2. SITE CHARACTERIZATION

The purpose of this section is to summarize key information relevant to developing a study design for the Polaris Mine. This information will include:

- Regulatory requirements under various federal and territorial jurisdictions.
- General site characteristics.
- Hydrology and effluent mixing.
- Anthropogenic influences.
- Aquatic resources characteristics.
- Mining operations and environmental protection practices.

Results of historical investigations at the site have been incorporated throughout the document to provide supporting information and rationale to justify various approaches, methods and alternatives to our environmental sampling and study design.

2.1. Regulatory Context

The Polaris Mine site is located on land leased from the Federal Government. The land leases expire in 2011. Use of fresh water at the mine (e.g., withdrawn from Frustration Lake for domestic use and tailings transport) is regulated by the Nunavut Water Board though issuance of a Class A Water License. The current Water License came into effect on March 1, 2003 and expires on December 31, 2011. As the Polaris Mine was in commercial production when the new MMER came into effect, the regulations apply to the mine. Polaris ceased commercial production September 3, 2002 and is currently undergoing decommissioning and reclamation activities. The Polaris Mine notified the Environment Canada Authorizing officer of cessation of commercial production in December 2002. Decommissioning and reclamation activities are outlined in the report 'Polaris Mine Decommissioning and Reclamation Plan – March 2001' (the 'Closure Plan'; Gartner Lee, 2001). The Nunavut Water Board and DIAND jointly approved the Closure Plan. A portion of the work identified in the Closure Plan includes decommissioning Garrow Lake dam, the marine dock and adjacent foreshore areas in Polaris Bay. This work will be done under Section 35(2) Fisheries Authorization to be issued by DFO, Iqaluit (Appendix D). Once decommissioning and reclamation work is completed in the fall of 2004, the only activity at the site will be regular monitoring as required under the MMER (the summer of 2005) and the Closure Plan approvals (annually until 2011).

2.2. General Site Characteristics

The intent of this section is to describe the major physical/chemical and biological features of each of the four major environments of the study area: Garrow Lake, Garrow Creek, Garrow Bay and a marine reference area.

2.2.1. Local Climate and Oceanography

Polaris Mine (75°23'N 96°50'W) is situated on the south end of Little Cornwallis Island, Nunavut, in the high Arctic. This region is characterized by short, cold summers and extremely cold, long and dark winters. Mean average air temperature is –8°C with an average of 8 frost-free days annually. Precipitation is very low and is typical of desert conditions with only 25 cm of annual precipitation, most of this as snowfall. Winds are strong and predominantly from the north or north-north east with an average wind speed of 20 kph. Maximum wind speed between 1961 and 1991 was 105 kph (Gartner Lee, 2001).

Oceanographic conditions of the marine environment in this region are poorly known. Tides are semi-diurnal with an amplitude of less than one meter. Currents are very strong in Crozier and Pullen Straits causing a counter-clockwise gyre within Garrow Bay as water is pulled west and south. Break-up of the ocean typically occurs in July with freeze-up in September. During summer, however, Crozier and Pullen Straits (Figure 1-1) are filled with drifting ice that frequently accumulate in Garrow Bay, and in some years, does not leave the bay at all. In some years, the local lakes can remain ice covered year-round.

Given the unique features of Polaris, a number of difficulties have been encountered by previous researchers that may influence the success and/or quantity and spatial coverage of data acquired. A summary of these is as follows:

- Shifting ice pans in Garrow Bay frequently clog the bay and in some years there is no reliable open water, which makes working from a boat extremely difficult. In previous investigations, boats were hauled over ice pans or driven into leads to find open water through which to drop a grab sampler.
- The bottom is hard and scoured to a depth of approximately 3 – 5 m and up to at least 300 m offshore, with a patchy, heterogeneous mixture of fine sediment (sand, silt) and gravel/cobble, making sampling of infauna difficult.
- Winds and rough weather frequently hamper researchers working on the water, prevent sampling, or make sampling efforts dangerous.

- Because of difficulties working on the water, several studies have been conducted in May, through the ice. However, at this time of year, there has been no effluent discharged for several months. In addition, there are many logistical difficulties posed by through-ice operations. As well, the ability of divers to capture fish from a sufficiently wide spatial area working through a small hole in the ice is very limited.
- Walrus have been known to be very aggressive and force divers out of the water in a previous survey.

2.2.2. Garrow Lake

Garrow is a small, meromictic lake with a surface are of 4.18 km^2, a maximum depth of 49 m (Fallis et al., 1987) and unique limnological characteristics. The lake is situated in an area of continuous permafrost and is ice-covered for much of the year and in some years, does not thaw at all. The lake slopes steeply from the narrow littoral zone into the anoxic, hyper-saline profundal zone within tens of meters from shore (Figure 2-1).

The drainage area of Garrow Lake is very small and is only double the surface area of the lake. Annual precipitation is extremely low, approximately 250 mm per year, with 50 mm falling as rain, and the remainder as snowfall. This, combined with the small drainage area means that total annual discharge from the lake is correspondingly small.

Surface water of Garrow Lake is brackish (6 to 8 ppt) and extends to a depth of about 10 m where the pycnocline (salinity/temperature barrier) is encountered. Limnological studies conducted on the lake indicate that water temperature (9.5°C at 20 m) and salinity (88 ppt or nearly three times marine water salinity in Garrow Bay) rises rapidly at greater depths just below the pycnocline and more slowly towards the bottom (BC Research, 1975; Ouellet and Dickman, 1984; Fallis et al., 1987). This salinity/temperature barrier separating surface (epilimnion) (<12 m) and deep (>14 m) water of Garrow Lake effectively prevents mixing of the surface and bottom layers. Because the deep layer (the monimnolimnion) is anoxic, hypersaline and contains high hydrogen sulphide concentrations, there are no living biota in the water column and only a few sulphate reducing bacteria species living in bottom sediments.

