Golder Associates Ltd.

500 - 4260 Still Creek Drive
Burnaby, British Columbia, Canada V5C 6C6
Telephone (604) 298-6623
Fax (604) 298-5253

Golder Associates

REPORT ON

ASSESSMENT OF METAL MINE SUBMARINE TAILINGS DISCHARGE TO MARINE ENVIRONMENTS

Submitted to:

Environment Canada
Environmental Protection Branch
224 West Esplanade
North Vancouver, B.C.
V2M 3H7

DISTRIBUTION:

10 copies -	Environment Canada North Vancouver, B.C.
2 copies -	Golder Associates Ltd. Burnaby, B.C.

April 4, 1996

952-1928

First Printing: May 1996 -100 copies
Second Printing: Dec 1998 - 30 copies

Environment Canada Environnement Canada

DISCLAIMER

Environment Canada sponsored the research for this report using funding available during 1995 for national pollution prevention programs in the mining industry.

The views and opinions expressed by the authors of this report do not necessarily state or reflect the policies of Environment Canada.

Readers wishing to comment on this report should do so before June 30, 1996, to;

Head, Industrial Sector
Pollution Abatement Branch
Environment Canada
224 West Esplanade
North Vancouver, BC
V7M 3H7
CANADA

Canada

TABLE OF CONTENTS

SECTION PAGE

TABLES

FIGURES

Not copied, for economies in printing.
R. McCandless
May 9/96
Dec 18/98

1.0 INTRODUCTION

This report is the second of a two-phase study conducted for Environment Canada that reviews the technical aspects surrounding the management of mine effluents including tailings in deep marine environments. The Terms of Reference were provided to Golder Associates Ltd. (Golder) in the request for proposal dated October 13th, 1995 and are attached as Appendix I for references purposes.

Under the federal AQUAMIN initiative, Environment Canada, the Department of Fisheries and Oceans, the mining industry and other stakeholders are collectively assessing various aspects of mining practices and their associated effects on the *freshwater* environment. The purpose of this program is to better define future environmental effects monitoring (EEM) programs for mining in Canada. Several coastal metal mine operations exist in Canada and, accordingly, there is a parallel interest in such activities as they relate to potential discharges to the *marine* environment.

Under the Canadian federal Metal Mining Liquid Effluent Regulations (MMLER), coastal metal mine operations are not permitted to discharge tailings to submarine receiving environments, although liquid effluents which comply with the MMLER (1977) are permitted. Presently, there is no regulatory restriction to proposing such practices as an option for consideration by granting authorities, and such proposals must be given due consideration. Several historical cases exist, primarily in British Columbia, in which submarine tailings disposal (STD) occurred prior to the proclamation of the MMLER, notably the Island Copper Mine in Rupert Inlet, Vancouver Island which operated between 1971-1995. In additionally, there has been one historical exemption to the MMLER granted with respect to the permissible effluent solids content. Submarine tailings discharge was permitted at the Kitsault Mine in Alice Arm, B.C., 1981-1982. Thus, there is a substantial information base and experience upon which to draw for examination of coastal mine discharges.

As future coastal mine developments may be considered, Environment Canada and DFO have articulated an interest in conducting a scientific review of the ecological issues and findings associated with the Canadian experience of submarine tailings discharge. This information would then be taken into consideration, in parallel to the AQUAMIN program, to provide the scientific basis for setting future allowances for submarine effluent discharges and the associated environmental effects monitoring desired prior to, during, and following operation of a coastal facility.

The project was structured in two phases. The purpose of Phase I was to:

(i) compile a bibliographic database of monitoring reports and other documentation on coastal metal mines of Canada,

(ii) procure and review the reports at a preliminary level of detail and develop conceptual environmental models for each sites, and

(iii) write a scoping document which summarized the findings and recommend a case study for subsequent more detailed analysis.

The report for Phase I (Golder 1996) has previously been submitted and a condensation of it is provided in Appendix II.

The present document provides the findings from Phase II of the project, the purpose of which is to:

(i) conduct an analysis of a case study as per the recommendation of the previous report;

(ii) identify data gaps; and

(iii) based on the results of the case study, provide recommendations on the type and scope of investigation programs that should be undertaken to predict the effect on the environment of submarine disposal of tailings, and the type and scope of monitoring effort required to confirm the predicted effects.

The site selected as the case study is the Island Copper Mine near Port Hardy, B.C., in Rupert Inlet. This site was selected because of its size, comprehensive environmental database and recent operation. In some respects, the Island Copper site is unique. Therefore it was recognized that additional valuable data would be obtained and examined from the Kitsault Mine in Alice Arm, B.C., and the Britannia Mine in Howe Sound, B.C. to broaden the conclusions of this review.

It is important to note that examination of the Island Copper Mine experience was not designed, nor intended to be, an audit of regulatory or environmental performance.

Rather, the Island Copper Mine experience presented an opportunity from which to learn for the purpose of optimizing approaches to future potential STD proposals. To this end Island Copper personnel and its associated research scientists provided much appreciated insight and data. This effort of technical information exchange was only constrained by the time available to complete the review of the large database developed over 25 years of operation. Further time and effort to examine the database and the investigative decisions made during operation would undoubtedly further enhance the ability to optimize new evaluative approaches to STD undertakings.

The research team consisted of a multi-disciplinary group with expertise in ecotoxicology, risk assessment, physical and chemical oceanography, marine biology, and mine engineering geosciences. The general approach to the project was somewhat different from the format of the AQUAMIN program in that the present study used the *principles* of ecological risk assessment methods to *conceptualize and structure the analysis*; however, a quantitative assessment of ecological health risks was not developed at this stage.

A multi-stakeholder meeting was hosted by Environment Canada in March 1996 to discuss the issues raised in the draft version of the present report. Attendees included provincial and federal Canadian regulators, U.S. regulators, several representatives of the mining industry, non-governmental organizations form Canada and the U.S. and scientists of various disciplines related to STD operations.

To the extent possible, comments and opinions articulated during the meeting and following it were considered for incorporation into this final report. A condensation of the meeting is available form Environment Canada (contact: Robert McCandless)

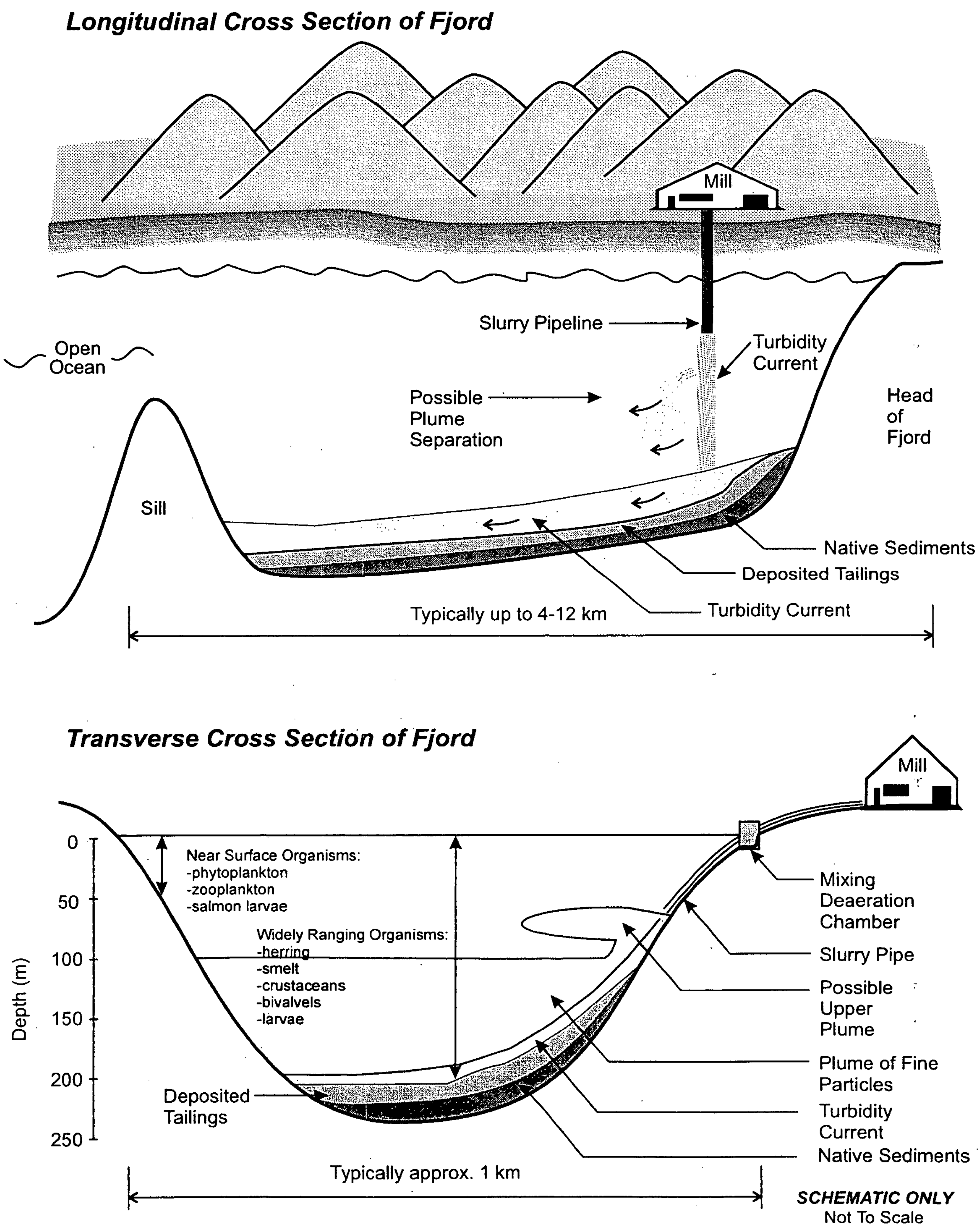
2.0 DESCRIPTION OF SUBMARINE TAILINGS DISPOSAL

For purposes of this project it is important to establish a working definition of the term *submarine tailings disposal* (STD) as it has been applied to describe various mine operations which differ due to evolution in practices over the years. Modern *bonafide* STD operations are considered to be those which facilitate placement of tailings solids in deep compartments of the ocean by discharging a tailings slurry *at depth,* typically 50 to 100 m below surface, following which a *density current* (turbidity current) facilitates transport to deeper waters. The resultant placement of tailings has typically been targeted for approximately 100 to 400 m although depths to 1500 m are currently achieved. Examples of such operations include the Island Copper Mine (Rupert Inlet, B.C.), Kitsault molybdenum mine (Alice Arm, B.C.), Black Angel lead-zinc mine (Maarmolik, Greenland) and Misima gold-silver mine (Papua New Guinea).

The objective in designing and implementing STDs is to place tailings in a "semi-contained" deep marine environment which has minimal oxygen concentrations. This will significantly reduce the potential for bound metals to be mobilized (dissolved) due to O_2-induced oxidation in comparison to surface tailings disposal designs. In discharging the tailings, an additional objective is to prevent the potential for the tailings to become suspended in the water column, particularly in shallower and more biologically productive euphotic zones.

Figure 2-1 illustrates some basic considerations of a contemporary STD operation located in a coastal fjord, showing both transverse and longitudinal cross sections of the receiving environment. Following the processing, tailings are typically concentrated to a slurry with solids content of approximately 40 to 50% and piped to a seawater mixing chamber where seawater is added to increase density to slightly more than ambient seawater. Upon discharge from the pipe below the pycnocline, the tailings are transported down the sloping sea floor to the ultimate resting depth. During the transport stage, plume separation of the density current may occur if improper density differences exist between the slurry and the water column and this may lead to undesirable suspension of particulates (i.e., formation of turbidity plumes).

It should be realized that while it is not an objective of STD operations to smother or obliterate bottom fauna in the receiving zone of the marine environment, to some extent



Longitudinal Cross Section of Fjord

Transverse Cross Section of Fjord

SCHEMATIC ONLY
Not To Scale

PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-08-96 FILE LOCATION: J:\9521928\0396\TDISP.CDR

Golder Associates

SCHEMATIC CROSS-FJORD AND ALONG-FJORD SECTIONS OF SUBMARINE TAILINGS DISCHARGE, TURBIDITY FLOW AND CHANNELLED SEABED DEPOSITS (from Hesse and Ellis 1995)

Figure
2-1

it is an *expected outcome* of the practice. The large discharge rates, energy of the density current and solids content characteristic of STDs make it a foregone conclusion that both habitat and fauna situated in the pathway will be smothered. Therefore, the issue is not whether smothering will occur, but more specifically i) over what areal extent will smothering occur (e.g., will it be confined to the less productive deep benthos); ii) to what extent will the smothered habitat recover (recolonize) after mine closure and iii) how does the magnitude of (i) and (ii) compare to options involving terrestrial management of tailings.

The modern concept of STD has its roots in the design and implementation of the Island Copper Mine which became operational in 1971 (Ellis *et al.* 1995). So its practice has a history of approximately 25 years. However, it is important to note that several decommissioned mines, centred in the BC region, have historically discharged tailings to the marine environment, although not in a manner consistent with the above definition of STD. Examples include the Britannia Mine (Howe Sound), Jordan River Mine (Jordan River), Yreka Mine (Neurotsos Inlet) and Anyox (Granby Bay), all of which were operational before contemporary STD design principles were practiced. The majority of these mines were examined and characterized in Phase I of this project, and the reader is referred to Appendix II and the Phase I Report (Golder 1996) for more information if desired. These historical operations were generally excluded from the present undertaking as their design and environmental relevance are not representative of contemporary STDs. In essence, the lessons learned from these historical sites are already well appreciated and their re-analysis is unlikely to advance the design and optimization of contemporary STDs. One exception to this exclusion rule is the use of sediment chemistry data from the Britannia Mine operation, which was considered useful for general consideration in this report.

It is important to note that at least two contemporary Canadian coastal arctic mine operations exist which discharge tailings into nearby water bodies which are distinct and separate from the ocean environment (i.e., Polaris Mine and Nanisivik Mine). In these cases the tailings settle out and only the liquid decant is discharged to the marine environment, consequently these too do not constitute STDs.

STDs have been proposed in circumstances where (i) it provides an economic advantage to the proponent, or (ii) is believed to be a more ecologically acceptable alternative to land-based tailings disposal. In regards of the latter, past rationale for STDs have included consideration of the acid generating potential of ores in land-based operations, impracticality of managing excessive precipitation on tailings, impracticality of impoundment dams given the local land topography, lack of suitable topography for impoundments, esthetic impacts associated with land-based management systems, and risk of failure of impoundment dams in seismically sensitive areas.

In consideration of whether STD is an appropriate strategy for a coastal mine undertaking, additional considerations are warranted. These include the potential for the ore body to leach metals upon placement in a marine environment (i.e., geochemical stability in the marine environment), dispersive nature of the marine receiving environment (e.g., high-energy exposed shorelines versus entrainment circulation in a fjord), magnitude of the tailings discharge rate, its duration, area of tailings distribution and ultimate discharged volume, and how these collectively relate to the potential for ecological impacts.

3.0 APPROACH AND METHODS

3.1 Consideration of Risk Assessment Principles

As noted earlier this analysis is intended to compliment the efforts of the AQUAMIN initiative which focusses on mining activities in the freshwater environment. However, while the AQUAMIN process followed an established format, Golder undertook the present analysis of marine operations using the *principles* of an ecological risk assessment (ERA) framework to characterize the issues. It should be noted that the intent was not to conduct a risk assessment, but rather to present the issues in the context of ERA principles.

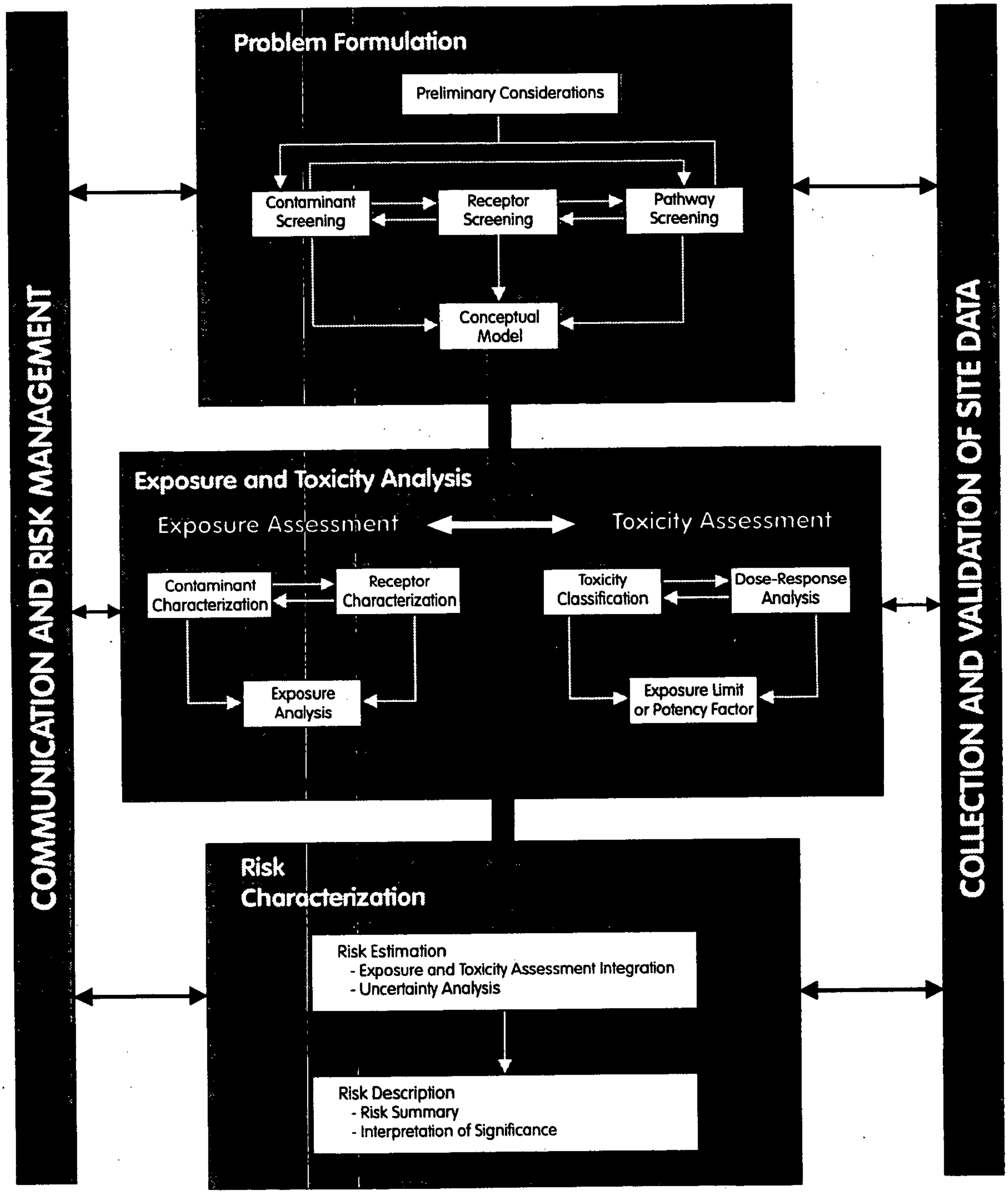
Briefly, the ERA framework is composed of three major phases which are described below and illustrated in (Figure 3-1).

1. **Problem Formulation** is the first phase of the risk assessment and involves screening of the three main components risk: stressors (e.g., chemicals, solids), pathways and receptors. The screening is based on preliminary considerations of the site including likely site activities. The objective of the problem formulation phase is to form a conceptual exposure model for receptors. The development of a conceptual site model assists in determining how much additional data may be required to complete the risk assessment and to determine, which of the stressors, pathways and receptors are significant and most relevant to the site in question. The goal of this phase is to limit the quantitative risk assessment to those contaminants, pathways and receptors that have the greatest potential to contribute to measurable risk.

2. **Exposure and Toxicity Analysis.** The second phase of the risk assessment is comprised of exposure and toxicity assessment.

   Exposure Assessment involves the estimation of exposure concentrations, loading and/or the daily intake of chemicals associated with site contamination. The exposure concentration or total daily intake for a specific chemical is the sum of the daily intakes for each pathway identified in the problem formulation as being of concern. The total daily intake (or observed exposure rate), is used later in the risk characterization phase to mathematically derive a risk estimate.

   Effects (Toxicity) Assessment is conducted for all chemicals of potential concern and involves identification of the potential effects of these chemicals and the estimation of the dose/concentration for each chemicals which will not cause measurable adverse effects for the receptors in. The reference dose/concentration



PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-08-96 FILE LOCATION: J:\9521928\0396\TDISP.CDR

Golder Associates

RISK ASSESSMENT FRAMEWORK

Figure **3-1**

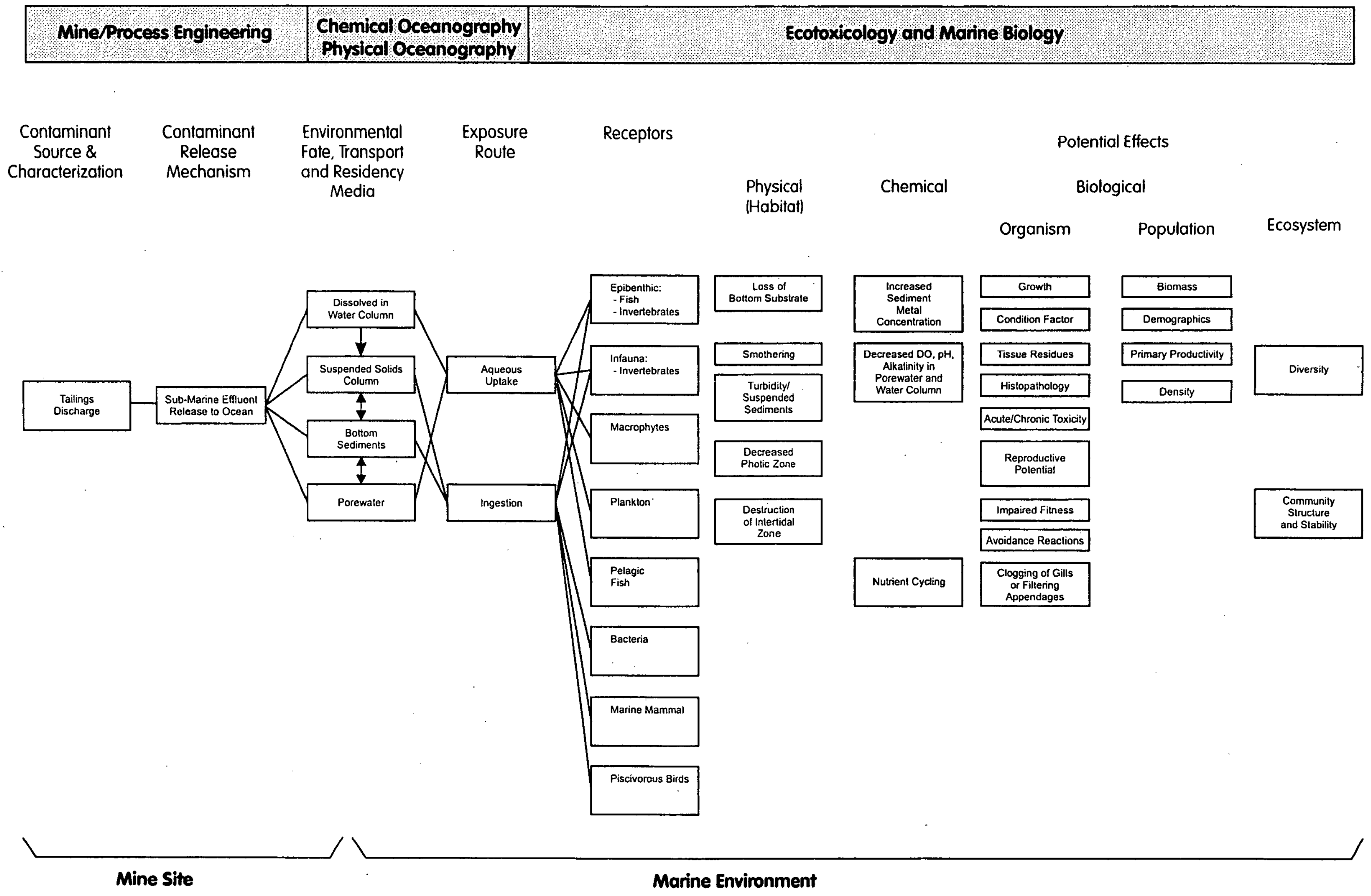
is used later in the risk characterization phase to mathematically derive risk estimates.

3. **Risk characterization** involves quantifying the risks to potential receptors associated with exposure to chemicals of concern, and the description of these estimated risks. Risk characterization is conducted for all chemicals, exposure pathways and receptors identified in the problem formulation as having the greatest potential to contribute to measurable risk.

Thus the strategy was to examine and characterize (i) the stressor sources (i.e., contaminants and particulates), (ii) the release and transport of the stressors in the environment leading to contact with potential receptors, (iii) the factors governing the fate and transformation of the stressors and (iv) the effects of the stressors on the receptors which have typically been studied. These items essentially embrace the *Problem Formulation* and *Effects Assessment* components of the ERA framework, but do not entail a quantitative exposure assessment or derivation of quantitative risk estimates. This approach would then provide an effective link to subsequent agency objectives of developing an environmental effects monitoring strategy for coastal STD mining operations. While the principles of ecological risk assessment were used to examine the issues surrounding STD operations, it is unlikely that risk assessment alone could be used to fully assess all such biological health risk. For example, risk assessment is not easily applied to ecosystem level elements such as biodiversity and nutrient cycling. Rather, a complimentary merging of ecological risk assessment with environmental impact assessment (EIA) is needed to fully assess real world effects.

The typical product of an ERA Problem Formulation is the illustration of a conceptual exposure model. In the grandest sense, a generic conceptual exposure model for coastal marine mines is presented in Figure 3-2. This illustrates various potential sources of ecological stressors and how they might behave in the environment and lead to exposure of potential receptors. For the purposes of this report it was agreed in earlier Phase I discussions with the agencies that the effort would focus specifically on the stressor source being the submarine tailings discharge. It is recognized that STD mines may have other sources of ecological stressors (e.g., acid rock drainage from shoreline waste rock dumps, and fugitive metal dust concentrates); however, the present interest is to gain further insight on the specific practice of STD. The present analysis is conducted in consideration of the Island Copper Mine (Island Copper) as a case study of STD, and also through consideration of larger generic STD principles and issues. Therefore, the

PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-04-96 FILE LOCATION: J:\9521928\0396\FACTORS.CDR



Golder Associates

GENERIC ERA CONCEPTUAL MODEL FOR COASTAL METAL MINE MARINE DISCHARGES

Figure 3-2

generic exposure model noted above is presented for consideration at the outset of this report, but is not intended to be specific to or reflective of the Island Copper case study.

3.2 Methods

To conduct this case study and to examine some of the broader issues of STDs beyond the Island Copper Mine site, research questions/tasks were developed to guide the analysis and provide consistency with the general ERA framework. The questions are grouped into three major areas and listed below, and form the structure of the remaining aspects of this report:

Physical Oceanography

The objective of the following questions is to identify and characterize the physical oceanographic processes that influence dispersion of tailings in the marine environment following submarine discharge using the Island Copper mine as a case study.

1. What are the major physical oceanographic processes that influence dispersion of tailings in the marine receiving environment?
2. Characterize (qualitative/quantitative) the physical dispersion mechanisms above with respect to Island Copper.
3. Comment on the relative importance of the physical dispersion mechanisms with regard to tailings dispersion at Island Copper.
4. Develop a schematic of the conditions favouring dispersion versus containment of submarine tailings in a coastal marine environment.
5. Identify physical oceanographic parameters for each of the above processes which should be measured and/or addressed in pre-operational modelling and operational monitoring. Comment on current modelling capabilities.

Chemical Oceanography

The objective of the following questions is to identify the chemical oceanography mechanisms that influence the bioavailability of metals to aquatic biota particularly with respect to sediment chemistry.

1. What are the determining mechanisms in marine chemistry that influence the relative proportion of contaminants associated with the freely dissolved phase versus contaminants bound to dissolved or particulate carbon or tailings particles?

2. Characterize these mechanisms (qualitative and quantitative to the extent possible).

3. Develop an Influence Diagram of the factors that govern the bioavailable forms of metals in the marine environment.

4. Develop a schematic demonstrating the conditions favouring bioavailable forms of metals versus unavailable forms.

5. Identify chemical oceanographic parameters for each of the above processes which should be measured and/or addressed in pre-operational modelling and operational monitoring. Comment on current modelling capabilities.

Biological Effects

The objective of the following questions is to identify and characterize the biological effects that have occurred at Island Copper mine and identify additional data that could be used for a clearer understanding the effects that have occurred.

1. What biological parameters were monitored at Island Copper and what were the objectives?

2. Characterize the effects reported.

3. Critique the methods of analysis in the context of the original objectives. Could the monitoring program meet the objectives?

4. What additional biological parameters would enhance the understanding of the biological effects occurring or that have occurred at Island Copper or coastal mines practicing submarine tailings disposal? From an organism level? population level? ecosystem level?

5. Discuss the factors governing recolonization of sediment during and after mine operation and develop an influence diagram.

To address these questions/tasks, reports from the Island Copper Mine monitoring program were consulted along with various publications in the primary literature, theses and special project reports sponsored by industry or governmental agencies.

Additionally, technical discussions were pursued with experts in the field including Dr. D. Ellis (University of Victoria, B.C.), Dr. D. Bright (Royal Roads University, Victoria, B.C.), Dr. Jim Murray (University of Alberta), Dr. B. Burd (Ecostat Research Ltd., Brentwood Bay, B.C.), and Mr. I. Horn (BHP Minerals, Port Hardy, B.C.).

A guiding principle in conducting this analysis of Island Copper Mine was to ascertain what lessons could be learned in the broader context of STDs, for the purpose of optimizing future analyses of STD issues. In some cases this required first an analysis of what was initially conducted during the baseline feasibility studies and comparing this early understanding to subsequent observations over the course of the monitoring program. It became useful to approach some of these issues by first establishing what was postulated based on best (early) estimates, characterizing what constituted a best estimate, qualitatively ascribing a confidence level to these estimates (e.g., high, medium, low) using present day standards applied retrospectively, and attempting to identify what the consequences of an incorrect conclusion (at the feasibility stage) would have been.

4.0 CHARACTERIZATION OF STRESSOR SOURCES IN STDS

4.1 Island Copper Mine

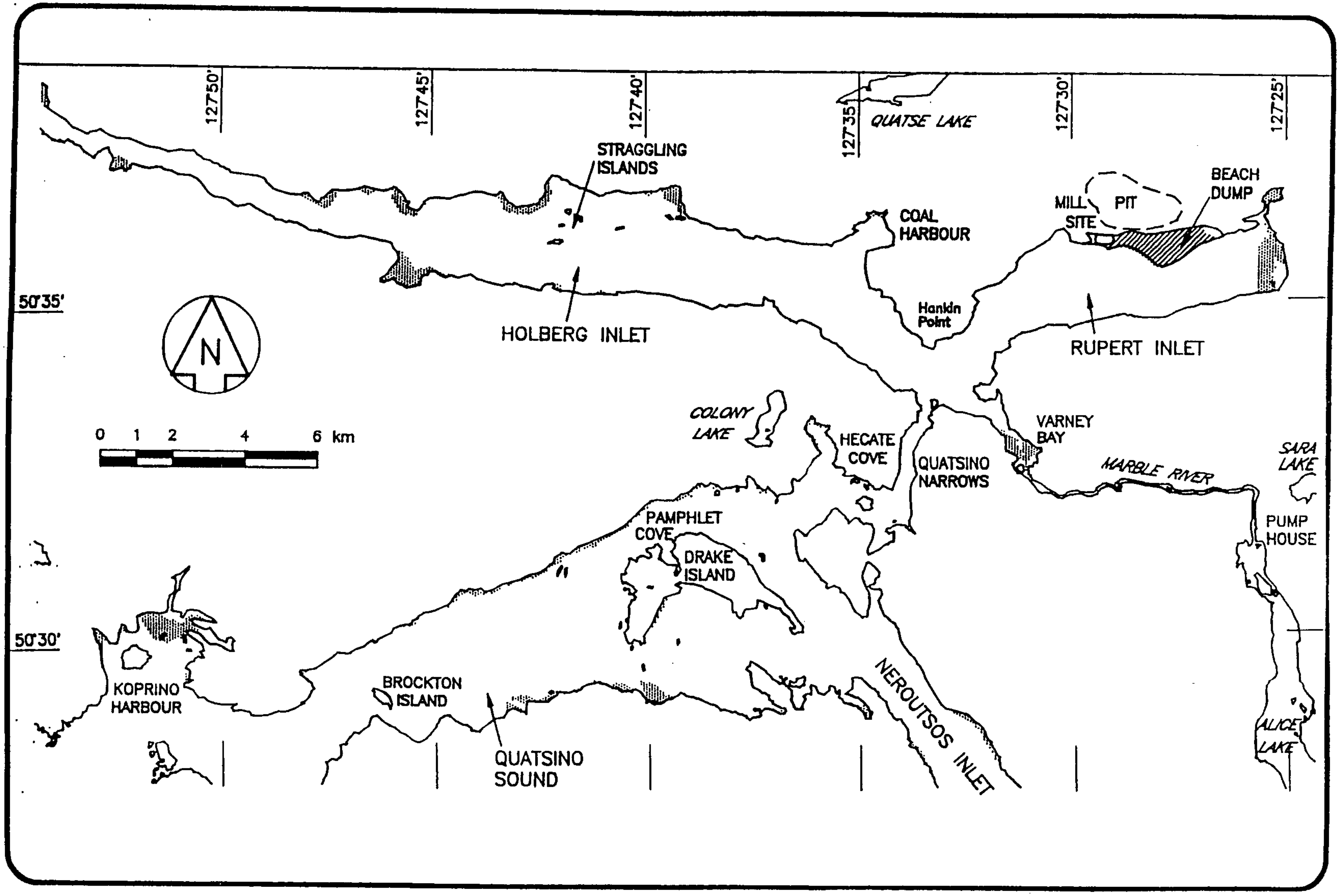
The Island Copper Mine (Island Copper) is located in Rupert Inlet, an arm of a complex fjord along the north west coast of Vancouver Island (Figure 4-1a, 4-1b). Island Copper was operated by BHP Minerals since 1971 and ceased operation in December 1995.

Ellis et al. (1995) described the ore body as a low grade porphyry-type copper-molybdenum deposit. The principal ore minerals are chalcopyrite (1.5 %) and molybdenite (0.02%) which contain 90 and 60% of the copper and molybdenum, respectively. Other sulphide minerals include pyrite (3.0%), sphalerite (0.02%), bornite and galena (0.01%). The mine primarily produced copper and molybdenum, with smaller production of gold, silver and rhenium using a froth floatation method (see Table 4-1 for process reagents and Figure 4-2 for a schematic of the mine process).

The daily process volume was substantial (and representative of contemporary STD operations) ranging from 33,000 MTPD initially in 1971 to 50,000 MTPD in 1995. The mining operation was "open pit" situated adjacent to the fjord. The waste rock pile (also containing some tailings) formed the shoreline and extended into the marine environment. In addition to the tailings effluent and waste rock discharge, additional waste discharges sources included "pit water" and some acid rock drainage.

Tailings discharge was mediated through a submarine outfall (380 kg solids/sec., 40-45 % solids by wt.) located initially at a 50 m depth and more recently (1993) relocated to a 36 m depth. Daily discharge volume was on average 85,000 m^3. The particle size distribution of the solids consisted of about 60% < 63 µm in diameter in the form of aluminosilicates. Table 4-2 provides a summary of the elemental content of the tailings in comparison to natural local marine sediment. The similarities of the two are striking, with the exception of copper and molybdenum which reflect the natural enrichment of the ore deposit.

Table 4-3 provides a summary of the dissolved metals concentrations in the effluent during 1993. Copper, molybdenum, lead cadmium, manganese, zinc and arsenic were among the elements of interest in the discharge. Ellis *et al.* (1995) note that the effluent



Project No. ....
Drawn ....
Reviewed ....
Date ....

Golder Associates

Location of Island Copper Mine in Rupert Inlet,
North Vancouver Island, B.C.

Figure
4–1a

Figure 4–1b – ISLAND COPPER MINE, RUPERT INLET, B.C. - 1994

Table 4-3
Summary of physical and chemical analysis of effluent January to December 1993

Parameter	Unit	n	Mean	Standard deviation	Min.	Max.	Permit or prov. objectives	
							1985	1993
Daily volume	10^6 gallons	365	19.16				17.62/24.21*	20.91/24.21*
Daily volume	m^3	365	85,800				80,100/110,100*	95,000/110,000*
% Solids	% by weight	52	40.9	2.5	34.7	45.3	50	50
Temperature	C	52	23.3	4.9	15.6	30.0	none	none
pH		52	10.0	0.6	8.8	11.2	7.5–11.5	7.5–11.5
Diss. arsenic	µg/L	52	7.4	4.2	< 2.0	26.0	100	100
Diss. cadmium	µg/L	52	0.15	0.05	< 0.10	0.20	5	5
Diss. copper	µg/L	52	6.0	2.1	2.7	12.0	50	50
Diss. lead	µg/L	52	4.4	3.2	1.0	12.0	50	50
Diss. manganese	µg/L	52	6.9	6.2	1.4	37.0	100–1000**	100–1000**
Diss. molybdenum	µg/L	52	283	71	160	450	500	1000
Diss. zinc	µg/L	52	5.3	4.3	1.5	31.0	200–1000**	200–1000**

* Permit objectives for volume: Annual daily mean volume/daily maximum volume.
** Provincial objective (unmarked values are permit objective).

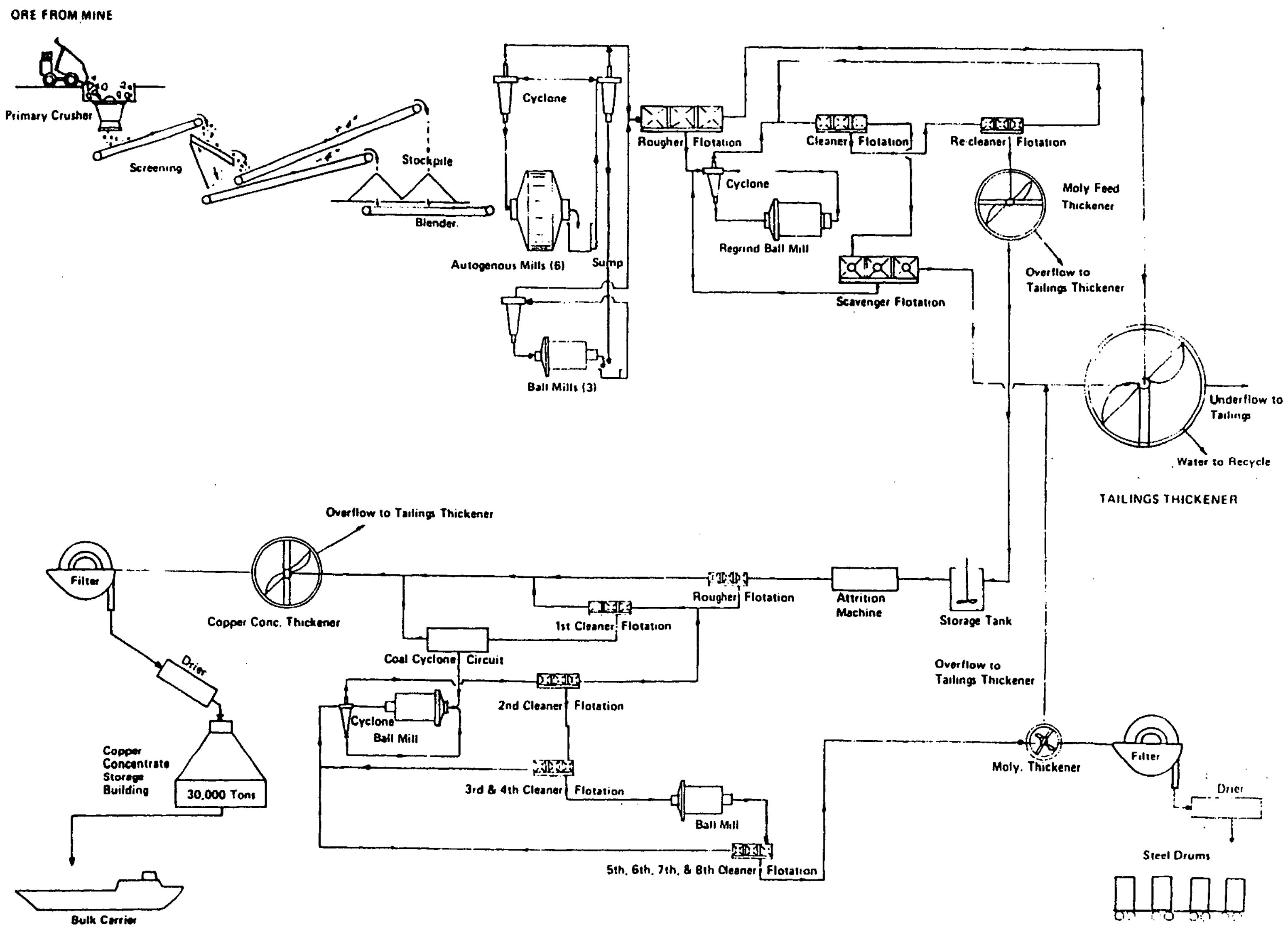
TABLE 4-2

Typical Chemical and Mineralogical Compositions of Tailing Solids and Natural Sediments in Rupert Inlet, B.C.

Element or Oxide, etc.	Content of Sediments		Ratio A:B	Mineral Species	Tailing Content
	A Tailing	B Natural			
	%	%			
SiO_2	62			Quartz	50-70%
Al_2O_3	14			Feldspar	2-20%
Ca,K,Na, & Mg Oxides	10			Biotite and Chlorite	5-10%
Fe Oxides	8			Magnetite	2-4%
Fe Sulphide	2-3	2-3	1:1	Pyrite	2-4%
CO_2	2	-		Calcite	∿ 2.5%
Total	98-99	∿ 99	1:1		
Element	ppm	ppm			
Cu	700	44	16:1	Chalcopyrite	0.2%
Mn	650	640	1:1	Mn Oxides	n.d.
Cr	140	125	1:1	In silicates	n.d.
Zn	80	88	1:1	Sphalerite	0.02%
Mo	40	2	20:1	Molybdenite	0.01%
Co	20	20	1:1	In silicates	n.d.
Ni	20	40	1:2	In silicates	n.d.
Pb	20	25	1:1	Galena	0.002%
As	5	5	1:1	Arsenopyrite	n.d.
Cd	3	2	3:2	In sphalerite	n.d.
Hg	0.03	0.06	1:2	Cinnabar	$> 4 \times 10^{-6}$%

n.d. = not determined

From Poling, G.W. 1982. Characteristics of mill tailings and their behavior in marine environments. In: Ellis, D.V. (ed). Marine Tailings Disposal. Ann Arbor Science.



Project No. ....
Drawn ....
Reviewed ....
Date ....

Golder Associates

Simplified flowsheet Island Copper Mine.

Figure 4-2

Table 4-1

Typical mill process reagents used at the Island Copper concentrator

Reagents	Total consumption (lb)	Mineral feedstock (tons)	Consumption rate on treated material (lb/ton)	Consumption rate on tailings solids (lb/ton)
Copper circuit[1]				
Collector (potassium amyl Xanthate)	148,484	20,220,329	0.0073	0.0074
Frother (methyl isobutyl carbinol)	1,730,237	20,220,329	0.085	0.087
Aerodri 100 + 104 (sodium sulfosuccinimate)	11,244	21,340	0.53	0.0006
Polybac E (surfactant)	6440	1,581,996	0.004	0.0003
Molybdenum circuit				
Arylene M-60 (dioctyl sodium sulfosuccinate)	8129	12,390	0.66	0.0004
Sodium hydrosulfide	1,622,251	255,028	7.21	0.081
Sodium cyanide	129,361	125,163	1.03	0.0065
Vansene (EDTA)	65,961	1399	47.1	0.0033
Gold leach				
Soda ash	25,210	112,792	0.22	0.0013
Hydrogen peroxide	28,155	2669	10.5	0.0014
Sodium cyanide	45,616	2511	1802	0.0023
Activated carbon	2205	1689	1.30	0.0001
Production thickener[2]				
Alchem 87079 or Superfloc 1202 (flocculent)	30,906	309,186	0.010	0.0015
Tailings thickener[3]				
Lime (calcium oxide)	23,041,440	20,220,329	1.14	1.15

[1] Total plant feed 20,220,329 tons.
[2] Total copper and molybdenum conc. produced 247,479 tons.
[3] Total tailings 19,972,850 tons.

From Ellis et al., 1995

quality met permit requirements for most parameters over the course of the mine operation.

4.2 Other STD Ore Bodies and Performance Volumes

The Island Copper ore body was a low-grade porphyry operation and several other existing or proposed STD operations have also been predicated on similar ore bodies. The historical operation at Kitsault Mine (Alice Arm Fjord, B.C.), and that proposed at Quartz Hill (Wilson Arm Fjord, Alaska) both involve low grade porphyry ores with the valued mineral being molybdenite.

In contrast to the previous sites, the ore body mined at Black Angel lead-zinc mine (Greenland) was a massive sulfide deposit comprised mainly of pyrite (FeS_2), sphalerite (ZnS) and galena (PbS), hosted in a talc bearing marble and containing tremolite. The tailings consisted of 50% marble/dolomite and 50% pyrite. While initial predictions expected the metal sulfides to be stable and not leach metals into the marine environment, it was soon discovered within one year from start-up that lead, zinc and later cadmium were being mobilized (Poling and Ellis 1995). Subsequent studies indicated that the ore and tailings contained significant oxidized lead and zinc minerals which were soluble at ambient pH sea water. This was further exacerbated by the use of sea water in the mill process.

Table 4-4 provides a short summary of representative tailings characteristics and performance parameters of other STDs against which Island Copper may be compared.

Stressors associated with STD operations can include the tailings solids, the site specific metals associated with the tailings, the process reagents, shoreline waste rock acid/metal leachate and conventional surface acid/metal leachate from material stored on the site.

For the purposes of this review, the stressors of interest have been limited to the physical deposition of tailings solids and their associated metals, as these constituents have the least potential for control once released to the environment.

TABLE 4-4

Summary of Representative Tailings Characteristics and Performance Parameters of Submarine Tailings Discharge

Mine (dates of operation)	**Particle Size Distribution (um)**	**Discharge Rate**	**Discharge Depth**	**Production Volume (tonnes/day)**	**Slurry Solids Content**	**Mineral Mined**	**Ore Body**
Island Copper Mine (1971-1995)	65-75% ≤74 um	~ 89,000 m³/day	50 m (pre 1993) 36 m (post-1993)	38,000 (1980) to 54,400 (1995)	40%	copper, molybdenum	chalcopyrite, molybdenite, quartz, feldspar, pyrite, magnetite
Kitsault Mine (1967-1972 1982-1983)	45-600 um (mode of 100 um)	~1500 m³/day	50 m	12,000	42%	molybdenum	molybdenite, diorite, monzonite, alaskite, porphyry
Black Angel Mine (1973-1990)	55% at 74 um	1350 tonnes/day	80 m	2,150	24.8%	lead, zinc	pyrite, sphalerite, galena

5.0 OCEANOGRAPHY, STRESSOR RELEASE AND TRANSPORT

5.1 Preliminary Considerations

Mine wastes discharged through a submarine disposal system consist of both liquid and solid components, mixed to form a dense slurry. Contaminants such as heavy metals and/or unconsumed process reagents may be present as dissolved materials in the liquid waste fraction, or bound to the solid tailings. Once discharged to marine waters, both liquid and solid wastes may be transported away from the point of discharge through the effects of the physical processes described in this chapter. A general discussion of the physical aspects of waste dispersion in coastal waters (Section 5.2) is followed by the oceanographic and related data requirements for a fate assessment (Section 5.3), a site-specific discussion of studies associated with the Island Copper Mine (Section 5.4) and considerations for the future assessment and permitting of proposed submarine tailings disposal systems (Section 5.5).

5.2 Physical Aspects of Waste Dispersion

The dispersal of both the solid and liquid components of mine wastes is driven by oceanographic processes in the receiving waters, but also depends on the characteristics of the discharged materials, the properties of the tailings discharge system and the geomorphologic characteristics of the body of water into which wastes are discharged. The data requirements for an assessment of the fate of mine wastes discharged into a marine environment are intrinsically linked to the relevant processes involved in waste dispersion. Both the processes involved in waste dispersion and the associated data requirements are discusses in simplified terms in the following section.

5.2.1 Oceanographic Processes

Oceanographic processes in the receiving waters are the major factors affecting the dispersal of both solid and liquid wastes introduced into the marine environment. The relevant oceanographic processes are those that lead to transport of the waste materials away from the discharge site, and those that create or enhance mixing between the waste materials and the ambient waters and sediments. Ocean currents act to transport materials away from the discharge site and to mix discharged wastes with the waters and sediments of the receiving environment. Surface waves play an important role in the deposition and resuspension of solids to or from the seabed, and the density structure of the water column affects the mixing of the waste effluent with the receiving waters.

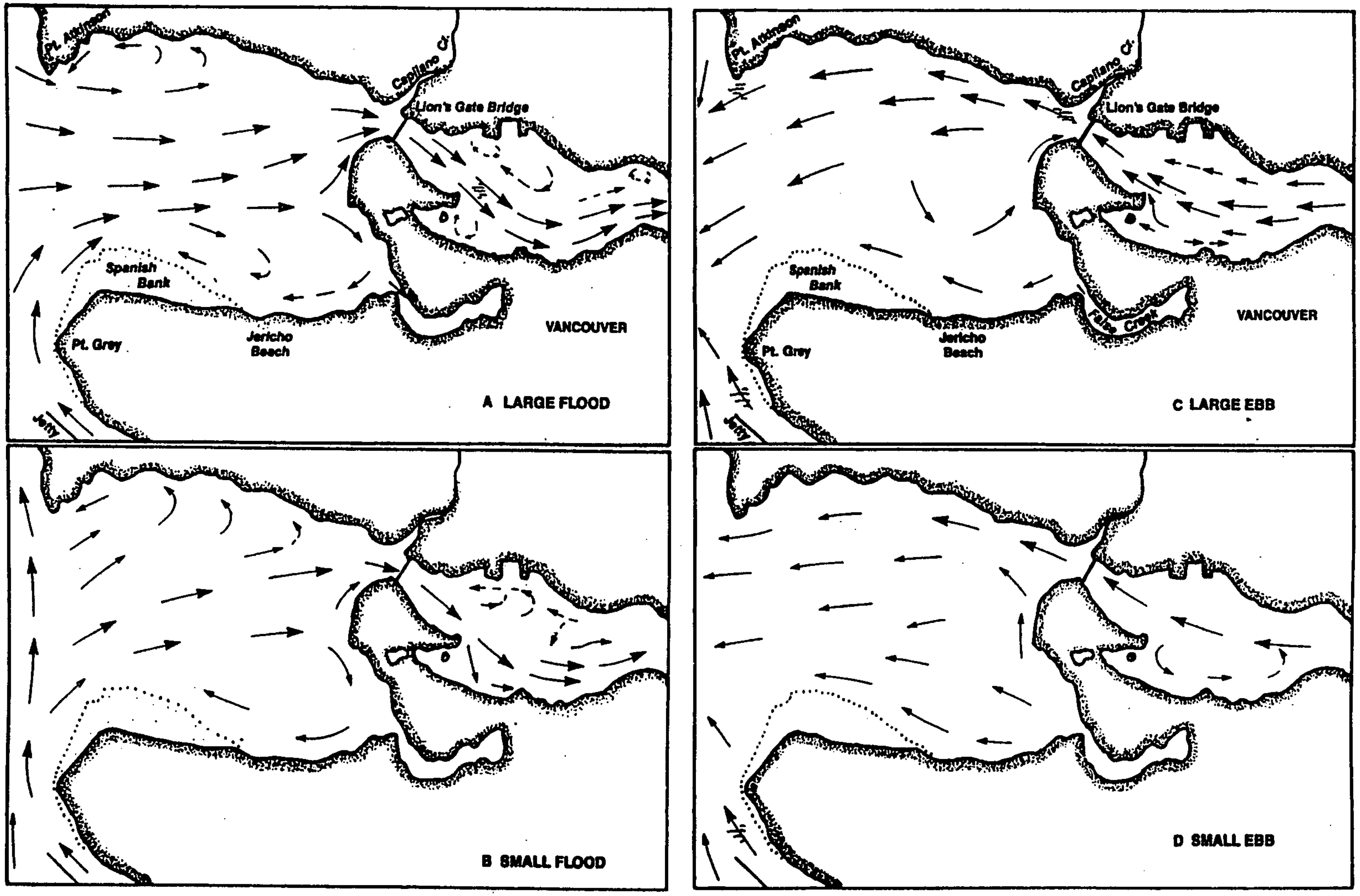
A variety of processes can generate or affect currents in coastal waters. These include forces related to the rotation of the earth, fresh water inflows to the marine environment, tidal fluctuations in water levels, winds, surface waves and catastrophic events such as tsunamis. Several of these processes are described here in more detail in order to illustrate the differing characteristics of each current component. It should be realized, however, that the relative importance of each oceanographic process is site-specific and must be evaluated on that basis. The following processes have been selected for more detailed discussion; the list is not meant to be exhaustive nor is any relative ranking in terms of waste dispersion meant to be implied.

