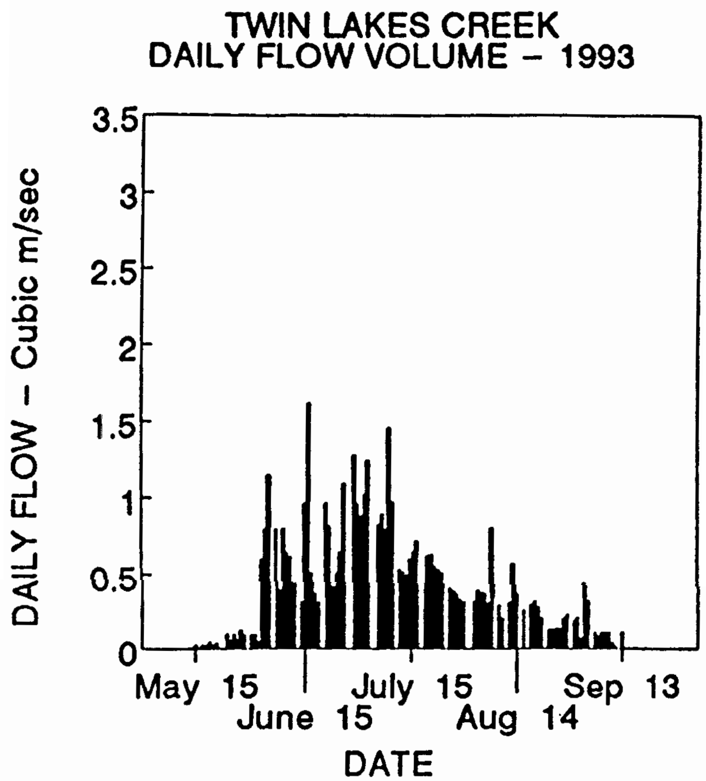


Figure 3. Twin Lakes Creek watershed, Baffin Island, NT (from Nanisivik Mines Ltd. 1984). Elevations are in metres.



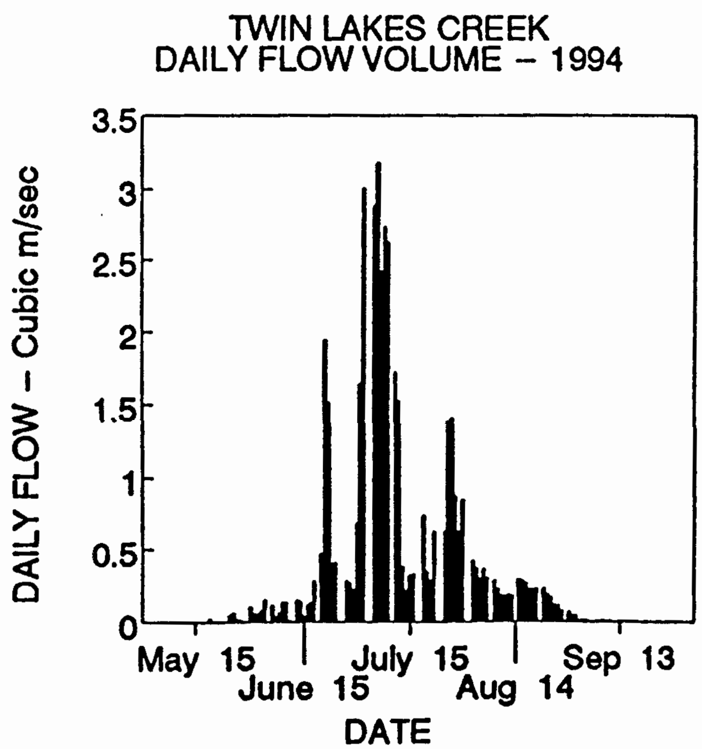


Figure 4. Daily flow volume in Twin Lakes Creek, Baffin Island, NT (from Nanisivik Mines Ltd. 1984).

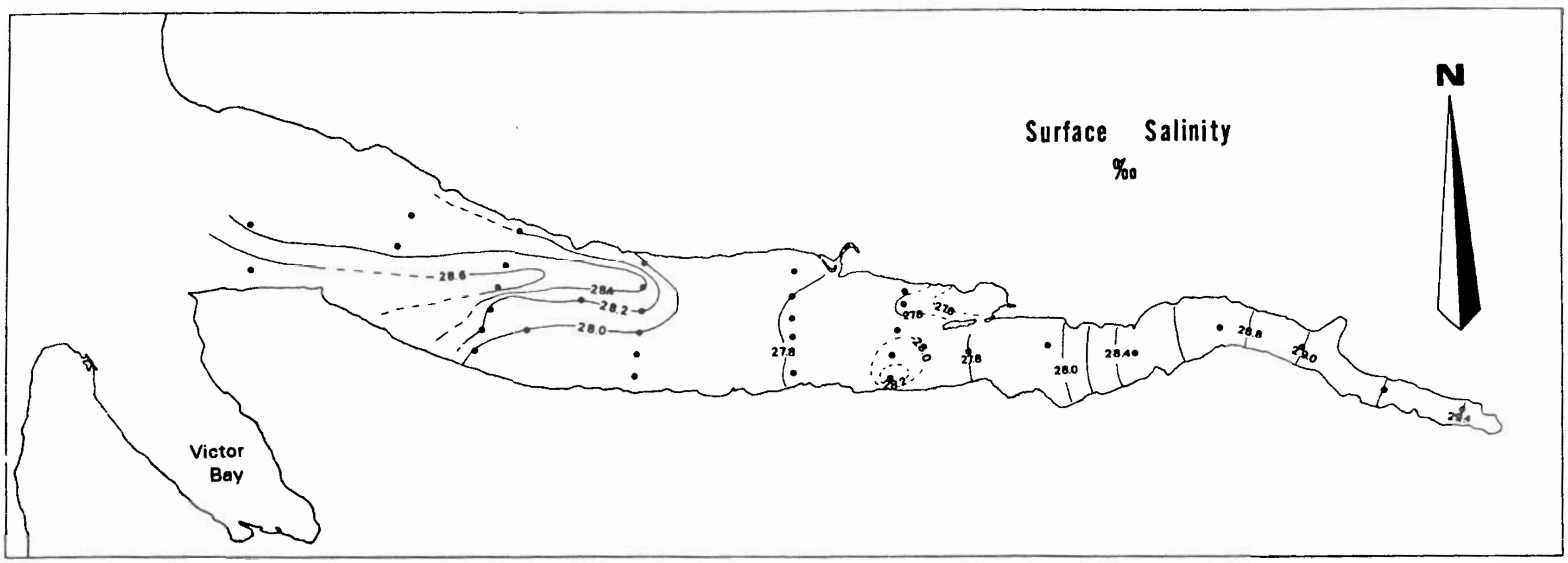


Figure 5. Distribution of surface water salinity, Strathcona Sound (from Bornhold 1976).

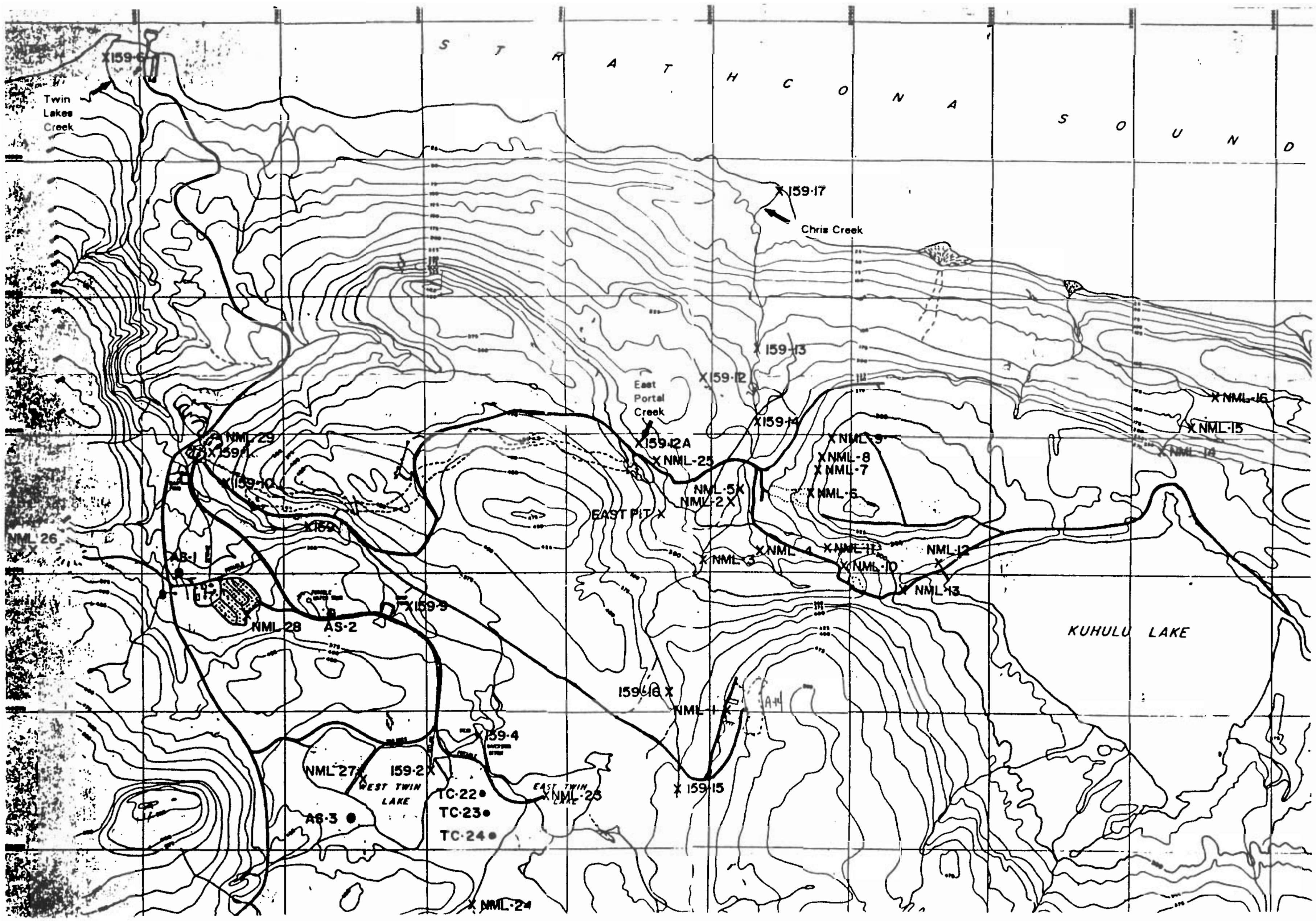


Figure 6. Water and air equality sampling stations in the area of Nanisivik Mine, Baffin Island, NT. These include sites used by the Surveillance Network Program (159-1 to 159-16) and the Twin Lakes Creek Metal Loading Study (159-4, 159-6, 159-10, 200-10), Nanisivik Mine Property samples (NML-1 to NML-30), and 1998 Air Quality Dust Sampling sites (AS-1, AS-2) (from Nanisivik Mine-CanZinco Ltd. 1997).

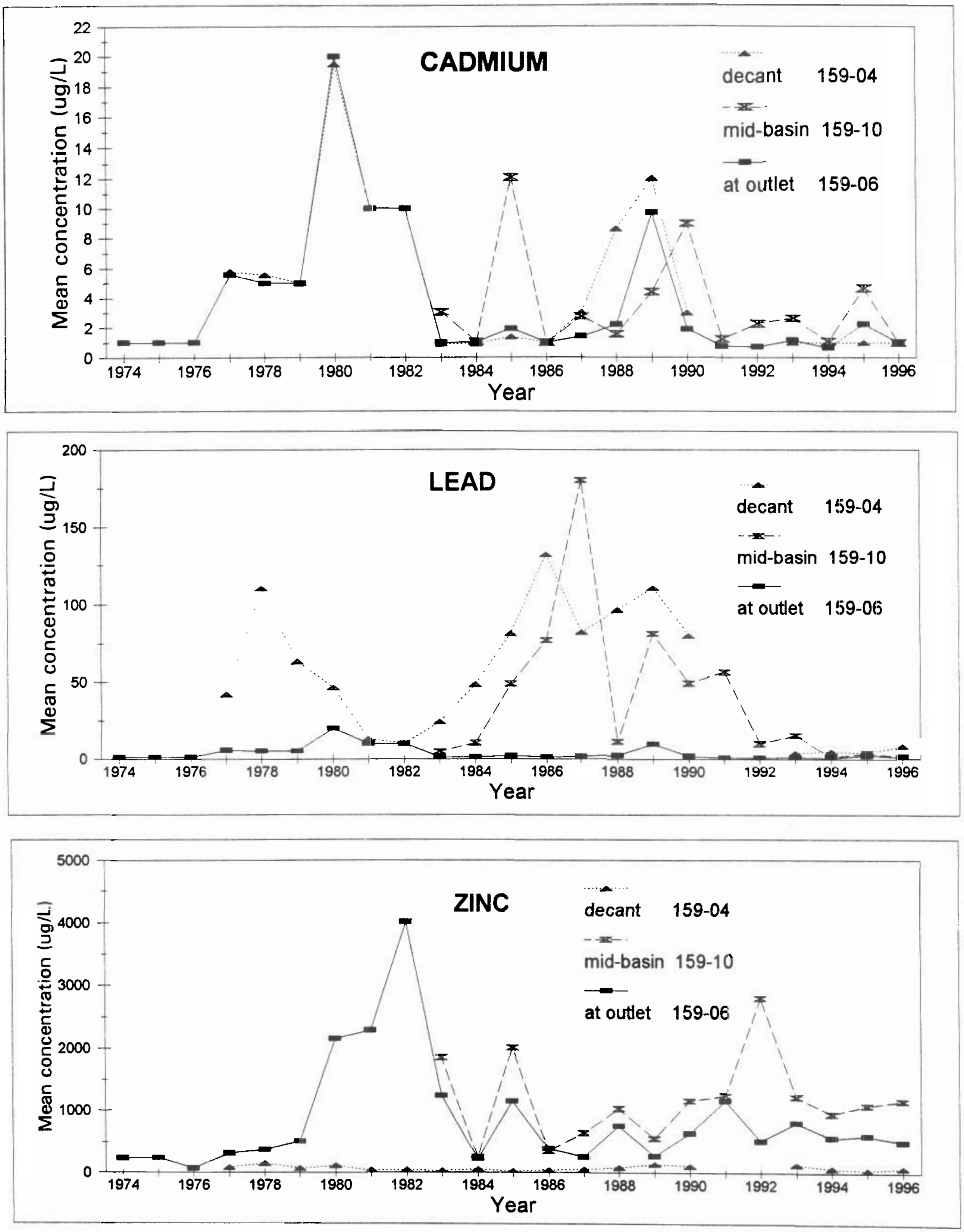


Figure 7. Metal concentrations in Twin Lakes Creek at the decant (Fig. 6, site 159-4), in mid-basin (159-10 and at the outflow into Strathcona Sound (159-6). Data from Fallis (1982), Grey (1989), DINA (1991) and Nanisivik Mines Ltd. (1994a, 1995, 1996, 1997b). Concentrations are total metals except 1974 and 1975 which are dissolved metals.

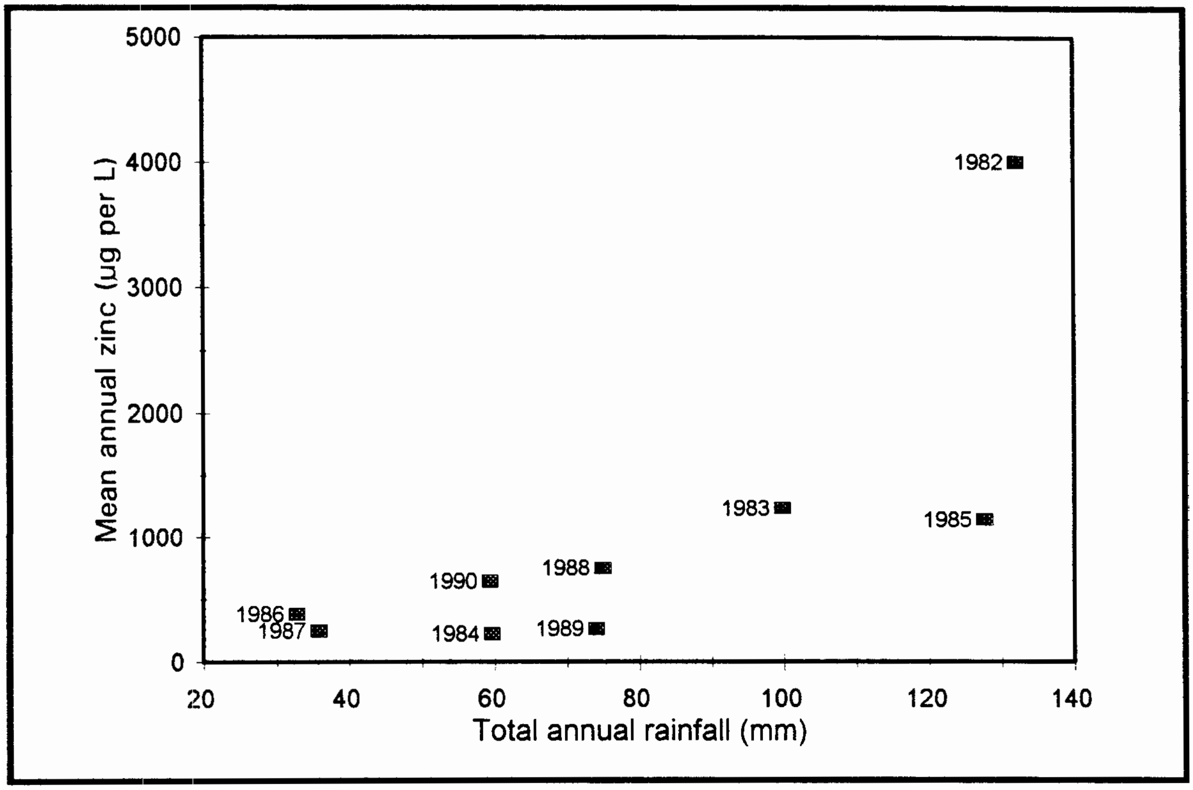


Figure 8. Plot of the total annual rainfall (mm) at Nanisivik vs. the mean annual total zinc concentration (µg/l) at the outlet of Twin Lakes Creek into Strathcona Sound (Station 159-6) from 1982 to 1990. Data from DINA (1991).

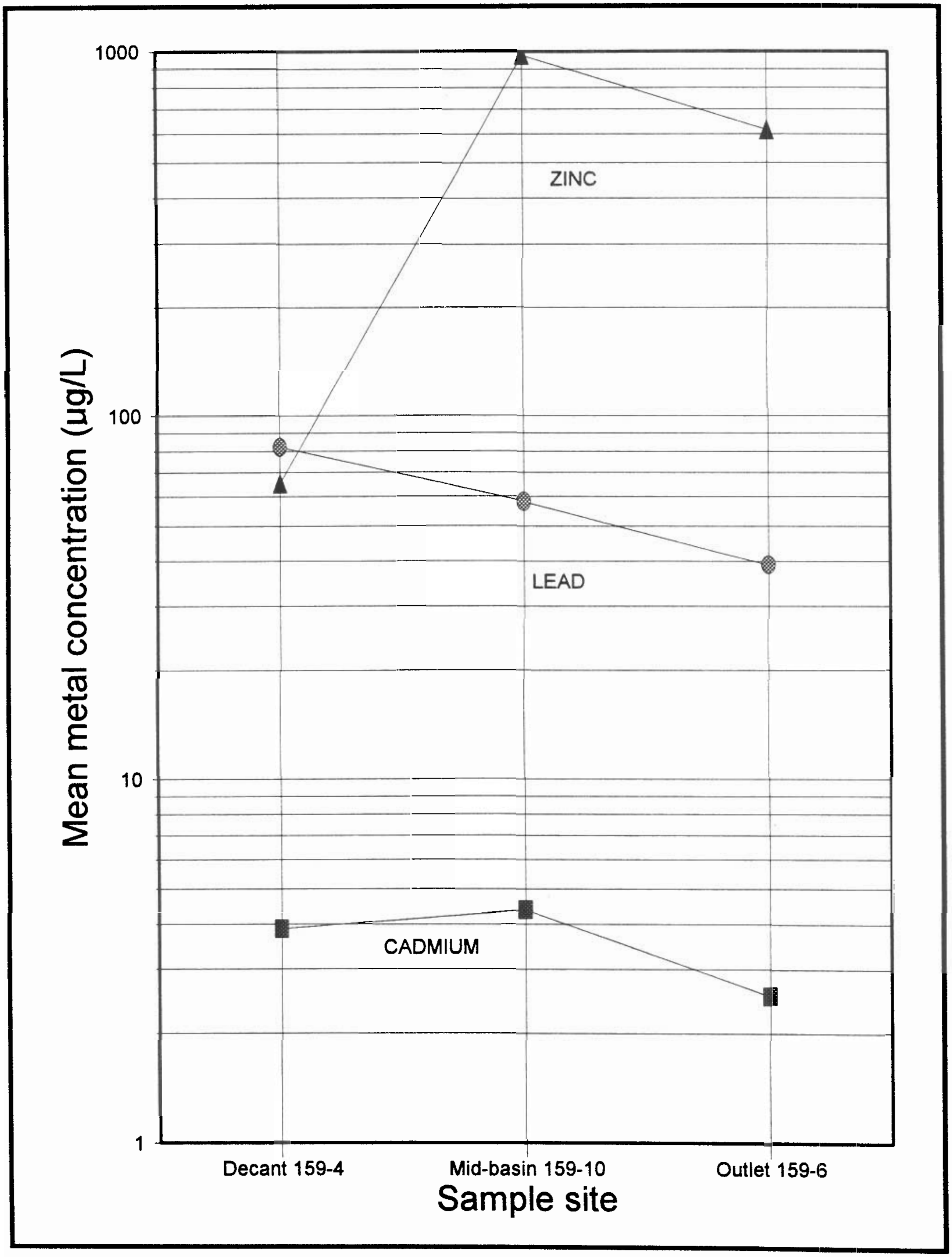


Figure 9. Average concentration (8-year means 1983-90; µg/L) of cadmium, lead, and zinc in Twin Lakes Creek at the decant (see Fig 6., site 159-4), in mid-basin (159-10), and at the outlet (159-6) to Strathcona Sound. Data from Grey (1989) and DINA (1991). Note logarithmic scale.

