APPENDIX B

ADDENDUM
ENVIRONMENTAL EFFECTS MONITORING (EEM) STUDY DESIGN –
TECK COMINCO POLARIS MINE, NUNAVUT (AZIMUTH, 2004a)

Addendum

Environmental Effects Monitoring (EEM) Study Design – Teck Cominco Polaris Mine, Nunavut

Prepared for

Environment Canada
Prairie and Northern Region
Rm 200 4999 – 49th Ave.
Edmonton Alberta
T6B 2X3

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Azimuth Consulting Group Inc.
218-2902 West Broadway
Vancouver, BC
V6K 1K1

Project No. TC-03-03

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1. INTRODUCTION

The purpose of this Addendum is to finalize the study design for the environmental effects monitoring (EEM) program at Teck Cominco's Polaris Mine, Nunavut. Specifically, the Addendum supplements the draft study design report (Azimuth, 2003) by outlining final study components and methods that will be adopted for biological monitoring. Note that while the accompanying table documents the complete study design, emphasis in the text has been placed on identifying deviations and refinements made to the initial program[1].

Development of a final EEM strategy for the Polaris Mine incorporated the following information:

- Results of 2003 field reconnaissance studies conducted in Garrow Bay (**Appendix A**), including:
    - Field effluent plume delineation
    - Underwater video survey
    - Fish survey
    - Sediment survey
- Results of theoretical effluent plume modeling (**Appendix B**).
- Feedback obtained from members of the Technical Advisory Panel (TAP) during the December 2003 workshop held in Edmonton (**Appendix C**) and on the draft study design outline submitted to the TAP in March 2004 (**Appendix D**).

The Addendum, which follows a letter report format, consists of five sections organized as follows:

- Introduction (Section 1)
- Overview and key considerations (Section 2)
- Fish survey and tissue analysis (Section 3)
- Benthic invertebrate community survey (Section 4)
- Supporting environmental variables (Section 5)

Note that the field program for biological monitoring studies is currently scheduled for August 14 – 28, 2004, when the likelihood of safe access to Garrow Bay for sampling is

[1] Sampling analysis procedures generally follow those described in Azimuth (2003) and Environment Canada (2002).

optimal. An interpretative report incorporating results of all EEM study components will be prepared and submitted to the Authorization Officer by June 6, 2005.

2. OVERVIEW AND KEY CONSIDERATIONS

The receiving environment for EEM at the Polaris Mine poses a number of logistical challenges that have been documented as part of reconnaissance studies completed in 2003 (**Appendix A**). These challenges have led to some refinements of the draft study design (Azimuth, 2003) as well as to the prioritization of study components in the event that field conditions and/or other safety issues limit access to Garrow Bay. **Table 1** present the main components of the final study design developed for the Polaris Mine (see **Figure 1** for sampling locations). Implementation of the program will take into account the following key considerations:

- The overall sampling strategy consists of a control/impact design focusing on one high exposure area (i.e., aquatic receiving environment that is nearest to the mouth of Garrow Creek and that contains an appropriate habitat type with sufficient geographic area to accommodate the necessary number of replicate stations; Environment Canada, 2002) and one reference area. Both areas are located in Garrow Bay, approximately 1 km apart (**Figure 1**).
- Our rationale for targeting one high exposure area, rather than multiple near-field and far-field exposure areas, follows guidance from Environment Canada (2002) and reflects findings of the 2003 reconnaissance studies (**Appendix A**) and theoretical effluent plume modeling (**Appendix B**). These clearly indicated the lack of an exposure gradient between the mouth of Garrow Creek and the reference area.
- Standard and accepted quality assurance/quality control (QA/QC) procedures (Environment Canada, 2002) will be used throughout the program. Only those pertaining to novel or site-specific techniques (e.g., clam gonadosomatic index, diver-assisted benthic sampling) will be briefly discussed in this Addendum.
- The final study design is optimistic. While every attempt will be made to achieve the goals of the program, field conditions and safety issues may require us to focus on a few priority study components. As discussed with members of the TAP, all clam, benthos, and sediment collections will be diver-assisted, so local weather and ice conditions will dictate level of effort. Based on feedback received from the TAP (**Appendices C and D**), field work will be prioritized as follows:

    1. Fish survey and tissue analyses
    2. Supporting environmental variables (water and sediment quality surveys)
    3. Benthic invertebrate community survey

4. Seabed imaging and mapping system (SIMS) survey

3. FISH SURVEY AND TISSUE ANALYSES

A detailed outline of the final study design for the fish survey and tissue analyses is presented in **Table 1** (see also Azimuth, 2003). Additional relevant information includes:

- Softshell clams (*Mya truncata*) were selected as the only candidate species for EEM at Polaris.
- Clams will be collected with the assistance of divers during ice-free conditions; only intact clams will be retained for analysis.
- Sample size and replication used for the fish survey and tissue analyses are presented in **Table 1**.
- Following collection, every effort will be made to keep the clams alive until shipping (on ice, not frozen) to the laboratories for analysis; clams will be maintained in seawater (changed daily) and air pumps will be used to keep water well oxygenated. Special 3M ice packs used in the health industry for the transport of live organs will be used to preserve the clams during transport.
- With the exception of tissue chemistry, all measurement endpoints will be determined by Integrated Resource Consultants (IRC) under the general supervision and QA/QC oversight of Dr. Sylvie St-Jean, National Water Research Institute. Of particular interest is the determination of a gonadosomatic index. The latter is used to determine reproductive investment by assessing gametes production and storage in the mantle lobes. A brief summary of the steps to determine the gonadosomatic index[2] of bivalves includes:
    - Measurement of animal length, width, height and the whole animal wet weight to be used in determination of animal condition factor.
    - Dissection of each animal.
    - Determination of sex.
    - Removal and weighing of each mantle lobe and determination of the body mass for each individual.
    - If female: one mantle lobe is used for dry weight and calculation of gonadosomatic index ratio (ratio between body weight [minus gonads] and the

[2] If possible, the gonadosomatic index should be determined when 90% of the mantle lobe consists of gonads, generally slightly prior to spawning. Due to the limited field sampling season at Polaris, it is not possible to determine *a priori* whether the timing of clam collection will be optimal.

gonad). If male, both lobes are used, female calculation should be extrapolated for both lobes.

- The second lobe in females should be used to assess reproductive effort[3], through egg measurement and count.
- A minimum of 20 eggs per animal are measured at the outer layer axis, representing yolk and other material and from the nucleus. These measurements will allow the stage of oocyte development to be determined.
- Eggs present in the subsamples are counted and an estimation of each female reproductive effort determined.

- As required under EEM, the latitude and longitude of each sampling area will be documented.

4. BENTHIC INVERTEBRATE COMMUNITY SURVEY

A detailed outline of the final study design for the benthic invertebrate community survey is presented in **Table 1** (see also Azimuth, 2003). Additional relevant information includes:

- Sediment samples for benthic analysis will be collected using divers rather than standard grab samplers due to the coarse nature of the substrate in Garrow Bay. Five subsamples will be collected within each station and pooled prior to processing.
- Each subsample will be collected consistently using a 1 L plastic container with a 10 cm wide opening. The container will be inserted horizontally into the sediment (to a 10 cm depth) and filled by moving the container laterally. This method ensures that penetration and sediment volume is the same for all subsamples.
- Processing will be performed using a stacked set of 1 and 0.5 mm mesh size (the 0.5 mm screen will be archived and only analyzed if appropriate).
- Identifications will be performed to the lowest practicable taxonomic level.
- As required under EEM, the latitude and longitude of each sampling station will be documented.

A SIMS survey will also be conducted in the high exposure and references areas (**Table 1**) to assess potential gross impacts to macrobenthic epifauna. Methods will follow those described in Azimuth (2003).

[3] This endpoint will only be determined if the clams are in the appropriate reproductive stage.

5. SUPPORTING ENVIRONMENTAL VARIABLES

A detailed outline of the final study design for supporting environmental variables is presented in **Table 1** (see also Azimuth, 2003). Additional relevant information includes:

- With the exception of benthic supporting variables (see below), water quality monitoring will be conducted at one representative station within each of the two sampling areas.
- At each representative station, field measurements made at 1 m depth intervals, except for the first meter (0.1, 0.5, and 1 m) and water samples for chemical analysis will be collected subsurface (0.1 m) and near the bottom (0.25 m from substrate). Further details are provided in **Table 1**.
- Consistent with Table 5-7 of Environment Canada (2002), total organic carbon, grain size, sediment Eh, total sulphides, substrate characteristics, and a suite of metals will be measured at each benthic station. In addition, physical-chemical measurements will be taken in the water column at 0.25 m from the substrate. These will include depth, dissolved oxygen, transparency, and salinity.

6. REFERENCES

Azimuth (Azimuth Consulting Group Inc.). 2003. Environmental effects monitoring (EEM) study design, Teck Cominco Polaris Mine, Nunavut. Draft (June 2003) prepared for Environment Canada on behalf of Teck Cominco.

Environment Canada. 2002. Metal Mining Guidance Document for Aquatic Environmental Effects Monitoring. Document available at: www.ec.gc.ca/eem

Table 1: Polaris Mine EEM - outline of study design for biological monitoring studies.

Study Component	Sampling Areas	Sample Size and Replication		Mesurement Endpoints	Sampling Method
Fish Survey and Tissue Analyses - Species selected: softshell clam (*Mya truncata*)	**Garrow Bay high exposure area**: located in the area closest to the mouth of Garrow Creek where sufficient clams can be collected (approx. 6 - 8 m depth)	- Target of 40 clams[1]	- Individual clams (subset of 35)	- Length, width and height[2] - Whole animal wet weight[2] - Shell weight[2] - Soft tissue fresh and dry weight[2] - Gonad fresh and dry weight[2] - Sex[2] - Condition index - Gonadosomatic index[2] - Reproductive effort[2,3]	- Diver-assisted sampling; collection of individuals by hand, only intact clams will be retained - Following collection, every effort will be made to keep the clams alive until shipping (on ice, not frozen) to the laboratories for analysis; clams will be maintained in seawater (changed daily) and air pumps will be used to keep water well oxygenated
			- Individual clams (subset of 5)[4]	- Tissue chemistry: moisture and lipid content, suite of metals	
	Garrow Bay reference area: located approximately 1 km to the northeast, upstream of the predominant current direction (approx. 6 - 8 m depth)	- Target of 40 clams[1]	- Individual clams (subset of 35)	Same as high exposure area	Same as high exposure area
			- Individual clams (subset of 5)[4]	Same as high exposure area	
Benthic Invertebrate Community Survey	**Garrow Bay high exposure area**: located in the area closest to the mouth of Garrow Creek where benthic communities can be sampled (approx. 6 - 8 m depth)	- 5 replicate stations (approx. 10 m x 10 m each and separated by approx. 50 m)	- 5 x 1L subsamples per station	- Total invertebrate density - Taxon richness - Simpson's diversity index - Bray-Curtis index - Evenness - Taxon density - Taxon proportions - Taxon presence/absence	- Diver-assisted sampling; upper 10 cm of sediment will be collected for each subsample using a 1L plastic container - All 5 x 1L subsamples for a given station will be physically pooled prior to processing - Processing will be performed using a stacked set of 1 and 0.5 mm mesh size (the 0.5 mm screen will be archived and only analyzed if appropriate) - Identifications will be performed to the lowest practicable taxonomic level
	Garrow Bay reference area: located approximately 1 km to the northeast, upstream of the predominant current direction (approx. 6 - 8 m depth)	- 5 replicate stations (approx. 10 m x 10 m each and separated by approx. 50 m)	- 5 x 1L subsamples per station	Same as high exposure area	Same as high exposure area

Table 1: (Continued)

Study Component	Sampling Areas	Sample Size and Replication		Mesurement Endpoints	Sampling Method
Supporting Environmental Variables					
- Water quality monitoring	**Garrow Bay high exposure area**: location matching fish and benthic survey sampling area	- 1 representative station located at the center of the sampling area[5]	- Measurements made at 1 m depth intervals, except for the first meter (0.1, 0.5, and 1 m)	- Field measurements: DO, pH, temperature, salinity, conductivity, transparency and water depth	- Calibrated YSI meter, pH probe, and depthmeter will be used for all field measurements - Surface water samples will be collected directly into sample containers - Subsurface sampling will be conducted using divers; care will be taken not to disturb sediments during sampling - Timing of sampling will match routine MMER effluent characterization as well as EEM effluent and water quality monitoring
		- 1 representative station located at the center of the sampling area	- Sample collected subsurface (0.1 m) and near the bottom (0.25 m from substrate)	- Laboratory analyses: pH, temperature, DO, hardness, alkalinity, Al, As, Cd, Cu, cyanide, Fe, Hg, Pb, Mo, Ni, Zn, TSS, ammonia, nitrate, radium 226	
	Garrow Bay reference area: location matching fish and benthic survey sampling area	- 1 representative station located at the center of the sampling area[5]	- Measurements made at 1 m depth intervals, except for the first meter (0.1, 0.5, and 1 m)	Same as high exposure area	Same as high exposure area
		- 1 representative station located at the center of the sampling area	- Sample collected subsurface (0.1 m) and near the bottom (0.25 m from substrate)	Same as high exposure area	
- Sediment quality monitoring	**Garrow Bay high exposure area**: location matching fish and benthic survey sampling area	- 5 replicate stations (matching benthic replicate stations)	- 5 subsamples (matching benthic subsamples) per station	- Sediment chemistry: TOC, grain size, sediment Eh, total sulphides, substrate characteristics, suite of metals	- Diver-assisted sampling; upper 10 cm of sediment will be collected for each subsample using a 1L plastic container - All 5 x 1 L subsamples for a given station will be composited prior to analysis
	Garrow Bay reference area: location matching fish and benthic survey sampling area	- 5 replicate stations (matching benthic replicate stations)	- 5 subsamples (matching benthic subsamples) per station	Same as high exposure area	Same as high exposure area
Additional Studies - Seabed Imaging and Mapping System (SIMS)	**Garrow Bay high exposure area** and **Garrow Bay reference area**	- Numerous georeferenced tracklines within each area	- Continuous imagery	- Seabed classification maps including: substrate type, vegetation type and cover, distribution and relative abundance of macrofauna	- Towed underwater camera (SIMS) providing semi-quantitative survey of physical and biological features of the seabed

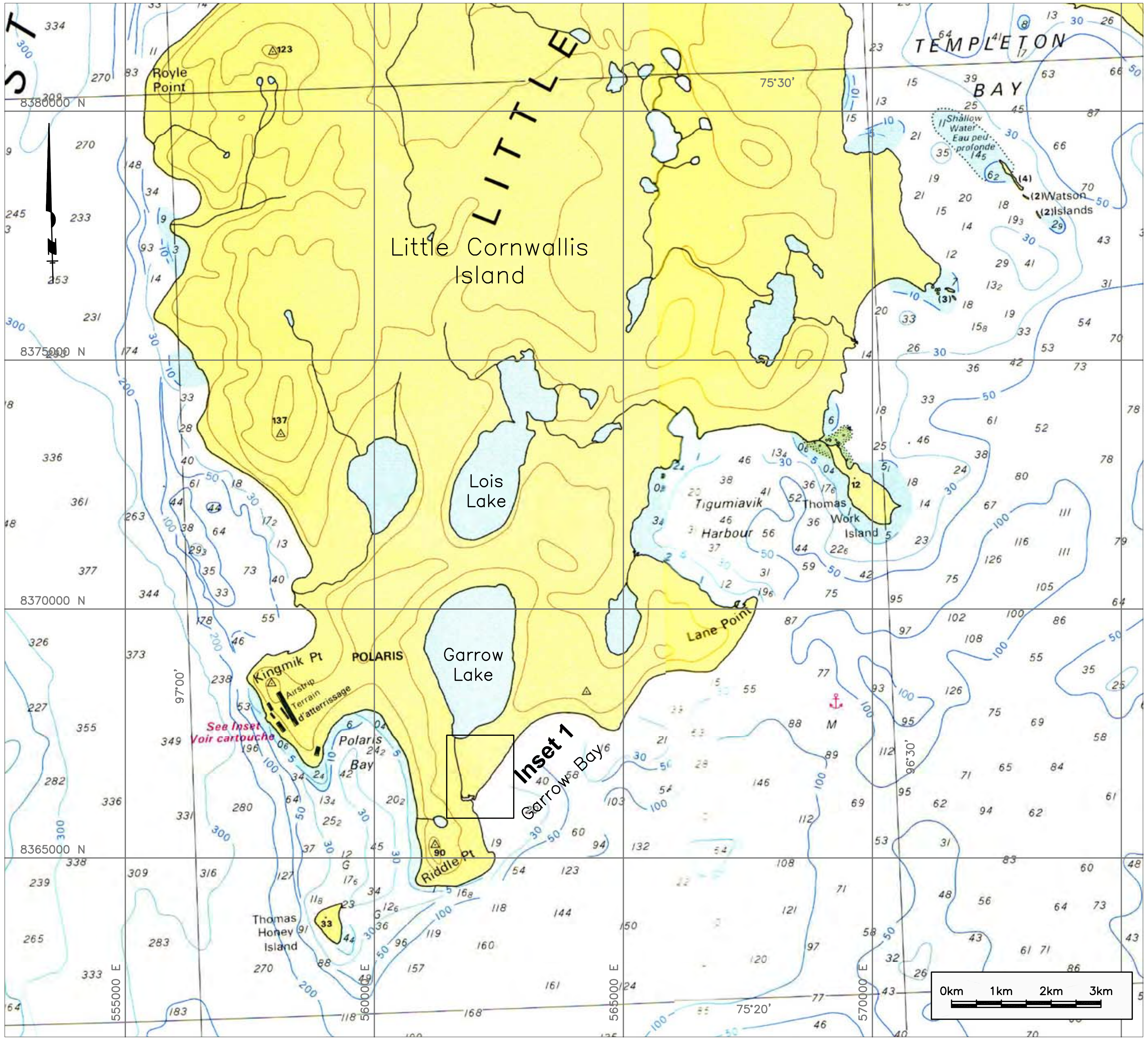
[1] During the 2003 reconnaissance studies, a total of 29 clams were collected by divers; access to Garrow Bay for diving was limited to 3 out of 14 field days due to harsh weather conditions (e.g., presence of ice flows, strong winds, blizzard). Every effort will be made during the 2004 field program to meet the mininum EEM requirement of 40 individuals per sampling area; however, the total sample size may be limited by field conditions. In addition, the inherent difficulty in identifying clam sexes in the field may result in a departure from the requirement for 20 males and 20 females.