5.2.1.1 Tides

Of the various current-generating processes, tides are the most ubiquitous, and are particularly significant in many coastal areas of British Columbia. Cyclic tidal currents are generated in response to tidal fluctuations in water levels. Tides can be semi-diurnal, with two cycles per day; diurnal, with one high and one low water level during each day; or a mixture of semi-diurnal and diurnal components. Longer period tidal constituents produce fluctuations in both tidal range and current speed occurring over fortnightly, monthly and longer time frames.

As tides propagate through coastal waters, variations in water depth affect the direction and speed of propagation. As a result, spatial variations in the strength of tidal currents are significant. This is illustrated in Figure 5-1, showing tidal currents in the surface waters of the outer parts of Burrard Inlet, B.C. for both large and small tidal exchanges. This figure illustrates the inherent variability in speed and direction of tidal currents in the inlet.

While tidal forcing may generate the largest currents in many coastal regions, these currents are oscillatory in nature, and are usually associated with relatively small net water movements. Thus, tidal currents often lead to little net transport of contaminants away from the discharge site, but can have a very strong effect on the mixing of waste materials with the ambient waters and sediments of the receiving environment.



Project No. 952-1928
Drawn —
Reviewed S.P.
Date Mar. '96

Golder Associates

Surface tidal currents in Burrard Inlet: (A) large flood, (B) small flood, (C) large ebb, (D) small ebb. Larger arrows, 25-50 cm/s; small arrows, less than 25 cm/s (except First Narrows, where flow speed is generally over 50 cm/s). (from Thompson 1981).

Figure
5–1

5.2.1.2 Estuarine Circulation

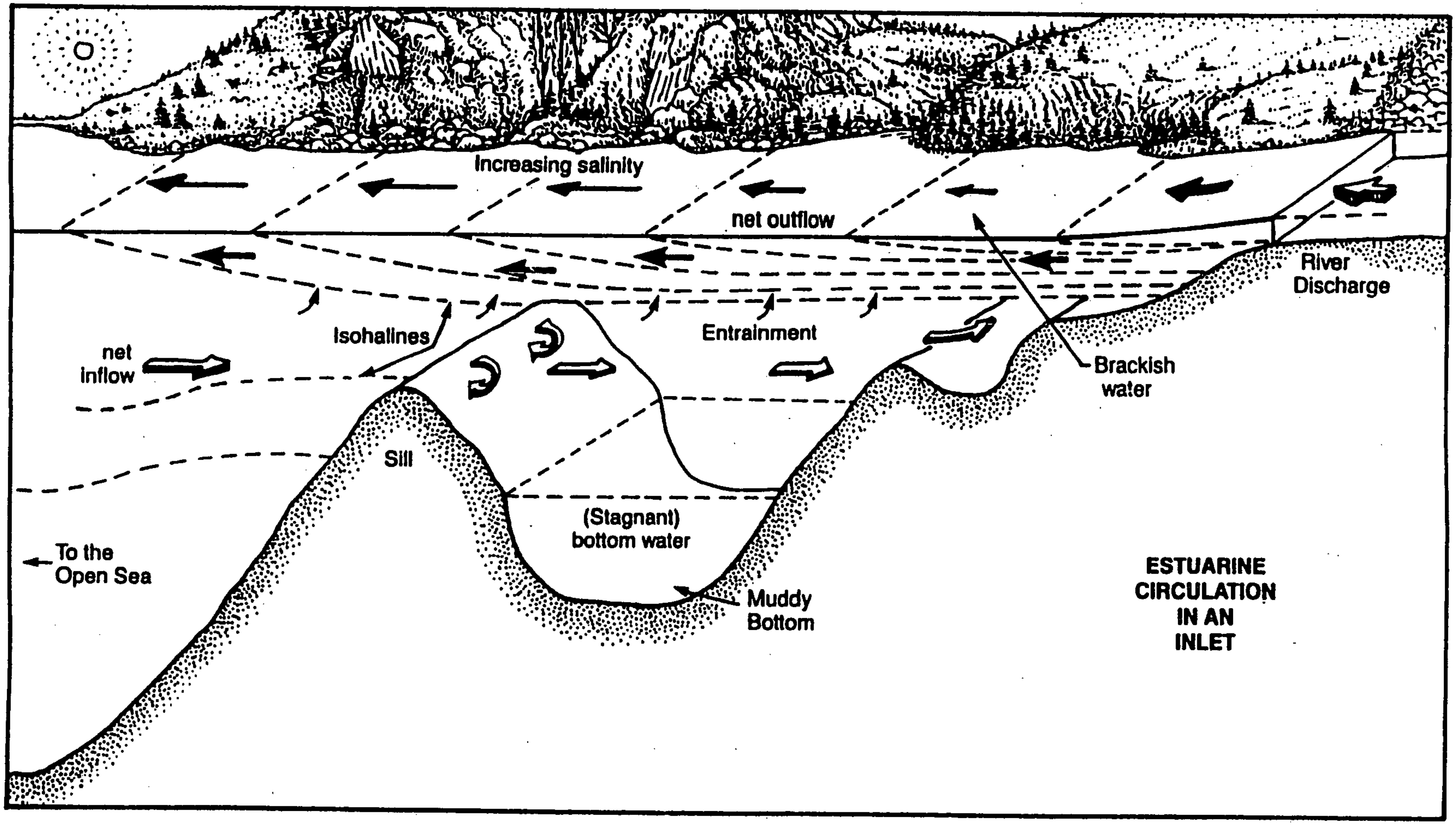
Fresh water inflows to the coastal environment affect several types of density-driven currents, one of which is the estuarine circulation system. Estuaries are coastal regions characterized by high fresh water loading through river discharge, where the loading rate is sufficient to result in dilution of seawater. Since fresh water is lighter than sea water, fresh water entering an estuary tends to form a surface layer flowing outwards overtop of heavier marine water. As freshwater flows away from its source, it mixes with underlying seawater, leading to a brackish surface layer increasing in depth and salinity with distance away from the river mouth. This process is illustrated in Figure 5-2.

As underlying saline water is entrained into the outwardly-flowing surface layer and carried out of the estuary, it must be replaced by a compensating volume of water flowing into the estuary. The net outflow of surface waters, coupled with the inflow at depth, is termed estuarine circulation. The relative strength of the estuarine circulation system can vary significantly from inlet to inlet, depending on both the magnitude of the fresh water inputs and the location of those inputs within the inlet. The strongest estuarine circulation systems are set up by fresh water sources located at the head of the inlet, with the estuarine circulation system generally weakening as the fresh water source moves towards the inlet mouth.

The currents associated with the estuarine circulation system tend to be relatively steady, with the time-scale of change related to changes in the fresh water input rate. Thus, estuarine circulation is often a major factor in the long-term transport of waste materials away from the discharge site.

5.2.1.3 Deep Water Renewals

The estuarine circulation system as shown in Figure 5-2 is generally confined to the surface waters of coastal inlets. Many of the inlets along the British Columbia coast are actually fjords, characterized by steep rocky walls and a deep inner basin separated from the waters of the open ocean by a shallow sill or series of sills (Figure 5-2). The bottom waters of the inner basin may be isolated from exchange with outer waters for relatively long periods of time, typically leading to anoxic conditions in the deep basin waters.



Project No. 952-1928
Drawn —
Reviewed S.P.
Date Mar. '96

Golder Associates

Estuarine circulation in a typical British Columbia inlet (from Thomson 1981).

Figure
5-2

When flushing of these deep waters does occur, it is usually in response to variations in the density of the water outside the fjord at sill level. When the density of the water outside the sill exceeds that of the water in the deep inner basin, water flowing into the inlet at sill level will run down the inner slope of the sill, mixing with and flushing the deep basin waters. The density variations in the outer waters may be driven by changes in the fresh water supply to coastal waters, variations in the strength of tidal mixing, or by changes in the prevailing wind direction (i.e. coastal upwelling). Deep water renewal events may be relatively abrupt and dynamic, and may occur seasonally, or may not occur at all for periods of several years. Deep water renewal events are often the only process leading to transport of waste materials out of the bottom waters of a coastal fjord.

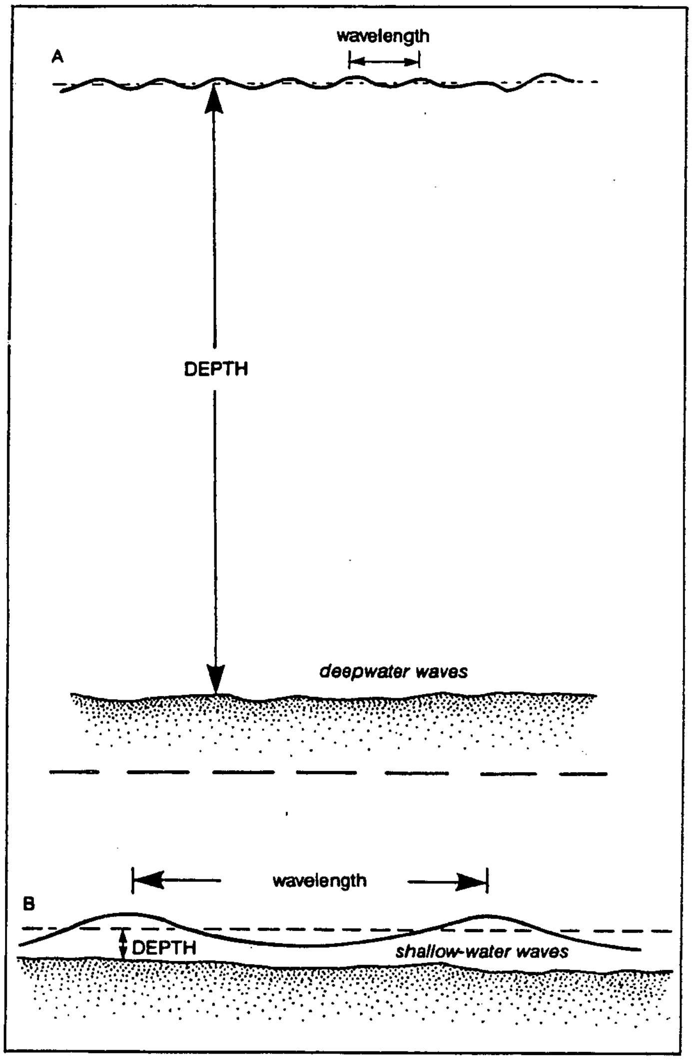
5.2.1.4 Surface Waves

The net drift associated with surface waves is generally very small and is usually ignored, unless the surf zone (area between the region of wave breaking and the shoreline) is the area of concern. However, surface waves can create large oscillatory currents, as illustrated in Figures 5-3 and 5-4. Wave-induced oscillatory currents have periods ranging from several seconds to several tens of seconds. In deep waters, these currents can be an important process in the vertical mixing and dispersal of waste materials in surface waters. In shallow waters, wave-induced oscillatory currents can have significant impacts on the remobilization and redistribution of seabed sediment deposits, including both natural sediments and tailings. Wave effects on solids transport are discussed further in Section 5.2.2.4 of this report (Seabed Remobilization).

5.2.1.5 Vertical Density Structure of the Water Column

The vertical density structure of the water column is an important factor affecting both vertical variations in many of the current-generating processes described above and mixing between the discharged wastes and the receiving waters. In Canadian waters, density stratification of the receiving water is commonly governed by salinity content, and thus is strongly affected by the magnitude of the local fresh water inputs. Under some conditions, temperature variations may also contribute significantly to density stratification. Whether governed by salinity or temperature, the density stratification in the receiving environment can be expected to vary on a seasonal basis, and perhaps also in response to variations in the strength of the local tidal mixing. To illustrate typical

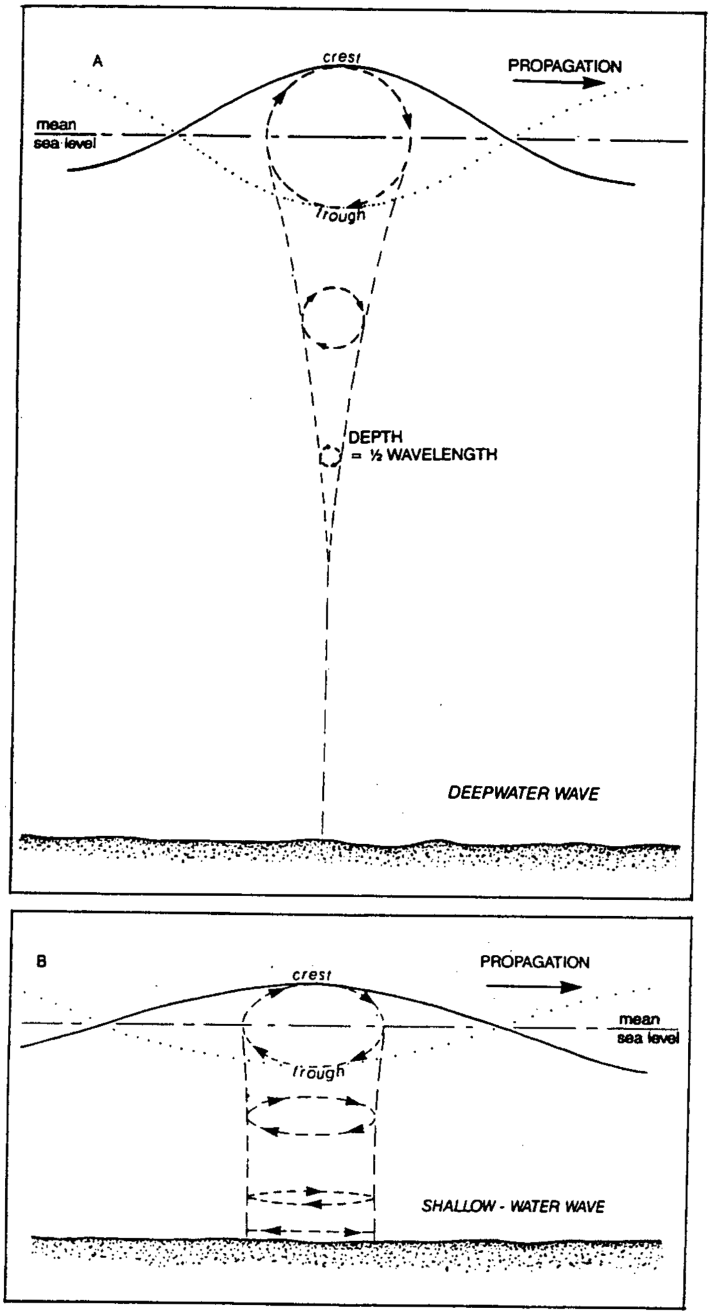
Project No. 952-1928 Drawn — Reviewed S.P. Date Mar. '96



Golder Associates

For deep water waves (A), the wavelength is short compared to the water depth and surface wave effects do not reach to the seabed. In shallow water wave conditions (B), the wavelength is long compared to the water depth and surface wave effects are significant at the seabed (from Thomson 1981)

Figure 5-3



Project No. 952-1928 Drawn — Reviewed S.P. Date Mar. '96

Golder Associates

Surface waves create large oscillatory water movements and currents. For deep water wave conditions (A), wave effects decay with depth downwards from the water surface. Shallow water waves (B) generate large oscellatory currents throughout the water column to the seabed. Water particles move forward (in the direction of wave travel) under the crest of the wave and backwards under the wave trough for both deep and shallow water waves (from Thomson 1981)

Figure 5–4

vertical, longitudinal and seasonal variations in salinity content in the waters of a coastal inlet, Figure 5-5 shows conditions during July and February in Burrard Inlet.

5.2.1.6 Length and Time Scales

In summary, many marine processes can generate ocean currents and affect the transport and dispersion of waste materials discharged into the marine environment. While some oceanographic processes act to advect waste materials away from the point of discharge, others are more important to the mixing of discharged materials with the water and sediments of the receiving environment.

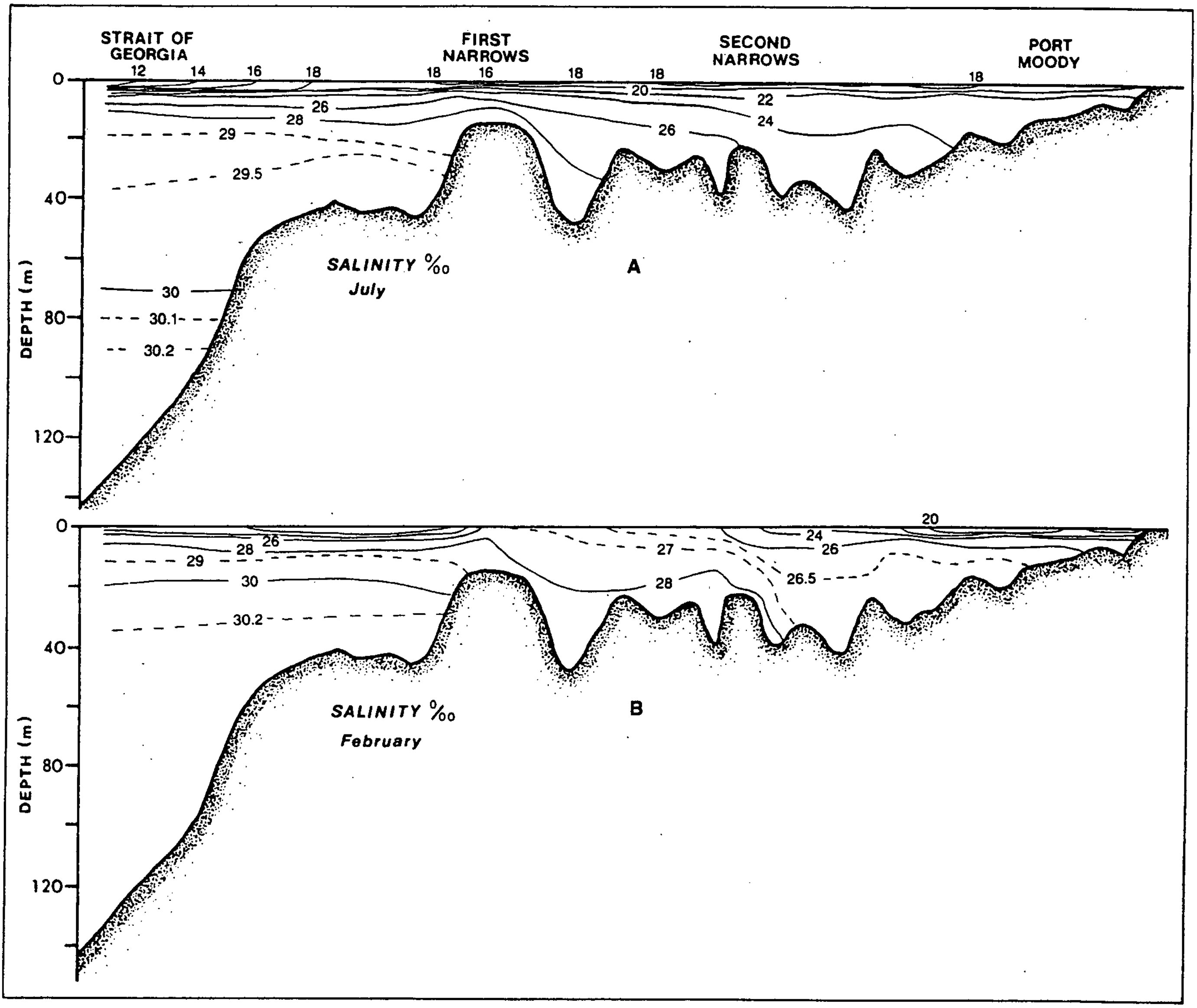
The relative importance of each oceanographic process to the dispersal of waste materials in the marine environment is related to the length and time scales over which each process generates ocean currents. The above examples (tides, estuarine circulation, deep water renewals, surface waves) show that time scales can vary from seconds (e.g., surface waves) to months or years (e.g., deep water renewals). Corresponding length scales can vary from tens or hundreds of metres (e.g. surface waves) to tens of kilometres (e.g. estuarine circulation system). The design of any data measurement program must take into account the relevant time and length scales for each oceanographic process of concern.

The above examples have also shown that the various components of the current field can vary significantly in speed and direction of flow, and that spatial and temporal variations within the area and time period of interest are often significant. Similarly, spatial and temporal variations in vertical stratification of the water column are to be expected. All of these factors require site-specific assessment on a project-by-project basis.

5.2.2 Solids Transport

5.2.2.1 Turbidity Flows

The solid and liquid components of the STD effluent combine to form a heavy slurry. On entering the receiving waters, this slurry forms a negatively-buoyant plume and flows downslope as a turbidity current. As the turbidity current flows along the seafloor away from the submerged outfall, ambient seawater is entrained, enlarging the discharge plume



Project No. 952-1928 Drawn — Reviewed S.P. Date Mar. '96

Golder Associates

Salinity (parts per thousand) distributions in vertical sections through the mid-channel of Burrard Inlet. (A) 7-9 July 1966; (B) 15-18 February 1962 (from Thomson 1981)

Figure 5-5

and reducing the overall density of the turbidity flow. The turbidity current generally becomes stratified, with higher concentrations of coarser sediments closer to the seabed and lower concentrations of finer particles higher up in the water column. These processes are illustrated in Figure 5-6.

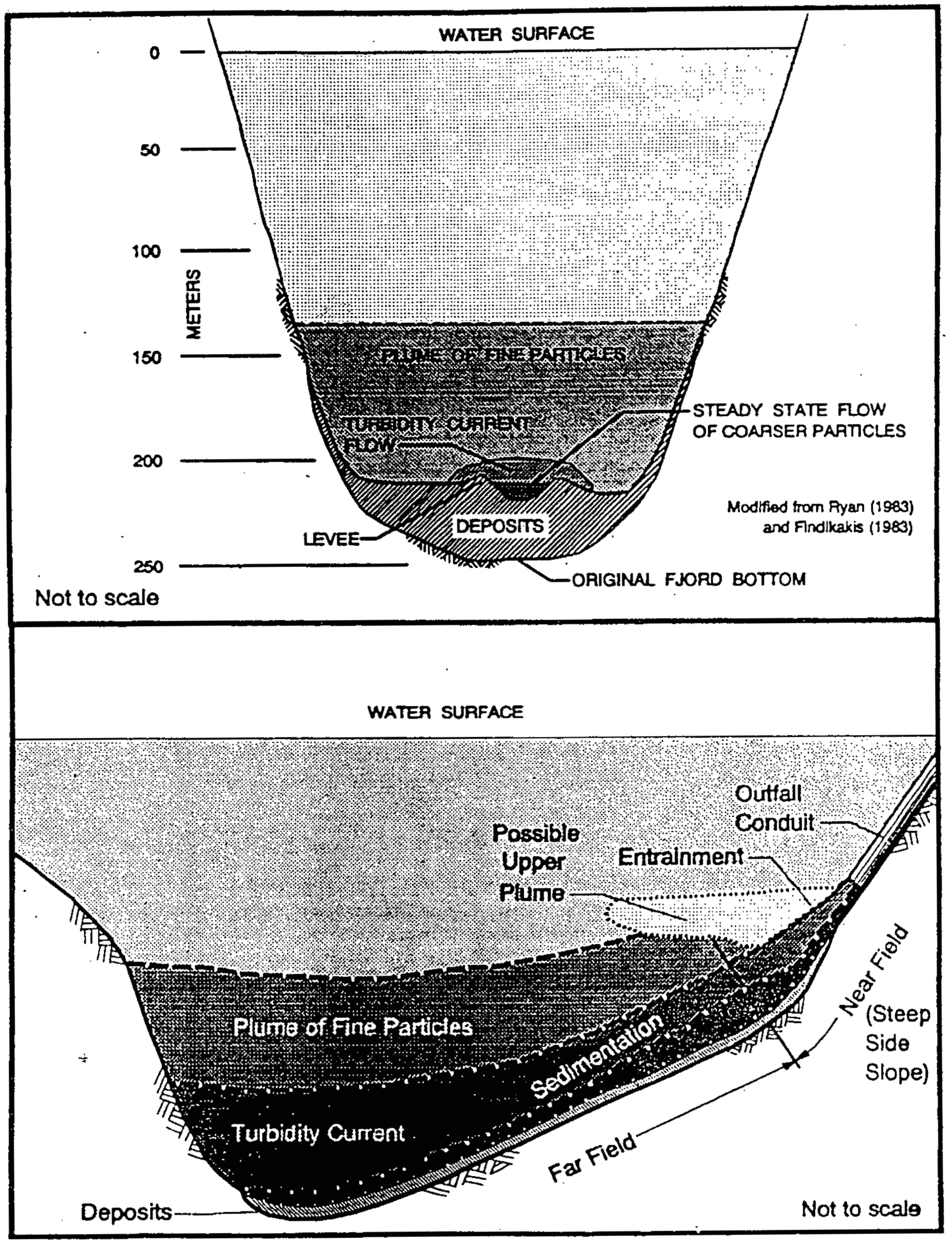
At some point, an upper plume may separate from the main part of the turbidity flow (Figure 5-6). Plume separation is driven by density differences between the liquid component (fresh water) of the discharged effluent and the receiving waters, and is controlled somewhat by the addition of seawater to the effluent prior to discharge. If plume separation occurs, finer tailings are subject to transport by the ambient currents in the receiving environment. Depending on the oceanographic characteristics of the receiving waters, the potential exists that fine tailings may be transported into shallower waters, or considerable distances away from the discharge location.

5.2.2.2 Tailings Deposits

As the turbidity flow travels away from the outfall, a range of flow morphologies may be present. Near to the outfall, jet or sheet flow may occur, forming a fan-like deposit similar to river delta deposits. As tailings discharge continues, the thickness of the tailings deposits generally increase over time. As the tailings deposits thicken and the seabed slope decreases in the vicinity of the submerged outfall, the turbidity flow may contain enough energy to cut through previously formed tailings deposits. If this occurs, a channelled flow pattern may develop (upper portion of Figure 5-6), with the morphology of the channel similar to river forms. Channelled flow patterns may also occur in response to steep seabed slopes.

The channelled flow pattern may persist for many kilometres, and may be a major mechanism enhancing transport of tailings large distances away from the discharge site. Although the coarser tailings materials are generally deposited relatively close to the point of discharge, the high flow velocities associated with channelled flow patterns may transport coarse tailings significant distances downstream.

As flow energy decreases in the channelled turbidity flow (in response to decreases in seabed slope or entrainment of ambient sea water), the channel may become less distinct



Project No. .... Drawn .... Reviewed .... Date ....

Golder Associates

SCHEMATIC CROSS-FJORD AND ALONG-FJORD SECTIONS OF SUBMARINE TAILINGS DISCHARGE, TURBIDITY FLOW AND CHANNELLED SEABED DEPOSITS (from Hesse and Ellis 1995)

Figure 5–6

and eventually disappear. A ponded, lobe-shaped deposit is often associated with the terminal end of the turbidity flow.

5.2.2.3 Slope Failures

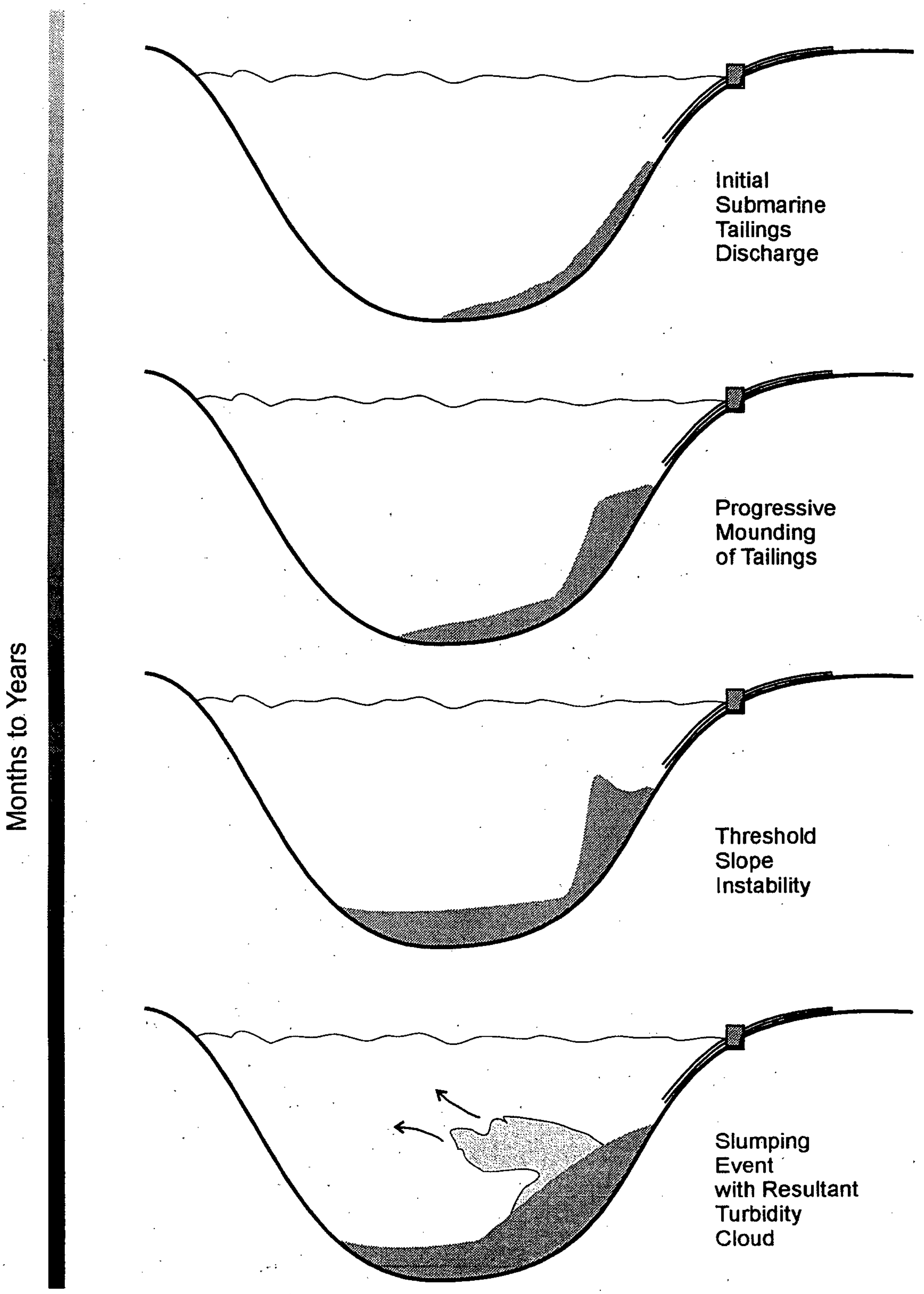
The thickness of the tailings deposits on the seafloor generally increases relatively rapidly with continuing discharge. Eventually, however, the relatively loose tailings deposits are likely to become unstable, and slumping occurs (Figure 5-7). Slumping can be triggered by a variety of processes, including seismic activity, wave loading, and increased pore pressures resulting from high rates of tailings deposition.

Slope failures can occur as large events, leading to significant redistribution of the tailings deposits in a downslope direction. Additionally, such failures may also inject tailing fines into the water column (resuspension) leading to farther tailing redistribution. In a channelled flow regime, smaller failures of the channel levees can occur, leading to channel infilling and relocation of the flow path.

5.2.2.4 Seabed Remobilization

Tailings deposited on the seabed can be subject to redistribution through naturally-occurring marine sediment transport processes. If the near-bed currents in the receiving waters reach a high enough level, tailings remobilization and redistribution will occur. Strong near-bed currents may be generated on a regular basis by tidal forcing, or more irregularly through upwelling or surface waves associated with episodic storm events, or through other oceanographic processes. The frequency and duration of tailings remobilization events can have a major impact on the ultimate distribution of tailings in the marine environment, and can act to introduce fine tailings into the surface waters. These remobilization events may also be significant in exposing tailings to oxygenated waters, increasing the rate of transfer of metal ions into the water column.

Remobilized tailings may be transported either as *bedload* or as *suspended load*. Bedload transport occurs in a thin layer at the interface between the seabed and the water column; in general, coarser sediments are transported in this manner. Finer sediments and tailings may be lifted into suspension higher in the water column, where they are transported by the ambient water movements.



Golder Associates

SCHEMATIC OF A SLOPE FAILURE INVOLVING TAILINGS DEPOSITS FROM A SUBMARINE DISCHARGE SYSTEM

Figure 5-7

PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-08-96 FILE LOCATION: J:\9521928\0396\TDISP.CDR

Although suspended solids settle downwards in the water column, settling can be relatively slow, allowing fine materials to be transported considerable distances before settling to the seabed. Settling of fine sediments is, under certain conditions, enhanced by flocculation, where individual sediment particles group together in flocs. In general, the flocs have much higher settling velocities than do the individual sediment particles. The flocculation process is controlled by a variety of factors including particle size, mineralogy and degree of turbulence in the water column.

The oscillatory currents generated by surface waves can be an important factor in the periodic resuspension of sediments from the seabed. In exposed areas subject to long-period waves, wave-induced currents at the seabed can be significant in water depths exceeding 100 m. These oscillatory currents provide a stirring mechanism, acting to resuspend material previously deposited on the seabed. The resuspended sediments can then be transported elsewhere by even relatively weak components of the near-bed current field.

Fine tailings can be introduced into surface waters through the seabed remobilization events discussed above, particularly if upwelling currents are significant. However, tailings can also be introduced into surface waters if plume separation occurs, or if the submarine discharge system is not located deep enough in the water column. In any of these cases, increases in surface water turbidity levels may be observed over a considerable region.

5.2.2.5 Summary of Solids Transporting Processes

In summary, tailings can be transported and dispersed through the marine environment by a variety of processes. These include turbidity flows, slope failures and natural marine sediment transport processes (bedload transport and suspended load transport). Of these processes, turbidity flows are always associated with submarine tailings discharges, although the form of the tailings deposits on the seabed will vary with the geomorphology of the receiving environment. Slope failures are also common in the marine environment, and the consequences of slumping events should be considered in any tailings fate assessment. Similarly, the consequences of tailings redistribution through naturally occurring sediment transporting processes should be assessed. The degree of confidence with which these tailings dispersal mechanisms can be quantified is discussed in Section 5.5 of this report.

5.3 Physical Data Needed For STD Assessment

The physical data required to assess the fate of mine wastes discharged into a marine environment can be sub-divided into pre-operational and operational requirements. The pre-operational data should be sufficient to provide a basis for predictions of the fate of mine wastes and to characterize the physical characteristics of the marine environment prior to waste disposal. Operational data should be oriented towards confirming the dispersal predictions, as well as providing a multi-year time series of relevant measurements.

5.3.1 Pre-Operational Data

Sufficient data should be collected in the design stages of a proposed submarine tailings discharge system such that the spatial distribution of contaminants in the marine environment can be predicted with some degree of confidence. In order to do this, the movement of water masses and sediments within the disposal area must be understood. Temporal variations should be identified, and “worst case” scenarios considered.

Physical data collected at this stage should also include a baseline characterization of physical parameters that may change as a result of submarine tailings discharge. These parameters include factors such as levels and composition of suspended solids in the water column, nature of seabed substrate and natural siltation rates.

5.3.1.1 Oceanographic Data

In terms of ocean currents, the magnitude, direction, duration and spatial and seasonal variations in the current patterns in the area affected by the discharge must be determined. As a first step in assessing the local oceanographic regime, the relative importance of the various current-generating processes should be estimated (i.e. are tidal currents likely to be stronger or weaker than wind-driven currents, estuarine flows, etc.). This estimation requires data on the bathymetry, local winds, fresh water inflows and tidal ranges in the area of concern. Seasonal variations and infrequent events should also be considered.

Once the major oceanographic processes have been identified, the associated currents should be quantified (magnitude, direction, duration and variability) through an ocean current measurement program. The time period covered by the ocean current measurement program should be sufficient to capture the relevant processes (i.e. at least one month for tidal currents, several months for storm events or deep water renewals) and to quantify seasonal and perhaps longer term variations in these processes. Vertical variations in the current field must also be assessed. As well as quantifying the various components of the current field, the measured current data will also provide a check on the assumptions concerning the relative importance of the various oceanographic processes.

In addition to ocean current measurements, concurrent water column stratification data (i.e. CTD profiles) are also required in order to define the vertical structure of the water column. Although not strictly a physical measurement, vertical profiles of dissolved oxygen levels often yield valuable insights into mixing and flushing processes. These measurements are often obtained in conjunction with CTD profiles. Where wave exposure is significant, wave height and period information is needed to describe both typical and extreme conditions. The frequency and locations of measurements of these parameters must be determined on a site-specific basis.

Oceanographic data measured near the discharge site will enable quantification of the conditions in the immediate vicinity of the proposed tailings outfall. However, spatial variations in the oceanographic environment are likely to be significant. In order to assess the long-term dispersal and accumulation of waste materials in the marine environment away from the vicinity of the discharge site, additional regional data are required to characterize spatial variations in the oceanographic characteristics of the receiving environment. The particular data needs will be specific to each disposal site.

5.3.1.2 Geological Data

The geomorphologic characteristics of the receiving environment should also be examined as part of the pre-operational data collection program. In addition to bathymetry, a regional geophysical survey program provides insights into the nature of the existing seabed (sediment type, seabed mobility, depositionary environment, etc.).

Seabed grainsize samples are required to describe the natural substrate, as are measurements of the natural siltation rates (cores, in situ instrumentation).

The existing sources of sediments to the area of concern should be identified and sediment loads quantified. The suspended solids content in the receiving environment should be monitored prior to tailings discharge; again, spatial and temporal variations must be examined. Concentrations of suspended solids in the water column should be determined, as opposed to measurements of the turbidity in the water column. Organic content of both suspended solids and sediment deposits on the seabed should also be assessed.

5.3.1.3 Tailings Discharge System

Characteristics of the tailings themselves and the proposed discharge system are also required in order to estimate the dispersal of tailings in the marine environment. Important factors include the depth of discharge, the density of the slurry to be discharged, the salinity content and density of the fluid portion, the size of the discharge pipe and the slurry discharge rate. The grain size distribution of the discharged tailings must be known, as well as the mineralogy.

5.3.2 Operational Monitoring Program

The operational monitoring program has two goals: to ensure that the pre-operational estimates of the dispersion of mine wastes in the marine environment are accurate, and to provide a long-term data set. The basis for the first requirement is self-evident; the second requires further explanation.

Due to the time constraints associated with mine development, most technical feasibility and environmental impact assessments are based on limited data. Typically, a year or two of data are available for the important physical parameters; seasonal data coverage may be poor. While these data may be sufficient to assess average conditions in the receiving environment, they may be insufficient to assess the relative importance and magnitude of processes that occur infrequently (e.g. El Nino events), or interannual variations in important processes such as estuarine circulation or deep water renewal events. A long-term data set serves two purposes: it provides additional data that can be used to refine pre-operational estimates of waste dispersal, and it provides a valuable data set that could be utilized in the design of remedial measures if the environmental impacts of marine waste disposal were found to be unacceptable.

The operational oceanographic data collection program should continue with the ocean current measurements and collection of water column stratification data. However, the data collection program should be modified as necessary over time to reflect changes in the level of understanding of the important oceanographic processes and to eliminate data gaps. Additional oceanographic data collection in the monitoring phase should focus on the measurement and characterization of suspended solids and contaminants in the water column.

The seabed monitoring program should focus on defining the spread of mine tailings on the seabed. To achieve this objective a variety of techniques can and should be utilized. Geophysical monitoring such as repetitive side scan sonar and echo sounder surveys will indicate large-scale changes in the nature of the seabed, both in terms of surficial characteristics and depth of sedimentary deposits (natural sediments and/or tailings). Surficial grab samples and sediment cores can be used to define the limits of tailings dispersion in the seabed sediments, and to give more accurate estimates of siltation rates and the degree of mixing between native sediments and mine tailings.

An important component of any monitoring program is the analysis and interpretation of the collected data, in addition to reporting of the observed values. A primary goal of the monitoring program is to test the hypotheses related to mine waste dispersal developed during the pre-operational mine assessment studies. If data are not interpreted and compared with the dispersal hypotheses, the monitoring program should be considered incomplete.

5.4 Island Copper Mine

As discussed in Section 1.0, Island Copper Mine was selected as a case study of previous practices related to prediction and monitoring of environmental effects of STD. The following discussion focuses on those studies and data collection programs directly related to the physical aspects of mine waste dispersal. Both pre-operational and operational studies will be reviewed in the following discussion.

5.4.1 Physical Setting

The Island Copper Mine is located near the north end of Vancouver Island, on the northern side of Rupert Inlet (Figure 4-1). Rupert Inlet is one of three narrow inlets (Holberg Inlet, Rupert Inlet and Neroutsos Inlet) connected to the Pacific Ocean through Quatsino Sound. Rupert Inlet itself forms a relatively small portion of this inlet system, with an overall length of 10 km and a width of 1.8 km. In contrast, Holberg and Neroutsos Inlets are about 35 km and 25 km long, respectively, while Quatsino Sound extends over 35 km from Quatsino Narrows to the Pacific Ocean.

Rupert and Holberg Inlets form one large basin, with water depths reaching a maximum of 172 m near Hankin Point prior to mine operation (Hay 1981). This basin is connected to Quatsino Sound through Quatsino Narrows, a long, slender channel with shallow water depths reaching a minimum of 18 m over the sill at the northern end. A longitudinal profile of the inlet system prior to mine start-up is shown in Figure 5-8.

Tides in this region are mixed, mainly semidiurnal, with tidal ranges at Coal Harbour of 2.9 m on an average tide and 4.2 m on a large tide (Canadian Hydrographic Service 1995). The major source of fresh water to Rupert Inlet is the Marble River, discharging a mean annual flow of roughly 44 m^3s^{-1} (Inland Waters Directorate 1991). This discharge is located at the mouth of Rupert Inlet near Quatsino Narrows (Figure 4-1). Smaller sources of fresh water include Waukwaas Creek and Washawlis Creek, both flowing into the eastern end of Rupert Inlet (Utah Construction & Mining Co. 1971). Discharge peaks in winter and late fall in response to rainfall events, with minimum stream flow occurring in the summer months.

5.4.2 Pre-Operational Studies

The following summary of pre-operational studies related to mine waste dispersal in Rupert Inlet is primarily based on the material presented in the brief prepared by Utah Construction & Mining Co. (1971) in support of their application to discharge mine wastes to Rupert Inlet.

5.4.2.1 Oceanographic Studies

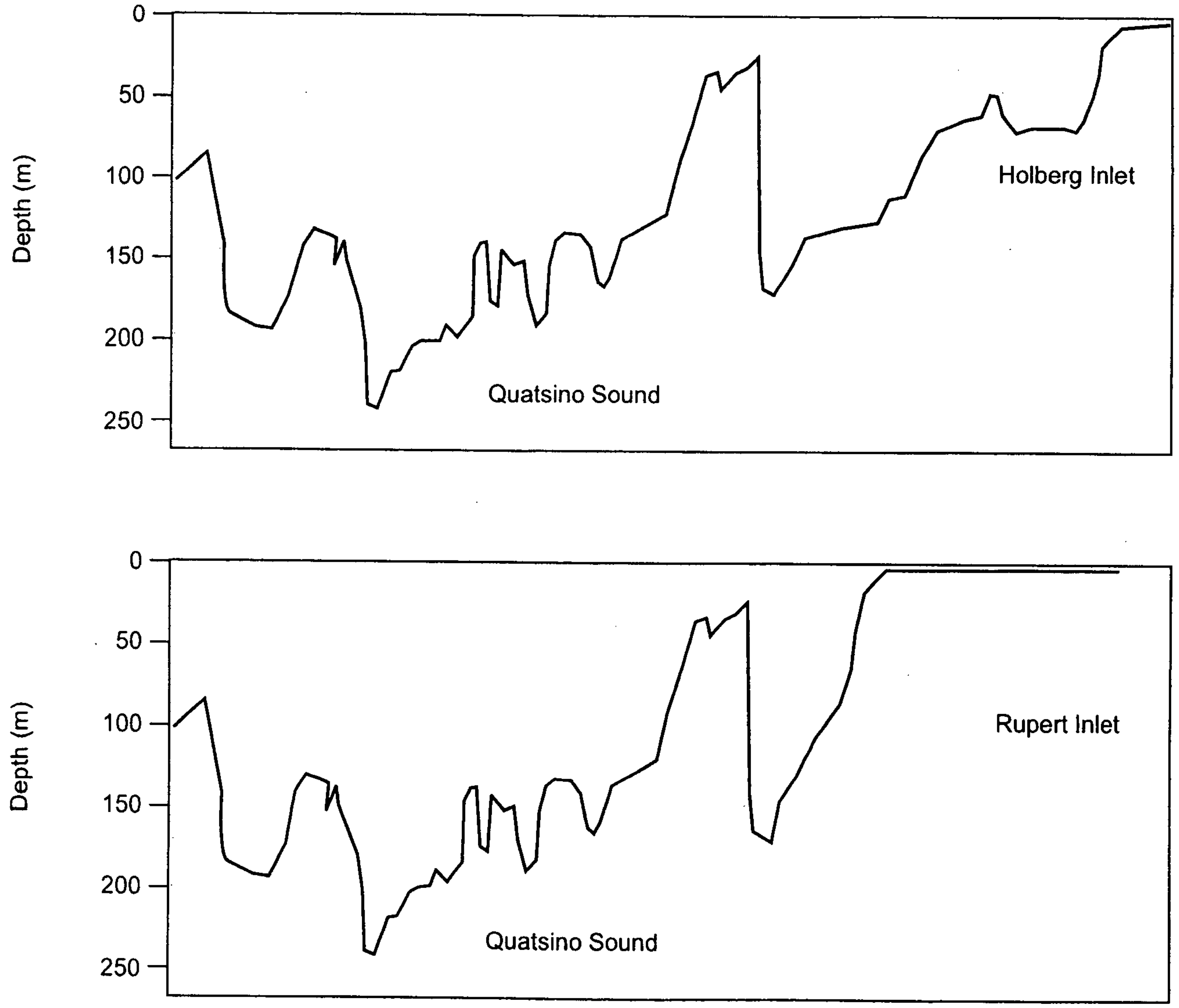
The oceanographic characteristics of many of Vancouver Island's coastal inlets have been described in general terms by Pickard (1963). Holberg, Rupert and Neuroutsos Inlets were surveyed in May 1959 by the University of British Columbia. Salinity, temperature and dissolved oxygen profiles were measured at two stations in Rupert Inlet and five stations in Holberg Inlet, along with inlet bathymetry. Pickard (1963) found that the Holberg-Rupert Inlet system is characterized by the location of the major fresh water source at the mouth of the inlet rather than the head, by the relatively high dissolved oxygen values in the bottom waters, and by the remarkable uniformity of the water column from the seabed to the near-surface waters. Pickard (1963) stated that very few oceanographic observations were available in the winter months for the Vancouver Island inlets, and that the annual cycle of water property changes, including the possible effects of the winter maximum in river discharge, remained to be described. Additional measurements of water column properties in Rupert Inlet are described by Waldichuk et al. (1968).

Specific studies of the physical oceanography in Rupert Inlet were conducted in support of Utah Mine's application for marine disposal of mine tailings (Utah Construction & Mining Co. 1971). These studies included both measurements of ocean currents and the vertical structure of the water column. Ocean currents were measured at Stations A and B shown in Figure 5-9; Station A is in deep waters (158.5 m water depth) adjacent to Quatsino Narrows while Station B is located near the proposed tailings discharge site (62 m water depth).

Approximately 25 hours of current measurements were collected at each site during the period 19 - 22 May 1970 by B.C. Research (1970). A Savonius rotor current meter equipped with a vane to monitor current direction was used together with a continuous, hard-copy recorder mounted on the ship's deck. Current velocities were typically measured for 30 minutes at the seabed and 15 minutes at several intermediate water depths.

Difficulties were encountered in anchoring the survey vessel (a 20 m seiner) at Station A due to the high surface current velocities at the start of the flood tide. On occasion, the suspension cable for the current meter was found to deviate from vertical by as much as

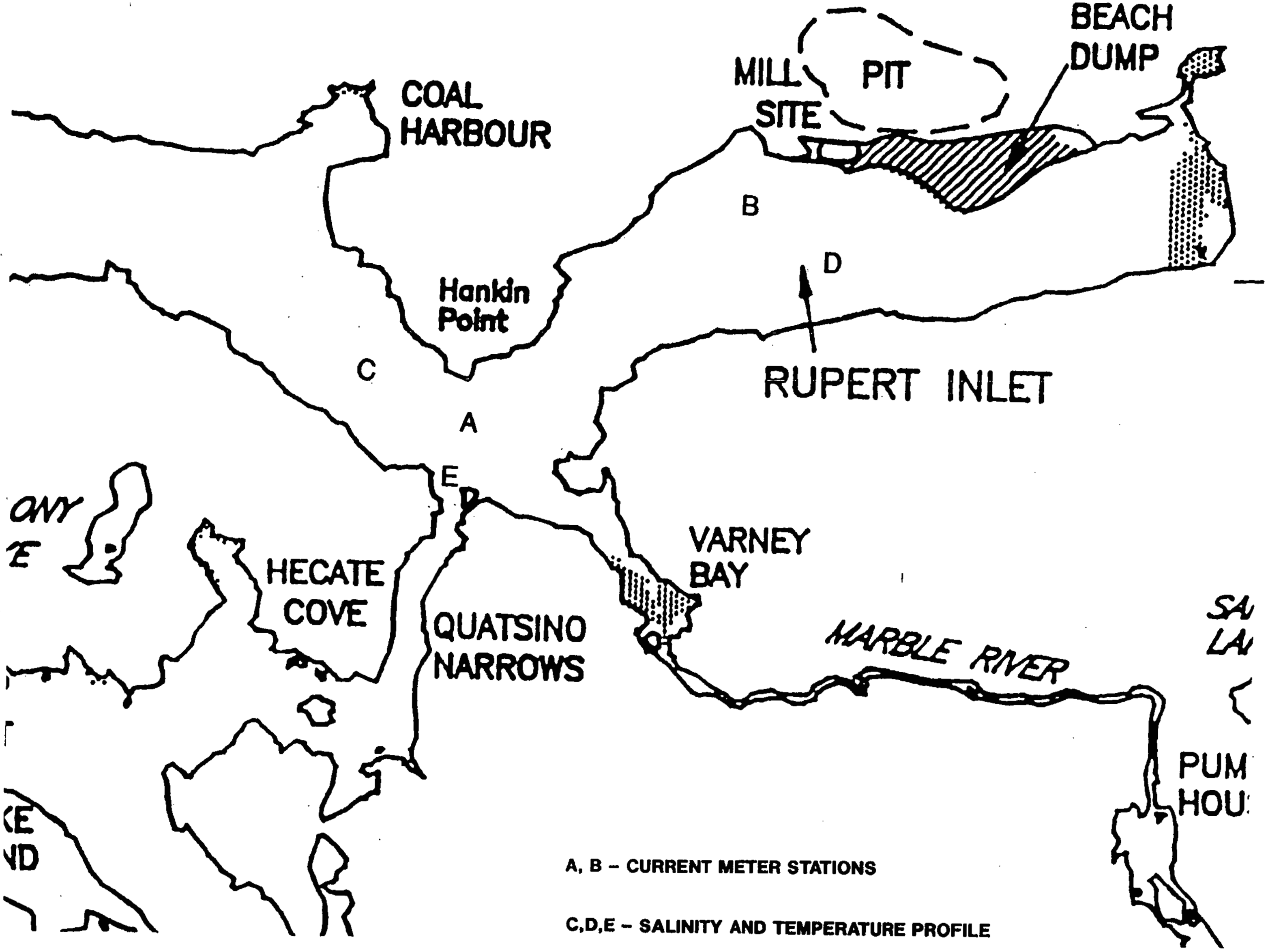
PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-04-96 FILE LOCATION: J:\9521928\0396\FACTORS.CDR



Golder Associates

LONGITUDINAL SECTIONS THROUGH QUATSINO SOUND, QUATSINO NARROWS, HOLBERG INLET AND RUPERT INLET

Figure
5-8



Project No. 952-1928
Drawn —
Reviewed S.P.
Date Mar. '96

Golder Associates

Station locations for current meter measurements (19-22 May 1970) and salinity and temperature profiles (22 June 1970)

Figure 5-9

20° at Station A. No anchoring or current meter deployment problems were encountered at Station B.