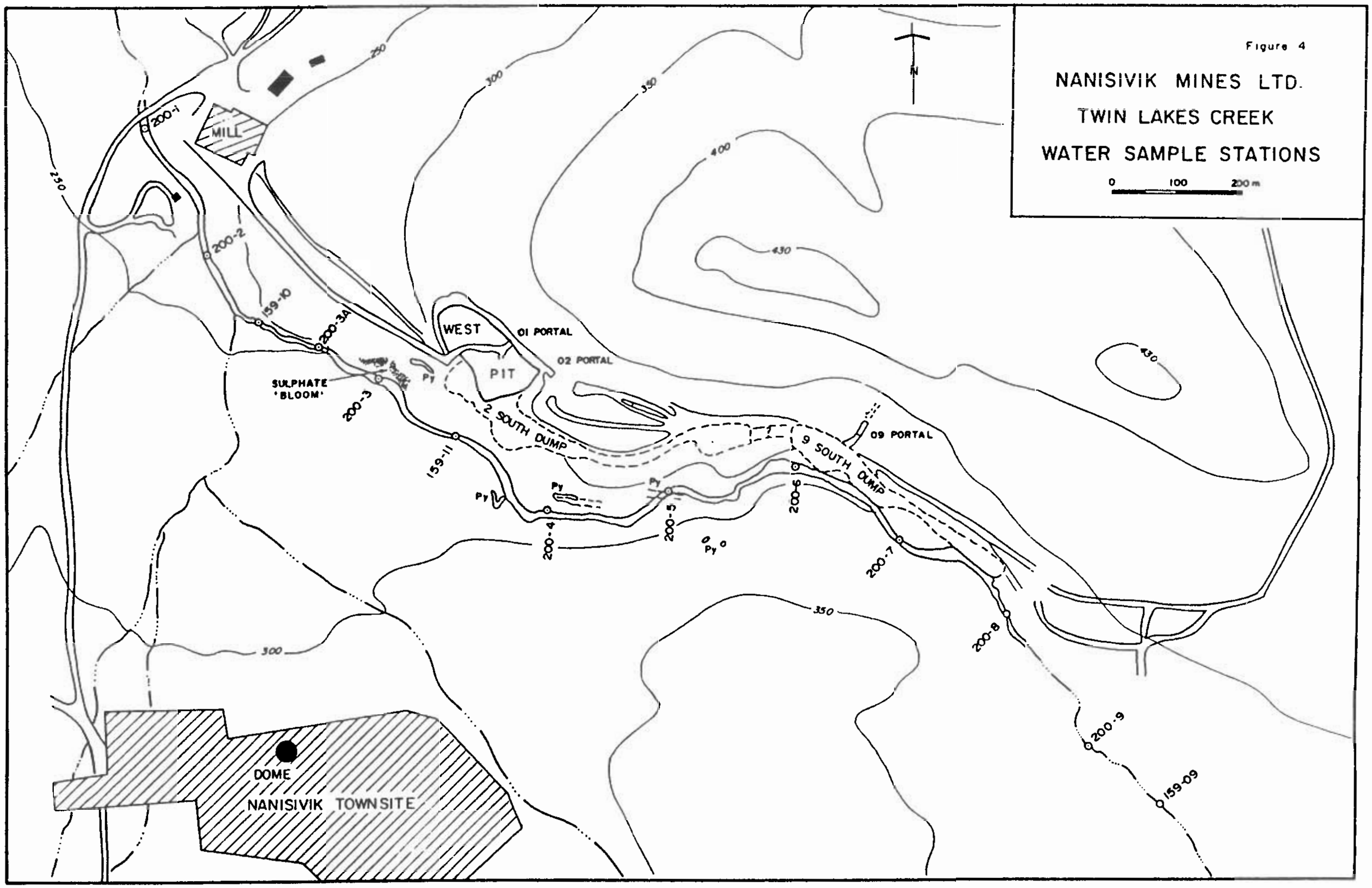


Figure 10. Water sampling sites for the Nanisivik Mines Ltd. study of metal loading in Twin Lakes Creek (Nanisivik Mines Ltd. 1994).

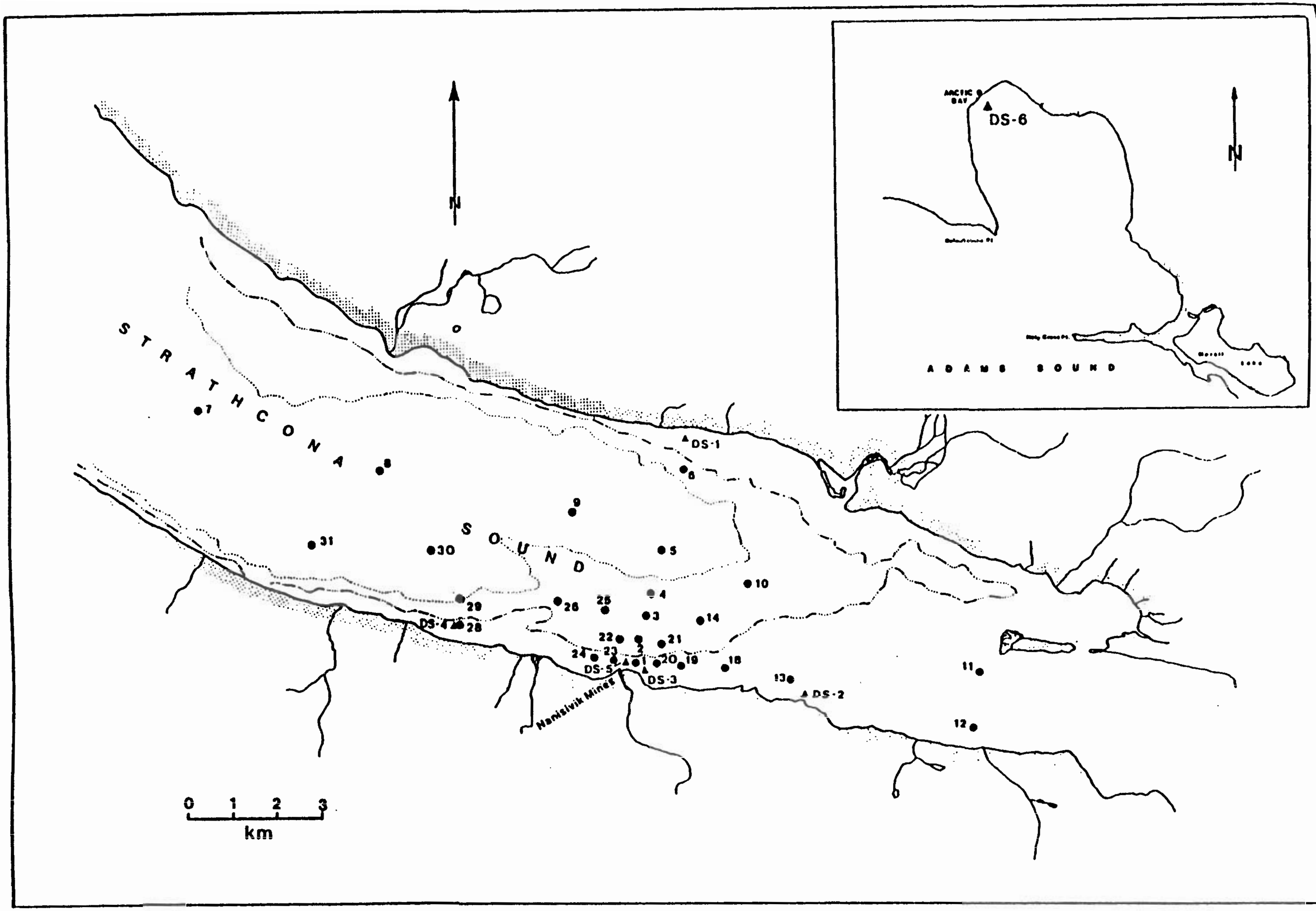


Figure 11. Sites sampled in Strathcona Sound, NT, in 1982 by Thomas et al. (1983). Solid dots are stations sampled during the first field trip (May28-June 6, 1982). Solid triangles mark locations of dive stations on second sampling trip (August 16-18, 1982) (From Thomas et al. 1983).

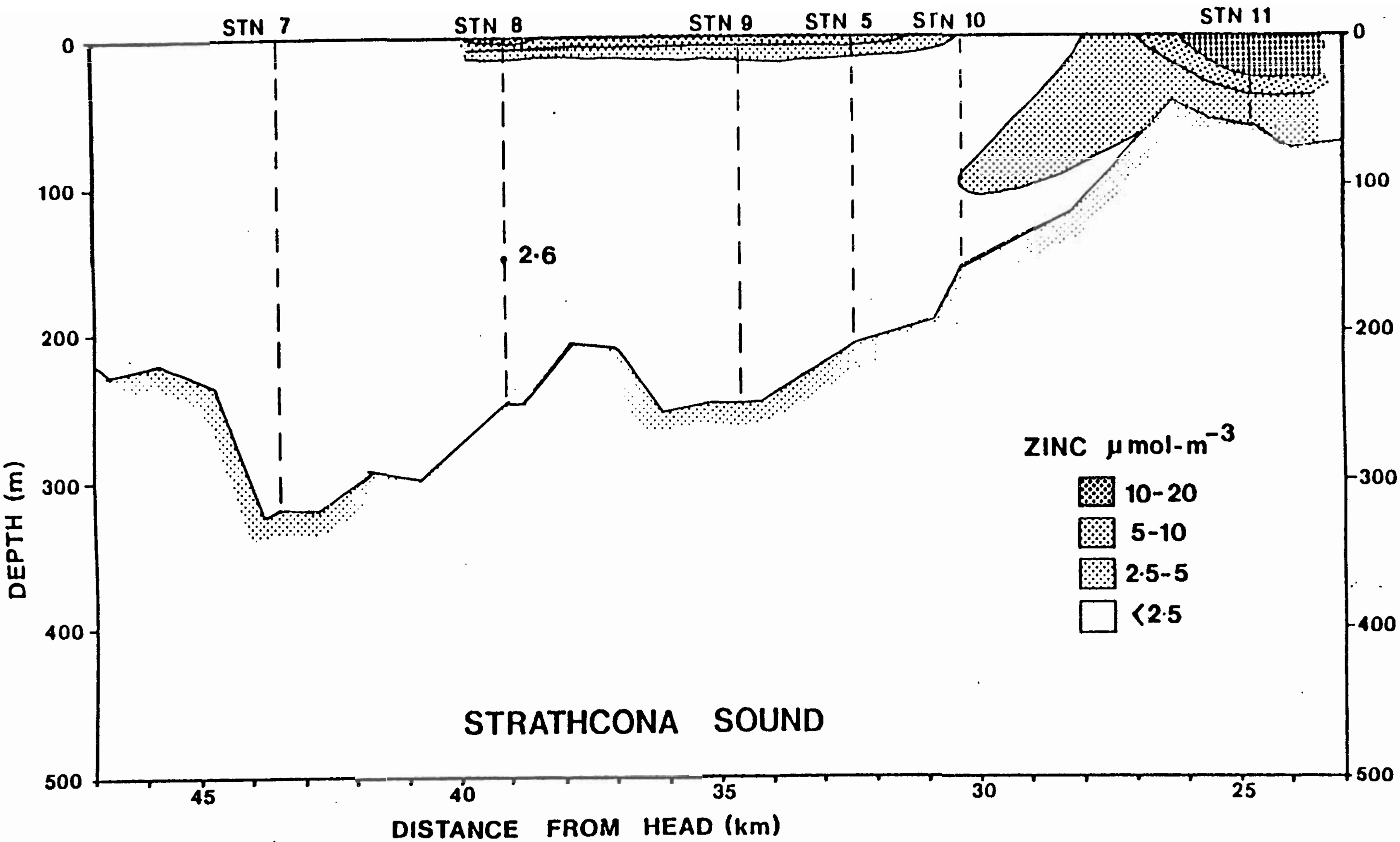


Figure 12. Longitudinal section of zinc concentrations in Strathcona sound, June 1-5, 1982 (see Fig. 11) (from Thomas et al. 1983).

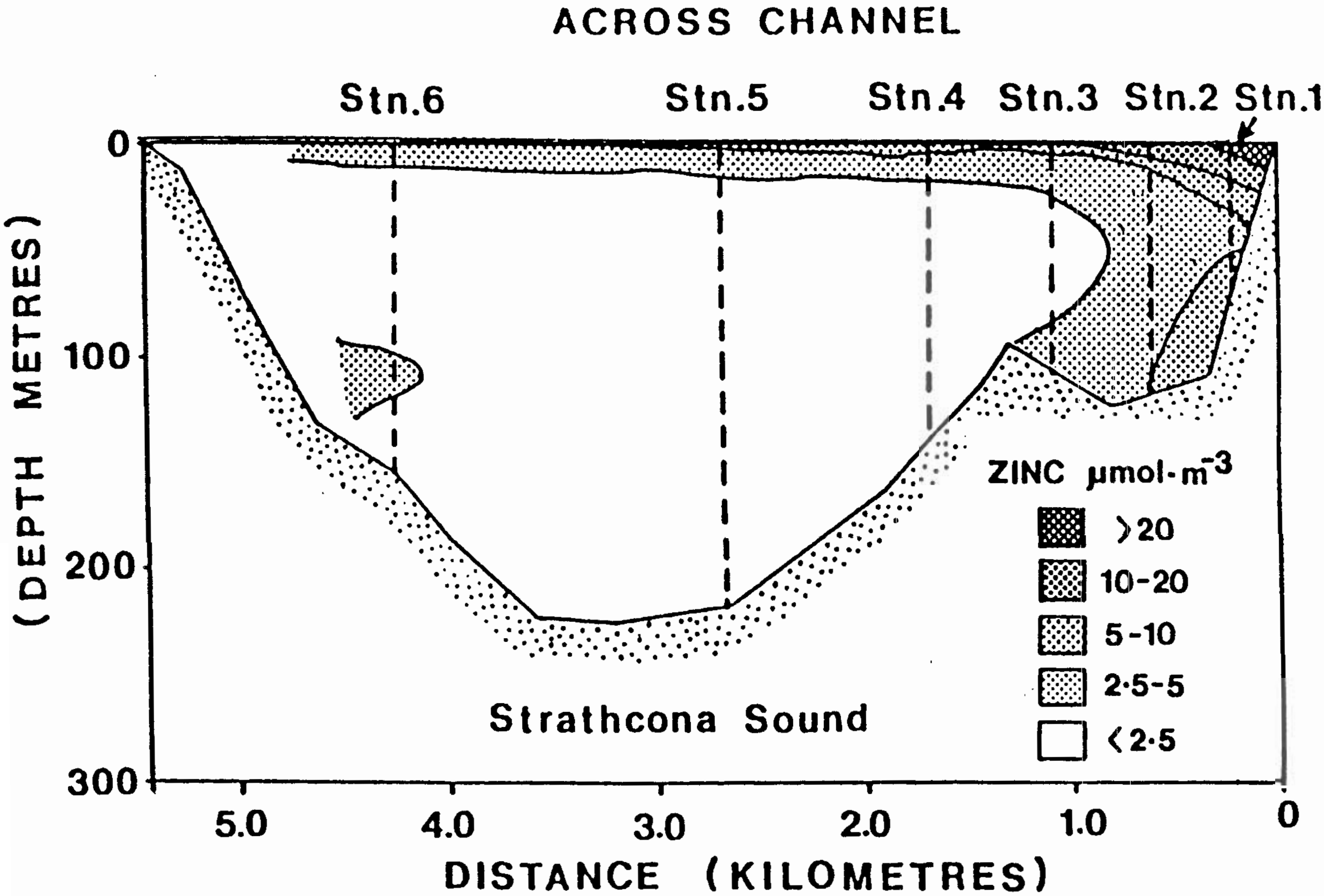


Figure 13. Cross-channel section (Sites 1 to 6, Fig. 11) of zinc concentrations in Strathcona Sound, 2-5 June 1982 (from Thomas et al. 1983).