The unique limnological properties of the lake have provided a convenient, but effective location to store thickened mine tailings since this practice began when the mine commenced operations in 1981. During mine operations, thickened tailings were discharged directly into the monimnolimnion of Garrow Lake at depths below 26 m via a pipe that was moved around the lake to more evenly disperse tailings over the bottom. This system was very effective the majority of the time, except for an incident in 1984/85 where a failure of the pipe resulted in tailings discharge into near-surface waters of

Garrow Lake. The result of pipe failure was an increase in dissolved zinc concentrations in surface waters that persist to the present time and are slowly diminishing.

In 1989/1990, Cominco constructed a dam across Garrow Creek, about half way between the outlet and the mouth to raise the water level of Garrow Lake to dilute surface waters and to increase the depth of the epilimnion. Since the spill, zinc concentrations in surface waters have been slowly declining. The slowness of the decline is due to the very small drainage area of the lake and its slow replacement or turnover time, resulting in minimal dilution of surface water.

Mixing of the freshwater used to entrain the tailings with the hypersaline water of the monimnolimnion has resulted in a more homogeneous body of water below the halocline and a gradual displacement of the halocline upwards in the water column. It is predicted that once the lake is drawn down to its original level in 2003, the depth of the epilimnion about the pycnocline will diminish to 7.5 m. However, given the magnitude of the thermal and salinity difference between the epilimnion and the monimnolimion in the lake, Gartner Lee (2001) predicted that the integrity of density layers within lake will not be compromised over the long-term, once the dam in Garrow Creek is removed.

Tailings were discharged to Garrow Lake year round during mine operations. This, combined with increased lake levels due to precipitation (primarily in winter) and runoff due to snow melt in spring cause surface waters to decant from the lake into Garrow Creek. Discharge of surface waters from Garrow Lake into the creek normally take place over an eight to ten week period (Figure 2-1) beginning shortly after break up on the lake and thawing of the stream channel. Between 2001 and 2003, the lake level is being drawn down by pumping water over the dam, prior to its removal. Consequently, the volume of water discharged from Garrow Lake in 2002 and 2003 is greater than historic values. Normally, the net increase in water level of Garrow Lake between spring highs and winter lows is about 1 m. In 2003, Garrow Lake will be drawn down about 2 m.

Garrow Lake continues to be recognized as a Tailings Impoundment Area by the current MMER.

2.2.3. Garrow Creek

Garrow Creek is 1.4 km in length between the outlet at Garrow Lake and the creek mouth at Garrow Bay. A dam constructed 700 m downstream of the natural outlet of Garrow Lake in 1989/89 raised water level in Garrow Lake by about 2.5 meters. This was accomplished to diminish surface water zinc concentrations in Garrow Lake by increasing depth of the epilimnion to provide increased stability in the lake and eliminate the possibility of mixing of the monimnolimnion and the epilimnion (see Section 2.2.2;

Gartner Lee, 2001). Currently, zinc concentrations in Garrow Creek (the effluent stream) average about 0.12 ppm (Table 2-1). The permit limit for zinc in the discharge stream, established in 1992, is 0.5 ppm. Note that the maximum zinc concentration for protection of aquatic life in marine environments in British Columbia (BC) (chronic exposure) is 0.086 ppm (BCE, 1998).

Prior to installation of the dam, flow in Garrow Creek was ephemeral with discharge typically occurring over an eight to ten week period beginning in mid-June, once the stream mouth and channel have thawed. Stream flow began with melting and freshet, which lasted about three weeks (0.5 – 1.5 m^3/sec) before rapidly diminishing to relative low discharge volumes (0.10 m^3/sec) for the remainder of the summer/fall until freeze-up in early September (Figure 2-1). Average discharge during the open water period ranged from 0.2 to 0.3 m^3/sec.

After completion of the dam, the lake level was allowed to rise between 1990 and 1993 without being discharged. Beginning in 1994, stream discharge and lake level was controlled by active pumping of water over the dam into Garrow Creek between mid-July and mid- to late September (Table 2-2). Because water was actively siphoned over the dam, discharge was relatively constant throughout the discharge period. Total volume discharged depended upon the number of siphons working and the number of days that siphoning occurred, which was dictated by the volume of water that was required to discharge from Garrow Lake to reach the desired lake elevation. Between 1994 and 1999, mean discharge rate ranged between 0.19 m^3/s and 0.55 m^3/s (note that the total annual volume of water pumped was relatively constant). In 2000, annual average discharge was increased (0.68 m^3/s) to begin drawing down the lake over a three year period. Predicted discharge volume and rate in 2003 is predicted to be 6.5 million m^3 at an average discharge rate of 1.25 m^3/sec (J. Knapp, Polaris Mine Manager, personal communication, June 10, 2003). This rate at considerably higher than historic discharge rates (Table 2-2).

Garrow Creek flows through a very wide (10 m) and shallow (10 cm) channel over much of its length, discharging through the gravel and boulder bottom before reaching Garrow Bay. There are no fish and very few benthos inhabiting the stream as it basically functions as a channel between the lake and the marine environment.

2.2.4. Garrow Bay

Garrow Bay is situated directly offshore of Garrow Creek, east of the Mine Site and Crozier Strait. Relatively little is known about the physical/chemical and oceanographic conditions of the bay because of its remote location and the logistical difficulties of working in this environment. The bay is ice covered virtually the entire year, with the exception of unpredictable periods during a few weeks in August and early September, prior to freeze-up. Wind driven ice pans frequently move in and out of the bay, effectively preventing reliable open water conditions during the open water season. The remainder of the time, the marine environment is frozen, with maximum ice thickness of about 2.5 m in May.