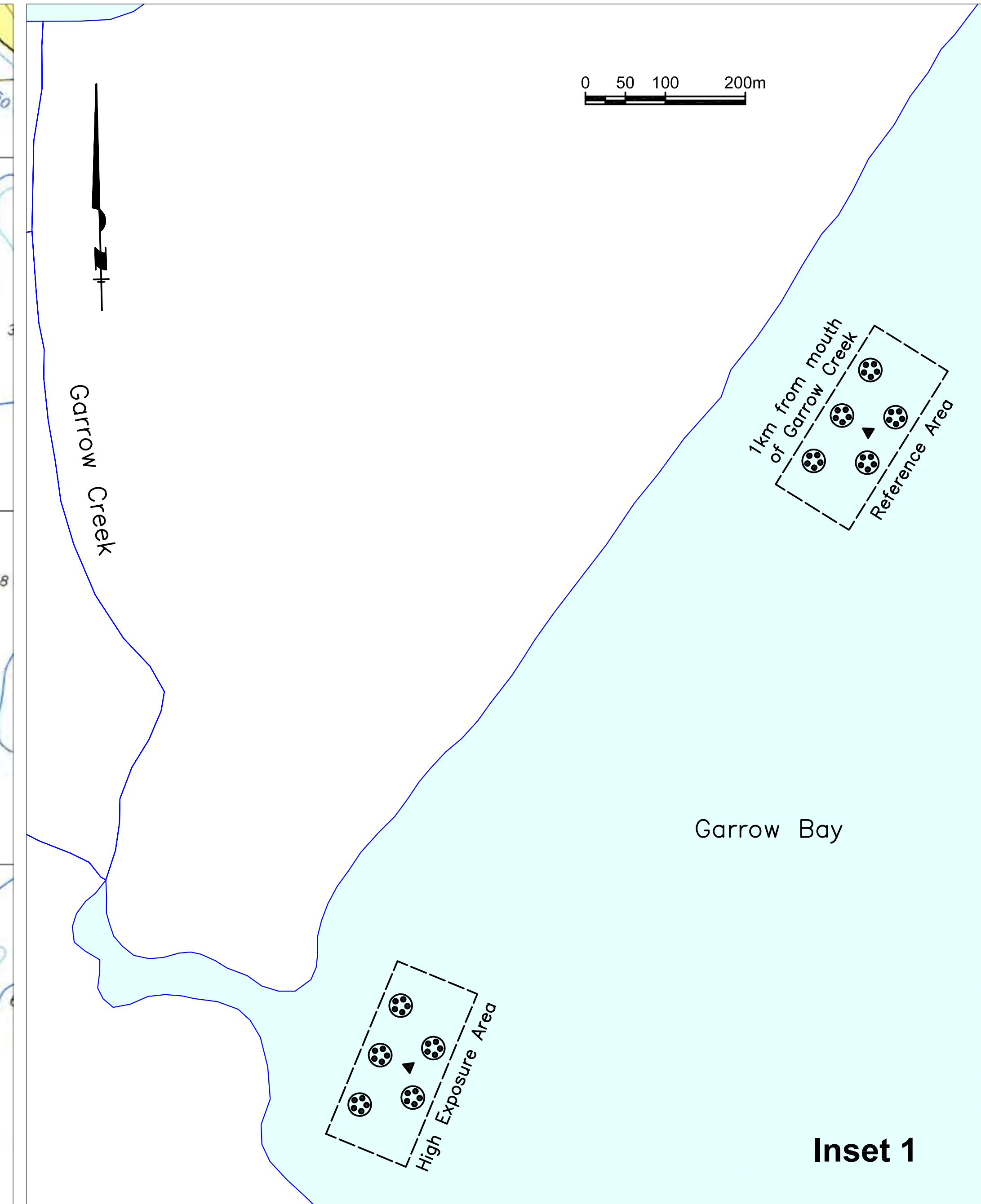
[2] These endpoints will be determined by Integrated Resource Consultants (IRC) under the general supervision and QA/QC oversight of Dr. Sylvie St-Jean, National Water Research Institute. The sample size will be assessed once field work is completed.

[3] Reproductive effort (i.e., number and size of eggs) will only be determined if clams are in the appropriate reproductive stage.

[4] A subset of 5 clams will be analyzed individually for tissue chemistry. They will be selected among the 40 clams to represent various size classes. Other measurements on these individuals will include length, width, height, whole animal wet weight, and condition index.

[5] Note that to support the benthic community survey (Table 5-7 of the Metal Mining Technical Guidance Document), water depth, DO, transparency and salinity will be measured in the field at each of the benthic stations; all measurements will be made 0.25 m from the bottom.





Sampling area for fish survey and benthic invertebrate community survey

Replicate station - benthos, sediment, water (benthic supporting environmental variables only; see below for general water quality monitoring)

Subsample - benthos, sediment

Representative station - water (field measurements and laboratory analyses); note that field measurement will be made at 1m depth intervals (except for the first meter: 0.1, 0.5 and 1m) whereas water samples will be collected subsurface (0.1m) and near the bottom (0.25m from substrate)

Inset data and surrounding creeks digitized from Map 1 Sampling Sites 1980 prepared by B.C. Research January 1978

Other data from Crozier Strait And/Et Pullen Strait 7935 corrected 2003-03-28 published by the Canadian Hydrographic Service

AZIMUTH

Azimuth Consulting Group Inc.
218-2902 West Broadway
Vancouver BC, V6K 2G8

PROJECT:	Polaris
TITLE:	**Polairs Mine EEM Study Design for Biological Studies**
DRAWN BY:	BT
CHK. BY:	PA
DATE:	6/15/2004 9:39 AM
PROJECT No:	TC-03-03
CLIENT:	Teck Cominco
	Figure 1

APPENDICES

APPENDIX A

TECHNICAL PRESENTATION AT DECEMBER 2003 WORKSHOP

Polaris Mine EEM: Finalization of Study Design

Teck Cominco Metals Ltd. &
Azimuth Consulting Group Inc.

December 16, 2003

Meeting Overview

Goal

- Finalize the EEM study design (implementation scheduled for August 2004)

Approach

- Review results of 2003 effluent characterization and field reconnaissance studies in Garrow Bay

Meeting Overview (cont'd)

Context

- To guide finalization of 2004 study design, 2003 results need to be reviewed in light of MMER requirements and EEM guiding principles:

  1. Scientific defensibility
  2. Cost effectiveness
  3. Provide flexibility for site-specific requirements, without subjecting field crews to unsafe sampling conditions

Outline of Presentation

- Effluent characterization (chemistry and toxicity)
- Reconnaissance studies in Garrow Bay
  - Field conditions and safety issues
  - Plume delineation (field and modeling)
  - 2003 reconnaissance design
  - Video survey
  - Fish survey
  - Sediment survey
- Weight-of-evidence assessment
- Options for EEM Study Design

Effluent Characterization

Effluent Chemistry (weekly):

- 9 weeks of discharge into Garrow Creek (July 22 to September 16, 2003)
- Flow rates varied between 0.4 to 1.3 m^3/s (expected to be considerably lower in future)
- As expected, the effluent is brackish (2-7 ppt)
- No exceedances of MMER limits
- Lead and zinc exceed BC AWQG
- Mercury concentration in Garrow Lake surface water < 1.1 ng/L (much lower than MMER trigger for fish tissue analysis which is 100 ng/L)

N.B. All analyses completed within appropriate holding times

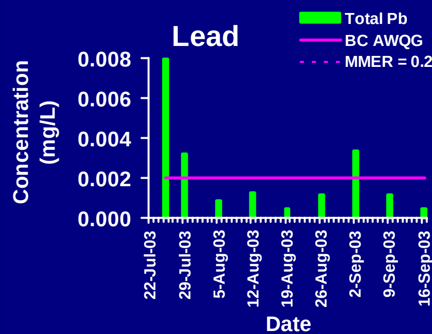
2003 Effluent Chemistry Data

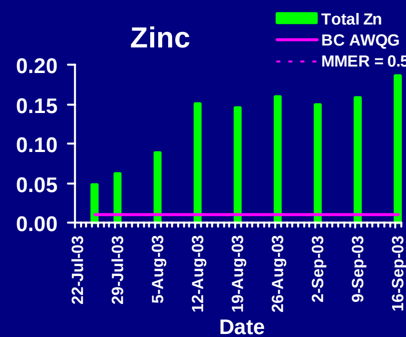
	Water Quality Guidelines		Garrow Creek Concentrations		
	MMER	BC AWQG	Mean ± SD	Min	Max
Physical Tests & Cyanide (mg/L)					
pH	NG	6.5 - 9.0	7.94 ± 0.10	7.77	8.10
Salinity o/oo	NG	NG	5 ± 2	2	7
TSS	15	25	5 ± 3	3	11
Total Cyanide	1	NG	<0.005	<0.005	<0.005
Total Metals (µg/L)					
Aluminum	NG	100	90 ± 0.03	<10	100
Arsenic	500	12	<1	<2	<20
Cadmium	NG	1	0.33 ± 0.13	0.12	0.47
Copper	300	2	0.91 ± 0.19	0.57	1.22
Iron	NG	50	33 ± 45	10	150
Lead	200	2	**2.2** ± 2.4	0.5	**7.9**
Mercury	NG	0.020	<0.05	<0.05	<0.05
Molybdenum	NG	1000	2.9 ± 1.4	<2	5.0
Nickel	500	8.3	2.3 ± 0.9	1.2	3.7
Zinc	500	10	**128** ± 49	**48**	**186**
Radium-226 (Bq/L)	0.37	NG	0.006 ± 0.002	<0.005	0.01

Note: BOLD concentrations exceed BC AWQG
Note: Boxed concentrations exceed MMER limits

[1]BC Approved Water Quality Guidelines for the protection of marine life
[2]BC AWQG 30-day average for freshwater (no guideline for marine water)
[3]BC AWQG interim marine water guideline
[4]BC AWQG 30-day average for marine water
[5]BC AWQG recommeded marine water guideline
[6]No guideline for total (strong acid dissociable cyanide), or Radium-226

Contaminants of Potential Concern





Effluent Characterization (cont'd)

Effluent Toxicity – Acute toxicity testing (freshwater):

- 3 tests conducted in 2003
- Tests included a salinity control due to brackish effluent
- No toxicity to rainbow trout (96 hr LC_{50} >100% effluent v/v)
- No toxicity to *Daphnia magna* (48 hr LC_{50} >100% effluent v/v)

Effluent Characterization (cont'd)

Effluent Toxicity – Sublethal toxicity testing (marine):

- Tests required salinity (brine) adjustment – 72% effluent v/v is highest concentration tested
- No toxicity to Topsmelt (survival and growth endpoints) (NOAEL = 72% effluent v/v)
- For echinoderm fertilization test, the IC_{25} was 3.8% v/v
- For algae reproduction test, the IC_{25} was 13.6% v/v

N.B. All tests completed within appropriate holding times

Effluent Characterization (cont'd)

Implications of sublethal toxicity test results:

- Zinc concentration in effluent at time of testing (Aug 19) was 146µg/L; lead concentrations were below BC AWQG
- Echinoderm IC_{25} corresponds to 5.5µg/L zinc
  - Result suggests either high sensitivity of test organism to zinc (< BC AWQG) or other cause(s) of toxicity
- Algae IC_{25} corresponds to 19.9µg/L zinc
  - Result consistent with 1) zinc reference toxicant for *Champia* and 2) available toxicological literature used to derive zinc BC AWQG

Effluent Characterization (cont'd)

Relevance of sublethal toxicity test results:

- Temperature known to affect toxicity: echinoderm tested at 15°C; algae tested at 23°C; Garrow Bay ~ 0°C
- Studies conducted at Polaris by Chapman (1992) using arctic amphipods showed no acute toxicity at [Zn] > 11.8 mg/L
- Field observations confirm presence of millions of marine amphipods at mouth of Garrow Creek
- Healthy populations of fourhorn sculpins were documented in Garrow Lake during 2003 study

Reconnaissance Studies in Garrow Bay

Overview:

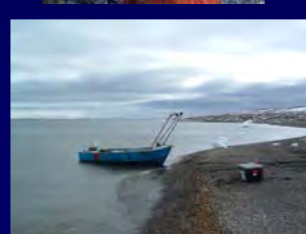
- Field conditions and safety issues
- Plume delineation (field and modeling)
- 2003 reconnaissance design
- Video survey
- Fish survey
- Sediment survey

Field Conditions & Safety Issues

- Timing: first 2 weeks of August (summer)
- Garrow Bay covered with ice for 7 out of 14 days
- Small craft warning (winds > 20 knots) for 4 days out of the remaining 7 days, including 2 days with blizzard conditions
- 3 polar bear sightings (mine safety officers advised against field work)


Field Conditions & Safety Issues (cont’d)



Field Conditions & Safety Issues (cont’d)

Plume Delineation

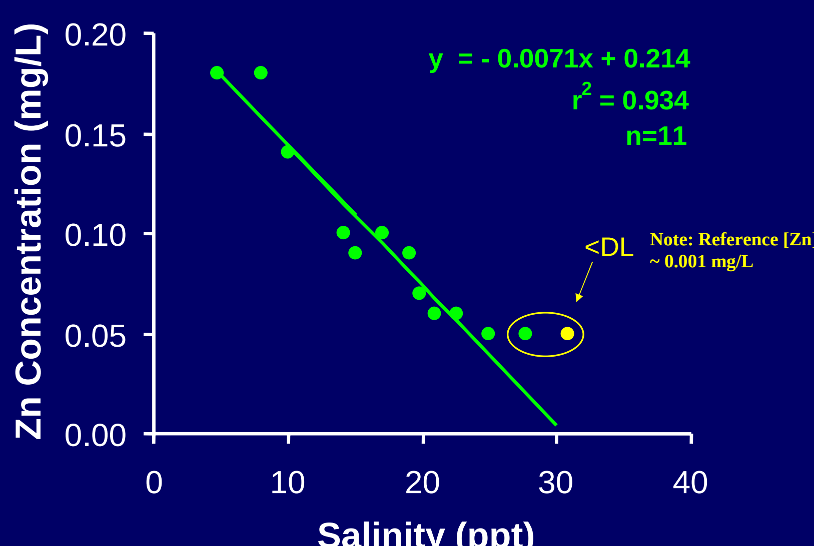
Two components:

1. Field measurements (temperature, salinity, [Zn])
2. Modeling (EPA’s Visual Plumes software; Frick et al., 2003)

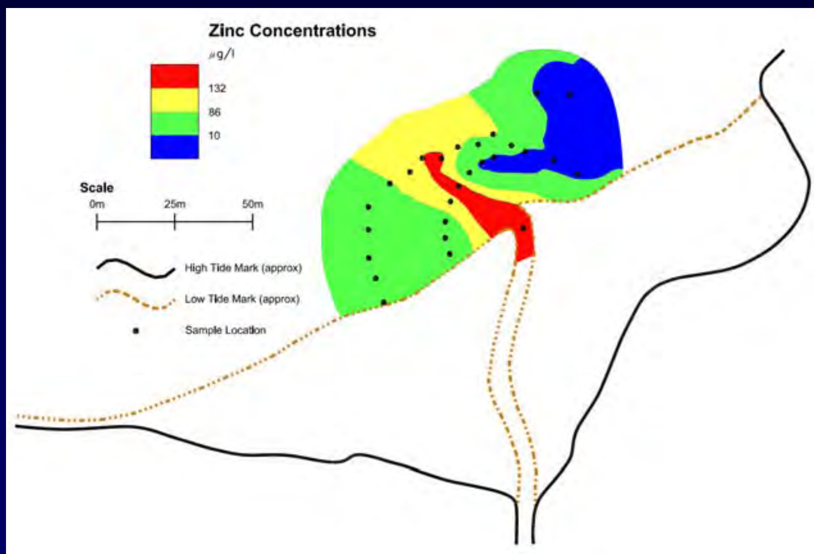
Plume Delineation – Field

- Creek discharge ~ 1.0 m^3/s; 6 ppt salinity
- Vertical temperature/salinity profiles during high and low tide
- Water samples acquired from boat moving from offshore to onshore within plume
- Samples acquired at surface (top 30 cm) and below surface plume (10 cm off bottom)

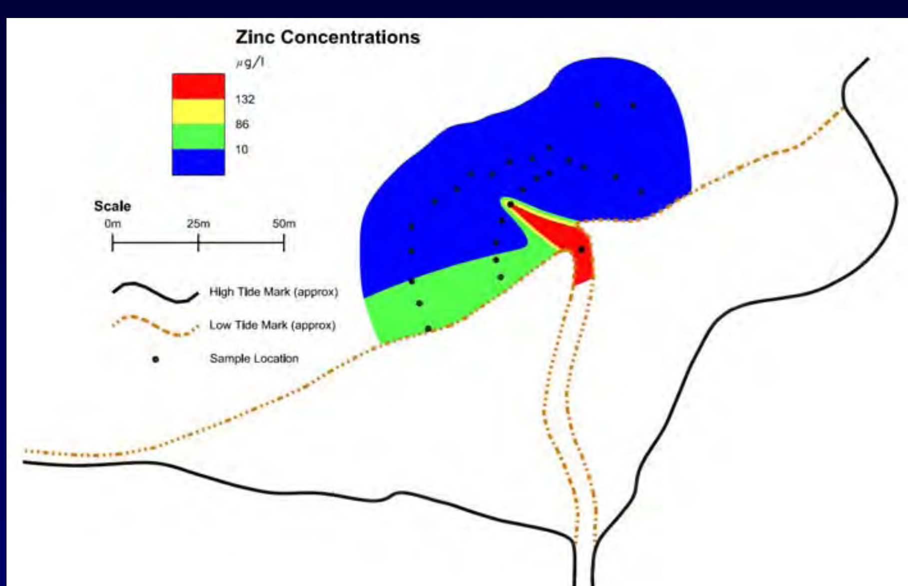
Relationship Between Zn and Salinity



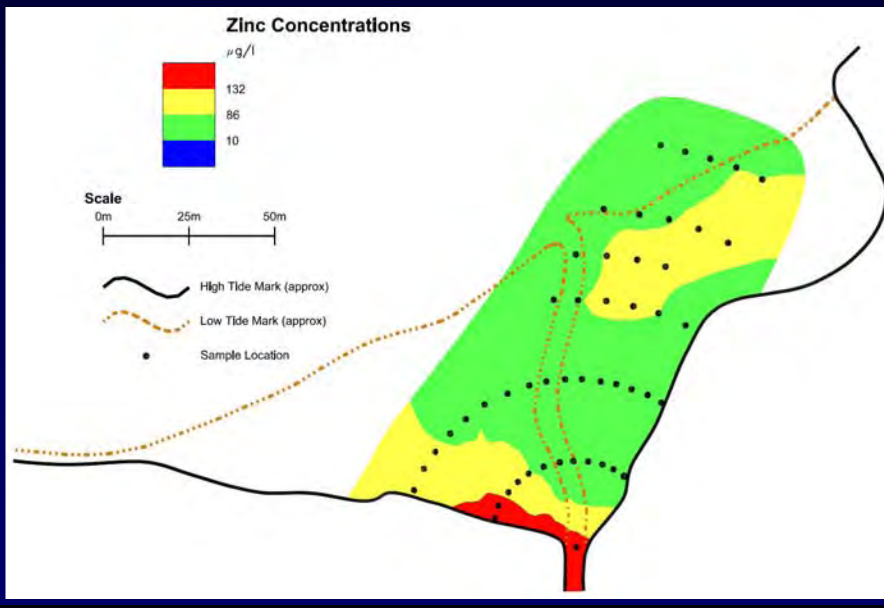
Plume Delineation – Trends in Surface [Zn] During Low Tide