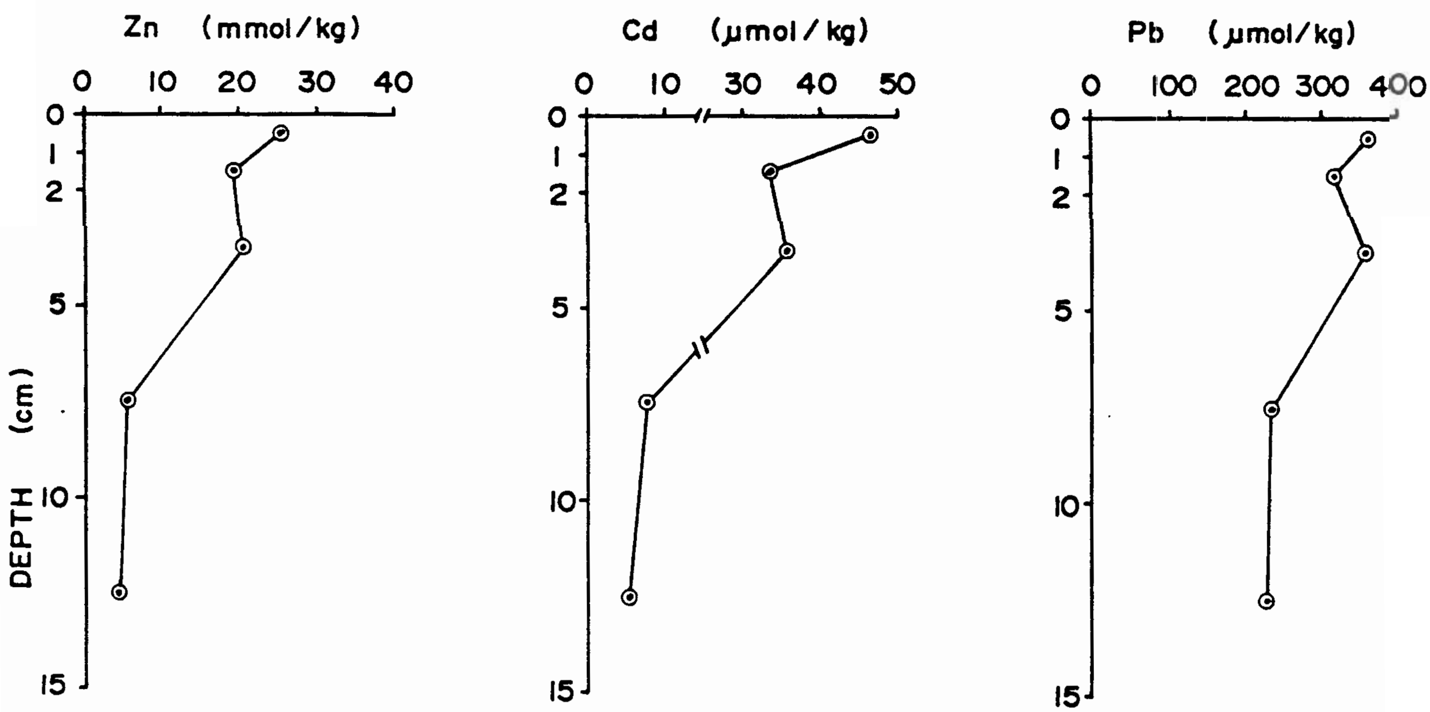


Figure 14. Zinc, cadmium, and lead concentrations at different depths in a sediment core sample from Strathcona Sound, NT, off the mouth of Twin Lakes Creek (Site 1, Fig, 11) on 1 June 1982 (from Thomas and Erickson. 1983)

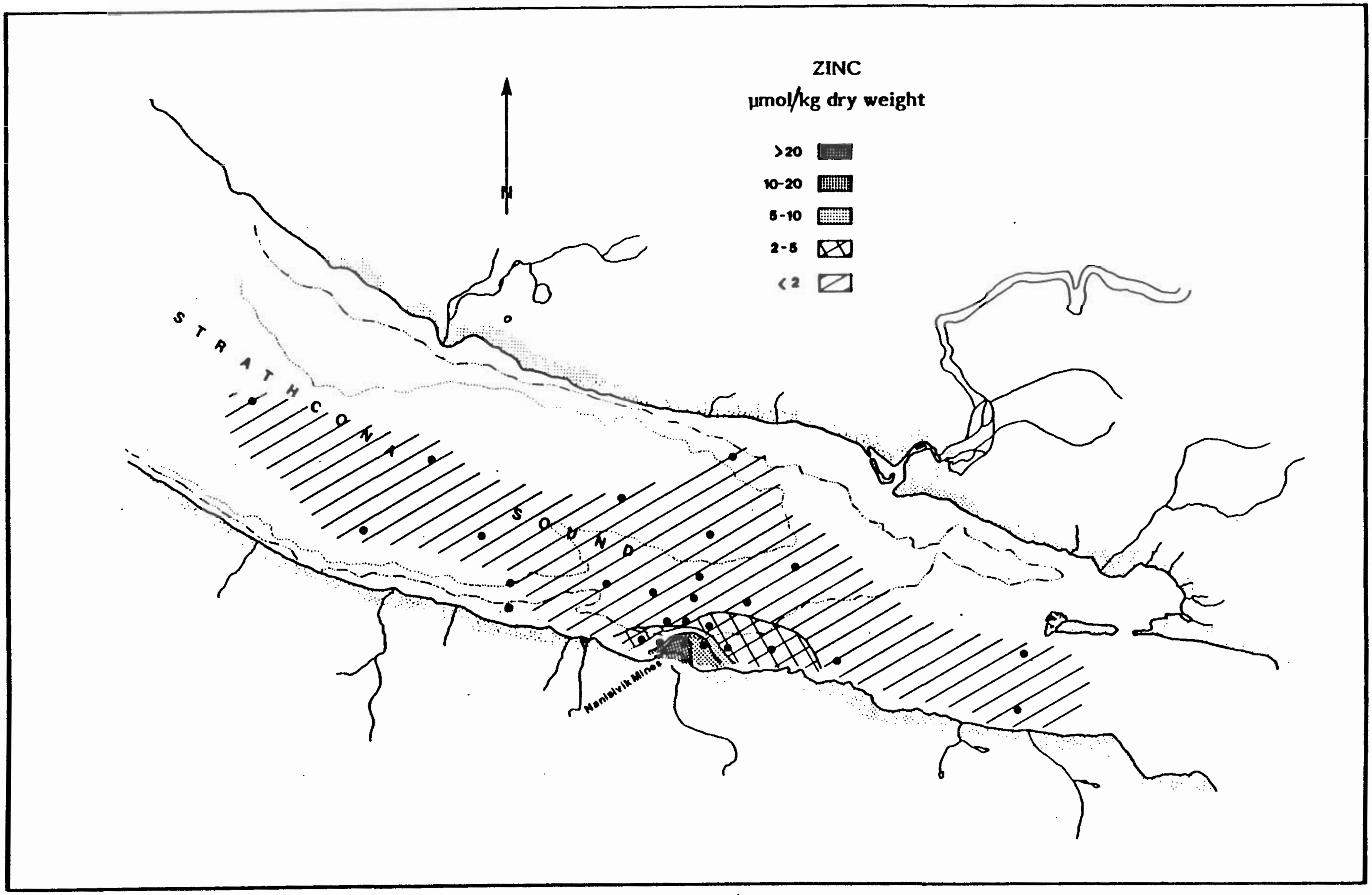


Figure 15. Concentrations of zinc in the 0-1 cm (surface) portion of sediment surface cores collected in Strathcona Sound, NT, from 29 May to 6 June 1982. Station numbers are shown in Figure 11 (from Thomas and Erickson 1983).

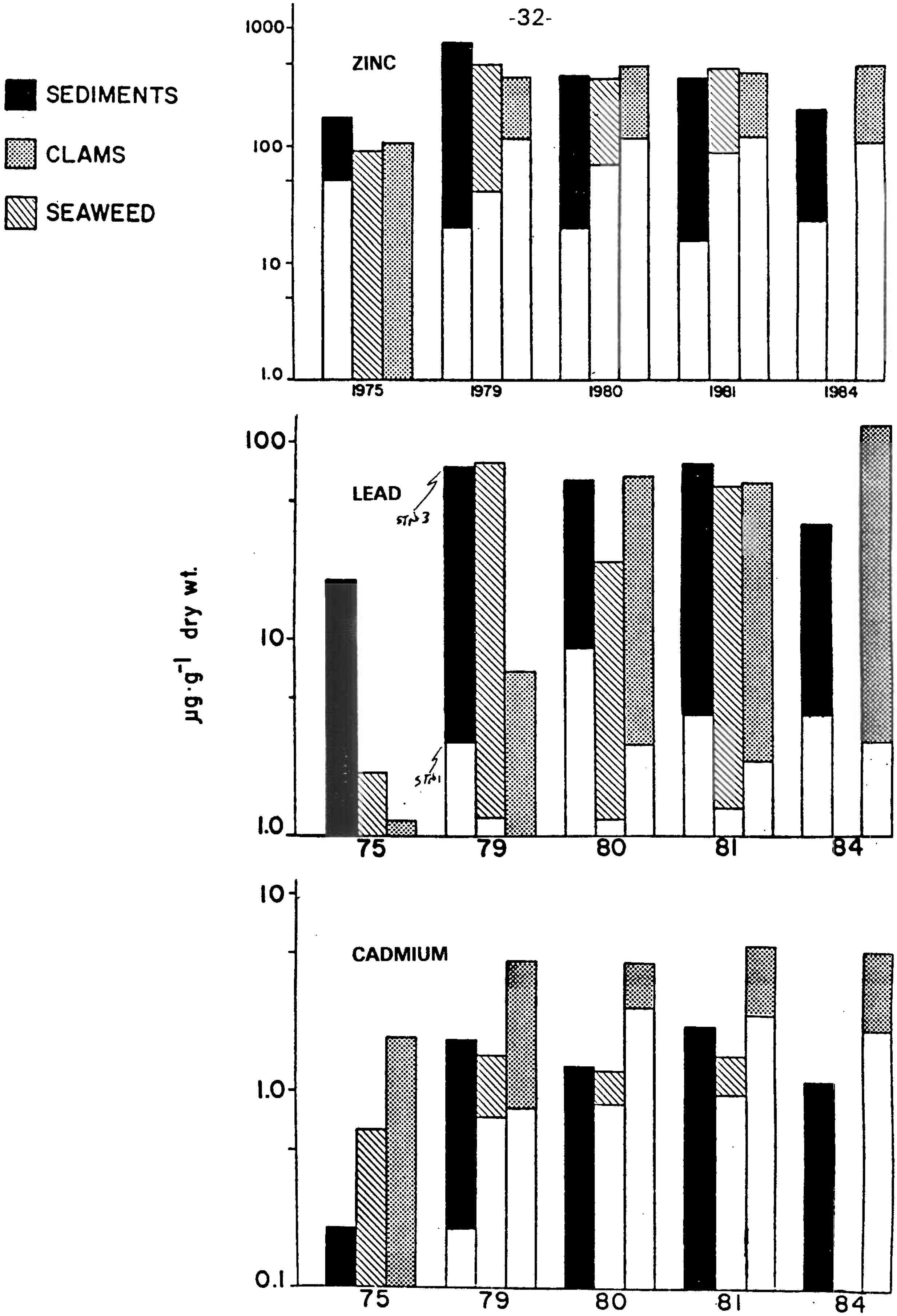


Figure 16. Time series of the ranges of values for zinc, lead, and cadmium measured in sediments (< 1 mm fraction), clams (Mya truncata soft body parts) and seaweed (old growth portions of Fucus vesiculosus) for samples collected in Strathcona Sound, NT, near the mouth of Twin Lakes Creek (station 3--shaded) and near the entrance of Strathcona Sound (Station 1--unshaded). (see Appendix Fig. A9 for sites)(Courtesy of B.W. Fallis).

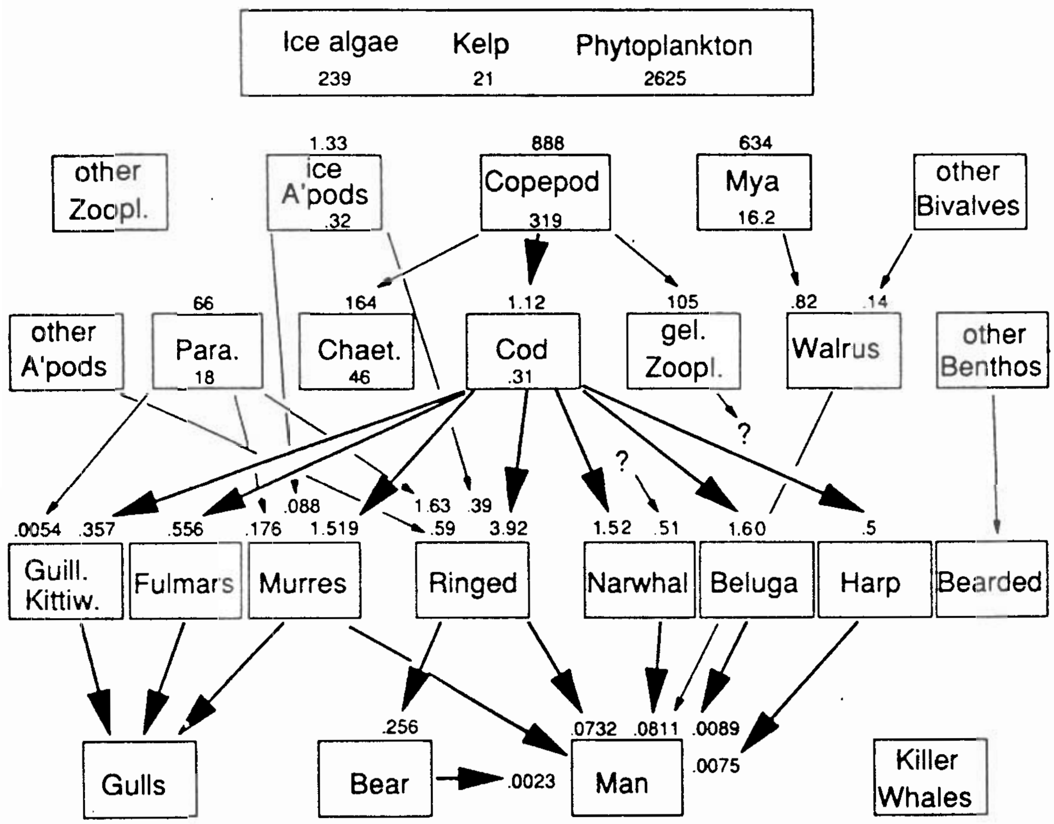


Figure 17. Energy flow (kJ/m^2/yr) through parts of the marine food web in the Lancaster Sound region. Numbers at the tops of the boxes are ingestion; numbers inside the boxes are calculated growth; numbers for man are kill rates. Heavy arrows highlight energy flow mediated by Arctic cod (from Welch et al. 1992).

Table 1. Ranges of heavy metal concentrations[a] in water and Arctic charr from tributaries to Strathcona Sound and from seawater, sediments and biota from Strathcona Sound, NT, in 1974 and 1975--before mining operations began. See also Table 2.

Material tested	Date	Iron	Lead	Zinc	Cadmium	Arsenic	Copper	Nickel	Reference
FRESH WATER									
Kuhulu Lake	1974	6-8	0.7-0.8	20-22	0.15-0.16	<5	-[b]	-	B.C. Research 1975b
East Twin Lake	1974	40-49	0.7-0.8	10-18	0.07-0.13	<5	-	-	B.C. Research 1975b
West Twin Lake	1974	15-23	0.8-0.9	7-27	0.15-0.25	<5	-	-	B.C. Research 1975b
creeks outside mine area	1974	18-100	0.7-2.0	19-90	0.12-0.20	5	-	-	B.C. Research 1975b
creeks inside mine area	1974	6-39	0.7-1.6	9-700	0.14-2.20	<5	<1.0	-	B.C. Research 1975b
Arctic charr fillets (Kuhulu Lake)	1974	16-34	-	-	-	-	-	-	B.C. Research 1975b
	1974	-	-	14-33	-	0.3-0.8	1.1-4.2	-	Bohn and Fallis 1978
Arctic charr liver (Kuhulu Lake)	1974	639-6473	-	-	-	-	-	-	B.C. Research 1975b
	1974	-	0.2-0.5	35-180	1.6-2.3	0.3-1.2	22-220	-	Bohn and Fallis 1978
MARINE									
seawater	1974	<2-5	<5	<1-42	<1	<1-3	<1-7	<5	B.C. Research 1975a
sediments	1974	2820-34000	4-100	4-171	<1-5	1-8	4-29	4-27	B.C. Research 1975a[c]
kelp (*Fucus* sp)	1975	170-920	0.5-1.4	22-170	0.7-1.8	21-32	2.1-4.7	-	Bohn 1979
	1975	-	-	-	-	-	-	4-5	B.C. Research 1975a
sea urchin (*Strongylocentrotus* sp.)	1975	305-2610	-	22-78	0.6-1.8	2.7-4.5	2.3-4.0	-	Bohn 1979
zooplankton	1975	32-87	-	43-90	1.2-7.0	5.6-7.9	3.4-26	-	Bohn and McElroy 1976
shrimp	1974	244-461	<16	58-69	1.5-3.5	39-58	45-64	<5-8	B.C. Research 1975a

Table 1. Continued.

Material tested	Date	Iron	Lead	Zinc	Cadmium	Arsenic	Copper	Nickel	Reference
shorthorn sculpin fillets	1974	26-347	-	-	-	-	-	<8	B.C. Research 1975a
	1974	-	-	28-100	1.0-1.6	10-130	1.6-9.9	-	Bohn and Fallis 1978
shorthorn sculpin liver	1974	34-312	-	-	-	-	-	<23	B.C. Research 1975a
	1974	-	0.1-1.2	47-160	0.9-16	14-320	1.8-26	-	Bohn and Fallis 1978
Arctic cod whole	1975	55-240	-	56-142	0.3-1.5	6-38	2.1-7.7	-	Bohn and McElroy 1976
Arctic cod fillets	1975	20-41	-	28-39	-	26-83	2.9-5.4	-	Bohn and McElroy 1976
Arctic cod liver	1975	29-58	-	15-29	0.4-1.6	3-8	1.7-5.4	-	Bohn and McElroy 1976

[a] Metal concentrations were expressed in μg/L (total?) for water and in μg/g dry weight for other materials. Data from different authors and years should not be compared without reference to the original reports as study methods vary.

[b] Dashes indicate no data.

[c] Low values in the sediment were from a sandy area.

Table 2. Heavy metal concentrations in water from Twin Lakes Creek and in sediments and biota from Strathcona Sound, NT, near the creek mouth (see Appendix 1, Fig. A9, Site 3) between 1974 and 1981 (after Fallis 1982).

MATERIAL TESTED	YEAR	NUMBER OF SAMPLES	MEAN METAL CONCENTRATION[a]				
			LEAD	ZINC	CADMIUM	ARSENIC	MERCURY
Fresh water - Twin Lakes Creek							
decant structure	1977	5	34	62	<5	<10	<0.2
	1978	31	60	51	<5	<10	<0.2
	1979	10	45	53	<5	-[f]	<0.2
	1980	14	<20	68	<20	-	-
creek mouth	1974	3	<1	223	<0.2	-	-
	1975	5	<1	236	<0.7	<0.5	-
	1976	3	<1	47	0.9	<0.6	-
	1977	15	52	341	<5	<10	<0.2
	1978	3	56	147	<5	<10	<0.2
	1979	8	19	583	<5	-	-
	1980	11	<20	2500	<20	-	0.3
Marine bottom sediment[b]	1974	-	20	155	0.3	4	0.1
	1975	-	18	175	0.2	3	0.1
	1979	-	76	750	1.8	9	0.03
	1981[g]	7	72	364	1.6	6	-
Seaweed[c] (Fucus vesiculosus)	1976	2	2	88	0.6	25	0.02
	1979	1	59	493	1.7	35	0.02
	1981[g]	7	18	346	1.2	-	-
Sea urchin[d] (Strongylocentrotus droebachiensis)	1976	6	2	58	1.0	4	0.02
	1979	17	24	278	0.7	4	0.04
	1981[g]	33	15	141	0.8	-	-
Bivalve mollusc[e] (Mya truncata)	1975	1	1	105	1.8	-	-
	1979	24	2	388	2.7	25	0.45
	1981[g]	30	62	418	2.5	-	-

[a] = concentrations for water are in μg/L dissolved for 1974-76 (Fallis 1982), and μg/L total for 1977-80 (Nanisivik Mines Ltd. in Fallis 1982); concentrations for other materials are in μg/g dry weight.
[b] = 1974 and 1975 sediments particles were <0.18 mm in diameter, 1979 and 1981 were <1.00 mm.
[c] = washed whole plants minus stipe. [d] = whole urchins. [e] = soft tissues.
[f] = dashes indicate no data. [g] = 1981 values from Fallis (unpubl. data).

Table 3. Enrichment factors for cadmium, lead, and zinc in surface sea water of Strathcona Sound off the mouth of Twin Lakes Creek (Fig. 11, Station 1). Concentrations are in $\mu mol/m^3$ (from Arctic Laboratories Ltd. 1986).

Metal	Run-off Concentration Mouth of Twin Lakes Creek		Background* Surface Seawater (A)	Surface Concentration at Station 1			B/A	C/A[a]	D/A
	Mean Summer 1982	June 1985		June 1982 (B)	June 1985 (C)	December 1985 (D)			
Zn	1.0×10^5	1.2×10^4	6	53	47	9.5	8.8	7.8	1.6
Pb	12	12	0.46 (0.30)[a]	2.4	0.62	1.04	5.2	2.0	2.3
Cd	26	12	0.34	0.43	0.28	0.40	1.3	0.8	1.2
Fe	3.5×10^4	1.1×10^3	30	117	51	-	3.8	1.7	-

* Mean of data from middle of channel: December 1985, June 1985, June 1982. For Pb: June 1985 data is in brackets.

a For Pb, background surface seawater in June, 1985 is for June 1985 data only.

Table 4. Baffin Region Inuit Association estimates of the numbers of fishes and marine mammals harvested by residents of Arctic Bay and Nanisivik, an average of harvest estimates for the 5 year period from January 1980 to December 1984[a] (Donaldson 1983, 1984; Pattimore 1985, pers. comm.).

Species	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
ARCTIC BAY													
Ringed Seal	41	47	54	83	96	670	270	271	309	142	66	31	2080[b]
Bearded Seal	–[c]	2	2		1		5	17	9	3		–	39
Harp Seal	–	–	–	–	–	–	2	40	54	3	–	–	99
Walrus	–	–	–		1		1		1	–	–	–	3
Narwhal	–	–	–	–	2	6	56	23	4	–	–	–	91
Beluga	–	–	–	–	2	1	1		–	–	–	–	4
Arctic Charr (anadromous)	278	498	263	1100	585	728	211	2034	782	611	2848	924	10862
Arctic Charr (non-anadromous)	–	–	–	–	31	45	5	1	26	11	–	–	119
Sculpin	–	–	–	–	–	–	4	2	–	–	–	–	6
NANISIVIK													
Ringed Seal	6	5	2	15	10	97	61	60	58	38	19	2	389
Bearded Seal	–	–	–	–	–	–	1	2	2		–	–	5
Harp Seal	–	–	–	–	–	–		1	7	–	–	–	9
Walrus	–	–	–	–	–	–	–	–	1	–	–	–	1
Narwhal	–	–	–	–	–	1	8	4	–	–	–	–	13
Arctic Charr (anadromous)	–	–	–	2	29	22	69	292	278	–	108	116	965
Cod	–	–	–	–	–	–	–	–	1	–	–	–	1
Sculpin	–	–	–	–	–	–	–	2	–	–	–	–	2

a = Data were not collected in January, February, and March of 1984.
b = Totals are based on all data and may differ from the sum of the monthly mean harvests due to rounding.
c = Dashes indicate months with no reported harvest, blanks indicate months with harvests but where the kill estimates averaged over 5 years were less than 0.5.