At each depth, mean, minimum and maximum current speeds were calculated for each separate recording period (15 or 30 minutes), along with the mean current speed over all recording periods (spanning roughly 25 hours). The results of the current monitoring program as reported by B.C. Research (1970) are summarized in Table 5-1. This study had the following conclusions:

- current speeds are normally lower at station B than at Station A;
- current speeds at mid-depths are lower than those at the surface;
- some correspondence between stage of tide and current speed is indicated at all depths;
- deep water currents occur in the area between Hankin Point and Makwaznhit Island;
- currents of measurable magnitude exist at all stages of the tide and at all depths; and
- current directions were highly variable at each depth with marked vertical variations.

However, it was recognized that deep water current monitoring procedures were not optimal and that the short duration of data records were insufficient for detailed analyses. The B.C. Research study recommended that more deep water current measurements be obtained over several extended time periods at each individual depth, with particular emphasis placed on the near-bottom waters.

As part of the B.C. Research study, three temperature profiles were measured at Station A and two at Station B. These profiles measured the temperature variation with depth over the top 43 metres of the water column. Profiles showed temperature stratification of the surface waters at Station B, with warm surface water overlying colder water at depth. Temperature profiles were described as "more complex" at Station A, with surface and intermediate layering of the water column. Salinity and dissolved oxygen measurements were not obtained during this field study, although they were recommended for future surveys.

An independent review of the current meter data is described by Johnson (1970). Johnson recommended that the current measurements at Station B be accepted as reasonable, while those from Station A warranted reassessment. Based on the difficulties encountered in obtaining the current data at Station A, combined with an independent review of the current meter records, Johnson (1970) presented these conclusions:

- the high current speeds measured at Station A appear to be questionable;
- in general, the mean current speeds near the bottom are relatively low;
- the deep currents observed at Station A are along the axis of the Holberg-Rupert Inlet (i.e. east-west direction);
- higher velocity flows at Station A are confined to the depths above about 61 m (200 ft);
- mean current speeds at Station A below about 61 m (200 ft) generally are less than 0.13 ms^{-1};
- the bulk of the water entering Rupert Inlet on the flood tide flows across the inlet above about 61 m depth; and
- currents are weak and variable in direction at Station B.

Finally, Johnson (1970) concluded that “the current measurements by B.C. Research are adequate to indicate the general character and strength of currents in the area of Rupert Inlet where tailings disposal is to occur.”

Additional oceanographic measurements pertaining to the vertical density structure of the water column were obtained by Carter (1970). Temperature and salinity measurements were made at the three stations (C-E) shown in Figure 5-9, on 17 June 1970. Station C was sampled during the height of the flood tide and again for temperatures only during a short ebb flow, Station D was sampled near slack tide, and Station E was sampled at the end of the flood tide.

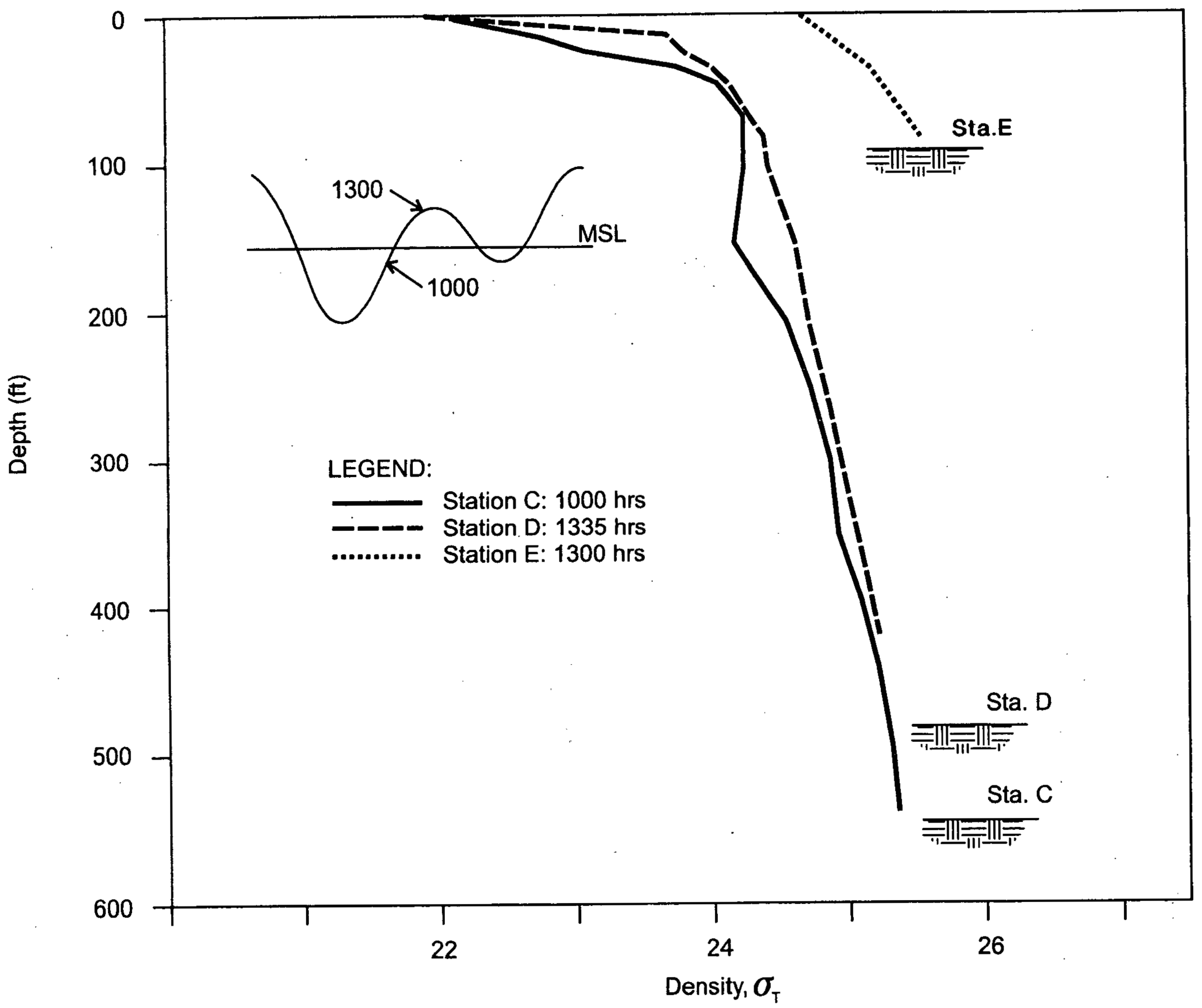
Water column density profiles obtained during this study are shown in Figure 5-10. Based on these observations and assumptions regarding the ratio of mixing between incoming water (Station E) and water in Rupert Inlet (Station D), the following conclusions were made:

- sea water entering Rupert Inlet is denser than the waters within the inlet;
- the significant thermal gradients in the top 30 m (100 ft) will result in the maintenance of a stable strata of water above a depth of 15 m (50 ft);
- during the period of observation, incoming water appeared to be mixed with inlet water and to layer above 91 m (300 ft) depth rather than flow to the bottom of the inlet;
- waters below 76 m (250 ft) appear to be vertically stable;
- the maximum amount of vertical mixing during flood tide occurs in the zone between 15 and 61 m (50 and 200 ft); and
- internal waves appear to be present in the water column, at about the 30 m (100 ft) level.

Using the conclusions of these studies, the high dissolved oxygen levels observed by Pickard (1963) in the bottom waters of Rupert Inlet were explained (Utah Construction & Mining Co. 1971) as follows:

> "The waters of Rupert and Holberg Inlets are characterized by a relatively high dissolved oxygen content throughout the water column. Dr. G.L. Pickard who reported on the oceanographic characteristics of inlets on Vancouver Island, favours the hypothesis that the high oxygen content is caused by an annual replacement of the deep waters of the inlets. He presents data to indicate that the deeper inlet water has a density slightly less than that of ocean water off the Pacific coast of Vancouver Island between October and December. At this same time of year the Fisheries Research Board of Canada reports the shelf water at sill depth to have maximum density. Oxygen will enter this dense near surface ocean water from the atmosphere and it can increase in concentration due to photosynthesis. This well oxygenated water will be carried to the inlet, then move as a density flow over the sill in Quatsino Narrows and under the less dense waters of Rupert Inlet. Current

PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-04-96 FILE LOCATION: J:\9521928\0396\FACTORS.CDR



Golder Associates

WATER COLUMN DENSITY PROFILES
17 June 1970 (from Carter 1970)

Figure
5-10

> velocities associated with such flows would be extremely low because of the small difference in specific gravity between the two waters."

5.4.2.2 Geological Studies

Attempts were made to obtain bottom sediment samples in the vicinity of Stations A and B (Figure 5-9) during the May 1970 oceanographic field program (B.C. Research 1970). Seabed sampling at Station A was unsuccessful; samples were obtained at Station B using a dredge made up on board from a weighted can. Conventional grab and corer samplers were not successfully deployed in this survey.

Additional seabed sediment samples were collected by Utah Construction & Mining Co. on 28 May 1970 (Johnson 1970). A 38 mm diameter gravity core sampler was used to obtain cores from 10 locations in Rupert Inlet (Figure 5-11). Samples were sealed in plastic containers and shipped to the laboratory for examination and description. The sample handling procedures and the extent to which samples were disturbed during this process is unknown. Grain size distributions are not reported.

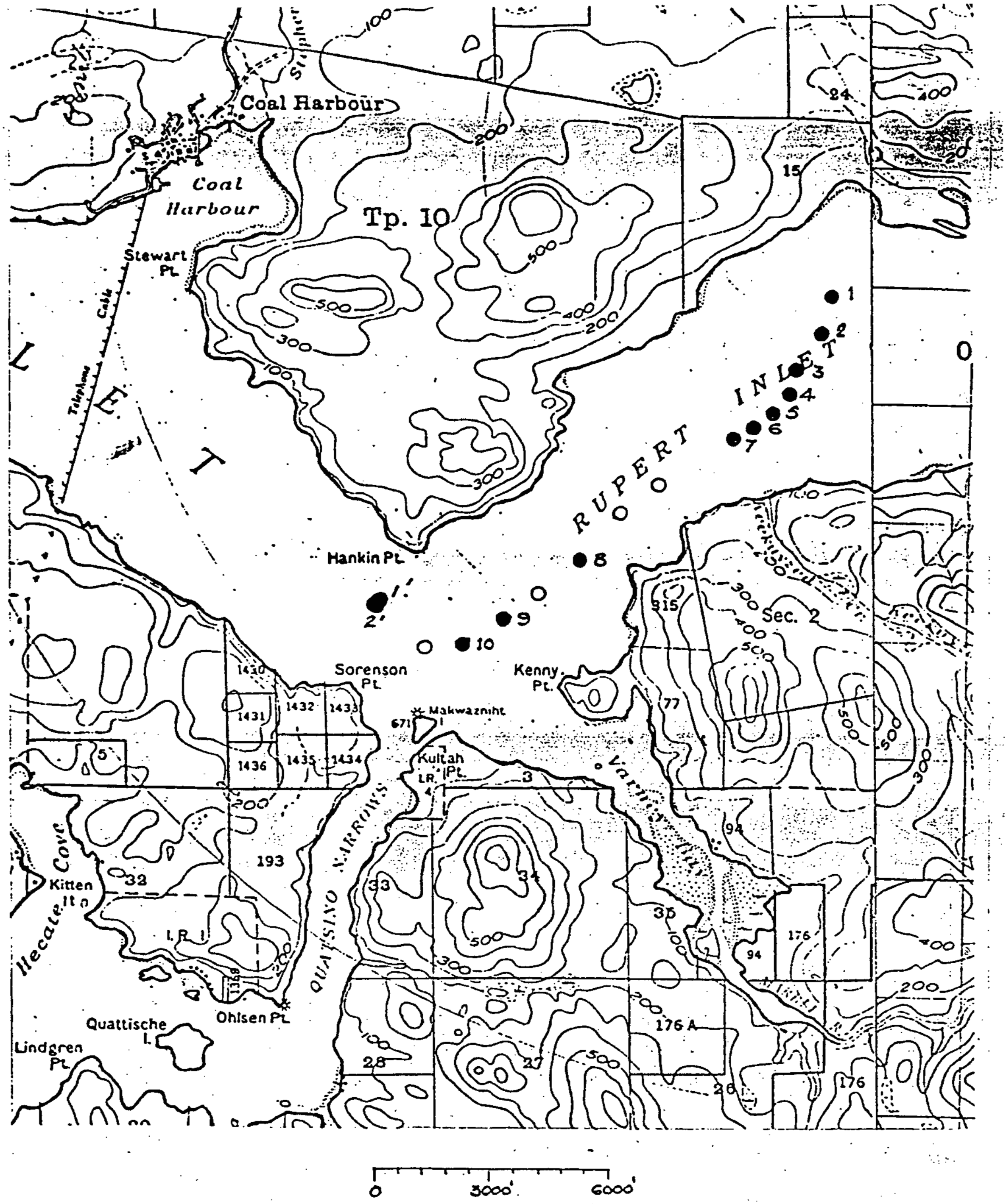
Johnson (1970) describes these samples as follows:

> "Of particular importance in the examination of the ten samples which were available was the cohesiveness of the material. Violent shaking of the containers failed to break up the cohesive mass of the firm mud-like sample. This resistance to agitations indicates that only relatively high current speeds could dislodge and transport such material. Conversely, since such firm or cohesive material (which is a mechanical characteristic of deposits of material of the clay and silt sizes) has been deposited on the bottom of Rupert Inlet over the years, then the natural prevailing current speeds must be relatively low."

An additional two seabed core samples were obtained near the mouth of Holberg Inlet during the survey on 17 June 1970 (Carter 1970). These samples are described as similar in texture to the cores taken in May.

5.4.2.3 Tailings Characteristics

In order to extract the minerals from the Island Copper Mine ore, the rock must be reduced in size to roughly 0.07 mm. Thus, it would be expected that the tailings



Core No.	Depth in ft.
1	210
2	250
3	300
4	390
5	420
6	450
7	450
8	540
9	540
10	550

LEGEND

●	Sample collected
○	Sample not collected

— MAP SHOWING LOCATIONS OF BOTTOM SAMPLING

Project No. 952-1928 Drawn — Reviewed S.P. Date Mar. '96

Golder Associates

Locations for seabed samples, May 1970 (from Carter 1970)

Figure 5-11

produced would be fine sands plus potentially finer materials. After separation, the tailings would be thickened to 40% to 50% solids by weight, and then mixed in a 1:1 ratio with seawater before discharge to the marine environment. Flocculents would be added to the tailings prior to discharge in order to enhance settling of the fines (Utah Construction & Mining Co. 1971). The tailings discharge was proposed to be located at a depth of at least 46 m (150 ft).

5.4.2.4 Predicted Waste Dispersion

The fate of both the solid and liquid mine waste components was considered by Utah Construction & Mining Co. as part of the submission for permission to discharge mill tailings to Rupert Inlet (Utah Construction & Mining Co. 1971). Primarily on the basis of bioassay tests showing zero mortality for fish, and recognizing that dilution would occur in the marine environment, the liquid portion of the effluent was judged to pose no significant threat to the marine environment.

Assessment of the fate of the solids portion of the tailings discharge was more complicated. The following excerpts describe the expected tailings fate scenario (Utah Construction & Mining Co. 1971).

> "As the tailings leave the discharge end of the tailings line, mixing and dilution will occur. A cloud will fan out in a horizontal direction for a distance of up to a few hundred feet. The final mixture will always have a density greater than the receiving waters, and accordingly the mixture will coelesce (sic) and form a density current, on the order of 2' to 10' in thickness, which will flow down the sloping bed of Rupert Inlet and come to rest in the deepest portion of the inlet. As the flow comes to rest the solid fraction will settle.
>
> ...As the density current approaches the vicinity of Quatsino Narrows, it will be at a depth of 400' or more, and therefore in a zone of vertical stability well below any significant influence from tidal effects coming through the Narrows.
>
> From estimates of the quantity of tailings proposed to be released into the Inlet each year, the deposition area over the 25 year life of the mine is estimated to be about 1,600 acres occupying approximately one-tenth of the volume of the inlet, (Appendix 7.) This will consist of a deposit of the coarse fractions on a very flat slope near the end of the disposal pipe line.

> The fine fractions will flow on into the deep portion of the Inlet where ponding will occur."

This scenario was developed based on three main arguments:

1. Laboratory and field observations of density currents in fresh water reservoirs had shown that sediment-laden turbidity flows tend to follow the reservoir floor without surfacing.

2. Fine, cohesive sediments entering marine waters have been shown to flocculate, enhancing settling and deposition. Laboratory tests on natural muds from San Francisco Bay showed that sediment erosion started at a mean flume velocity of 0.24 ms^{-1}.

3. Estimates of current velocities in Rupert Inlet showed that mean velocities were expected to be less than about 0.13 ms^{-1} in bottom waters.

5.4.3 Operational Studies

Permission to discharge mine tailings to the marine environment was granted to Utah Mines Ltd., and discharge started in October 1971. In the initial years of mine operation, two independent monitoring programs were established. The first, by federal agencies, was conducted by Environment Canada, with the goals of monitoring the distribution and movement of tailings in the marine environment in relation to pre-operational predictions. The second monitoring program was required under the conditions of Utah Mines' discharge permit, and was conducted by an interdisciplinary team of faculty members from the University of British Columbia and the University of Victoria. This monitoring program was designed to detect significant changes to the physical, chemical and biological conditions of the receiving environment related to the mining operation. In addition, several scientific studies of the physical processes active in Rupert Inlet have been conducted.

Many reports and technical papers have been produced as a result of the various studies of Rupert Inlet. A complete review of all of these studies is not possible given the constraints of this project; for the purposes of this report, the results of several studies related to the physical dispersion of mine wastes will be summarized. This section will focus on those studies conducted in the early years after tailings discharge was initiated.

Chemical and biological aspects of waste dispersion and the associated environmental impacts are discussed elsewhere in this report.

5.4.3.1 Environment Canada Monitoring Program

The results and conclusions of the Environment Canada monitoring program are described by Goyette and Nelson (1977). Over the first few years of mine operation, Environment Canada monitored turbidity levels in the water column and deposition of mine tailings on the seabed.

Water column turbidity was monitored using a variety of methods:

- routine transmissometer profiles from two stations in Rupert Inlet, one in Holberg Inlet and one at the northern end of Quatsino Narrows;
- aerial observations and photographic records of surface turbidity in Rupert Inlet, Holberg Inlet and Quatsino Sound;
- visual observations of water clarity along the shoreline during SCUBA surveys; and
- visual observations of water clarity during submersible dives in Rupert Inlet, Holberg Inlet and Quatsino Sound.

Some measurements of suspended solids concentrations in the water column were also made in conjunction with one transmissometer survey. Seabed samples collected from the shoreline by SCUBA divers in the vicinity of Hankin Point were also analyzed for grain size distributions.

The distribution of tailings on the seabed was monitored through periodic grab sampling of the seabed sediments. Seabed sediments were assessed visually, with sample colour taken as an indication of the presence of tailings (light grey compared to the light brown/olive green colour of natural sediments). Thickness of tailings deposits were estimated where possible from the grab samples. Underwater observations of mine tailings deposition were also made by SCUBA divers and from the submersible dives in February 1975.

The Environment Canada monitoring program found that:

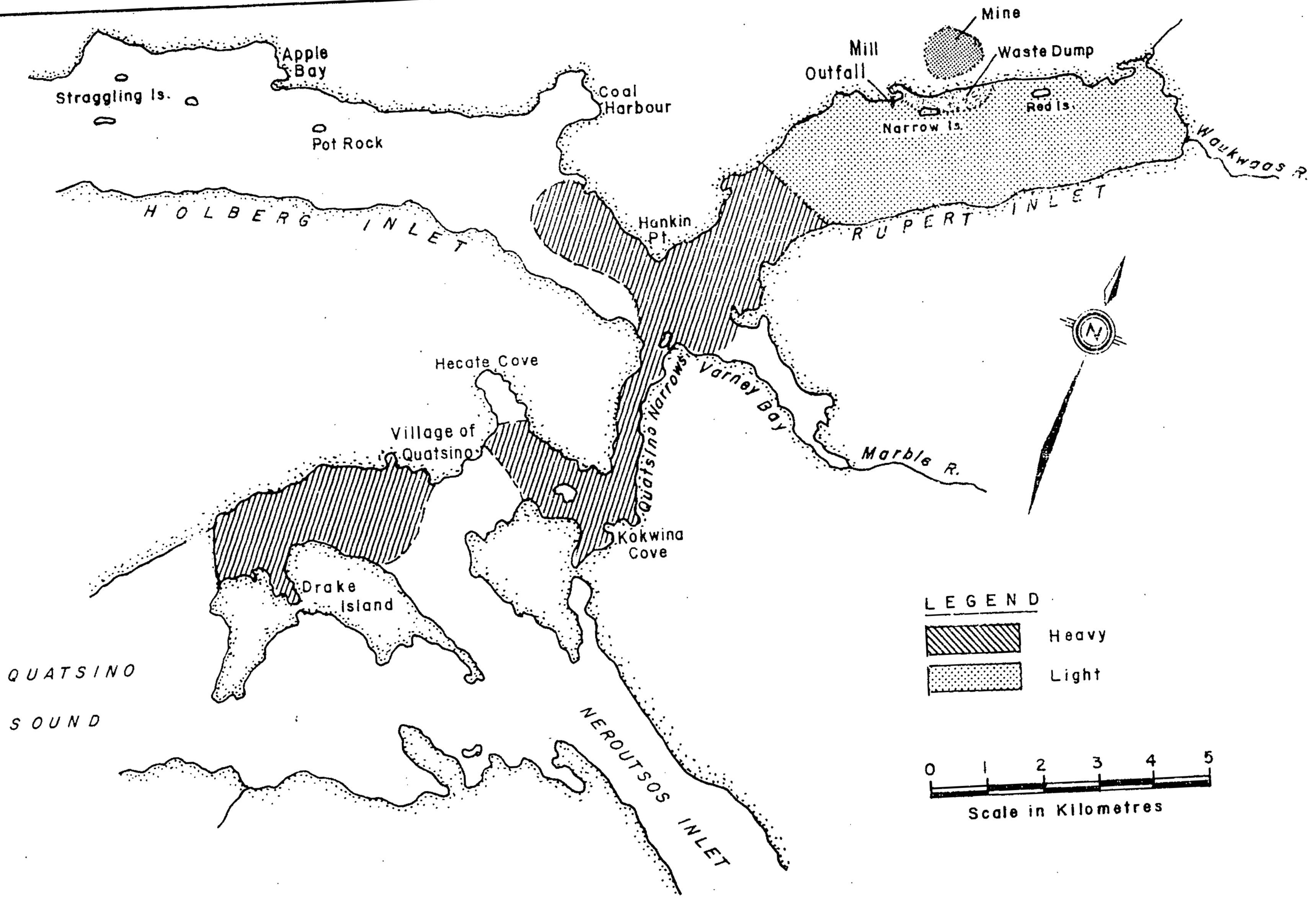
- During the first two years of mine operation, surface turbidity levels were increased over natural levels primarily in the immediate vicinity of the waste rock dump. By the spring of 1972, periodic increases in surface turbidity were noted around the northern end of Quatsino Narrows. By August 1973, increased surface turbidity levels were observed throughout Rupert Inlet and Quatsino Narrows and in portions of Holberg Inlet and Quatsino Sound (Figure 5-12). Surface waters had a distinct grey appearance, similar to the colour of mine tailings. Large, grey-coloured "boils" of turbid water were seen off Hankin Point during the latter part of the flood tide.

- Sub-surface turbidity measurements showed that, by 1973, a sub-surface turbidity field had developed throughout most of Rupert Inlet. Below 80 m water depth, transmissibility was significantly higher in Holberg Inlet than in Rupert Inlet. Seasonal fluctuations in transmissibility were apparent, with maximum turbidity levels occurring during periods of large tidal ranges. Submersible observations showed extreme turbidity throughout the water column in Rupert and Holberg Inlets, on the same day, visibility was good at all water depths in Quatsino Sound.

- Water column particle size analyses showed that more than 80% of the suspended solids were fine silts and clays. Benthic samples taken during July and November of 1975 showed the presence of fine, light grey sediments in the shoreline areas around Hankin Point.

- The extent of tailing deposition on the seafloor as determined through visual inspection of the bottom grab samples is shown in Figure 5-13 for surveys conducted in 1973 and 1974. Observations by SCUBA divers in 1975 showed that tailings deposition was much more extensive than indicated by grab sampling, particularly for shoreline areas. Intertidal and subtidal tailings deposition was noted to be approximately equivalent to the area of surface turbidity shown in Figure 5-12, and to include most of Rupert Inlet, Quatsino Narrows and portions of Holberg Inlet and Quatsino Sound. The thickness of tailings deposits ranged from a light film to heavy deposits, with high rates of sedimentation in intertidal and shallow subtidal zones, particularly around the mouth of Rupert Inlet.

By 1975, the total area of mine sediment deposition determined by grab sampling and SCUBA observations was estimated to represent roughly 9,500 acres. By 1996, the total area of tailings deposition was estimated to be 9,600 acres (D. Goyette, pers.com.) with maximum tailings thickness in the central trough of the fjord of approximately 50 metres (Ellis et al., 1995).



AREA OF SURFACE TURBIDITY - AUGUST 3, 1973

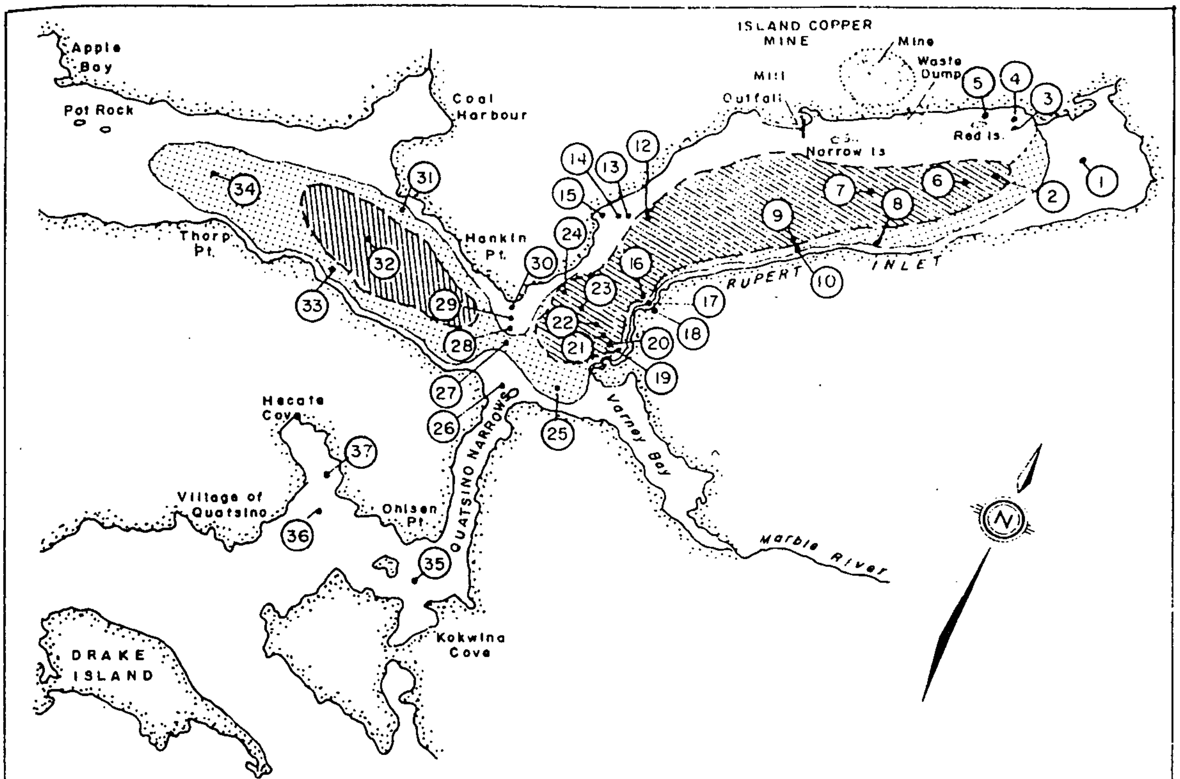
Project No. 952-1928
Drawn —
Reviewed S.P.
Date Mar. '96

Golder Associates

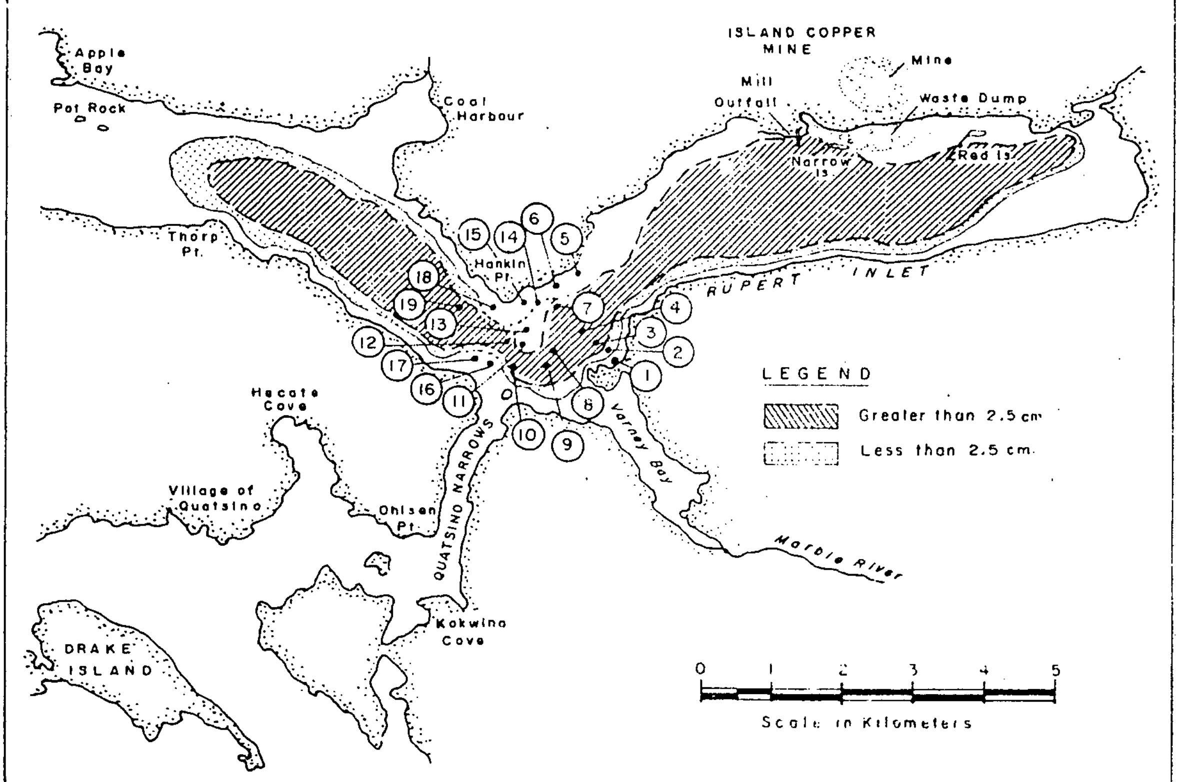
Area of surface turbidity observed during aerial overflights, 3 August 1973 (from Goyette and Nelson 1977)

Figure
5-12

Project No. 952-1928 Drawn — Reviewed S.P. Date Mar. '96



TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - OCTOBER 6, 1973



TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - MAY-JUNE 1974

Golder Associates

Seabed tailings distribution based on visual inspection of grab samples, 1973 and 1974 (from Goyette and Nelson 1977)

Figure **5-13**

5.4.3.2 Oceanographic Studies

Several studies of the dynamics of tidal flows through Quatsino Narrows and deep water renewals in the Rupert/Holberg Inlet system were conducted subsequent to mine start-up. These studies are described in detail by Drinkwater (1973), Drinkwater and Osborn (1975), Stucchi and Farmer (1976) and Stucchi (1985). Johnson (1974) measured near-bed currents at several locations in Rupert Inlet as part of a study of the dispersal of natural sediments and tailings in the inlet. The following represents a summary of the database used and knowledge gained as a result of these studies.

As part of the marine monitoring programs associated with mine development, regular measurements of the temperature and salinity structure of the water column were made. Drinkwater (1973) analyzed available data covering the period from March 1971 through June 1972; he found that:

- Temperature, salinity and dissolved oxygen levels follow seasonal trends in Rupert Inlet. Temperatures are lowest in early spring and highest in late summer or early fall. Salinities (below the surface layer) are highest in summer or early fall, and lowest in early spring. Seasonal trends in dissolved oxygen levels are less distinct.
- The trends in temperature, salinity and dissolved oxygen are similar at all depths in Rupert Inlet, although seasonal variations are large.
- Salinities of the upper waters in Quatsino Sound are similar to the deep water salinities in the Rupert-Holberg basin.

The vertical uniformity of the water column and the large annual variations in water column properties were attributed to the strong tidal exchanges and high levels of turbulence in Quatsino Narrows. The downward penetration of turbulent mixing in the waters of Rupert Inlet was not resolved by this study; however, zones of intense mixing were observed to a depth of 90 m (maximum depth of observations) between Quatsino Narrows and Hankin Point.

Near-bed currents were measured by Johnson (1974) at several locations in Rupert Inlet using a bottom-mounted instrument system. Current measurements were attempted at or near spring tides during summer and fall of 1973. These measurements showed the presence of strong bottom currents, exceeding 100 cms^{-1} at times. Strong currents were observed in both up-inlet and down-inlet directions. Johnson postulated that the strong, down-inlet currents occurred when density flows intruded into Rupert Inlet at some intermediate water depth, rather than along the seafloor.

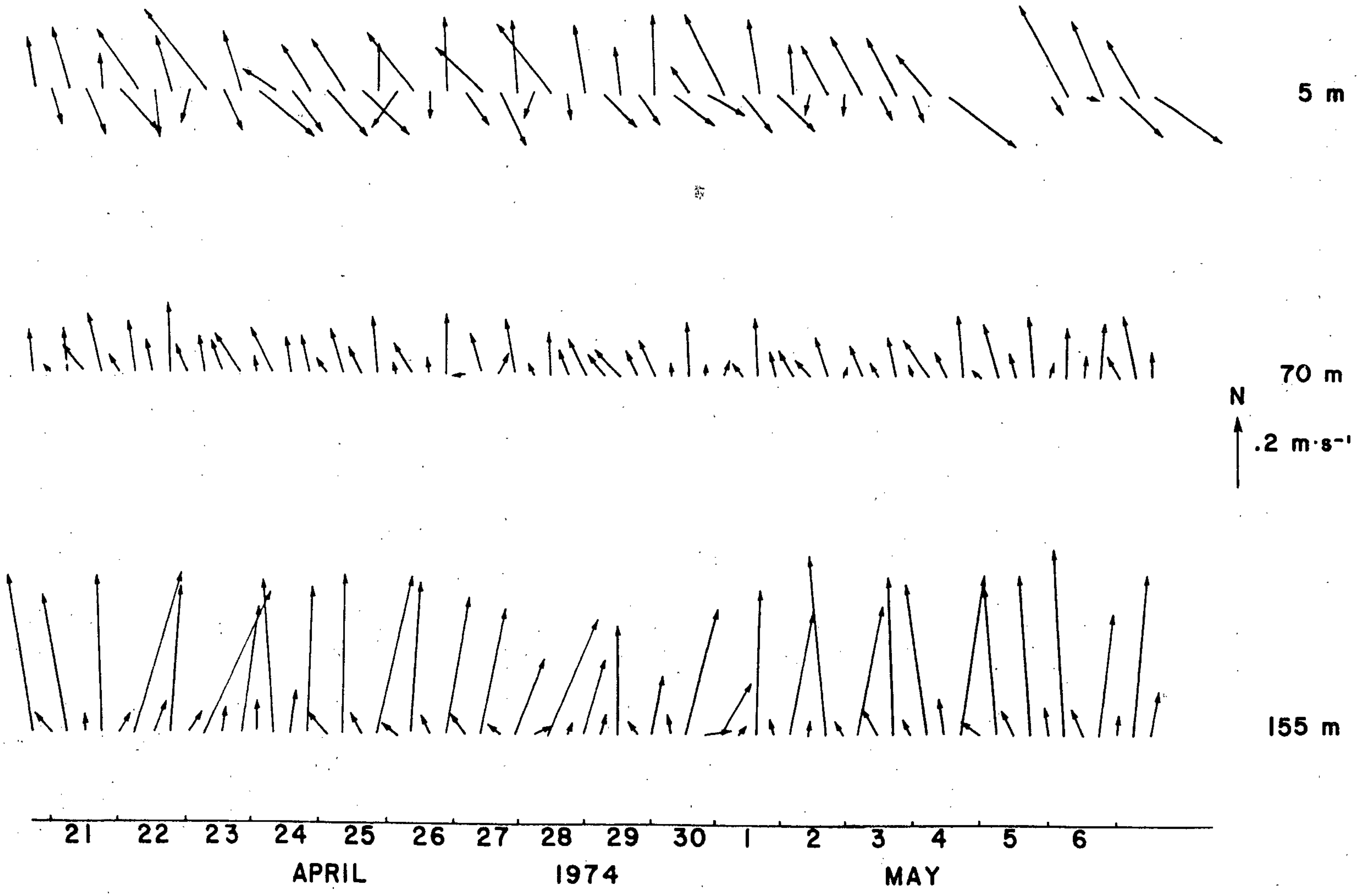
Deep water renewals in Rupert and Holberg Inlets were examined by Stucchi and Farmer (1976). A string of three current meters was moored between Hankin Point and the northern end of Quatsino Narrows for a three-week period in the spring of 1974; salinity and temperature were also measured. Current measurements were obtained near-surface (5 m), at mid-depth (70 m) and near the seabed (155 m); averaged currents are shown in Figure 5-14. These measurements clearly show:

- the strongest currents occur near the seabed, on the flooding tide;
- during the flood tide, the bulk of the exchange occurs near the seabed; whereas, during the ebb tide the exchange is confined to the surface waters;
- near-bed currents averaged 40-45 cms^{-1} during the flood tide, with peak speeds reaching 154 cms^{-1}; and
- higher than average salinities are associated with the high bottom currents.

Stucchi and Farmer (1976) conclude that the strong near-bottom currents represent a turbulent density flow, occurring during the latter portion of the flood tide throughout the period of observation. A portion of the density flow is deflected upwards by the shoreline at Hankin Point. Examination of long-term trends in temperature and salinity suggested that deep water renewals in Rupert Inlet occur primarily during spring and summer, and perhaps for short periods during the fall and winter months.

5.4.3.3 Geological Studies

The near-bed current measurements described by Johnson (1974) were made as part of a study of the dispersal of both natural sediments and mine tailings in Rupert Inlet. In addition to current meter measurements, Johnson analyzed records from three seismic profiling surveys of the inlet. The first survey was conducted in March 1971, prior to mine operation, with the second survey in September 1971 after roughly one year of mine operation, and the third in September 1973. Survey lines included both longitudinal and transverse sections.



Project No. 952-1928
Drawn —
Reviewed S.P.
Date Mar. '96

Golder Associates

Mean ebb tide and mean flood tide currents, 1974 measurements in the vicinity of Station A (from Stucchi and Farmer 1976)

Figure 5-14

Interpretation of the seismic profiles obtained prior to mine operation showed Rupert Inlet to have two main surficial sedimentary units:

- Unit B, a flat-lying, uniform, grey, clayey-silt, represents sediments deposited prior to the effective connection of Quatsino Sound to the Rupert-Holberg basin through Quatsino Narrows. Unit B is found outcropping at the surface in the region between Quatsino Narrows and Hankin Point, and extending into Rupert Inlet itself. In these areas, the surface of Unit B appears to have undergone considerable erosion.

- Unit A is found as well-stratified deposits of softer sediments towards the heads of both Rupert and Holberg Inlets. In Rupert Inlet, Unit A occurs primarily along the northern flank of the inlet. Unit A is interpreted as reworked Unit B sediments that have been transported up-inlet by the strong bottom currents that occur under the present-day oceanographic regime and redeposited in more quiescent areas of the inlet.

The seismic profiles obtained after mine start-up show the development of a tailings fan along with evidence of large submarine slumps or slides associated with both the tailings discharge and the waste rock dump (Johnson 1974).

A subsequent study of the tailings deposits and mechanisms for tailings dispersal in Rupert Inlet is described by Hay (1981). By 1974, the routine annual seismic reflection surveys conducted as part of the mine monitoring program had shown the presence of a leveed submarine channel in the tailings deposits. Hay (1981) used acoustic survey methods to study the form of the leveed channel and the turbidity current created by the tailings discharge.

Hay (1981) found that, over a three-year period, the morphology of the tailings deposit evolved through three successive regimes: an initial meandering channel, followed by an apron-like depositionary regime, and, finally, a rechannelled formation. The morphology of the meandering reach was found to be geometrically similar to river forms and to depend upon bed slope and rate of flow in the turbidity current. The channel was apparent for a distance of roughly 5 km away from the submerged outfall (Hay 1983), becoming indistinct in the southern reaches of Rupert Inlet. Channel overspills were common, as were surges in the turbidity current related to slumping of previously-deposited tailings.

5.4.4 Discussion

As described previously, permission to discharge mine tailings to the marine environment was granted to Utah Mines based on these assumptions:

- the tailings discharge would form a confined density current that would flow along the seafloor, coming to rest in the deepest portion of the inlet;
- tailings deposits would be isolated from the tidal effects of Quatsino Narrows;
- the deposition area over the 25-year life of the mine would occupy approximately 1,600 acres of the seabed; and
- fine tailings would not enter the surface waters of the inlet.

The Environment Canada monitoring program showed that, in the first few years of mine operation, the fine fraction of the tailings were entering surface waters, formed a sub-surface turbidity field, and deposited in shallow waters over an estimated total area of 9,500 acres.

The differences betwen the preoperational predictions of tailings dispersal and the observations made by Environment Canada were partly due to the much stronger than expected bottom currents near Hankin Point. This and other factors are discussed below, as they illustrate the effects of the site-specific conditions in Rupert Inlet.

The above predictions of tailings dispersal in Rupert Inlet were based on three main arguments (Section 5.4.2.4), which in themselves involve certain assumptions about the physical processes governing tailings dispersal. The limitations inherent in these arguments are presented here.

Firstly, it was suggested (Utah Construction & Mining Co. 1971) that the behaviour of the turbidity flow created by tailings discharge into the marine environment would resemble that of turbidity currents in fresh water reservoirs. This argument underestimates the role of salinity in determining the density structure of the water column and thus the behaviour of the discharge plume. Salinity differences between the fluid component ,of the discharged effluent and the receiving waters are an important factor in plume separation and maintenance of plume integrity. In retrospect, the effects of salinity differences do not appear to have been adequately investigated in the pre-operational studies.

Secondly, it was argued that the fine tailings fraction would flocculate and settle to the seabed upon discharge to the marine environment. While this behaviour has been frequently observed in marine waters, the extent to which flocculation will occur cannot be easily predicted. The degree of flocculation, and thus the rate at which fines settle to the seabed, depends on many factors. These include the particle size and shape, the mineralogy of the fine materials, the level of turbulence in the receiving environment and the salinity in the receiving waters.

Finally, the tailings fate assessment relied on the assumption that mean currents in the deep waters of Rupert Inlet would be low, and, as a consequence, remobilization of the fine fraction of the tailings deposits would not occur. The original assessment of current speeds in Rupert Inlet was based on very limited data, with questionable accuracy. These original current measurements indicated the possibility of strong bottom currents near Hankin Point, and additional measurements were recommended. In our view, the relatively consolidated state of the natural sediments found in the area (Johnson 1970) also suggests the presence of strong bottom currents, as does the geologic interpretation presented by Johnson (1974).

Subsequent review of the current data by Johnson (1970) discounted the accuracy of the high-speed current measurements near Hankin Point; however, no additional data were obtained to resolve this issue. Further measurements of near-bed currents were obtained after the observations of dispersion of tailing fines in the Rupert-Holberg Inlet system. These measurements confirmed the presence of strong bottom currents during flooding tides.

5.5 Assessment of Future Submarine Tailings Discharge Systems

As shown in Sections 5.2 and 5.3, a variety of processes can affect waste dispersion, and these processes act over a range of length and time scales. The relative importance of each oceanographic and solids transporting process is site-specific, and thus must be assessed separately for each individual mine site. Consequently, the data required to quantify these processes are also site-specific. Data collected prior to the permitting process should be sufficient to both characterize the physical aspects of the marine environment prior to waste disposal and to provide a basis for predictions of the fate of mine wastes.

The Island Copper Mine case study described in Section 5.3. has illustrated the importance of collecting sufficient data to characterize the relevant oceanographic, and sediment transporting processes in the receiving environment. It is particularly important to collect sufficient data to characterize the spatial and temporal variations in these processes.

5.5.1 Conceptual Basis for Tailings Fate Assessment

Throughout this report, a common conceptual basis for the assessment of the environmental impacts of marine disposal of mine wastes has been emphasized. This conceptual basis can be summarized as:

- Predictions of the dispersal of mine wastes in the marine environment must be made using the best available technology. There will be some level of uncertainty associated with these predictions. The sources and level of uncertainty must be reported along with the fate predictions.

- The implications of errors in the fate predictions should be considered and articulated, particularly when uncertainties are large.

- If the uncertainties in mine waste dispersal predictions are large and the implications of errors are such that unacceptable environmental impacts might occur, a contingency plan with remediation measures should be developed and approved as part of the permitting process.

This conceptual assessment framework will next be related to the physical aspects of tailings dispersal in the marine environment.

5.5.2 Predicting the Physical Fate of Mine Wastes in the Marine Environment

In order to predict the fate of mine wastes in the marine environment, the important processes governing water movement and solids transport must be identified and quantified. This procedure involves both data collection and data analyses, and may also include the development and/or application of numerical and/or physical models. This is well summarized by Farmer (1983):

> "...This includes a careful evaluation of the problem prior to observation, development of a sound plan for data gathering and then, following the field program, a careful analysis and interpretation of the results....The final result must not be limited to a compilation of data reports...nor a superficial summary or purely descriptive account of the relevant processes. Rather, the goal should be to focus on specific physical processes that govern the circulation of the water and might influence the disposal scheme, and to interpret the data quantitatively in terms of simple models of these processes.
>
> Models can assist in the interpretation in various ways. They may be physical models or mathematical models of various complexity, from simple analytical representations to complex computer schemes. Mathematical models have the attraction that once formulated, numerous experiments can be run using different parameters with relatively little trouble. However, a mathematical model is only as good as the physics that goes into it. The literature is littered with numerical models that are little more than sophisticated interpolation formulae, or worse still, purport to describe complex phenomena such as mixing on the basis of wholly inappropriate parameterizations. Mathematical models can be useful for testing concepts and developing insight, but it is important to see them clearly for what they are: a mathematical representation of certain physical concepts which may or may not be correct.
>
> Laboratory models can also provide insight and offer a means by which complex flows can be directly observed. A consideration with such models is the accurate scaling of the flow, which must be carried out such that the important physical processes are adequately reproduced.
>
> Ideally, we should strive for interaction between experimental work, data analysis and theoretical or laboratory modelling. The modelling can be used to test ideas that can be checked against the data. Often questions will arise that suggest further experimental work and the process can be repeated. Thus in planning an experimental program it is desirable to avoid the temptation of having one large and expensive field project followed by data analysis and interpretation. The same amount of money is often better spent on a more limited pilot study, followed by careful evaluation of results, followed again by a second more selective field study."

The above comments apply to both the processes governing water movement and those affecting solids transport. In terms of water movement, our ability to quantify and model the relevant processes has improved considerably in recent decades. Although the details of many processes are still unclear, a variety of numerical models are now available to model different oceanographic processes or combinations of processes. The main issues become identifying the major processes, choosing the correct model formulation and collecting enough field data to calibrate and verify the model predictions and assess the level of uncertainty associated with model results.

In comparison, our knowledge of the physics governing solids transport is relatively poor. Many models exist for predicting sediment movement in the marine environment, however, most of these are virtually untested and are indeed based on inappropriate parameterizations derived from empirical studies of sediment movement in rivers. This is particularly true for the dynamics of fine sediment movement, where flocculation and cohesive effects may dominate. These effects are difficult to predict and to quantify accurately. Thus, an appropriate combination of field, laboratory and theoretical analyses are particularly important in determining the fate of fine tailings discharged to the marine environment, and the level of uncertainty associated with the fate predictions.

In assessing the fate of tailings in the marine environment, potential interactions between mine operation and marine physical processes must be considered. For example, the possibility has been raised by Stucchi and Farmer (1976) that tailings deposited in Rupert Inlet may alter the nature of the exchange processes through Quatsino Narrows. The considerable accumulations of tailings on the seafloor of Rupert Inlet have changed the bathymetry of the inlet and this in turn may alter the circulation patterns and the nature of the ocean currents.

Table 5-1

Current speeds recorded in Rupert Inlet, 19-22 May 1970

Water depth (metres and feet)	Overall mean current speed (ms^{-1})	Maximum mean current speed (ms^{-1})	Maximum recorded current speed (ms^{-1})
Station A:			
9.1 (30)	0.19	0.51	0.72
30.5 (100)	0.23	0.59	0.72
61.0 (200)	0.13	0.36	0.72
106.7 (350)	0.09	0.17	0.39
149.4 (490)	0.11	0.33	0.51
Station B:			
6.1 (20)	0.09	0.16	0.30
27.4 (90)	0.06	0.10	0.18
57.9 (190)	0.05	0.07	0.21

6.0 MARINE CHEMISTRY: DETERMINANTS OF BIOAVAILABLE CONTAMINANTS FROM STDS

6.1 Preliminary Considerations

In regards of potential STD chemical stressors (i.e., contaminants), the key question for consideration is how the contaminant chemically behaves in the marine environment and transforms between inert and bioavailable forms. It is only in the latter case that a contaminant (e.g. metal) can exert a toxic deleterious effect. For this reason the focus of this section is on the abiotic mechanisms and equilibria which determine whether metals in tailings solids (sediments or suspended) will dissociate to a dissolved ionic form available for direct uptake by organisms.

6.1.1 Chemical Oceanographic Mechanisms Influencing Bioavailability of Metals to Aquatic Biota

For the purposes of this report, it is assumed that bioavailability of metals follows the generalized system as expressed in Figures 6-1a & b. That is, the most bioavailable (and therefore the most toxic) forms of metals are those in which the metal ion is free and uncomplexed with any other substance. The discussions which follow take into account the conditions found in most natural water systems, notably the marine and estuarine environments, though it is understood that in some situations metal bioavailability may change within acidic gastrointestinal tracts of organisms even when the ambient conditions are reasonably benign. Figure 6-2 provides a summary of the factors that have a major influence on the bioavailability of metals in the marine environment.

FIGURE 6-1a
Conceptual relationships of differing metal forms and their bioavailablity to aquatic organisms.