Detailed bathymetry of Garrow Bay is unknown. The hydrographic chart and various field projects indicate that the depth of the bay increases slowly from the intertidal region to the 5 m depth contour, about 300 m offshore and continues to increase at about the same rate, reaching 10 – 12 m depth at least 500 m offshore, eventually reaching 340 m in Crozier Strait.

Garrow Bay is subject to regular semi-diurnal tides with an amplitude of 0.8 m. There are also strong ocean currents that run north-south through Crozier Strait, and past the Mine Site and Garrow Bay (Leblond, 1980; Melling, 1997). Although no information on current velocity exists for Garrow Bay, observations made by divers and in various field investigations indicate that current velocity is moderate and the flow is counter-clockwise, running from east to west along the shore. This suggests a back-eddy effect in the bay that is caused by the stronger north-south currents of Crozier Strait. In addition, wind driven currents in Garrow Bay will further contribute to horizontal and vertical mixing of water.

Given the harsh climate, unpredictable ice conditions, currents, tides, hardpan bottom and other logistical problems, there is relatively little known about the ecological resources in Garrow Bay. However, based on dive surveys, the bay appears to have a reasonably abundant and diverse benthic community. To our knowledge, no benthic infauna surveys have been conducted in the bay, however, abundant clam beds, which have been observed in deeper water (>7 to 8 m), have been sampled several times in the past (Table 2-3). Walrus use these clam beds for feeding. From an ecological relevance perspective then, clams would make an ideal candidate for monitoring purposes, especially because they are bottom dwelling, sessile filter feeders and are most likely to be affected mine-related contaminants if present.

Very little is known about the abundance, distribution and species composition of fish in Garrow Bay. During the 25 year history of environmental studies at the Polaris Mine, only 10 sculpins have been collected from the bay and not more recently than the 1974 BC Research (1975) survey. Review of documents and dive video surveys indicated that sculpins are not abundant in Garrow Bay, and seem to be more abundant in Polaris Bay. The only other fish species observed in dive videos were unidentified snail fish (*Liparis* sp.) and prickleback (F. Stichaeidae).

Metals (cadmium, copper, lead, zinc) concentrations in water, sediment and clams from Garrow Bay are low and do not appear to have changed between the 1970s, prior to mining and 1999, just before mining ceased (Table 2-3). Metals concentrations in water and sediment are well below environmental quality guidelines for the protection of aquatic life (BCE, 1998; CCME, 1999) and are in the range of background data for open ocean levels from published data elsewhere in the Arctic.

This area is also frequented by Atlantic walrus (*Odobedon rosmarus*) as part of the North Water (Baffin Bay – Eastern Canadian Arctic) stock. The North Water (NW) stock has its main summering grounds along the southeast coast of Ellesmere Island, Jones Sound and along the north shore of Lancaster Sound (Born et al., 1995). Small groups of this stock are known to summer as well as overwinter, in polyna's (i.e., areas of open water surrounded by ice) along the east coast of Bathurst Island, near Crozier Strait. Walrus have been observed feeding, presumably on clams, in the vicinity of Garrow Bay and Polaris Bay.

2.2.5. Reference Area Environment

According to Environment Canada (2002), an appropriate reference area for EEM biological monitoring studies includes the following features: located adjacent to the exposure area, not exposed to effluent, and has similar hydrology, habitat and fish species as the exposure area. In addition, historic data should be considered as part of the temporal history of the region when selecting a reference area. Note that logistical considerations such as access must also be taken into account.

Considering the above, Tigumiavik Harbour has been selected as the reference area for the Polaris EEM program. Our rationale is as follows:

- Tigumiavik Harbour is adjacent to Garrow Bay and therefore subject to the same oceanographic and hydraulic influences.
- It is sufficiently removed from Garrow Bay so that it is unlikely that a fish such as sculpin would move between the bays.
- General bathymetry and aspect are similar, although Tigumiavik Harbour is more enclosed than Garrow Bay.
- Sediment grain size and metals concentration of both bays appears to be similar (Axys, 1991).
- Tigumiavik Harbour has been sampled in the past, so there is useful historic data from which to draw.
- Tigumiavik Harbour is the nearest bay to the Mine Site, making access relatively easier, although it is still difficult to access because of the absence of roads, reliable vessels and problems with ice.

2.3. Hydrology and Effluent Mixing

2.3.1. Effluent Discharge

The effluent stream of the Polaris Mine basically consists of decant flow from Garrow Lake via Garrow Creek that discharges directly to the marine environment at Garrow Bay (Figure 1-2). There is very little dilution of the effluent stream between the final discharge point in Garrow Creek (currently at the dam, 700 m upstream of the mouth) and the stream mouth. Therefore, the effluent stream reaching Garrow Bay basically consists of Garrow Lake surface water.

The volume of water discharged to Garrow Bay by the creek is highly dependent on year (Table 202), precipitation timing of freshet, with maximum volumes discharged from the lake soon after the outlet and creek channel become ice-free. Prior to installation of the dam in Garrow Creek, stream flow was ephemeral with discharge typically occurring over an eight to ten week period between late July and mid September. Maximum discharge at freshet has historically ranged from 0.5 – 1.7 m^3/sec before rapidly diminishing to relative low discharge volumes (0.10 m^3/sec) during the remainder of summer/fall, until freeze-up in late September (Figure 2-1; Teck Cominco flow records). Note that this flow volume would be slightly higher than pre-mine conditions because stream outflow also includes the amount of water displaced by the annual volume of mine tailings deposited to the bottom of Garrow Lake.