APPENDIX 1. CHRONOLOGICAL LISTING OF SUMMARIES OF KEY REPORTS CONCERNING CONTAMINANTS IN THE VICINITY OF THE NANISIVIK MINE, NT

Reference material in this appendix is organized chronologically by the period in which the research took place.

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LIST OF FIGURES

REFERENCE:	B.C. Research. 1975a. Baseline survey of the marine environment at Strathcona Sound, N.W.T. Prepared for Strathcona Mineral Services. vii + 84 p. + figures and appendices. [Project 1552, Progress Report 1]
Sampling period:	Pre-operational: August 1974
Sampling sites:	Offshore stations (Figure A1), longline sets (Figure A2), sled and plankton tows (Figure A3), nearshore sampling sites Figure (A4), and stream sampling sites (Figure A5) are shown on figures provided in text.
Measurements:	Physical oceanographic measurements included tide gauges, current and water temperature profiles, and turbidity; chemical oceanographic measurements including salinity, dissolved oxygen, pH; metals concentrations (arsenic, zinc, lead, cadmium, copper, iron, and nickel) were measured in freshwater streams, seawater, marine sediments, seaweed, shrimp, plankton, fish (liver and muscle of shorthorn sculpin <u>Myoxocephalus scorpius</u>); biological sampling included dredging for benthic invertebrates, horizontal and vertical plankton tows, angling and longlining for fish from below the intertidal zone, seabird observations, and taxonomic identification of biota collected.
Main findings:	Waters in Strathcona Sound were relatively clear with August secchi disc readings of 6 to 13 m--higher turbidities tending to be close to shore. They ranged near neutral pH, from 7.6 to 8.2, with measurements at a deepwater station decreasing gradually with depth from the surface measurement of 8.1 to 7.6 at 300 m. Surface water temperature in mid-August varied from 0.4° to 9.2°C depending on the warming effects of freshwater runoff and rainfall. Temperature below the surface decreased with increasing depth above 100 m and then began to increase. At the 100 m level it reached a minimum of -1.5°C, and then increased to -0.5°C at 300 m. Below the 100 m level there was relatively little temperature variation between stations or seasons. Water column stratification was stable below 50 m and subject to summer wind mixing and winter convection currents above 50 m. The early summer salinity profile of Strathcona Sound was characterized by a steep halocline to about the 10 m level with a more gradual increase in salinity thereafter. During break-up, when it was depressed by runoff and meltwaters, salinity at the surface ranged from 15 to 20 ppt (parts per thousand). It increased rapidly to 31 ppt by 10 m, and then gradually thereafter, increasing to 33.5 ppt at 300 m. Peak dissolved oxygen levels in Strathcona Sound occurred at depths of between 5 and 30 m, ranging from 8.6 to 15.0 ml • L^{-1} , and decreased gradually with increasing depth. The Sound had a relatively rich benthic fauna, including about 90 species of polychaetes. Zooplankton collected from Strathcona Sound include copepods, amphipods, decapods, chaetognaths, coelenterate medusae, pteropods, and arrow worms. Schools of Arctic cod were seen in Strathcona Sound. Elevated zinc levels in the sea water and elevated zinc and lead in <u>Fucus</u> and bottom sediments near the mouth of Twin Lakes Creek in 1974, indicated that there was zinc-enriched drainage from the area of the ore body into Strathcona Sound before Nanisivik Mine began to operate (Table 1). Typical zinc levels in seawater seldom exceed 20 μg/L, whereas those in Strathcona Sound ranged from 14 to 42 μg/L. The concentrations of arsenic, cadmium, copper, iron, lead, and nickel in the water and in marine tissues resembled those from other non-industrial locations. Concentrations of zinc, cadmium, and lead were usually highest in the surface sediments and decreased with depth. Elevated arsenic levels were found in the muscle and liver tissues of shorthorn sculpin (<u>M. scorpius</u>).

Comparability:	While this study was intended to provide baseline data against which later studies could be compared, it was not designed to facilitate long term monitoring. The brief nature of the study meant that there could be no understanding of the range of natural variability in the system--for example the day-to-day and year-to-year variations in metal inputs from Twin Lakes Creek related to runoff. Analytical methods were not described in sufficient detail that they could be replicated, nor were estimates of the accuracy and precision of the analyses provided. The size fraction of the sediments, the sizes of the invertebrates which were grouped for analysis, and the age and size of the fish analysed were not reported. Depressed oxygen levels observed below 100 m were not observed in 1975, and may be due to instrument problems (Walker 1977). Data were also reported for metals in fourhorn sculpin (<u>M</u>. <u>quadricornis</u>) and Arctic charr (<u>Salvelinus</u> <u>alpinus</u>) collected by the Department of Fisheries and Oceans (see also Fallis 1982).

REFERENCE:	B.C. Research. 1975b. Terrestrial environmental studies at Strathcona Sound, N.W.T. Prepared for Strathcona Mineral Services by B.C. Research, Vancouver, B.C. vi + 32 p. + appendices. [Project 1552, Progress Report 2]
Sampling period:	Pre-operational July and August 1974
Sampling sites:	Creeks and lakes in vicinity of the ore body and across Strathcona Sound (Figure A6).
Measurements:	Water samples were analysed for pH, dissolved oxygen, turbidity (ppm SiO_2), conductivity; dissolved organic and total carbon; dissolved, suspended and total solids; hardness, alkalinity, colour; major ions and nutrients; heavy metals; and coliform bacteria--not all parameters were measured at each sampling location. Depth-sounding transects and dissolved oxygen/temperature profiles were taken at West Twin and Kuhulu lakes. Flow rates and stream gradients were measured, bedload samples were taken, and invertebrates collected from a number of streams. Vegetaion maps were prepared and observations were recorded on seabirds and mammals.
Main findings:	Pre-development studies were conducted on three lakes in the vicinity of the ore body, East Twin (Quasaqtoq), West Twin (Kuviku), and Kuhulu. East Twin Lake, the Nansivik water supply, drains into West Twin Lake, the mine tailings pond, which drains via a periodic stream, Twin Lakes Creek, into Strathcona Sound. These lakes are elevated about 370 m above sea level, and West Twin Lake is over 20 m deep. Kuhulu is a deep lake (>60 m) located 2 km south of Strathcona Sound at an elevation of 264 m. It has a surface area of 3.2 km^2 and drains directly into the Sound via a seasonal stream. The lakes are oligotrophic and cold monomictic. They were not thermally or chemically stratified in late July or August of 1974, and had low ion concentrations, nutrient levels and productivity, and near neutral pH. Metal concentrations are shown in Table 1. Coliform counts from Kuhulu and West Twin Lakes in July and September 1974 were zero coliform organisms per 100 ml. A non-anadromous population of Arctic charr inhabits Kuhulu Lake, but no fish have been reported from the other lakes. Creeks in the Nanisivik area are small, with steep gradients and seasonal flow. The smallest streams only flow for a short period in summer and are often dry at freeze-up. Annelid worms, tipulids, and chironomids were collected from creeks in the region of Nanisivik Mines' property. High concentrations of zinc (700 $\mu g \bullet L^{-1}$) were found in East Portal Creek, which drains the eastern end of the ore body, prior to mine development. Creeks outside the mine development area exhibited relatively low levels of zinc and iron.
Comparability:	Analytical methods used to determine the water chemistry were not described. Pre-development water quality data from Twin Lakes Creek and other drainages into Strathcona Sound, some showing high levels of zinc and cadmium, are of questionable value as a "natural baseline" given the high variability in metal concentration associated with rainfall events, and the fact that exploratory work had already exposed surface metal deposits in several of the basins (Grey 1989; Thomas 1989).

REFERENCE:	B.C. Research. 1975c. Lethal and sublethal bioassays on tailing from Nanisivik Mine ore. Prepared for Strathcona Mineral Services by B.C. Research, Vancouver, B.C. iii + 27 p. [Project 1552, Progress Report 3]
Sampling period:	Pre-operational: 1974
Sampling sites:	Laboratory testing.
Measurements:	The lethal and sub-lethal effects of pilot plant flotation tailings from the Nanisivik ore body were investigated on coho salmon (Onchorhynchus kisutch), rainbow trout (Salmo gairdneri), soft-shelled clam (Mya arenaria), and nereid worms (Nereis vexillosa). Ore samples were collected from Strathcona Sound, Baffin Island where construction of an underground zinc-lead mine, concentrator and ancillary facilities is proposed. Sub-lethal tests used included: buccal cannulation, residual dissolved oxygen assay, swimming performance, and oxygen uptake rate.
Main findings:	The acute toxicity of the tailing was attributed mainly to its high pH; neutralization with carbon dioxide or dilution with sea water reduced or eliminated toxicity. No conclusions could be drawn concerning the chronic or sublethal effects of the tailing.
Comparability:	Details were not provided on the methods of chemical analysis used or on the precision and accuracy of those methods.

REFERENCE:	Bohn, A., and B.W. Fallis. 1978. Metal concentrations (As, Cd, Cu, Pb and Zn) in shorthorn sculpins, Myoxocephalus scorpius (Linnaeus), and Arctic char, Salvelinus alpinus (Linnaeus), from the vicinity of Strathcona Sound, Northwest Territories. Water Research 12: 659-663.
Sampling period:	Pre-operational: August and September 1974
Sampling sites:	The benthic sculpins were captured using gillnets or baited hooks below the intertidal zone along the north and south shore of the Strathcona Sound. Landlocked Arctic charr were captured from Kuhulu Lake. Specific sampling locations were not given.
Measurements:	Samples of liver and muscle from landlocked Arctic charr and marine shorthorn sculpin were analysed for arsenic, cadmium, copper, lead, and zinc.
Main findings:	The mean and range of metal concentrations in the muscle and liver of the sculpins were within the ranges for marine fishes from more southern latitudes. In the shorthorn sculpin, arsenic was the only element that showed a positive correlation with body weight. It did so over the entire size range of fish and for both liver and muscle tissues. The other metals either were not correlated with body weight or else the data were non-linear. The concentrations of arsenic in the muscle and liver of shorthorn sculpins substantially exceeded the Canadian Food and Drug Directorate guidelines for marine animal products that were in place for arsenic at that time (5 ppm wet wt). These limits are no longer in force (M. Hendzel, pers. comm.) No correlation between metal concentrations and body weight was found in the landlocked Arctic charr from Kuhulu Lake, which is not subject to drainage from the ore body. Arsenic, cadmium, and lead in the charr were similar to concentrations reported in fish from other lakes in the NWT, whereas copper and zinc concentrations were high compared to data available for other northern freshwater fishes.
Comparability:	National Bureau of Standards Reference Material 1571 (bovine liver) was analysed in triplicate for cadmium, copper, iron, and zinc to test the accuracy and precision of the methods. Replicate samples were analysed. Specific sampling sites and the ages of the organisms sampled were not provided.

REFERENCE:	Bohn, A. 1979. Trace metals in fucoid algae and purple sea urchins near a high Arctic lead/zinc ore deposit. Marine Pollution Bulletin 325-327.
Sampling period:	Pre-operational: mid-August 1975
Sampling sites:	Six sites were sampled at different distances (0.1, 1, 2, 7, 15, and 18 km) from the nearest stream draining the ore body (Figure A7).
Measurements:	Whole seaweed plants (Fucus distichus) and samples of the growing tips, intermediate portions of the thallus, and the lower thallus including the stipes were analysed for arsenic, cadmium, copper, iron, lead, and zinc. Whole sea urchins (Strongylocentrotus droebachiensis) and samples of gonads were analysed for the same metals except lead.
Main findings:	In this study, which was conducted before the Nansivik Mine began operating, higher concentrations of iron and zinc were found in seaweed and urchins near the lead/zinc ore body, than further away. The concentrations of copper, iron, and zinc in seaweed increased with the age of the tissue, while arsenic and cadmium were lowest in tissue of intermediate age--suggesting a reversible bonding mechanism for the two elements. Fucus growing tips which are eaten by the urchins had lower concentrations of iron than whole urchins and lower concentrations of zinc than urchin gonads. Iron is higher in whole urchins than in their gonads, and the reverse was observed for arsenic and zinc.
Comparability:	National Bureau of Standards Reference Material 1571 (Orchard leaves) were analysed in triplicate by identical methods to test the accuracy and precision of the methods. Replicate samples were analysed.

REFERENCE:	Bohn, A., and R.O. McElroy. 1976. Trace metals (As, Cd, Cu, Fe, Zn) in Arctic cod, <u>Boreogadus saida</u>, and selected zooplankton from Strathcona Sound, northern Baffin Island. J. Fish. Res. Board Can. 33: 2836-2840.
Sampling period:	Pre-operational: August 1975
Sampling sites:	Bottom trawls were conducted at depths of 120 to 300 m in Strathcona Sound. Zooplankton were collected using vertical hauls in the vicinity of the trawl locations. Site locations are not provided.
Measurements:	Whole cod, cod liver, and cod muscle were analysed for arsenic, cadmium, copper, iron, and zinc. Smaller cod and plankton were grouped to provide sufficient material for analysis. The plankton were grouped into copepods, amphipods (Lysianassidae), and Chaetognaths (<u>Sagitta</u> sp.). They were not separated by species, age, or size.
Main findings:	This study was intended to provide data on background metal levels prior to development of the Nanisivik Mine. Because Arctic cod are very mobile and the sampling procedures are difficult to replicate, the results are of limited use for assessing contaminants entering Strathcona Sound. Cod muscle was found to have higher concentrations of arsenic and zinc than cod liver, which had higher concentrations of cadmium and iron. Arsenic, copper, iron, and zinc were present in higher concentrations in the cod than in the copepods they eat; cadmium concentrations were 5-8 times greater in the unsorted copepods than in the cod.
Comparability:	Direct comparisons with these data are difficult since smaller fish and zooplankton were grouped for analysis, size and age data are not provided, zooplankton were not sorted by species, and sampling locations were not given. National Bureau of Standards Reference Material 1571 (bovine liver) was analysed in triplicate for cadmium, copper, iron, and zinc to test the accuracy and precision of the methods. Replicate samples were analysed. Reference material was not analysed for arsenic, but duplicate analysis of 8 samples found the analytical precision to be $\pm 5\%$.

REFERENCE:	Bornhold, B.D. 1976. Marine surficial geology: central and eastern Arctic. Geol. Surv. Can. Pap. 76-1A: 29-31 p.
Sampling period:	Pre-operational: September 1975.
Sampling sites:	Four sampling transects across Strathcona Sound and one transect the length of the sound (Figure A8).
Measurements:	Sediment cores were taken from the bottom, and temperature and salinity were measured at 5 m depth intervals in the upper part of the water column at each station.
Main findings:	In September 1975, surface water temperatures were generally low, -0.9° to 0.0°C, at the mouth and high, 1.0°C, near the head of the Sound. A tongue of high salinity (up to 28.7 ppt) entered the south side of the Sound and extended towards the north coast. The central part of the Sound was characterized by salinities of about 28.0 ppt. Beyond the narrow constriction, towards the head of the Sound, the salinities increased steadily to >29.4 ppt, suggesting that there is little interchange of water between the upper and lower parts of the Sound. There was a marked temperature and salinity discontinuity (i.e. halocline) between the depths of 15 and 20 m. Sediments in the upper basin of Strathcona Sound consist of a soft brown clay overlying intensely mottled, compact grey clay with abundant black streaks throughout. Sediments in the main basin and at the entrance to the sound are similar, but lighter brown in color. Samples taken on the sills between the basins and in the mouth of the sound contain more sand and pebbles than those from within the basins. Metal concentrations in the cores were determined, but are not included in this brief paper. They have been reported in part by Fallis (1982) and Thomas et al. (1983). To quote Thomas et al. (1983) "The concentrations of zinc and lead measured in the surficial sediments at some locations were higher than those normally encountered in uncontaminated coastal marine sediments. A remarkable cross-channel distribution of lead in the surface layer was also evident in the data. Concentrations of lead were highest near the shore of the fjord draining the Strathcona ore body and decreased to about one-half these values at the opposite side of the fjord. The spacing of the stations was too coarse, however, to provide a good indication of metal levels in the sediments near the mouth of Twin Lakes Creek."
Comparability:	These sediment data are not directly comparable to the 1979 DFO data due to differences in depth at the sampling sites (Fallis 1982). Sediments were analysed for metals by J.C. Van Loon of the University of Toronto, but the methods have not been reported in Bornhold (1976), Fallis (1982), or Thomas et al. (1983)--the methods may be on file.

REFERENCE:	Reish, D.J., T.V. Gerlinger, C.A. Phillips, and P.D. Schmidtbauer. 1977. Toxicity of formulated mine tailings on marine polychaeta. Prepared by Marine Biological Consultants Inc., Costa Mesa, California, for Environment Canada Toxic Studies Division, Fisheries and Marine Service, Winnipeg, MB. variously paginated
Sampling period:	Pre-operational: 1976
Sampling sites:	Laboratory study
Measurements:	The toxicity of cadmium, zinc, lead, and Nanisivik Mine tailings was tested (28 day LC_{50} and 96 hour LC_{50}) on four species of laboratory reared benthic polychaetous annelids (Neanthes arenaceodentata, Capitella capitata, Ctenodrilus serratus, Ophryotrocha diadema) at 15 and 20°C.
Main findings:	The authors concluded that the discharge of mine tailings into Strathcona Sound would adversely affect the survival and reproductive rate of benthic polychaetous annelids.
Comparability:	It is not clear how these findings relate to actual concentrations and conditions that might be experienced by organisms affected by Nanisivik mine tailings, and to what extent these findings are applicable to Arctic biota living in a cold sea.

REFERENCE:	Smith, T.G., and F.A.J. Armstrong. 1978. Mercury and selenium in ringed and bearded seal tissues from Arctic Canada. Arctic 31(2): 75-84.
Sampling period:	Pre-operational: 1976
Sampling sites:	Arctic Bay area
Measurements:	Total mercury (μg/g wet wt) was measured in the liver of ringed seals (Phoca hispida)
Main findings:	First year (mean age 3-4 months) ringed seals taken from the Arctic Bay area in 1976, had total mercury concentrations of 0.32 ± 0.08 ppm wet wt. in the liver (n = 36) and 0.08 ± 0.07 ppm wet wt. in the muscle (n = 37). These mercury levels were extremely low relative to the other Arctic seals measured. Two older seals from the area had higher levels. The mean total mercury concentration in the blood of Arctic Bay Inuit in 1976 was 23.3 ppb wet wt. (SD = 12.39; n = 45), 88.8% in the form of methyl mercury. Only 6% of the relatively high mercury content in the seal liver was in the methylated form, while 75% of the relatively low mercury content of the muscle was in the methylated form. Since the main source of mercury in the Inuit diet is thought to be seal, this suggests that the human body can methylate mercury.
Comparability:	Tissues were analysed by the method of Armstrong and Uthe (1971) for total mercury and that of Uthe et al. (1972) for methyl mercury. These mercury data are not directly comparable to those of Wagemann (1989), who measured μg/g dry wt., for seals from Strathcona Sound and Admiralty Inlet.