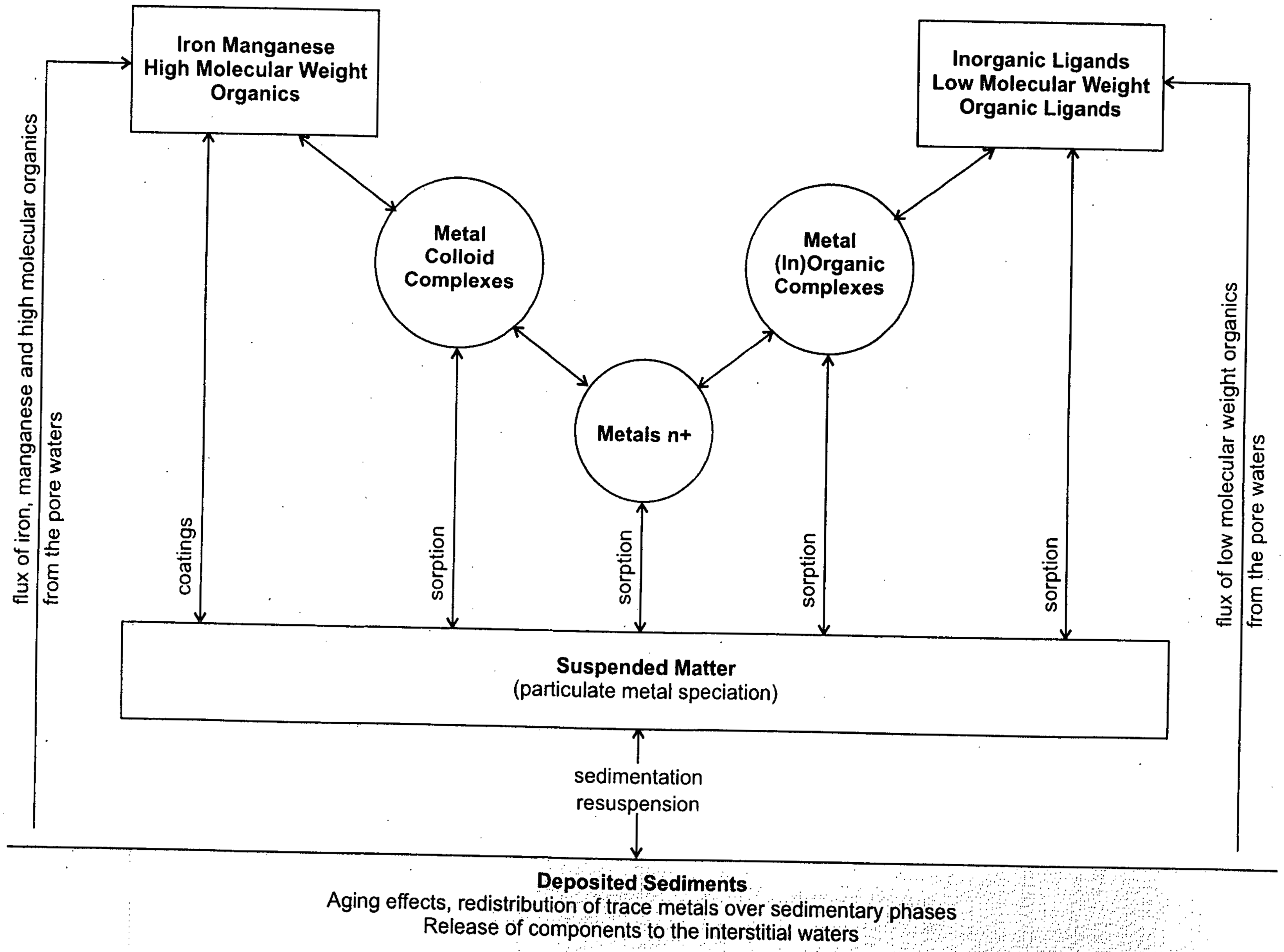
Metal Forms	Availability	Uptake Mechanisms
Ions or inorganic/organic compounds in solution	Easily available →	Passive/active bonding to the cell walls/surfaces translocation inside cell/body
Exchangeable ions in organic or inorganic exchange complexes (e.g. humic materials and clay particles).	Partially Available →	
Complexes or chelates with large organic materials	Less available →	Ingestion as "food", passage throughout digestive system, absorption and incorporation into tissues or organs absorption and incorporation into tissues or organs
Precipitated insoluble compounds and coprecipitate on solids	Available only after altered chemical conditions →	
Incorporated in solid biological materials	Available only after decomposition →	
Incorporated in the crystalline structures or primary and/or secondary minerals	Available only after weathering →	
Metal Pool ←	**Feedback Mechanisms** Excretions of metals in liquid and solid forms; Excretion of complexants; Leaching and decay	← **Aquatic Organisms**

6.2 Chemical Mechanisms Influencing Bioavailability of Metals in Marine Systems

6.2.1 Chlorinity (salinity)

Generally, an increase in the salinity of ambient water leads to a decrease in the ionic, or bioavailable forms of metals. This is because in water of low ionic strength (i.e. river water) ions are kept apart from each other by repulsive forces associated with rather large electrical double layers, and therefore stay suspended, or in solution. Upon encountering waters with a higher ionic strength (i.e. seawater), the higher quantity of available ions reduces the thickness of these double layers surrounding suspended materials, to the point that adjacent ions are close enough that the weaker, but attractive, intermolecular van der Waals forces overcome the repulsive electrical forces. As a result, ions,

PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-04-96 FILE LOCATION: J:\9521928\0396\FACTORS.CDR

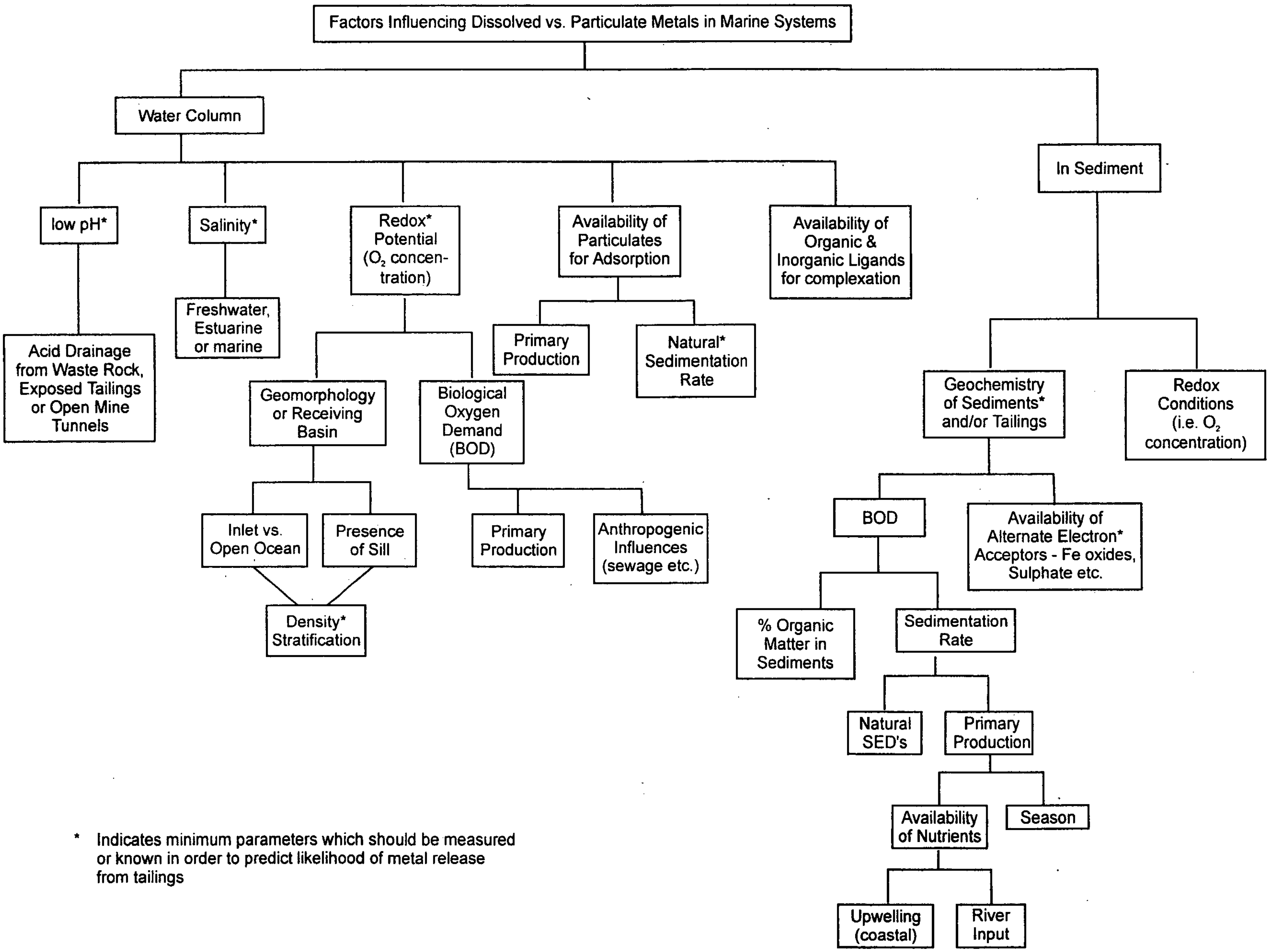


Golder Associates

CONCEPTUAL DIAGRAM OF METALS SPECIATION IN DISSOLVED AND PARTICULATE FRACTIONS OF THE WATER COLUMN AND SEDIMENTS IN THE MARINE ENVIRONMENT

Figure 6-1b

PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-04-96 FILE LOCATION: J:\9521928\0396\FACTORS.CDR



* Indicates minimum parameters which should be measured or known in order to predict likelihood of metal release from tailings

Golder Associates

FACTORS INFLUENCING BIOAVAILABILITY OF METALS IN A MARINE ENVIRONMENT GENERAL INFLUENCE DIAGRAM

Figure 6-2

molecules, and other suspended materials tend to flocculate in estuarine systems. Trace metal ions are among those suspended materials which undergo adsorption, flocculation, and/or co-precipitation under conditions such as these. A common observation, upon mixing river water with seawater, is the appearance of a fine-grained brown sediment within a short period of time (e.g. Sholkovitz, 1976). Analysis of this material reveals the presence of high-molecular-weight organic matter (humic and fulvic acids), co-precipitated and chelated trace metals and iron oxides, all precipitated as a result of the increase in salinity of the ambient water.

Cadmium follows this general trend of removal from the dissolved phase, but to a lesser extent than other metals. Since the majority of dissolved Cd (97%) is complexed with Cl^- ion ($CdCl_2$), an increase in chlorinity leads to competition for Cd^{2+} between chloride ions and solid surfaces. Salomons (1980) found that an increase in chlorinity from 0 to 5% decreased the amount of Cd previously adsorbed onto solid particle surfaces by ~50%.

6.2.2 pH

There is a direct correlation between pH and solubility of metals. The pH ranges for adsorption of 50 mM of several metal species have been determined by Leckie et al. (1980), and are as follows:

TABLE 6-1
pH Range of Maximum Adsorption of Selected Metals

Pb	15% adsorbed at pH 4.5	97% adsorbed at pH 6.0
Cu	<5% adsorbed at pH 5.0	>95% adsorbed at pH 6.5
Zn	~2% adsorbed at pH 5.7	~97% adsorbed at pH 7.3
Cd	~2% adsorbed at pH 6.1	~90% adsorbed at pH 8.0

This demonstrates clearly that the tendency for metal ions to remain in solution (or conversely, adsorbed onto particle surfaces) may be radically altered by a change in pH of only 1 or two units. Table 6-1 indicates the pH ranges under which maximum adsorption of Pb, Zn, Cu and Cd onto various particle surfaces takes place. It is from studies of this nature that lead researchers to place the adsorption potentials for these metals in the order Pb>Cu>Zn>Cd. In other words, Pb and Cu are bound most strongly to particle surfaces, and cadmium the least, under conditions found in most marine and freshwater environments. The pH of ocean water (7.9-8.1), slightly basic, favours adsorption to the solid phase as the more stable over dissolved metal forms. It follows then, that steps taken to prevent acidification of the receiving environment's water cover will increase the opportunities for long-term stability. In other words, *acid drainage from unused mine tunnels and/or waste rock impoundments on land will not only introduce dissolved metals to the basin from the surface, but may lead to increased fluxes of otherwise stable metals from the sediments.*

6.2.3 Redox Potential

Along with pH, the redox potential of the surrounding environment is the factor most critical in determining the degree of partitioning between the dissolved and solid forms of metals. Redox potential is a measure of conditions which favour reduction or oxidation of a molecule. The redox condition within sediments is influenced by the overall sedimentation rate, the quantity and quality of organic matter, the presence or absence of bottom-dwelling fauna, and the oxygen content of the overlying water (Sholkovitz, 1973). In general, oxidizing conditions cause most trace metals (Cu, Zn, Cd, Pb, Mo) to assume a more soluble form, while manganese and iron tend to form insoluble oxides and oxyhydroxides. In reducing conditions, and with abundant dissolved sulphur species (H_2S, HS^-), trace metals tend to precipitate with iron, as insoluble sulphides.

To understand how these conditions can arise in aqueous systems, it is necessary to explain some of the basic chemical reactions that occur in sediments and bottom waters. The breakdown of organic matter in sediments, assisted by microbially-mediated oxidative processes, is called respiration, though we also know it as decomposition or decay. In the course of decomposition, an oxidizing agent (electron acceptor) is reduced or removed, while nutrients and carbon dioxide are released in dissolved form to the surrounding medium along with other by-products specific to the particular oxidizing agent used.

Oxygen is the most efficient oxidant available; in other words, there is more energy released per mole of oxygen utilized during respiration than for any other oxidant. Above ground, there is not usually a shortage of oxygen, so oxidation almost always involves the consumption of this element with no real limitations. However, within aqueous systems, the only oxygen that is available for respiratory purposes is that which is dissolved in the surrounding water. When this is used up, bacterial populations must resort to less efficient oxidants to carry out the decomposition process. The oxidants utilized in natural water after oxygen are (in order from most efficient to least): dissolved nitrate (NO_3^-), hydrous Mn and Fe oxides, and sulphate ion (SO_4^{2-}). As each of these are sequentially exhausted bacteria employ the next most efficient oxidizing agent.

In environments where the supply of an available oxidant is limited by its diffusion rate (such as within sediments), the result is a step-by-step consumption of oxidizing agents that is predictable and measurable by the quality and quantity of the by-products released in each reaction. The oxidants, and their corresponding by-products, are listed in Table 6-2.

TABLE 6-2
Summary of redox reactions which occur with depth in sediments. Oxidants are listed in the order of decreasing energy availability.

Reaction	Oxidant	Products (besides N and P nutrient molecules, and CO_2)
Aerobic respiration	O_2	
Nitrate reduction	NO_3^-	
Mn reduction	MnO_2	Mn^{2+}
Fe reduction	FeO(OH)	Fe^{2+}
Sulphate reduction	SO_4^{2-}	H_2S, HS^-
Methanogenesis	CO_2	CH_4

Called *early diagenesis*, these reactions produce zones within sediments (and within some water bodies) which radically change the reactibility of trace metals and other substances present within the sediments. During diagenesis many elements are remobilized from the solid phase and released into the dissolved phase. When this occurs at the sediment/seawater interface, the oxidation products are released directly to the overlying water. If it occurs after burial, they accumulate in porewater and may migrate upward or downward along concentration gradients until they encounter conditions which cause them to participate in other precipitation and/or dissolution reactions. Thus, the study of porewater chemistry is critical to an understanding as to which of these early diagenetic reactions is occurring.

Figure 6-3 shows the dissolved products which would be expected to appear with depth in sediments as a result of early diagenesis in an ideal, steady-state system.

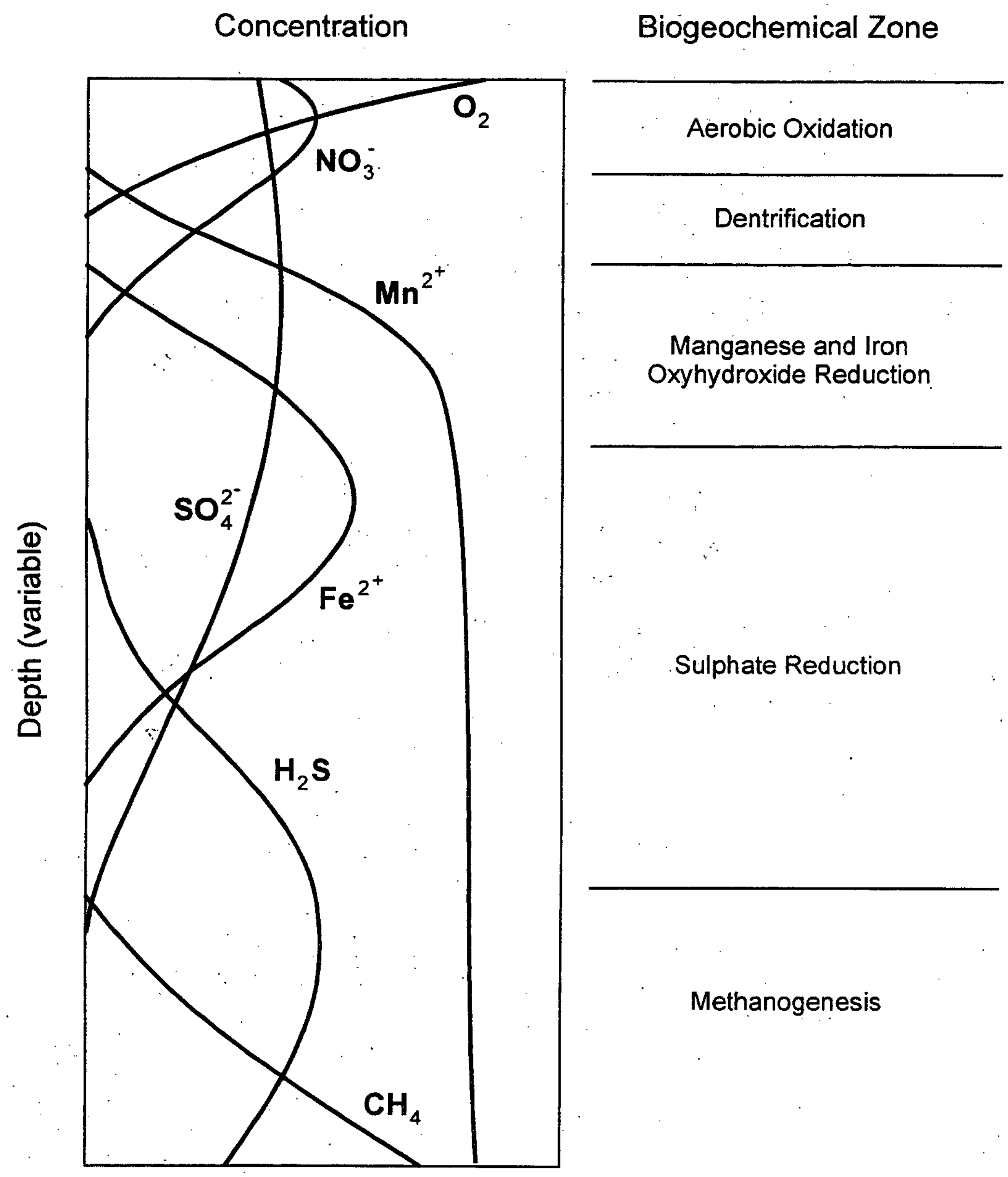
The lack of a depth scale on the y-axis means that this zonation may be expanded or contracted depending on a variety of factors, including the sedimentation rate, dissolved oxygen concentration of the bottom water, and quality/quantity of organic matter within the sediments. In coastal regions, this "biogeochemical rubber band" as it has been called (Shimmield and Pedersen, 1990), is considerably contracted, such that the sulphate-reducing zone is within millimetres of the sediment/seawater interface.

The relevance of the fundamental relationships described above is that they explain which metals will exist in the dissolved or bioavailable form. Within each of the above zones, trace metal solubility is determined by the redox reactions with which it may be associated. Thus, if O_2 is the oxidant, trace metals associated with decaying organic matter or adsorbed onto inorganic surfaces may be mobilized to more soluble forms (oxides); whereas, if SO_4^{2-} is the oxidant, remobilized trace metal ions may be precipitated as insoluble sulphides.

In very general terms, trace metal chemistry is affected by these reactions as follows:

1. Bioavailable metal forms (ionic, or complexed with organic or inorganic ligands in the water column) are delivered to the sediment surface by adsorption onto falling particulates in the water column. These particle surfaces may be silica grains, clay minerals, or, most importantly, solid organic detritus. Once on the sea floor, these adsorbed metals are subject to remobilization by inorganic processes such as cation exchange processes (in clays) or respiratory processes acting on particulate organic matter. There is abundant evidence from sediments all over the world, polluted and pristine, lake and ocean, coastal and deep-sea, that these reactions cause a measurable flux of trace metals from the sediment/seawater interface to the overlying waters. Therefore such fluxes from sediment to overlying water are not unique to a tailings deposition area only. It is also important to note that this flux represents a small percentage of the labile metal which has been delivered to the sediments via sinking detritus; thus, the sediments are actually a sink for most metals, since the majority of sequestered metals are permanently buried with the sediments.

   For this reason, it is vital that monitoring systems which are intended to measure the fluxes of metals into and out of sediments take into account the rate of



Source: T.W. Pederson

PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-08-96 FILE LOCATION: J:\9521928\0396\TDISP.CDR

Golder Associates

SCHEMATIC DISTRIBUTION OF BIOCHEMICALLY IMPORTANT SPECIES IN INTERSTITIAL WATERS IN SEDIMENTS

Figure

6-3

delivery of labile metals to sediments (via sediment trap measurements) as well as the measurable flux out of them.

2. Some metals are scavenged by freshly-forming Mn and Fe oxides just above the corresponding reducing zone. In other words, dissolved Mn and Fe diffusing up from anoxic layers lower in the sediments are precipitated as poorly-structured oxides upon contact with oxygen diffusing into sediments from above. Trace metals released from decaying organic matter at the sediment/seawater interface are often included in this adsorption process, some more strongly bound to the Mn phases, others (e.g. Cd, Cu) more strongly bound to the Fe phases. When these Mn and Fe oxides are themselves reduced as more efficient oxidants are used up, the adsorbed metals are again released to the sediment porewaters. Thus, there is a recycling process below the sediment surface which results in the alternate removal and remobilization of metals between the solid and dissolved phases. It is believed that *this near-surface enrichment of metals bound to oxide phases acts as an effective cap on the release of dissolved metals from deeper in the sediments.*

3. Within the sulphate-reduction zone in sediments (and some anoxic waters), where the redox condition is very low and there are reduced sulphur ions present, trace metals tend to precipitate as insoluble sulphides. Some may be co-precipitated with iron in the formation of authigenic pyrite, though there is some evidence that at least some metals may form their own sulphides (e.g. copper→authigenic covellite). Another possibility, little explored, is that metals may form polysulphide complexes which may be more soluble than solid sulphides. If the sulphate-reducing zone is very close to the sediment/seawater interface, some of these soluble complexes may escape into the overlying water.

6.2.4 Sedimentation Rate

If the natural sedimentation or tailings-deposition rate is high, sulphate reduction (and precipitation of trace metals) may be induced fairly close to the sediment/seawater interface, even in highly oxygenated bottom waters. The reason for this paradox is that the oxidant pool available to bacteria in this case consists of the dissolved oxygen and sulphate *buried* with the sediments; the extent to which diffusion from overlying seawater can replace the soluble oxidants consumed in the sediments is strongly limited by the rapid burial rate. In contrast, in regions of *low* natural sedimentation rate, replacement oxidants from overlying water may diffuse deeper into the sediments, enlarging the zone of rapid oxidation of organic material (and release of associated trace metals).

6.2.5 Dissolved Oxygen

This factor is critical to the determination of redox potential, since most recycling of trace metals is either directly or indirectly involved in oxidation reactions, as explained above. In some coastal inlets, bottom waters acquire periodic or permanent anoxia, due to a combination of factors, some physical (i.e. silled, stratified basins), others geochemical (high primary productivity in surface waters leading to a high biological oxygen demand in deeper waters and in the sediments). In Howe Sound, it is postulated that increased anthropogenic activity in the overlying waters (log-booming, pulp mill effluent, sewage, agricultural runoff etc.) may be inducing more intense and long-lasting anoxic events in the bottom waters than in previous years. Indeed, periodic or permanent anoxia in the bottom water may pose a far greater hazard to benthic ecosystems and recolonization than the deposition of metal-rich, but largely inert, tailings in fjord sediments. Notwithstanding, a low concentration of dissolved oxygen in bottom waters may be beneficial for damping the release of metals from sediments on the ocean floor: it may slow down the oxidative release of metals from decomposing organic matter, and it may cause some metal scavenging in an anoxic sulphide layer close to the sediment/seawater interface.

6.2.6 Particle Size

The surface-to-volume ratio of mineral particles affects the degree to which contained metals are exposed to oxidative weathering processes that might result in more soluble forms. Generally, metals bound within silicate lattices are largely unreactive. The forms that are involved in most geochemical transformations are the dissolved forms that adsorb onto particle surfaces or are associated with organic matter. However, there is some evidence that metals in tailings may be released upon exposure to oxygenated seawater (Hoff et al., 1982), although it is uncertain as to whether it is the residual heavy metal sulphides that are the source of labile metals or soluble oxide or carbonate phases produced during the milling process. At any rate, at the grain sizes to which much of the ore in porphyry deposits is ground (i.e. 0.02-0.08 mm - Poling, 1982), the potential for this chemical weathering is considerably enhanced. Therefore, particle size is a critical factor in attempting to determine the availability and reactivity of metals within metal-rich tailings fines.

6.2.7 Quantity and Composition of Suspended Material

As noted above, suspended particulates provide ideal surfaces for the adsorption of dissolved metal ions. There is general agreement that of all sedimentary components, organic material has the greatest affinity for trace metals (Khalid et al., 1978; Klinkhammer, 1980; Oakley et al., 1981; and others). However, in carbon-poor or rapidly-accumulating sediments a range of other materials are thought to sequester metal ions from the surrounding water. Inorganic detritus such as silts, clays and silicates all provide opportunities for trace metal adsorption in the form of charged surfaces. This natural sedimentary process is an important means of delivering dissolved trace metals to the sediments.

6.2.8 Quality and Composition of Organic Material in Sediments

Although coastal sediments tend to have a much higher organic carbon content than deep-sea sediments, the quality of the organic matter is more important in sediment diagenesis than the quantity. Terrestrial organic matter is generally considered to be quite refractory, while organic matter derived from marine phytoplankton is much more reactive and easily degraded by bacterial respiratory processes. These different sources for sedimentary carbon are easily distinguished by their C:N ratios. Terrestrial material, with its low nitrogen content, may have C:N ratios from 16 to well over 50, while marine organic detritus generally follows the standard Redfield ratios of C:N=6:1. In Howe Sound, the primary source for the high organic carbon content is clearly terrestrial: C:N ratios less than 10 were observed in only one of 100 surface sediment samples. The implications for metal release are clear: since organic matter has a high affinity for dissolved trace metals, those metals will be more quickly re-introduced into the water column if they are associated with easily-degradable forms.

6.2.9 Mineralogy of Natural Sediments and Ore Body

It has been found that the impact of tailings to a nearby water body is considerably less when the rock in which the metal sulphides are dispersed are similar to other rock types in the drainage basin. Thus, in tailings from the Britannia Mine and Island Copper, while containing high concentrations of certain metals (Zn, Cu, Mo, Pb), the remainder of the rock matrix is almost indistinguishable from natural sediments being introduced via rivers into the basin. The converse is also true: that when the ore body is radically different than the natural sediments in a region, the resulting impact can be considerable. Massive sulphide ore bodies produce tailings in which much of the residual Pb, Zn and Fe sulphides would be exposed to seawater. Such was the case in the Black Angel mine in Greenland during the 1970s and 1980s, when assumptions about the potential solubility of the ore minerals in a marine environment proved to be wrong. Although the metal sulphides were considered to be insoluble, soluble hydroxide, carbonate and sulphate phase of Cu, Pb, Zn and Cd that formed during the milling process were quickly released to seawater as tailings were deposited into the nearby fjord. The lesson to be learned from this is that well-designed leaching experiments must be conducted on waste rock and simulated tailings particles before any assumptions are made as to the potential impact of tailings disposal into a marine environment.

In contrast, the Island Copper mine ore body is a low-grade porphyry copper-iron and molybdenum complex. Most of the Cu, Fe and Mo exists as sulphide crystals occluded within other silicate minerals. With a large enough particle size, most of the metal sulphides present in tailings would not be exposed to seawater, and oxidative weathering of exposed sulphides would be hindered.

6.2.10 Chemicals Added to Slurry

Most substances added to ground ore are intended to enhance separation between the ore and the matrix minerals. Most chemicals used today are non-toxic and tend to be concentrated with the usable fraction rather than the tailings slurry (Poling, 1982). Most of the tailings volume is produced by the first separation by froth flotation, which utilized chemicals that render the valuable mineral particles hydrophobic. However, chemicals which increase the solubility of trace metals, such as carbonates and sulphates, may cause otherwise-insoluble metals to be released as dissolved phases from tailings (e.g. Black Angel Mine).

6.3 Characterization of Mechanisms Influencing the Relative Proportion of Bioavailable metals using Howe Sound and Rupert Inlets as Examples

In Howe Sound, tailings were deposited into the northernmost portion of the sound by the Britannia Mine, which released tailings, containing high concentrations of copper, lead, and zinc, into the bottom water over a period of 75 years. The mine ceased operation in 1974, and since then natural sedimentation has been the chief process delivering material to the fjord floor. A shallow sill separates this inner basin from the outer portion of the sound, and has proven to be a fairly effective barrier, not only to movement of tailings but to frequent deep water renewals. The result is that the tailings have been for the most part contained within this deep, periodically anoxic fjord. In 1987, a study was initiated to determined the reactivity of the metals within the tailings deposit as compared to the tailings-free outer basin (Drysdale, 1991). The discussion which follows is excerpted from this study, and addresses the geochemical behaviour of the three metals of interest (copper, lead and zinc).

6.3.1 Howe Sound

6.3.1.1 Dissolved Copper

Copper exhibits a very complex biogeochemistry in marine systems. The fraction contained within detrital silicates is largely unreactive and generally not involved in sediment transformations (Price, 1973; Gambrell et al., 1976; Davies-Colley et al., 1984). Dissolved copper within the water column is; however, easily scavenged by suspended material and is subsequently delivered to the sediments in particulate form. There is general agreement that of all sedimentary components, organic material has the greatest affinity for trace metals (Khalid et al, 1978; Klinkhammer, 1980; Oakley et al, 1981). However, in carbon-poor or rapidly-accumulating sediments a range of other sediment components are thought to sequester Cu ions from the surrounding water. Some workers (Boyle et al., 1977; Klinkhammer, 1980; Sawian and Murray, 1983) suggest that an additional carrier phase is Mn oxides, but more recent work (Davies-Colley et al., 1984; Pedersen, 1985; Tipping et al., 1986) indicates that Fe oxides may also play a role. At any rate, this adsorbed copper is much more labile than that held in crystal lattices, and may undergo several cycles of remobilization and removal within porewaters before being either released to bottom waters or permanently buried in insoluble constituents within the sediment. The rates of which these processes occur are strongly dependent on porewater pH, redox potential, and sediment accumulation rate, as well as on the relative proportions of various sedimentary components such as organic material, reducible oxides, clays and dissolved sulphide (Tipping et al., 1986; Khalid et al., 1978; Duchart et al., 1973; Oakley et al., 1981; Davies-Colley et al., 1985).

Most Cu^{2+} released at the sediment surface enters the bottom water (Sawlan and Murray, 1983; Heggi, 1983), but a fraction may diffuse downward to be reprecipitated on hydrous

Mn and/or Fe which form an enriched layer below the sediment surface. When these materials are themselves reduced, Cu may once again be released to porewater, to be subsequently removed as insoluble sulphides or, in the presence of extremely high sulphide concentrations, to form soluble chloride, bisulphide and/or polysulphide complexes (Davies-Colley et al., 1985; Shea and Helz, 1988). It has long been assumed that after burial in sediments, trace metals are permanently removed as insoluble sulphides. However, recent work (Shea and Helz, 1988) suggests that bisulphide and polysulphide complexes of Cu are extremely stable and may exist in high concentrations in equilibrium with CuS (covellite). In sediments with clearly defined oxic, and nitrate-, Mn- and Fe-reducing zones, scavenging by freshly-forming colloidal oxides of Fe and Mn in surface sediments may effectively seal off the underlying pool of dissolved trace metals from the overlying water. In highly-reducing sediments, however, where sulphate-reduction begins very close to the sediment/seawater interface, these dissolved or complexed metals may be released into the bottom water before they can be sequestered by Fe and/or Mn oxides.

Bioturbation can substantially affect porewater concentrations of Cu and other trace metals by introducing dissolved oxygen more deeply into sediments than could enter by diffusive processes alone. The oxidation to sulphate of dissolved sulphide which has built up in the porewaters may subsequently lower the trace metal removal capacity of reducing sediments (Emerson et al., 1984).

In the outer basin of Howe Sound dissolved Cu is highest (13.6 ppb) in the top 0.5 cm, decreasing rapidly to <1.3 ppb at a depth of 1.5 cm and becoming nearly undetectable near the bottom of the core. The very low dissolved Cu levels (i.e. < .32 ppb) in the bottom third of the core are accompanied by low Fe concentrations. In the inner basin, where the tailings are, the surficial Cu concentration (8.4 ppb) is considerably lower than in the outer basin, and decreases within the top centimetre to < 1.3 ppb. In the lower half of the core, where tailings are clearly present in the solid phase, dissolved Cu values are low (0.25 ppb - 2.5 ppb).

The dissolved Cu concentrations in the surface pore water sample of both cores are higher than those reported for inshore anoxic sediments: 0.25 - 4.9 ppb (Shaw et al., 1990; Presley et al., 1972; Sawlan and Murray, 1983; Heggie et al., 1987), but lower than those from organic-rich, oxic sediments in such areas as the Bering Sea continental shelf:

21.4 ppb (Heggie et al., 1987). The distributions in the Howe Sound cores suggest that in these sediments Cu behaviour is controlled by several processes: 1) release of adsorbed Cu from labile organics in the presence of oxygen at the sediment/seawater interface, 2) release from oxides in the Fe and/or Mn reduction zones, and 3) removal of depth by precipitation as CuS, coprecipitation with authigenic Fe sulphides, adsorption onto particle surfaces, or sequestration by buried organic material.

A fourth process to be considered in Howe Sound sediments is release of dissolved Cu from the tailings. The surficial Cu^{2+} values reported here are higher than those observed in tailings-contaminated surface sediments in Rupert Inlet, B.C. (25 nmol/L; Pedersen, 1985). However, the higher values in this inlet may be related to local productivity rather than the presence of tailings. The dissolved Cu distributions observed in both inner and outer basin sediments are similar to those in a number of other coastal and open ocean settings (Klinkhammer, 1980; Emerson et al., 1984; Heggie et al., 1986; Heggie et al., 1987), and thus Howe Sound sediments support a benthic efflux of copper to the overlying water column which is similar in magnitude to fluxes seen elsewhere. There is no indication that the tailings or natural sediments in the inner basin of Howe Sound are releasing Cu to the water column at a level in excess of that observed in pristine coastal, hemipelagic or pelagic sediments. Indeed, assuming that the profiles presented here are representative, *the benthic copper efflux in the inner basin of Howe Sound, where tailings were deposited in the past, is about half that in the tailings-free outer basin.*

In strongly reducing sediments measured elsewhere interfacial porewaters exhibit little or no enrichment of metals (Presley et al., 1972; Salwan and Murray, 1983; Westerlund et al., 1986; Heggie et al., 1987). Likewise, the low oxygen values in the bottom water of the inner basin, which render the sediments anoxic very close to the interface, appear to inhibit the release of Cu from the surface. This situation could change rapidly after a deep water renewal, when the influx of well-oxygenated seawater could drive the oxic zone deeper into the sediment, thereby causing the release of large quantities of metals which had been adsorbed onto easily-reducible fractions within the sediments.

It is not conclusive whether Fe or Mn oxides are an additional source for Cu in Howe Sound. The very thin zone of Cu enrichment at the surface of the sediments clearly implicates organic matter as the primary adsorbent; however, subsurface peaks in both cores (if real) point to a possible secondary association with Fe.

6.3.1.2 Dissolved Zinc

The behaviour of zinc in aquatic sediments is, like that of Cu, intimately linked with major biological and geochemical cycles. Dissolved Zn in scavenged from the water column onto particle surfaces, notably the opaline frustules of diatoms. When the silica dissolves at the sediment surface, the Zn^{2+} which is released may enter the overlying water or be incorporated into a number sedimentary components, of which colloidal Mn oxides are likely the primary phase (Spear, 1981; Balistrieri and Murray, 1986). Upon dissolution of the latter in suboxic sediments, Zn^{2+} ions may diffuse upwards (to be reprecipitated on freshly-forming Mn oxides on contact with oxygen near the sediment/seawater interface), or downwards, where their concentrations are controlled by precipitation of sulphides or by complexation with dissolved organic or inorganic ligands. Thus, the dissolved Zn distribution in sediment porewaters often parallels those changes in Mn and Si concentrations which are due to diagenetic recycling (Adams, 1986).

The adsorbed fraction, which may take up to 40% of the total Zn in organic-rich estuarine sediments (Presley et al., 1972; Khalid et al., 1978), is highly labile and easily released upon minor changes in such physicochemical properties of the sediment as pH and redox potential. This causes Zn to be potentially very bioavailable, which may be significant in areas where large quantities of Zn are added to the sediments by anthropogenic activity. For example, Grieve and Fletcher (1976) found high concentrations of exchangeable trace metals (including zinc, lead and copper) in sediments and biota near a metal-rich sewage outfall. The existence of tailings on the sloping walls of Howe Sound well above the zone which is subject to periodic hypoxia (i.e. near the original tailings outfall), and the probability that some of the very fine suspended fraction of the tailings slurry has been transported to the outer basin, has made this particular mobility of Zn a cause of some concern.

In both the inner and outer basin cores taken in Howe Sound, Zn^{2+} was enriched in the surface porewaters. Concentrations in the top half centimetre of the outer basin core were over 2.09 ppm but decreased by three orders of magnitude by a depth of 4 cm. In the inner basin, surface concentrations were much lower, (~105 ppb) decreasing to ~1.9 ppb within the top 2 cm. The concentration measured in the upper five mm of the outer basin core was extraordinarily high. Porewater zinc measurements are rare in the literature. Enhanced Zn^{2+} levels up to 98 ppb were measured in surficial sediments of acidic (pH<5) lakes (Tessier et al., 1989), but in lake sediments with higher pH, and in reducing marine sediments, the few available data suggest that Zn^{2+} occurs in very low quantities (i.e. <2.6 ppb) in interfacial porewaters (Elderfield et al., 1981; Pedersen, 1983; Westerlund et al., 1986; Tessier et al., 1989).

The subsurface portions of the cores reveal slightly different profiles. Below 4 cm in the outer basin $[Zn]^{2+}$ averages 3.14 ppb. $[Zn]^{2+}$ in the inner basin is moderately high but variable (6.5 - 21 ppb) in the natural sediments above the mine tailings. Below 14 cm the values are generally lower (0.26 - 5.5 ppb) and less variable.

Like the Cu^{2+} profiles, the Zn distributions suggest 1) releases of Zn^{2+} from dissolution of some organic phase are at the surface; 2) removal at depth is by adsorption by oxyhydroxides or other particle surfaces; and 3) precipitation of zinc sulphide or coprecipitation with iron sulphide occurs within the anoxic zone. The subsurface bulge in the outer basin core between 2 and ~10 cm suggests secondary release through dissolution of Mn oxide, but this is not conclusive.

As with dissolved Cu, the data here suggest that although Zn is released from sediments to the overlying waters in quantities heretofore unreported in the literature, the tailings in the inner basin (presently buried well below the oxic zone) do not appear to be the source of this labile zinc. It is instructive to note that *the extremely high values of Zn release are from the tailings-free outer basin, not the location of the main tailings deposit.*

6.3.1.3 Dissolved Lead

Like other trace metals, Pb is known to be sequestered from the water column and delivered to sediments within falling particulates (Price, 1973; Boyle et al., 1977). The complexing affinity of the element for humic material is greater than that of Zn but less than that of Cu (Luther et al., 1986), thus it is partially contained within organic compounds which are subject to breakdown at the sediment/seawater interface. Recent work also suggests that a secondary association with authigenic Fe compounds contributes to a passive involvement in redox-mediated recycling within sediments (Gobeil and Silverberg,1989).

In Howe Sound there is little evidence of an enrichment at the sediment surface similar to that shown for Cu and Zn. In the outer basin Pb^{2+} concentrations are low throughout the core, ranging from 0.23 ppb at the surface to undetectable levels below 31 cm. A secondary enrichment lower in the core between 14-30 cm corresponds generally to the zone in which elevated Fe values are observed.

In the inner basin core Pb^{2+} concentrations are low throughout, ranging from undetectable levels to ~0.62 ppb. The surface sample contains 0.3 ppb, and that immediately underlying, 0.004 ppb. Although this could reflect release of Pb at the interface, the concentrations are so low that this suggestion cannot be promoted with any degree of certainty. Thus in Howe Sound, the association of Pb with organic matter is not as clear-cut as are those of Cu and Zn, or alternatively, that Pb is adsorbed more strongly or is bound to more refractory portions of the particles.

Gobeil and Silverberg (1989) present porewater data from Laurentian trough sediments which strongly implicate Fe oxides as an additional carrier for adsorbed Pb. In both cores, there at least appears to be more of a connection between Pb and Fe than with any other phase, especially in the subsurface horizons. There is no evidence to indicate that the Pb associated with the mine tailings is being released to the overlying water, as there is little variation with depth in the generally low dissolved Pb concentrations in the inner basin core.

6.3.1.4 Summary of Factor Influencing Bioavailability of Metals at Howe Sound

In summary, while it is well known that Howe Sound has a trace metal problem, it has been shown conclusively that the buried tailings deposit on the fjord floor is not the source of the dissolved metals. Conditions which are areas of concern in Howe Sound are: (1) acid rock drainage from old mine tunnels discharge highly acidic, metal-rich water to Britannia Creek, and thence to Howe Sound in the surface waters; (2) tailings which accumulated in the past along the steep sides of the fjord may still slump and slide, causing some resuspension and exposure of old tailings fines; (3) while natural sedimentation has buried and diluted the tailings to a high degree, higher than background Cu and Zn solid-phase levels continue to be measured in surface sediments in the inner basin, and especially in the shallow sediments near the old mine outfall; (4) a portion of the beach which was covered in the 1920s with pure tailings for a year or two, as well as the area around loading dock where there was undoubtedly some spillage of concentrate during loading, may still have higher concentrations of oxidizable metals; and (5) periodic deep-water renewal events could potentially drive the oxic zone deeper into the sediments of the inner basin, causing some release of previously-insoluble metals.

On the positive side, the increased anthropogenic activity in and around Howe Sound has produced one condition which is favourable to the retention of trace metals in insoluble forms: the cyclic depletion of oxygen in the bottom water of this fjord estuary. The stratification induced by estuarine circulation, the presence of very shallow sill (< 70 m below the water surface), and the fact that normal decomposition processes operating in the water column gradually use up the available dissolved oxygen leads to a periodic depletion of dissolved oxygen in the bottom water. This condition renders the sediments also anoxic (though they may already be anoxic fairly close to the sediment/seawater interface), which is a condition that strongly favours the formation of insoluble metals sulphides vs. more soluble oxides which might form in the presence of oxygen. Unfortunately, the induced anoxia will have a deleterious effect on much of the benthic community, but the lower levels of bioturbation will also favour the retention of metals within the sediments. The sill has also acted as a barrier to all but the finest of tailings particles, efficiently containing the bulk of the deposit in the inner basin. Surface sediments outside the basin show solid-phase Cu, Zn and Pb levels that approach background levels for inlets along the B.C. west coast. The high natural sedimentation rate caused by the Squamish River, which drains a large region with several glaciers at high levels, is also beneficial, as it not only tends to bury previously-deposited tailings, but dilutes the metal contents by the sheer volume of the natural sediments.

A summary of the factors influencing bioavailability of metals in Howe Sound is presented in Table 6-3 below.

TABLE 6-3
Summary of Factors Influencing Bioavailability of Metals in Howe Sound

Factors Favouring Metal Removal from the Water Column	Factors Favouring Metal Remobilization from Tailings to the Water Column
Low O_2 in bottom water	Exposure of mine tailings on shores and sides of basins (slumping)
High organic carbon content of sediments	Potentially low pH due to ARD from Britannia Creek
Presence of Fe^{3+} and HS^- ions in anoxic sediments	Periodic deep water renewal events
High natural sedimentation rate	
Insoluble (inert) tailings buried by natural sediments	
Low levels of bioturbation	

6.3.2 Rupert Inlet

6.3.2.1 Copper

Pedersen (1985) found that three factors control the behaviour of copper in Rupert Inlet:

- release to solution at the sediment surface from labile organic matter (though the total organic content of sediments was very low due to dilution by tailings);
- release to solution by newly-deposited tailings, supported by way of oxidation of some sulphides to produce a more soluble product (e.g. $CuCO_3$); and
- precipitation of authigenic sulphides at depth.

An analysis of porewater in concert with solid phase revealed that even though Rupert Inlet bottom water was well-oxygenated, the tailings/sediment mixture was anoxic very close to the sediment/seawater interface. Dissolved Cu decreased with depth in both natural and tailings-rich sediments, likely due to coprecipitation with authigenic pyrite and/or precipitation of extremely insoluble CuS. The usual flux of copper from sediments was observed in Rupert Inlet, and *was similar in magnitude to that observed in* *other natural sediments.* The author concluded that in areas close to the tailings outfall, the rapid accumulation of tailings resulted in the labile organic phase being buried before decomposition could occur, thus inhibiting the release of the primary source of dissolved copper to bottom water.

6.3.2.2 Molybdenum

The same study examined the behaviour of molybdenum in the tailings and sediments of Rupert/Holberg Inlets. The author reviewed a number of studies that concluded the following:

a) Mo is subject to similar general controls as Cu: sulphide precipitation, oxide dissolution and association with organic material;

b) The concentration of dissolved Mo is related to the sedimentary organic carbon concentration;

c) A correlation was found between porewater Mo and dissolved organic matter (humic matter) in the upper twenty cm of anoxic sediments in a Scottish fjord, with precipitation to a sulphide phase at depth;

d) Some dissolved Mo increases which have been observed to shallow depths in nearshore carbonate-rich cores from Bermuda were due to remobilization of Mo from iron monosulphides during the transition from metastable FeS to stable pyrite; and

e) Laboratory experiments have shown that molybdenum is efficiently coprecipitated with FeS in anoxic iron-bearing solutions in the pH range 5 - 8.

Dr. Pedersen's study of Rupert inlet noted that in contrast to copper, there was no evidence of consumption of molybdenum at depth in tailings-contaminant sediments. Moreover, the tailings were clearly the source of the dissolved molybdenum, which was thought to result from dissolving oxide phases (MoO_3) which exist as coatings on tailings particles. MoO_3 or molybdite results from oxidation of MoS_2 during milling of molybdenite ore and has a high solubility at seawater pH or higher. However, the calculated flux of Mo to the inlet was on the order of ~5mol/day, which given the 13 day residence time of Rupert inlet water, amounted to a contribution of less than 0.002% to the total Mo budget of the inlet. He concluded that, given the normal concentrations of

Mo in seawater, this release would have no measurable effect on the waters of Rupert inlet.

6.3.2.3 Summary of Factors Influencing Bioavailability of Metals at Rupert Inlet

The conditions which favour STD at Rupert Inlet are the following: (1) While the basin is not anoxic, as it is in Howe Sound, the rapid rate of tailings deposition has ensured that anoxia has been induced fairly close to the sediment/seawater interface, with all the conditions that go along with it - low redox potential, precipitation of metals into insoluble forms, lack of bioturbation etc.; (2) the fact that the tailings closely approximate the basin's natural sediments, in all ways except for the enrichment of metals, means that the ecosystem has not been altered a great deal in a chemical way; (3) the presence of iron in the ore body means that dissolved Fe in the anoxic sediments is available to adsorb and coprecipitate other metal ions in the formation of authigenic pyrite, a common and well-documented occurrence in anoxic sediments; and (4) the pH of the inlet is within the range (7.9-8.1) for maximum adsorption of most metal ions in dissolved waters.

A summary of the factors influencing bioavailability of metals in Rupert Inlet is outlined in Table 6-4 below.

TABLE 6-4
Summary of Factors Influencing Bioavailability of Metals at Rupert Inlet

Factors Favouring Metal Removal	Factors Favouring Metal Remobilization
Sulphate-reduction active close to sediment/seawater interface	Milling practices (Mo release)
Iron-rich anoxic porewaters	Exposure of tailings fines to oxygenated seawater during resuspension and settling
Seawater pH (7.9 - 8.1)	
Organic carbon dilution by tailings	
Rapid tailings deposition rate	
Low levels of bioturbation	

6.4 Other Metals

6.4.1 Cadmium

The following describe various characteristics of Cd and conditions which affect solubility of cadmium in the marine or freshwater environment:

a) At pH<6, and salinity < $4^0/_{00}$ the dominant form of dissolved Cd is Cd^{2+}; at higher pH (7-8) and salinities $4\text{-}40^0/_{00}$ the dominant forms are $CdCl_2$ and $Cd(OH)^+$.

b) Cd is preferentially bound to CO_3 phase due to the high stability of $CdCO_3$ under pH and Eh of natural waters; also Cd coprecipitates with $CaCO_3$.

c) Cd is isoelectric with phosphate, and therefore closely follows a nutrient-type profile in seawater, i.e. depletion in surface waters by uptake during photosynthesis, enrichment at mid-depths due to decomposition of falling organic matter, and further release in the Fe-oxide reduction zone in sediments due to release from reducing Fe-oxides.

d) Cd in anoxic waters precipitates as CdS; under oxic conditions some desorption from these compounds may take place.

e) Considerable Cd release to mobile forms may occur as Cd-contaminated sediment is transported from a near neutral pH, reducing environment to a slightly acid, oxidizing one (Gambrell et al., 1977).

f) Cd adsorbed onto sedimentary particles is weakly held in easily exchangeable positions, and is easily removed by minor perturbations in pH and salinity.

g) Soluble humic material tends to enhance Cd adsorption or coprecipitation onto hydrous Fe oxides (Laxen 1983)

h) Complexed Cd ($Cd\,Cl^+$) adsorbs less strongly on sediments than the uncomplexed form.

i) 97% of dissolved Cd in seawater is complexed with Cl^-; 3% exists as free ion (Cd^{2+}).

j) Free ionic Cd is the toxic agent in natural waters, not necessarily dissolved Cd-Cl complexes or Cd-NTA (nitrilotriacetic acid) complexes. Toxicity of high Cd levels to some organisms drops radically with increased salinity.

6.4.2 Arsenic

Dissolved arsenic profiles follow dissolved iron profiles in sediments, not particulate arsenic concentrations. This suggests that determination of dissolved arsenic levels in porewaters would be a better measure of bioavailability than particulate arsenic in sediments. Regardless of As concentrations in tailings relative to natural sediments, the difference in other properties of the tailings probably determines the extent of As diagenesis, not the total amount of As in particles.

In natural sediments there is usually a discernible flux of arsenic that is released from decomposing organic matter. In Alice Arm there is a flux of As to porewaters which is close to that of natural sediments.

It appears that some organisms are able to detoxify dissolved free arsenic by producing mono-, di-; or tri-methylated arsenic compounds (oxidized arsenic with organic methyl groups attached). Organoarsenic compounds are less toxic than their inorganic precursors. These compounds are incorporated into organic tissue and are released in the same form to seawater during decomposition of the organic matter. The process of bio-methylation appears to be correlated to redox reactions in sediments or low-oxygen seawater, whereby As^{V} is reduced to As^{III}, then methyl groups added to form successive chain methylates of arsenic.