After the dam was installed in 1990, there was no discharge from the stream until 1994, once lake level had risen sufficiently. Between 1994 and 2000, discharge to Garrow Creek was accomplished by siphoning water over the dam at a rate of between 0.35 and 0.55 m^3/sec (Table 2-2). This volume was equivalent to the volume of tailings discharged to the lake and natural inflow from precipitation and snow melt.

Between 2001 and 2003, the lake is being actively drawn down to return the lake to its original, pre-dam elevation. In 2003, to achieve historic lake level, this requires siphoning at a mean rate of 1.25 m^3/sec, which is three to five times greater than historic rates. It is expected that once the dam is removed and the lake has returned to its original level, that discharge from Garrow Lake to Garrow Bay will return to pre-mine discharge volumes.

2.3.2. Receiving Environment Conditions

Little is known about oceanographic conditions and hydrology of Garrow Bay except on a large scale, and few quantitative data exist. During winter, the entire area is ice covered (from mid-September through July or August) and water temperature is uniformly homogeneous from top to bottom (-1.78 °C) with a uniform salinity of 33 ppt (parts per thousand) (Axys, 1991), which is typical of Arctic water. During open water in Garrow Bay in September, surface water (0 – 10 m) was slightly warmer (about 1°C warmer) and slightly less saline (1.5 ppt) than water below the pycnocline. It should be noted, however, that "open-water" is not necessarily guaranteed at Polaris. For example, during the BC Research (1975) field studies in 1974, there was no open water on Garrow, Frustration and Lois lakes, Garrow Bay and North Bay. Crozier Strait and Polaris Bay were fraught with drifting ice that sunk the research vessel, limiting the researchers to a sampling from a small dinghy that was not suitable for working on the ocean. These conditions make for very difficult sampling conditions and pose logistical challenges. These factors have probably played a major role in why there is so little information on this area – it is difficult to acquire.

Crozier Strait is very deep (>350 m) and is one of the major channels through which Arctic water flows as part of the global conveyor system (Leblond, 1980; Melling, 1997). Local tidal movements of water likely play a minor role in oceanographic conditions in the vicinity of the Polaris Mine, by virtue of the relatively small tidal amplitude of 0.8 m. Rather; ocean currents dominate water movement via the north-south transport of water through Crozier and Pullen straits. The movement of water through Crozier Strait causes a counter-current movement of water in Garrow Bay (BC Research, 1975) that tends to draw effluent from Garrow Creek along shore in a westward direction.

Wind can also play a major role in horizontal and vertical mixing of the water column. Average wind speed at Polaris is 20 kph and is predominantly from the north and north-north-east (Gartner Lee, 2001). Storms and high wind events are frequent and will cause strong mixing, especially during open water or low ice conditions.

The combination of ocean currents, tidal movements and wind will generate strong mixing currents in the marine environment of Garrow Bay. No information exists on how the brackish water outflow from Garrow Creek mixes with marine water of Garrow Bay.

2.3.3. Plume Delineation at Polaris and Ecological Relevance

To date, no quantitative oceanographic studies have been undertaken at Polaris to determine the spatial extent of a plume from Garrow Creek into Garrow Bay. However, limited water quality sampling was conducted in Garrow Bay during effluent discharge in September 2001. On September 7, 18 and 21, water samples were collected from the surface and 1 m deep 200 m offshore of Garrow Creek, and 200 m east and west of the creek mouth in Garrow Bay. Water depth was 2 to 3 m 200 m offshore (J. Knapp, Polaris Mine Manager, personal communication, June 2003).

Mean zinc concentration in effluent was 180 μg/L in September. Note that the BCE (1998) guideline for zinc in marine water is 86 μg/L (Table 2-2). Two hundred meters offshore in Garrow Bay, zinc was below detection (<0.5 μg/L) at most stations. On September 7 and 18, zinc concentration in surface water was above detection (33 μg/L along the west shore on September 7 and 12 μg/L along the east shore on September 18) but below detection at other locations at surface and at all locations at 1 m depth. These values are less than 1% of zinc concentrations in Garrow Creek. A similar pattern was seen on September 21, as zinc ranged from 9 to 23 μg/L in surface water, 200 m offshore of the creek, but below detection elsewhere and at 1 m depth. These data illustrate that a small plume exists in Garrow Bay that is restricted to surface waters and is diluted to less than 1% of creek concentrations within 200 m from shore. All concentrations measured were well below BCE guideline for the protection of aquatic life.

In spring 1991, the physical properties of Garrow Lake water (i.e., effluent) were examined relative to water from Garrow Bay and subjected local marine epontic (i.e., under-ice) amphipods collected from Garrow Bay to water from Garrow Lake. This was conducted at a mobile laboratory set up on the bay to investigate the toxicity of effluent from Garrow Lake (Chapman and McPherson, 1992; 1993). Effluent was also returned to the EVS Environment Consultants laboratory in Vancouver, BC for toxicity testing using standard organisms: amphipods (*Rhepoxinius abronius*) oyster (*Crassostea gigas*), blue mussel (*Mytilus edulis*) and sea urchin (*Strongylocentrotus purpuratus*).

Adult and juvenile amphipods showed no toxicity (i.e., 100% survival) in any of the tests when exposed to 100% effluent with a zinc concentration of 0.36 mg/L and lead of 0.0052 mg/L. In addition, effluent and lake water were spiked with zinc to concentrations of up to 11.8 mg/L and still no toxicity was observed in any of the test organisms. These results led Chapman and McPherson (1992) to conclude, "undiluted Garrow Lake surface waters are not acutely toxic to resident arctic marine fauna. Furthermore, the species tested showed no evidence of distress even when exposed to well over 10X the zinc concentrations and 100X the lead concentrations presently found in Garrow Lake surface waters or to Garrow Lake chemocline waters". In the laboratory oyster showed some effects at concentrations similar to undiluted Garrow Lake surface waters, but those effects were exacerbated due to higher water temperatures in test chambers than ambient water and high bacterial populations in surface waters of Garrow Lake. Invertebrates exposed to effluent were surprisingly intolerant to the lead and zinc concentrations found in effluent (Chapman and McPherson, 1993).