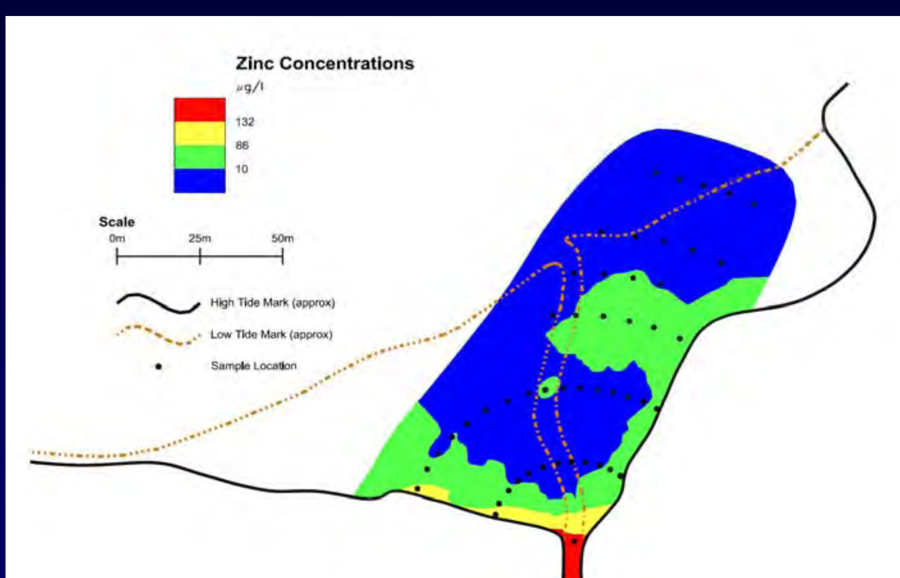
Plume Delineation – Trends in Subsurface [Zn] During Low Tide



Plume Delineation – Trends in Surface [Zn] During High Tide



Plume Delineation – Trends in Subsurface [Zn] During High Tide

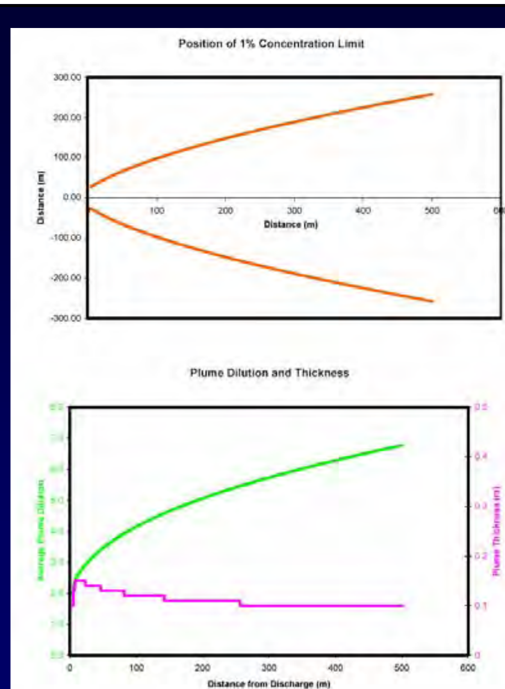


Plume Delineation – Modeling

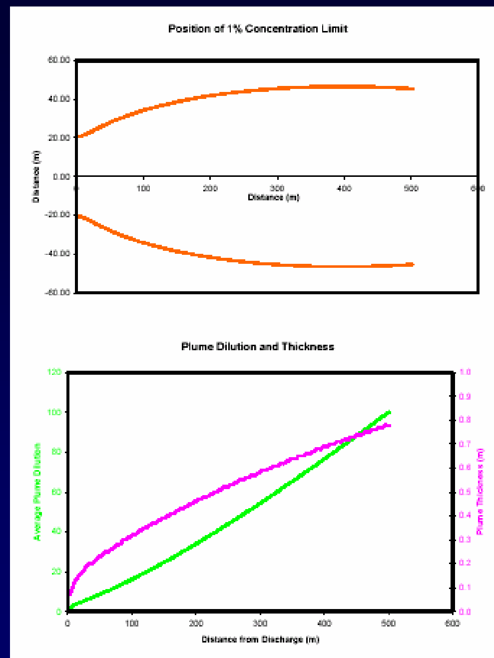
Main conditions of model runs:

- Typical discharge of 0.2 m^3/s vs. maximum discharge of 2.5 m^3/s
- No wind or current mixing vs. wind/current mixing to create 0.3 m/s current

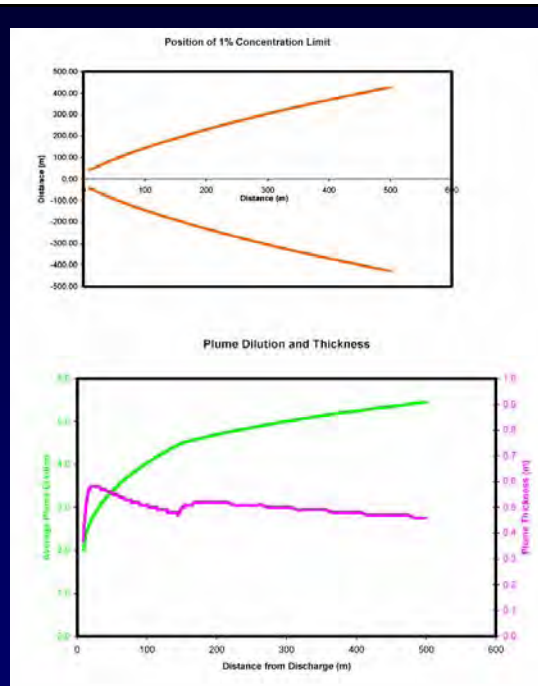
Plume Modeling:
0.2 m^3/s with no
wind/current



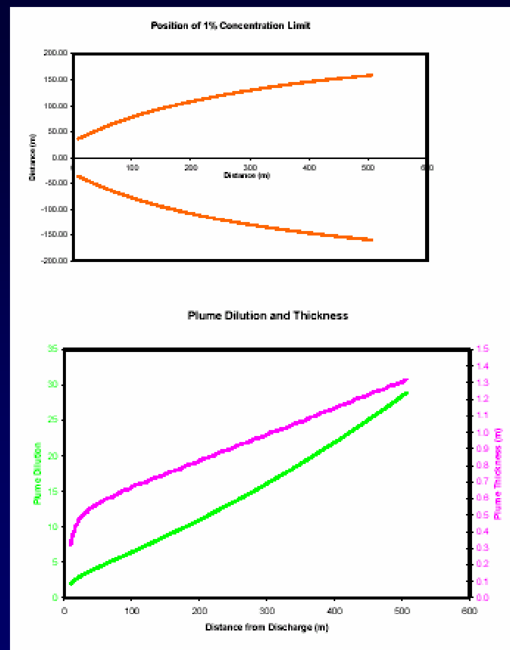
Plume Modeling: 0.2 m^3/s with typical wind & current



Plume Modeling: 2.5 m^3/s with no wind/current



Plume Modeling: 2.5 m^3/s with typical wind & current



Plume Delineation Summary

Strong density differences between effluent and receiving marine waters drive plume characteristics:

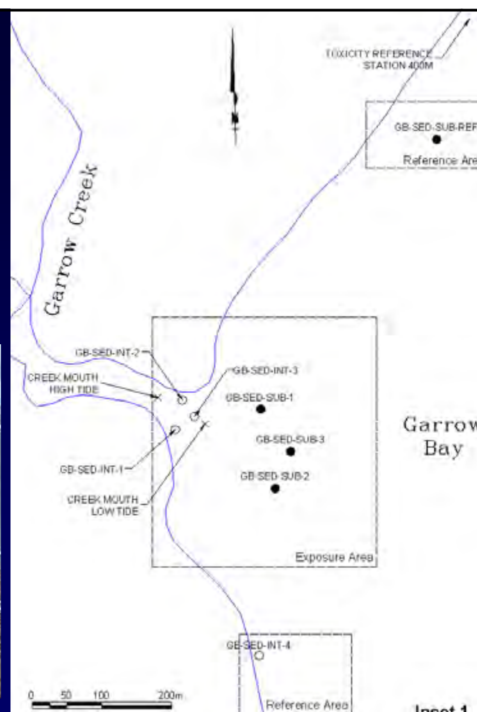
- Plume limited to surface water (< 0.5 m under extreme worst-case conditions)
- Plume consists of relatively narrow band that stretches offshore

Mixing strongly influenced by wind and current conditions

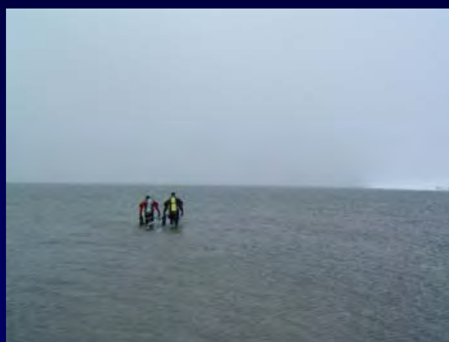
2003 Reconnaissance Design - Reference Area

- Access to Tigumiavik Harbour very difficult over land (terrain & polar bears) and unsafe over water (shifting ice flows, wind conditions)
- Reference was relocated to Garrow Bay (~ 550 m from mouth of creek) based on results of field plume delineation
- Monthly water quality monitoring confirmed background conditions (also supported by sediment and clam tissue data)

2003 Reconnaissance Design



Diver Video Survey



Fish Survey

- Few fish (e.g., sculpins) observed during video survey and during diver-assisted sampling of sediment and clams
- Fish trap deployed in exposure area – destroyed overnight by drifting ice

- Focus on diver-assisted clam sampling:
  - 29 soft-shell clams (*Mya sp.*) collected over 4 dives
  - Tissue composited according to 4 discrete size classes
  - Exposure area (3 stations collected as close to creek mouth as possible
  - Reference area (1 station)

Average Metals Concentrations in Clam Tissue - 2003

	Site 1 (n=3)	Site 2 (n=4)	Site 3 (n=4)	Ref (n=3)
Physical Tests				
Moisture (%)	82.1	82.9	84.1	83.0
Total Metals (mg/kg ww)				
Aluminum	37	19	31	8
Arsenic	1.85	2.03	1.41	1.43
Cadmium	0.612	0.781	0.926	0.769
Chromium	0.6	0.3	0.4	<0.1
Cobalt	0.13	0.10	0.07	0.05
Copper	1.98	1.72	1.91	1.71
Lead	0.12	0.11	0.25	0.08
Mercury	0.013	0.019	0.012	0.010
Nickel	0.8	1.4	0.6	0.3
Zinc	26.5	24.8	29.2	25.0

Note: There was no significant relationship between metals concentrations and size of clams

Historical Metals Concentrations in Clam Tissue

	Pre - Mine Development		Post - Mine Development						
	Fallis 1984[a]	BC Research 1978[b,c]	AXYS 1991[b,c]		Gartner Lee 1999[b,c]	Azimuth 2003[b,c]			
Metal (mg/kg ww)	n=8	n=33	n=2	Ref (n=1)	n=2	Site 1 n=3	Site 2 n=4	Site 3 n=4	Ref n=3
Lead	0.14	0.19	0.05	0.14	<0.1	0.12	0.11	0.25	0.08
Zinc	9	16.6	14.8	24.2	21	26.5	24.8	29.2	25.0

[a] 1981 Data; converted to wet wt using 85% moisture; depurated clams

[b] Non-depurated clams

[c] Reflects composite from larger number of clams (typically > 5 individuals)

Sediment Survey

Objectives:

1. Determine feasibility of benthic community survey using grab sampler

2. Evaluate sediment chemistry
   - Intertidal sediment adjacent to creek mouth – worst-case exposure
   - Subtidal sediment paired with clam tissue samples – exposure area (3 stations) and reference area (1 station)

Sediment Survey (cont’d)

Grab sampling efforts & results:

- > 40 attempts with std. Ponar grab over both exposure and reference areas (~ 10 m depth)
- Some sediment recovered in 3 grabs; however all grabs were unacceptable for benthos:
  - Incomplete closure (kelp, gravel)
  - Inadequate and inconsistent penetration

Sediment Survey (cont'd)

Intertidal Sediment – Near-field Area

Metals Concentrations in Sediment - 2003

	Sediment Guidelines		Garrow Bay - Intertidal				Garrow Bay - Subtidal			
	ISQG	PEL	1	2	3	REF	1	2	3	REF
Total Metals (mg/kg dw)										
Aluminum	NG	NG	5890	5830	6660	5960	4110	4210	3920	4320
Arsenic	5.9	17	**11**	**11**	**15**	**13**	**8**	5	**6**	**6**
Cadmium	0.7	4.2	<0.5	<0.5	<0.5	**<1**	<0.5	<0.5	<0.5	<0.5
Chromium	37.3	90	14	14	16	15	12	11	10	12
Cobalt	NG	NG	4	4	4	<4	2	<2	<2	<2
Copper	18.7	108	18	16	18	18	9	9	8	9
Lead	30.2	112	19	21	21	11	11	11	10	7
Mercury	0.17	0.49	0.07	0.09	0.09	0.08	<0.05	<0.05	<0.05	<0.05
Nickel	18	36	**22**	**20**	**25**	**25**	12	11	9	10
Zinc	124	271	103	72	86	73	34	39	29	29
Organic Parameters										
Total Organic Carbon (%)	NG	NG	5.6	<0.6	<0.6	2.4	<1	<0.8	<1	1.2
Particle Size (%)										
Gravel (>2.00mm)	NG	NG	42.4	35.4	40.2	39.8	24.6	10.7	56.3	60
Sand (2.00mm - 0.063mm)	NG	NG	52.3	59.7	57	59.4	42.2	30.7	10.5	13.4
Silt (0.063mm - 4um)	NG	NG	4	4.2	2	0.4	28.1	49.1	28.3	21.4
Clay (<4um)	NG	NG	1.3	0.7	0.8	0.4	5.1	9.5	4.9	5.2

BOLD concentrations exceed ISQG
Boxed concentrations exceed PEL

[1]Canadian Council of the Ministers for the Environment Interim Sediment Quality Guideline
[2]Canadian Council of the Ministers for the Environment Probable Effects Level Guideline
[3]NG = no guideline

Historical Metals Concentrations in Sediment

Metals (ug/g)	CCME Sediment Quality Guidelines[1,2] ISQG	PEL	Pre - Mine Development: Fallis 1984, Thomas & Erickson 1983, BC Research 1978,1981 (Subtidal)	Post - Mine Development: BC Research 1988 (Subtidal)	AXYS 1991 (Subtidal)	Gartner Lee 1999 (Subtidal)	Azimuth 2003 (Intertidal)	Azimuth 2003 (Subtidal)
Lead	30.2	112	6.0 - 11.6	4.6 - 7.6	3.8 - 4.5	7.5	11 - 21	7 - 11
Zinc	124	271	21 - 45	32 - 41	30 - 37	38	72 - 103	29 - 39

[1] Canadian Council of the Ministers for the Environment Interim Sediment Quality Guideline
[2] Canadian Council of the Ministers for the Environment Probable Effects Level Guideline

Overall Weight-of-Evidence Assessment

Study Component	Finding
Discharge Conditions	Limited to 9 weeks of flow in 2003
Effluent Chemistry	Pb and Zn > BC AWQG
Effluent Sublethal Toxicity	
- Topsmelt Survival and Growth	No toxicity
- Echinoderm Fertilization	IC_{25} = 3.8% effluent v/v (related to high Zn sensitivity and/or other causes)
- Algae Reproduction	IC_{25} = 13.6% effluent v/v (likely Zn-related)
Plume Delineation	1% plume relatively narrow and thin (exceeds 1% beyond 250 m) Wind, currents and ice are key drivers of dilution
Tissue Chemistry	No Exposure (based on clams)
Sediment Chemistry	
- Intertidal	Negligible Exposure (lower than CCME guidelines)
- Subtidal	No Exposure
Resident Benthic Communities	No apparent signs of gross impacts based on field observations and diver video survey; substrate does not support quantitative benthic survey
Fish	None captured (trap destroyed); one observed by divers
Overall Assessment for Garrow Bay	**Exposure to contaminants negligible and limited to surface water only**

Effects to biota unlikely

Options for EEM Study Design

Current design intended to meet MMER requirements, but also consider EEM guiding principles:

1. Scientific defensibility
   - **Negligible exposure (in time and space)**
   - **Effects to fish and benthos unlikely**

2. Cost effectiveness
   - **Polaris one of most remote and expensive mines to study (~ 2003 costs $140,000 to date)**

3. Provide flexibility for site-specific requirements, without subjecting field crews to unsafe sampling conditions
   - **Field conditions are severe and there is high concern regarding safety issues (polar bears, ice flows, strong winds)**

Design Options (cont'd)

Four options:

1. Attempt to conduct EEM "compliant" study despite prevailing information collected in 2003

2. Conduct limited field studies using alternative tools:
   – Diver-assisted sampling of sediment and clams
   – Towed underwater video survey (SIMS) to further document status of subtidal benthic communities

3. No further biological monitoring studies; continue ongoing effluent (chemistry and toxicity) and water quality monitoring

4. Other?

Design Options (cont'd)

Notes:

- Consider consequences of Option 1 (no data)
- Both Options 2 and 3 require some departure from MMER requirements but not from EEM guiding principles

APPENDIX B

PHYSICAL ASSESSMENT OF GARROW CREEK EFFLUENT PLUME (SEA SCIENCE INC)

SEA SCIENCE Inc.