REFERENCE:	Fallis, B.W. 1982. Trace metals in sediments and biota from Strathcona Sound, NWT; Nanisivik Marine Monitoring Programme, 1974-1979. Can. Tech. Rep. Fish. Aquat. Sci. 1082: v + 34 p.
Sampling period:	Pre-operational: August of 1975-76, May 1976; September 1976--sediments only; Post-operational: August and early September 1979
Sampling sites:	Eight stations located at different distances from the mouth of Twin Lakes Creek were sampled in 1979 (Figure A9). Only Station 3, 1 km from the creek mouth, was sampled before mine production began (1974-6). The purpose of the 1974-6 study was to determine the abundance and diversity of organisms within Strathcona Sound. It was not initially intended as the pre-operational phase of a metal monitoring program. In 1976, seaweed samples were taken from Arctic Bay as a control.
Analyses:	Ekman (1974-76) and core (1979) samples of marine bottom sediments were fractionated and the <1.00 mm fraction was analysed for arsenic, cadmium, lead, mercury, selenium, and zinc. Whole organism analyses of arsenic, cadmium, lead, mercury, selenium, and zinc in seaweed (Fucus, Laminaria, Agarum), purple sea urchins (Strongylocentrotus droebachiensis), clams (Mya), starfish (Leptasterias polaris), and fish (Myoxocephalus spp.).
Main findings:	Analytical results indicated that by the summer of 1979, in the vicinity of the marine terminal (Station 3), concentrations of lead, zinc, cadmium and arsenic in sediments, seaweed, and molluscs had increased substantially relative to pre-mining development as had the concentrations of lead, zinc and arsenic in the sea urchins (Table 2). At that time, the concentrations of lead and zinc in the sea urchins and zinc in Mya exceeded the maximum recommended levels (1.0 μg/g lead, 100 μg/g zinc) for marine animal products established by the Canadian Food and Drug Directorate. These recommended levels are no longer in force (M. Hendzel, pers. comm.)
Comparability:	A detailed description of the scientific methods used was provided. Organisms of various sizes (ages) were grouped for analysis. The 1975 sediment data collected by the Geological Survey of Canada (see also Bornhold 1976) are not directly comparable to the 1979 DFO data due to differences in depth at the sampling sites. Comparable data sets: Fallis unpubl. data.

REFERENCE:	Eaton, R.D.P. 1982. Metallic contaminants of significance to Northwest Territories residents. Science Advisory Board of the Northwest Territories, Yellowknife, NT. 33 p.
Sampling period:	Pre-operational: 1976 Post-operational: 1978, 1980
Sampling sites:	Arctic Bay
Measurements:	Blood samples taken from residents of Arctic Bay were analysed for cadmium, lead, and mercury.
Main findings:	This paper discusses the occurrence of four metallic contaminants, cadmium, lead, arsenic and mercury, and their significance to residents of the NWT. The discussion was based on a review of available literature as well as some original research. It includes data on lead, cadmium, and mercury in people from the community of Arctic Bay. Elevated blood lead levels of (>25 μg/100 ml) were found in 20% of the Arctic Bay Inuit tested in 1976, prior to the start of mine operation. These levels were not correlated with mine development related employment. In 1978, 49% of the male mine employees had elevated blood lead levels, and in 1980, 27% had elevated levels. This change was attributed to the ingestion of particulate lead caused by less than adequate hand washing. In 1976, cadmium levels in Arctic Bay residents were found to be normal. Given the low solubility of cadmium ore and the fact that the mine would not be smelting ore, it was considered extremely unlikely that cadmium would prove a significant biological hazard. In 1976, the mean blood levels of mercury in Inuit residents of Arctic Bay was about 20 ppb, with a range of 5-65 ppb. Seal meat and liver were suggested as the likely source of the mercury.
Comparability:	Analytical methods were not described.

REFERENCE:	Fallis, B.W. unpublished data
Sampling period:	Post-operational: August of 1980, 1981, and 1984
Sampling sites:	Eight sites along the coasts of Strathcona Sound were sampled in 1980. These sites corresponded to those sampled in 1979 (Fallis 1982; Figure A9). In 1981 and 1984, the same sites along the south shore of Strathcona Sound, 1 to 4, were sampled and three additional sites along the south coast were added, site 9 located between sites 2 and 3, site 10 located between sites 3 and 4, and site 11 off the point east of the mouth of the stream that drains Kuhulu Lake.
Measurements:	Samples of bottom sediments (<1 mm, <1 mm->180 μm, <180 μm->150 μm, <150 μm fractions), seaweed (<u>Fucus vesciculosus</u>-- new growth, old growth, and slime; <u>Agarum cribrosum</u>--stipes and total plant minus stipes), sea urchin (<u>Strongylocentrotus droebachiensis</u>; test, soft tissues, and total body), and clam (<u>Mya truncata</u>; siphon sheath, soft tissues minus siphon sheath, and total soft tissues) were analysed for metal concentrations. The metals tested were lead, zinc, cadmium, arsenic, manganese, copper, and iron.
Main findings:	Trace metal concentrations in the vicinity of the marine terminal (station 3) were monitored by DFO in 1980, 1981, and 1984. Cadmium and zinc concentrations in the sediments, seaweed, and clams remained fairly constant at about the 1979 level; lead concentrations behaved likewise, except in clams where it continued to increase in 1980 and then levelled off. The zone of influence of anthropogenic inputs of trace metals appears to extend to stations 2 and 4 situated 4.5 and 5.8 km towards the mouth and head of the Sound respectively.
Comparability:	Directly comparable with Fallis (1982), detailed descriptions are provided of the analytical methods and quality control of the analyses.

REFERENCE:	Thomas, D.J., P.E. Erickson, and J.D. Popham. 1983. Chemical and biological studies at Strathcona Soundm N.W.T., 1982. Prepared by Arctic Laboratories Ltd, Sidney, B.C., for Department of Indian Affairs and Northern Development, Yellowknife, N.W.T. xv + 120 p. + appendices.
Sampling period:	Post-operational: 28 May - 8 August 1982
Sampling sites:	Thirty-one sites in Strathcona Sound were sampled through the ice between 28 May and 6 June, six additional sites were sampled by divers from 16-18 August (Figure 11--in text). Approximate geographical coordinates are provided for the sites. Four sites on Twin Lakes Creek were sampled on 18 June, 21 July, and 8 August. The Creek sites (TLC--01, TLC-02, TLC-06, TLC-09) correspond to those designated in 1981 by DIAND Water Resources Division (Figure A12). West Twin Lake was sampled on 3 June, and East Twin lake on 21 July.
Measurements:	Seawater samples were analysed for lead, cadmium, iron and zinc; salinity; and reactive silicate, nitrate, and phosphate. The 200 mesh fraction of each sediment core section was analysed for total zinc, cadmium, and lead. Sedimentation rates were determined using Pb-210, and sediments were examined using both light and electron microscopes. The soft tissues of the clams (Mya truncata) excluding the siphons, were analysed for water content, protein concentration, lipids, glycogen, and sugars as possible indicators of biochemical stress; and for zinc, cadmium, and lead. The condition index was calculated, and reproductive condition was examined histologically. Freshwater samples from Twin Lakes Creek and East Twin and West Twin lakes were analysed for lead, zinc, cadmium, iron, and sulphate.

Main findings:	In sea water, dissolved zinc and lead concentrations ranged from levels that are comparable with recent open-ocean concentrations to levels that are as much as 100 times higher and more typical of contaminated coastal water. Iron concentrations also ranged over almost two orders of magnitude, but the lowest iron concentrations were many times greater than open-ocean levels. Cadmium concentrations, by comparison, had a very narrow range at or slightly below mean oceanic concentrations and showed little variation with depth or location. Concentrations of lead, zinc, and iron were elevated in Strathcona Sound in the vicinity of the mouth of Twin Lakes Creek and the ore concentrate loading dock; and in the shallow region of the inner sill (Figures 12 and 13--in text). Zinc and lead concentrations were highest at the surface. Enrichment factors of 100 for lead, 25 for zinc, and 2 for iron were observed in surface water adjacent to the Creek mouth and loading dock compared to surface metal concentrations at mid-inlet stations. The spatial and vertical distribution of metals in the sediments of Strathcona Sound suggests a source of metals adjacent to the mouth of Twin Lakes Creek (Figure 15--in text). In 1982, the concentration ranges of zinc, cadmium and lead in the sediments of Strathcona Sound were 38.6-1641 μg/g dry wt. (0.59-25.1 mmol/kg dry wt.), 0.09-5.2 μg/g dry wt. (0.84-46.6 μmol/kg dry wt.), and 8.9-100 μg/g dry wt. (43-483 μmol/kg dry wt) respectively. Values were usually highest at the surface and decreased with depth along the cores (Figure 14--in text). The metal concentrations are generally higher than those reported for uncontaminated coastal marine sediments. Estimates of the sedimentation rate ranged from 0.5 to 6 mm • a^{-1}. Microscopic examinations found a greater proportion of sulphide particles at sediment stations immediately north and east of the marine terminal, but could not identify their source. Sampling during the on-ice period suggested that concentrate dust rather than Creek drainage was a probable source of metals near Twin Lakes Creek. However, Twin Lakes Creek is a significant source of lead, zinc, and cadmium for Strathcona Sound during the summer. Short-term build-up of these metals in the receiving water could be expected. The duration and extent of the build-up will depend on the effectiveness of natural oceanographic processes in dispersing these inputs. There was no apparent relationship between health of the *Mya truncata* specimens examined and their proximity to the Twin Lakes Creek mouth/marine terminal area.
Comparability:	Sediment data on which parts of this report are based are contained in Thomas and Erickson (1983). The data are directly comparable to Thomas and Erickson (1983) and Asmund et al. (1991). Performance characteristics of the analytical methods used are presented. Reference materials obtained from the National Research Council of Canada were used to measure the accuracy of the methods. Replicate samples were taken.

REFERENCE:	Thomas, D.J., and P.E. Erickson. 1983. The concentrations of zinc, cadmium and lead in sediment cores from Strathcona Sound, N.W.T. Prepared by Arctic Laboratories Ltd., Inuvik, N.W.T. for Department of Indian Affairs and Northern Development, Yellowknife, N.W.T. variously paginated.
Sampling period:	Post-operational: 29 May to 6 June 1982.
Sampling sites:	Thirty-one sites were sampled (Figure 11--in text). Approximate geographical coordinates are given for each site. Other data collected at these sampling sites are presented by Thomas et al. (1983).
Measurements:	Sediment core samples were fractionated and the 200 mesh grain size was analysed for lead, zinc, and cadmium.
Main findings:	This is a data report with limited discussion of the results. The data it contains are discussed in greater detail by Thomas et al. (1983). The highest concentrations of all metals occurred where Twin Lakes Creek enters Strathcona Sound. The profiles of zinc, cadmium, and lead with depth were generally similar within cores (Figure 14--in text) Concentrations were usually highest at the surface and decreased smoothly with depth.
Comparability:	Directly comparable to Thomas et al. (1983) and Asmund et al. (1991). Performance characteristics of the analytical methods used are presented. Reference materials obtained from the National research Council of Canada were used to measure the accuracy of the methods. Replicate samples were taken.

REFERENCE:	Asmund, G. Johansen, P., and B.W. Fallis. 1991. Disposal of mine wastes containing Pb and Zn near the ocean: an assessment of associated environmental implications in the Arctic. Chemistry and Ecology 5: 1-15.
Sampling period:	Post-operational: Summer 1979-81 (Fallis 1982) and summer 1982 (Thomas et al. 1983).
Sampling sites:	This paper discusses seawater and clam (<u>Mya truncata</u>) samples collected by Thomas et al. (1983) (Figure 11--in text), and sediments, <u>Mya</u>, and seaweed (<u>Fucus</u>) collected by Fallis (1982) (Figure A9).
Measurements:	Samples were analysed for lead and zinc as described by Fallis (1982) and Thomas (1983).
Main findings:	This study compares and assesses the tailings and waste rock disposal practices at two lead/zinc mines, one in the Canadian Arctic at Nanisivik and one in Greenland, and at a cryolite mine in Greenland. Tailings deposited by Nanisivik Mine into West Twin Lake release an estimated 78.7 $kg \cdot y^{-1}$ zinc, 3.88 $kg \cdot y^{-1}$ cadmium, and 70.2 $kg \cdot y^{-1}$ lead. The concentrations of heavy metals measured in the water, sediments, seaweed, and molluscs in the vicinity of the Twin Lakes Creek outfall into Strathcona Sound were lower than at the Greenlandic mines where tailings are disposed of directly into the sea or on land close to the ocean shore. In order to minimize environmental contamination, waste rock and tailings should be placed in areas that confine solids and restrict exposure to runoff and tidal action. Disposal into a freshwater lake with subsequent discharge of effluent to an ocean tributary, as at Nanisivik, results in the release of lower quantities of available metals to the marine environment.
Comparability:	Directly comparable to Arctic Laboratories Ltd. (1986), Fallis (1982, unpubl. data), Thomas and Erickson (1983) and Thomas et al. (1983)

REFERENCE:	Wagemann, R. 1989. Comparison of heavy metals in two groups of ringed seals (<u>Phoca hispida</u>) from the Canadian Arctic. Can. J. Fish. Aquat. Sci. 46: 1558-1563.
Sampling period:	Post-operational: April and May 1983
Sampling sites:	Strathcona Sound and Admiralty Inlet (Figure A10)
Measurements:	Tissue samples (liver, kidney, muscle) of ringed seal were analysed for copper, cadmium, lead, zinc, mercury, arsenic, and selenium (μg/g dry wt). Seal ages were estimated from thin sections of the lower left canine.
Main findings:	Higher lead concentrations were found in a group of seals from Strathcona Sound in the vicinity of Nanisivik Mine, than in a reference group from Admiralty Inlet. The seals sampled from Strathcona Sound were younger on average than those from Admiralty Inlet.
Comparability:	Analytical methods were described in detail. Accuracy and precision of the metals analyses were determined using blanks and U.S. National Bureau of Standards Reference Material (Bovine Liver # 1577A). The Department of Fisheries and Oceans (FWI, Winnipeg) collected 11 more ringed seal from the area in 1993. These samples, and narwhal from 1983, 1986, and 1987, have not yet been analysed (R. Wagemann, pers. comm.). A further 60 seals were sampled in 1997-98 from Admiralty Inlet, but these samples have not been analysed (S. Innes, pers. comm.). Biological data, including teeth for ageing and stomach contents, are available for the sampled seals. Mercury data are not directly comparable to the Arctic Bay ringed seal data of Smith and Armstrong (1978) whose concentrations are in wet wt, not dry wt. Wagemann and Stewart (1994) and Wagemann et al. (1995, 1996) compared the metals data from ringed seals in this paper with metals in other Arctic marine mammals (see Procite bibliography).

REFERENCE:	Macdonald, C.R., and J.B. Sprague. 1988. Cadmium in marine invertebrates and arctic cod in the Canadian Arctic. Distribution and ecological implications. Mar. Ecol. Progr. 47: 17-30.
Sampling period:	Post-operational: October 1983
Sampling sites:	Arctic Bay
Measurements:	Whole body cadmium concentration in Arctic cod (<u>Boreogadus saida</u>).
Main findings:	Arctic cod (n = 50) collected by seine at Arctic Bay, NT, in October 1983, had mean whole body cadmium concentrations of 0.40 μg/g dry wt. (SD 0.21-0.76) and ranged in cadmium concentration from 0.13 to 1.51 μg/g dry wt.
Comparability:	Bohn and McElroy (1976) measured the cadmium concentrations of whole Arctic cod from Strathcona Sound. Analytical methods were described in detail. Blank samples, spiked blank samples, and National Bureau of Standards (Washington, USA) bovine liver standard 1577a were analysed to test the analytical accuracy and precision.

REFERENCE:	Arctic Laboratories Ltd. 1986. Cadmium, lead, and zinc particulate fluxes and seawater concentrations, Strathcona sound, N.W.T.: winter-spring studies, 1984-5. Prepared for Indian and Northern Affairs Canada, Yellowknife, NT. v + 30 p. + appendices.
Sampling period:	Post-development: 4 December 1984 to 5 June 1985.
Sampling sites:	Sediment traps were suspended from the ice of Strathcona Sound from 4 December 1984 to 5 June 1985, at 3 locations in a line out from the mouth of Twin Lakes Creek, at a site toward the head of the Sound, and at a control site (Figure A11). Seawater samples were collected from the water column when the traps were deployed and recovered. All but the latter site correspond directly to those used by Thomas et al. (1983). Meltwater from Twin Lakes Creek was collected in June 1985.
Measurements:	The water and sediment samples were analysed for cadmium, lead, zinc, and iron. The water was also analysed for salinity, and the sediments were examined by scanning electron microscopy.
Main findings:	During the study, no ore concentrate dust was visible on the ice and none was detected by electron microscopic analysis of trapped particulates from the water column. The winter particle flux was low, 8.3 $\mu g \bullet cm^{-2} \bullet d^{-1}$, and the concentrations of metals in the trapped particulates were similar to those previously reported from surficial sediments. Particle fluxes were the same at near shore and mid-Sound sites but the zinc and lead concentrations of particulates were higher close to shore. Cadmium concentrations in the Strathcona Sound seawater showed little variation with depth, season, or location. They were lower than levels found in spring runoff from Twin Lakes Creek (Tables 1 and 2). The concentrations of zinc and lead in the seawater were highest near the surface and decreased with increasing depth. Under-ice sampling in December 1984 did not find a surface concentration gradient of zinc or lead with distance from the loading dock. In June 1985, however, the concentration of zinc was much higher (15x), and that of lead somewhat higher (2x), near the mouth of Twin Lakes Creek than further offshore. The elevated zinc concentration near shore can be accounted for by zinc rich (1250x winter sea water) spring runoff from Twin Lakes Creek. Comparison of the distribution and relative concentrations of lead, zinc, and iron in the June 1985 water samples with those from June 1982, suggest that spillage of ore concentrate may have contributed to elevated lead and zinc concentrations in the 1982 observations.
Comparability:	Directly comparable to Thomas and Erickson (1983) and Thomas et al. (1983). Performance characteristics of the analytical methods used are presented. Certified reference materials were used to measure the accuracy of the methods. Replicate samples were taken at each depth/location.

REFERENCE:	Grey, B. 1989. Summary report on surface water quality at Nanisivik: with emphasis on cadmium, lead and zinc 1977 to 1988. Indian and Northern Affairs Canada, Water Resources, Yellowknife. ix + 63 p.
Sampling period:	Post Development: Surveillance Network Program (1977-88) and Monitoring Program (1981-84) of Twin Lakes Creek and East Portal Creek, and a dustfall sampling program (August 1981-September 1982)
Sampling sites:	Different sites were used for water quality sampling by the two programs but records can be compared on the basis of spatial similarity for the sampling sites (Figure A12). Water quality sampling stations were located on Twin lakes Creek, from the tailings pond decant (site 159-4) to the marine outfall (site 159-6), and on East Portal Creek downstream from the confluence of the west tributary (Figure 6--in text).
Measurements:	Total metal values for cadmium, lead, and zinc in the fresh water of the Twin Lakes Creek, and East Portal Creek.
Main findings:	Water quality data for Twin Lakes Creek suggest that the creek is a major source of zinc to Strathcona Sound . Metals inputs from the tailings pond decant are relatively low compared to those resulting from runoff over disturbed surface materials and metalliferous outcrops, and operational problems that contribute metal dust to streams and the Sound directly. About 40 kg of zinc passed through the decant structure in 1982. This represented only 0.033% of the total zinc loading that passed into Strathcona Sound at the creek outfall. The 2.4 kg of cadmium decanted made up only 14% of the cadmium passing into the sea from the creek. In contrast, 227% more lead passed through the decant than entered the sea--indicating a settling out of lead in the creek downstream of the decant. Most of the high zinc and cadmium inputs to the mid-basin of Twin Lakes Creek were related to mining operations which exposed mineralized surface areas. The concentrations of cadmium and zinc in the creek increased by an order of magnitude downstream of the open pit outfall, more after rainfall events. The mining company was able to mitigate some of these sites but periodic, dramatic increases continued during monitoring in 1984-89. These increases were strongly correlated with high rainfall events that leach metals from surface metal deposits. The average concentration of zinc at the creek outfall into Strathcona Sound from 1984-88, was 547 μg/L (SD 355 μg/L). Flow volume was much greater at the marine outfall than at the decant.
Comparability:	The Monitoring Program had an intensive quality assurance/quality control process incorporated into its design. The Surveillance Network Program, did not, and consequently can be used to identify general trends in metal levels, but not necessarily to detect statistical differences. The author states that there are too few pre-development metal values from creeks in the Nanisivik area (BC Research 1975) to form a reasonable baseline record. Further, that the extemely high value from one small creek is a reflection of early pre-development mining in East Portal Creek, which also makes the data set suspect as a representative of the pre-development situation.