In the absence of quantitative plume delineation data, Sea Science, Vancouver, BC has been commissioned to conduct a theoretical modeling study of oceanographic conditions in Garrow Bay. The modeling study will involve acquiring all relevant physical and chemical oceanographic data as well tide and current data to allow a semi-quantitative evaluation of the spatial bounds of the effluent plume in Garrow Bay. Conducting a dye study in 2003 would provide a snapshot perspective of a plume that has no relevance to discharge patterns from Garrow Creek after 2003.

The effluent stream from Garrow Creek appears to mix quickly and on the surface of Garrow Bay, largely because of the temperature/salinity difference and was not detected below surface depth, although empirical data are limited. The slightly warmer, less saline water from Garrow Creek forms a discrete layer on top of the marine water that disperses outwards into the bay. Water movements caused by tides, ocean currents, ice and wind will affect the shape and integrity of the "plume". Given that zinc and occasionally lead, are the only parameters to exceed ambient water quality guidelines for the protection of aquatic life (BCE, 1998), zinc, as well as conductivity, do provide good tracers. Although data are limited, zinc concentrations in the receiving environment quickly fall below the BCE (1998) guideline criterion because of the large and rapid dilution. Also, as shown above, Chapman and McPherson (1992) demonstrated no toxicity of undiluted Garrow Lake water to receiving environment organisms in Garrow Bay.

Based on available information as well as data that will be generated by the theoretical plume modeling study, we do not recommend that detailed plume delineation work be conducted in summer 2003 for the following reasons:

- In 2003 Garrow Lake is being actively drawn down and discharge is expected to be several times greater than historic values and will not represent typical or on-going flow conditions.
- Long-term discharge patterns from Garrow Lake are going to be encountered in 2004, in the absence of influence from the dam and from input of mine tailings. If a plume delineation study is warranted at all, data collected in 2004 will support the most realistic or typical exposure scenario.
- The average discharge volume of Garrow Creek (1982 – 1989 data) is <2.5 million m^3, which is very small relative to the tidal movement of water into and out of Garrow Bay (10.5 million m^3 of water) on a single day (Chapman, P.M., Letter to Cominco, August 2000).
- The brackish effluent entering the marine waters of Garrow Bay will be restricted to surface waters and is unlikely to contact benthic organisms at depths > 5 m, where biota are first encountered.
- The ice scoured, rocky shore to at least 200 m offshore of Garrow Bay contains no depositional areas and few resident biota. The nearest area to the creek where historic studies were able to collect sediment and/or biota is expected to be outside the influence of the plume.
- Tides, currents, winds and ice movements apparently rapidly mix effluent shortly after entering Garrow Bay (see above).

- The effluent has been demonstrated not to cause any toxicity to local biota (Chapman and McPherson, 1992).
- There is an existing aquatic community residing in 100% "effluent" in Garrow Lake.

Knowledge of the spatial extent of the surface water plume will not assist in station selection for biota sampling in 2004. Because of local substrate and oceanographic conditions, stations will be selected based on where environmental media can be collected and will not be dependent on results of a plume delineation study.

Overall, it is expected that results of the theoretical modeling study will provide better information on the spatial bounds and confidence limits of the effluent plume in Garrow Bay than a dye survey, especially in light of the unusual flow conditions expected in 2003.

2.4. Anthropogenic Influences

Other than the mine effluent discharge, there are no substantial anthropogenic influences to the receiving environment of Garrow Bay. The Polaris Mine is located far away from any other industrial activity and is not situated near any shipping route. The only possible impact to the receiving environment is episodic passage of bulk carriers moving into or out of Polaris Bay during transport of equipment and goods to Polaris or transporting ore concentrate. These activities take place only during summer months when ice conditions permit.

There has been no known historic or traditional use of local aquatic or terrestrial resources by residents of Resolute Bay (Gartner Lee, 2001).

2.5. Aquatic Resource Characterization

The purpose of this section is to describe known features of aquatic biological communities of Garrow Lake, Garrow Creek and Garrow Bay from historic studies conducted prior to and during mining activities. Because of the severe Arctic climate at Polaris, the abundance and distribution of aquatic resources is strongly affected by physical features including ice, currents, tides, substrate, temperature and salinity. Also, each of the areas discussed (Garrow Lake, creek and bay) are inherently very different and will have naturally different aquatic communities. Sampling and understanding of aquatic communities has been hampered by the severe climate of the high Arctic.

2.5.1. Garrow Lake

Garrow Lake is currently designated as a Tailings Impoundment Area by the MMER and has been the recipient of mine tailings since the mine began operations in 1980. Tailings were deposited into the monimnolimnion, below the biologically active zone (the epilimnion), with the exception of the pipeline break in 1985. Notwithstanding this, surface waters of Garrow Lake appear to continue to support aquatic communities, including fourhorn sculpin (*Myoxocephalus quadricornis*), 40 species of phytoplankton, a single species of zooplankton (*Limnocalanus macrurus*) and a benthic community consisting of nematodes, oligochaetes (true worms), polychaetes (presumably marine relic species that have survived because of the brackish water), small bivalve clams, chironomids, mysids (*Mysis oculata*), ostracods, harpacticoid copepods and foraminiferans (Fallis et al., 1987). Sculpins continue to be observed in the lake (Gartner Lee, 2001; W. Gzowski, Arctic Divers Ltd., Yellowknife NWT personal communication, May 5, 2003). The species composition and abundance of aquatic biota do not appear to have changed since quantitative studies were first undertaken in 1974 (Gartner Lee, 2001).