In Rupert inlet the fluxes of As from tailings are very small and the tailings may even be sinks for As, possibly due to the rapidly-accumulating nature of the tailings. It has been postulated that once tailings-deposition ceases, that there could be much greater release from tailings. However, Pedersen (1985) reports SO_4-reduction (and therefore the presence of reduced sulphur ions) close to the sediment surface in tailings-rich sediments, so it is possible that precipitation of sulphides in near-surface sediments may depress the expected arsenic release, instead incorporating available As into those authigenic sulphides.

The following comments describe various factors and characteristics which govern arsenic speciation and behaviour in natural waters.

a) As is precipitated in reducing-sulphide precipitation reactions by reduction of oxidizing sulphate waters (i.e. in the sulphate rection zone in anoxic sediments).

b) AsO_4 is weakly bound onto amorphous Fe oxyhydroxides, alumina and SiO_2 in sediments, rather than to Mn phases (Jones and Bowser, 1978).

c) In reducing sediments, porewater As concentrations decrease with time due to precipitation as sulphides; in other cases it correlates with solid-phase Fe.

d) Adsorption of As on sediments is strongly dependent on pH, with maximum adsorbance on Fe hydroxides at pH 8.

e) With increase in salinity, As tends to adsorb to suspended matter.

f) Sometimes As complexes with low molecular weight dissolved organic matter, and therefore acts conservatively during estuarine mixing.

6.5 Generalization of Conditions Favouring Bioavailable Forms of Metals vs. Unavailable Forms

Based on the discussions above, Table 6-5 outlines the conditions that generally favour bioavailable verses unavailable forms of metals in the marine environment.

TABLE 6-5
Generalization of Conditions Favouring Bioavailable Forms of Metals vs. Unavailable Forms

Conditions Favouring Non-Bioavailable Forms	Conditions Favouring Bioavailable Forms
Neutral to high pH (seawater)	Low pH caused by ARD or acid rain
Low redox potential, i.e. low O, in water, with rare or no renewal events	High oxygen content in water and/or sediments (high redox potential)
High salinity (estuarine or marine water)	Low salinity (freshwater)
Metals contained within crystal lattices of silicates	Massive sulphides in ore bodies
Rapid sedimentation rate (rapid burial of fresh tailings and removal from oxic zone)	Low sedimentation rate (prolonged exposure of tailings to overlying oxic water)
Exposure of dissolved metals to sulphide ions (HS^-) with or without excess Fe^{3+}	Fe and Mn reduction-zones in sediments allowing release of adsorbed trace metals
Milling practices that discourage oxidation of sulphides	Milling practices which produce soluble metal oxides, sulphates or carbonate coatings on tailings particles
Presence of solid-phase organic material for adsorption	Low organic content of sediments
Abundance of inorganic particle surfaces for adsorption, precipitation, or cation exchange	Lack of significant quantities of clays, silica, oxides as sites for trace metal adsorption

6.6 Requirements and Capabilities for Predicting and Monitoring Dominant and Significant Forms of Metals that will Occur in the Marine Environment

a) Determination of sedimentation rate (sediment-trap plus ^{210}Pb data).

b) Determination of organic concentration of sediments in both tailings-rich sediments and natural sediments of receiving basin.

c) Regular measurements of porewater concentrations of metals of interest (plus Fe^{2+} and Mn^{2+}) in sediments over short depth scales (e.g. 0.5 cm for first 3-5 cm, then very 2 cm to ~16 cm, then every 5-10 cm to bottom of cores). Cores should be minimum 30 cm depth. Locations should be chosen to represent zones of rapid tailings deposition, slow tailings deposition and unaffected sediments.

d) Regular measurements of metal concentrations in water column at various locations, both affected and unaffected areas.

e) Determination of bottom water O_2 concentrations over a period of months or years to determine the occurrence of anoxic or deep renewal events.

f) Relative proportions of various solid sedimentary components such as organic material, reducible oxides, clays and silicates.

g) Well-designed leaching experiments, using natural sediments and real tailings/slurry mixtures, and varying the grain size, organic content etc.

h) Elimination of potential ARD-producing sites: i.e. exposed water rock dumps, tailings impoundments etc.

i) Regular measurements of pH and alkalinity of receiving water.

j) Knowledge of physical processes which could potentially resuspend or redistribute tailings fines (tidal jets, estuarine currents, storm-driven renewal events etc.).

k) Particle size data.

7.0 BIOLOGICAL EFFECTS OF STRESSORS AT ISLAND COPPER

7.1 Preliminary Considerations

7.1.1 General Considerations

The biological effects that may occur as a result of an STD operation have been postulated on many occasions (Goyette and Nelson 1977, Waldichuk and Buchanan 1980, Westwater Research 1985, and Kline 1994). Additionally, considerable effort has been expended in collecting and analyzing biological monitoring data to determine if such effects have occurred, and this is perhaps best exemplified by the 25 years of monitoring conducted to-date by Island Copper.

By their design, STDs mines are large scale operations and because of the receiving environment into which they discharge (e.g., fjords, deep open ocean) they have the inherent potential to alter large scale ecosystems if not appropriately designed, monitored and controlled. To this end, it is important to not only understand the potential effects of such operations from a regulatory and environmental impact assessment perspective (i.e., the goal of an EEM program), but for practical purposes for effecting mitigative actions, should an unacceptable effect be discovered during operation of the site. The goal in this latter case would be to ensure the findings of environmental effects monitoring provide a feedback to mine operations for appropriate performance adjustments to mitigate any observed effects and facilitate continued ecologically acceptable operations.

As noted above, possible biological effects of STD operations have been postulated on various occasions and Table 7-1 provides a cross section of issues raised by various experts in the field. Table 7-1 also includes possible effects which are not biologically based, but have been included here for comprehensiveness and because in many cases they are factors relating indirectly to biological receptors. The focus of this chapter is on aspects which relate to items (5), (6) and (7) and in some cases there simply has not been adequate data collected from any site to confirm or negate some of the listed items. A further consideration in weighing the importance of these items is whether a statistically significant deviation from the norm is biologically significant, and also whether statistical significance is required to infer biological/ecosystem significance. In this latter case, large scale ecosystem parameters can often be quite "noisy" (i.e., variable) and this may hamper the ability to statistically resolve trends in time series analyses.

TABLE 7-1
Partial List of Effects Postulated to be Associated with Marine Mine Waste Inputs

Major Category	Possible Effects
1) Physical Disturbance to Sea Bed	• acute and chronic smothering of benthic habitat • severe dilution of detrital organic carbon. • catastrophic effects of sediment instability: turbidity currents, scouring, and massive resuspension.
2) Physical Disturbance to Water Column	• increased turbidity and light attenuation with depth in the water column. • changes in thermohaline circulation in coastal embayments and fjords due to changes in bathymetry and water density.
3) Geochemical Effects	• increased concentrations of dissolved metals/metalloids in water, sediment, and sediment interstitial water. • massive changes in sediment particle size distribution, leading to packing or delayed consolidation following deposition; enhanced nepheloid layer. • enhancement of upward pore water diffusion to the water column in association with massive sediment compaction. • changes in oxidation-reduction potential of near-surface sediments. • alterations in benthic-pelagic fluxes of metals and nutrients.
4) Chemical Effects	• increased bioavailability of metals. • alterations in chemical speciation (e.g., methylation/demethylation) and fate.

Major Category	Possible Effects
5) Organism-level Effects	• effects on microbial community of water column or sead bed. • avoidance reactions by mobile species, or other behavioural responses such as valve closure in bivalves or changes in burrowing behaviour. • acute and/or chronic toxicity. • clogging of fish or invertebrate gills and invertebrate filtering appendages. • sub-organismic effects (adaptive and maladaptive biochemical, physiological, ultrastructural and/or histological alterations).changes in energy allocation with effects on growth and reproduction. • impaired fitness of transient species such as highly mobile epifauna and pelagic fish species
6) Ecological/Ecosystem-level Responses	• smothering or impairment of hard-substrate communities. • deleterious effects on benthic community structure. • deleterious effects on planktonic communities. • effects on primary productivity (of macrophytes, phytoplankton, or autotrophic microplankton). • effects on heterotrophs (secondary production). • effects on predation or competition, leading to shifts in community structure. • loss of rare organisms; reduced biodiversity. • reductions in microhabitat diversity and ecosystem complexity owing to large-scale spatial redistribution of uniform sediment type.

Major Category	Possible Effects
7) Human Resource Use	• food-source contamination. • interference with harvesting, tourism, or recreation. • aesthetic effects.

Source: Bright, (personal communications) 1996

7.1.2 Consideration Of Potential Receptors

Fundamental to conducting an effects monitoring program is the identification of appropriate species (receptors) in which to examine effects. There are no mandatory species for consideration but rather principles which should be followed, as exemplified in Figure 7-1. Additionally, in the case of STD and large ecosystem monitoring, it is important to check for representation of important ecological niches. For example, receptors should be included to represent both infaunal and epifaunal invertebrates in both deep and shallow water environments. Further within this context, an array of different life strategies and feeding mechanisms ought to be considered so as not to exclude potentially sensitive receptors. This makes for a significant undertaking when applied to large scale systems such as fjords, and requires much planning to optimize efforts.

Island Copper Mine represents one of the earliest efforts to undertake a large scale environmental effects monitoring program, and like any pioneering effort much can be learned to optimize present day approaches. Many of the receptors and their niches studied by Island Copper are logical outcomes of the principles provided in Figure 7-1. The following sections examine the monitoring program, summarize the findings and offer perspectives where the efforts could be improved to optimize a current day application.

7.2 Evolution of the Monitoring Program at Island Copper

On January 20, 1971, the Pollution Control Branch of the Provincial Water Resources Service issued the Utah Construction and Mining Co. a provisional permit (#379-P) to discharge 9,300,000 g.p.d tailings from a copper and molybdenum ore dressing plant into Rupert Inlet. A stipulation of the permit was that the proponent, Utah Construction and

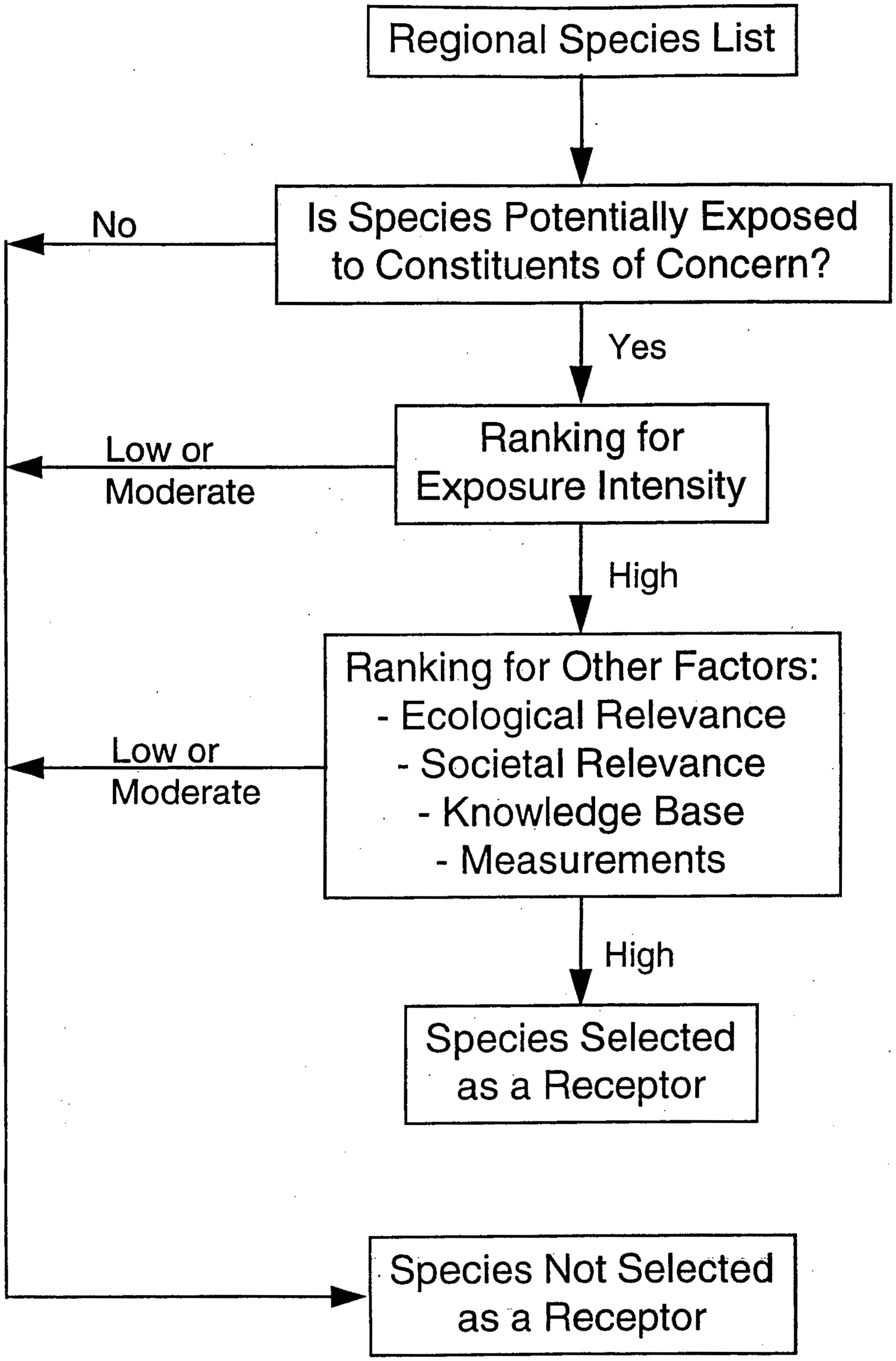


Figure 7-1
Overview of Receptor Selection Protocol

Mining Co., would *'engage an independent agent or organization to set up and conduct a two-phase sampling and surveillance program which will be carried out for at least five operating years after discharge commences'*.

As part of the 1971 permit, the proponent was required, under Phase I (pre-operational) to establish i) baseline 'physical-chemical-biological characteristics of Rupert Inlet, Holberg Inlet, Quatsino Narrows and related waters' , ii) the vertical and horizontal zone and degree of influence of the discharge and, iii) sampling control stations.

Under Phase II (on discharge), the proponent was required to i) ascertain the effects of the effluent discharged through monitoring of the physical-chemical-biological characteristics of Rupert Inlet, Holberg Inlet, Quatsino Narrows and related waters, ii) to continue sampling of control stations, and iii) sample and monitor effluent characteristics.

The data collected under the monitoring program were required by the Pollution Control Branch to be tabulated and submitted quarterly. In addition, comprehensive reports containing data tabulated and interpreted *in a form that may be published* were required to be submitted annually to the Pollution Control Branch. There was also a stipulation *that the program may be modified at any time at the discretion of the Director of Pollution Control.*

As part of the 'works' required, the permittee was required to design and construct an emergency tailings pond on or before December 31, 1973, or prior to discharge, whichever date is the sooner.

Appended to the 1971 permit was a list of criteria for suspended solids, total solids, pH range and concentrations of several metals. The stipulation in the appendix was that characteristics of the effluent should be equivalent to or better than the criteria listed. These appended criteria set the limitations on the discharge of tailings from the mine to Rupert Inlet.

There were several amendments to the January 20, 1971 permit, which for the most part could be considered minor. On September 21, 1971, an updated drawing of the Utah Construction and Mining Company lots was amended to the permit. On December 6, 1971, the name on the permit was changed to Utah International Inc. The permit was further amended on April 17, 1972, however, the contents of that amendment are not known.

On May 17, 1972, the outline of the proposed environmental monitoring program pursuant to PCB Permit #379-P (Phase II) was prepared by J.B. Evans, based on a meeting held on May 9 and attended by the following individuals:

Individual	Representing
R. Hansen	Utah International Inc.
C. Pelletier	Utah International Inc.
D.Ellis	University of Victoria
T. Griffing	T.W. Beak
L Everson	T.W. Beak
A. Lewis	University of British Columbia
J. Leja	University of British Columbia
K. Fletcher	University of British Columbia
J. Evans	University of British Columbia

The proposed monitoring program outlined the i) parameter studied, ii) frequency of measurement, iii) material sampled, iv) measurement or analysis made, v) water depth, vi) station designation, vii) number of samples per station, viii) method of measurement (sampling equipment), ix) party responsible for sampling and, x) party responsible for analyses.

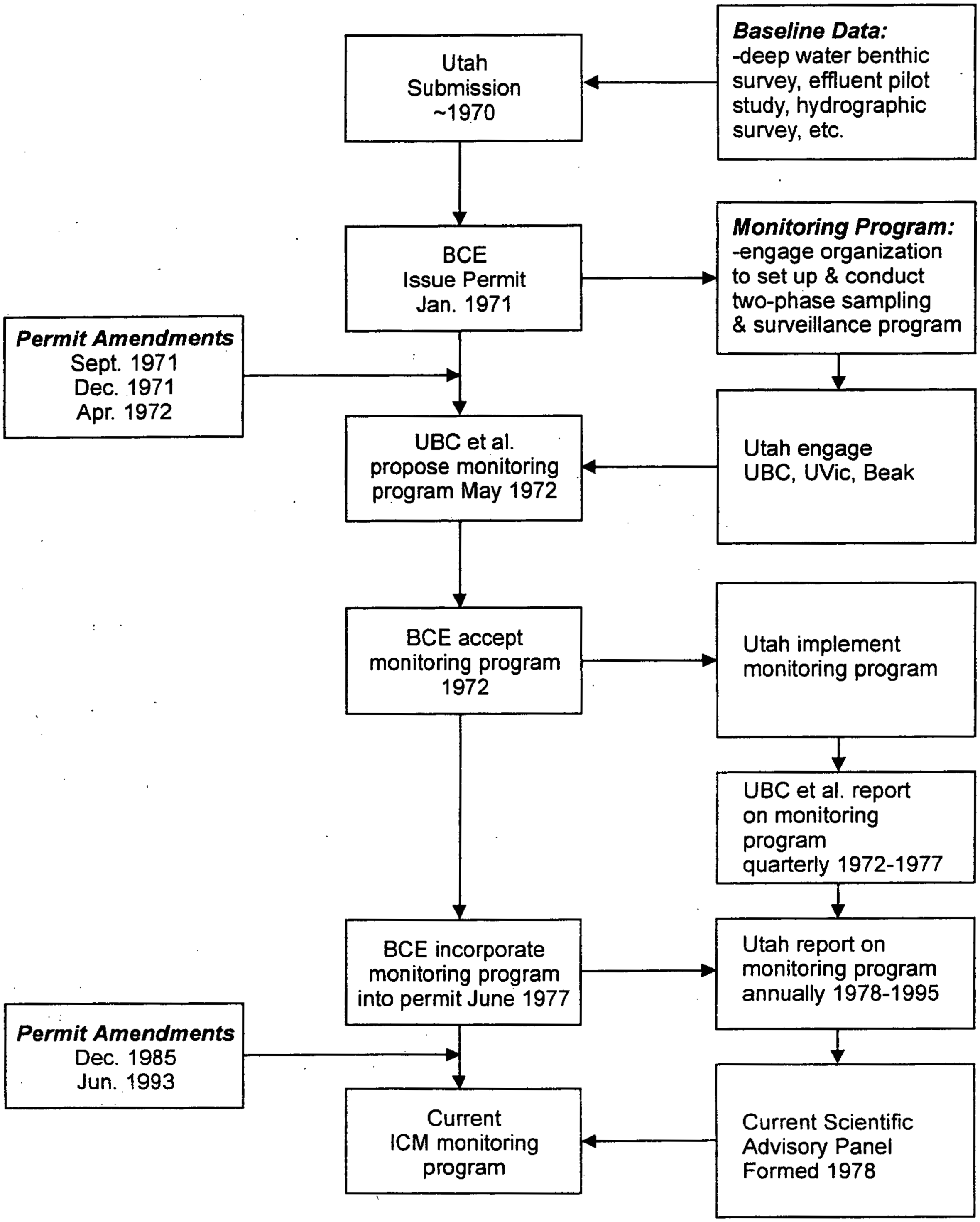
The proposed monitoring program was accepted by the Pollution Control Branch in a letter to Utah International that same year (I. Horne, pers. comm.).

On June 30, 1977, the pollution control permit No. PE-379 was amended to include, among other items, the proposed monitoring program of 1972. The proposed monitoring program was refined, however, to include an objective associated with the measurement of each parameter. For example, the objective associated with collecting crab from 6 stations to determine body condition and metal concentration was to monitor crab population and metal content. Similar objectives were associated with each of the parameters measured.

Coincident with the incorporation of the proposed monitoring program into the pollution control permit was the expiration of the 5-year surveillance program specified in the 1971 permit and the involvement of the original independent scientific advisory committee. In 1977, the original scientific advisory committee dissolved and was re-formed and consisted of the individuals that advise on environmental issues to this day: D.V. Ellis, C.A. Pelletier, J.W. Murray, G.W. Poling and T. Parsons. Furthermore, from 1971 to 1977, monitoring reports were published quarterly from the University of British Columbia. In 1977, Utah assumed the responsibility of publishing reports which were, from then on, published annually (I. Horne, pers. comm.)

Additional amendments have been made to the pollution control permit since June 30, 1977. On both occasions, December 24, 1985 and April 1993, modifications were made to the monitoring program to respond to issues raised at that time. For example, in the mid 1980s, resources were rechanneled to the issue of ARD associated with surface waters which had become an environmental concern over recent years (I. Horne, pers.comm.). A summary of the evolution of the Island Copper monitoring program is outlined in Figure 7-2.

The environmental monitoring program for the Island Copper Mine could be considered a pioneering effort in the development of monitoring programs for industries that discharge to the marine environment. At the time the permit was granted, it seemed clear that a monitoring program was appropriate, however, there was no precedent for what should be included in a monitoring program for a mine discharging to the marine environment. The province of British Columbia, through the Pollution Control Branch made it the responsibility of Utah Construction and Mining to assemble a team of independent scientists to devise an appropriate monitoring program that would meet the requirements specified in the original January 20, 1971 permit. Although the monitoring program was not officially adopted as part of the pollution control permit until June 30, 1977, unofficially, the monitoring program was adopted by Utah in 1972.



Golder Associates

EVOLUTION OF ISLAND
COPPER MONITORING PROGRAM

Figure 7-2

PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-08-96 FILE LOCATION: J:\9521928\0396\TDISP.CDR

7.3 Results of Fish Monitoring Program

7.3.1 Biological Parameters Monitored, Objectives and Effects Reported

The components of the Island Copper monitoring program related to fish and the objectives are outlined in Table 7-2. A summary of the parameters measured by year is provided in Table 7-3.

7.3.1.1 Acute Effluent Toxicity Testing

Acute bioassays were performed on salmonids monthly to determine the acute toxicity of the effluent and to effect changes for process and effluent quality if warranted. A 96-hour LC_{50} test with salmonids was conducted using a decanted sample of mill effluent entering the discharge mix tank. Additional bioassays were conducted if toxicity was observed. Coho salmon (*Oncorhynchus kisutch*) were used for testing in 1978 and until September in 1979. Although some overlap occurred in the use of coho salmon and rainbow trout, the consistent use of rainbow trout (*Oncorhynchus mykiss)* for the acute bioassays commenced in October 1979 and continued through 1994. Additional bioassays were performed if toxicity was observed.

From October 1977 to December 1994, a total of 228 bioassays were performed, with the majority (216) with passing and only 12 failing. Most failures occurred within a cluster in 1979 suggesting a temporary anomaly in process; otherwise the effluent was generally not acutely lethal. An earlier cluster of bioassays indicating the presence of acute toxicity occurred in 1976. This observation resulted in the discovery of an upstream process change that had occurred and was quickly rectified.

Discussion and Critique of Monitoring Program for Acute Toxicity of Effluent

In light of the above observations, the monitoring program for acute toxicity of effluent was considered to be sufficient to meet the objectives. In this case the use of coho salmon versus rainbow trout is of minor consequence as both are generally regarded to be a sensitive fish species.

7.3.1.2 Population Parameters

Fish were collected as part of the monitoring program to monitor fish population dynamics. The monitoring program was conducted on an annual basis from 1971 to 1976 (Island Copper, 1991).

TABLE 7-2

Marine Monitoring Program - Fish

	Description	Frequency	Objective
Acute Bioassays	Conducted acute bioassays with effluent on coho or rainbow trout	monthly	monitor acute toxicity of effluent
Intertidal Fish	At 7 intertidal sites sculpins are collected by beach seining. Identify, weigh, measure and analyze for Cu, Mo, Cd, Pb, Zn, As and Hg. (6 sites in 1990)	Annually from 1971-1976, every 5 years from 1980	Monitor metal content. Population not monitored
Bottom Fish	Longlines set at 4 stations to collect bottom fish. Identify, weigh, measure, sex and analyze for Cu, Mo, Cd, Pb, Zn, As, and Hg. (6 sites in 1990)	Annually from 1971-1976, every 5 years from 1980	Estimate population and monitor metal content.
	At 6 sites jigging is done to collect reef-dwelling and bottom species. Identify, weigh, measure, sex and analyze for metals. (sex not monitored, 1990)	Annually from 1971-1976, every 5 years from 1980	Monitor metal content
Pelagic Fish	At 5 sites gill nets are set to collect pelagic species. Identify, weigh, measure, sex and analyze for metals.	Annually from 1971-1976, every 5 years from 1980 (not in 1990)	Monitor metal content.

Spiny dogfish was the focus of the population study. Fish were collected by longlining with the same catch per unit effort at each station. Measurements of length, weight and width were taken and sex was determined.

The fish population monitoring program was tied in with the fish tissue metals monitoring program. In 1976, Island Copper reduced the fish population monitoring to five-year sampling intervals since the metals data indicated no apparent enhancement of tissue metals (Island Copper, 1986).

Island Copper reported no change in spiny dogfish population from 1971 to 1994.

Discussion and Critique of Monitoring Program for Population Parameters

The monitoring program provided some useful information but could not fully meet the objectives of assessing effects on potentially impacted fish populations. A critique of the monitoring program is provided below:

- Appropriate fish for monitoring effects of tailings deposition or other stressor would be a relatively long-lived, territorial species such as one of the numerous species of rockfish that inhabit Pacific coastal waters. Relatively little is known about the spiny dogfish, but it is known that the spiny dogfish can range longer distance and would therefore not reflect conditions in the immediately local environment.

- Length and weight data were not sorted for presentation based on age and gender of the fish. These variables would have a defining influence on the length and weight of the fish. Lack of age and gender for this data set compromises its information value.

- Wadichuk and Buchanan (1980) noted that although there was no decline reported in stocks of commercially important species during the period of mine operation no data were available for confirmation.

- Suspended sediments are known to cause avoidance behaviour in salmonid species (Newcombe, 1994). The effects of increased turbidity on salmon migration in Rupert Inlet has been suggested for inclusion in the monitoring program (Westwater Research Center, 1985).

TABLE 7.3
ICM Monitoring Program
Fish (Intertidal and Bottom Fish)

		1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Acute Bioassays																									
Coho/Rainbow Trout		o	o	o	o	o	o		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Population																									
Dogfish (Bottom Fish)		o	o	o	✓	✓	✓				✓					✓					✓				
Metal Content		o	o	o	o	o	o																		
Cu	Intertidal Fish										●					●					●				
	Bottom Fish										●					●		o			●				
Mo	Intertidal Fish										●					•					•				
	Bottom Fish										●					•					•				
Pb	Intertidal Fish										●					•					•				
	Bottom Fish										●					•					•				
Zn	Intertidal Fish										●					●					●				
	Bottom Fish										●					●		o			●				
Cd	Intertidal Fish										●					•					•				
	Bottom Fish										●					•					•				
As	Intertidal Fish										●					●					•				
	Bottom Fish										●					●					•				
Hg	Intertidal Fish										●					•					•				
	Bottom Fish										●					●					•				

o Note: Reports pre-1977 were not available for review by Golder; results of metal analyses in later ICM reports

Notes for Metals:

• Metals analyzed, but no discussion of statistical analyses

● Metals analyzed, and discussion of statistical parameters in report

1) Species of interest in 1980: **dogfish**, sixgill mudshark, shiner seaperch, **kelp greenling**, copper rockfish
2) Species of interest in 1985: **dogfish**, big skate, **yellowtail rockfish, kelp greenling, staghorn sculpin**
3) Species of interest in 1990: **dogfish, yellowtail rockfish, kelp greenling, staghorn sculpin**

r:\enviros\952-1928\sap\years.xls

Recommendations for Additional Parameters

- Assessments of effects of a stressor on animal populations requires a consistent effort over a given period of time. This is consistent with the longlining approach used by Island Copper. Additional information that would provide clarity on the issue of effects of submarine discharge of mine tailings on fish populations would include *bona fide* population studies on fish species representing different trophic levels. Given that tailings were deposited at depth and settled to the sea floor, candidate fish species should include a demersal species and a deep water pelagic species. A more shallow pelagic species would be useful in the event that tailings are resuspended into more shallow zones affecting near-surface organisms or nursery habitat (See Figure 2-1). In all cases, the most useful species would be resident to the area and one that typically uses a small territory. Appropriate reference sites would also provide information on yearly variability in local populations, not related to mine tailings.

7.3.1.3 Metals Accumulation

As part of the population monitoring studies, various intertidal and bottom fish from each station were selected for analysis of metal content in dorsal muscle tissue (large fish) and whole body analysis for small fish (i.e., sculpin). Tissue metal content over time was graphed in 1990 for yellowtail rockfish, pacific staghorn sculpin, kelp greenling and spiny dogfish. In 1985, tissue metal content also were reported for big skate, and in 1980, data were reported for may different species of fish. Metals monitored in fish tissue were copper, molybdenum, cadmium, lead, zinc, arsenic, and mercury. The objective of this program was to monitor metal content in fish.

Island Copper reported no trends in metal concentrations of fish muscle tissue or whole body over the years of discharge of tailings in Rupert Inlet.

Discussion and Critique of Monitoring Program for Metals Accumulation

- Dorsal tissue was analyzed for metals from large fish, and whole body analyses were performed on small fish such as sculpin. It is unclear, based on the statement of objectives and the tissue analyzed, whether metals concentrations in fish were being monitored for the protection of humans consuming fish or to monitor potential adverse effects to fish themselves. Whole body analysis would provide a better assessment of metal accumulation in fish than muscle tissue. Muscle tissue, although relevant for most human consumption of fish, is not relevant to all humans who consume fish and does not reflect accumulation of metals by other tissues. Concentrations of metals like copper and zinc could be maintained at relatively low concentrations in muscle, while increasing dramatically in liver and kidney and to some extent, bone tissue (Miller et al., 1992).

- Island Copper reported increases in arsenic and zinc in dogfish from 1971 to 1975 in Rupert and Holberg Inlets (Island Copper, 1985). Although these data were not retrieved, a re-assessment of the 1980 to 1990 data, including consideration of standard deviation, does not show any trend. It was not clear if statistical analyses were considered in the assessment of the 1971 to 1975 data.

- The monitoring program apparently did not consider power analysis in specifying sample sizes. Therefore, statistical assessment of the data, if conducted would be weak. Island Copper noted retrospectively that the small sample sizes limited statistical evaluation of the data.

- A mix of species were monitored at all stations each year of the monitoring program. Pursuant to the power analysis issue, above, insufficient numbers of the same fish species were analyzed at the different stations and over time at the same stations for a comprehensive assessment. Fish representing different niches, sizes and ages could possibly accumulate different amounts of metals, but this hypothesis is not testable within the constraints of the data.

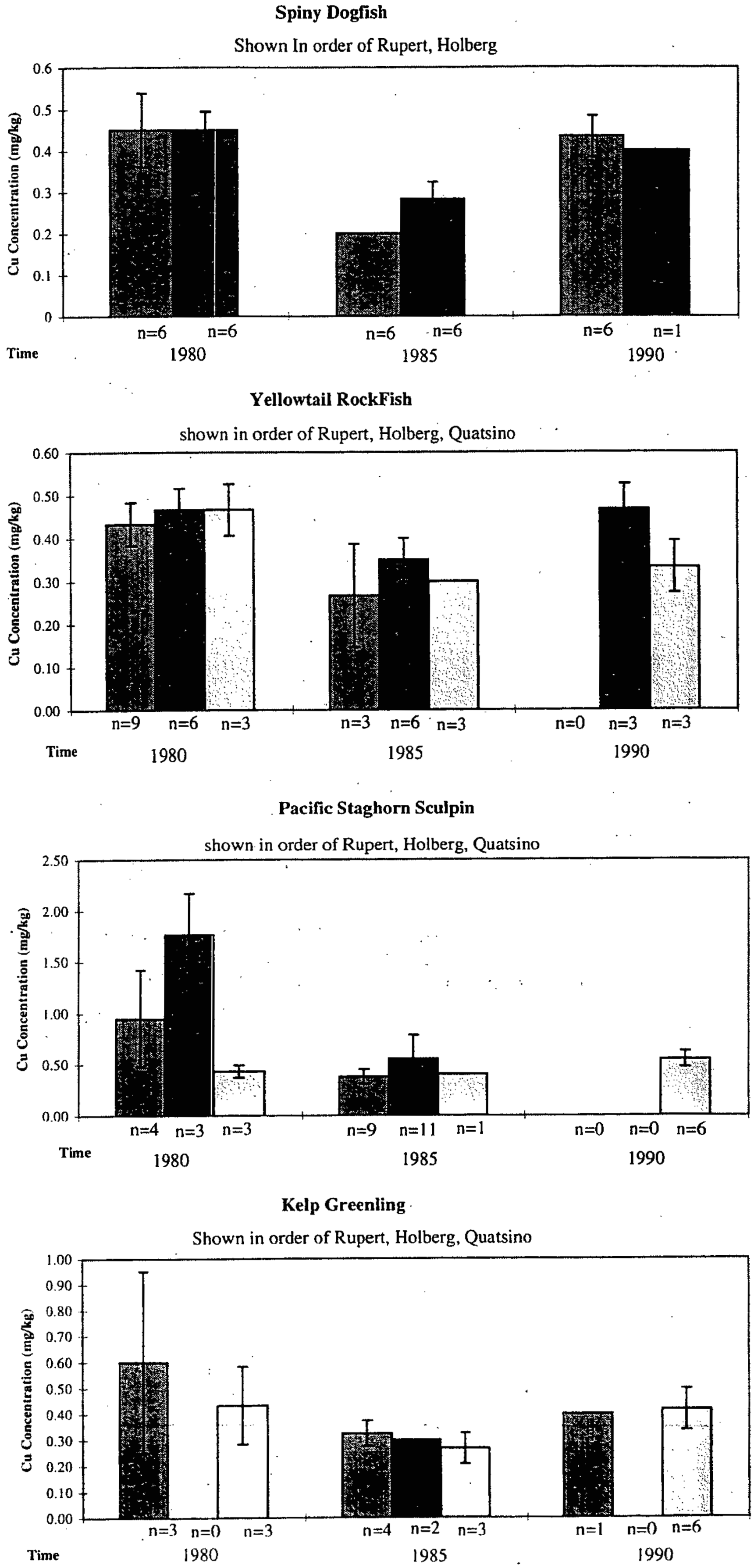
- Sample sizes and standard deviations for data were not shown on the graphs used in the main report. Again fish were not sorted according to age and gender, variables that could have a significant impact on metal accumulation in fish. The variability in metal accumulation in fish is demonstrated by the data for the spiny dogfish (Figure 7-3).

- Reference stations may have been in the zone of tailings deposition. The Environmental Protection Service (EPS) of The Department of Environment reviewed the monitoring program, and suggest that "the tailings had spread so far that no stations acted as controls, and therefore, further stations should be added in Quatsino Sound out of the zone of tailings influence" (Westwater Research Center, 1985).

Recommendations for Additional Biological Parameters for Metals Accumulation

- Management decisions are required in the design of a monitoring program regarding what changes in a given parameter are desirable to detect. This information is used in a power analysis that takes into consideration variability, and can then be used to determine appropriate sample sizes.

- A great deal of variability can usually be expected when analyzing field samples, particularly when compared to analyses of samples collected from laboratory studies. Given the greater variability in the field, greater sample sizes are



Project No. .... Drawn .... Reviewed .... Date ....

Golder Associates

COPPER CONCENTRATION IN FISH OVER TIME

Figure 7-3

required to be in a position to detect changes that may be occurring. When there is no apparent difference in a parameters measured among stations, it does not prove there is no difference, it implies there is not sufficient evidence to prove that there is a difference (i.e., reject the null hypothesis) (Zar, 1984).

- Clarification is required concerning the objective of monitoring tissue metal concentrations in fish. Monitoring for both human health and metal accumulation in fish tissues would provide useful information, but requires different sampling; muscle for human health and liver, kidney or bone for accumulation of metals in fish.
- In recognition that different species of fish occupy different niches and could accumulate different concentrations of metals, the most useful information for fish metal accumulation would be generated with the consistent use of selected species (selected based on a number of parameters including exposure potential and sensitivity), representing different niches, at each sample station, year after year.

7.4 Crab, Shrimp/Prawn, Bivalve

7.4.1 Biological Parameters Monitored Objectives and Effects Reported

The biological effects monitoring program for macroinvertebrates is outlined in detail in Table 7.4. A yearly account of the monitoring program is outlined in Table 7.5.

TABLE 7.4
Marine Monitoring Program - Macroinvertebrates

	Description	Frequency	Objective
Crab	At 6 stations collect to determine body condition and metal concentration Cu, Mo, Cd, Pb, Zn, As and Hg. Hg not in 1992-1994	Quarterly 1977-1994	Monitor crab population and metal content.
Shrimp	At 3 locations collect shrimps with standard commercial shrimp traps. Metal analysis includes Cu, Mo, Cd, Pb, Zn, As, and Hg., size	Annually 1980, 1987 - quarterly 1981-84,86 Mar/Jun 1985	Monitor metal content No assessment of population
Intertidal Invertebrates			
Clam	Collect various species of clams at 9 sites; identify, weigh, measure and analyze for Cu, Mo, Cd, Pb, Zn, As, and Hg. Hg not done in 1991-1994	Quarterly 1977 - annually 1978-1994	Monitor body condition and metal content. body condition only in 1977
Mussel	Collect blue mussels at 3 sites. Measure, weigh, and analyze for Cu, Mo, Cd, Pb, Zn, As and Hg. Hg not done in 1992-1994	Quarterly 1977 - annually 1978-1994	Monitor body condition and metal content. body condition only in 1977
	Collect blue mussels at 2 sites, identify, weight, measure, and analyze for Cu, Mo, Cd, Pb, Zn, As and Hg	Annually 1986-1991	Monitor metal content
Shrimp/Prawn	Collected shrimp and prawn and analyzed for Cu, Mo, Pb, Zn, As	Variable 1976-81, -annual 1981-1992	Monitor metal content
Deep Benthic Invertebrates Clam (*H. kennerleyi*)	Analyze from Hankin Point and other sites where found, weigh, measure, and analyze for Cu, Mo, Cd, Pb, Zn, As, Hg	Annually or quarterly 1976-1988, 1991/92	Monitor metal content

TABLE 7-5
ICM Monitoring Program
Benthic Invertebrates

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
POPULATION																								
Crab	°	°	°	°	°	°																		
Dungeness Crab							✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Rock Crab[1]							✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
METAL CONTENT	°	°	°	°	°	°																		
Crab																								
Dungeness crab							3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn
Rock crab							-	-	-	-	-	3/stn	3/stn	1-3/stn	1-3/stn	1-3/stn*	-	-	-	-	-	-	-	-
Mussel																								
blue mussel							3/stn	6/stn	3/stn	3-6/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3-6/stn	6/stn	6/stn	6/stn	6/stn	6/stn	6/stn	6/stn	6/stn
Prawn[3,4]																								
Prawn (*Pandalus platyceros*)							-	-	-	3-6/stn	3/stn				3/stn	3-6/stn	6/stn	-	6/stn	6/stn	6/stn	6/stn	6/stn	6/stn
Shrimp (*Pandalus borealis*)							-	-	-	6/stn	3/stn				3/stn	3-6/stn	6/stn	-	-	-	-	-	-	-
Humpback (*Pandalus hypsinastus*)							-	-	-	3/stn	3/stn				3/stn	3-6/stn	-	-	-	-	-	-	-	-
mixed prawn species tested							-	-	-	-	-	3/stn	3/stn	3/stn	-	-	-	-	-	-	-	-	-	-
Clam																								
butter and littleneck clam							3/stn	3/stn	3/stn	3-6/stn	3/stn	3/stn	3/stn	3/stn	3/stn	6/stn	6/stn	3-6/stn	6/stn	6/stn	6/stn	6/stn	6/stn	6/stn
softshell clam							3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	6/stn	6/stn	3-6/stn	6/stn	6/stn	6/stn	6/stn	6/stn	-
polluted macoma							3/stn	3-6/stn	3/stn	3-6/stn	3/stn	3/stn	3/stn	3/stn	3/stn	6/stn	6/stn	6/stn	6/stn	-	-	-	-	-
additional clam species[2]							3/stn	3/stn	3/stn	3/stn	3/stn	3/stn	-	-	-	-	-	-	-	-	-	-	-	-
Deep water clam																								
Humilaria kennerlyi							-	HP+ Q	HP SA	HP+ Q	HP SA	-	HP A	HP+ SA	HP SA	HP+ Q	HP+ SA	-	-	-	-	-	-	-

°	Note: Reports pre-1977 were not available for review by Golder
1)	rock crab population over time not discussed in main report
2)	additional clam species include: bent-nose clam, california mussel, cockle, horse clam
3)	1986 reported also compares deep sea control prawn
4)	Yellow-legged pandalid and coonstripe shrimp tested in 1980 and 1981, respectively
Notes for Metals:	
#/stn	Number of samples analyzed for metal tissue content per station (* if data were not discussed in the main report)
-	No samples collected
Note for *Humilaria kennerlyi* data	
HP	samples obtained at Hankin Point only
HP+	samples also obtained from Ilstad Island or Orr Island
A, Q, SA	A - annually, Q - quarterly, SA - semi-annually

7.4.1.1 Metals Accumulation

Island Copper monitored metal concentrations (As, Cd, Cu, Pb, Hg, Mo, Zn) in a number of shallow water benthic invertebrates including several species of crab, shrimp, prawn, clam, and mussel quarterly or annually from 1970 to 1994 (See Table 7-4). In addition, the deep water clam, *Humilaria kennerleyi,* was collected from Hankin Point, and other sites where found, and was analyzed for the same parameters, variably from 1977 to 1987, and in 1991/92. All samples collected were identified, weighed, and measured prior to sampling of tissue for metal content. Sites used as sampling stations varied for each species, and are shown in the attached figures (Figures 7-4 to 7-7).

Crab Tissue Metal Content

Three crab collected from each station in Rupert Inlet (3 stations), Holberg Inlet (2 stations) and Quatsino Sound (1 station) (see Figure) were analyzed for leg tissue metal content. Large crab (more than 16 cm) dominated the samples, as the commercial traps used to catch the crab are designed to allow smaller crab to escape.

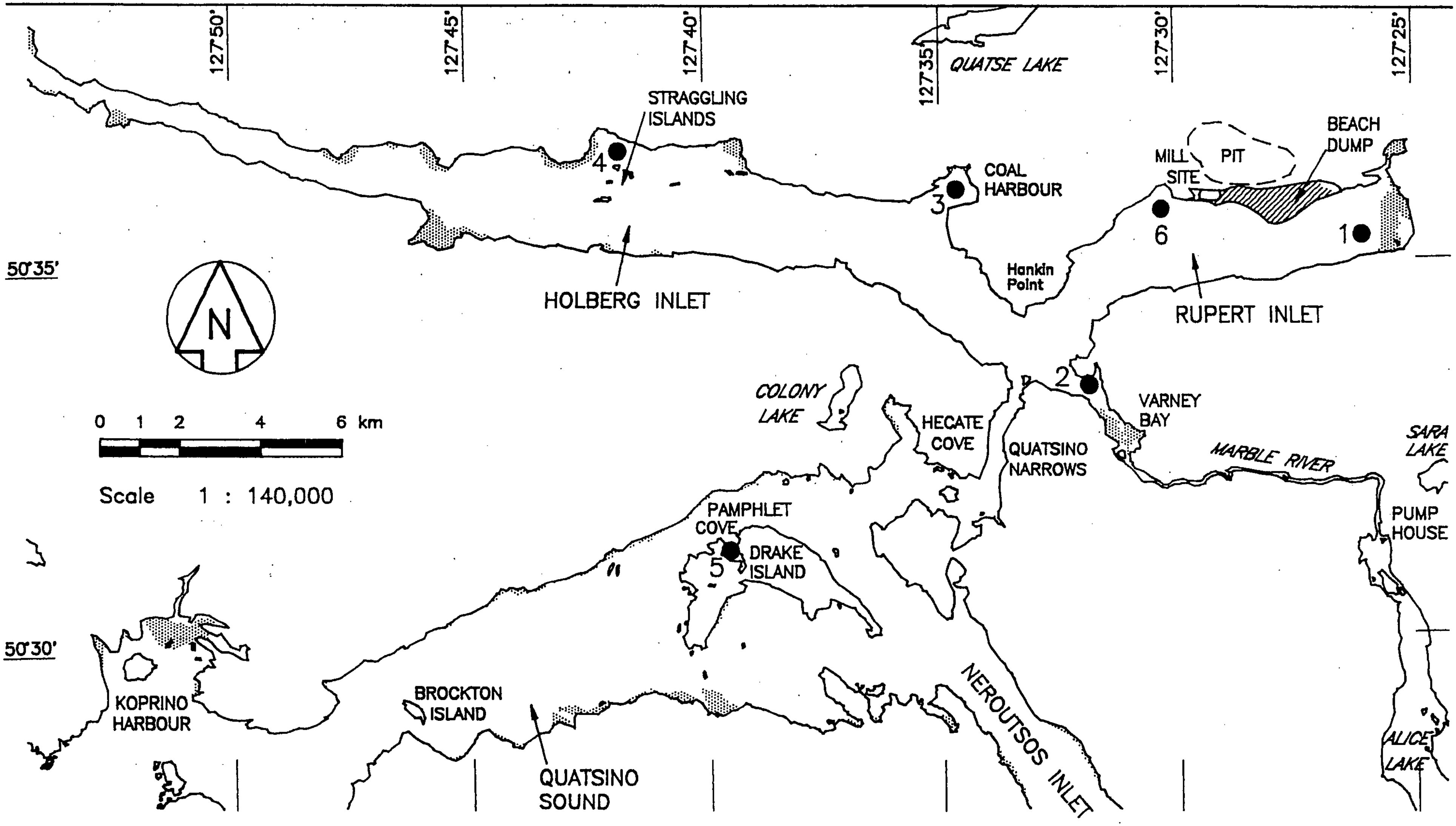
Island Copper (1995) reported that dungeness crab tissue has not shown evidence of impact from the mine tailings. Tissue copper concentrations have shown little change in recent years with mean concentrations of 9.9 mg/kg and 10.6 mg/kg in Quatsino Sound and Rupert Inlet, respectively. Copper concentrations in crab tissue have been variable, with an apparent increase from 1971 values. Zinc levels in crab tissue in Rupert, Holberg, and Quatsino Sound are reported to be within the range observed at the reference stations (Koprino and Winter Harbours) and the high arsenic concentrations in Quatsino were reported to reflect the natural oscillations in tissue over time.

Island Copper reported that no trends over time were obvious for any of the metals, at Rupert Inlet, Holberg Inlet or Quatsino Sound and there is no evidence to suggest that biomagnification of metals through the food chain is occurring.

Discussion and Critique of Monitoring Program for Metal Content in Crab

- No external reference site outside the Quatsino Sound area was consistently used over time for comparison of tissue metal levels. Island Copper included Koprino Harbour (see attached maps) and Port Hardy as reference sites for most of the sampling period; however, for some species the sampling periods were

Island Copper Submarine Tailings Monitoring Program



Project No. ....
Drawn ....
Reviewed ....
Date ....

Golder Associates

Dungeness Crab Sampling Station

Figure
7–4

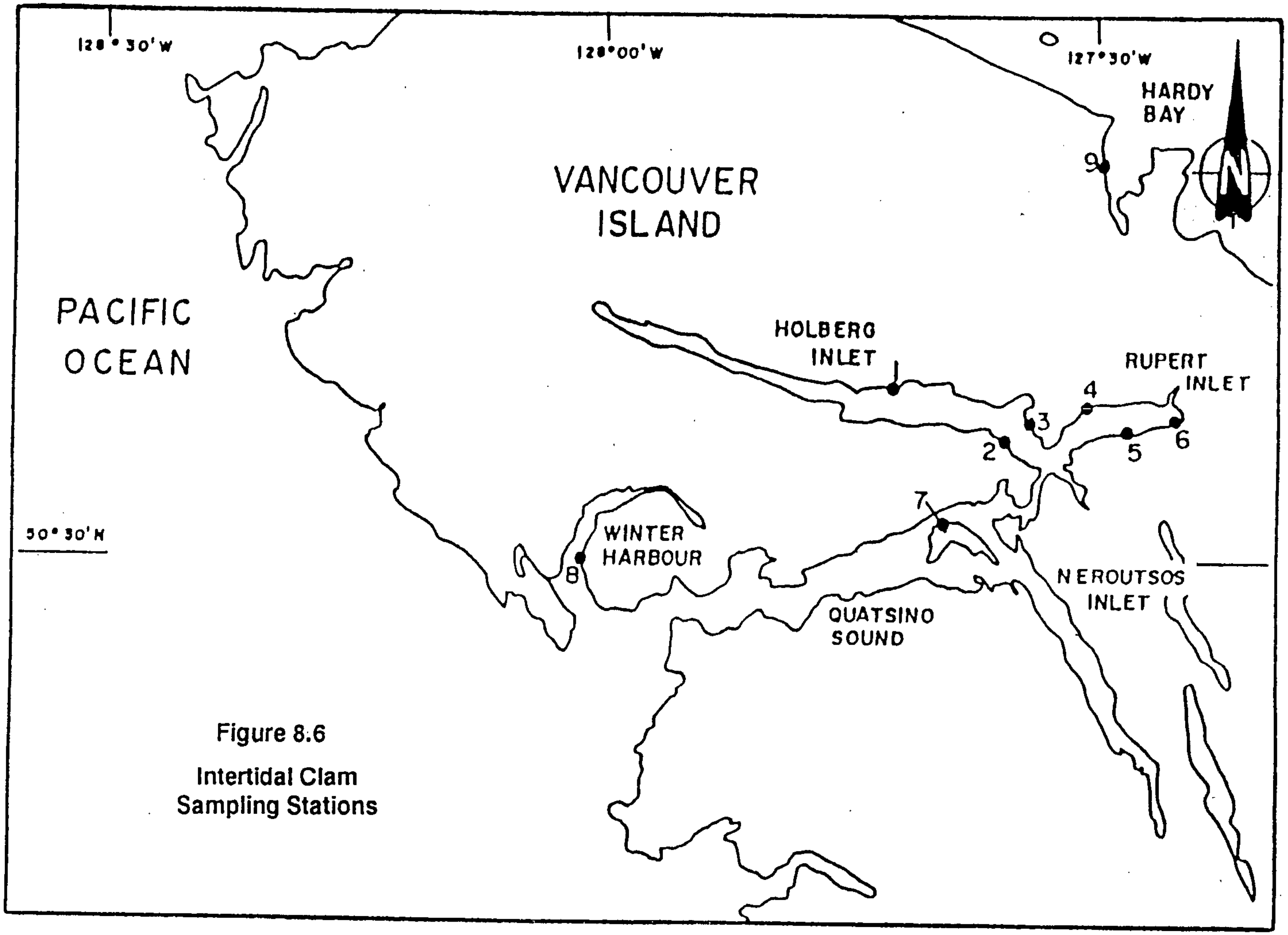


Figure 8.6

Intertidal Clam Sampling Stations

Project No. ....
Drawn ....
Reviewed ....
Date ....