Physical Assessment of the Garrow Creek Effluent Plume Polaris Mine Little Cornwallis Island Nunavut

prepared for

Azimuth Consulting Group Inc.
218 – 2902 West Broadway
Vancouver, B.C.
V6K 2G8

15 December 2003

Sea Science Inc.
200 - 1311 Howe Street
Vancouver, B.C., Canada
V6Z 2P3

(604) 682 2661

1 INTRODUCTION

The Polaris Mine site is located on Little Cornwallis Island in the territory of Nunavut in the Canadian Arctic (Figure 1). The lead-zinc mine, owned and operated by Teck Cominco Ltd., began production in 1981 and ceased operation in September 2002. During the period of mine operation, thickened tailings were discharged into the bottom waters of Garrow Lake, a meromictic lake adjacent to the mine itself. Tailings disposal to the lake ended as concentrate production ceased in 2002. Garrow Lake is designated as a Tailings Impoundment Area in the Metal Mining Effluent Regulations issued by the Government of Canada in June 2002.

Garrow Lake is ice-free for two to three months in the late summer and early fall of each year. During the short ice-free period, discharge from the lake flows through a small creek to the marine waters of Garrow Bay, roughly 1500 m from the lake outlet (Figure 2). No discharge occurs during the remainder of the year.

The Metal Mining Effluent Regulations (MMER) apply to mines where effluent discharges exceed a flow rate of 50 m^3 per day, and the effluent contains a deleterious substance as defined by the MMER and the Fisheries Act. Both of these conditions are met, on a limited seasonal basis, by the effluent discharging through Garrow Creek to Garrow Bay. The MMER apply to mines in commercial operation on the date of registration of the Regulations, 6 June 2002.

The MMER require environmental effects monitoring studies to be conducted for qualifying effluent discharges. The required studies consist of effluent, water quality and biological monitoring studies as set out in the Regulations. The study design for the first biological monitoring studies must contain a site characterization, including:

(a) a description of the manner in which the effluent mixes within the exposure area, including an estimate of the concentration of effluent in water at 250 m from each final discharge point;

(b) a description of the reference and exposure areas where the biological monitoring studies will be conducted that includes information on the geological, hydrological, oceanographical, limnological, chemical and biological features of those areas.

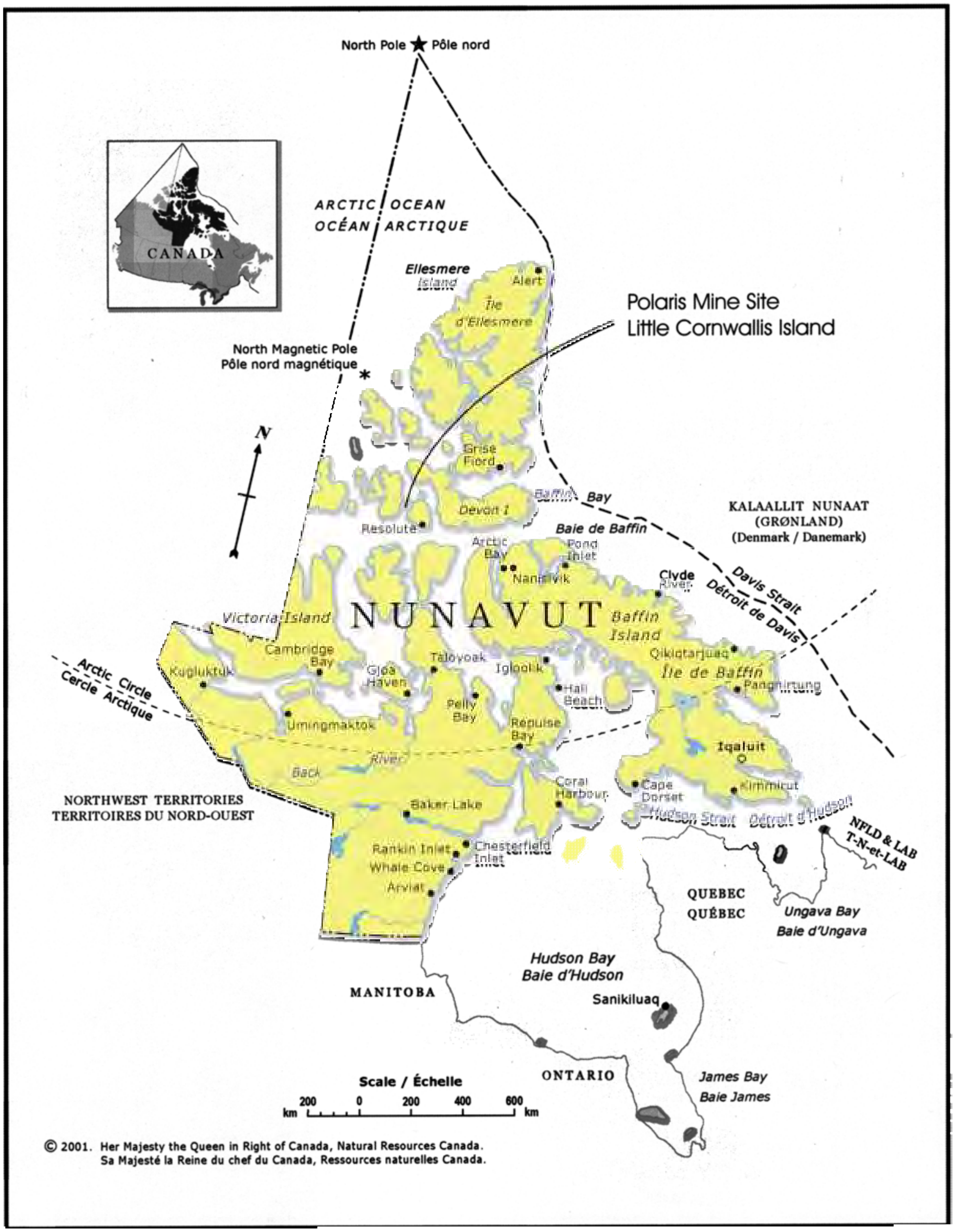


Figure 1. Location of Polaris Mine on Little Cornwallis Island, Nunavit.

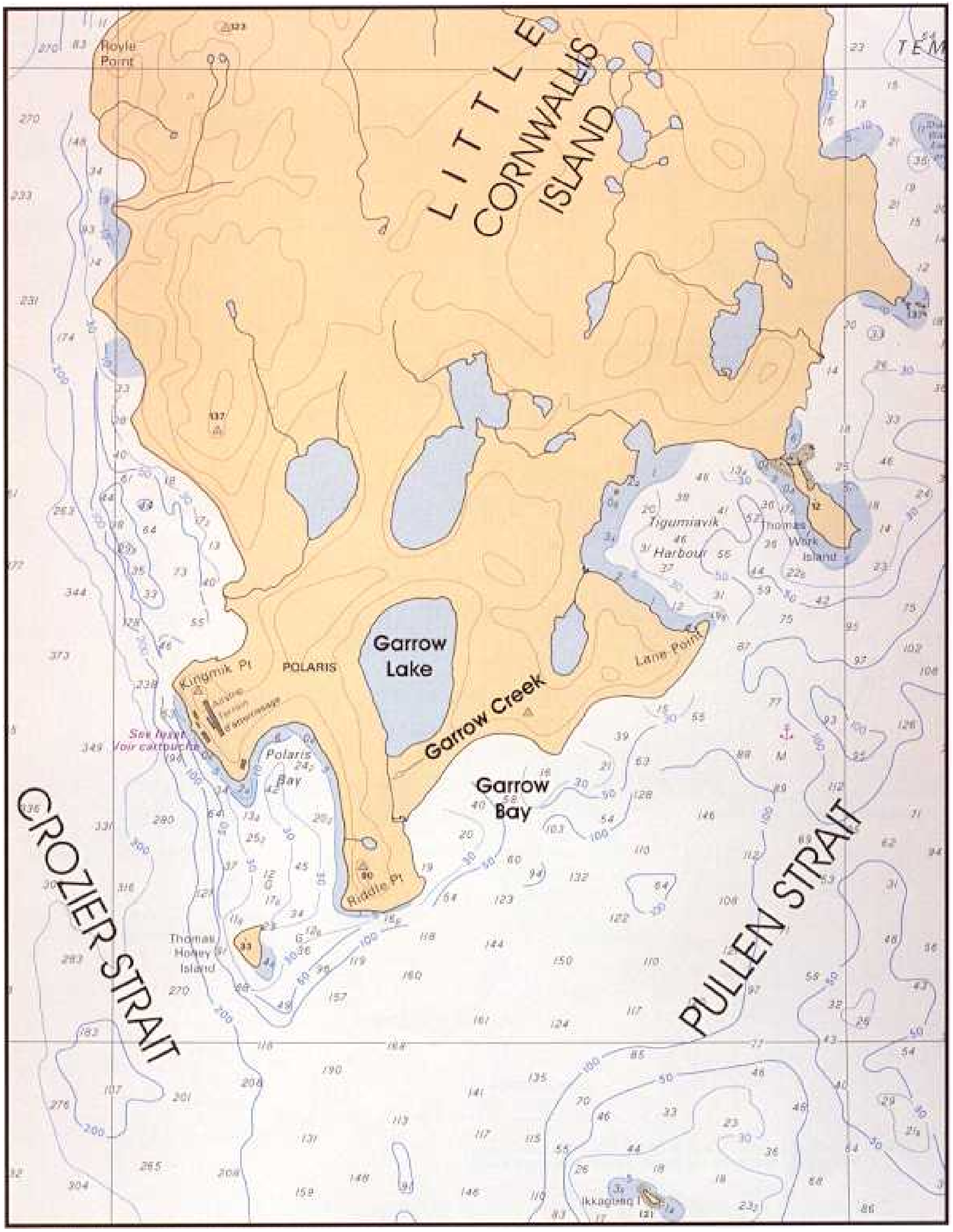


Figure 2. Location of Garrow Lake and Garrow Bay on Little Corwallis Island.

> When the effluent characterization work indicates that the concentration of effluent in the exposure area is greater than 1% at a distance of 250 m from a final discharge point, the biological monitoring studies must include a fish population survey and fish tissue analysis.

Under the MMR, the final discharge point for the effluent flowing out of the tailings impoundment in Garrow Lake has been designated as the point where Garrow Creek enters Garrow Bay (Figure 2). Using this interpretation, the Regulations require the dispersion and dilution of effluent to be determined in the marine waters of Garrow Bay.

The effluent flowing into Garrow Bay forms a surface plume, where it is transported away from the final discharge point by the effects of ocean currents. These currents result primarily from the effects of tides, winds, and density differences in the water column. As the plume is transported away from the discharge point, the effluent mixes with the ambient marine water and is diluted as it is dispersed.

This report describes the work completed by Sea Science Inc. to provide preliminary estimates of the dilution and dispersion of the effluent plume in Garrow Bay. These estimates have been based on the available data as described in Section 2, and have been conducted using the numerical modelling techniques described in Section 3. A discussion of the project results is presented in Section 4.

2 SITE CHARACTERISTICS

The seasonal discharge of effluent from Garrow Lake enters the marine waters of Garrow Bay as a surface plume, where it mixes with the ambient ocean water as it travels away from the mouth of Garrow Creek. The rate of mixing, or dilution, of the effluent plume depends upon a number of factors:

- The physical characteristics of the effluent discharge system;
- The effluent density and flow rate;
- The density structure of the marine waters; and
- The ocean currents and circulation patterns.

This section summarizes the available information and data used to assess the dilution of the effluent plume in Garrow Bay. The characteristics of the effluent discharge will first be discussed, followed by the characteristics of the receiving environment as they pertain to effluent dilution.

2.1 Discharge System and Effluent Characteristics

Tailings from the Polaris Mine were discharged to the bottom waters of Garrow Lake over the period of mine operation from 1981 through to the summer of 2002. The physical and chemical characteristics of Garrow Lake have been studied prior to development of the mine (e.g. B.C. Research 1975, 1978), throughout mine operation as part of the environmental monitoring program (e.g. Fallis et al. 1987, McElroy 1988) and as part of recent studies related to mine closure (e.g. Erickson and Bennett 2001).

Garrow Lake is shown in Figure 3. The lake is meromictic, permanently stratified into three well-defined layers:

1. A well-mixed, aerobic surface layer with slightly brackish water;
2. A deep, anaerobic bottom layer with salinities almost three times that of ocean water and high concentrations of dissolved sulphide; and
3. An intermediate halocline, or zone of rapidly increasing salinity, providing a transition between the surface and bottom waters of the lake.

Figure 3. Garrow Lake, showing the dam across the outlet and Garrow Bay in the background.

The lake is frozen throughout much of the year, with periods of unstable ice or open water typically extending from July through September each year. The natural inflow to the lake occurs as a combination of early-summer snowmelt and summer rainfall events. Using the mean total yearly precipitation of 13.6 cm as measured at Resolute (B.C. Research 1975) and the watershed area of 14.7 km^2 (B.C. Research 1978) yields an estimated average annual inflow volume to Garrow Lake of 2 million m^3 of water each year. This natural inflow volume can be equated to an average annual fluctuation in water level in Garrow Lake of roughly 0.5 m.

1.1.1 Discharge System

The discharge from Garrow Lake flows through Garrow Creek (Figure 4) to the ocean at Garrow Bay. Prior to mine development, the creek outflow was described as "diffuse, with no clearly-defined creek channel" (B.C. Research 1978). A single measurement of natural discharge through Garrow Creek was obtained in August 1974; at this time, the discharge rate was 0.21 m^3s^{-1}, with an average flow depth of 10 cm. In August 1977, the flow in Garrow Creek was described as primarily sub-surface, with minimal observable surface flow. No other observations of the natural discharge in Garrow Creek (prior to the addition of mine tailings to Garrow Lake) were available for use in this project.

Figure 4. Garrow Creek as seen from the vicinity of the Garrow Lake outlet.

The disposal of thickened tailings to the bottom waters of Garrow Lake added a volume of approximately 1 million m^3 per year to the lake, increasing the annual fluctuation in lake levels and consequently increasing the annual discharge to Garrow Bay. Monitored discharges through Garrow Creek are shown in Figure 5 for the period 1984 through 1989. These flows include both the natural outflows from the lake and the additional flows related to tailings disposal. Assuming that the level of the lake outlet did not change over the measurement period, the consequence of tailings disposal would be to increase the volume of surface water discharged from the lake by an amount equivalent to the volume of tailings added each year.

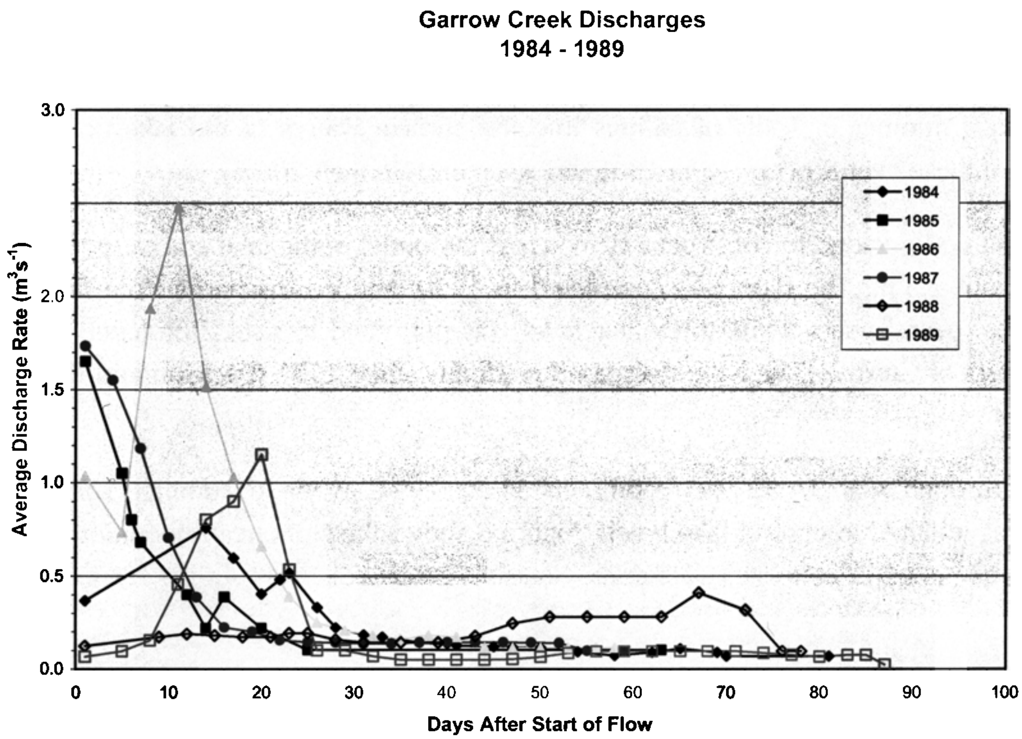


Figure 5. Monitored discharge rates for Garrow Creek, covering a time period when Garrow Lake was utilized for tailings disposal.

In a typical year, the highest measured flow rates were on the order of 1.7 m^3s^{-1} and occurred near the beginning of the discharge period. The high initial discharges are thought to be associated with snowmelt and/or rainfall events while the lake is still ice-covered (McElroy 1988). The highest recorded flow rate of 2.5 m^3s^{-1} was measured in 1986. The discharge rate typically drops rapidly over the first month of flow, reaching a relatively stead flow of about 0.2 m^3s^{-1} for the remaining ice-free period. The maximum time period over which flow occurred in Garrow Creek was 90 days, in 1989.

No information was available regarding the methods used to measure the discharge rates shown in Figure 5. However, it appears that the total volume discharged from the lake was measured or estimated at periodic intervals ranging from daily to monthly, with average flow rates then calculated for the period between measurements. Thus, shorter-term flows in Garrow Creek may have varied significantly from those shown in Figure 5. It is not known if peak discharges in the creek are adequately represented by these measurements.