REFERENCE:	Stephens, G.R. 1989. A review of Nanisivik Mines Limited's Nanisivik Mine. Prepared by Department of Geography, University of Waterloo, Waterloo, ON, for Indian and Northern Affairs Canada, Water Resources Division, Yellowknife, NT. iii + 165 p.
Sampling period:	Post-operational: 1977-1988
Sampling sites:	No samples were taken. Samples discussed were taken from the tailings pond decant into Twin Lakes Creek, Station 159-04 (Figure 6--in text) by Nanisivik Mine Ltd.
Measurements:	Reviews the water quality record for the tailings pond decant based on data provided by the Mine to the NWT Water Board. Water use and cadmium, lead, and zinc concentrations in the decant were reviewed.
Main findings:	From 1977 to 1988, water decanted from the West Twin Lakes tailings pond exceeded the maximum average concentrations permitted under the Nanisivik Mine's Water Licence on 48 occasions for lead and 26 for cadmium. Maximum allowable zinc concentrations (average and grab) were not exceeded. Cadmium limits were below the detection limit of the Mine's laboratory from 1980-82. The Nanisivik project also exceeded its allowance for monthly water use on 8 occasions. In 1988, the treatment efficiency of the tailings pond was still good, but it was declining as West Twin Lake began to fill. The tailing pond was still able to reduce the slurry to below the NWT Water Board Water Licence limits for all required parameters. This report provides brief descriptions of the ore processing and operation of the tailings pond.
Comparability:	Note: The report conclusions stated that "zinc" concentrations were exceeded. This is a typographical error and should have read "lead".

REFERENCE:	Sackman, T. 1990. Fisheries Act inspection of Nanisivik Mines Limited. Environmental Protection, Conservation and Protection, NWT District Office. 3 p. + attachments.
Sampling period:	Post-operational: 20 July 1990
Sampling sites:	Surveillance Monitoring Stations 159-4, 159-6, 159-9, 159-10, 159-11, 159-12A, AWR-1 (Figure 6--in text).
Measurements:	Water samples were analysed for arsenic, cadmium, copper, lead, nickel, and zinc.
Main findings:	None of the water samples taken from Twin lakes Creek during this routine inspection was found to contain total metals in excess of the Metal Mining Liquid Effluent Regulations. Elevated zinc concentrations were found in the East Adit Treatment facility feed, as might be expected. Waste oil was found leaking from the mine dump area, and a warning was issued.
Comparability:	A quality control report assessing the accuracy and precision of the analyses is included. Comparable to Grey (1989), Nanisivik (1996, 1997).

REFERENCE:	DINA. 1991. Nanisivik Mines Limited application for renewal and amendment of Water Licence N5L3-0159 for water use and waste disposal for industrial purposes, public hearing July 30, 1991. Prepared by Department of Indian and Northern Affairs, Yellowknife, NT. 13 p.
Sampling period:	Post-operational: 1977-90
Sampling sites:	Twin Lakes Creek Surveillance Program Sites 159-4 (decant), 159-6 (mid-basin), and 159-10 (outlet) (Figure 6--in text).
Measurements:	Cadmium, lead, and zinc in water.
Main findings:	This report discusses the environmental screening for Nanisivik Mines' Water License renewal. It includes a brief review of the spatial and temporal variability in metal concentrations in the water of Twin Lakes Creek. Cadmium levels were fairly low and consistent over time and between the West Twin Lake decant and the outlet to Strathcona Sound. Lead and zinc levels varied widely from year to year. While lead levels decreased from the decant to the outlet, zinc increased substantially below the decant, in mid-basin. A significant correlation was found between total annual rainfall and the average annual zinc concentration at the mid-basin (159-10) and outlet (159-6) stations.
Comparability:	Analytical methods were not described.

REFERENCE:	SENES Consultants Limited. 1991. Acid generation potential tests. Prepared by SENES Consultants Limited, Richmond Hill, ON, for Nanisivik Mines Limited, Nanisivik, NT. 6 p.
Sampling period:	Post-operational: 1991
Sampling sites:	Nanisivik Mine area
Measurements:	Tailings from the West Twin tailings area, waste rock from the No. 9 south and No. 39 east waste dumps, and composite shale samples from area 14, Mt. Fuji, and the East Adit were analysed for their potential to produce or neutralize acid using the B.C. Research Acid Generation Test. The rock samples were also analysed for 30 elements.
Main findings:	Tailings are net acid generators. They can be flooded or frozen to control the long-term release of acidity. Waste rock and local shale neutralize acid. The tailings and waste rock contain substantial levels of metal sulphides, particularly zinc sulphide. If these minerals are allowed to oxidize the metals will dissolve and may not precipitate upon neutralization with carbonate minerals, therefore some metal leaching can be expected if the tailings are exposed to oxidation.
Comparability:	Analytical methods were not described in the report.

REFERENCE:	Nanisivik Mines Ltd. 1991. Nanisivik Mines Ltd., License No. N5L3-0159, on-land disposal data summary. Prepared by Nanisivik Mines Ltd, Nanisivik, NT. 13 p.
Sampling period:	Post-operational: August 1990 to March 1991
Sampling sites:	On-land tailings disposal
Measurements:	Leachate water quality including pH, temperature, conductivity, total suspended solids, zinc, lead, and cadmium was measured in effluent leaving the Test Pond via the trench to West Twin Lake. Dust fall samples were collected and weighed at 8 stations. The height of the tailings in the on-land deposition area was also measured.
Main findings:	Nanisivik Mines began depositing tailings on land on 27 August 1990. The area of deposition was from the approximate elevation of 384.5 m at the NW end of the West Twin Lake basin. Tailings were deposited via a spigot and accumulated on land with the toe extending to the "Test Pond". Water from the Test Pond flowed via a trench into West Twin Lake. On-land deposition ended for the season on 23 February 1991, at which time sub-marine disposal into West Twin Lake commenced. The quality of effluent water from the Test Pond was analysed daily for the first two months and then weekly. Sampling ceased after ice thickness made sample collection impossible. Dust fall buckets and a thermocouple to track frost levels in the tailings were monitored monthly. The ranges of water quality in the tailings leachate before treatment in West Twin Lake were: pH 10.04-12.46; conductivity 1000-3850 μmhos; Total suspended solids 0.54-11.46; lead 0.109-2.711 mg/L; zinc 0.001-1.591 mg/L, cadmium 0.001-0.027 mg/L.
Comparability:	Analytical methods were not described.

REFERENCE:	Nanisivik Mines Ltd. 1994. Nanisivik Mines Ltd., NWT Water LIcence N5L3-0159, Metal Loading--Twin Lakes Creek. Prepared by Nanisivik Mines, Ltd., Nanisivik, NT. 20 p. + appendices.
Sampling period:	Post-operational: May to September 1991-94
Sampling sites:	Water at 13 sites on Twin Lakes Creek (Figure 10--in text), between the decant and Mill, was sampled at weekly intervals.
Measurements:	Water samples were analysed for total zinc, lead, and cadmium; total suspended solids, pH, conductivity, and temperature. Stream flow was calculated at station 159-10.
Main findings:	Flow rates in Twin Lakes Creek averaged 0.4 cubic metres per second in the 1993 runoff period, and ranged up to 1.6 cubic metres per second. In 1994, the average flow increased to 0.5 cubic metres per second and the maximum flow doubled to 3.2 cubic metres per second. The creek begins to flow with local snowmelt in mid-May. Flow rates increase dramatically in early June when East Twin lake discharges, and continue to increase slightly with spring runoff until early July (Figure 5--in text). Flow rates then decrease gradually as average temperatures decline until freeze-up in late September. Short term peaks in flow are caused by rain or unusually warm temperatures. Water flowing through the canyon adjacent to the mine is affected by acid rock drainage generated from massive sulphide exposed in the western mine workings--mainly the West Pit, sulphide bodies in the 2 South and 9 South waste dumps, and sulphide bodies exposed in the creek banks or covered with overburden but subject to the annual freeze-thaw cycle. The average zinc content in the water is increased by a factor of more than 20 as it passes through the canyon, from 0.06 to 1.50 ppm (60 to 1500 μg/L). Metal loading in the creek water varies dramatically during the flow season. Maximum loading occurs during the latter part of the summer when thaw of the surface layer is deepest. The total loading of zinc metal in Twin Lakes Creek in 1993 was 3,280 kg. In 1994, the total loading fell to 1,700 kg. The decrease was attributed to a shorter and cooler melt season and to less mining disturbance in the West Pit. Loading to the creek from natural sources and from some mining disturbances, mainly unreclaimable dump remnants, is expected to continue indefinitely. Remedial actions proposed in the Abandonment and Restoration Plan are expected to substantially reduce the metal loading, either by removing the sulphides or by causing them to become permanently frozen. These actions include: 1) removal to underground or to the West Pit of the sulphidic waste in 2 South and 9 South dumps, 2) backfill the pit to cover exposed sulphides, 3) cover the pit and the dump remnants with shale to ensure freezing, and 4) seal the portals to prevent thawing of the exposed sulphides by warm air in summer.
Comparability:	Analytical methods were not described. Earlier data from the same water quality surveillance stations have been reported by Grey (1989) and Stephens (1989). The metal loading study was continued in 1995 and 1996 (Nanisivik Mines Ltd. (1996, 1997), and a proposal has been submitted (Nanisivik Mine-Can-Zinco Ltd. 1997c) that would see the study continue. The authors noted that high variability in metal loading during the flow season limits the value of pre-operational (i.e. 1974-76) spot checks on the water quality for comparative purposes.

REFERENCE:	Nanisivik Mines Ltd. 1994a. 1993 annual water report, License No. N5L-0159. Prepared by Nanisivik Mines Ltd., Nanisivik, NT, and submitted to the N.W.T. Water Board, Gjoa Haven, NT. ii + 6 p. + appendices.
Sampling period:	Post-operational: 1993
Sampling sites:	Surveillance Network Program site 159-1, 159-4, 159-6, 159-9, 159-10, 159-12, 159-12a, 159-15, and 159-16 (Figure 6--in text)
Measurements:	Water samples were analysed for total and/or dissolved zinc, lead, and cadmium; total suspended solids, pH, conductivity, and temperature. Lead, zinc and iron solids were also measured at the tailings line discharge into West Twin Lake, and nickel in the decant from West Twin Lake. Water levels were measured at the East Twin and West Twin lakes.
Main findings:	At the decant from West Twin Lake into Twin Lakes Creek (site 159-4), the total cadmium concentration was <0.001 mg/L, the total lead concentration ranged from 0.001 to 0.011 mg/L, total zinc from 0.075 to 0.194 mg/L, and the total nickel was <0.001 mg/L. At the outflow of Twin Lakes Creek into Strathcona Sound (site 159-6) the total cadmium concentration ranged from <0.001 to 0.007 mg/L, the total lead from <0.001 to 0.150 mg/L, and total zinc from 0.150 to 2.113 mg/L. In 1993, Nanisivik Mine used 137,312 m^3 of potable water from East Twin Lake. Data are provided on the levels of East Twin and West Twin lakes. One spill was reported. The total volume of reclaim water pumped from West Twin Lake was 1,115,167 m^3. A total of 1.3 million m^3 of tailings (water and solids) were discharged to the surface cell of the West Twin Disposal Area--either on land or under water. Allowing for one metre of water cover and an abandonment lake level of 369 m elevation, there was potentially 669,060 m^3 available for tailings storage in West Twin Lake (about 3 years). West Twin Lake dyke construction was continuing. Controlled ice capping was tested as a method of tailings dust abatement. The tailings discharge point was also relocated to a sheltered area, the thickness of the ice cap was increased, and 1.2 km of snowfence were set out.
Comparability:	Sampling, sample preservation and quality control procedures were conducted in accordance with methods approved by the Controller. Reference standards were analysed and quality assurance plan data appended. The laboratory participated in an Interlaboratory Comparison Study.

REFERENCE:	SENES Consultants Limited. 1992. Study of cover requirements for flooded tailings. Prepared by SENES Consultants Limited, Richmond Hill, ON, for Nanisivik Mines Limited (c/o Strathcona Mineral Services Limited, Toronto, ON) variously paginated.
Sampling period:	Post-operational: July and August 1992
Sampling sites:	West Twin Lake tailing pond
Measurements:	Pore water was analysed for cadmium, lead, and zinc to provide data for modelling calculations.
Main findings:	This study examined the question of whether a covering of water will be sufficient to limit long-term releases of contaminants into Twin Lakes Creek to permissible discharge limits, or whether an inert cover will be required for the sub-aqueous tailings when the mine is decommissioned. Mathematical modelling, based upon the study of a large flooded tailings test cell which operated from 1985-90, indicated that long term leaching of metals from tailings should not be a problem provided the tailings are flooded with 1 m of water. Placement of a 0.5 m cover of inert material such as sand, gravel, or crushed dolstone over the tailings under the water would further reduce contaminant fluxes by about one half of an order of magnitude.
Comparability:	Analytical methods were not described.

REFERENCE:	Environment Canada, Yellowknife. unpubl. data
Sampling period:	Post-operational: 1992
Sampling sites:	Two control sites in Admiralty Inlet and 18 sites in Strathcona Sound. All but two of the latter corresponded to sites sampled by Thomas et al. (1983) (Figure 11), although different site numbers were used.
Measurements:	Sediment samples (<75 μm fraction) were analysed for heavy metals (mercury, zinc, copper, lead, nickel, chromium, selenium, cadmium), total organic carbon, and total inorganic carbon. Bioassays of acute and chronic sediment toxicity were to be performed on invertebrates.
Main findings:	The objectives of this study were to: 1) determine spatial/temporal variations of contaminants and establish whether concentrations of selected contaminants have increased over background levels within Strathcona Sound; 2) provide recommendations for future monitoring, such that the Nanisivik Study can be used as a potential model for future environmental assessments in Arctic marine areas; and 3) establish the toxicity of sediments collected within the area. North/South Consultants of Winnipeg was contracted in 1996 to complete the study. In March 1998, the study report had not been released pending its review by Environment Canada.
Comparability:	Unknown.

REFERENCE:	Nanisivik Mines Ltd. 1995. 1994 annual water report, License No. N5L-0159. Prepared by Nanisivik Mines Ltd., Nanisivik, NT, and submitted to the N.W.T. Water Board, Gjoa Haven, NT. iii + 8 p. + appendices.
Sampling period:	Post-operational: 1994
Sampling sites:	Surveillance Network Program site 159-1, 159-4, 159-6, 159-9, 159-10, 159-12, 159-12a, 159-15, and 159-16 (Figure 6--in text)
Measurements:	Water samples were analysed for total and/or dissolved zinc, lead, and cadmium; total suspended solids, pH, conductivity, and temperature. Lead, zinc and iron solids were also measured at the tailings line discharge into West Twin Lake, and nickel in the decant from West Twin Lake. Water levels were measured at the East Twin and West Twin lakes.
Main findings:	At the decant from West Twin Lake into Twin Lakes Creek (site 159-4), the total cadmium concentration was 0.001 mg/L, the total lead concentration ranged from 0.002 to 0.009 mg/L, total zinc from 0.001 to 0.144 mg/L, and the total nickel was 0.001 mg/L. At the outflow of Twin Lakes Creek into Strathcona Sound (site 159-6) the total cadmium concentration ranged from 0.001 to 0.002 mg/L, the total lead from 0.001 to 0.043 mg/L, and total zinc from 0.076 to 1.013 mg/L. In 1994, Nanisivik Mine used 125,817 m^3 of potable water from East Twin Lake. The lake was always at least 0.37 m higher in elevation than the West Twin Lake tailings pond. The total volume of reclaim water pumped from West Twin Lake was 1,219,152 m^3. A total of 1.35 million m^3 of tailings (water and solids) were discharged to the surface cell of the West Twin Disposal Area, either on land or under water. Three spills were reported. Allowing for one metre of water cover and an abandonment lake level of 369 m elevation, there was potentially 982,080 m^3 available for tailings storage in West Twin Lake (about 2 years). A two metre lift was added to the West Twin Lake dyke and dust abatement efforts were continuing.
Comparability:	Sampling, sample preservation and quality control procedures were conducted in accordance with methods approved by the Controller. Reference standards were analysed and quality assurance plan data appended.

REFERENCE:	Nanisivik Mines Ltd. 1996. 1995 annual water report, License No. N5L-0159. Prepared by Nanisivik Mines Ltd., Nanisivik, NT, and submitted to the N.W.T. Water Board, Gjoa Haven, NT. ii + 11 p. + appendices.
Sampling period:	Post-operational: 1995
Sampling sites:	Surveillance Network Program site 159-1, 159-4, 159-6, 159-9, 159-10, 159-12, 159-12a, 159-15, and 159-16 (Figure 6--in text)
Measurements:	Water samples were analysed for total and/or dissolved zinc, lead, and cadmium; total suspended solids, pH, conductivity, and temperature. Lead, zinc and iron solids were also measured at the tailings line discharge into West Twin Lake, and nickel in the decant from West Twin Lake. Stream flow was calculated at station 159-10. Water levels were measured at the East Twin and West Twin lakes.
Main findings:	At the decant from West Twin Lake into Twin Lakes Creek (site 159-4), the total cadmium concentration ranged from <0.001 to 0.002 mg/L, the total lead from <0.001 to 0.016 mg/L, total zinc from <0.001 to 0.109 mg/L, and the total nickel was <0.001 mg/L. At the outflow of Twin Lakes Creek into Strathcona Sound (site 159-6) the total cadmium concentration ranged from <0.001 to 0.006 mg/L, the total lead from <0.001 to 0.073 mg/L, and total zinc from 0.117 to 2.099 mg/L. In 1995, Nanisivik Mine used 136,749 m^3 of potable water from East Twin Lake. The lake was always at least 0.82 m higher in elevation than the West Twin Lake tailings pond. The total volume of reclaim water pumped from West Twin Lake was 1,176,585 m^3. A total of 1.3 million m^3 of tailings (water and solids) were discharged to the surface cell of the West Twin Disposal Area. Four spills were reported. Allowing for one metre of water cover and an abandonment lake level of 369 m elevation, there was potentially 446,739 m^3 available for tailings storage in West Twin Lake (about 2 years). West Twin Lake dyke construction was continuing. Efforts to abate dust movement from the surface tails deposit included: 1) the distribution of water on the surface to saturate dry areas and provide an ice cap during sub zero conditions; 2) the use of shale to cover tailings placed on the upstream side of the retention dyke, and 3) the use of snow fence to assist with tailings surface stabilization.
Comparability:	Sampling, sample preservation and quality control procedures were conducted in accordance with methods approved by the Controller. All analyses were conducted in accordance with methods prescribed in the current edition (no date provided) of "Standard Methods for the Examination of Water and Wastewater". Reference standards were analysed and quality assurance plan data are appended.

REFERENCE:	Vista Engineering. 1996. Domestic sewage treatment assessment, Nanisivik, Northwest Territories. Final Report. Prepared for Municipal and Community Affairs, Government of the Northwest Territories, Yellowknife. 29 p. + 10 p.
Sampling period:	Post-operational: 2-6 August 1996
Sampling sites:	Samples of water were taken from Twin Lakes Creek 100 and 1000 m from Strathcona Sound, and upstream of the sewage discharge. The sewage discharge was also sampled.
Measurements:	A complete battery of water quality analyses were conducted, including: pH, dissolved Oxygen, conductivity, alkalinity, hardness, major ions, colour, turbidity, filterable and non-filterable residue, volatile non-filterable residue, BOD, COD, fecal coliforms, total coliforms, nutrients and 24 metals.
Main findings:	During the early development of the mine at Nanisivik, an Are-o-Flo extended aeration sewage treatment system was installed to service the camp. In 1977, during development of the townsite, a rotating biological contactor was built and this unit was incorporated as the sludge storage tank. The sewage treatment plant was abandoned ca. 1983 due to severe condensation and frosting inside the building resulting from inadequate ventillation. Since then, untreated sewage from the community and mine has been pumped into Twin Lakes Creek, just north of the treatment plant, to flow into Strathcona Sound. This assessment of the domestic sewage disposal at Nanisivik found that the filterable residue, biological oxygen requirement (BOD), and fecal coliforms (1.7 x 10^6 CFU/dL) at the sewage outfall into Twin Lakes Creek, exceeded the Guidelines for the Discharge of Treated Municipal Waste Water (GDTMWW) established by the NWT Water Board. Further downstream, at stations located 100 m and 1000 m from Strathcona Sound, the GDTMWW receiving water metal criteria, which are based on 110% of background, were exceeded by barium, copper, molybdenum, rubidium, strontium, and uranium--at one or both stations. The fecal coliform counts greatly exceed the Canadian Guidelines for Drinking Water Quality (0 CFU/dL). The water of Twin Lakes Creek is not safe to drink upsteam <u>or</u> downstream from the sewage outfall. The continuation of current sewage disposal practices will require the approval of the regulatory authorities. Vista Engineering Ltd. (1996) assessed a number of other options, including: 1) construction of a sewage treatment lagoon with a small primary cell for solids removal and a larger secondary cell for treatment and storage, 2) construction of a smaller primary cell only, 3) refurbishing the existing treatment plant for primary and secondary treatment, and 4) refurbishing the plant for primary treatment only. The latter option was recommended as providing the lowest cost and most aesthetically pleasing option.
Comparability:	Samples were analysed by the Indian and Northern Affairs Water Resources Laboratory in Yellowknife, NWT..