The sculpin community of Garrow Lake is unique and has survived in this small, brackish water lake since glacial uplift isolated it from the marine environment nearly 3,000 years ago. Fallis et al. (1987) conducted a detailed biological investigation of the lake and sculpin biology (length, weight, growth, age, metals) in particular in 1976, prior to mining. All 51sculpins captured were acquired from above the pycnocline and none were found below 13 m. Fourhorn sculpins are small (12 – 19 cm) with an average weight of only 29 g. In 1978, BC Research captured 137 sculpins, ranging in length from 2 to 17 cm. BC Research (1978) stated that sculpins were ubiquitous throughout the lake and appeared to be very abundant and easily captured. The dominant dietary item identified in the gut of sculpins in both studies was zooplankton, which is not typical for this species (Scott and Crossman, 1979; Scott and Scott, 1988). Other material identified were eggs (sculpin eggs?) a few amphipods and plant material.

Fallis et al. (1987) examined 27 sculpins for maturity and found that no fish were sexually mature. Of the 22 females examined, 12 had developing eggs and would have spawned several months later, probably during late fall or early winter. According to Scott and Scott (1988), spawning is variable and may take place in fall or early winter; in Tuktoyaktuk Harbour, spawning extended until March. Very little is known about the biology of this species, especially in Arctic waters.

Metals concentration was documented for sculpin fillets, livers and whole fish by Fallis et al. (1987) and in whole fish by BC Research (1978). The range in metals concentration was similar among studies.

According to requirements under the DFO Fish Habitat Authorization permit (Appendix D), Teck Cominco is required to collect sculpins from Garrow Lake for analysis of metals. Sculpins have not been collected from Garrow Lake since the 1977 BC Research study, so data acquired from 2003 will provide valuable information from a number of perspectives. Given that fourhorn sculpins appear to have survived and reproduced within the lake during the period of tailings discharge, documenting life history characteristics (length, weight, age, reproductive status) and tissue metals concentrations will provide contrasting data to the pre-mine period. Subsampling of a small number (10 – 15) of sculpins for tissue metals will also provide a baseline for post-mine fish metals data. In addition to fish collections, Azimuth also proposes to collect sediment (for metals analysis to contrast with pre-mine data) and estimate density of zooplankton and benthic invertebrates from the lake to augment our understanding of the biological properties of Garrow Lake in the post-mining environment.

2.5.2. Garrow Creek

Garrow Creek provides no direct habitat value to fish. The only quantitative survey of benthos and fish in the creek was conducted by BC Research (1975) in 1974 and revealed only a paucity of benthos, consisting of a few individuals of oligochaetes and chironomids. No fish have been found in the stream, although it is possible that a few individuals could exit the lake in spring and become trapped in a downstream pool. Because discharge from Garrow Lake is ephemeral and flows through a 10 m wide, very shallow (10 cm) channel, there is little actual habitat available, mostly because of the nearly continuous snow and ice cover.

During 2003 field activities, Azimuth plans to conduct a quantitative survey of the benthic community using a Surber or Hess sampler to assess whether a benthic community exists and to survey the creek for the presence of fish. Again, this will provide a baseline for the post-mining environment.

2.5.3. Garrow Bay

The nearshore area surrounding the mouth of Garrow Creek is erosional, consisting of sand and gravel with no fine sediments. The nearshore region is scoured by wave action and by ice to a depth of about 3 – 5 m that limits habitat utilization by epifauna (sea urchins, anemone, fish) as well as benthic infauna, such as polychaetes and bivalves. At depths greater than 5 m increasing quantities of silt and clay is present in sediments, with a relatively abundant bottom benthic fauna community, although sediment still contained much coarse substrate.

Several studies have examined the biology of Garrow Bay and nearby Polaris Bay, most notably by BC Research in the late 1970s and by DFO in the late 70s and early 1980s, documenting water and sediment chemistry, qualitative observations on the benthic community and metals in clams and fourhorn sculpins. In 1974, Dobrocky Seatech conducted a dive survey of Garrow Bay (BC Research, 1975) and documented a "rich and varied subtidal biota" with extensive clam beds that are fed upon by walrus. In 1981, Fallis (1984) collected sediment, sea urchins and bivalve clams from several stations around the Polaris Mine for analysis of metals to document concentrations in these receptors prior to mining. Concentrations of lead, zinc and cadmium were significantly, naturally higher (up to 842 times) in sediment, urchins and clams at stations opposite the current wharf structure than in Garrow Bay, which had relatively low concentrations.

Table 2-3 summarizes cadmium, copper, lead and zinc concentrations in water, sediment and clams (*Mya truncata*) from Garrow Bay during pre-mining and current-mining time periods (BC Research, 1978; 1981; Thomas and Erikson, 1983; Fallis, 1984; BC Research, 1988; Axys, 1991; Gartner Lee, 2001). Sediment and clam collections were made at different depths (between 5 m and 10 m) and distances offshore (between 300 m and 800 m) of the creek in Garrow Bay. Metals concentrations in seawater and sediment are well below environmental quality guidelines for the protection of aquatic life (BCE, 1998; CCME, 1999) and have not changed between pre-mine and recent times. Axys (1991) concluded "there was no significant difference ($P<0.05$) in [seawater] metal concentrations in Garrow Bay with respect to either distance from the mouth of Garrow Creek or with depth". The concentration of metals in Garrow Bay sediment was also similar to metals in the adjacent Tigumiavik Harbour and "are in the range of accepted background open ocean levels" when compared with other published, open-ocean Arctic data. Metal concentrations in *Mya* clams has also remained unchanged since pre-mining data were collected, indicating that clams have not accumulated metals from either the sediment or overlying water column. These data illustrate that metals concentrations in all media have not changed between pre-mining and current periods, over a span of 20 years.