Over a several year period in the mid-1980's, monitoring of the chemical properties of Garrow Lake indicated both increasing zinc levels in the surface waters of the lake and a slow, upward displacement of the halocline layer. These changes have been attributed primarily to a number of spills of tailings into the surface waters of the lake; the most significant of these events occurred in 1985 (Erickson and Bennett 2001).

As a result, it was decided to construct a dam across the outlet of the lake and raise the lake level by about 2.5 m. The dam was completed in 1990, and no discharge from the lake occurred for several years while the water level was permitted to rise. Zinc levels in the surface waters of Garrow Lake have decreased gradually since 1991 (Erickson and Bennett 2001).

Discharge through Garrow Creek recommenced in 1994, when a summer siphoning program was initiated to control lake levels. Figure 6 shows the siphons in operation on 23 July 2003.

Figure 6. Siphoning of Garrow Lake surface water across the outlet dam into Garrow Creek (looking downstream).

In the mine closure planning process, the decision was made to remove the Garrow Lake dam, return the lake to its previous level and allow natural drainage to occur. Drawdown was commenced in 2000, with plans to remove the dam in the spring of 2004 and allow natural drainage patterns to resume. Effluent discharge volumes and average discharge rates over the season are given in Table 1 for the years from 1994 through 2003 (Randy Baker, Azimuth Consulting Group, per. comm., 2003).

Table 1
Effluent Discharge Volumes and Rates
Garrow Lake, 1994 – 2003

Year	Discharge Duration	Number of Days	Total Annual Discharge (m^3)	Mean Discharge Rate (m^3s^{-1})
1994	July 12 - Sept 13	63	1,034,136	0.19
1995	July 12 - Sept 12	60	2,862,470	0.55
1996	July 22 - Oct 7	78	2,652,081	0.39
1997	July 21 - Oct 7	79	3,256,677	0.48
1998	July 2 - Aug 25	55	2,165,671	0.46
1999	July 13 - Sept 30	80	2,446,242	0.35
2000	July 20 - Sept 30	72	4,262,427	0.68
2001	July 24 - Sept 25	63	2,955,954	0.54
2002	July 26 - Oct 3	69	5,048,667	0.85
2003*	late July - late Sept	60	6,500,000	1.25

*Projected flow based on planned drawdown of lake; actual data not available for this project.

At moderate flow rates, Garrow Creek discharges through a distinct channel as can be seen in Figure 4. The creek drops roughly 7 m in elevation over a distance of 1450 m between the lake outlet and the creek mouth at Garrow Bay. On entering the bay, Garrow Creek crosses a coarse sand and gravel beach approximately 100 m in width. Figure 7 shows the channel mouth in August 2003, with a discharge rate of roughly 1.0 m^3s^{-1}. Under this flow rate, the channel was about 0.3 m deep and 6 m wide at the mouth.

Figure 7. Garrow Creek at the entrance to Garrow Bay.

2.1.1 Effluent Characteristics

The difference in density between the effluent leaving Garrow Creek and the receiving waters in Garrow Bay is a significant factor affecting effluent dilution. For both the effluent and the receiving waters, the primary factors influencing density are temperature and salinity. The salinity and temperature characteristics of the marine waters in Garrow Bay are discussed in more detail in Section 2.2.2 of this report.

Although there are few salinity and temperature measurements available for the creek itself, there is an extensive database of historical data for the surface waters of Garrow Lake, the source of Garrow Creek waters. The long-term trends in salinity of the surface waters of Garrow Lake are shown in Figure 8, which compares field observations with the predictions of a numerical model for the physical and chemical characteristics of Garrow Lake (Erickson and Bennett 2001). This figure illustrates both the long-term variability in surface salinities in Garrow Lake and the expected future trend once tailings discharge had ceased. It can be seen that both historical and predicted mean salinities in the surface waters of Garrow Lake vary over the range between about 5‰ and 8‰.

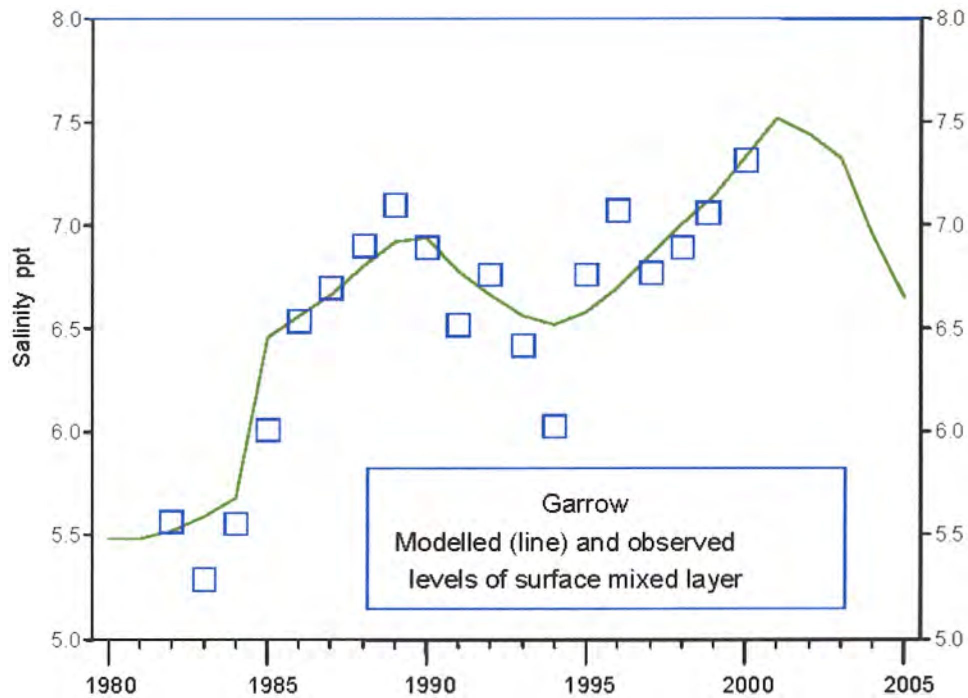


Figure 8. Long-term trends in the mean salinity of the surface layer of Garrow Lake, comparing actual measurements (blue boxes) with model predictions (Erickson and Bennett 2001).

The limited measurements of salinity in Garrow Creek show some variability over the course of a single summer discharge season. Early in the season, while Garrow Lake is still essentially ice-covered, the discharge through Garrow Creek consists of a high percentage of snowmelt water and a relatively low percentage of surface water from the lake. At this time, the salinity in Garrow Creek is lower than that in the lake, and can be assumed to be near 0‰. As the discharge season progresses and the surface of Garrow Lake becomes free of ice, this ratio changes until the salinity of the discharge in Garrow Creek is essentially the same as that of the surface waters in the lake.

Historical data for temperatures of the surface waters of Garrow Lake suggest a range between about 0°C and 4°C. Measurements of the effluent temperature collected from late

July through the end of September 2001 are shown in Figure 9. The range of observed effluent temperatures through this single discharge season is similar to the historical range for the surface waters of Garrow Lake. A trend towards decreasing water temperatures as the discharge season progresses is evident in Figure 9, albeit with large scatter. This trend may reflect the changing composition of the effluent over time from essentially freshwater runoff to primarily brackish lake water, combined with decreasing ambient air temperatures through August and September.

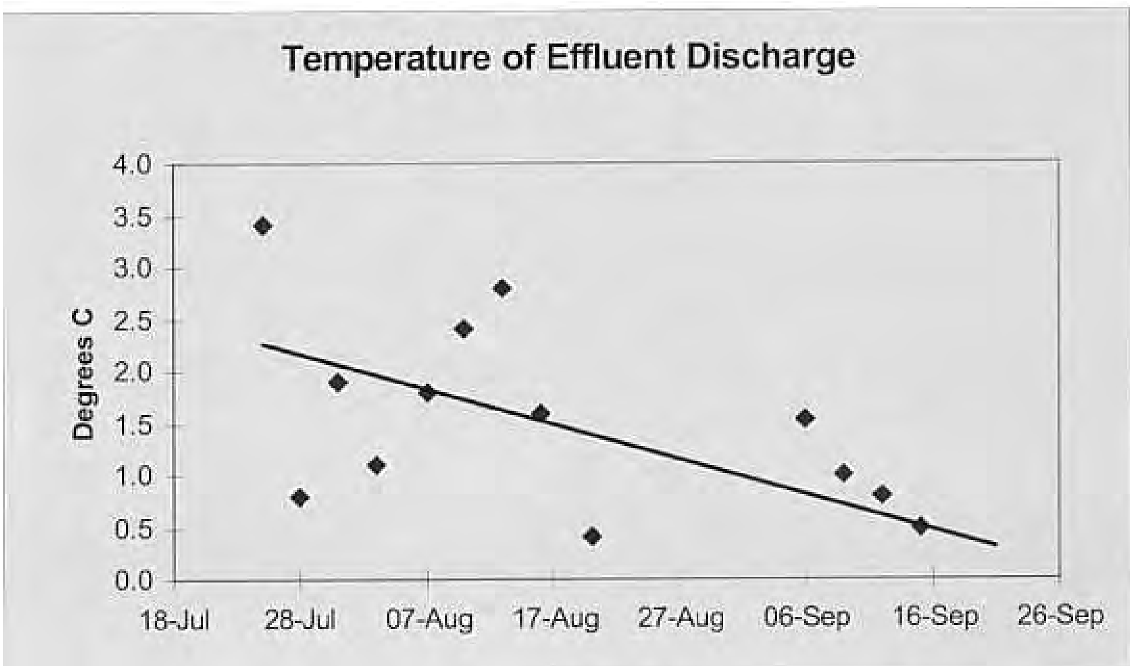


Figure 9. Temperature of Garrow Creek flows measured during the 2001 discharge season.

2.2 Receiving Environment

The discharge from Garrow Lake flows through Garrow Creek to the ocean at Garrow Bay (Figure 2 and Figure 7), where it enters the marine waters as a surface discharge. The factors impacting effluent dilution in the marine environment include the geometry of the discharge area, the density structure of the water column, and the ocean currents and circulation patterns.

2.2.1 *Bathymetry and Water Levels*

Garrow Bay is located on the eastern side of Riddle Point, at the southern end of Little Cornwallis Island (Figure 2). At Riddle Point, the waters of McDougall Sound to the south of Little Cornwallis Island split into Crozier Strait to the west and Pullen Strait to the east.

Garrow Bay forms a relatively open embayment, facing southeast onto the waters of Pullen Strait. The bay extends roughly 3.5 km in the shore-parallel direction, and 1.0 km from the shore to the comparatively open waters of Pullen Strait. Garrow Creek enters the bay towards the southern end, but well within the embayed area (Figure 2).

The available bathymetric information in Garrow Bay is limited, with the published chart information based on selected spot measurements obtained through the ice during the Polar Continental Shelf Project in 1979. Shoal areas were not identified and charted. These data suggest a gradually sloping seabed from the shoreline out to water depths of about 50 m at the mouth of the bay. Diver observations indicate the near-shore areas of the seabed to be highly disturbed by ice-scouring.

Water levels have been measured at the mine site in Cominco Bay by the Canadian Hydrographic Service. Tides in the area are mixed semi-diurnal, with a range of 1.4 m on a large tide and 0.9 m on a mean tide. Mean water level is 0.9 m above chart datum. Water level information is summarized in Table 2.

Table 2
Tidal Fluctuations in Water Level, Elevations Above Chart Datum
Little Cornwallis Island

	Higher High Water	Lower Low Water
Large Tide	1.3	-0.1
Mean Tide	1.1	0.2

2.2.2 *Water Column Density Structure*

The density structure of the water column is determined by the variations in temperature and salinity with water depth. Local measurements of salinity and temperature are limited, and, for the purposes of this project, have been supplemented with regional data. The available data include both through-ice measurements and measurements during the open water season. The focus of this project is on conditions during the open water season, primarily the months of July, August and September.

A series of six CTD (conductivity-temperature-depth) profiles through the water column were collected in a transect across McDougall Sound on 3 September 1997. Surface ice was not present in the sound at the time. The measurements typically show temperature and salinity increasing with depth at least in the surface layer, with the top of the halocline or thermocline often found only a few metres below the water surface. Surface salinities ranged from 30.9‰ to 31.6‰, and from 32.3‰ to 32.5‰ in deeper waters. Surface water temperatures varied between -1.7°C and -1.3°C, with maximum values in deeper waters ranging from -1.3°C to -1.1°C.

The results of CTD casts in Garrow Bay were reported by Axys Environmental Consulting (1991). In September, they found the water column to be stratified, with salinities varying between 30.4‰ at the water surface, 31.5‰ at 17 m water depth and 32.0‰ at 36 m depth. Temperatures increased from -1.6°C at the surface to -0.7°C at depth.

Selected spot measurements of salinity and temperature were obtained at two stations in Garrow Bay by B.C. Research (1978) on 28 August 1977. The data from Station 2, away from the mouth of Garrow Creek, indicate salinity readings of 31.7‰ at the water surface and 33.0‰ at both 10 and 20 m water depths. Recorded temperatures were 3.7°C at the water surface and 4.1°C at 5 m water depth.

Both the local and regional under-ice measurements indicate a uniform water column, with salinities very near to 33.0‰ and temperatures of approximately -1.7°C.

2.2.3 Ocean Currents and Circulation Patterns

Ocean currents arise primarily through the actions of tides, the effects of density differences in the water column, atmospheric forcing and storm events. In the case of surface waters, local winds can play a major role in determining water movements.

No local measurements of ocean currents in Garrow Bay were available for use in this project. Regional-scale measurements of ocean currents in Crozier and Pullen Straits were made in 1977 from late spring through summer; these measurements show the strong dominance of under-ice flows by tidal currents. The Pullen Strait records show mid-depth currents speeds ranging up to 0.40 ms^{-1}, with mean speeds on the order of 0.20 ms^{-1}. Surface currents were weaker due to the proximity of the instrument to the ice boundary.

These measurements were made in the narrow section of Pullen Strait between Wilkes Point on Little Cornwallis Island and Marshall Peninsula on Cornwallis Island. Garrow Bay fronts onto a wider and deeper portion of Pullen Strait, where currents are expected to be significantly weaker than those measured in 1977. Garrow Bay itself is somewhat shielded from the open channel currents by the headlands to the northeast and southwest (Riddle Point).

The tidal currents in the Arctic Archipelago have been modelled by Dupont et al. (2002). The model grid is not sufficiently detailed to resolve Garrow Bay itself, but the model predictions indicate very low current speeds adjacent to Little Cornwallis Island, typically less than a few centimetres per second. It is not known if a backeddy forms within Garrow Bay on certain tidal conditions.

Qualitative observations of currents within Garrow Bay have been made on several occasions. B.C. Research (1978) reported a pronounced along-shore current in Garrow Bay during both the flood and ebb tides, with current speeds estimated from roughly 0 to 0.3 ms^{-1}. The current was observed to flow along the shore in a southwards direction at all tidal stages. Azimuth Consulting Group (2003) describes very weak currents during their summer fieldwork program.

When tidal currents are very weak as appears to be the case in Garrow Bay, wind can play an important role in water movement, particularly for surface waters. For the purposes of this project, wind records from the airport at Resolute have been examined in order to estimate the effects of wind. Although there is an airport on Little Cornwallis Island, wind records were not available in a useable format.

Wind records for Resolute Airport were available for the period from 1967 through 2003. Monthly statistics for frequency of occurrence by direction and speed class were obtained. Wind conditions for the typical discharge months of July, August and September were compared. These records show that the strongest winds blow from the east, northeast and north, with mean wind speeds of 31, 28 and 25 $km \cdot hr^{-1}$, respectively. Wind speeds greater than 40 $km \cdot hr^{-1}$ occur less than 7.5% of the time in July and August, and roughly 13% of the time in September. Wind directions are variable, but blow less frequently from the south and southwest.

Using a "rule-of-thumb" for wind-driven currents of 3% of the wind speed in surface waters gives mean wind-driven current speeds on the order of 0.20 to 0.25 ms^{-1}. Although this is a simple, order of magnitude estimate and does not consider the effects of topography or bathymetry, it strongly indicates the dominance of wind-forcing over tides in determining the magnitude and direction of ocean currents in the surface waters of Garrow Bay.

3 PLUME DILUTION AND DISPERSION MODELLING

The dilution and dispersion of the effluent plume in the marine environment have been examined using the Visual Plumes software developed and distributed by the United States Environmental Protection Agency (Frick et al. 2003). The Visual Plumes software provides a graphical user interface and software management system for several plume dispersion models and represents the most recent version of a series of software systems developed by the USEPA for this purpose. These models are accepted as industry-standard for effluent plume analyses.

Of the various sub-models imbedded in the Visual Plumes system, the PDS (Prych-Davis-Shirazi) submodel has been selected for use in this project. The PDS model has been designed to simulate the discharge of a buoyant fluid into the surface layer of a moving ambient body of water. The model includes the effects of buoyant spreading and surface heat transfer. The model is a Eulerian integral flux model originally coded in Fortran but embedded in Visual Plumes as executable routines.

As the plume moves away from the discharge point (in this case, the mouth of Garrow Creek), it is subject to buoyancy, drag and interfacial shear forces. These forces act to keep the plume at the water surface, and cause it to spread as it moves away from the point of discharge. At the same time, ambient ocean water is entrained into the plume through the actions of both jet entrainment and ambient turbulent mixing. These mixing processes act to reduce the differences in composition between the plume waters and the ambient receiving environment.

The PDS model provides predictions of the plume width and depth as a function of distance away from the discharge location. In addition, the minimum and average plume dilutions are provided. The minimum plume dilution is assumed to occur along the plume centre-line, while the average dilution represents the mean value over the plume cross-section. Again, the mean and average dilutions are given as a function of distance away from the point of discharge.

The PDS model assumes a Gaussian distribution in the horizontal direction. For the purposes of this project, the position of the 1% concentration limit has been calculated using the available model outputs and the theoretical assumptions embedded in the model formulation.

A sensitivity analysis has been performed by varying the model input parameters over the range of effluent and receiving water conditions described in Section 2 of this report. This analysis has shown that the model predictions for effluent dilution are relatively insensitive to the temperature and salinity of both the Garrow Creek and Garrow Bay waters. Over the range of observed values, the density differences between the effluent and the receiving waters are sufficient to maintain a stable, buoyant plume at the water surface, at least within the near-field region.