Golder Associates

Intertidal Clam Sampling Station Locations

Figure 7-5

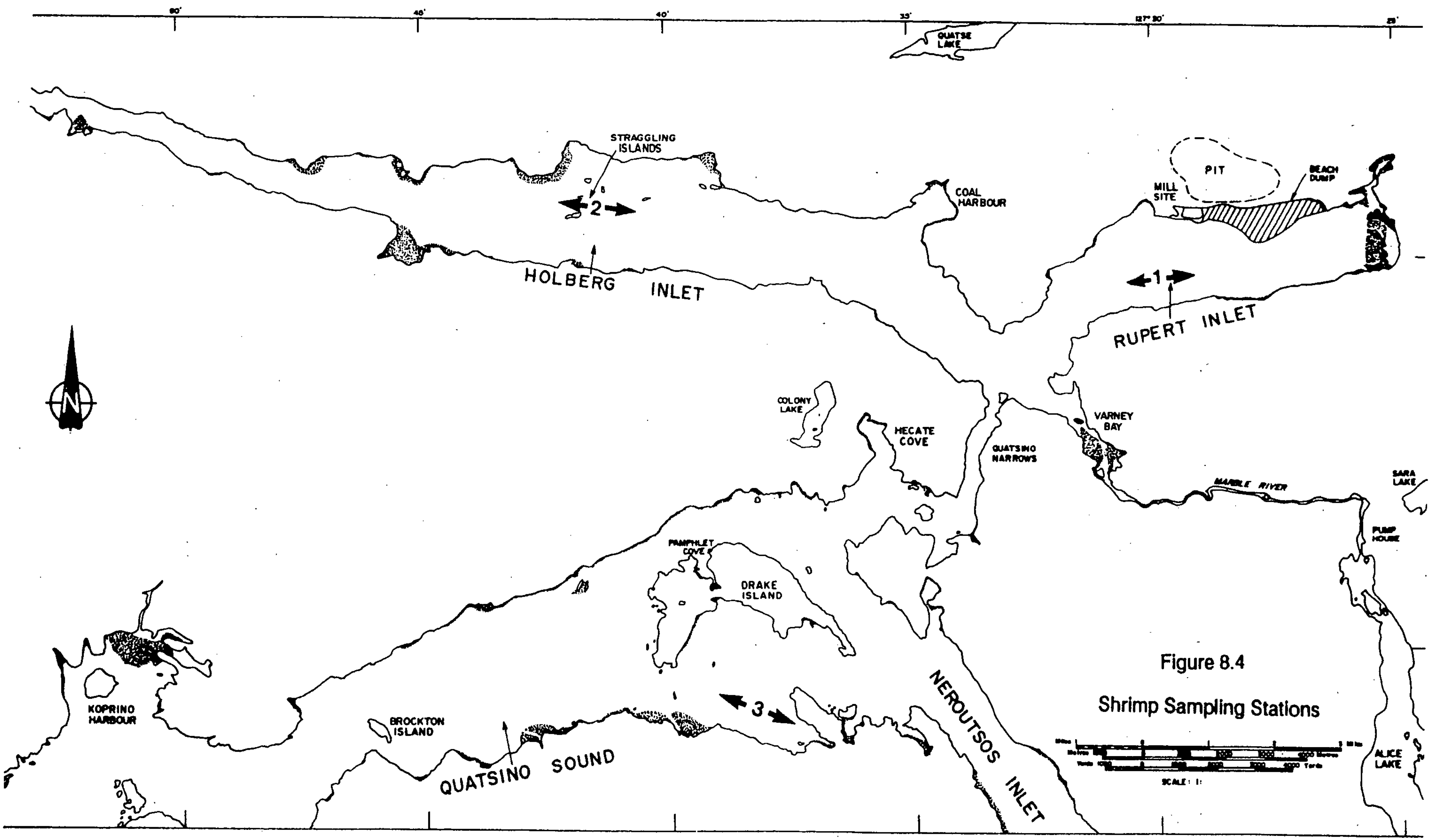


Figure 8.4

Shrimp Sampling Stations

Project No. ....
Drawn ....
Reviewed ....
Date ....

Golder Associates

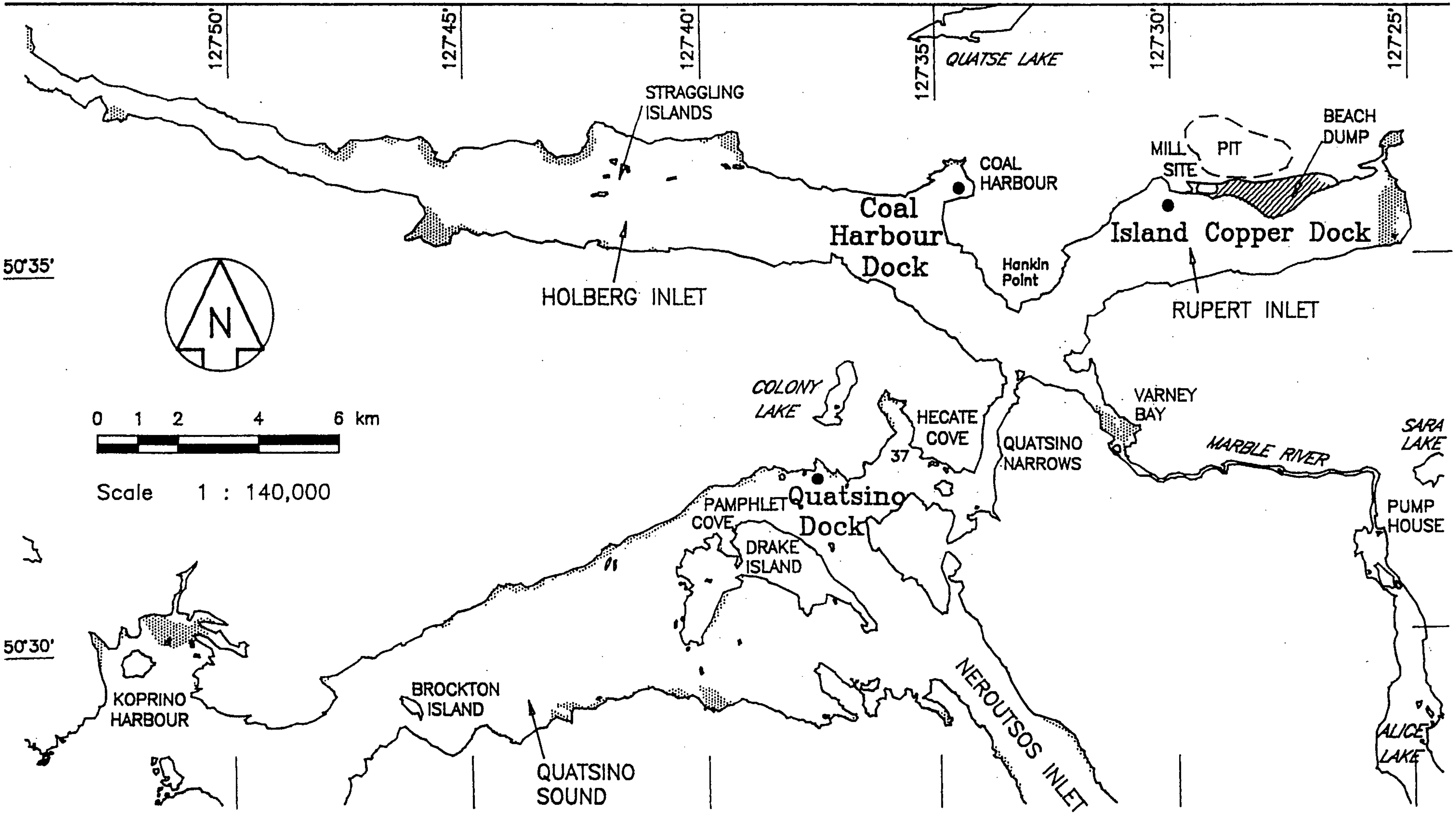
Island Copper Submarine Tailings Monitoring Program

Shrimp Sampling Station Locations

Figure

7–6

Island Copper Submarine Tailings Monitoring Program



Project No. ....
Drawn ....
Reviewed ....
Date ....

Golder Associates

Mussel Sampling Station Locations

Figure

7-7

inconsistent, and none of the information was presented in the graphs. Koprino and Winter Harbours were sampled in 1991 to 1994, and Koprino and Browning Inlet were sampled inconsistently from 1980 through 1990.

- In addition, references sites should be selected based on similarity to the test sites in all ways except the parameter under consideration. The reference sites selected for the monitoring program may not have represented unimpacted areas, both in terms of tailings and in terms of other contaminant sources. Pamphlet Cove in Quatsino Sound, for example, had trace metal concentrations in sediments indicative of tailings deposition as early as 1977. Port Hardy, as a regional centre, is the site of a variety of activities and the harbour would be expected to reflect these activities. Other pre-operation data for the area were not available to use as a baseline reference for tissue metal concentrations.

- Island Copper (1995) reported that dungeness crab tissue metal concentrations have not shown evidence of impact from the mine tailings over the years. However, the number of samples taken at each site was small (n=3) and given the variability that is normally seen in field samples, only extreme differences could be expected to be observed.

  In order to determine what sample size would be required to see a 10% or 20% difference between a 'test' site (e.g. Rupert Inlet) and reference site, a power analysis of the data is required. A power analysis takes into consideration the variability in the data to determine what sample size is required to see a difference between sites if a difference exists.

  In order to provide an indication of what sample size would be required to see a 20% difference in metal concentrations between crab from Rupert Inlet and Quatsino Sound, a power analysis of a partial data set from 1994 was conducted[1]. Station 5 (Pamphlet Cove) was selected to represent Quatsino Sound and Station 6 (Mine Site) was selected to represent Rupert Inlet. The March 1994 copper analysis data were used. It should be noted that the use of power analysis in the development of a monitoring program should be considered an iterative process. A power analysis based on only a few samples (e.g. n=3) may provide an over-estimation of the required sample size. Once more data are collected (e.g. n=12) a re-analysis may suggest that fewer data than originally predicted are required for the desired power. This is a reflection of the relatively high variability that is associated with small sample sizes.

  The probability of detecting a 20% difference in copper concentrations in crab between these two sites with a sample size of n=5 is only 26%. With a sample

---

[1] The reader is referred to any standard biostatistics textbook such as Zar, 1984 for a complete discussion of power analysis, Type I and Type II error.

size of n=3, there would be a very low probability of observing a 20% difference in copper concentrations in crab muscle tissue. With a sample size of n=25, the probability of detecting a 20% difference increases to 83%, (the level of generally acceptable probability).

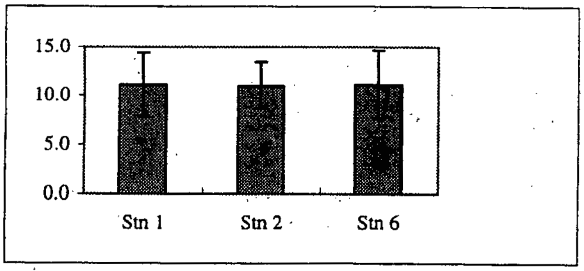
This analysis was based on the March 1994 copper analysis of crab tissue using a sample size of n=3. The large numbers of samples required to see a 20% difference in copper concentrations is a reflection of the low sample size (n=3) and the variability. A reanalysis of the data with more measurements (i.e. greater sample size) may indicate that actually fewer than 25 samples are required. A reanalysis of the power of the sampling effort should be done periodically as a check, to determine the power of detecting the desired observation.

- The effect of tailings on crab tissue metal concentrations in Rupert Inlet was represented by 3 sampling stations in the Inlet. One was located at the head of the Inlet (Station 1), one near the tailings outfall (Station 6), and one in Varney Bay (Station 2). Intuitively, there are reasons to suggest that Stations 1 and 2 would not reflect tailings impacted areas compared to Station 6. Station 1 is located at the head of the fjord corresponding to sediment core Station 21 where no evidence of tailings were recorded (ICM, 1995). A similar observation could be made for Varney Bay, where core sampling Station 11 also showed no evidence of tailings accumulation (ICM, 1995). Furthermore, chemical concentrations in Varney Bay would be expected to be more representative of contributions from the Marble River, rather than Rupert Inlet, since the Marble River represents a significant body of fresh water entering Varney Bay.

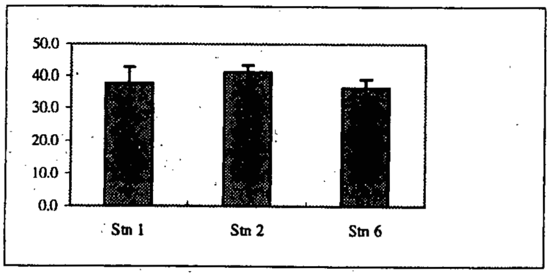
Before these three stations can be pooled to represent Rupert Inlet, they should be tested to see if they differ from each other. If they are not different, they can be pooled. Golder plotted the data for each of the crab tissue metal monitoring stations in Rupert Inlet (Figure 7-8). Error bars represent one standard deviation from the mean. Plotting data with error terms can be useful to evaluate whether populations are different. If the mean value at a sample location differs from another by more than two standard deviations this suggests that the two sampling locations are different populations and cannot be pooled.

Plotting the data with error terms also serves to demonstrate the variability in the data. Large error bars represent high variability in the data, which is a function of both sample size and the inherent variability in field sampled data. Although the error bars on the Golder plotted data suggest that the stations are not different, they also suggest that the data are variable and the sample sizes are too small to allow detection of even large differences among the stations.

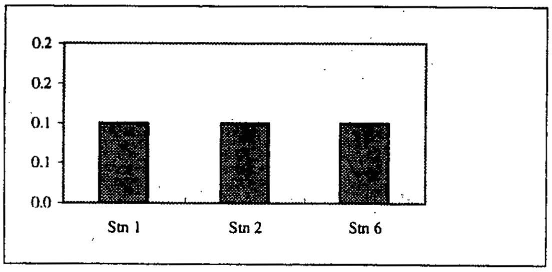
Copper



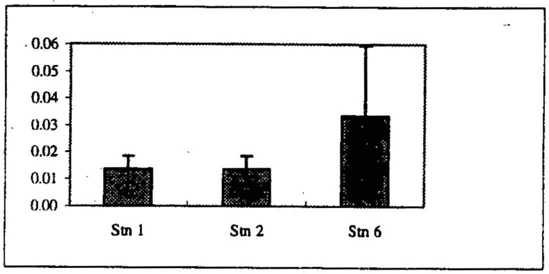
Zinc



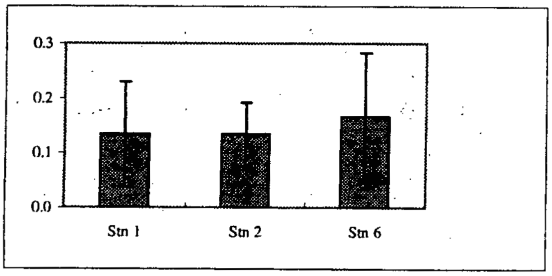
Molybdenum



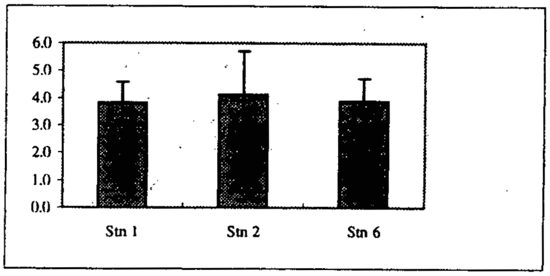
Cadmium



Lead



Arsenic



Note:
1) Seasonal data pooled from 1994
2) error bars = 1 standard deviation
3) no error term for molybdenum since never above detection limit
4) sample size, n=3

Project No. .... Drawn .... Reviewed .... Date ....

Golder Associates

Tissue Metal Levels - Interstation Comparison - Rupert Inlet
Dungeness Crab - 1994 (yearly ave)

Figure 7-8

In order to determine what sample size would be required to see a 10% or 20% difference between these three stations, a power analysis of the data, as described briefly above, is required.

Shrimp/Prawn - Tissue Metal Content

Shrimp and prawn were collected 1980 through 1987, either annually, semi-annually, or quarterly. They were collected on an "ad-hoc" basis during the 1970s and after 1987. Several different species were collected over the years, but since their tissue metal concentrations were judged to be similar, they were considered as one. Shrimp and prawn were collected, 6 per station, using standard commercial traps, or obtained from commercial fishermen in later years. On two occasions in 1986, deep sea prawns were obtained by a local dragger. Excised abdominal tissue from shrimp and/or prawn was homogenized for metal analysis.

From 1987 through 1992, there were data gaps, with a lack of prawn samples collected at each station. No prawn samples were shown for Quatsino Sound in 1987, all data were lost in 1988, no data were shown for Rupert Inlet from 1989 to 1991. In 1992, prawn were sampled only in Rupert Inlet and in the 1992 monitoring report (ICM, 1993), prawn tissue metal data were presented in time series graphs from 1981 to 1992.

The 1992 monitoring year was the last year for which shrimp or prawn samples were collected for analyses. As noted above, samples were collected only in Rupert Inlet. Island Copper (1993) reported that copper and arsenic concentrations were lower than in other years and that cadmium and zinc were on the low end of the range previously seen. Island Copper (1992) reported that concentrations on cadmium, arsenic, copper and zinc have shown no consistent trends over time and that the higher concentrations of copper and zinc observed in 1990, fell to within the normal range in 1991.

Discussion and Critique of Monitoring Program for Metals Accumulation in Prawn

Inconsistent sampling over time, both in terms of species and catch stations impedes the interpretation of the data. As discussed above for the crab, before the various shrimp and prawn data can be pooled, they should be tested to ensure that there are not differences among species. This may have been done by Island Copper, however, the data were not presented.

The monitoring reports (ICM, 1992; 1993) provide time series data for shrimp/prawn tissue metal concentrations. However, the earliest data reported are for 1981, ten years after the discharge of tailings to Rupert Inlet began. These graphs then serve to demonstrate that there have been consistent metal concentrations in shrimp/prawn while the tailings discharge has been occurring. The absence of baseline data from these graphs limits the interpretation of the effects of tailings on metal concentrations in shrimp or prawn.

Several additional sites were sampled over time (Scott channel, a deep sea reference, Neurotsos Inlet, and Browning Inlet); however, no reference sites were sampled for shrimp or prawn consistently over time. Island Copper (1982) report that shrimp tissue metal levels are similar to those observed in Alice Arm and other coastal areas. Alice Arm may not, however, be an appropriate reference site due to the mining activity at the Kitsault mine (both by B.C. Molybdenum and AMAX). The location of the other coastal areas used for comparison was not provided.

Bivalve Tissue Metal Content

The butter clam (*Saxidomus giganteus*) and the littleneck clam (*Prothaca staminea*) were obtained from seven stations: three in Rupert Inlet, three in Holberg Inlet, and one in Quatsino Sound (ICM, 1995). Three to 6 replicates were collected from each station over time. Prior to 1993, several types of clam were analyzed for metal content.

Blue mussel *(Mytilus edulis)* were collected from one station in each of Rupert Inlet, Holberg Inlet and Quatsino Sound. Six replicates were collected from each station quarterly, in March, June, September and December post-1986; three replicated were collected pre-1986. Samples were also collected from Port Hardy and Winter Harbour from 1984 through 1994.

Arsenic, copper and zinc were graphed for the butter clam and the littleneck clam for the 1971 through 1994 (ICM, 1995). Arsenic in butter clam was reported to be the highest in Quatsino Sound during the sampling period. Concentrations of copper in the butter clam have been higher in Rupert Inlet in some years, but not all. Concentrations of zinc were greatest in Quatsino Sound for the 1994 monitoring year. No other trends were reported at any of the areas sampled.

Concentrations of zinc were also greatest in Quatsino Sound littleneck clam for the 1994 monitoring year. Tissue copper concentrations in littleneck clam also showed a general increase at all stations and concentrations were the highest in Rupert Inlet. Island Copper (1995) reported that no trends have developed in the data over the life of the monitoring program.

Island Copper (1995) reported that blue mussel tissue concentrations of copper have been greater at the Island Copper dock in Rupert Inlet compared to the two other sampling locations since sampling began in 1971, and cadmium concentrations have been greater at this location since 1985. In 1994, copper concentrations in blue mussel showed a general increase at all stations, however, Island Copper concluded that copper concentrations have been variable over time and no trend has emerged. The high concentrations of copper in the blue mussel at the Island Copper dock were attributed to copper concentrate from loading of ships.

Discussion and Critique of Monitoring Program for Metal Content in Bivalves

- The sampling effort for metal concentrations in bivalves appears to have been adequate to show some differences over time. For example, copper concentrations in both the butter and littleneck clam have shown increases in some years, substantially over even the 1971 values. Given the variability in the data, the probability of detecting a 20% difference in copper concentrations between the Rupert Inlet Station 4 (North Shore) and the Quatsino Sound Station 7 (Pamphlet Cove) was only 15% for a sample size of n=10 using the June 1994 data.

- Copper concentrations have been consistently greater in Rupert Inlet mussels compared to those collected in Holberg Inlet and Quatsino Sound. The concentrations in the mussels collected from the Island Copper dock were attributed to accumulation of copper spilled from concentrate loaded on to ships, rather than to copper in the tailings. Had Rupert Inlet been represented with a greater number of strategically positioned stations, then the hypothesis that the elevated tissue copper was associated with the concentrate rather than the tailings could be tested. Although the explanation offered is plausible and reasonable, the origin of the higher concentrations of copper (and cadmium) in the Rupert Inlet mussels can not be deduced further from the present sampling design.

- As discussed for other elements of the monitoring program, since the tailings were deposited in Quatsino Sound as early as 1977, this reference site may not have represented a truly unimpacted area. Ideally, a reference site should capture seasonal, yearly and other variability not attributed to the tailings for comparative purposes. No baseline data (pre-tailings disposal) appeared to be available to make comparisons in tissue concentrations pre and post tailings disposal.

Deep Water Clam Tissue Metal Content

The deep water clam *(Humilaria kennerleyi)* were collected by scuba diving from 1977 to 1988 either annually, semi-annually or quarterly. Generally, three samples were collected at Hankin Point (in tailings), with periodic sampling at Ilstad Island (Holberg Inlet) and Orr Island (Quatsino Sound). Samples were analyzed for copper, zinc, arsenic and cadmium. No samples were collected pre-1976, and the 1988 samples were lost due to a freezer breakdown.

Island Copper (1988) reported that none of the elements analysed showed any temporal trends and metal concentrations are similar to those found in Holberg Inlet and Quatsino Sound.

Discussion and Critique of Monitoring Program for Metal Content in *H. kennerleyi*

- As discussed for other elements of the monitoring program, the sampling effort for *H. kennerleyi* was inconsistent over time in sampling at Hankin Point, and in the sampling of a reference station. No baseline data are available to facilitate comparison of conditions pre and post tailings disposal.

7.4.1.2 Population Assessment

Dungeness crab *(Cancer magister)* population was monitored annually from 1970 to 1994, in Rupert Inlet (3 sites), Holberg Inlet (2 sites), and Quatsino Sound (1 site). Two baited traps were set at each station for 18 hours. All crab collected were identified weighed, measured, and sex determined. Three legal sized specimens were retained from each station for metals analyses. The objective of this exercise was to monitor population dynamics.

Owing to the sampling method, 50% of the population sampled was comprised of crab in the 16-18 cm group (ICM 1995). No crab smaller than 14 cm can be caught with the commercial traps used as they allow smaller crab to escape. Island Copper (1995) report that the commercial crab catch has not diminished over the 25 year period of mine tailings disposal.

Discussion and Critique of Monitoring Program for Population Assessment

- As discussed for the crab tissue metal concentration monitoring, Rupert Inlet was represented by three sampling locations, two of which intuitively appear to reflect areas not impacted by tailings. Core sediment analyses confirmed this suspicion. Therefore the three stations within Rupert Inlet do not reflect tailings impacted areas.

These results also reflect lack of an *a priori* testable hypothesis. If the null hypothesis was stated to be 'there is no effect of tailings deposition on crab population', then this statement would have provided direction to select stations in the tailings impacted areas of Rupert Inlet.

7.4.2 Recommendations for Additional Biological Parameters

The monitoring program should be developed prior to tailings discharge so that baseline data can be collected for all parameters. Baseline data, different from reference data, provides the only information on whether effects have occurred in the tailings impacted area, in this case Rupert and Holberg Inlets, due to tailings deposition. Baseline data collection should be focused on the areas of expected tailing deposition. The reference data in not collected from the tailings impacted area (Rupert and Holberg Inlets), it is collected outside these areas and provides information on seasonal and yearly variation.

Efforts should be made to consistently sample the same reference site at each sampling event. Tailings were not expected to enter into Quatsino Sound, but when they were documented there, the Pamplet Cove station became another 'test' station and not a reference station. Furthermore, efforts should be made to use reference stations such as Koprino or Winter Harbour, that would be expected to represent annual and seasonal variability in the area. The use of reference stations that could be contaminated with the same or other chemicals or be subject to other stressors (fishing, differences in habitat) should be avoided.

The statement of testable hypothesis should be made in the development of the monitoring program. These statements should then be used to guide the selection of sampling stations in the area of potential impact, and in the reference area. Hypothesis testing in conjunction with power analysis should also be used to guide the selection of sample sizes for each parameter under investigation. The data should also be subject to follow-up tests, and the monitoring program adjusted should the variability be greater than expected.

7.5 Benthic Infaunal Monitoring and Biological Recovery of Deposited Tailings

7.5.1 Considerations Surrounding Recovery of Deposited Tailings

Recognizing that STD discharges will smother both habitat and organisms within the path of the density current, topics of key interest are the likelihood and degree to which the benthos will recover, and the timeframe over which this occurs.

Benthos *recovery* has also been interchangeably described as *recolonization* and it is important to develop an operational definition for communication purposes and also define other related concepts. We suggest *recovery* refer to the *progressive nature* of the newly deposited abiotic sediments (tailings) to become inhabited over time and develop in terms of organism abundance, diversity and biomass. The key concept here is the progressive nature of the development. *Succession* refers to the predictable changes from low to high diversity over the course of recovery. The term *community stabilization* is used to describe the final phase of recovery where benthos abundance, diversity, biomass and spatial homogenity have all achieved a degree of consistency (stabilization) reflective of the native site. However, this "stability" is likely to be characterized by large fluctuations over time, reflective of the dynamic competition for benthic habitat and food resources. The term *recovery* is preferred over the term *recolinization* in that the latter suggests a return to the *original* benthic *faunal assemblage*, or species composition which is unlikely to occur. We suggest the use of the term *colonization* to refer to the act of an organism taking up residence within the newly deposited sediment. Thus, recovery of deposited tailings is the extended and repeated process of colonization, and culminates in a community stabilization.

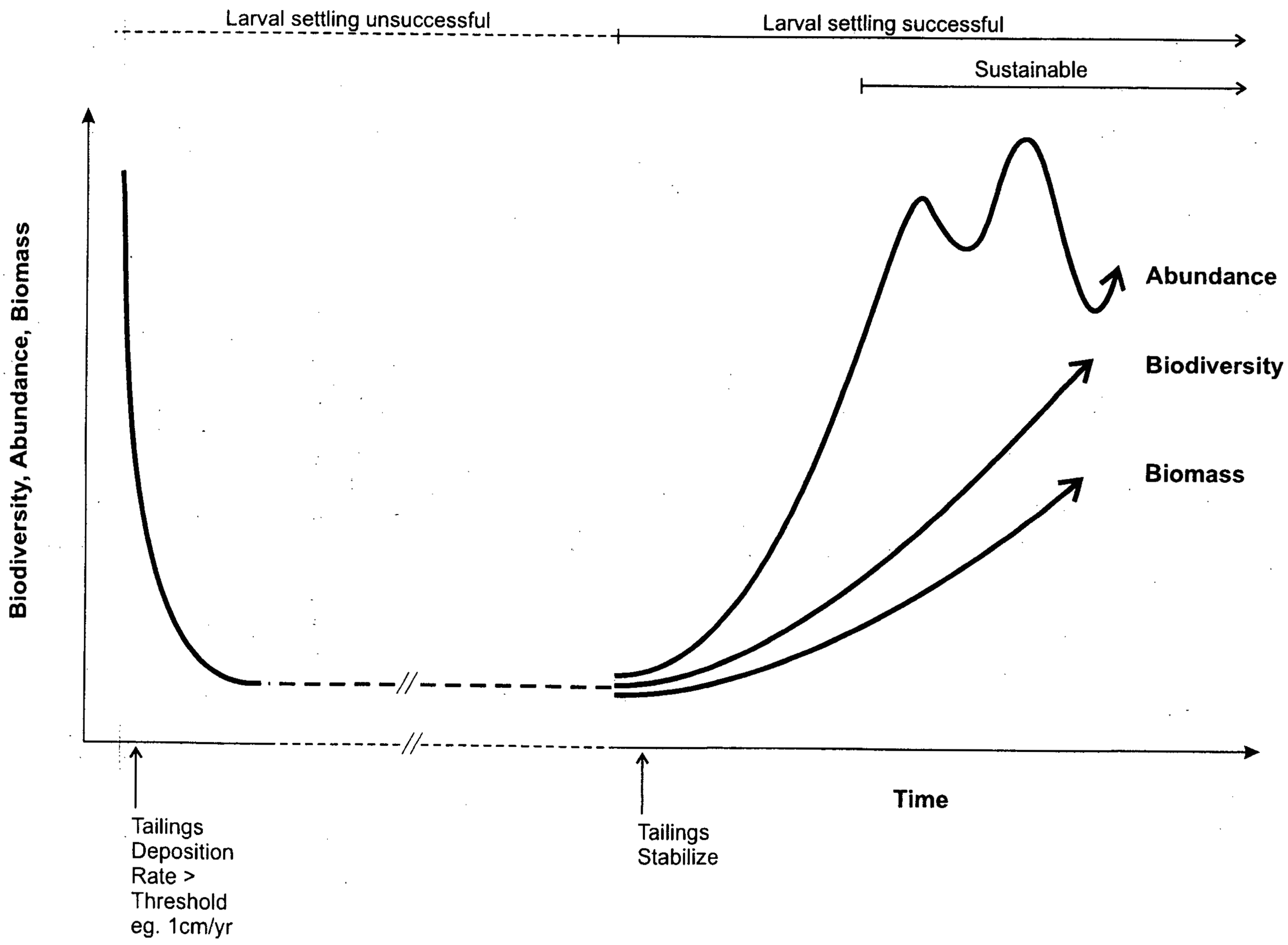
It should be noted at this stage that the community which ultimately results following an STD operation is likely to be different from the pre-operation era in terms of the faunal assemblage. In many cases this can be deduced simply from first principles. For example, if the benthic substrate has been changed from a rocky or coarse gravel bottom to one of a soft muck resulting from tailings, the habitat will have changed dramatically for microinvertebrates and consequently the infaunal and epifaunal assemblages will take on a new profile. This does not, however, infer that *all* species will be replaced. Some species, perhaps more plastic with regards to habitat needs may take up residence in the new habitat providing the essentials for survival (e.g., food source, shelter etc.) are met.

Finally, it should be noted that although the original faunal assemblage may not be achieved (i.e., restored), the new community may continue to support key higher order organisms which may be important socio-economically (e.g., crab fishery, bottom fish, etc.).

These principles are illustrated in Figure 7-9, which shows the conceptual relationships of benthic faunal abundance, diversity and biomass as a function of time. The graph illustrates a fairly quick elimination of benthic community due to the physical impacts of the density current (i.e., tailings deposition greater than the tolerance threshold of benthic invertebrates, > 1.0 cm/yr). In this example the impact is shown to be nearly complete (i.e., reduction of community parameters to near zero) but it may simply be a marked reduction rather than elimination, depending on the point of reference to the density current. Note that larval settling becomes successful when tailings have stabilized.

Note *abundance* is the first parameter to respond during the *recovery phase*. This is reflective of the establishment of opportunistic species (e.g., certain polychaete species) which proliferate, but do not appreciably influence the diversity or biomass parameters. Initially the abundance of these opportunistic species will increase relatively rapidly as little or no competition for resources exists. As time progresses and the colonization of the sediment proceeds new species become established, reflective of an increasing diversity (successional change). As new species compete with the original opportunistic species a net decline in abundance will occur as the community moves from numerous simple organisms to fewer but more complex and dense species (e.g., higher trophic levels, molluscans, echinoderms, crustaceans, etc.). Ultimately a dynamic plateau is anticipated where species diversity, abundance and biomass become more stable although fluctuations will continue to occur. As the area over which this condition increases

PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-04-96 FILE LOCATION: J:\9521928\0396\FACTORS.CDR



Golder Associates

CONCEPTUAL RELATIONSHIP OF TAILINGS COLONIZATION IN TEMPERATE REGIONS

Figure
7-9

(i.e., increase in spatial homogenity of community) the ecosystem community is regarded to be more stable (Burd and Ellis, 1995).

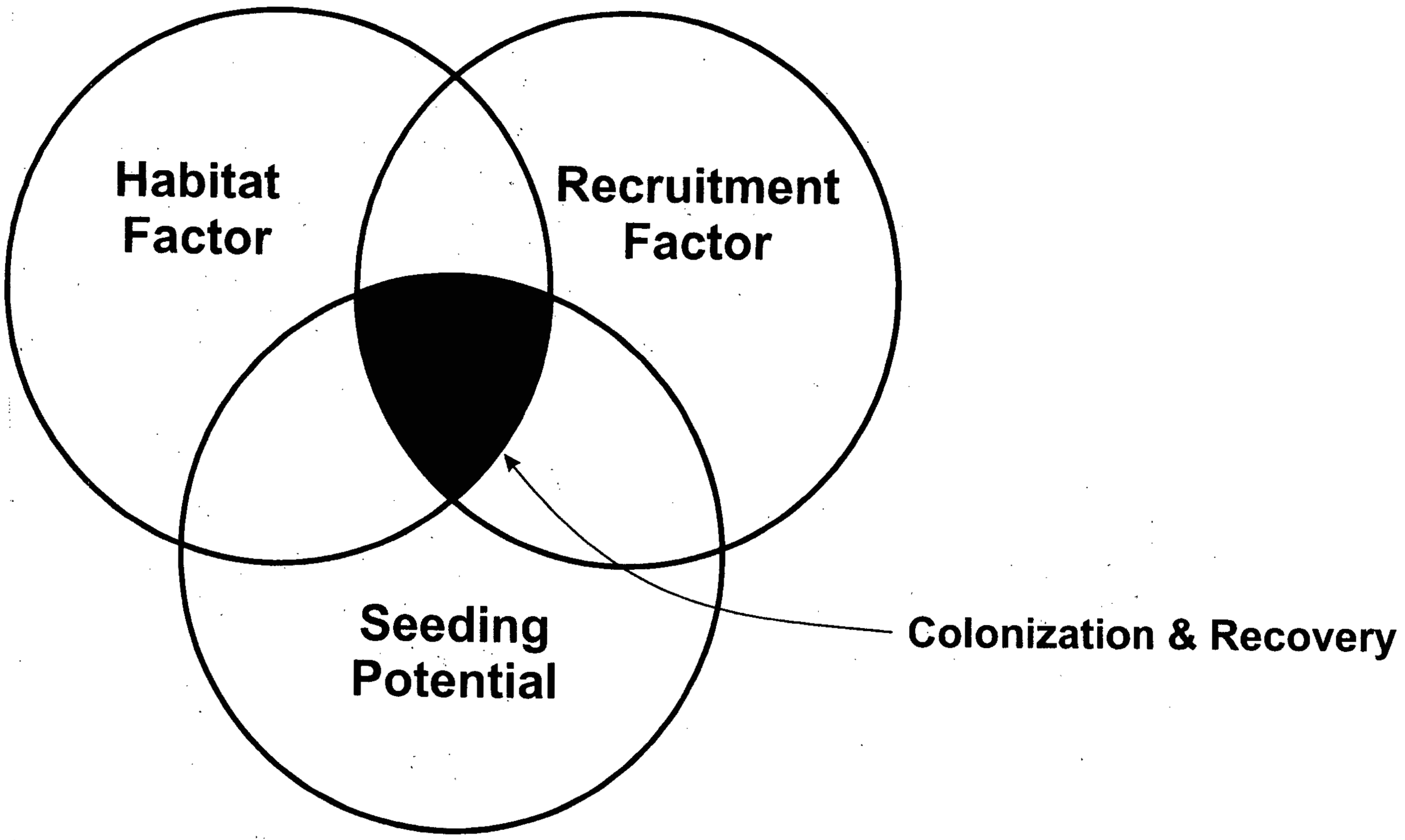
7.5.2 Factors Governing Biological Recovery of Deposited Tailings

Figure 7-9 is conceptual in nature and therefore simplistic. In reality the recovery of new tailings is not as predictable and smooth as the illustration would suggest and the highly variable data from benthic studies at Rupert Inlet (ICM) reflect this well (Burd and Ellis 1995). Additionally, there is a lack of data to suggest that a stable and homogenous community has been achieved at any of the contemporary STD operations (although the presence of key species suggest succession is occurring). This is, in part, due to insufficient time for recovery to proceed, and lack of comprehensive data from all sites.

Prediction of the recovery phase is complicated by numerous factors which govern the establishment and survival of new species within the benthic community of tailings sediments. Through discussion with experts in the field (Ellis, Burd, pers. com.) we have characterized three biological requirements which are essential for recovery of sediments to proceed; these include: (i) *acceptable habitat*, (ii) *larval seeding potential*, and (iii) *recruitment* (Figure 7-10). Exclusion of any one of these factors will prevent either the initiation or the long-term recovery of the benthic community. Each of these essential factors can be further described by their determinants and these are illustrated in an influence diagram (Figure 7-11).

An acceptable habitat is determined by three factors which include the adequate provision of *food*, an acceptable *physical environment* on, or in which to reside, and an *acceptable chemical environment* in which to reside. At the initiation stage of recovery, food may simply be defined by the rate of organic carbon deposition onto the tailings. The physical substrate in this case will be a soft muck, and will be influenced by the particle size distribution of the tailings, the current and tidal actions present, the rate of continued burial by suspended tailings deposition, and the physical stability of the sediments (e.g., propensity to slumping), as previously described in Section 5. The acceptability of chemical environment includes influence of metals and nutrients and oxygen in the dissolved phase both at the sediment-water interface and within the porewater as previously described in Section 6.

PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-04-96 FILE LOCATION: J:\9521928\0396\FACTORS.CDR

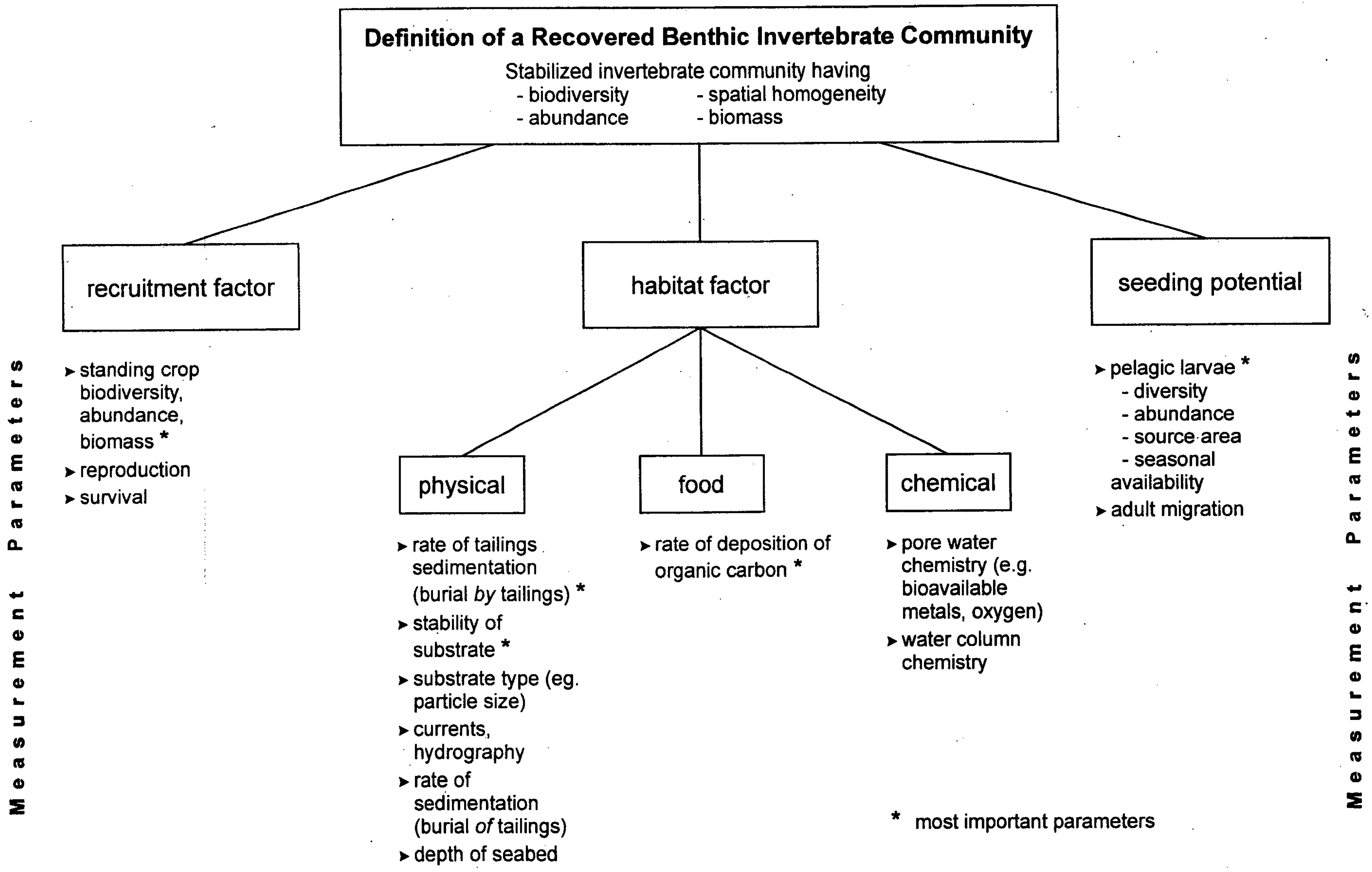


Golder Associates

KEY FACTORS INFLUENCING COLONIZATION OF TAILINGS BEDS

Figure 7-10

PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: MAR-04-96 FILE LOCATION: J:\9521928\0396\FACTORS.CDR



Golder Associates

FACTORS INFLUENCING COLONIZATION OF TAILINGS BEDS

Figure 7–11

Seeding potential refers to the potential for organisms to physically access the new tailings and this may be achieved through settlement of pelagic larvae of benthic species, or through arrival of motile adult species. At the initiation stage, larval seeding is far more important and is governed by the concentration of larvae in the water column, general productivity of the regional waters and prevailing currents which deliver the larvae to the site (Ellis, in press).

Recruitment refers to the concept of the in situ benthic community contributing new individuals to the population. Although an acceptable habitat and seeding potential may exist to initiate colonization, long-term recovery requires the established organisms to survive, reproduce and develop a standing crop of animals. This is the element of self propagation, without which the community cannot advance beyond the dependency for external sources of individuals, most of which are larvae.

7.5.3 Results of the Benthic Infaunal Biodiversity Monitoring Program at Island Copper

7.5.3.1 Biological Parameters Monitored, Objectives and Effects Reported

Parameters

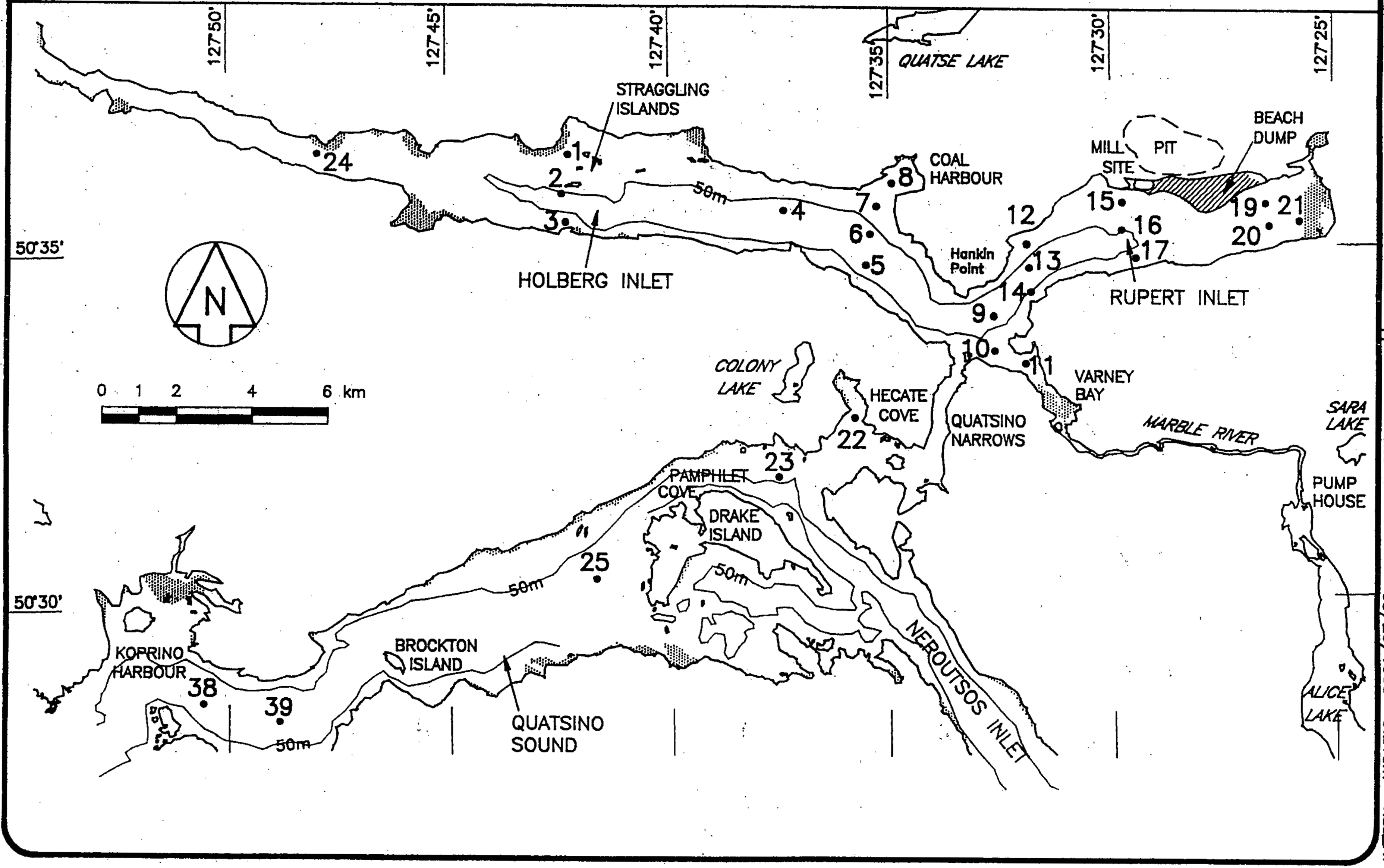
Parameters monitored by Island Copper include benthic infaunal diversity and abundance. The monitoring included collection of benthic samples at 26 stations annually, first order identification of the samples, and collection of 3 samples at each of the 26 stations for detailed identification at the species level. A summary of the Island Copper benthic organism monitoring plan is included as Table 7-6. Sampling station locations for these parameters are shown in Figure 7-12.

Objectives

The objective of the Island Copper monitoring program was to conduct sampling and analyses which would enable comparative impact analysis of deposited tailings on infaunal community assemblages:

i) between stations,
ii) between Rupert Inlet versus Holberg Inlet versus Quatsino Sound; and
iii) between baseline conditions and conditions during/following the mine operation.

Island Copper Submarine Tailings Monitoring Program



Cad No. C0591 5 P11 Island Copper Job No. 269-1 09/26/1995- 9:21am RES_AV

Project No. 952-1928
Drawn -
Reviewed S.A.P.
Date Mar. '96

Golder Associates

ANNUAL BENTHOS SAMPLING STATION LOCATIONS (FROM ICM, 1995)

Figure
7-12

TABLE 7-6
Marine Monitoring Program
Benthic Infaunal Diversity and Abundance

	Description	Frequency	Objective
BIOLOGICAL (ANIMALS) Benthic Organisms	Collect benthic organisms at 26 stations; sort to polychaetes, molluscs and others aboard ship for live counts and biomass.	Semi-annually (1977)	Monitor benthic population
	At 26 stations collect benthic samples for first order identification and diversity study.	Annually (1978-1981)	Monitor benthic population and diversity.
	At each of 26 stations collect 3 samples for detailed identification and biomass.	Annually (1983-1994)	Monitor in detail, change in benthic communities.

TABLE 7-7
Marine Monitoring Program - Zooplankton Analyses

	Description	Frequency	Objective
BIOLOGICAL (ANIMALS)			
Zooplankton	At 4 sites collect zooplankton for density, diversity and metal analysis. Identify various larvae of crabs, clams, mussels, etc. Metals include Cu, Mo, Cd, Pb, Zn, As & Hg. (Hg not done in 1994)	Quarterly (1970-1983, semi-anually from 1984)	Monitor population changes and metal concentration.

TABLE 7-8
ICM Monitoring Program
Zooplankton

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Zooplankton																								
Population	○	○	○	○	○	○	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Metal Content	○	○	○	○	○	○																		
Cu		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Mo		●	●	●	●	●	●	●	●	●	●	●	●	●	·	·	·	·	·	·	·	·	·	·
Pb		·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Zn		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Cd		●	●	●	●	●	●	●	●	●	●	●	●	●	·	·	·	·	·	·	·	·	·	·
As		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	·	·	·	·	·
Hg		●	●	●	●	●	●	●	●	●	●	●	●	●	·	·	·	·	·	·	·	·	·	·

○ Note: Reports pre-1977 were not available for review by Golder (data obtained from later graphs)

Notes for Metals:

· Metals analyzed, but no discussion of statistical analyses in ICM (1995)

● Metals analyzed, and discussion of statistical parameters in ICM (1995)

TABLE 7-9
Marine Monitoring Program - Plants

	Description	Frequency	Objective
MARINE PROGRAM **BIOLOGICAL (PLANTS)** Primary Production Study			
Phytoplankton	At 7 stations collect a composite water sample from surface to 5 m	Weekly Apr-Oct 1986-90	Monitor population for dynamics
Euphotic Depth Survey	At 7 stations, measure amount of light attenuation and scatter at depth.	- Monthly 1977 - Monthly Apr-Oct, 1978-82, 1986-93 - May,July,Sept 1983 - out of service 1984/85 - June and Sept 1994	Record depth of photozone in the water column.
Chlorophyll "a"	At 7 stations collect sample for chlorophyll "a" standing crop.	- Monthly 1977-84 - Apr-Oct 1985 - Weekly Apr-Oct 86/87 - Monthly Apr-Oct 88-93 - Monthly May-Oct, 1994	Record standing crop of primary producers in water column. (biomass determination)
Intertidal Plate Study	At 16 sites artificial substrate samplers set for continuous monitoring of flora and sediment deposition.	- Monthly 1977 - Jun,Aug,Oct 1978 - Mar,Jun,Aug,Oct 79-85 - bimonthly, Mar-Sep 86-94	Monitor settling flora and fauna in intertidal zone.
Metal Analysis of Fixed Algae	At 16 sites Fucus and Zostera are collected and analyzed for metal analysis (Cu, Mo, Cd, Pb, Zn, As, Hg). (Hg not mentioned in 1994)	- Quarterly 1977-80 - anually 1983-1994	Monitor metal concentration in sessile macrophytes.
Discrete Water Sample for Nutrients	Collect water samples at 6 stations for nutrients (silicates, nitrates, phosphates).	Monthly (1977 only)	Record nutrient levels in water column.
Carbon^{14}	At six stations monitor the assimilation rate of primary producers.	Monthly, April-Oct (1977-82, 1985)	Record assimilation rate of primary producers.
Macrophyte Study	At 3 sites detailed samples of flora and fauna.	Annually	Monitor plants and animals in the littoral communities and sub-littoral zone.