These data also strongly suggest that the ephemeral discharge of effluent (i.e., lake surface water) into Garrow Bay has not resulted in the accumulation of metals in any environmental media. Given that zinc and lead are the only metals to exceed guidelines for the protection of aquatic life and exist primarily in the dissolved phase in the effluent, this result is not surprising. Furthermore, the ephemeral nature of the flow, the low discharge volume, combined with the scoured, non-depositional environment within 300 m offshore of the creek mouth, and large mixing potential in the marine environment (see Section 2.3) likely explain why there does not appear to be accumulation of metals by biota. This is also important from a wildlife perspective in that walrus are known to inhabit and feed on clams in this general area (Salter, 1979; Born et al., 1995). It can reasonably be said that exposure of walrus to increased metals in a food source is not occurring.

One of the candidate species for biological monitoring in Garrow Bay is fourhorn sculpin, the same species as is found in Garrow Lake. However, there are natural differences in diet, growth rate, fish size and metals concentration by virtue of the fact that the sculpin population in Garrow Lake has been isolated for nearly 3,000 years. Only one study by BC Research (1975) reported observing or capturing sculpin in Garrow Bay. Eighteen fourhorn sculpins were analysed for total metals concentration from Garrow Bay and Polaris Bay. However, there was no distinction as to how many were from Garrow Bay vs. Polaris Bay (which has naturally much higher metals concentration in sediment), so these historic data are of limited use, nevertheless, there are some data on metals in fourhorn sculpin from Garrow Bay to be used to contrast with future data.

2.5.4. Tigumiavik Harbour

The nearshore area of the reference area, Tigumiavik Harbour, north of Garrow Bay towards Pullen Strait, is similar to Garrow Bay in that it is also erosional and ice scoured to a depth of about 5 m. These conditions limit productivity in nearshore waters and make sampling of sediment and biota difficult. Limited empirical data on metals in water, sediment and biota chemistry collected from Tigumiavik Harbour by Axys (1991) (Table 2-3) showed that metal concentration in all environmental media were similar to Garrow Bay. This is important in demonstrating that the physical and oceanographic environments do not differ substantially between the bays, but more importantly, this indicates that metals have not accumulated in sediment or biota in Garrow Bay. Moreover, metal concentrations in environmental media from Garrow Bay are similar to metals data elsewhere in the Arctic, such as Strathcona Sound where Nanisivik Mine is situated (Fallis, 1982; Fallis 1990).

2.6. Polaris Mining Operations and Environmental Protection Practices

Polaris is an underground zinc-lead mining operation and the world's most northerly metal mine. The Polaris orebody was discovered in the early 1970's. Following socio-economic, engineering and environmental studies, construction of the mine and facilities began in 1980. The first concentrate was produced in late 1981. As indicated in Section 1, Polaris ceased commercial production on September 3, 2002 and is currently undergoing decommissioning and reclamation activities. Approximately 21 million tonnes of ore have been processed to produce 4.4 million dry tonnes of zinc concentrate and 0.9 million dry tonnes of lead concentrate.

The orebody consisted of a Mississippi Valley type, situated completely in permafrost. The permafrost extends to more than 300 m below surface. Ore minerals were sphalerite and galena. The waste rock (host rock) was predominantly dolomite with calcite.

Hanging wall rocks are shales. The orebody was located as close as 60 m to surface and extended to 300 m below surface. Except for a very small open pit, the ore was mined by innovative underground methods. The voids from ore mining were backfilled to maintain rock stability and to allow increased recovery of the ore.

Mined ore was crushed underground and conveyed to the mill. The Polaris concentrator (mill) was a conventional grinding and flotation plant processing just over 1,000,000 tonnes of ore per year and producing between 250,000 and 300,000 wet tonnes of zinc and lead concentrate each year. Chemicals used in the mill as process reagents included sodium cyanide, zinc sulphate, potassium amylxanthate, MIBC (Methyl Isobutyl Carbinol) and copper sulphate. Reagent usage was dependant upon the metal content in the mill feed and the tonnage throughput. The concentrates were stored in a covered building through the winter and were shipped to market in the short arctic shipping season. The mill tailing was pumped via a 4 km tailing line to a tailing thickener located above Garrow Lake where process water was largely separated from the tailing solids. Process water was recycled from the thickener back to the mill via a duplicate pipeline. The thickened tailing solids were deposited at the bottom of Garrow Lake. In 1990 and 1991, construction of a frozen core dam was completed at the outlet of Garrow Lake. Summer runoff water is now controlled and, when necessary, the water is siphoned over the dam. Fresh water was obtained for the plant and domestic purposes by pipeline from Frustration Lake about 5 km from the mine.

The Polaris Mine was an extremely compact mining operation. The process barge contained the mill and most of the service facilities including: power house, maintenance shops, warehouse and offices. The other two main buildings on site were the concentrate storage building and the accommodation building.

The mine has a ship docking facility capable of handling ships up to 44,000 tonnes. Bulk supplies and equipment were transported to the site by ship. The arctic shipping season is restricted to the ice free season between July and October of each year. The mine is also serviced by aircraft from Resolute using the 1200m airstrip located adjacent to the accommodation building.