The two factors which have the greatest impact on the dilution of the plume as it moves away from the point of discharge are the initial discharge velocity (Garrow Creek) and the currents in the ambient receiving waters (Garrow Bay). These factors impact both the initial jet entrainment and the rate of turbulent mixing between the effluent and receiving waters. The initial discharge velocity varies with both the effluent discharge rate and the cross-sectional area of the creek channel; available information is summarized in Section 2 of this report. In general, the dilution of the effluent plume increases with both increasing discharge velocity and increasing current speed in Garrow Bay.

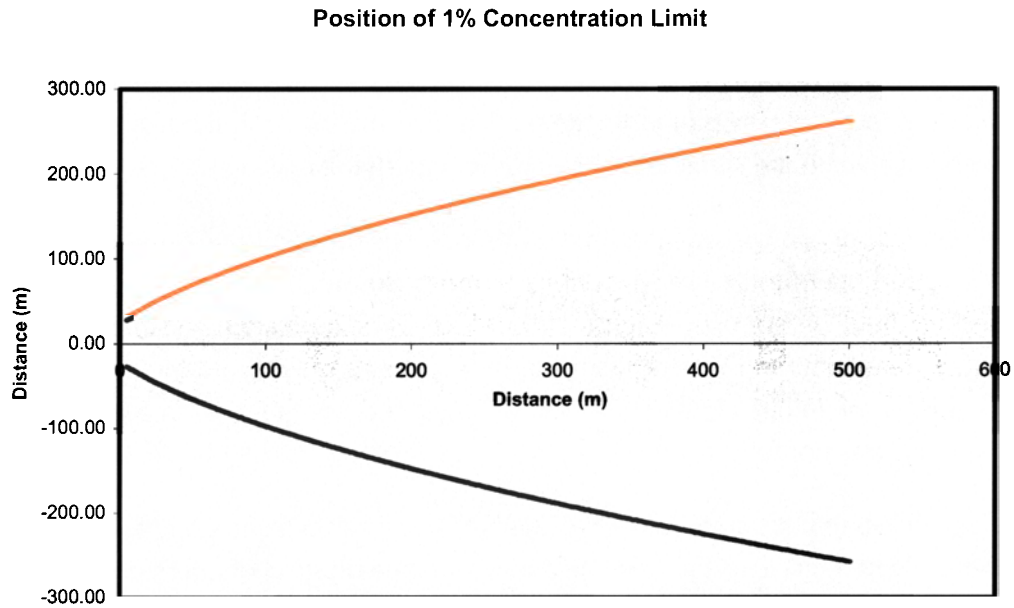
The main goal of this study has been to assess the near-field plume dilution and dispersion under both typical and extreme conditions at the Polaris site. For this study, a typical effluent discharge rate has been taken as 0.2 m^3s^{-1}, and a "worst-case" discharge of 2.5 m^3s^{-1} (see Figure 5). It should be remembered that these values are likely to be conservative, in that they include the volume of water displaced by mine tailings discharged to the bottom waters of Garrow Lake during the period from 1984 through 1989.

Model predictions have been given over a distance of 500 m from the point of discharge at the mouth of Garrow Creek. Beyond this region, it is felt that the model assumptions lose validity and a far-field approach should be used. The 500 m distance was selected on the basis of a qualitative analysis and has not been based on detailed computations.

3.1 Typical Discharge Conditions

Figure 10 shows the behaviour of the effluent plume for the typical effluent discharge rate of 0.2 m^3s^{-1} with minimal currents in the receiving environment (0.03 ms^{-1}). The top portion of the figure shows the position of the 1% effluent concentration line relative to the point of discharge at the mouth of Garrow Creek (located at the graph origin). The bottom portion of the figure shows the average plume dilution and plume thickness as a function of distance away from the point of discharge.

As the plume moves away from the discharge point at Garrow Creek, it gradually widens and spreads horizontally. The initial increase in plume thickness and relatively rapid entrainment of ambient water are driven by the jet entrainment process; however, this



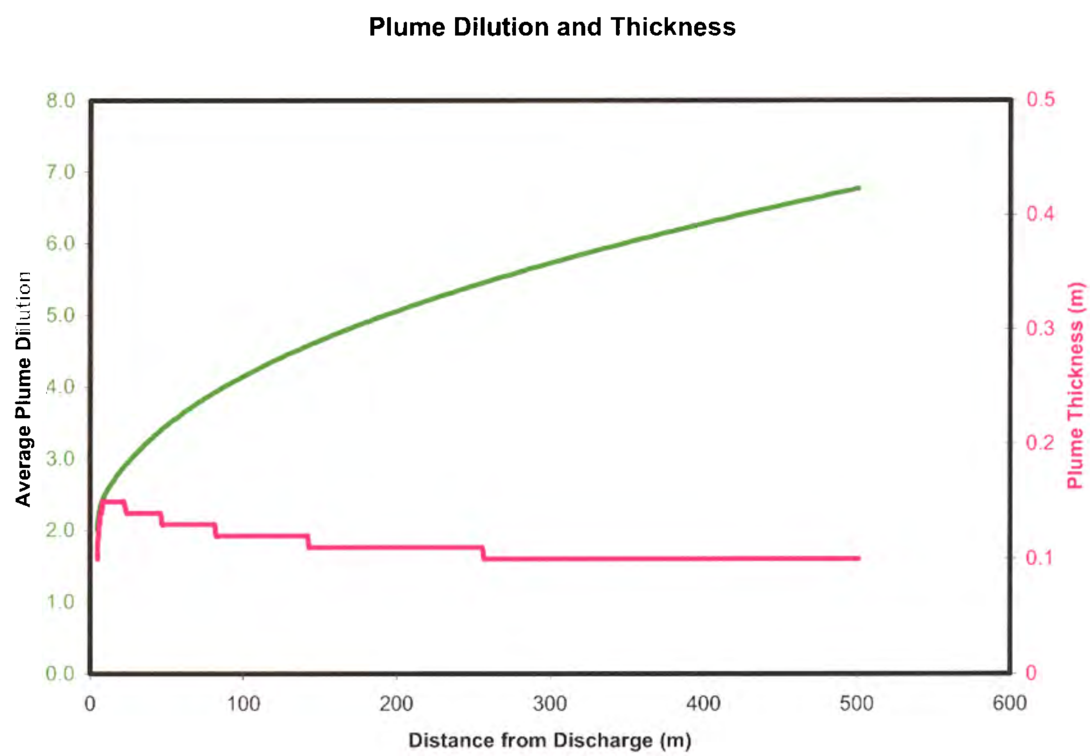


Figure 10. PDS model predictions for a discharge rate of 0.2 m^3s^{-1} and an ambient current speed of 0.03 ms^{-1}.

process is only important within a short distance of the discharge point. The much slower mixing driven by the ambient levels of turbulence is dominant over much of the plume. The ambient turbulent process is relatively slow, as can be seen by the low dilution levels and corresponding reduction in plume thickness. Vertical mixing is limited by the strong density difference between the surface plume and the underlying marine waters.

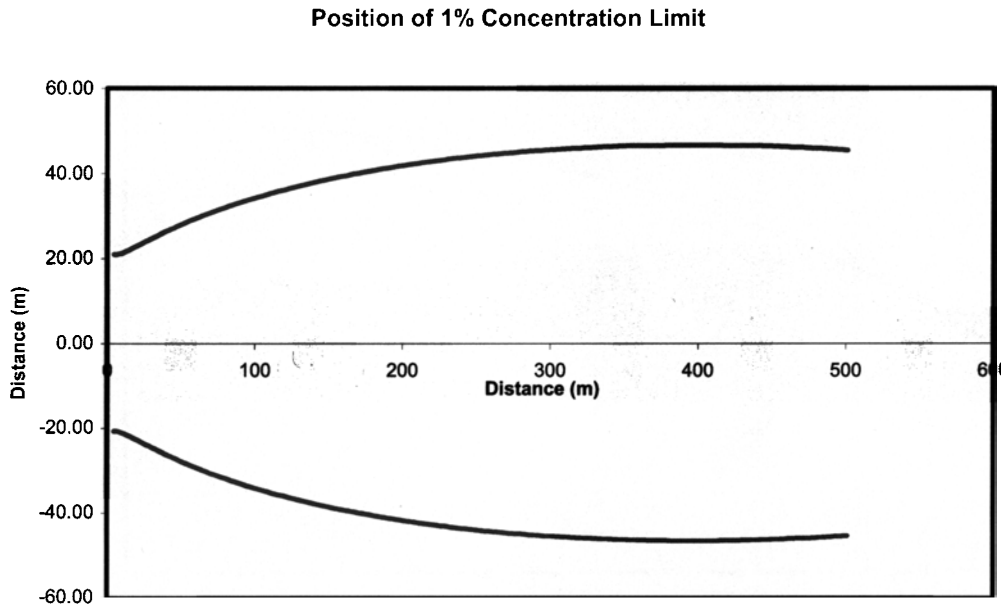
These model predictions are consistent with the observations of Azimuth Consulting Group (2003), who mapped the effluent concentrations in the region immediately adjacent to the discharge in their field program of August 2003. This work indicated a stable, buoyant plume overlying denser marine waters, with the plume thinning with distance away from shore. Some degree of initial effluent dilution is suggested by the field measurements, although the plume was not fully mapped.

For the typical effluent discharge rate of 0.2 m^3s^{-1} and low current conditions in the receiving environment, Figure 10 indicates an average plume dilution of approximately 5 at a distance of 250 m from the mouth of Garrow Creek. This corresponds to a mixture of effluent and ambient ocean water consisting of 20% effluent and 80% ocean water. At a distance of 250 m from the mouth of Garrow Creek, the width of the plume as defined by the 1% concentration line is about 340 m, and the plume thickness is approximately 0.1 m.

As discussed in Section 2, the effects of winds on surface currents are likely to be significant in Garrow Bay. Winds are persistent in the region, with mean wind speeds on the order of 30 $km \cdot hr^{-1}$. Using an order-of-magnitude approximation of 3% of the wind speed for surface currents leads to a wind-driven current speed of about 0.25 ms^{-1}.

Model predictions for a current speed of 0.30 ms^{-1} (wind plus tide) are given in Figure 11. A comparison of Figure 11 with Figure 10 clearly shows the enhanced ambient entrainment associated with the higher current speeds. This enhanced entrainment results in significantly higher average plume dilution and increasing plume thickness with distance away from the point of discharge. At a distance of 250 m, the average plume dilution is about 44 (corresponding to 2% effluent in the plume), the plume width is roughly 90 m between the 1% concentration lines, and the plume thickness is 0.5 m.

Figure 11 shows the plume behaviour for a variable current direction, up to the point where the plume attaches to the shoreline. Shoreline attachment is the expected behaviour for a plume exposed to relatively strong currents running in a shore-parallel direction. Once attached to the shoreline, ambient entrainment is reduced. Figure 12 shows the plume behaviour under a shore-parallel current with a speed of 0.30 ms^{-1}. In Figure 12, the shoreline is represented by the horizontal axis of the upper plot. At a distance of 250 m



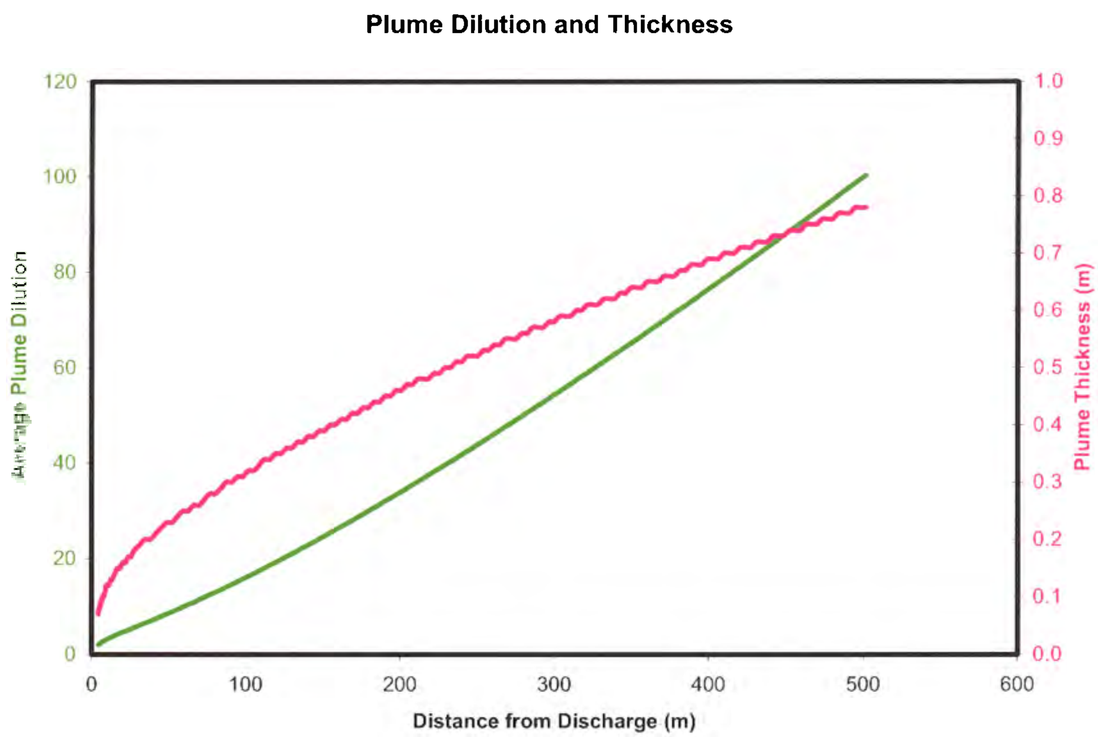
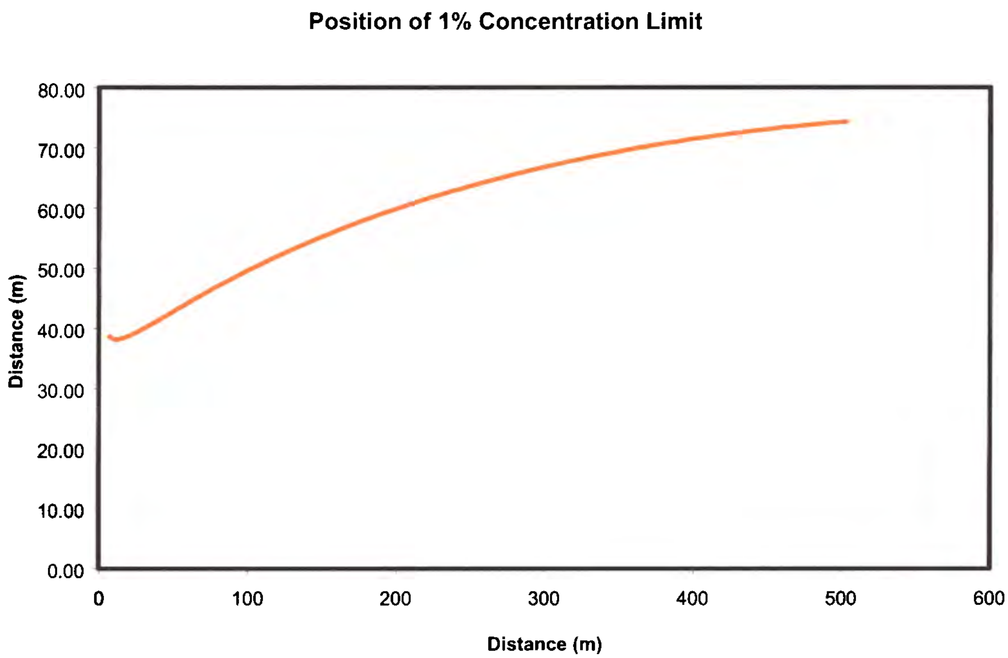


Figure 11. PDS model predictions for a discharge rate of 0.2 m^3s^{-1} and an ambient current speed of 0.30 ms^{-1}.



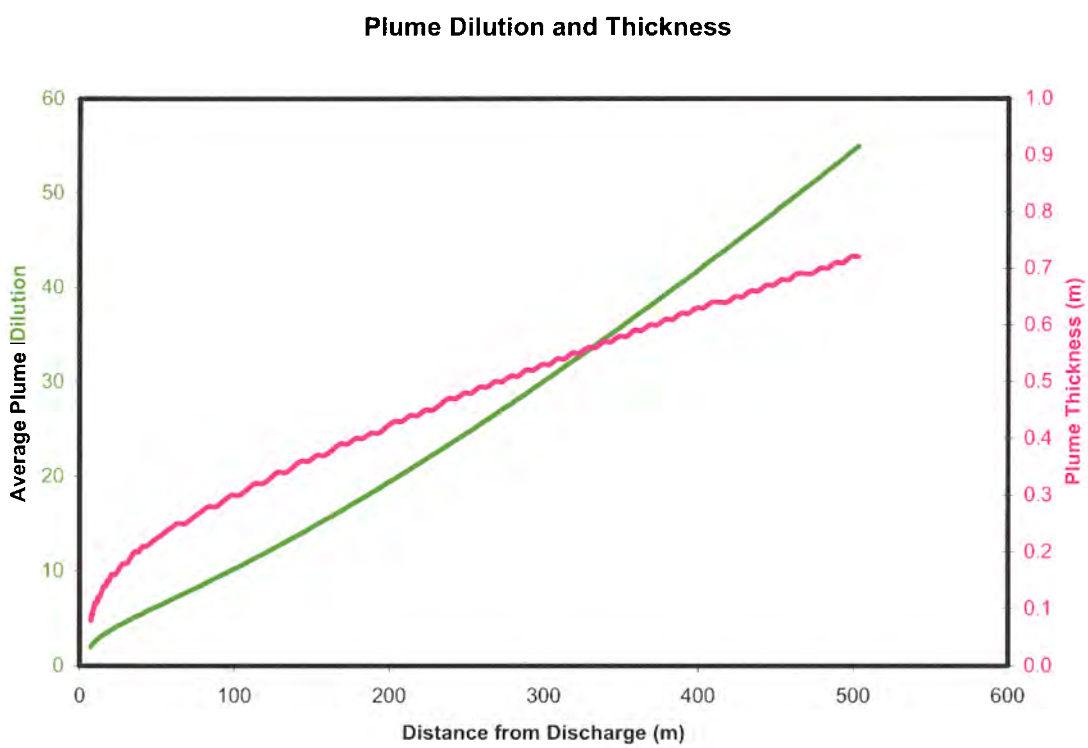


Figure 12. PDS model predictions for a discharge rate of 0.2 m^3s^{-1}, an ambient current speed of 0.30 ms^{-1} and a shore-attached plume.

from the point of discharge, the average plume dilution is estimated to be 24 (4% effluent), the plume extends 65 m from the shoreline to the 1% concentration line and the plume is predicted to be 0.5 m thick.