TABLE 7-10
ICM Monitoring Program
Primary Production Study (Plants)

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Phytoplankton	o	o	o	o	o	o	-	-	-	-	-	-	-	-	-	W	W	W	W	W	-	-	-	-
(population dynamics)																-------------Apr-Oct-------------								
Euphotic Depth Survey	o	o	o	o	o	o	M	M	M	M	M	M	M	-	-	M	M	M	M	M	M	M	M	M
(photozone depth)									-------Apr-Oct----------				Ma/ Jun/Se			------------------------Apr-Oct------------------------								Ju/Se
Chlorophyll "a"	o	o	o	o	o	o	M	M	M	M	M	M	M	M	M	W	W	M	M	M	M	M	M	M
(biomass determination)															----------------------------Apr-Oct----------------------------									Ma/Oc
Intertidal Plate Study	o	o	o	o	o	o	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
(settling flora/fauna)								Jun/ Au/O	-------------Mar/Jun/Au/O--------------------							---------------------------Mar/Sep---------------------------								
Metal Analyses	o	o	o	o	o	o	Q	Q	Q	Q	Q	Q	Q	Q	Q			A	A	A	A	A	A	A
(fixed algae)																								
Nutrients	o	o	o	o	o	o	M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(in water column)																								
Carbon 14	o	o	o	o	o	o	M	M	M	M	M	M	-	-	M	-	-	-	-	-	-	-	-	-
(assimilation rate)							-----------------Apr-Oct---------------								Ap-Oc									

o	Note: Reports pre-1977 were not available for review by Golder
-	Not reported in Outline of Monitoring Program
W	Weekly anaylses
M	Monthly analyses
Q	Quarterly analyses
A	Annual analyses

Burd and Ellis (1995) provide the most recent review of benthic surveys from 1970 to 1992. The testable hypotheses which were examined were as follows:

1) Faunal composition in any given year was homogeneous throughout the Rupert system (i.e., species diversity/composition did not differ among Rupert Inlet sampling stations);

2) Faunal composition within selected stations did not change significantly over the study period."

The effort invested in this aspect of the monitoring program was large and this aspect of the program is a key feature providing insight to the issue of benthos recovery. It is particularly valued because of the potential to test hypotheses.

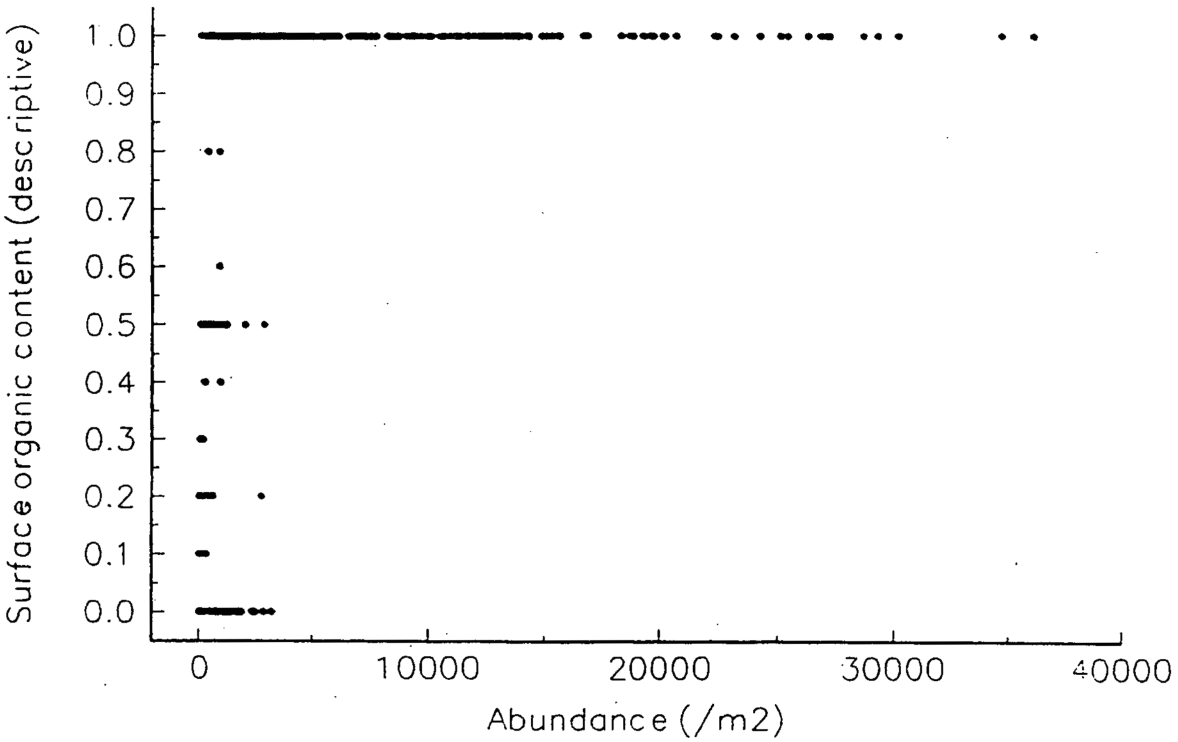
Effects

Effects of mining operations on the benthic community based on Island Copper monitoring data over the period 1972 to 1992 were recently reviewed and reported by Burd and Ellis (1995) and are discussed below as items one through ten. Additional related studies by Taylor, (1986) and Bright (1991) are discussed as items 11 and 12, respectively.

1) A subjective coded assessment of organic content on surface sediment plotted against abundance data shows a clear association of higher organism abundance with "organic-rich" sediments (Figure 7-13). It was concluded that despite the descriptive and subjective nature of the data, organism abundance is much higher in areas with organic debris.

2) Burd and Ellis (1995) reported that there was no clear relationship between the sediment copper levels and abundance, number of taxa and juvenile abundance, as shown in Figure 7-14. This is consistent with current observations for many contaminated sediments and effect levels (e.g., Puget Sound Criterion). However, it is noted that the highest abundance, number of taxa and abundance of juveniles is generally found in sediments where copper concentrations in the solid phase are less than 400 ppm.

3) Increasing tailings thickness is associated with a declining trend in faunal abundance, species richness and juvenile abundance (Figure 7-15). It is likely that this is a reflection of long term deposition (hence the tailings thickness) and only recent trend towards recovery.



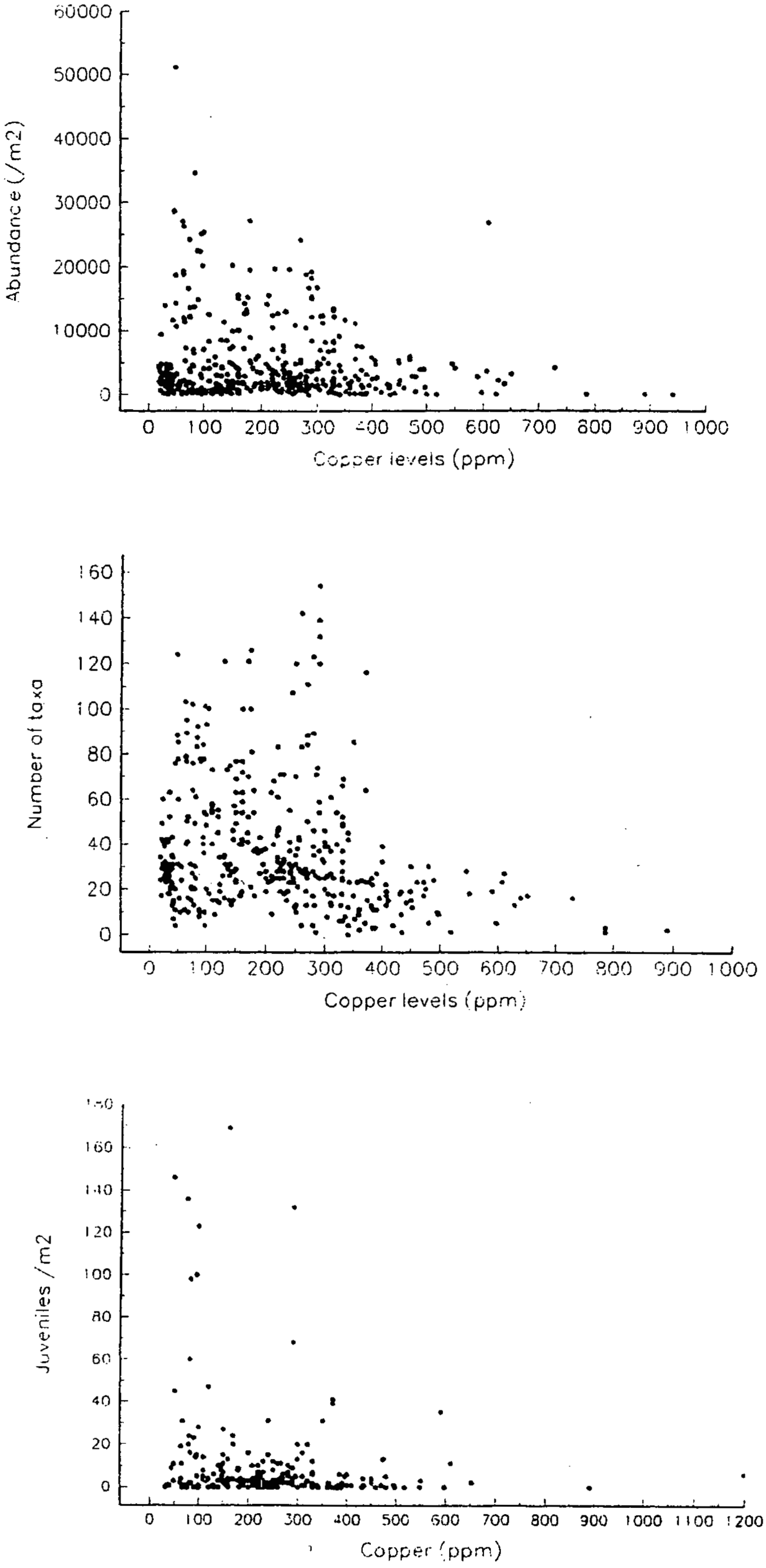
Project No. .... Drawn .... Reviewed .... Date ....

Golder Associates

SURFACE ORGANIC CONTENT VS ABUNDANCE (FROM BURD AND ELLIS, 1995)

Figure

7-13



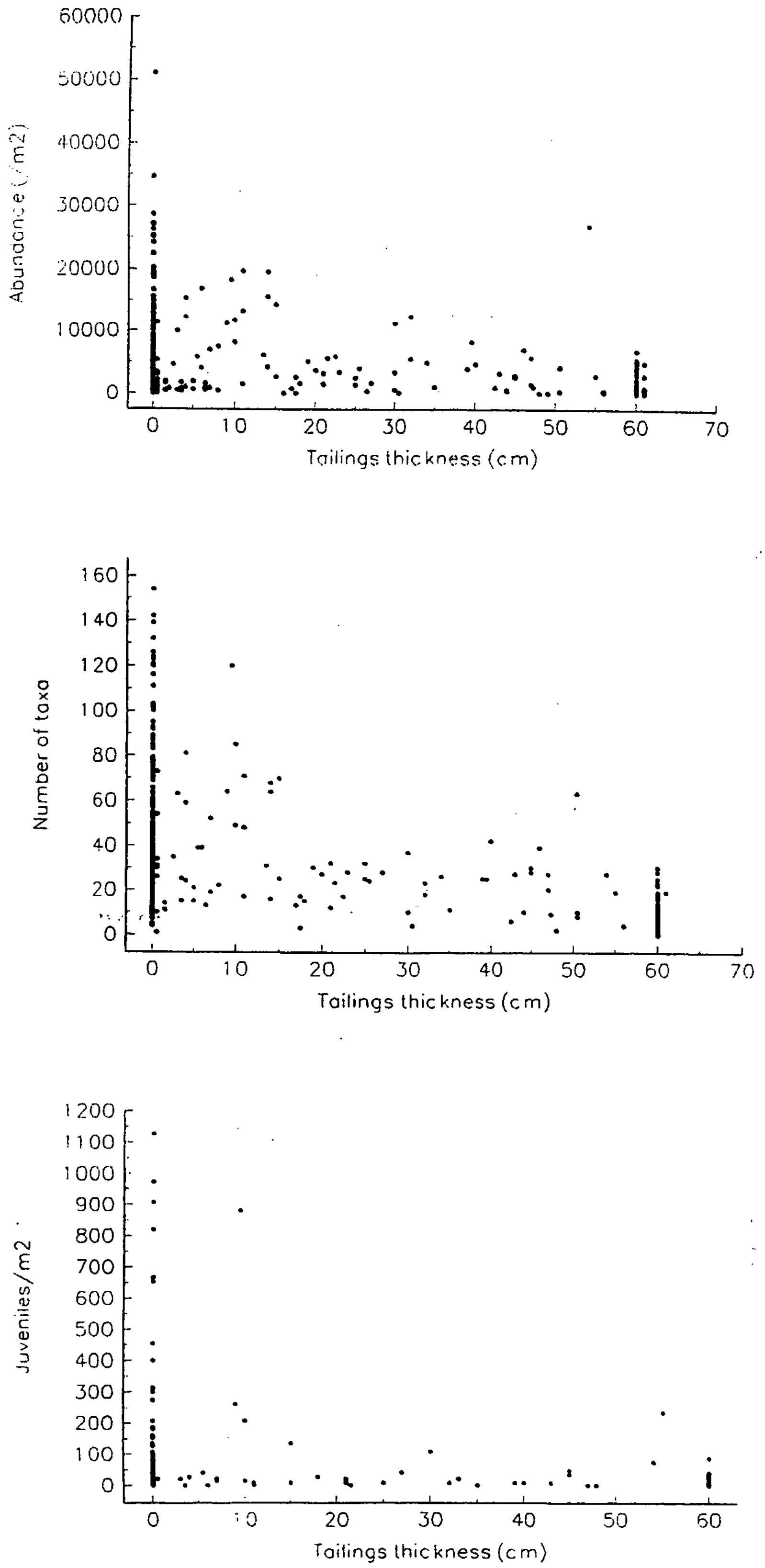
Project No. .... Drawn .... Reviewed .... Date ....

Golder Associates

ABUNDANCE, TAXA AND
JUVENILE ABUNDANCE PLOTTED AGAINST
SEDIMENT COPPER LEVELS
(FROM BURD AND ELLIS, 1995)

Figure

7-14



Project No. .... Drawn .... Reviewed .... Date ....

Golder Associates

FAUNAL ABUNDANCE, SPECIES RICHNESS AND JUVENILE ABUNDANCE PLOTTED AGAINST TAILINGS THICKNESS (FROM BURD AND ELLIS, 1995)

Figure

7-15

4) Areas with the thickest tailings, and therefore the highest deposition rates were at stations 13, 15, 16, 17. These stations show consistent low abundance over time, and low variability over time. A recent "trend" towards increases in abundance has been observed from 1988, as shown in Figure 7-16.

5) In deep stations (stations 4, 5, 6, and 9) located further away from the outfall than those noted above, but still characterized by heavy deposition, the abundance varied considerably from year to year without a positive trend, as shown in Figure 7-16.

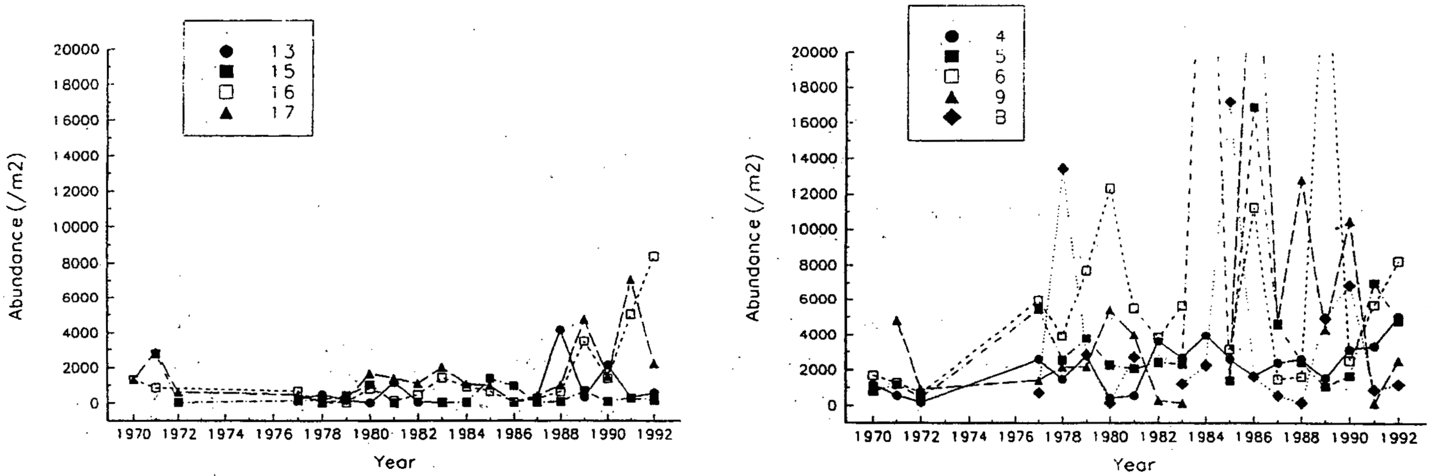
6) Data for mid-depth stations (stations 2, 3, 14, and 19 at depths of 50 to 100 m) are shown in Figure 7-16. The abundance at these stations was fairly low over time with a recent increasing and fluctuating trend at station 14, which had the highest tailings deposition among this cluster of stations. Increased abundance at this station was reported to be due to 1 or 2 opportunistic species.

7) In shallow stations (12, 20, 21, 22, 1, 7, 8, 10, and 11) of less than 50 m depth, a sharp decrease was observed at the outset of mine operations. A sharp increase occurred in 1979, with increasing abundance and yearly variations in the last 15 years (Figure 7-16).

8) Reference sites (Stations 23, 24, and 25) showed the same decline in abundance in year number 1 of operation (Figure 7-17) although this may be an artifact of sampling effort. Maps outlining the extent of tailings in sediments do not suggest these stations received tailings deposition in 1972 (Figure 7-18). Therefore, this initial decline is likely a reflection of a sampling effort which differed from the previous year (i.e., artifact of sampling), but does not appear to be related to mine operations.

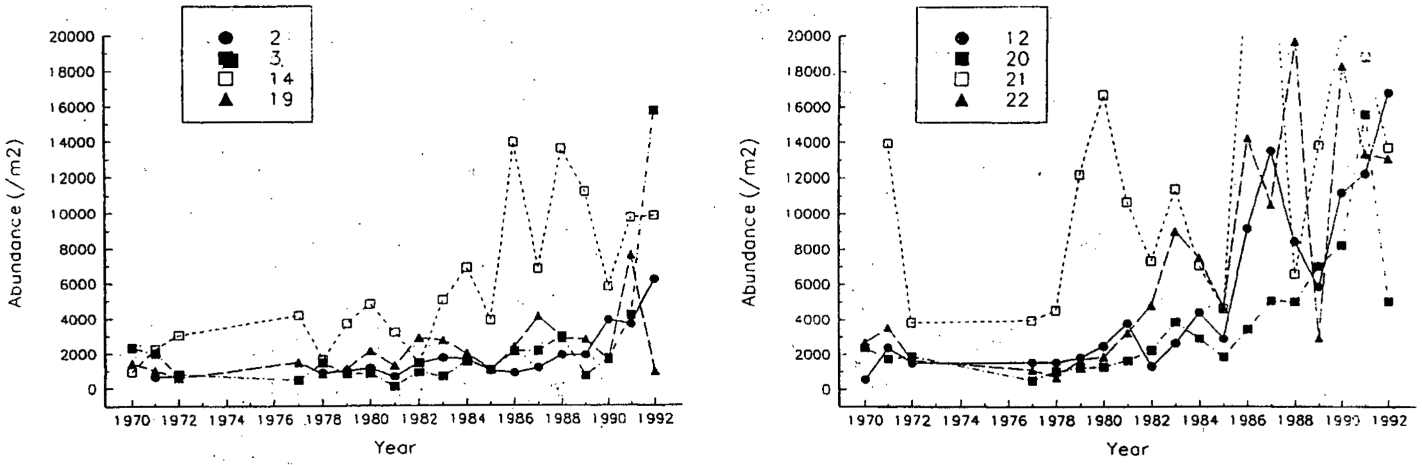
9) The proportion of taxa that are juveniles is shown to increase over time in Figure 7-19. This infers the benthic assemblage became progressively younger over time because there were more juveniles. This is suggestive of communities in the recovery phase wherein the organisms in the community are mostly juveniles derived from larval settlement rather than adults derived from immigration.

10) Following mine closure, Burd and Ellis (1995) anticipated that stable tailings will allow colonization of benthos within a two-year period, with high abundance and benthic diversity. Composition of fauna is expected to be different in areas with heavy tailings deposition compared with areas of light deposition and control areas for a period of over 5 years. The similarity gradient/analyses conducted by Burd and Ellis show that the baseline community structure was fairly homogeneous throughout the system but has since become relatively heterogeneous. In recent years (1990 to 1992) faunal homogeneity has increased



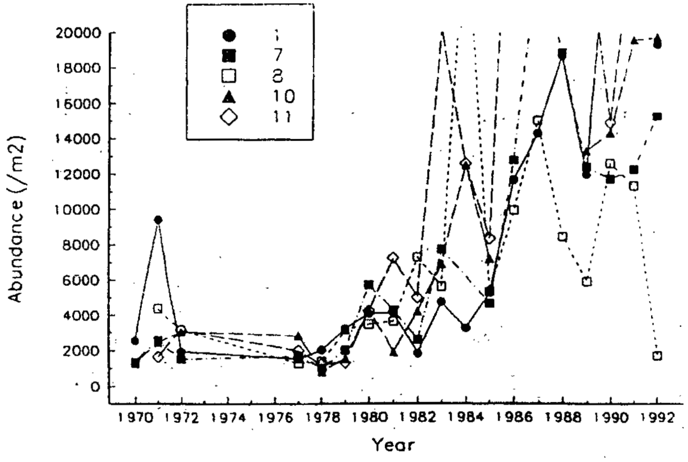
THICKEST TAILINGS

DEEP



MID-DEPTH (50-100m)

SHALLOW



SHALLOW

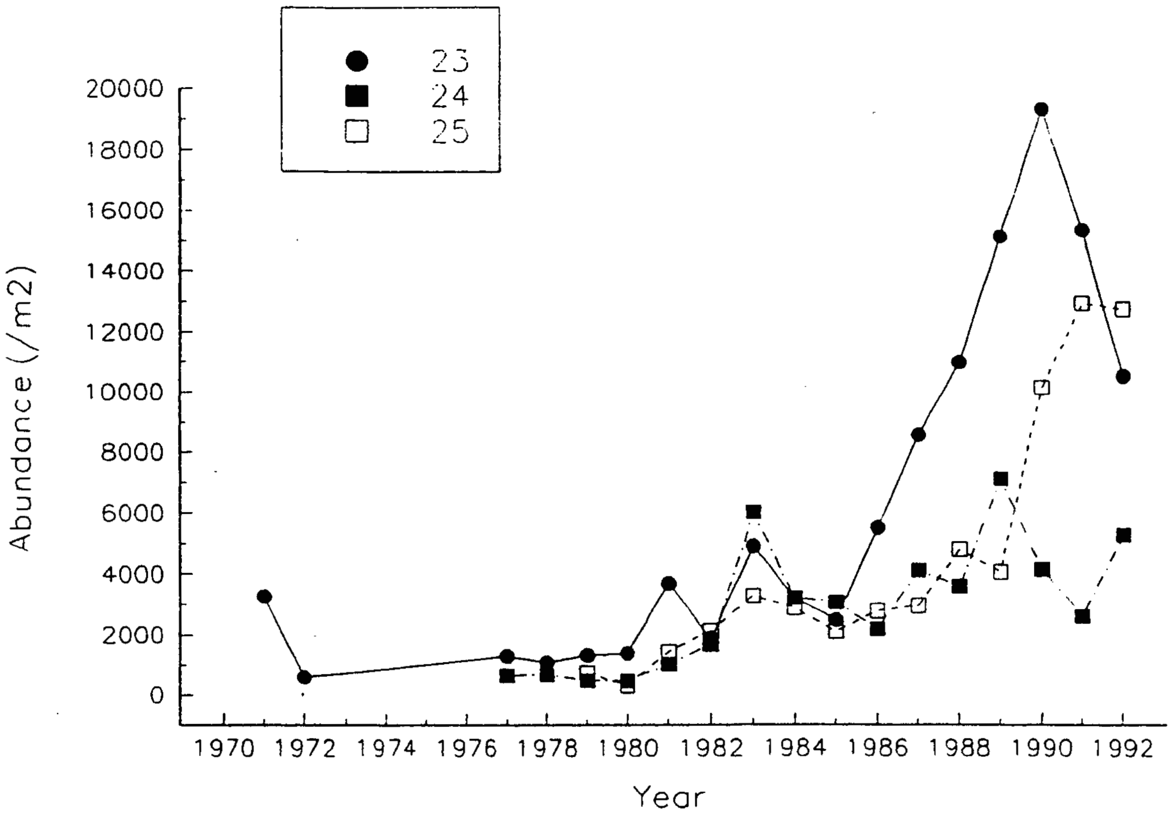
Project No. .... Drawn .... Reviewed .... Date ....

Golder Associates

ABUNDANCE AT DEEP, MID-DEPTH & SHALLOW STATIONS (FROM BURD AND ELLIS, 1995)

Figure

7-16



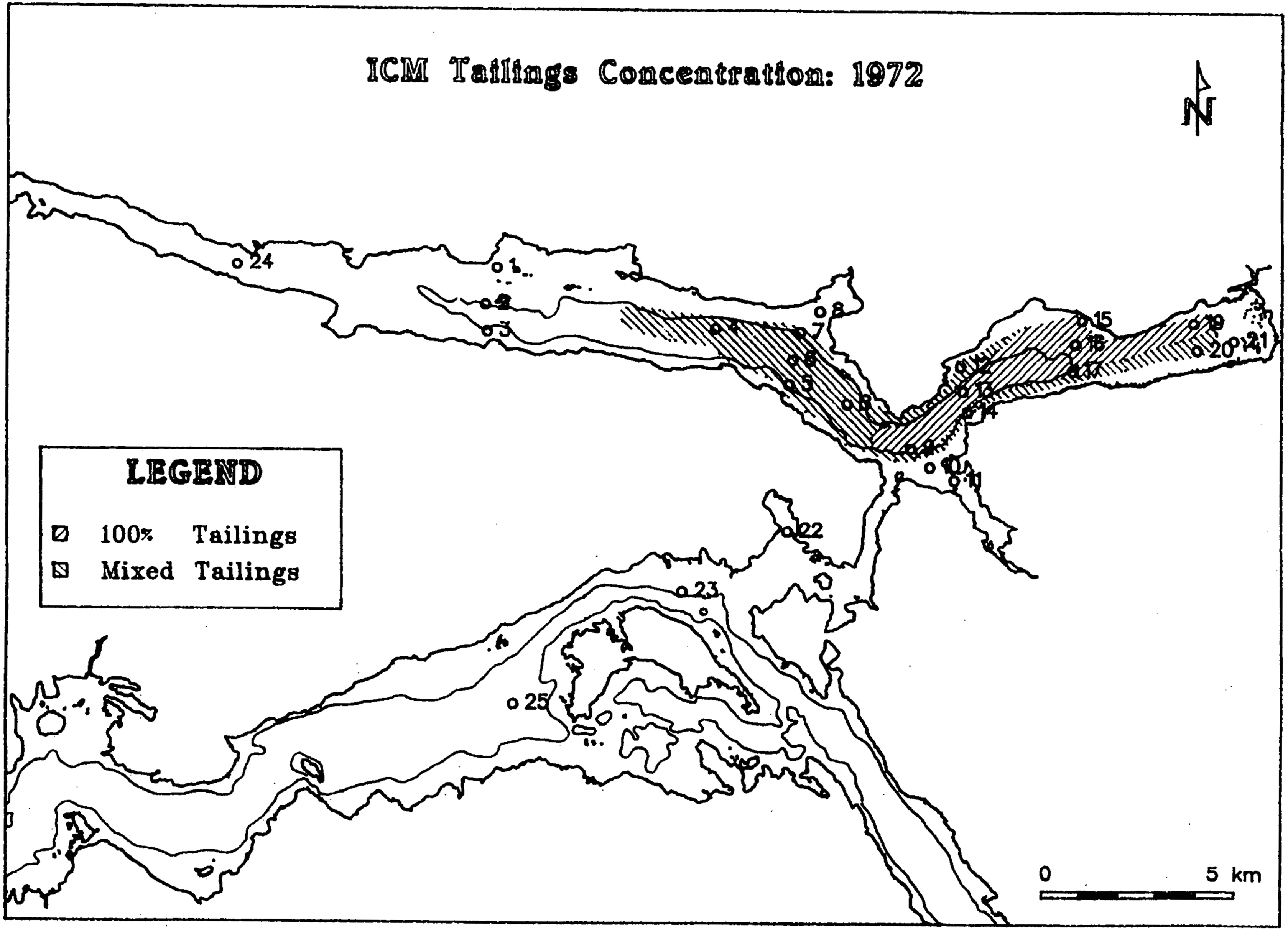
Project No. .... Drawn .... Reviewed .... Date ....

Golder Associates

ABUNDANCE AT REFERENCE SITES (FROM BURD AND ELLIS, 1995)

Figure

7–17

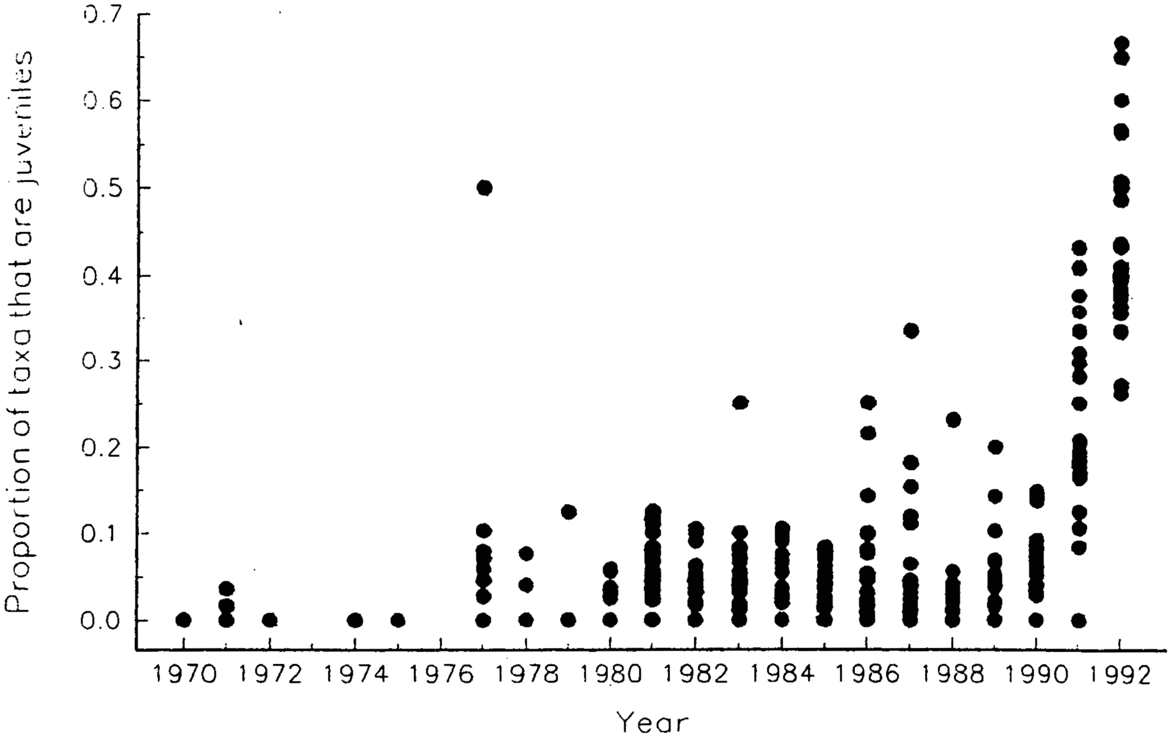


Project No. ....
Drawn ....
Reviewed ....
Date ....

Golder Associates

ICM TAILINGS CONCENTRATION: 1972
(FROM BURD AND ELLIS, 1995)

Figure
7–18



Golder Associates

PROPORTION OF TAXA THAT ARE JUVENILES (FROM BURD AND ELLIS, 1995)

Figure **7-19**

Project No. .... Drawn .... Reviewed .... Date ....

somewhat, presumably due to adaptation of the faunal assemblage to the high sedimentation conditions. With the recent closure of the mine, this will presumably change the sedimentation conditions again (i.e., decrease) and possibly destabilize the currently adapted faunal assemblage.

11) An artificial substrate apparatus containing tailings and control substrates was used to examine macrobenthic colonization (Taylor, 1986) over a period of two to 12 months. An artificial container with tailings and control substrates placed alternately was used. The container had three sides, which allowed entry and colonization from the open end by lateral benthic invertebrates. Additionally, colonization could occur by settlement of pelagic larvae. The study showed that tailings became colonized at a slower rate than the control substrate, and this occurred primarily by larval settlement rather than by adult immigration.

12) Bright (1991) investigated the potential of using the marine infaunal bivalve, *Axinopsida serricata,* to monitor biological impacts from mine tailings. *A. serricata* is a numerically dominant bivalve in numerous near-shore, silt-clay benthic communities of the northeast Pacific, is tolerant of stress and is also dominant in stressed environments including areas undergoing seasonal anoxia in bottom waters (Bright, 1991). *A. serricata* is one of a limited number of infaunal invertebrates that is abundant in areas of active tailings deposition in Rupert Inlet and has also been found in tailings-impacted areas at Anyox, Britannia, Tasu and Wesfrob mines. It is considered to be an early colonizer and is expected to play a role in succession upon cessation of mine tailings discharge.

Bright (1991) measured histopathology, fecundity, growth, and abundance of *A. serricata* along a gradient of tailings impacted areas in Rupert and Holberg Inlets. Several histopathological effects were noted in *A. serricata* associated with mine tailings in Rupert and Holberg Inlets, and effects were greater in areas of high tailings deposition. Digestive tubules, digestive ducts, mineralized granules in the kidney, tertiary lysosomes in stomach epithelial cells and ctenidial cells exhibited variation, both seasonally and across stations. The seasonal effect in tissue variability was attributed to reproductive status.

Bright (1991) reported that fecundity, growth and abundance of the bivalve *A. serricata*, although apparently influenced by tailings, did not parallel the dose-response relationship seen for the histopathological effects. In fact, fecundity appeared to increase with dose, with percent volume of oocytes in follicles being greater at sites located closer to the outfall. Bright noted several authors that had previously reported increased fecundity in bivalves under stress.

There was no apparent influence of tailings on growth of *A. serricata*. Although growth at some stations in Rupert Inlet was less that Holberg or reference stations, the difference was attributed to a variation in substrate particle size, rather than the tailings *per se*.

A decrease in abundance of *A. serricata* was reported for the Holberg Inlet station closest to the outfall. Bright reported that although this decrease may be attributed to tissue lesions, citing a complete lack of early age classes, he reported that the principle mechanism of population decline at this station was due to recruitment failure.

Despite both the histopathological effects and recruitment failure at the Holberg Inlet station, Bright (1991) reported that there were no apparent population level effects on fecundity, growth or abundance in *A. serricata.* Bright suggested that the lack of population level effects inspite of tissue lesions could be attributed to: i) selection of stress-tolerant individuals, ii) a time lag in population level effects, or iii) homeostatic maintenance of growth and reproduction at the expense of somatic maintenance. While there was a discernible difference between reproductively active verses quiescent individuals, since *A. serricata* inhabits an environment rich in dissolved metals, sulfides and organic breakdown products, it is likely that *A. serricata* is a stress-tolerant species.

7.5.3.2 Recommendations for Additional Biological Parameters

- In order to more thoroughly assess the potential impacts to bottom fauna, sampling and analysis should attempt to address epibenthic organisms in addition to infauna.

- Because select opportunistic organisms may be so abundant as to overwhelm diversity and/or similarity indices, Burd and Ellis (1995) recommend samples also be analyzed for biomass. This will provide an alternate descriptor of colonization and allow data transformations of other parameters (e.g., diversity, abundance) for further analysis.

- Because *in situ* colonization experiments suggest tailings are colonized at a slower rate than local natural sediments, additional studies to explore a cause-effect relationship are needed. Additional aspects warranting examination should include the role of particle size and shape and the role of bioavailable contaminants (e.g., metals). In respect of contaminants, this should be assessed using principles of the Triad approach which assess the cause-effect relationship using evidence from biodiversity data, sediment and porewater chemical analyses and bioassays (Chapman, 1990).

7.6 Results of Zooplankton Monitoring Program

7.6.1 Biological Parameters Monitored, Objectives and Effects Reported

Marine zooplankton were monitored for over 24 years while the mine was in operation. Zooplankton were monitored for population changes and metal concentration quarterly from 1970 through 1983 and semi-annually from 1984 through 1994. From 1984 to 1986, zooplankton were sampled in June and September. From 1987 to 1994, zooplankton were sampled in March and September to represent winter and summer populations. The components of the Island Copper monitoring program related to zooplankton are outlined in Table 7-7. A summary of the parameters measured by year is provided in Table 7-8.

The objectives of the zooplankton monitoring program were to monitor population changes and metal concentrations.

7.6.2 Population Parameters

The zooplankton population monitoring program was designed to assess potential impacts of the mine tailings on zooplankton density and diversity. The program involved collected of zooplankton at 4 sites, and identification of various larvae, including crabs, clams, and mussels. Collection of the zooplankton was performed at each station by towing mesh plankton nets: a) horizontally for 15 minutes at 5 meters, 30 meters, and at designated bottom depth; and b) from bottom to surface for a vertical haul.

Island Copper (1995) reported no change in the zooplankton community structure in Rupert Inlet, Holberg Inlet and Quatsino Sound over the sampling period. Zeng and Parsons (1994) statistically analyzed Island Copper vertical haul zooplankton data. Island Copper (1995) quote Zeng and Parsons (1994) as reporting that "abundance and variability of zooplankton are consistent with other areas not subject to mining activity".

The zooplankton percent composition was tabulated for 1989 to 1994 by Island Copper (1995). They reported that *Oithona helgolandica* as the most abundant species overall in 1994. *Pseudocalanus minutus* was one of the most frequent species of planktonic zooplankton sampled and is commonly found elsewhere. *O. helgolandica* made up over 50% of the composition in the samples taken at 30 metres and bottom depth decreasing to 12% or less in the samples collected at 5 metres for samples taken outside Rupert Inlet. Within Rupert Inlet, *O. helgolandica* was also abundant in the 5 metre samples taken in March and September 1994.

Discussion and Critique of Monitoring Program for Population Parameters

The monitoring program appears to have been designed to meet the stated objectives. A discussion and critique of the monitoring program is provided below:

- Island Copper (1994) reported data on adult zooplankton diversity, richness and density for the 1993 monitoring year. The results show no differences between stations in all these parameters. Results for adult zooplankton density are presented from March 1987 to September 1993. No baseline data are presented and no data from the early years in the monitoring program were included for comparison.

Recommendations for Additional Parameters for Population Parameters

- The zooplankton monitoring program appears to have generated a great deal of useful data. The monitoring program could benefit, however, by presenting the complete data set, 1970-1994 for comparative purposes. This would include the baseline data.

- As discussed for other biological parameters, the use of a reference station outside the tailings impacted area should be used for comparison of zooplankton density and diversity. The area around zooplankton sampling station D, Quatsino Sound became contaminated with tailings as early as 1977. Appropriate reference sites would also provide information on yearly variability in local populations, not related to mine tailings.

7.6.3 Metals Accumulation

The monitoring program to assess potential impacts of mine tailings on zooplankton metal content involved a separate collection for zooplankton metal analysis. Metals analyzed in zooplankton were arsenic, cadmium, copper, lead, mercury (up to 1993), molybdenum, and zinc. Samples were dewatered and homogenized prior to analysis. Separate analyses were performed on taxonomic orders when possible. Copper and zinc concentrations in unsorted zooplankton were graphed from 1972 through 1994 (ICM, 1995).

Island Copper indicated that there was no increasing trend in copper and zinc values over time.

Discussion and Critique of Monitoring Program for Metal Content

The monitoring program was able to meet the objectives of assessing potential effects on zooplankton metal content. A critique of the monitoring program is provided below:

Results are presented for metal concentrations in unsorted zooplankton samples (ICM, 1995). Since these samples would have a different composition of zooplankton, the results are difficult to interpret. Zooplankton were not sorted for metal anaylsis in the 1989 monitoring year. A cursory review of the raw data for metal concentrations in sorted zooplankton samples for 1993 and 1994 suggest higher copper and zinc concentrations in the Rupert Inlet samples compared to the other stations. Conclusions regarding a trend in copper and zinc concentrations in zooplankton over time would require a more detailed evaluation.

Recommendations for Additional Parameters for Metal Content

Data should be presented to provide the most meaningful interpretation of the data. Presentation of the zooplankton data in any form other than the sorted samples, by year and by station, including baseline and reference data, would not provide the necessary information to address the objectives of this part of the monitoring program.

7.7 Results of Plant Monitoring Program

Marine plants were monitored for over 20 years while the mine was in operation. An outlined of the monitoring program can be found in Table 7-9. A year-by-year summary can be found in Table 7-10. The results of the intertidal plate studies are also included in this section.

7.7.1 Biological Parameters Monitored, Objectives and Effects Reported

Phytoplankton

- Composite samples were collected from surface to a 5 metre depth from 7 stations. Samples were collected weekly from April to October 1986-1990.

The objective of the phytoplankton sampling was to monitor population dynamics through identification of species (or genus) present. Species were then categorized into 3 groups: diatoms, flagellates, and ciliates.

- Island Copper (1995) reported that there was no evidence of impact of mine tailings on phytoplankton in Rupert and Holberg Inlets. A general increase in phytoplankton was reported from 1971 to 1992 for Rupert and Holberg Inlets and Quatsino Sound, but the greatest increases were observed for the stations at the shallow ends of Rupert and Holberg Inlets. Zeng and Parsons (1994) suggested that the increase in phytoplankton production over the years was likely due to an increase in release of nutrients from freshwater contributions to the inlets.

Euphotic Depth Survey

- Light extinction at depth was used to record the depth of the photic zone in the water column to help characterize the phytoplankton habitat. Measurements were taken monthly in 1977, then on a varying schedule from 1977 to 1994.

- Zeng and Parsons (1994) reported that linear regressions on secchi disc depth data showed no trend in euphotic depth for each station from the period of 1971 to 1992. An exception to this was the station located in Quatsino Sound where the increase in turbidity noted could be due to resuspension of tailings coming through Quatsino Narrows. In addition, a comparison of secchi depth and turbidity prior to 1971 and after shows a significant decrease in secchi depth for the Rupert Inlet station located near the outfall and for the station at the mid point of Holberg Inlet. These results correspond to increases in turbidity for all stations, including Quatsino Sound, and excluding the station on the Holberg side of Hankin Point and the station at the head of Rupert Inlet.

Chlorophyll a

- Samples were taken at 7 stations for measurement of chlorophyll "a" on a monthly basis from 1977 to 1984 and a variable schedule from 1985 to 1994. The objective of the chlorophyll analysis was to monitor phytoplankton biomass.

- Island Copper (1995) reported that chlorophyll a concentrations were typically greatest in the summer months with the greatest standing stock occurring in July, August or September. Zeng and Parsons (1994) reported that concentrations of chlorophyll a were correlated with temperature, pH, Secchi depth and dissolved oxygen at all stations. With the exception of one station in Holberg Inlet for which there was a significant negative correlation of chlorophyll a with dissolved zinc, there were no correlations of chlorophyll a with dissolved metals.

- As reported above for phytoplankton, there was a significant increasing trend of chlorophyll a over all stations measured from the period of 1971 to 1992 (Zeng and Parsons, 1994). Since the greatest increases in chlorophyll a occurred at estuarine stations, it was suggested that the increases were due to increases in nutrient inputs to the system from the terrestrial environment.

Intertidal Plate Studies

- Plates were positioned at 16 sites using artificial substrate to monitor settling of flora and fauna in the intertidal zone. Analysis was conducted monthly in 1977 with a varying schedules from 1978 to 1994.

- Results of plate studies show that diatoms, algae and barnacles are dominant organisms that grow from the plates positioned in Holberg Inlet. Rupert Inlet was dominated by diatoms and macrophytic algae and Quatsino Sound had mainly diatoms with occasional algal growth (ICM, 1995). Biomass is represented by the volatile fraction of material settling out on the plates. Tailings settle on the plate but do not add to the total volatile fraction. In 1994, the plate located at Hankin Point in Rupert Inlet had the greatest settling rate but had a low percent volatile fraction suggesting reduced numbers of these organisms. Additional discussions of inter-tidal plate studies and colonization can be found in Section 7.5.3.1.

Metal Analyses

- Rockweed, a brown algae (*Fucus* sp.) and eelgrass (*Zostera* sp.) were used to monitor tissue metal concentrations in sessile macrophytes. Samples were collected at 16 stations quarterly from 1977 to 1980 and annually from 1983 to 1994.

- Results of chemical analyses (ICM, 1995) show an increase of copper and zinc in plant tissue (rockweed and eelgrass) over time, with higher concentrations of metals in flora closer to the mine. Island Copper suggested this may be due to difficulty in cleaning particles from the external surface of the plants; however, the increase in metal concentrations in the macrophytes was limited only to copper and zinc.

Nutrients

- Water samples were collected at 6 stations monthly in 1977 to record nutrient concentrations in the water column.

Carbon[14]

- Primary productivity was measured using a modification of the standard carbon 14 method. Samples were taken monthly from 1977 to 1982 and in 1985. The objective was to record the assimilation rate of primary producers.
- The 1976 to 1982 average carbon fixing rates were 12.1, 9.1 and 9.6 mg C/m^3/hr for Holberg Inlet, Quatsino Sound and Rupert Inlet, respectively. In 1985, the rates were consistent with these for Holberg Inlet and Quatsino Sound, but the rate for Rupert Inlet was 5 mg C/m^3/hr in 1985. The low rate for Rupert Inlet corresponded with the low chlorophyll a measurement for that year (ICM, 1986). Prior to 1985, Island Copper (1983) reported that there were no trends in carbon fixation rates for Rupert Inlet, Holberg Inlet or Quatsino Sound.

7.7.2 Discussion and Critique of the Monitoring Program

The objective of the monitoring program with respect to plants was to monitor change in the marine environment of Rupert and Holberg Inlets. Sixteen stations were used for intertidal plate studies and metal analyses of algae, seven stations were used for euphotic depth survey and chlorophyll a, and six stations were used for sampling of nutrients and carbon[14] in Holberg Inlet, Rupert Inlet, and Quatsino Sound on a regular basis.

The major limiting factors of the plant monitoring program were the inconsistent collection of data over timeframes and inconsistent sampling methods. As noted above, the sampling frequency varied for several parameters from monthly to seasonally to annually and even sporadically. In addition, there were inconsistencies in sampling locations. Zeng and Parsons (1994) noted some changes in the sampling program and that the 5m depth sample was the most consistent value over time and at all stations. These inconsistencies limit the potential of this otherwise comprehensive data set.

7.7.3 Recommendations for Additional Parameters

The recommendations come directly from the major limiting factors of the plant monitoring program. Sampling frequency should be standardized and it should be set on a timeframe that is meaningful for the biological parameter monitored. Sample locations should also be consistent over time and should be consistent with related parameters. For example, sample should be taken at the same location for phytoplankton, chlorophyll a, carbon fixation and dissolved metals. Thus, the result of these test could be used to reinforce each other and explain anomalies if/when they occur.

8.0 CONCLUSIONS

The following conclusions are based on observations derived from both the case study and from other mine sites as mentioned in this report. It should be noted that some aspects of these conclusions may be viewed differently depending on whether this retrospective analysis uses *present day knowledge* versus *knowledge of the time*, as the measuring stick by which to evaluate data, protocols, design, and results.

The goal in listing these conclusions is to draw to the readers' attention to both the major challenges and unique findings that have emerged for consideration in optimizing the evaluation of future Submarine Tailings Disposal (STD) operations.

1. ***Physical Smothering:*** Contemporary submarine tailing discharges, like naturally occurring density currents, will cover over deep water habitat and organisms. This is a generally *expected* outcome of the practice and as such, the question is not whether this effect will occur, but rather, over what areal extent in respect of:

   a) the deep water receiving compartment; and
   b) the shallower, biologically productive zones (i.e., euphotic zone)

   Therefore an important requirement for STD is to predict quantitatively the vulnerable area with some measure of certainty/uncertainty in the prediction.

2. ***Dispersion of Tailings:*** On the basis of Island Copper Mine, Kitsault Mine and Black Angel Mine, STDs have resulted in dispersal of tailings to a greater extent than predicted. This applies to dispersal in both the deep water receiving environment (i.e., bottom of fjord) and in shallow waters. On reflection, this appears to be a result of historically insufficient characterization of dispersive mechanisms (e.g., currents, separation, stratification, etc.), physical oceanographic processes and solids transport. With improved measurement and modelling efforts solids dispersion can be better forecasted . As a more recent example, a significant effort was noted in solids dispersal modelling for the Quartz Hill (Alaska) feasibility study and is considered to be more reflective of the present-day capabilities and needed effort.

3. ***Baseline Physical Oceanographic Measurements:*** Pursuant to (3), above, physical oceanographic processes can vary significantly in time and space.

Baseline oceanographic measurements at Island Copper Mine did not adequately address this potential and as a consequence the available data did not include the prediction of deep water intrusions and the resultant periodic turbidity boils at Hankin Point. Other examples exist where longterm measurements have adequately characterized the variability in site-specific oceanographic parameters and optimized the design, siting and performance of the STD outfall (e.g., Misima Mine, Papua New Guinea).

4. ***Tailings and Flocculation:*** The role of flocculation of suspended fines in the marine environment has been an important consideration in predicting sedimentation of suspended tailings and resuspension of bottom sediments. Many factors may influence the process including turbulence, salinity, particle size and shape and mineralogy. Although laboratory tests have been conducted in the past to predict field behaviour, it is clear that field characterization and follow-up studies are essential to validate laboratory predictions.

5. ***Ore Body Considerations:*** The discharged tailings at Island Copper were effectively inert in regards of leachable metals and this was a very positive feature of this ore body. However, not all tailings are suitable for STD application. While sulphide-based minerals are generally not a problem because of their resistance to leaching in deepwater marine environments, alternate metal species may also exist within the ore matrix which are prone to leaching (e.g., lead and zinc hydroxides at Black Angel Mine). Given the current state of knowledge in marine-geochemistry and analytical capabilities, these situations are predictable and avoidable.

6. ***Sediments as Sinks for Metals:*** Pursuant to (5), where tailings are relatively inert in deep marine conditions (i.e., low oxygen and slightly alkaline pH), the tailings-based sediments will likely act as a sink rather than a source for metals in the receiving environment. Diagenesis of metal species in the sediments and field measurements suggest a large majority of metals descending from the water column are assimilated in the sediments with a small fraction emanating from the sediments.

7. ***Environmental Monitoring Program (EEM):*** The environmental monitoring program for Island Copper Mine was, in effect, one of the earliest applications of an EEM plan, and is a commendable effort based on past and present standards. The monitoring program could now also consider the following:

   a) Provision of Testable Hypotheses - although in some case objectives were stated, hypotheses were not stated at the design stage and this compromised the sampling design by not conducting a power analysis and stating replicate sample requirements. In several instances, replication of measurements/sampling was considered inadequate to draw conclusions regarding interstation comparisons and time series trends.

b) Selection of Receptors - although both phyto- and zooplankton receptors were considered for monitoring, the largest focus appears to have been on *deep water* benthic invertebrates, as these were the receptors *expected* to be most likely affected. Equivalent consideration to shallow water communities was lacking and could have provided valuable information, given the dispersal of solids into the shallow water habitat of Rupert and Holdberg Inlets.

c) In establishing the presence of an effect, comparisons of abiotic and biotic conditions at monitoring stations versus baseline conditions and reference sites could be improved. In the case of baseline conditions (assessed in 1969/70) a more comprehensive effort was needed in characterizing abiotic and biotic variables. In the case of reference sites, some of these received tailings deposition and their usefulness is therefore drawn into question.

8. ***Habitat Alteration at Hankin Point:*** Pursuant to item (1), dispersion of tailings by deep water renewal events along the Quatsino Narrows-Hankin Point axis, have changed the original rocky substrate off Hankin Point (both deep and intertidal) to a soft bottom sediment. This change in habitat has undoubtedly displaced the original macroinvertebrates (e.g., prawns). Within the intertidal zone, alternate species and habitat involving eelgrass beds has developed. These appear to be well established, but is recognized to be a deviation from initial conditions.