REFERENCE:	Nanisivik Mines Ltd. 1997b. Revised 1996 annual water report, License No. N5L-0159. Prepared by Nanisivik Mines Ltd., Nanisivik, NT, and submitted to the Nunavut Water Board, Gjoa Haven, NT. ii + 11 p. + appendices.
Sampling period:	Post-operational: 1996
Sampling sites:	Surveillance Network Program site 159-1, 159-4, 159-6, 159-9, 159-10, 159-12, 159-15, and 159-16 (Figure 7--in text)
Measurements:	Water samples were analysed for total and/or dissolved zinc, lead, and cadmium; total suspended solids, pH, conductivity, and temperature. Lead, zinc and iron solids were also measured at the tailings line discharge into West Twin Lake, and nickel in the decant from West Twin Lake. Stream flow was calculated at station 159-10. Water levels were measured at the East Twin and West Twin lakes.
Main findings:	At the decant from West Twin Lake into Twin Lakes Creek (site 159-4), the total cadmium concentration ranged from <0.001 to 0.001 mg/L, the total lead from <0.001 to 0.013 mg/L, total zinc from 0.015 to 0.121 mg/L, and the total nickel was <0.001 mg/L. At the outflow of Twin Lakes Creek into Strathcona Sound (site 159-6) the total cadmium concentration ranged from <0.001 to 0.002 mg/L, the total lead from <0.001 to 0.024 mg/L, and total zinc from 0.16 to 0.425 mg/L. In 1996, Nanisivik Mine used 149,749 m^3 of potable water from East Twin Lake. The lake was always at least 0.84 m higher in elevation than the West Twin Lake tailings pond. The total volume of reclaim water pumped from West Twin Lake was 1,159,974 m^3. A total of 1,306,614 m^3 of tailings (water and solids) were discharged to the surface cell of the West Twin Disposal Area. Allowing for settling and water reclamation, about 292,552 m^3 of tailings were added to the surface cell. Because the tailings were deposited to the surface cell and not into the lake, the volume available for tailings storage in West Twin Lake remained unchanged from 1995 (see Nanisivik Mines Ltd. 1996). Four spills were reported. Efforts to abate dust movement from the surface tails deposit included: 1) the distribution of water on the surface to saturate dry areas and provide an ice cap during sub zero conditions; 2) the use of shale to cover tailings placed on the upstream side of the retention dyke, and 3) 3.5 km of snow fence to assist with tailings surface stabilization. A waste oil furnace was purchased to reduce the waste oil inventory. At 1996 year-end, the inventory was less than 25% of the original stockpile in 1994. Waste rock stockpiles in area 14 were covered with shale to induce permafrost aggradation and prevent sulphides from leaching, and reclamation of waste rock stockpiles at the East Adit and West Adit were ongoing.
Comparability:	Sampling, sample preservation and quality control procedures were conducted in accordance with methods prescribed in the current edition (no date provided) of "Standard Methods for the Examination of Water and Wastewater". Quality assurance plan summary data are appended.

Figure A1. Offshore sites in Strathcona Sound sampled by B.C. Research in August 1974 (from B.C. Research 1975a).

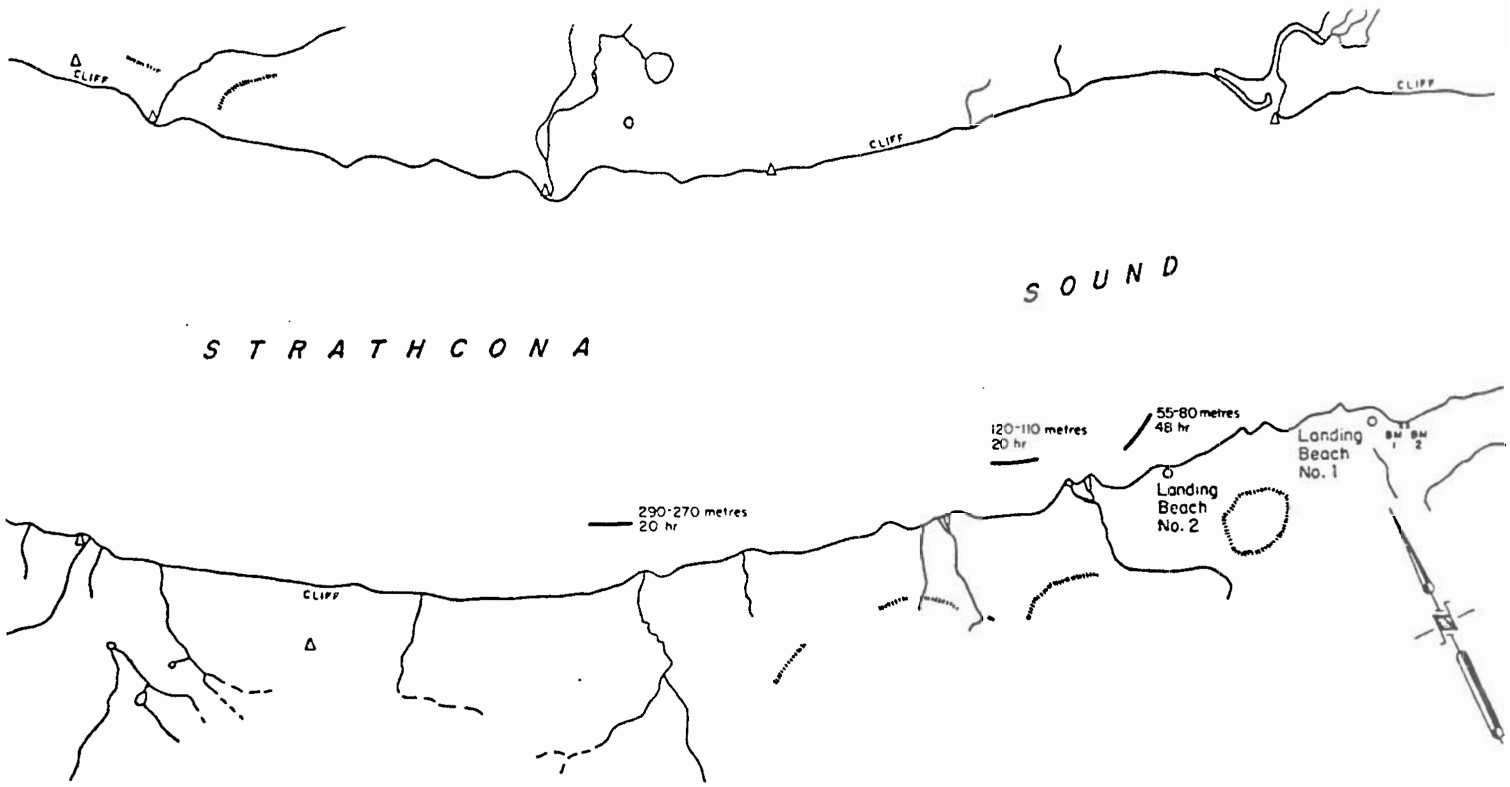

Figure A2. Location, depth and duration of longline sets in Strathcona Sound by B.C. Research in 1974 (from B.C. Research 1975a).

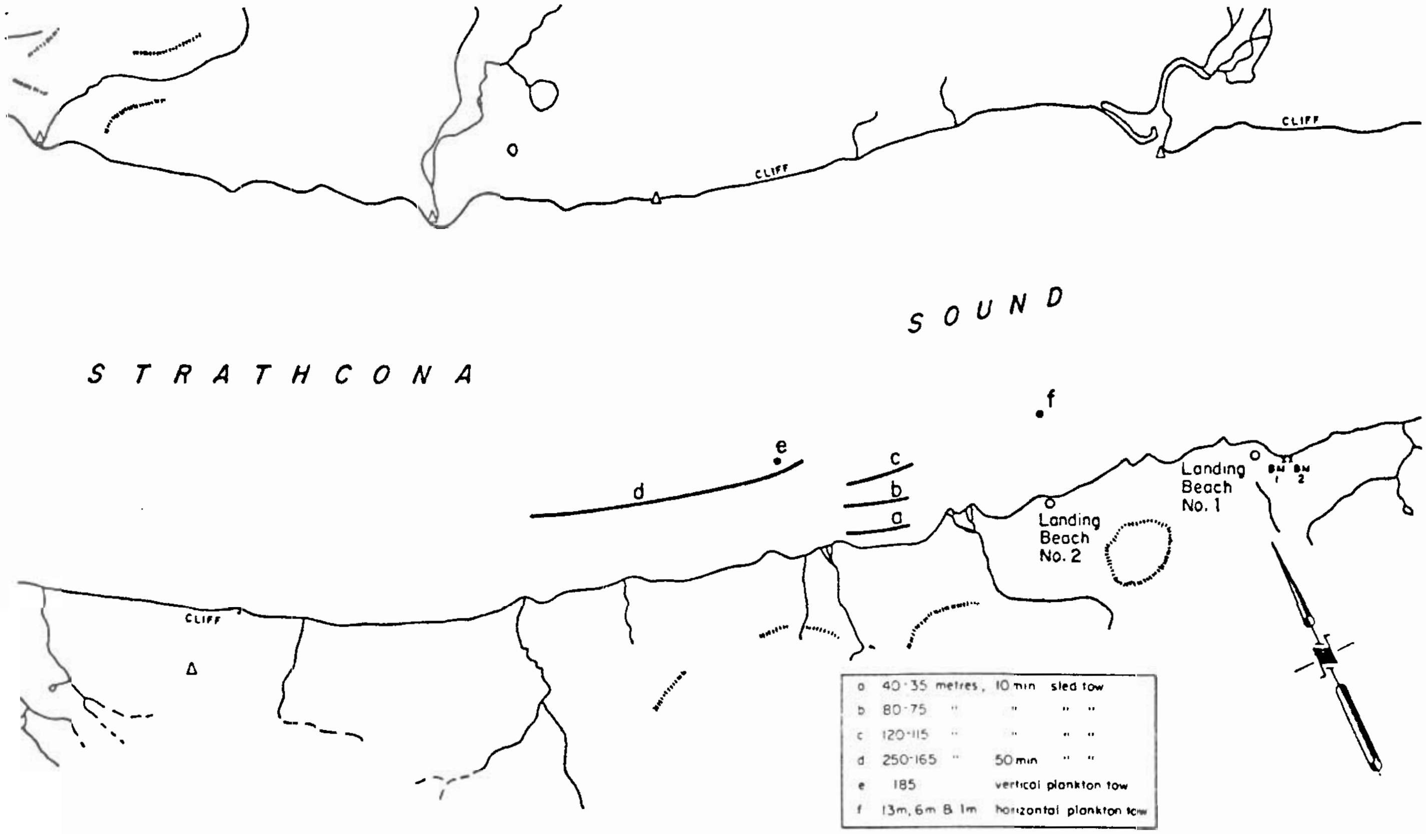

Figure A3. Location, depth and duration of sled tows and location and depth of plankton tows in Strathcona Sound by B.C. Research in August 1974 (B.C. Research 1975a).

Figure A4. Near-shore sites in Strathcona Sound sampled by B.C. Research in August 1974 (B.C. Research 1975a).

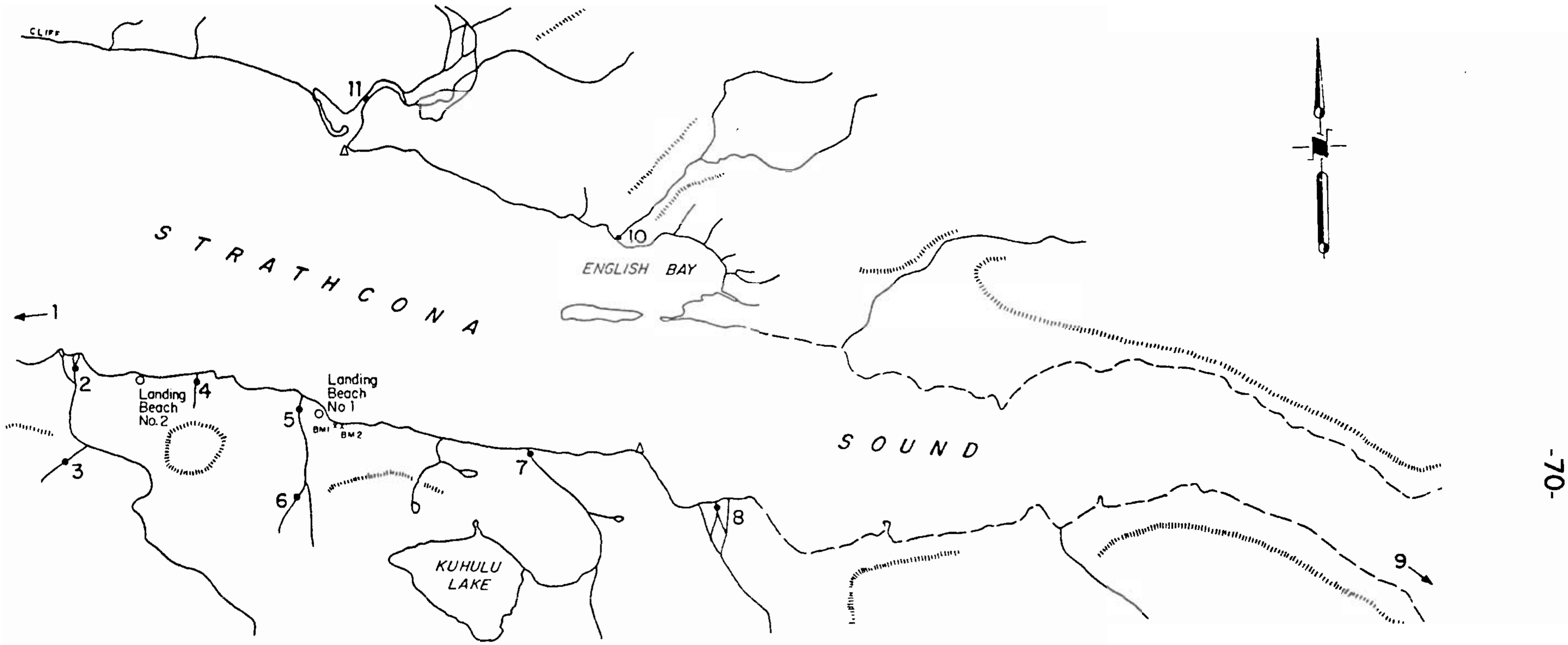

Figure A5. Sites on tributary streams of Strathcona Sound sampled by B.C. Research in August 1974 (from B.C. Research 1975a).

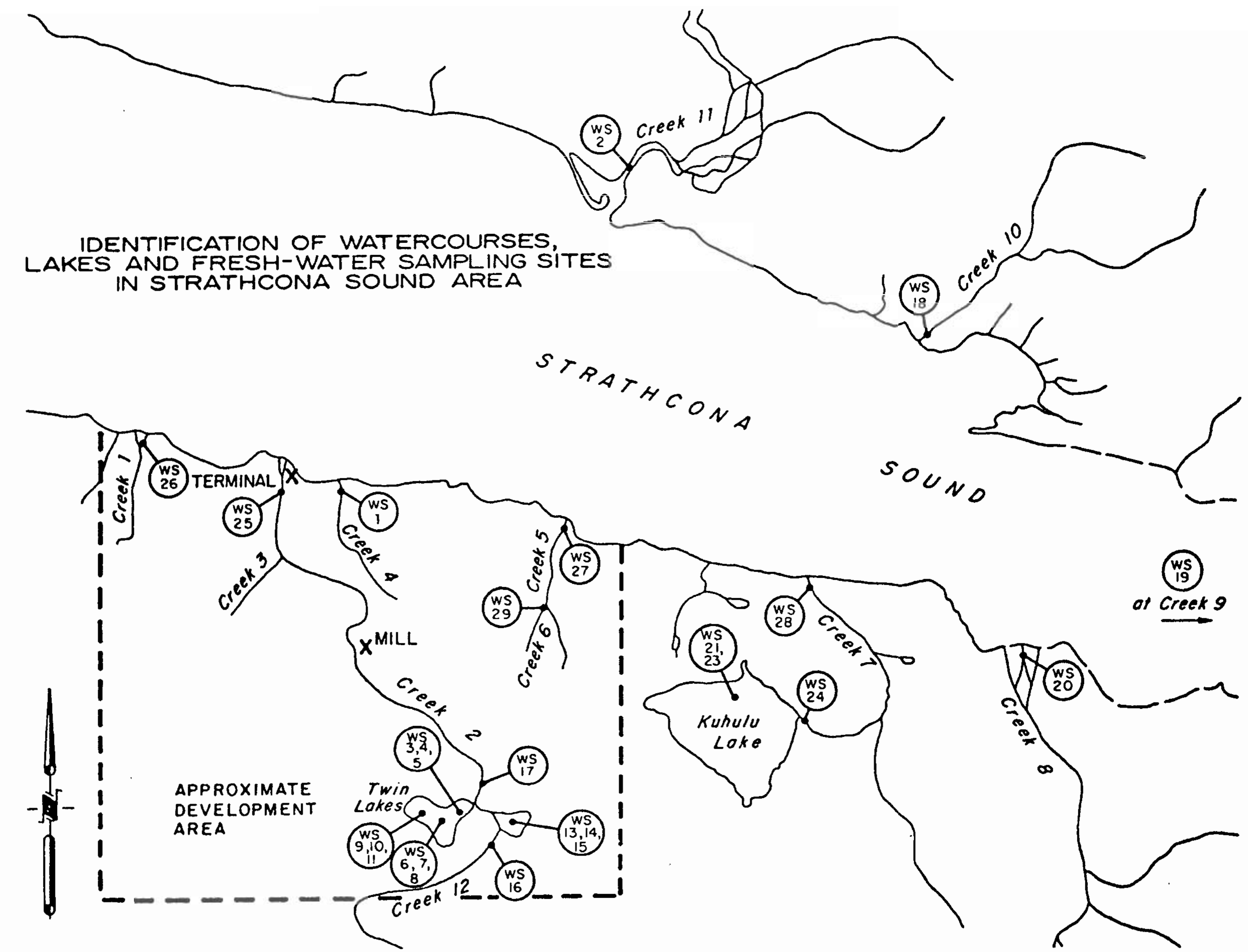

Figure A6. Freshwater sites in the Strathcona Sound area sampled in July and August 1974 by B.C. Research (from B.C. Research 1975b).

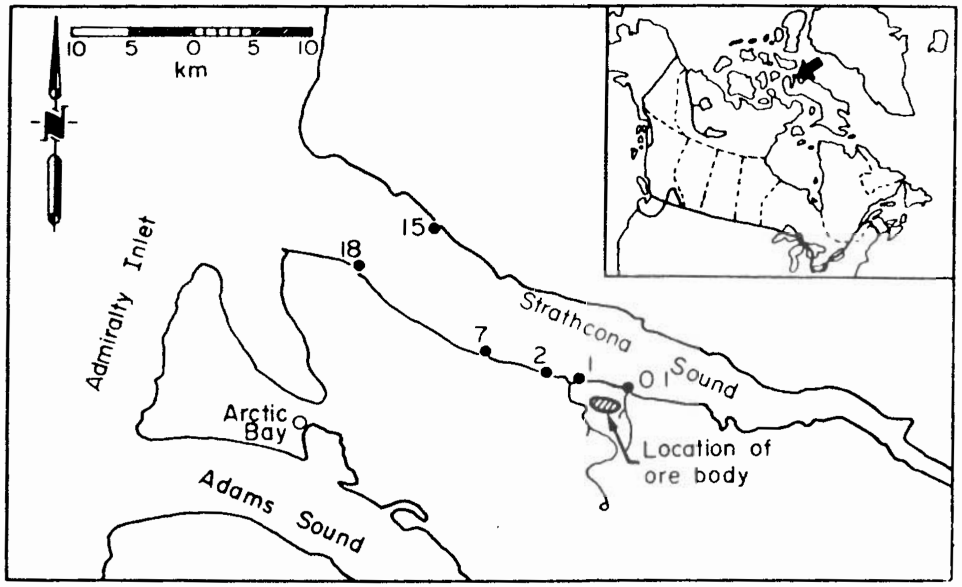

Figure A7. Locations of sites sampled in Strathcona Sound by Bohn in mid-August 1974 (from Bohn 1979). Site numbers refer to distance in km from the nearest stream draining the vicinity of the ore body.