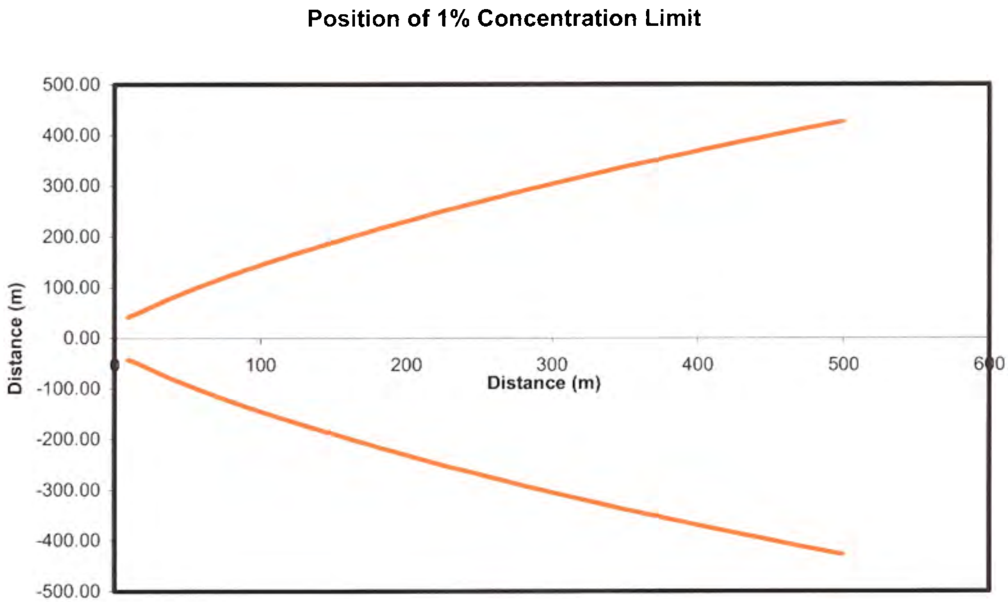
3.2 Extreme Discharge Conditions

A similar analysis has been performed using the estimated "worst-case" discharge value of 2.5 ms^{-1}. Figures 13 and 14 present the model predictions for cases with low (0.03 m^3s^{-1}) and moderate (0.30 m^3s^{-1}) current speeds, respectively. For the extreme discharge rate and low current speed in the receiving waters, Figure 13 indicates an average plume dilution of about 5 (20% effluent) at a distance of 250 m from the mouth of Garrow Creek. At this location, the width of the plume is roughly 535 m, with an estimated plume thickness of about 0.5 m.

Model predictions for a discharge rate of 2.5 m^3s^{-1} and an ambient current speed of 0.30 ms^{-1} are shown in Figure 14. Under these conditions, the PDS model predicts an average plume dilution of 13 (8% effluent), a plume width of 240 m and a plume thickness of 0.9 m at a distance of 250 m from the point of discharge. As for the lower discharge case described in Section 3.1, higher current speeds act to enhance ambient entrainment and increase plume dilution in comparison with the case where current speeds in the receiving waters are relatively slow.

A comparison with the model predictions for the typical discharge rate of 0.20 m^3s^{-1} (Section 3.1) indicates that the plume dimensions (width and thickness) are significantly larger for the higher discharge, as would be expected. For the low current case, plume dilutions are similar. However, there are significant differences between the plume dilutions at the different discharge rates for the moderate ambient current conditions. A comparison of Figure 14 with Figure 11 shows that plume dilutions are three to four times higher at the lower effluent discharge rate. This difference is likely a consequence of the proportionately lower surface area available for horizontal entrainment of ambient water into the larger plume at the higher discharge rate.

The case where the plume attaches to the shoreline is shown in Figure 15. Again, the shoreline is represented by the horizontal axis of the upper plot. At a distance of 250 m from the point of discharge, the average plume dilution is about 8 (13% effluent), the plume extends 155 m from the shoreline to the 1% concentration line and the plume is 0.8 m thick. If the plume attaches to the seabed as well as to the shoreline, the dilution will be reduced from the values given here.



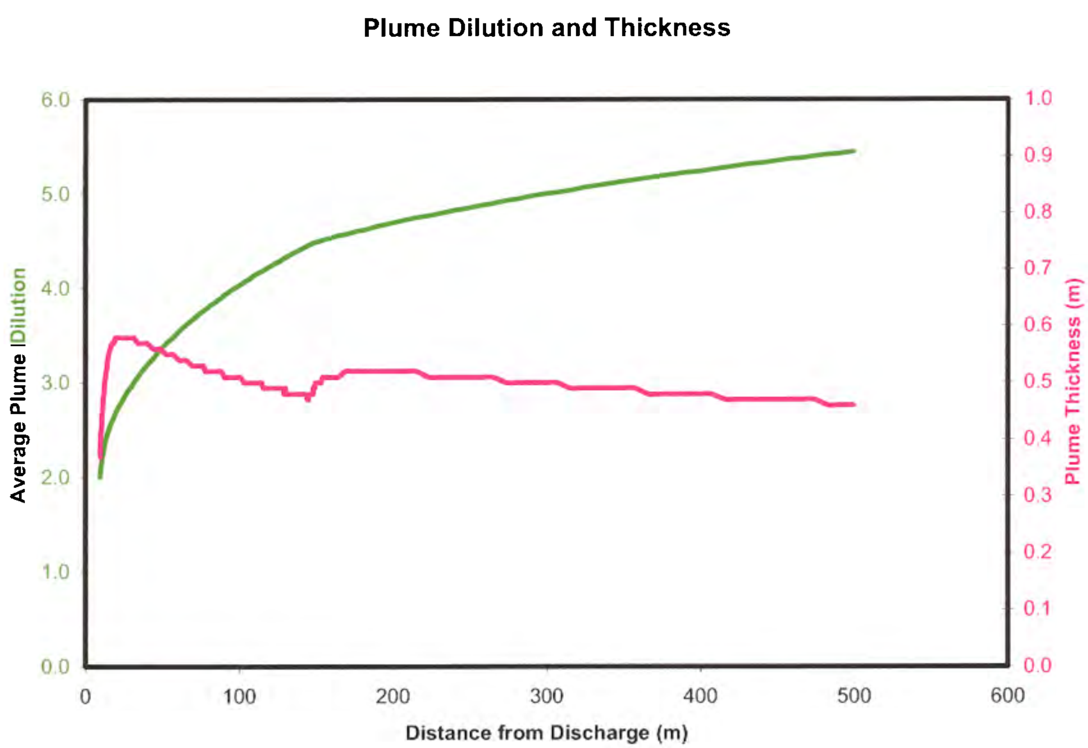


Figure 13. PDS model predictions for a discharge rate of 2.5 m^3s^{-1} and an ambient current speed of 0.03 ms^{-1}.

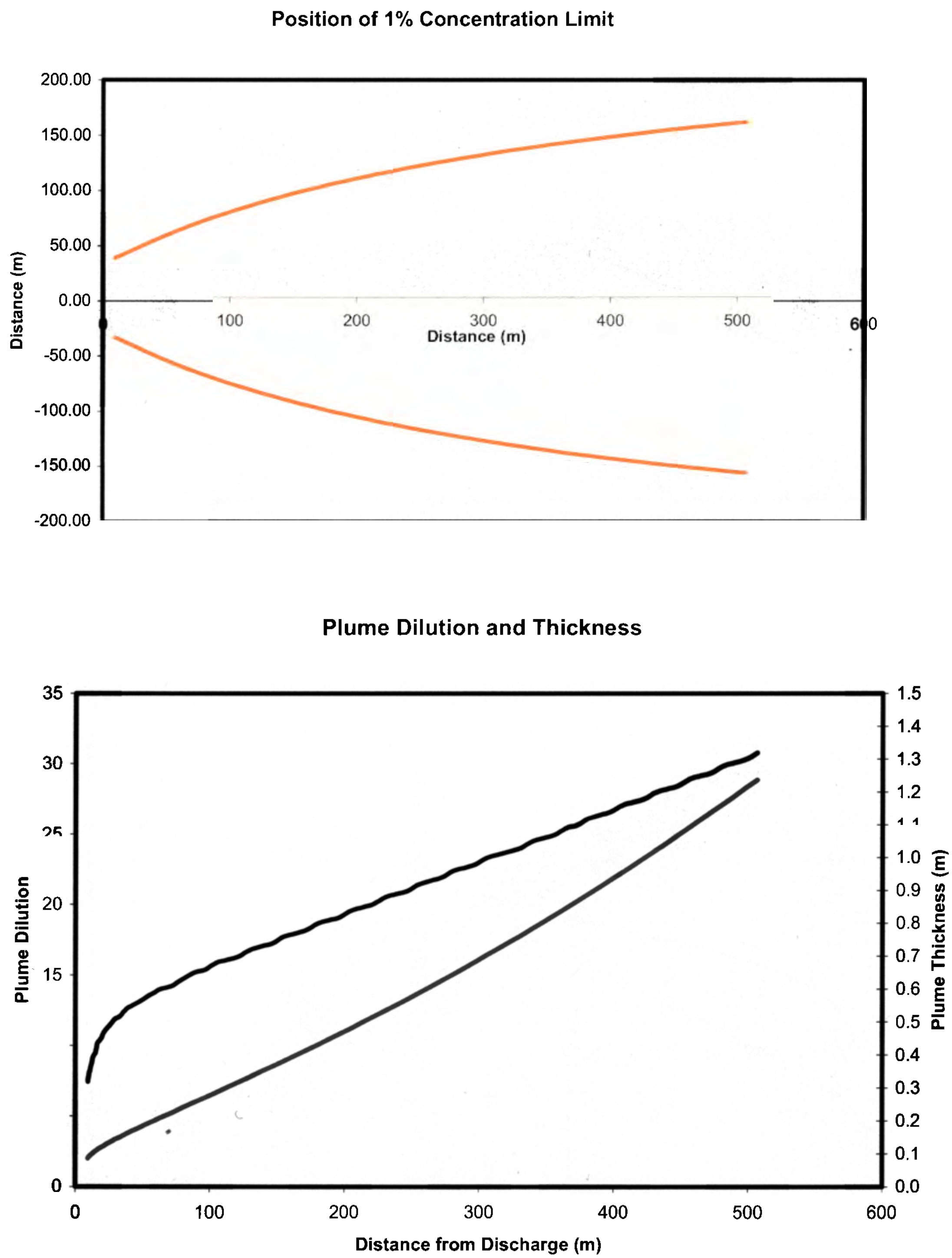
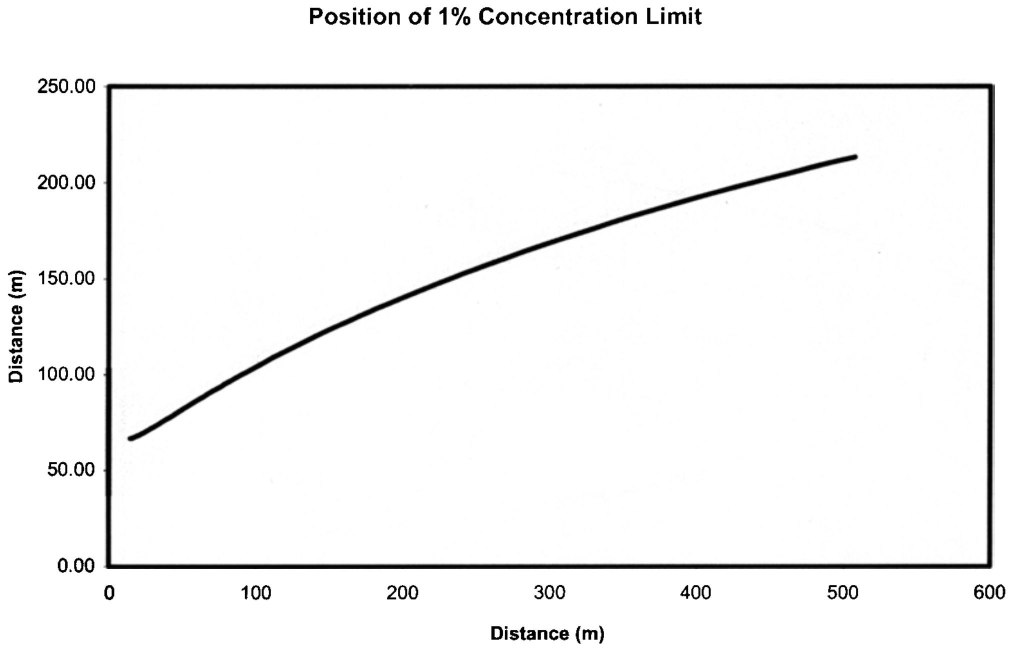


Figure 14. PDS model predictions for a discharge rate of 2.5 m^3s^{-1} and an ambient current speed of 0.30 ms^{-1}.



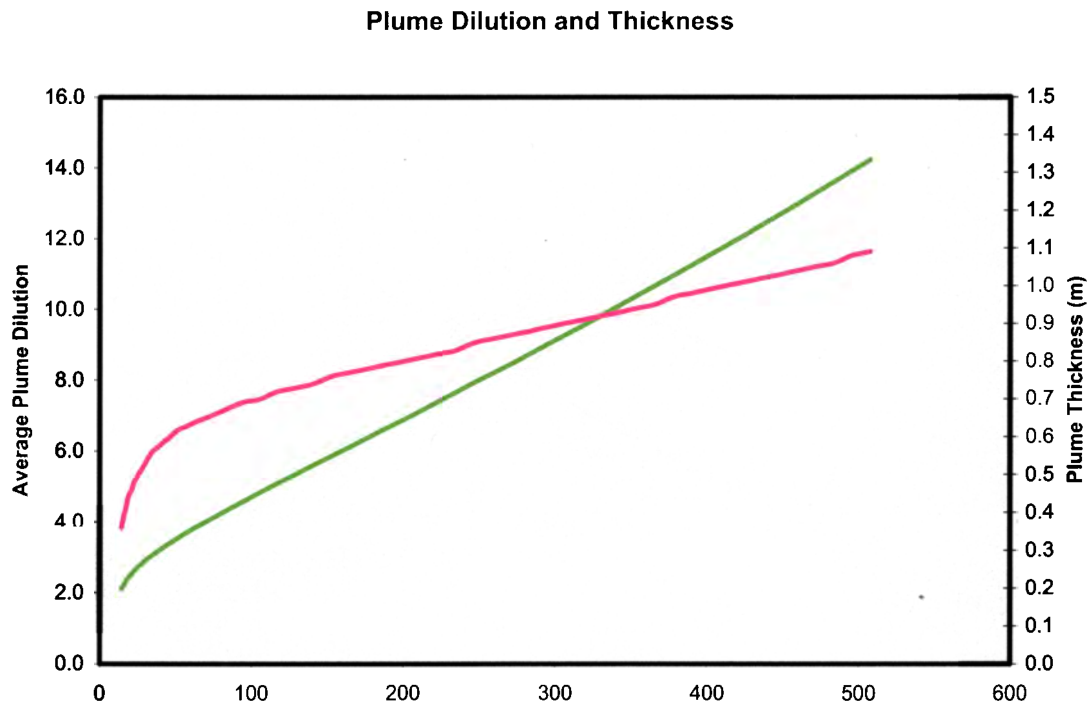


Figure 15. PDS model predictions for a discharge rate of 2.5 m^3s^{-1}, an ambient current speed of 0.30 ms^{-1} and a shore-attached plume.

3.3 Uncertainty in Model Predictions

There are two main sources of uncertainty inherent in this plume modelling exercise. These are uncertainties in our current state of knowledge regarding the dynamics of plume dilution and dispersion, and uncertainties in the appropriate model input parameters to use in this project.

With respect to uncertainties in the current state of knowledge regarding the dynamics of plume dilution and dispersion, one of the largest uncertainties is associated with the distribution of effluent across the plume cross-section. Most models include assumptions about the shape of this distribution; the PDS model used in this project uses a Gaussian formulation. Different assumptions about the shape of this distribution can lead to significant differences in the calculation of peak-to-mean dilution ratios and plume dimensions. This is a topic of current research (Frick et al. 2003).

Secondly, the analyses presented in this report include the effects of winds through the generation of surface currents. There is no differentiation in the model formulation between entrainment by wind-generated currents and entrainment by currents generated by other processes. This is a common factor of all of the plume models supported by the USEPA. As a result, the models may underestimate the plume dilution under certain conditions by under-estimating the vertical component of mixing induced by wind shear.

The sensitivity analyses conducted in this project have shown that variations in the effluent discharge velocity for a fixed discharge rate can impact the average plume dilution by at least a factor of two. Extremely limited information was available for this project on the relevant discharge characteristics at different discharge rates. The return period associated with the extreme discharge value of 2.5 m^3s^{-1} used in this project is unknown.

This project has shown the plume dilutions to also be sensitive to the ambient currents in the receiving waters. No measurements of currents were available for this project, hence the uncertainty associated with the current velocity estimates is not known.

During the period of high flows at the beginning of the discharge period, there typically are large numbers of ice floes in Garrow Bay. The floes may be floating in the bay or grounded near the shoreline or in the mouth of Garrow Creek. The impacts of ice on plume dilution are not well known. Care must be taken when using salinity data to map the presence of the effluent plume to differentiate between Garrow Creek water and water from melting ice floes in the bay.

4 SUMMARY AND DISCUSSION

The primary goal of this project has been to assess the initial dilution and dispersion of the effluent plume entering Garrow Bay from Garrow Creek, focusing on the 1% concentration limit under typical and extreme conditions. In achieving this goal, the relevant site data have been reviewed and assessed, and a specialized numerical modelling tool applied.

The review of the available site data has shown that information is limited for both the characteristics of the effluent and of the receiving waters. In terms of the effluent discharging from Garrow Creek, limited information is available with respect to the variability in discharge rates to be expected once the dam has been removed from Garrow Lake and the natural hydrological regime restored. The discharge rates used in this study may be conservative, in that they are based on measurements made during the period when tailings disposal to Garrow Lake was ongoing. However, a hydrologic assessment of the lake and creek would be required in order to determine the reduction in the high initial flows to be expected under natural flow conditions.