Several of the environmental practices in place at Polaris to ensure the protection of water resources have been described previously; the following is a brief summary:

- Tailings were placed in the bottom portion of Garrow Lake. The density difference between the bottom layer and the surface layer has generally prevented the upward movement of the tailing through the halocline. As well, the anoxic, sulphide-rich conditions that prevail in the bottom layer precipitate the dissolved metals contained in the tailing to form a stable solid phase.
- A double walled tailings line was used to prevent re-occurrence of line breaks.

- Recycled water was used to minimize fresh water use.
- A monitoring program was undertaken for the effluent and Garrow Lake.
- The Garrow Creek dam will be removed upon closure to eliminate on-going maintenance and the potential for catastrophic failure of the dam.
- Studies of the impact of effluent on the receiving environment (e.g., effluent toxicity evaluations using local organisms; Section 2.3.3) were conducted.

Figure 2-1. Garrow Creek discharge volume (m^3/d), 1984 - 1989.

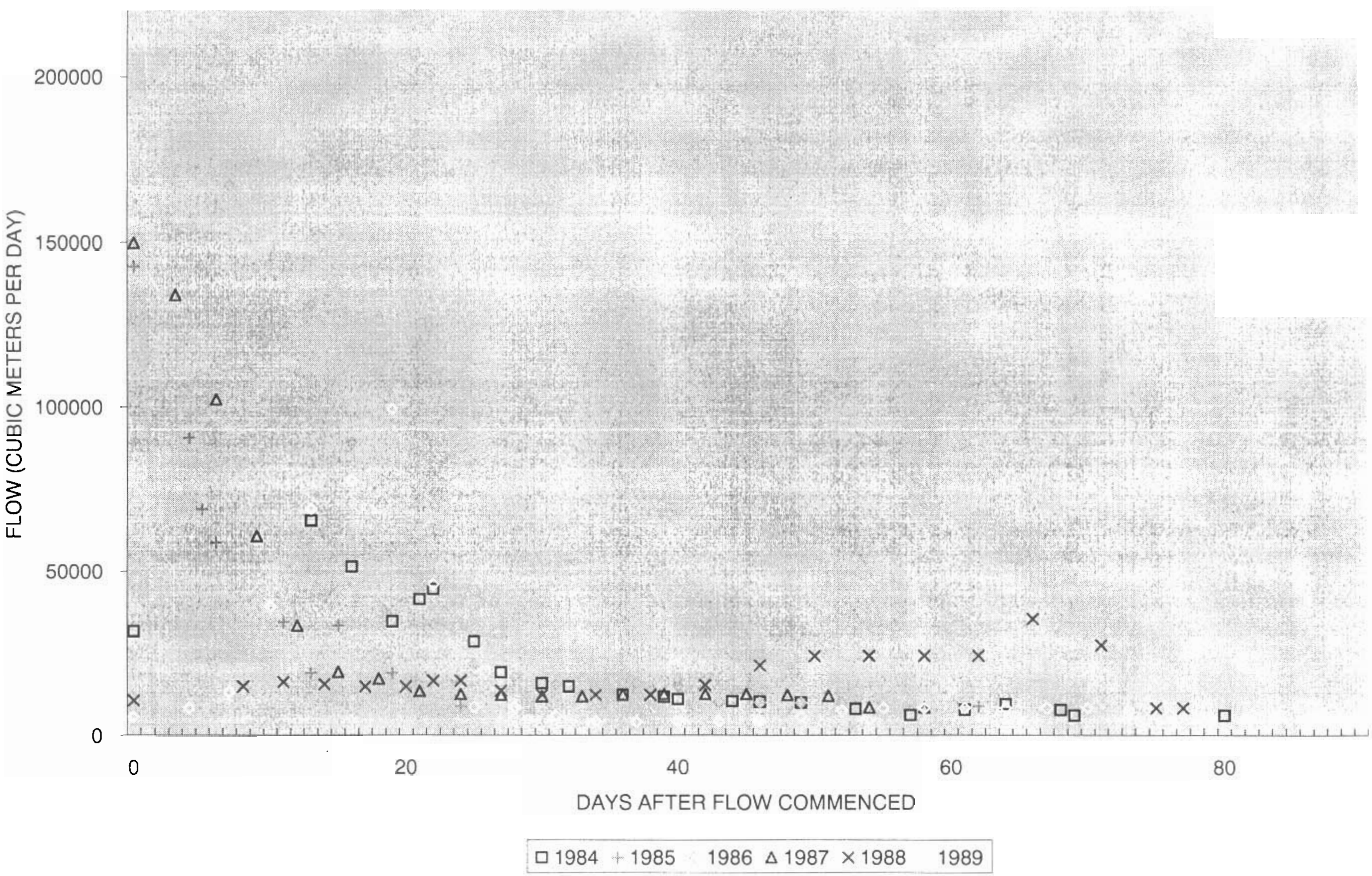

Table 2-1: Total metals concentrations (mg/L) and total suspended solids (mg/L) in Garrow Creek effluent, 2002.

			Metals (mg/L)						Suspended
	n	pH	Lead	Zinc	Arsenic	Copper	Nickel	Cadmium	Solids
July	1	8.22	0.0001	0.06	0.0001	0.0001	0.0001	0.0001	1
August	9	8.03	0.0001	0.07	0.0001	0.0001	0.0001	0.0001	0
September	9	8.01	0.0001	0.17	0.0001	0.0001	0.0001	0.0001	1
October	1	7.99	0.0001	0.18	0.0001	0.0001	0.0001	0.0001	1
Weighted Mean		8.01	0.0001	0.12	0.0001	0.0001	0.0001	0.0001	1.1

* Teck Cominco and BC Research, unpublished data, October, 2002.