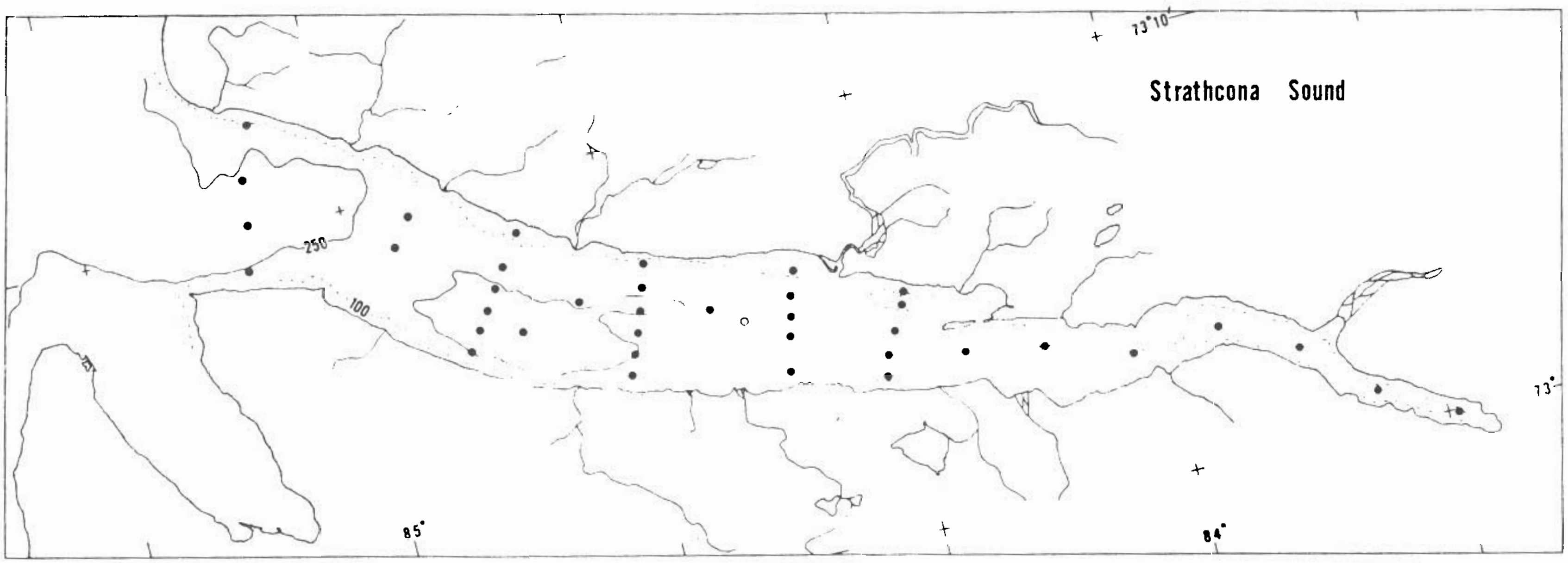

Figure A8. Locations in Strathcona Sound where Bornhold took grab samples (●) and gravity cores (○) of bottom sediment in September 1975; 100 m and 250 m bathymetric contours are indicated (from Bornhold 1976).

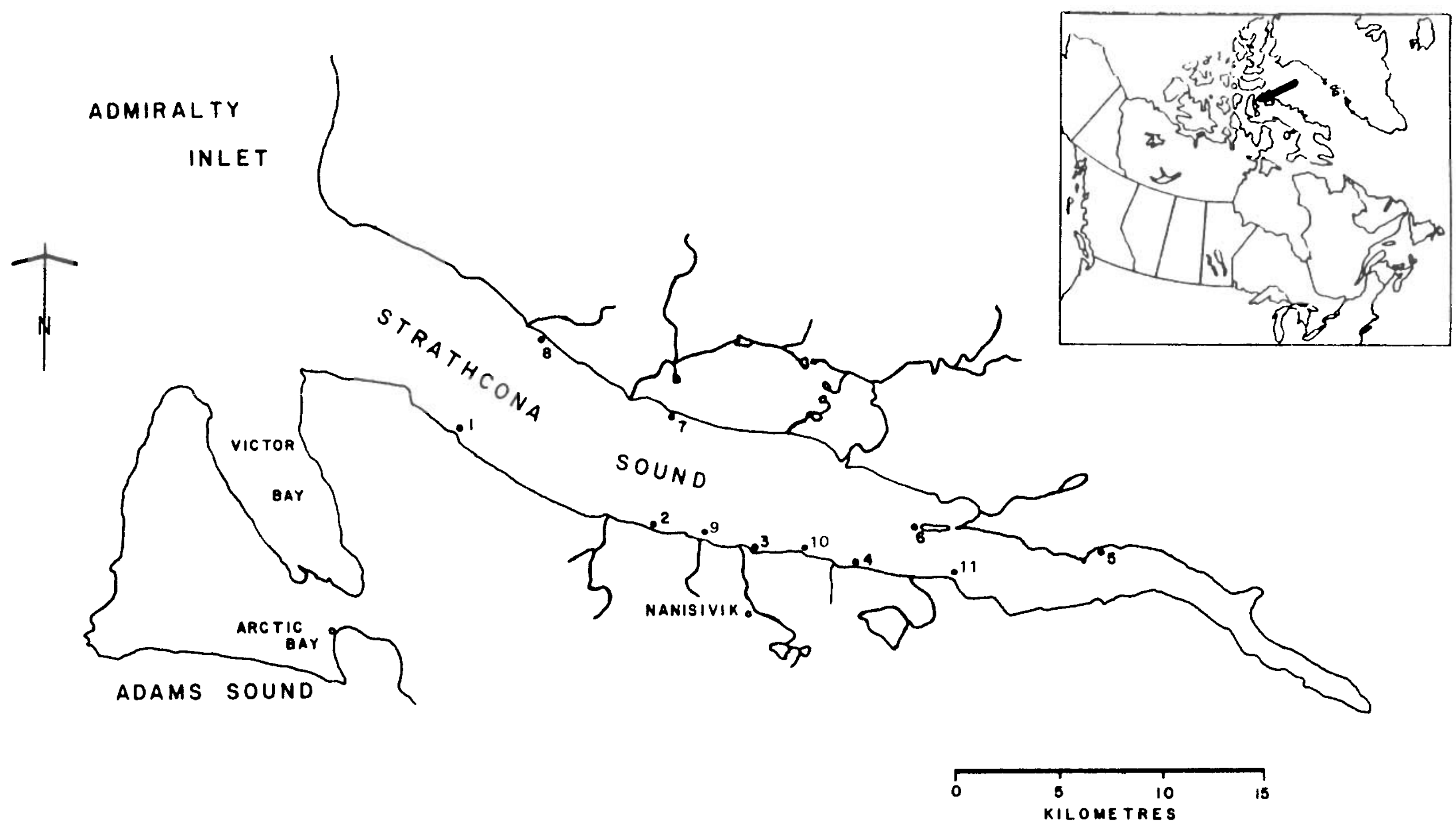

Figure A9. Sites in Strathcona Sound sampled by the Department of Fisheries and Oceans in 1979 (1-8), 1980 (1-8), 1981 (1-4, 9-11) and 1984 (1-4, 9-11) (B.W. Fallis pers. comm.)

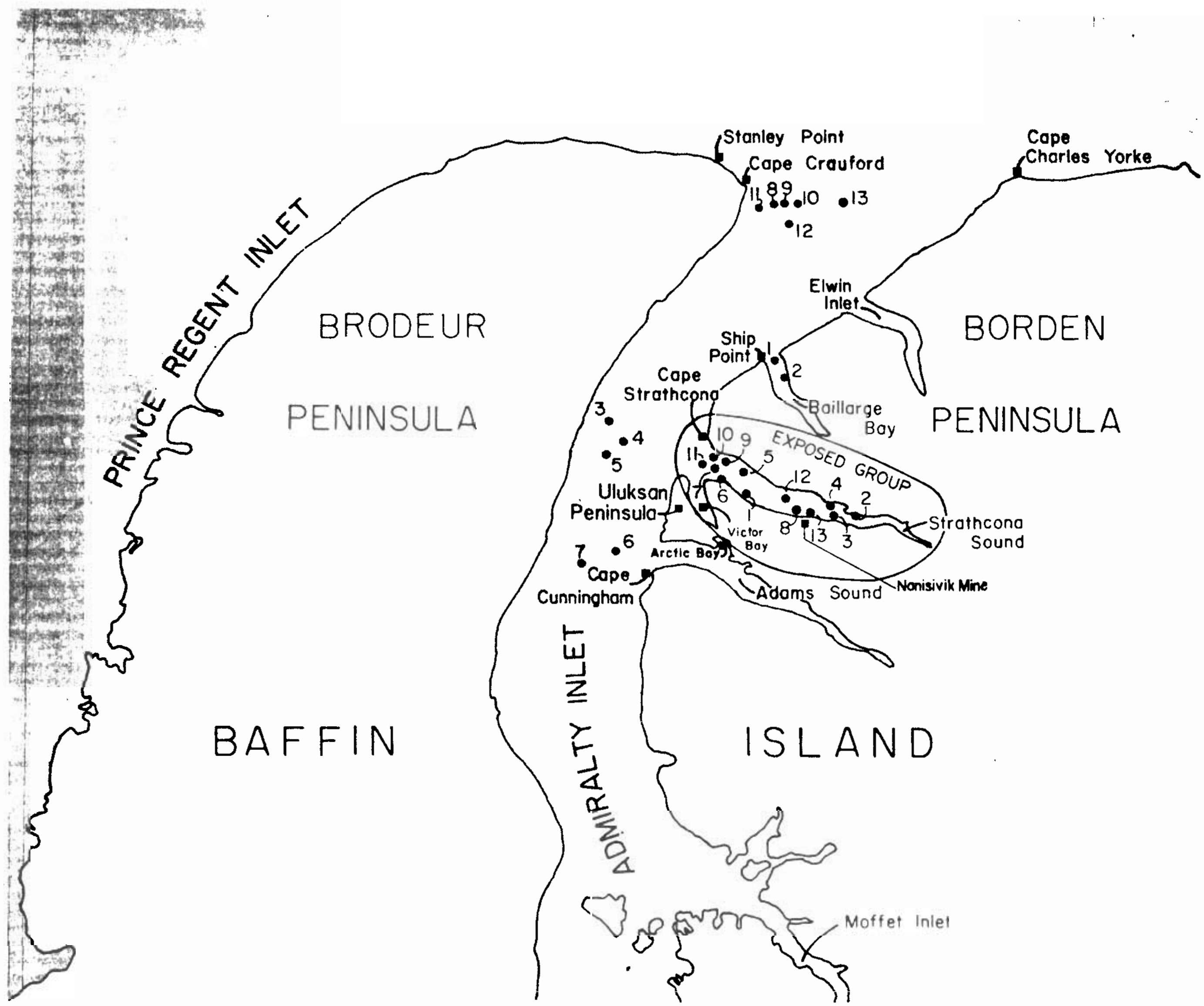

Figure A10. Locations where the ringed seals analysed for heavy metals by Wagemann were collected in April and May 1983 (from Wagemann 1989). The exposed group is within the circle, and the reference group is outside the circled area.

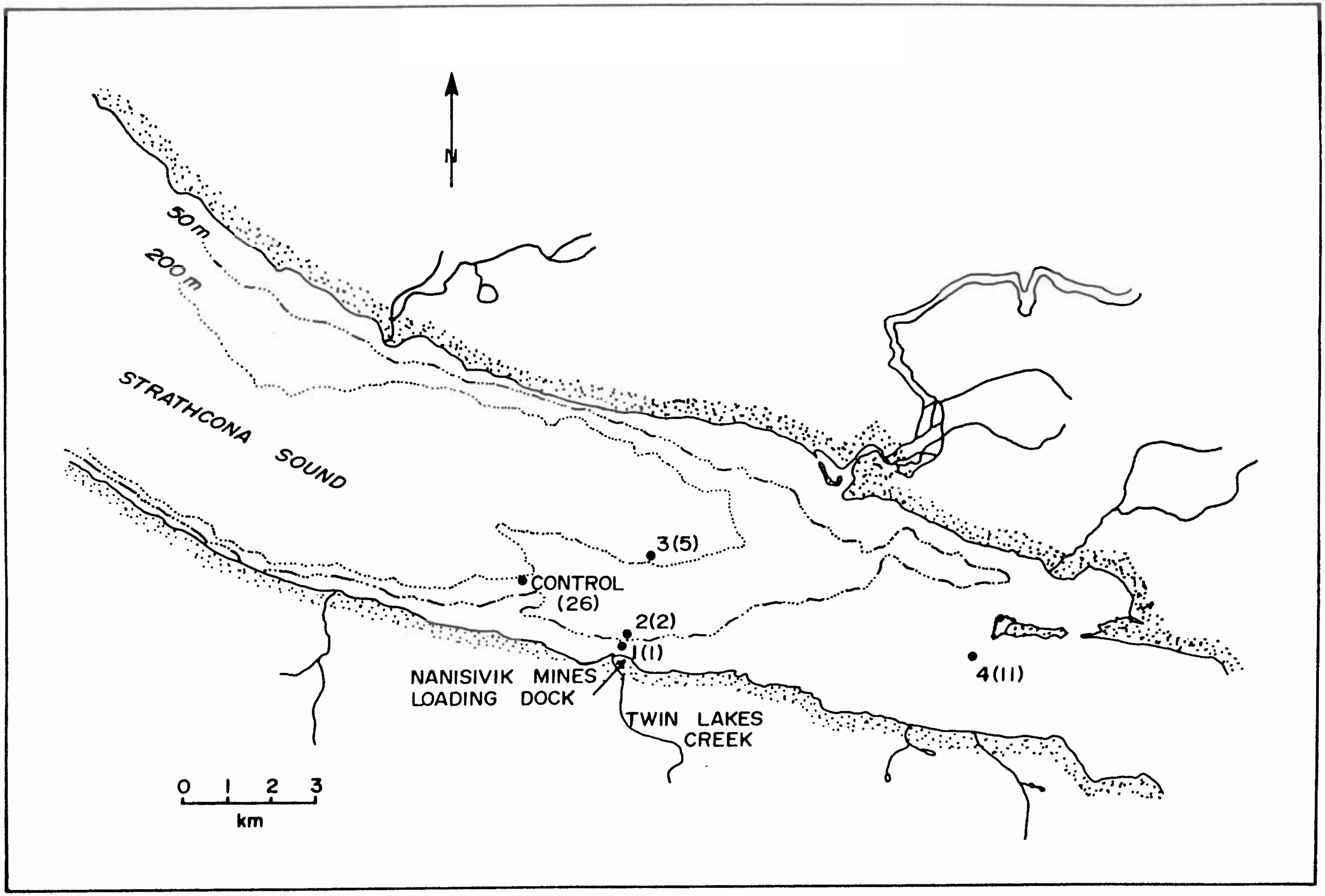

Figure A11. Sites in Strathcona Sound sampled in December 1984 and June 1985 by Arctic Laboratories Ltd. (from Arctic Laboratories Ltd. 1986).

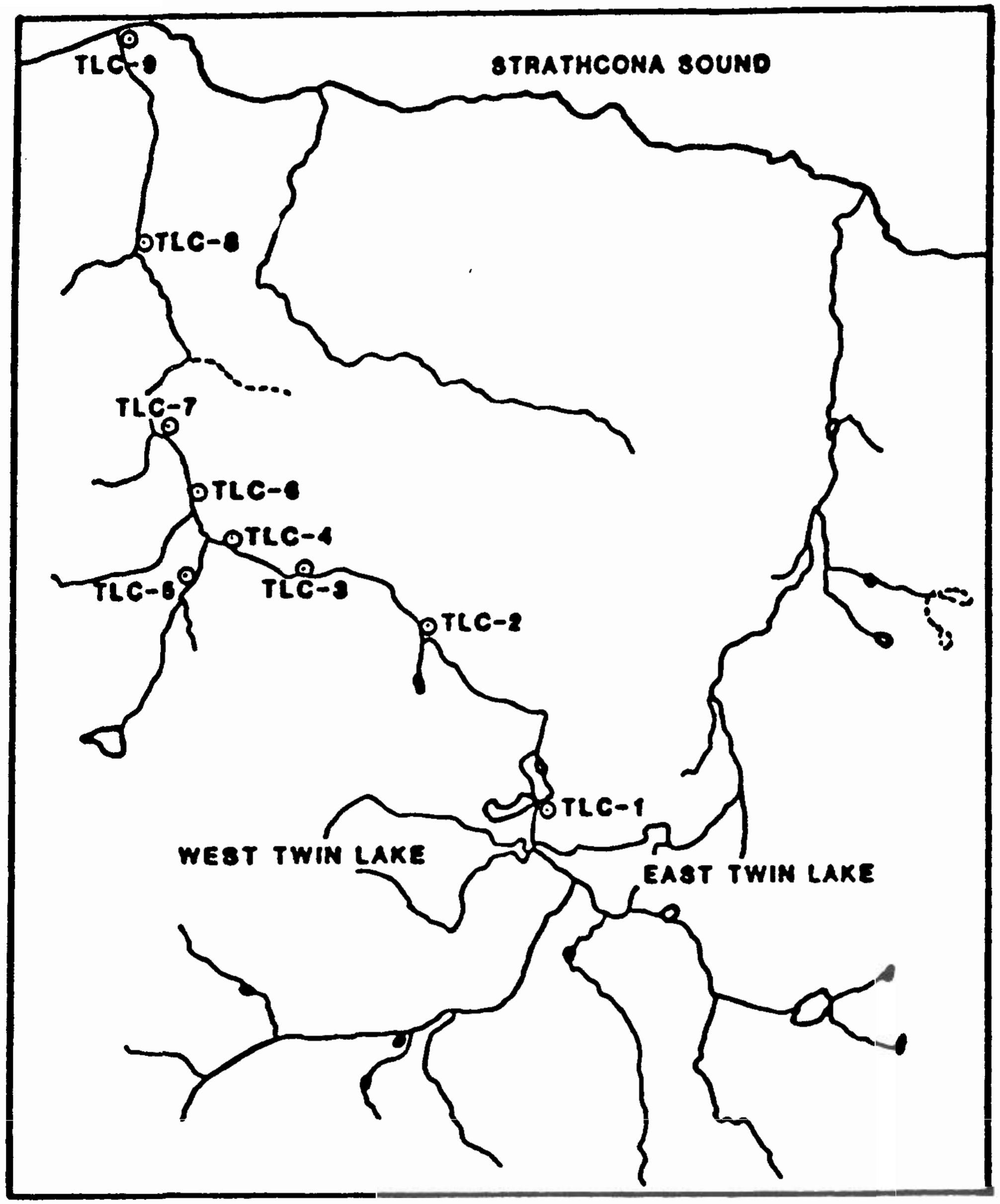

Figure A12. Water quality sampling stations for the Nanisivik Monitoring Program 1981-84 (from Grey 1989).

APPENDIX 2. BIBLIOGRAPHIC DATABASE FOR NANISIVIK MINE ON PROCITE SOFTWARE

This appendix is located on a computer disk at the back of the report. Its purpose is to facilitate searches for information on the Nanisivik Mine and its natural setting. It consists of a searchable bibliographic database (NANMINE.* files) in Procite (Ver. 2.0), a Pro-cite punctuation file (DFO.pnc) that can be used to print records in DFO format, and a listing of library codes in WordPerfect 7.0, which appear in the bibliographic records and can be used to locate copies (LIBRARY.lst).

To use this database you will require Pro-cite Version 2.0 (DOS) or later. Macintosh computers will require a "superdrive" that is capable of reading DOS files. The database can be edited or added to. Detailed user instructions are contained in two earlier reports:

Stewart, D.B. and B.E. Stewart. 1995. A bibliographic database for the proposed North Baffin National Park. Arctic Biological Consultants, Winnipeg, MB for Parks Canada, Ottawa, ON. ii + 14 p. + 3 disks.

and

Stewart, D.B., B.E. Stewart, and R.A. Ratynski. 1996. A bibliographic database for coastal zone planning in the Cumberland Sound and Yukon North Slope areas of Arctic Canada. Arctic Biological Consultants, Winnipeg, MB for Parks Canada, Ottawa, ON. ii + 15 p. + 3 disks.

Copies of both reports are archived in the Eric Marshall Library at the Department of Fisheries and Oceans (Freshwater Institute) in Winnipeg, MB; at the Department of Fisheries and Oceans office in Iqaluit, NT; at the Arctic Institute of North America Library, in Calgary, AB; and the Scott Polar Research Institute Library in Cambridge, England.