Of equal importance is the discharge velocity, which is a function of the discharge rate and the cross-sectional area of the discharge channel at the point of discharge. For natural channels, the cross-sectional area varies with discharge rate and can change over time in response to channel erosion and sedimentation. The available information consists of two observations of channel configuration at different times and different discharge rates.

Similarly, the current velocities in the receiving waters of Garrow Bay are the major factor impacting the plume behaviour in the turbulent entrainment phase. Currents in Garrow Bay have been estimated based on anecdotal observations and using order-of-magnitude estimation techniques applied to wind data from the town of Resolute. No actual measurements of currents within the bay were found for use in this project.

The PDS numerical model and the Visual Plumes model interface developed and distributed by the USEPA have been used to assess the near-field plume behaviour in Garrow Bay. The model has been run for three different current conditions in Garrow Bay, using estimated typical and extreme discharge rates from Garrow Creek. The results of this modelling exercise are summarized in Table 3, giving values for plume dilution and dimensions at a distance of 250 m from the mouth of Garrow Creek. The plume dilutions are given as a dilution ratio with percent effluent in brackets.

Table 3
Plume Characteristics at 250 m from the Point of Discharge

Discharge Rate ($m^3 s^{-1}$)	Ambient Currents	Plume Characteristics		
		Average Dilution	Width (m)	Thickness (m)
0.2	low	5 (20%)	340	0.1
0.2	moderate	44 (2%)	90	0.5
0.2	moderate, shore-parallel	24 (4%)	65	0.5
2.5	low	5 (20%)	535	0.5
2.5	moderate	13 (8%)	240	0.9
2.5	moderate, shore-parallel	8 (13%)	155	0.8

In all of the cases considered in this study, the concentration of effluent in the receiving waters is estimated to exceed 1% at a distance of 250 m from the final discharge point. However, the relative level of uncertainty associated with these predictions is high.

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APPENDIX C

MINUTES OF DECEMBER 2003 WORKSHOP

FINAL MEETING MINUTES

ENVIRONMENTAL EFFECTS MONITORING
STUDY DESIGN MEETING
POLARIS MINE (TECK COMINCO) & TECHNICAL ADVISORY PANEL
Tuesday, December 16, 2003
1:00 p.m to 5:00 pm.

Bev Burns Boardroom, Environment Canada, Edmonton

Attendees:

Bruce Donald	Teck Cominco, Cranbrook
John Knapp	Teck Cominco
Randy Baker	Azimuth Consulting Group Inc., Vancouver
Patrick Allard	Azimuth Consulting Group, Inc., Vancouver
Dionne Filiatrault	Nunavut Water Board, Gjoa Haven
Chris Baron	F&O Canada, Winnipeg
Meighan Wilson	Indian and Northern Affairs, Yellowknife
Stephen Harbicht	Environment Canada, Yellowknife
Sandra Blenkinsopp	Environment Canada, Edmonton
Jenny Ferone	Environment Canada, Edmonton
Paula Siwik	Environment Canada, Edmonton

1. Attendees introduced themselves.

2. No additional items were added to the agenda.

3. Review of the objective: To discuss the findings of the August 2003 reconnaissance studies, and to incorporate these findings into a revised EEM study, scheduled for August 2004.

4. Results of the August 2003 field reconnaissance studies on water chemistry, toxicity testing, plume delineation & modeling, sediment chemistry, benthos, and fish were presented by Randy Baker and Patrick Allard. Their presentation is appended (a hard copy will be sent with the final version of the minutes). An underwater video clip was also viewed. Information from the video presentation and slide presentation is appended at the end of the minutes.

5. General Discussion on Study Design Key Components

Adult Fish Survey

- Given that fin fish were found to be very rare in Garrow Bay, clams will be used in lieu of fin fish.
- The sampling design for collecting clams was discussed, given the limitations on the divers (2 dives per day, approximately 30 -35 minutes per dive). If discrete sampling stations are used similar to a benthic invertebrate sampling design with 5 stations, the divers will only be able to collect about 5 clams per station. Further discussion is needed to confirm if 20 - 25 clams, for example, are sufficient given the variability in a natural population. Another option is to collect clams on a per area basis.
- The range of EEM endpoints found in the MMER EEM Technical Guidance for caged bivalves should be measured on the wild clams, e.g. length, width, etc. (Note: The information is found in the Alternative Monitoring Chapter - Chapter 12).
- The exposure area clams should be collected along the first depth contour where clams are exposed to the effluent from Garrow Creek. This would probably be at the 5 to 6 m depth. Note: Steve Harbicht wants to see solid baseline data from this area in the event that Garrow Lake has a release in the future.
- The reference area will be in the subtidal area to the north of the mouth of Garrow Creek. The reference area clams will be collected along the same depth contour as the exposure area clams to remove the effect of depth. Note that results from the reconnaissance work indicated that metal levels in clams and sediment in this area as well as in the exposure area were similar to background concentrations measured in Tigumiavik Harbour.
- Exposure will be assessed by conducting soft tissue analyses for a suite of metals.

Action Item: Sandra Blenkinsopp to collect information on wild clam sample size. Done - Sandra spoke with Dr. Sylvie St.-Jean en route to the EEM Science Symposium. Dr. St.-Jean suggested a minimum of 40 clams of each sex per area, which usually requires a field collection of about 120 clams.

Action Item: Sandra Blenkinsopp will send Sylvie St.-Jean’s contact information to Patrick so that he can get the current information on reproductive endpoints, which are under development. Done. Patrick and Sylvie have discussed the study. Patrick indicated that it was agreed that while 40 clams of each sex per study area would be ideal, it is unlikely that such a large sample size can be achieved due to sampling limitations in Garrow Bay (e.g., diver-assisted, ice flows, weather conditions, etc). Rather, it was agreed that 40 clams total per study area will be targeted. While 20 males and 20 females are recommended for the fish survey, it was acknowledged that difficulties in sexing clams in the field may result in departures from this target ratio.

Benthic Invertebrate Community Survey

- Grabs from the surface will not work because the sediments are too hard.
- Could use diver-assisted cores or quadrats
  - Cores – subsurface too hard
  - Quadrats – difficult because of kelp beds
- Could do a combination – SIMS and diver assisted cores or through-ice cores.
- Benthic stations (5 per area) will be located along a depth contour (approx. 6 m) to remove effect of depth, using same areas as clam survey.
- Patrick suggested divers could use a 1L wide-mouth jar, and drag it at a consistent depth and in a consistent manner until full. Used this method at Burrard Inlet.
- TAP suggested increasing subsamples per station and using a smaller volume. Could possibly do 2 to 3 subsamples per 500 mL jar.
- Use of amphipods briefly discussed (& subsequently discarded).
- Unlikely to have enough time to collect samples from a far-field site. (Note to TAP: a far-field benthic site is not required for an initial MMER EEM survey.)
- SIMS will be back-up, used in same area.

Sediment Collection

- Grabs will not work because the sediments are too hard (see benthic above).
- Steve Harbicht asked about the sediment chemistry with respect to the digest, etc.

Action Item: Sandra Blenkinsopp to confirm if sediment is to be collected per station. Done - Sediment sampling is to be done at each benthic station.

Action Item: Sandra Blenkinsopp to check sediment chemistry guidance for marine environments to determine recommended digestion process for EEM. Status: In Progress.

Effluent and Water Quality Monitoring

- The effluent and water quality monitoring, which includes effluent sublethal toxicity testing, must continue for the full 3 year period until the mine receives recognized closed mine status
- Two effluent samples must be collected for sublethal toxicity testing per year. The mine indicated that it had only collected one in 2003 in 9 weeks of discharge.

Action Item: Sandra Blenkinsopp to follow up with Patrick Allard. Done. The 2004 and 2005 monitoring events will include two samples for sublethal toxicity testing.

Timing of Survey

- Survey will be conducted approximately Aug 10 – 25th, 2004.

- Based on experience during the field reconnaissance survey last year, ½ of days up there might be working days.
- Field support for divers was discussed. A lot of the infrastructure will be gone and the medical facility will be decommissioned by August. Sandra Blenkinsopp suggested that it may be better to sample in May through an ice platform when more infrastructure was present at the site. Bruce Donald indicated that effluent wouldn't be flowing in May. Sandra Blenkinsopp has discussed this site with the National EEM Office, and the National EEM Office indicated that the effluent would not have to be flowing during sampling at this site. The consultants decided to work in August. They want to concentrate on open water sampling.
- If due to inclement weather or other difficulties the survey can't be completed, Patrick asked what happens, and the following summarizes the discussion:
  - Sandra Blenkinsopp indicated that the consultants should keep in touch with her or the Authorization Officer (AO) during the field work so that the TAP can be informed if weather is causing a problem, etc., Weather problems, communications with EC, etc., should be documented by the consultants for use in writing up the interpretive report. **Human safety is of primary importance.**
  - Sandra indicated that two weeks is an acceptable level of effort to attempt to achieve the objectives of the field survey.
  - Fall-back position – Combine 2 years of data.
  - Jenny Ferone suggested prioritizing elements of study, e.g. collect clam biological endpoints first.
  - Seabed Imaging and Mapping System (SIMS – see below) will be a backup, since it will be done in the same area. There is value in having both – cores and visual.
- First weekend of September in 2004 – sea-lift. Everybody and everything goes.

Seabed Imaging and Mapping System (SIMS) – The consultants indicated that there is a F&O requirement for SIMS to be done at the dock site now that the dock structure has been removed. Ten to 15 m intervals parallel to shore will be done, followed by tows perpendicular to shore, and then oblique tows. Abundance, and presence / absence will be noted, as well as depth. Drop camera, magnify and do quadrat survey. This is a semi-quantitative method.

6. Steps Forward
   - Sandra Blenkinsopp to distribute minutes
   - Azimuth to finalize study design. Anticipate a 2 to 3 month turn-around time.
   - Randy will make a copy of the video for EC (Received by Edm Office January 7, 2004).

Video and Slide Presentation

Notes from video presentation:

- Video taken first weeks of August 2003
- Thin layer of sand/silt over cobble and gravel
- One fish; Clouds of amphipods (mysids)
- Starting at mouth of creek and moving out
- Ice scour area – rocky, no kelp
- Lot of cobble and gravel and attached kelp typical of 5 to 8 metres depth, 150 – 200 m offshore
- Stark difference in kelp/benthic community abundance between scoured intertidal and subtidal area
- Maximum depth sampled approximately 8 m. Floats were set for the collection of clams at approximately 8 m.
- Clams in softer sediments as well as between larger substrates
- Looking for clams as near to shore as possible, looking for siphons that stick out of the sand. Suspended material hung in water column
- Collected paired sediment and clam tissue samples
- Sediments collected by hand into jar prior to clam collection
- Clams (*Mya truncata*), 17 - 50 g wet body weight, approx. 4 size classes (17-19, 32, 40, & 50 g)
- Dragged a zooplankton net in shallows and collected specimens. Made a representative zooplankton collection.
- Water temperature was -0.5 to -1 ^{o}C water temp, 0 ^{o}C at surface
- 30 to 35 minutes per dive

Slide 4 - Garrow Lake Effluent Characterization

- Collected water samples weekly
- Early in the year the freshwater ice melt causes a drop in salinity
- Garrow Lake is siphoned over the dam then flows by gravity.
- Garrow Creek typical discharge was 0.1 to 0.2 m^3/s. Spring flow generally 1.5 to 2 m^3/s.
- Flow rates are higher this year because more siphons were on line.
- Approximately 20 cm remains to get lake down to level. The dam will be opened for this.
- Garrow Lake sampling performed for Fisheries & Oceans Canada in August 2003: Captured 19 sculpins, sacrificed 11; Zooplankton
- Garrow Lake top 9 or 10 m was brackish water; 2 ppt down to 7 or 8 ppt. Transition zone at 10 or 11m when salinity went from 10 to 60 ppt. Pretty well uniform at 60 ppt to bottom. Temperature inversion – about 8^{o}C at bottom.

Slide 6 – 2003 Effluent Chemistry Data

- BC Aquatic Water Quality Guidelines are marine limits based on toxicity to algae with a 2 fold safety factor

Slide 7 – Contaminants of Potential Concern

- Concentration of Zinc – low initially at ice melt and then increases
- Bruce Donald indicated that in the future Zinc concentrations should be lower, since only meltwater should be drawing down.
- High Pb, reason not known. Could have been due to new siphons.

Slide 8 – Effluent Characterization - Sublethal Toxicity Testing
- Didn't miss any holding times for getting samples to the toxicity lab in Vancouver.
- Acute Lethality Tests – included salinity controls
- SLTT – 72% v/v highest effluent concentration tested; used sea salts
- Randy Baker asked if other mines are doing the salinity adjustment. Sandra B indicated that for marine tests the standard protocol is to adjust salinity.
- Note: Only one effluent collection for SLTT was done. The mine discharged for approximately 9 weeks.

Slides 10 & 11 – Effluent Characterization - Sublethal Toxicity Testing
- Think Zinc was the cause of the toxicity. Paired samples - one for toxicity and one for chemistry.
- Arctic amphipods used by Peter Chapman were collected from discharge environment. Temperature known to affect toxicity. The higher the temperature, the higher the toxicity.

Slide 12 to 13 - Reconnaissance Studies in Garrow Bay
- 16' boat, rifle, communications – radio to mine
- Plume Delineation was done using a boat and chest-waders

Slide 14 to 20 – Plume Delineation
- Chest waders and boat survey, working from outside in
- Field measurements taken of temperature, salinity and zinc concentration
- Samples collected at surface (top 30 cm) and subsurface (10 cm off bottom)
- Effluent was 40 cm 'thick' at mouth of Garrow Creek and decreased to 10 to 20 cm 'thick' 200 m offshore
- At about 25 to 26 ppt salinity, Zinc was down to 0.05 mg/L (detection limit)
- Negative regression between zinc concentration and salinity
- Ice present in bay really accelerates mixing process as plume moves around and under ice blocks.

Slide 21 Modeling - Frick *et al.* 2003 EPA visual plumes software
- Wind and current influences mixing.
- No ice involved in model
- In the future, discharge will be approximately 1/5 to 1/10 of what it was in 2003

Slide 27 – 2003 Reconnaissance Design

- Had planned to use Tigumiavik Harbour as a reference area, but access was too difficult.
- Reference was moved to approximately 500 m north of Garrow Creek mouth, based on results of plume delineation.
- Water Quality Monitoring as well as sediment and clam tissue data indicate background conditions.

Slide 28
- Previous surveys, clams collected under ice but tried to get clams from closer to the creek mouth this time using divers. Intertidal area devoid of life except for amphipods.
- 2 reference areas, one for intertidal and one for sub-tidal, access limited.
- Plume moved both ways, went far enough away north/south to be out of the plume. Also suspected a back eddy but wind a bigger issue.
- Three exposure stations sampled & 1 reference– were limited by divers and clams.

Slide 30
- Prawn trap was baited with cat food. Worked very well in Garrow Lake when baited with cat food. Tried in marine environment – amphipods ate cat food. Was crushed by ice on second night.
- Clams – composited 3 to 4 clams per size category and analyzed composite.

Slide 31
- N=3 means 3 composite samples each comprised of 3 to 4 clams
- Metal suite on body tissue
    - Intended to depurate but not enough clams
    - Pulled them out, put them in bags, scrubbed them in lab, pulled siphon and cleaned as best as could
    - Results include everything: siphon, sediment, gut contents, etc.
- No relationship between size and metal concentration

Slide 32 – Historical Metals Concentrations in Clam Tissue
- Fallis' historical clam data was on depurated clams. Sample size is number of composites in all cases except for BC research who analyzed individual clams.

Slide 34 – Sediment Survey
- Unable to collect sediment with standard Ponar grab
- Recovered kelp on gravel most times in spaces allowed for water movement
- Rate of failure consistent between near-field, far-field and ref area

Slide 35 – Metal Concentrations in Sediment 2003
- Intertidal concentrations higher than sub-tidal concentrations.

- Did analysis on 2mm (sand) fraction and down. In both subtidal and tidal targeted fine sediments.
- Note: likely the first metals data for intertidal sediment collected at this site.

Four options raised for discussion:

  - conduct an EEM compliant study design
    - consultants don't think this can be done
  - conduct a limited field study using alternative tools
    - diver assisted clams and sediment
      - underwater imagery (SIMS)
      - F&O Canada requires SIMS for intertidal areas by barge
  - No further biological monitoring
    - Continue effluent and water quality monitoring
  - Other?

APPENDIX D

REVIEW OF POLARIS MINE EEM STUDY DESIGN OUTLINE

Review of Polaris Mine EEM
Study Design Outline for Biological Monitoring Studies

Highlights Section
The benthic survey component should be given the 3rd priority rather than the 4th priority. The benthic survey is a main EEM component. If time becomes an issue, the TAP recommends that sediment and water quality sample collection be reduced as indicated in the comments below.

Fish Survey and Tissue Analysis
Gonad dry weight and animal height should be added to the list of measured endpoints.

Benthic Invertebrate Community Survey
The MMER TGD recommends that in marine systems, a stacked set of 1.0 and 0.5 mm screens be used in the field with the 0.5 mm samples being archived and processed only if appropriate.

Benthic Supporting Environmental Variables (Chapter 5 of TGD)
Please see Table 5-7 of the MM TGD for the recommended supporting explanatory variables to be measured at each station in marine/estuarine benthic invertebrate habitats. In addition to the parameters listed in your outline, this table also recommends that dissolved oxygen near the bottom, sediment Eh (redox) and sediment total sulfides, as well as substratum characteristics be measured at each benthic station.

If time is limiting, the TAP recommends that **one sediment sample be collected per station** at the same time as the benthic invertebrate sampling.

Water Quality Monitoring during biological field work (Chapter 6 of MM TGD)
If time is limiting, the TAP recommends that the water quality sample collection work be done within each fish and benthic invertebrate sampling **area at one representative station** (pg 6-5, MM TGD).

Field Measurement of Water Quality Parameters - Please note that when water depth is greater than 4m, the standard water quality parameters measurable in the field should be taken throughout the water column at one to five metre intervals depending on total depth (pg. 6-9 MM TGD). The TAP recommends that the interval at which measurements are taken be less than every meter in the upper portion of the water column, in order to pick up where the freshwater lens is, etc. It is also recommended that conductivity be added to the list of standard field measurements.

Collection of Water Samples for Laboratory Analyses - The water collected for laboratory analyses of water quality should be collected at 2 depth intervals: the subsurface and near bottom (pg. 6-10 MM TGD), as described in your outline.