9. ***Organism versus Population Level Effects:*** Although the monitoring program at Island Copper Mine generated a great deal of data, there was a notable lack of biological studies of potential toxic effects occurring at the organism level. Studies of effects occurring at both the organism (e.g. growth, condition factor, fecundity) and population (e.g. abundance, reproductive success) levels are useful in establishing the significance of adverse effects associated with a stressor in the environment. Effects limited to the organism level may not manifest in a significant effect to the population, community or ecosystem as a whole. One notable exception was the work reported by Bright (1991), who assessed the histopathology, fecundity, growth, and abundance of a small infaunal bivalve, *A. serricata,* along a gradient of impacted areas in Rupert and Holberg Inlets. Several histopathological effects were noted in *A. serricata* associated with mine tailings in Rupert and Holberg Inlets, and effects were greater in areas of high tailings deposition. Despite the histopathological effects noted, Bright (1991) reported that there were no apparent population level effects on fecundity, growth or abundance in *A. serricata*. Since *A. serricata* inhabits an environment rich in

dissolved metals, sulfides and organic breakdown products, Bright suggested that *A. serricata* is a stress-tolerant species.

10. ***Tissue Metal Monitoring:*** Canadian Food and Drug Act (FDA) tolerance limits for arsenic, cadmium, copper, lead, mercury and zinc in marketable seafood were compared with heavy metals in fish and benthic invertebrates reported by Island Copper Mine (1995). On the basis of reported data over the operation of the mine, only arsenic exceeded the FDA tolerance limit for seafood, generally by less than three times the tolerance limit. It should be noted that tissue metals monitoring could be improved through increased sample replication, statement of measurement variability, and year-to-year consistency with respect to species and sample location. Details are provided below:

    a) No significant exceedences were noted for fish species; however, it is noted that there was inconsistent sampling, with insufficient numbers of fish over time for statistical analyses.

    b) Mean arsenic levels in *Humilaria kennerlyi* at Hankin Point exceeded the current FDA tolerance limit of 3.5 ppm during 1979 to 1989 (sampling period of 1977 to 1987), with a maximum value of less than twice the FDA limit.

    c) Arsenic levels in butter clam exceeded the FDA limit (by less than 1.5 times the limit) in Quatsino Sound and Rupert Inlet approximately 10 years during the sampling period of 1971 to 1994, with no trend evident over time.

    d) In prawn, arsenic levels exceeded the FDA limit from 1981 to 1989 (sampling period of 1981 to 1992) in Quatsino Sound, Rupert Inlet and Holberg Inlet, with exceedences of less than twice the FDA limit. It is noted that sampling was inconsistent in later years.

    e) Arsenic levels in dungeness crab exceeded the FDA limit in Quatsino Sound from 1971 through 1994, with levels rarely exceeding three times the FDA limit. Some exceedences were noted in Rupert and Holberg Inlets (approximately 12 and 4 respectively); however, levels in Rupert and Holberg Inlets were not reported to exceed the Quatsino Sound arsenic levels. Given the distal location of Quatsino Sound with respect to the mine discharge and the observed exceedences early in the mine's history, it is not clear whether these observations are a natural anomaly or a consequence of Island Copper Mine tailings.

11. ***Acute Effluent Bioassays:*** Acute effluent bioassays conducted by Island Copper Mine (96-hour LC_{50}'s) on coho salmon and rainbow trout were conducted over

the course of the mine operation. Data from 1977 through 1994 showed minimal acute lethal toxicity, with only 12 failures in 228 tests). The majority of these failures (i.e. 8 of the 12) occurred as an anomalous cluster and are not reflective of the longterm performance of the mine. A similar cluster occurred in 1976 which resulted in identification and rectification of a process anomaly. Overall, the process effluent did not display regular acute toxicity to salmonids.

12. ***Biological Recovery of Deposited Tailings:*** Biological recovery (recolonization) of recently deposited tailings is dependent on a multitude of factors including the potential for re-seeding by larval forms, food availability, physical acceptability of the particulates and porewater in the sediment, and recruitment of newly established organisms from year-to-year. Monitoring at both Island Copper Mine and Kitsault Mine indicate *initiation* of recovery may proceed relatively quickly following a smothering event with opportunistic species becoming established within the first few years. *Full* recovery is not expected to *replicate* the original (i.e., pre-operation) community or species list because the habitat has been changed. The concept of a *climax community* becoming re-established appears plausible but for marine benthic communities this is a very dynamic and changing community (in contrast to terrestrial climax forest communities). In the case of Island Copper Mine, several key species reflective of higher order trophic levels are present suggesting that succession is proceeding. However the timeframe to achieve a "climax community" is difficult to predict because of the effects of the instability of sediments (e.g., recurrent slumping) and episodic turbidity events which will continue for some time in spite of cessation of the mine operation.

9.0 RECOMMENDATIONS

On the basis of the foregoing discussion of STD experience at the Island Copper Mine, and STD issues in general, two broad recommendations are provided in this section to address:

i. An approach to evaluating new/proposed STD effluents;

ii. An approach to identifying the environmental parameters which should be considered in an environmental effects monitoring plan for operating and post-operating STD mines.

9.1 Conceptual Approach for Evaluation of Future STD Proposals

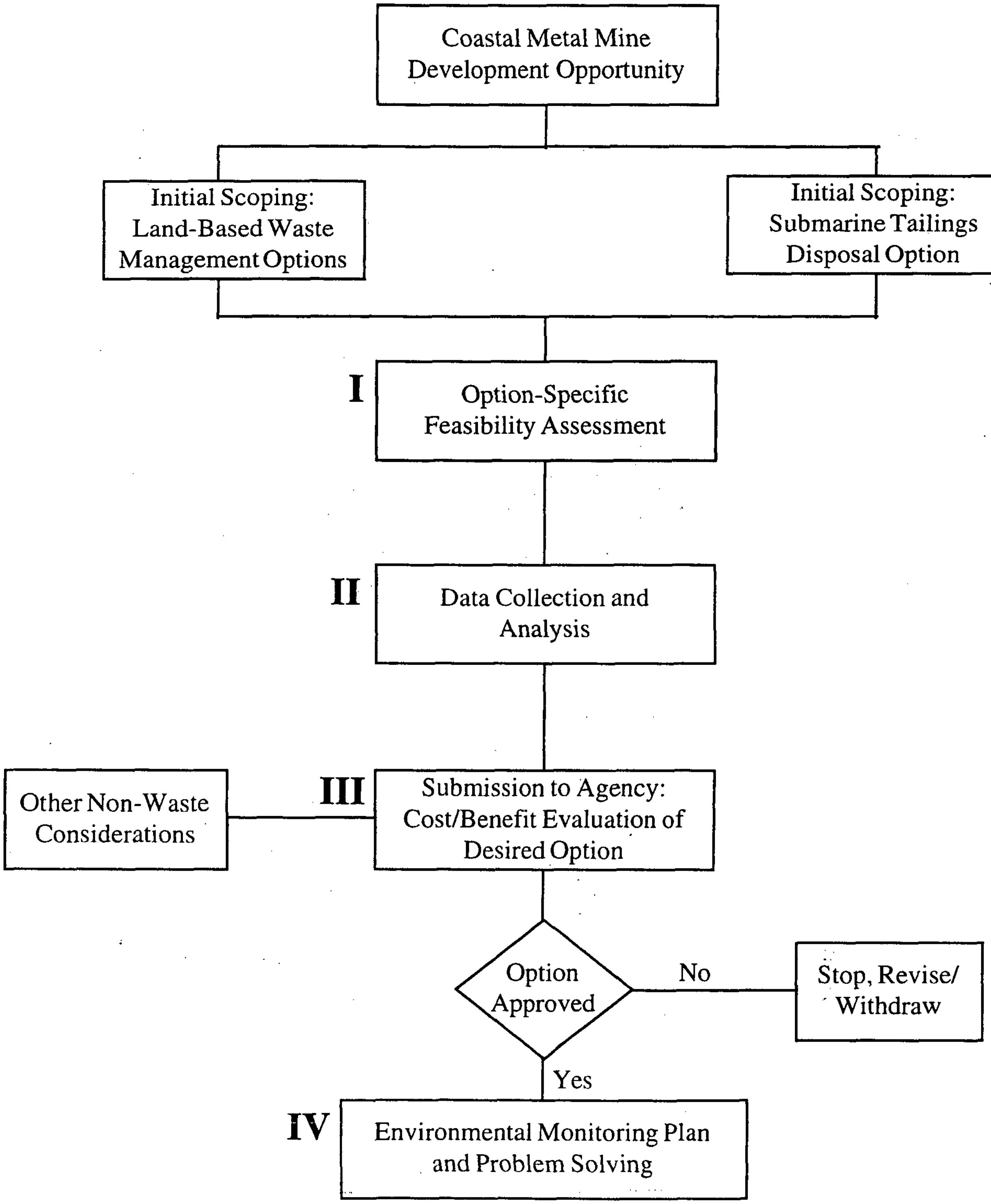
9.1.1 The Evaluation Paradigm

When a coastal ore-body is discovered and entertained for development; logistical, socio-economic, business and environmental considerations are triggered. The process for evaluation of new mine development proposals is well established and is not the focus of the present section. Rather, the present section provides a useable flexible framework relevant to STD undertakings which builds on existing paradigm of the mine development and approval process.

At a simplified level of detail, the paradigm is conceptually illustrated in Figure 9-1. In this case the paradigm focuses on the major steps to evaluate the mine waste management options available for the site. These are differentiated on the basis of land-based options versus the submarine tailing disposal option.

Both strategies may in turn have several discrete options, and each discrete option would be subject to the Initial Scoping Step to determine if it warrants further serious consideration.

These discrete waste management options which pass the initial scoping activity are then subject to Phases I and II of the paradigm. These phases focus in more detail on the option feasibility and data collection/analysis relevant to this end. The waste management option most likely to succeed and/or most preferred is typically tabled,



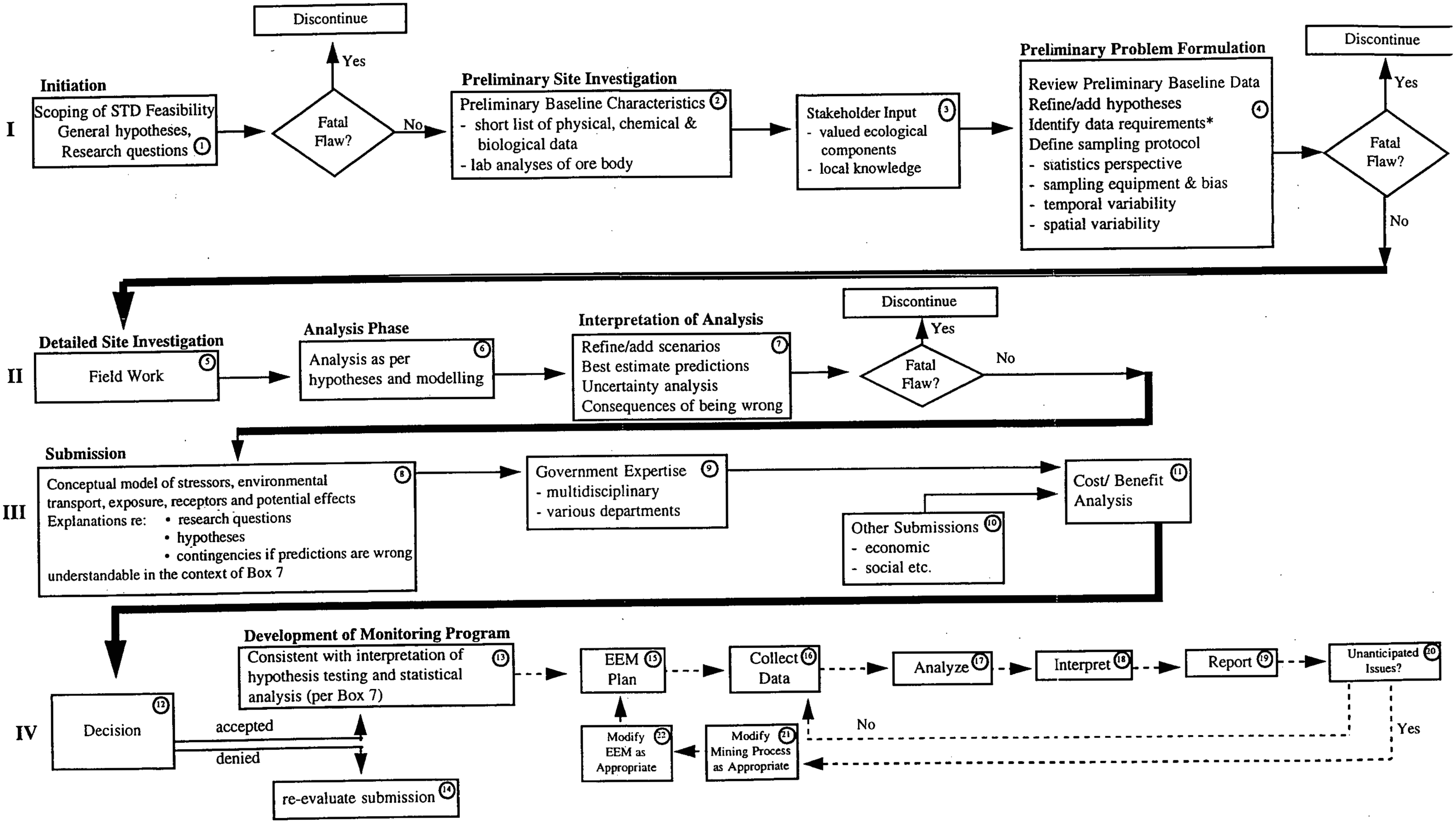
Project No. .... Drawn .... Reviewed .... Date ....

Golder Associates

Paradigm for Evaluating Coastal Mine Waste Management Options and Subsequent Monitoring

Figure **9-1**

Conceptual Approach for Marine Environment Evaluations of Future STD Proposals – A Government/Proponent Partnership



* As per “Generic Data Considerations” list.

J:\DRAWINGS\952-1928.ppt

Figure 9–2

<this page intentionally blank>

along with other non-waste issues, for a cost-benefit evaluation (Phase III) and decision. If the decision is one of approval, then Phase IV addresses the need for environmental effects monitoring and mitigation during and following the mine operation.

9.1.2 Conceptual Approach for Evaluation

Moving beyond the paradigm towards a more detailed yet flexible approach for evaluation the STD option specifically, several objectives were established to optimize the process.

The objectives were:

- Define a framework for a staged process that fosters development of general and specific hypotheses, the answer to which will form the basis for evaluation/approval;
- Provide stages for information exchanges and planning to optimize field data collection;
- Instill the practice of good scientific principles in respect of sample design and data analysis;
- Link baseline evaluations to monitoring program;
- Foster a partnership approach in planning stages between government and proponent.

The evaluation should include several key attributes. It should lead to the co-occurrence of physical oceanographic modelling, monitoring and model validation with respect to tailings dispersion. Similarly, it should also support the occurrence of predictive marine chemistry of contaminants and use monitoring data for retrospective validation of the fate predictions. The third attribute identified is the use of the two above attributes to design a biological effects monitoring plan on the basis of the stressor fate/transport/exposure pathways.

The result of merging these objectives with the paradigm is the recommended conceptual approach for evaluation of future STD proposals, as illustrated in Figure 9-2.

The paradigm is retained as indicated by Phases I and IV in the left margin. Each Phase consists of several tasks with relatively self-explanatory guidance. At various stages within Phases I and II action items have been inserted to raise the question if any fatal flaws exist (with respect to the STD option) such that unnecessary further efforts and expenditures can be avoided prior to submission.

Concept of Government/Proponent Partnership

The approach defined here is predicated on the concept of a partnership between government and industry in working towards the optimal set of data, analyses and interpretation to foster the best risk management decisions possible. This infers regular exchange of technical information resources and hypotheses relevant to the process of stressor, fate and transport modelling and evaluation of potential environmental effects. Ideally an agency "project facilitator" would be desirable who can expedite aspects of the exchange to information, offering of technical opinions and procurement of environmental sampling permits.

Integration of Hypotheses Testing Principles

At the outset of Phase I (Box 1) the process calls for the formulation of hypotheses and retains this concept throughout. Initially the hypotheses to be defined are broad and may be captured in the form of general project concept questions. These are used as guiding principles for the preliminary site investigation (Box 3) and further referred in preliminary problem formulation (Box 4) to optimize the collection and analysis of field data (Phase II).

Stakeholder Input

It is recognized that stakeholders such as local residents and fishers, for example, may be able to contribute valuable information at an early stage to optimize the preliminary problem formulation and field program. This has been accommodated (Box 3), but further recognized to be an element which ought to be considered to the extent possible in subsequent steps.

Field Sampling

Detailed field sampling (Box 5), its design and the nature of the data collected is driven by the refined hypotheses established during problem formulation. This ensures baseline data is collected at appropriate locations, over the required spatial and temporal boundaries and with the required number of replicates as defined by power analyses, of particular use is the General Data Consideration (Box 4) list which provides further guidance towards establishing a comprehensive field sampling protocol.

Data Analysis and Interpretation

All efforts to this point have focused on establishing a rationalized high quality database information for testing hypotheses and interpretation of analyses (Boxes 6 & 7). The latter items become the basis of understanding the scientific issues surrounding potential environmental effects of the proposed STD. As such they form the underpinnings for a comprehensible and informative submission (Box 8).

Multidisciplinary Regulatory Evaluation

The process highlights the need for multidisciplinary government expertise to conduct both the technical (scientific) and cost/benefit evaluation of the submission (Boxes 9, 10 and 11). It is emphasized that the partnership concept, if optimized, should improve the review process as much of the technical information (e.g. environmental modelling) ought to have already been shared/discussed before the submission.

Linkage of Environmental Effects Monitoring to Baseline Evaluation Issues

An objective in the process was to ensure environmental monitoring is logically designed to allow follow-up validation of modelled assumption in fate, transport, chemistry and hypothesized effects.

Additionally, the biomonitoring component should be a logical consequence of the defined stressor exposure models. This is achieved in Box 13 by cross referencing it to the interpretation of data analysis (Box 7), which in turn is linked back to the "Generic Data Consideration" list in the problem formulation (Box 4).

Practical Function of EEM Plan

The EEM plan must have a practical function beyond the role of simply monitoring for effects. This has been accommodated in two ways. The process first requires that following analysis, interpretation and reporting of the annual EEM activities (Boxes 17, 18 and 19); the finding be scrutinized to establish if i) the mine STD process needs to be modified to mitigate any newly discovered problems (Box 21) and/or ii) the EEM plan requires modification to focus on new issues and/or optimized resource allocation (Box 22). This latter aspect builds on the experience gained from Island Copper and their articulation of the need for a flexible rather than rigid approach to environmental effects monitoring.

GOLDER ASSOCIATES LTD.

Mike Rankin, M.Sc.
Senior Toxicologist

Dr. Reidar Zapf-Gilje, Ph.D., P. Eng.
Principal Environmental Group

List of Key Authors:

Susan Davidson, M.S., P.Eng.	Sea Science	Oceanography
Karen Drysdale, M.Sc.	University of Victoria	Oceanography
Trish Miller, M.Sc.	Golder Associates Ltd.	Toxicologist
Mike Rankin, M.Sc.	Golder Associates Ltd.	Toxicologist
Reidar Zapf-Gilje, Ph.D., P.Eng.	Golder Associates Ltd.	Project Director and Reviewer

MGR/RZG/kb
952-1928
J:\RPT-96\APR\MR-1928.DOC

REFERENCES

Adams, H.E., 1988. Trace element distributions in near-surface calcareous sediments of the East and Central Equaltorial Pacific Ocean Unpubl. B.Sc. Thesis, Dept. of Oceanography, Univ. of British Columbia.

Balistrieri, L.S. and J.W. Murray, 1986. The surface chemistry of sediments from the Panama Basin: The influence of Mn oxides on metal adsorption. Geochim Cosmochim Acta 50:2235-2243.

B.C. Research. 1970. Appendix 8.2 in Utah Construction and Mining Co. (1971).

Boyle, E.A., F.R. Sclater, and J.M. Edmond, 1977. The distribution of dissolved copper in the Pacific. Earth Planet Sci Lett 37:38-54.

Bright, D.A. 1991. Tissue variability in the infaunal bivalve *Axinopsida serricata* (Lucinacea:Thyasiridae) exposed to a marine mine-tailings discharge; and associated population effects. University of Victoria.

Burd, B.J. and Ellis, D.W. 1995. ICM Closure Plan: Review of Benthic Surveys 1970 to 1992 for Rupert/Holberg/Quatsino Inlet System.

Canadian Hydrographic Service. 1995. Canadian Tide and Current Tables. Vol 6. Department of Fisheries and Oceans, Ottawa, Canada.

Carter, R. 1970. Appendix 8.3 in Utah Construction and Mining Co. (1971).

Chapman, P.M. 1990. The sediment quality triad approach to determining pollution-induced degradation. Sci Total Env 97/98:815-825.

Davies-Colley, R.J., P.O. Nelson and K.J. Williamson, 1984. Copper and cadmium uptake by estuarine sedimentary phases. Environ Sci Technol 18(7):491-499.

Davies-Colley, R.J., P.O. Nelson and K.J. Williamson, 1985. Sulfide control of cadmium and copper concentrations in anaerobic estuarine sediments. Mar Chem 16:173-186.

Drinkwater, K.F.. 1971. The role of tidal mixing in Rupert and Holberg Inlets. Thesis, Department of Oceanography, University of British Columbia.

Drinkwater, K.F. and Osborn, T.R. 1975. The role of tidal mixing in Rupert and Holberg Inlets, Vancouver Island. Limnology and Oceanography 20:518-529.

Drysdale, K., 1991. Geochemistry of a buried marine mine tailings deposit, Howe Sound, B.C. M.Sc. Thesis, Dept. of Oceanography, Univ. of British Columbia, Vancouver, B.C.

Duchart, P., S.E. Calvert and N.B. Price, 1973. Distribution of trace metals in the porewaters of shallow water marine sediments. Limnol Oceanogr 18(4):605-610.

Elderfield, H., N. Luedke, R.J. McCaffrey, and M. Bender, 1981. Benthic flux studies in Narragansett Bay. Am Jour Sci 281:768-787.

Ellis, D.W., Pederson, T.F., Poling, G.W., Pelletier, C. and Horne, I. 1995. Review of 23 years of STD: Island Copper Mine, Canada. Marine Georesources and Geotechnology 13:59-99.

Emerson, S., R. Jahnke and D. Heggie, 1984. Sediment-water exchange in shallow water estuarine sediments. Jour Mar Res 42:709-730.

Farmer, D.M. 1983. Summary, Engineering and Scientific Principles. In: Ellis, D.V. (ed). Marine Tailings Disposal. Ann Arbor Science, MI.

Gambrell, R.P., Rk.A. Khalid and W.H. Patrick Jr., 1976. Physicochemical parameters that regulate mobilization and immobilization of toxic heavy metals. In Krenkel, P.A., Harrison, J. Burdick III, J.C. (eds). Proceedings of the Specialty Conference on Dredging and its Environmental Effects, Mobile, Alabama, Jan. 26-29, 1976.

Gobeil, C. and N. Silverberg, 1989. Early diagenesis of lead in Laurentian Trough sediments. Geochim Cosmochim Acta 53:1889-1895.

Golder, 1996. Draft progress report in the effects of metal mine effluent on the marine environment. Task 2 - Bibliographic database, mine summaries and trends. Prepared for: Environment Canada.

Goyette, D. and Nelson, H. 1977. Marine environmental assessment of mine waste disposal into Rupert Inlet, British Columbia (Surveillance Report/EPS PR 77-110). Fisheries and Environment Canada.

Grieve, D.A. and Fletcher, W.K. 1976. Heavy metals in deltaic sediments of the Fraser River, British Columbia. Cdn J Earth Sci 13:1683:1693.

Hay, A.E. 1981. Submarine channel formation and acoustic remote sensing of suspended sediments and turbidity currents in Rupert Inlet, B.C. Ph.D. Thesis, Department of Oceanography, University of British Columbia.

Hay, A.E. 1983. The effects of submarine channels on mine tailing disposal in Rupert Inlet, B.C. In: Ellis, D.V. (ed). Marine Tailings Disposal. Ann Arbor Science, MI.

Heggie, D.T., 1983. Copper in the Resurrection Fjord, Alaska. Est Coast Shelf Sci 17:613-635.

Heggie, D.T., G. Klinkhammer and D. Cullen, 1987. Manganese and copper fluxes from continental margin sediments. Geochim Cosmochim Acta 51:1059-1070.

Heggie, D.T., D. Kahn and K. Fischer, 1986. Trace metals in metalliferous sediments, MANOP Site M: Interfacial porewater profiles. Earth Planet Sci Lett 80:106-116.

Hoff, J.T., J.A.J. Thompson & C.S. Wong, 1982. Heavy metal release from mine tailings into seawater - a laboratory study. Mar Poll Bull 13:283-286.

ICM. 1982. Island Copper Mine 1981 Annual Environmental Assessment Report. Volume I and II. BHP Minerals Canada.

ICM. 1983. Island Copper Mine 1982 Annual Environmental Assessment Report. Volume I and II. BHP Minerals Canada.

ICM. 1985. Island Copper Mine 1984 Annual Environmental Assessment Report. Volume I and II. BHP Minerals Canada.

ICM. 1986. Island Copper Mine 1985 Annual Environmental Assessment Report. Volume I and II. BHP Minerals Canada.

ICM. 1988. Island Copper Mine 1987 Annual Environmental Assessment Report. Volume I and II. BHP Minerals Canada.

ICM. 1991. Island Copper Mine 1990 Annual Environmental Assessment Report. Volume I and II. BHP Minerals Canada.

ICM. 1992. Island Copper Mine 1991 Annual Environmental Assessment Report. Volume I and II. BHP Minerals Canada.

ICM. 1993. Island Copper Mine 1992 Annual Environmental Assessment Report. Volume I and II. BHP Minerals Canada.

ICM. 1994. Island Copper Mine 1993 Annual Environmental Assessment Report. Volume I and II. BHP Minerals Canada.

ICM. 1995. Island Copper Mine 1994 Annual Environmental Assessment Report. Volume I and II. BHP Minerals Canada.

Inland Waters Directorate. 1991. Historical Streamflow Summary, British Columbia. Water Resources branch, Water Survey of Canada, Ottawa, Canada.

Johnson, J.W. 1970 Appendix 8.1 in Utah Construction and Mining Co. (1971).

Johnson, R.D. 1974. Dispersal of recent sediments and mine tailings in a shallow-silled fjord, Rupert Inlet, British Columbia. Ph.D. Thesis, Department of Geological Sciences, University of British Columbia.

Jones, B.F., and C.J. Bowser, 1978. The mineralogy and related chemistry of lake sediments. In: Lerman, A. (ed). Lakes - chemistry, geology, physics. Springer, New York Heidelberg Berlin 179-235.

Khalid, R.A., W.H. Patrick and R.P. Gambrell, 1978. Effect of dissolved oxygen on chemical transformations of heavy metals, phosphorus, and nitrogen in an estuarine sediment. Est Coast Mar Sci 6:21-35.

Kline, E. 1994. Potential biological consequences of submarine mine tailings disposal: A literature synthesis. U.S. Department of Interior, Bureau of Mines.

Klinkhammer, G.P., D.T. Heggie & D.W. Graham, 1982. Metal diagenesis in oxic marine sediments. Earth Planet Sci Lett 61:211-219.

Laxen, D.P.H., 1983. Adsorption of Pb, Cd, Cu and Ni onto hydrous iron oxides under realistic conditions. Proc. International Conference on Heavy Metals in the Environment, Sept. 6-9, 1982, pp. 1082-1085, DEP-Consultants, Edinburgh.

Leckie, J.O., M. Benjamin, K. Hayes, G. Kaufman, and S. Altmann, 1980. Adsorption/co-precipitation of trace elements from water with iron oxyhydroxide. Final Report, EPRI RP-910, Electric Power Res Inst Palo Alto, Calif 94303.

Luther III, G.W., Z. Wilk, R.A. Ryans and A.L. Meyerson, 1986. On the speciation of metals in the water column of a polluted estuary. Mar Poll Bull 17(12):535-542.

Miller, P.A., Munkittrisk, K.R. and Dixon, D.G. 1992. Relationship between concentrations of copper and zinc in water, sediment, benthic invertebrates, and tissues of white sucker (*Catostomus commersoni*) and metal-contaminated sites. Cdn J of Fisheries and Aquatic Sci 49(5):978-984.

MMLER. 1977. Metal Mining Liquid Effluent Regulations. C.R.C. 1978, C.819 (as am. by SOR/95-429). Fisheries Act.

Newcombe, C.P. 1984. Suspended sediment in aquatic ecosystems: III Effects as a function of concentration and duration of exposure. province of British Columbia, Habitat Protection Branch. Ministry of Environment, Lands and Parks, Victoria.

Oakley, S.M., P.O. Nelson, and K.J. Williamson, 1981. Model of trace metal partitioning in marine sediments. Env. Sci & Technol 15:474-480.

Pedersen, T.F., 1983. Dissolved heavy metals in a lacustrine mine tailings deposit - Buttle Lake, B.C. Mar Poll Bull 14:249-254.

Pedersen, T.F., 1985. Early diagenesis of copper and molybdenum in mine tailings and natural sediments in Rupert and Holberg Inlets, B.C. Can Jour Earth Sci 22(10):1474-1484.

Pickard, G.L. 1963. Oceanographic characteristics of inlets of Vancouver Island, British Columbia. J Fish Res Board Can 20:1109-1144.

Poling, G.W. 1982. Characteristics of mill tailings and their behavior in marine environments. In: Ellis, D.V. (ed). Marine Tailings Disposal. Ann Arbor Science, MI.

Poling, G.W. and Ellis, D.V. 1995. Importance of geochemistry: The Black Angel lead-zinc mine, Greenland. Marine Georesources and Geotechnology 13:101-118.

Presley, B.J., Y. Kolodny, A. Nissenbaum and I.R. Kaplan, 1972. Early diagenesis in a reducing fjord, Saanich Inlet, British Columbia - II. Trace element distribution in interstitial water and sediment. Geochim Cosmochim Acta 36:1073-1090.

Price, N.B., 1973. Chemical diagenesis in sediments. Technical Report WHOI:73-79. Unpubl. MS. June, 1973.

Salomons, W.,1980. Adsorption processes and hydrodynamic conditions in estuaries. Environ Technol Lett 1: 356-365.

Sawlan, J.J. and J.W. Murray, 1983. Trace metal remobilization in the interstitial waters of red clay and hemipelagic marine sediments. Earth Planet Sci Lett 64:213-230.

Shaw, T.J., J.M. Gieskes, and R.A. Jahnke, 1990. Early diagenesis in differing depositional environments: the response of transition metals in porewater. Geochim Cosmochim Acta 54:1233-1246.

Shea, D. and G.R. Helz, 1988. The solubility of copper in sulfidic waters: Sulfide and polysulfide complexes in equilibrium with covellite. Geochim Cosmochim Acta 52:1815-1825.

Shimmield, G.B. and T.F. Pedersen, 1990. The geochemistry of reactive trace metals and halogens in hemipelagic continental margin sediments. CRC Critical Reviews in Marine Science.

Sholkovitz, E.R., 1976. Flocculation of dissolved organic and inorganic matter during the mixing of riverwater and seawater. Geochim Cosmochim Acta 40:831-845.

Sholkovitz, E.R., 1973. Interstitial water chemistry of the Santa Barbara Basin sediments. Geochim Cosmochim Acta 37:20.

Spear, P.A., 1981. Zinc in the aquatic environment: chemistry, distribution, and toxicology. NRCC, Publ. No. 17589, 11-31.

Stucci, D. 1975. The tidal jet in Rupert-Holberg Inlet, B.C. Atmosphere Ocean 23(2):118.

Stucci, D. and Farmer, D.M. 1976. Deep water exchange in Rupert-Holberg Inlet, Pacific Marine Science Report 76-10, Institute of Ocean Sciences, B.C.

Taylor, L.A. 1986. Marine macrobenthic colonization of mine tailings in Rupert inlet, British Columbia. University of Victoria.

Tessier, A., R. Carignan, B. Dubreuil and F. Rapin, 1989. Partitioning of zinc between the water column and the oxic sediments in lakes. Geochim. Cosmochim Acta 53:1511-1522.

Tipping, E., D.W. Thompson, M. Ohnstad, and N.B. Hetherington, 1986. Effects of pH on the release of metals from naturally-occurring oxides of Mn and Fe. Env Technol Lett 7:109-114.

Utah Construction and Mining Co. 1971. Brief in support of its Application under the Pollution Control Act, 1967, to discharge Mill tailings from its Island Copper Operation into Rupert Inlet.

Waldichuk, M., Markerrt, J.R. and Meikle, J.H. 1968. Physical and chemical oceanographic data from the west coast of Vancouver Island and the northern British Columbia coast, 1957-1967. Fish Res Board Can. Ms Rep Ser 990, 161 p.

Waldichuk, M. and Buchanan, R.J. 1980. Significance of environmental changes due to mine waste disposal into the Rupert Inlet. Fisheries and Oceans Canada, British Columbia Ministry of Environment.

Westerlund, S.F.G., L.G. Anderson, P.O.J. Hall, A. Iverfeldt, M.M. Rutgers van der Loeff, and B. Sundby, 1986. Benthic fluxes of cadmium, copper, nickel, zinc and lead in the coastal environment. Geochim Cosmochim Acta 50:1289-1296.

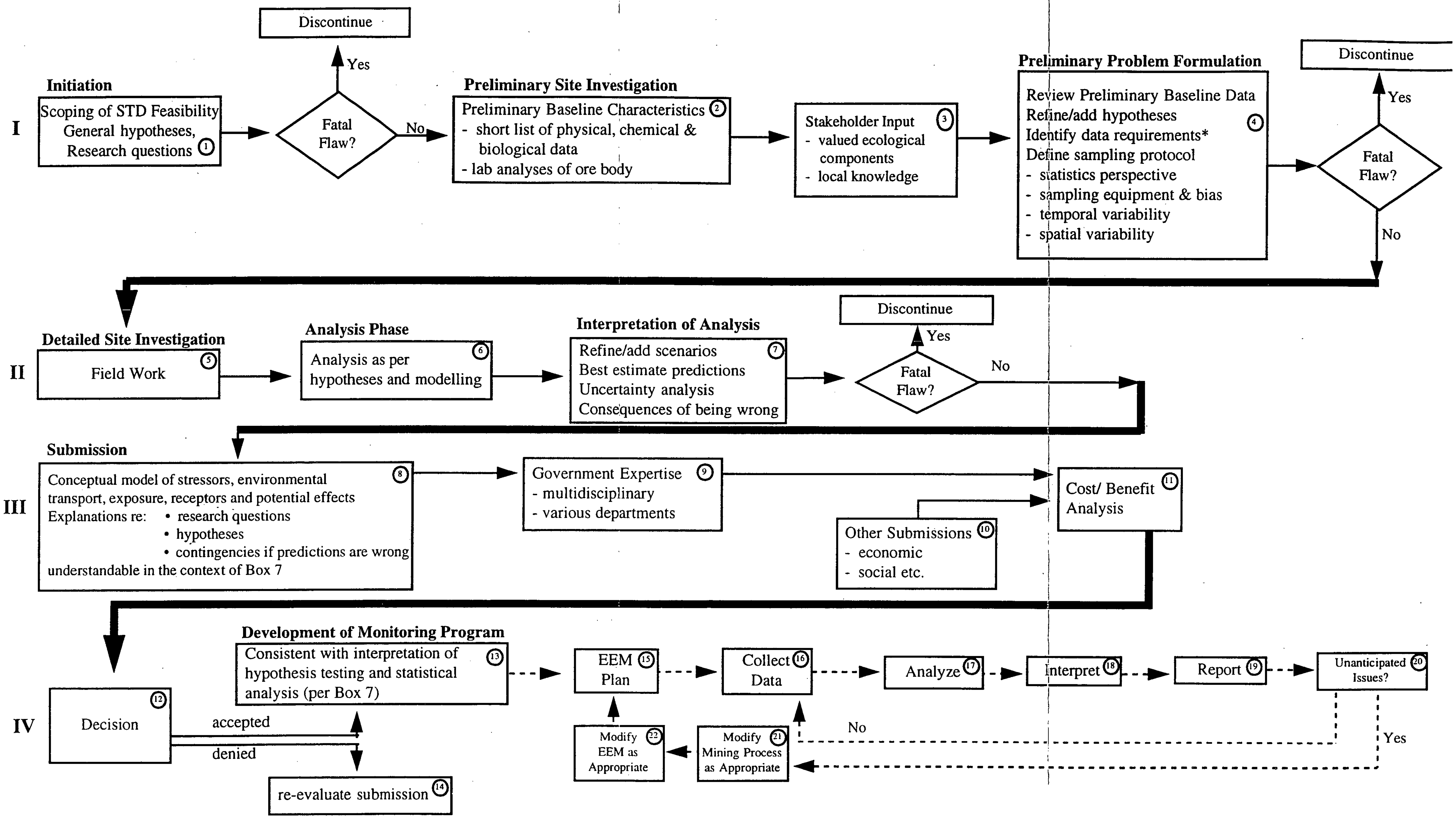
Westwater Research Center. 1985. Impact Assessment, Monitoring and Management: Case Study of Utah and Amax Mines. University of British Columbia.

Zar, J.H. 1984. Biostatistical Analysis. 2nd ed. Prentice-Hall Inc. Englewood Cliffs, NJ.

Zeng, J. and Parsons, T.R. 1994. An analysis of biological and chemical data in the near-surface waters of Rupert Inlet, Holberg Inlet and Quatsino Sound, 1971-1993. Sydat Environmental Consulting.

Zeng, J. and Parsons, T.R. 1994. An analysis for data of zooplankton in the waters of Rupert Inlet, Holberg Inlet and Quatsino Sound, 1971-1993. Sydat Environmental Consulting.

Conceptual Approach for Marine Environment Evaluations of Future STD Proposals – A Government/Proponent Partnership



* As per "Generic Data Considerations" list.

J:\DRAWINGS\952-1928.ppt

Figure 9–2

APPENDIX I

REQUEST FOR PROPOSAL

CATHY GRAHAM
GOLDER ASSOCIATES LTD.
2550 ARGENTIA RD
SUITE 213
MISSISSAUGA, ON, Canada
L5N 5R1 (01183890)

Request for Proposal Cover Letter

Environment Canada
Corporate Branch
Pacific & Yukon Region
224 West Esplanade
North Vancouver, B.C. V7M 3H7

October 13, 1995

Request for Proposal

Dear Sir/Madam;

Request for Proposal No. KA601-5-5132
Work Title: Effects of Mining Effluents on Marine Environments

Environment Canada has a requirement for the services described in the attached **STATEMENT OF WORK** (Appendix "A"). You are invited to submit a Proposal to fulfill this requirement.

Should you be **unable** to respond, please advise us by fax or in writing.

If you are interested in providing these services, please submit two (2) copies of your Proposal to the undersigned by November 27, 1995 at 14:00 hours PDT in accordance with these procedures:

1. Identify your proposal by Proposal Number and Work Title. It is requested that the Proposals submitted consist of two documents:

    1. Technical/Managerial and Organizational Proposal;
    2. Financial Proposal.

    Technical/Managerial and Organizational Proposal:

    Include the following in your Proposal, in sufficient detail for evaluation purposes and to form the basis of a possible contract: (NOTE: include NO financial information in this document):

    - A brief statement indicating your understanding of the work to be carried out;
    - A summary of your related experience;
    - A listing of staff (professional, technical, subcontractors) who will be assigned to the work, and their respective personal resumes;

- An explanation of the intended approach and/or methodology;
- Contingency plans to be carried out in the event assigned staff become unavailable during the contract period;

Financial Proposal:

Your Financial Proposal should include a detailed breakdown of the total estimated cost. The following is a guideline:

- a firm per diem rate and estimate of level of effort per task required to accomplish the work;
- Direct expenses (i.e. travel, living and miscellaneous) to be listed in detail;
- a TOTAL price for performing the work;
- The GST, where applicable, must be shown as a separate item;

> Note: Federal Departments, as a general rule, obtain services free of Provincial Sales Tax. The applicable authority for Provincial Sales Tax Licenses will be provided with the proposed contract.

- Complete, sign and include Appendix "B" (Offer of Services) as part of Financial Proposal.

2. **Submission of the Proposal document:**

Submit two (2) copies of requested proposals and return these to the Contracting Authority prior to the date and time indicated above.

Attention: Contracting Authority
Stephen Doss
Procurement Officer
Environment Canada
Corporate Branch
224 West Esplanade
North Vancouver, B.C.
V7M 3H7

Telephone: (604) 666-6700
Facsimile: (604) 666-6281
Email: dosss@epvan.dots.doe.ca

Proposals should be double-sided on recycled paper, and contain no glossy covers, binders or cerlox binding.

Proposals submitted by facsimile are acceptable provided that they are received prior to the time specified for closing of Proposals and contain the Proposal reference number and closing date. Hard copies must be provided within twenty-four (24) hours of bid closing time. Submissions by facsimile will constitute your formal proposal. Facsimile number: (604) 666-6281.

Such proposals must be comprehensive and in sufficient detail so as to permit complete evaluation in accordance with the criteria set out herein.

The bidder has the sole responsibility for ensuring that their proposal is received at the specified location prior to the time specified.

3. Validity Date:

Any proposal must remain open for acceptance for a period of not less than sixty (60) calendar days following the bid closing date.

4. Contractor Selection:

It is understood by the parties submitting proposals that to be considered valid, a proposal must meet all of the requirements detailed in the "Contractor Selection Method, Mandatory Requirements and Evaluation Criteria (Appendix "C").

It is the Proposer's responsibility to ensure their complete understanding of the requirements and instructions specified by the Department. In the event clarification is necessary, bidders are advised to contact the undersigned prior to making their submissions.

If additional information is required, please contact the undersigned at (604) 666-6700, or by facsimile at (604) 666 6281.

Yours truly,

Stephen Doss
Procurement Officer

Encl.: Appendix "A" Statement of Work
Appendix "B" Offer of Services
Appendix "C" Contractor Selection Method
Appendix "D" Additional Conditions

Statement
of
Work

Statement of Work:

EFFECTS OF MINING EFFLUENTS ON MARINE ENVIRONMENTS

BACKGROUND:

Canada regulates mining effluents including tailings into fish-bearing waters under the federal Fisheries Act, and the 1977 Metal Mining Liquid Effluent Regulations (MMLER), which apply to post-1977 metal mines and exclude gold mines using cyanide. Prohibitions against "deleterious substances" in effluents apply to all mines, and prevent for example any new direct discharge of mine tailings into the sea.

Canada's 1990 Green Plan directed that: "Pollution prevention regulations contained in the Fisheries Act were to be updated and strengthened beginning with the Pulp and Paper Regulations and the MMLER." Consultations began with a multi-stakeholder workshop on the MMLER in 1992, which recommended evaluating the MMLER by assessing the impacts of metal mining effluents on the aquatic environment. Subsequently, AQUAMIN (Assessment of the Aquatic Effects of Mining) working groups comprising industry, government, and environmental interests began reviewing the literature and mine environmental monitoring reports. AQUAMIN priorities have kept its focus on freshwater environment and no working group has considered marine effects in detail, especially for unconfined marine tailings disposal. AQUAMIN work ends March 1996.

Environment Canada requires a comprehensive review of the known effects of mine wastes (including unconfined tailings) on the marine environment to complement AQUAMIN working group conclusions on fresh water. Government cannot presently provide industry with regulatory certainty for any effluents to marine environments, especially in context of new discoveries like those recently announced at Voisey's Bay on the Laborador coast.

This project will make a synthesis of published and unpublished reports on the effects of mining effluents to marine environments. Most of these reports are available at Environment Canada in North Vancouver. This synthesis or overview together with the AQUAMIN conclusions on fresh water will give a sound science basis for Environment Canada's consultations with industry on options for amending the MMLER, and providing regulatory certainty for any future applications for marine discharge of mine effluents.

Bidders wishing to view the AQUAMIN Group 6 draft report, and other reports related to this contract may do so by arrangement with DOE's library in North Vancouver.
Contact: Andrew Fabro (604) 666-5914

OBJECTIVES:

1. Evaluate the effects of metal mine effluents including unconfined tailings on Canadian coastal marine environments.

2. Identify research gaps in marine effects monitoring, and recommend a national environmental effects monitoring program for the marine environment,

3. Propose regulatory approaches for permitting future effluents and monitoring and assessing their effects, such as through amendments to MMLER, or site-specific regulations.

TASKS:

1. Assemble, inventory and read relevant published and unpublished reports on marine environmental effects (see Appendix D)

2. With regard to methods used in AQUAMIN, assess marine environmental effects reported in ecological components like water quality, sediment chemistry, toxicity and persistence, fish, macrophytes and benthic organisms; assess the quality of tools and methods used, the extent, magnitude and reliablity of effects measured, and interpret these for each ecological component.

3. Refer to an AQUAMIN working group case study model to evaluate in an integrated fashion a case study which assesses and provides a rationale for the receiving environment's response to (and recovery from) metal mine effluents; and assess the adequacy of past monitoring programs and the potential of any recommended programs to detect and evaluate such effects.

4. Write a summary and conclusions, and make recommendations on regulatory means for ensuring adequate reporting and assessment of marine environmental effects of mining effluents.

5. Make a presentation of his or her results and recommendations to a day-long workshop on marine effects to be held at the end of the contract.

TIMETABLE, DELIVERABLES and ASSESSMENT CRITERIA:

1. Submitted work will be accepted on the basis of its scope, detail and clarity of explanation, and for the practicality of its recommendations.

2. By March 1, 1996, the Contractor will provide a copy of the draft reports on Tasks 1 2 & 3 to the Departmental Representative. The Contractor is encouraged to deliver separate draft Task reports well within the March 1 deadline.

3. By March 15, the Contractor will provide requested changes to the draft report.

4. Between March 15 and March 30 as agreed, the Contractor will make a presentation on his or her conclusions, and

4. By March 31, 1996, the Contractor will deliver to the Departmental Representative one copy, both camera-ready unbound and electronic of the Final Report.

CROWN INPUT: See Appendix D

CONTRACT ADVISORY GROUP: During the management of this contract, the Departmental Representative will consult representatives from other federal agencies and provincial governments, universities and industry who have interests in the research.

DEPARTMENTAL REPRESENTATIVE:

Robert G. McCandless P.Geo,
Sr Program Officer, Environmental Protection Branch
Environment Canada
224 West Esplanade
North Vancouver
V7M 3H7 tel 604 666-2199 fax 666-9107
e.mail: MCCANDLESSR@EPVAN.DOTS.DOE.CA,

SECURITY CLEARANCE: Not Required

Offer
of
Services

Appendix "B"
KA601-5-5132

OFFER OF SERVICE

1. **Offer submitted by:**

(Print or Type Complete or Business or Corporate Name and Address)

2. I (We) the undersigned hereby offer to Her Majesty the Queen in Right of Canada, as represented by the Minister of Environment, to furnish all necessary expertise, supervision, materials equipment and other things necessary to complete to the entire satisfaction of the Minister or his authorized representative, the work as described in the Request for Proposal according to the terms and conditions of the Department's Service Contract for the prices.

2.1 Professional Services and Associated Costs:

An all-inclusive fixed price of..............$______________ (Total of 2.1.1 + 2.1.2)
(Canadian Currency)

2.1.1 Professional Services:

The following is a breakdown of the above tendered amount for Professional Services (show fee structure all-inclusive of profit and overhead).

Category of Personnel	Per Diem Rates	# of Days Assigned	Total

Appendix "B"
KA601-5-5132

3. I (We) agree that the Offer of Services will remain firm for a period of thirty (30) calendar days after the tender closing date.

4. Payment for Professional Services and Associated Costs will be effected upon completion of each Phase, submission of invoices detailing work completed to date and upon acceptance by the Departmental Representative for services rendered/deliverables received.

   Claims for travel and accommodation expenses will be reimbursed at cost, in accordance with the Travel Directive, to be submitted with the aforementioned invoices and supported by receipts, vouchers, or other appropriate documents.

5. I (We) agree to submit herewith the following:

   (a) A PROPOSAL to undertake the work, indicating an understanding of the objectives and responsibilities, a methodology and a time schedule as it relates to the requirement;

   (b) a CORPORATE RESUME indicating relevant experience, the proposed personnel for the work team including their curriculum vitae;

   (c) a list, if applicable, of subcontractor(s) including full names and addresses, portion(s) of work to be subcontracted and relevant firm experience;

   (d) a duly completed OFFER OF SERVICES, in triplicate(3).

6. It is a condition that during the term of the contract any persons engaged in the course of carrying out this contract shall conduct themselves in compliance with the principles of the Conflict of Interest and Post-Employment Code for Public Office Holders. Should an interest be acquired or seem to cause a departure from the principles, the Contractor shall declare it immediately to the Department Representative.

OFFERS WHICH DO NOT CONTAIN THE ABOVE-MENTIONED DOCUMENTATION OR DEVIATE FROM THE PRESCRIBED COSTING FORMAT MAY BE CONSIDERED INCOMPLETE AND NON-RESPONSIVE.

Dated this day of ,19 , at in the Province of

BY: (Signing Officer) Title

Appendix "B"
KA601-5-5132

2.1.2 Associated Costs:

Associated Costs breakdown not included in Fixed price (2.1.1) on page 1.
(courier, long distance calls, reproduction, etc.)

2.2 Travel Expenses:

Reimbursable at cost in accordance with the attached Travel Directive, to a financial institution ....$________________

My/Our estimate for travel expenses is based upon the following anticipated travel requirement:

2.3 TOTAL TENDER PRICE...$________________

(Total of 2.1 + 2.2 above)

+ G.S.T. $______________

TOTAL: $______________

Contractor Selection Method

CONTRACTOR SELECTION METHOD, MANDATORY REQUIREMENTS AND EVALUATION CRITERIA

1. Contractor Selection Method:

It is understood by the parties submitting proposals that, to be considered valid, a proposal must:

- Meet all **Mandatory Requirements** as described in Item #2, and
- Achieve a **minimum of sixty-five (65) points** on a scale of 100. See Item #3 (Evaluation Criteria) for full details.

Proposals not meeting these conditions above will be given no further consideration. Neither the valid proposal that scores the highest number of rating points, nor the one that contains the lowest cost estimate will necessarily be accepted. The selection of the contractor will be made on the basis of the best overall value to the Crown in terms of technical merit and cost by using the following cost-per-point method.

Bidder's estimate
—divided by— =$xx.xx cost-per-point
Tech. scoring points

The bidder submitting the lowest cost-per-point calculated by this method will be recommended to be awarded this contract.

2. Mandatory Requirements

Bidders must clearly demonstrate that the following requirements are met:

(a) Proposed Personnel:

- The Principal Investigator must demonstrate (a) training in biological or chemical oceanography at the post-graduate level and extensive experience in applied oceanographic research, and (b) support from associate researchers who are available to the bidder to provide information and interpretations on subjects beyond his/her special (i.e. toxicology, physical oceanography, sedimentation, ecology of fishes, macrophytes and sub-tidal, soft bottom benthic communities and statistical methods and interpretation.
- Bidders must list in a concise way, directly-related projects the proposed personnel and/or firm have undertaken and specifically for each project:
  - a description of the project and it's duration;
  - the responsibilities of the proposed researcher(s) in the project, and

- Names and telephone numbers of project client(s) whom the Departmental Representative may choose to contact for assessment of the work performed.

Proposals not meeting the Mandatory Requirements as outlined above will be given no further consideration.

3. **Evaluation Criteria: (Subject to point rating)**

a) Study Strategy: (40 points)

The bidder:

- Understands the scope and importance of the project
- Understands the RFP Terms of Reference
- Organizes the project into logical tasks and plans for their completion
- Has means to handle potential problems during the project
- Has potential for successfully completing the work
- Demonstrates original and innovative ideas
- Has a realistic estimation of the time required

b) Training and Experience: (40 Points)

Evaluators will assess and assign values for the Contractor's:

- Experience directly applicable to the required project (e.g. in marine environmental effects monitoring surveys) or of a similar nature to the requirements and the suitability of the academic training of all researchers assigned to the project.

c) Project Organization: (20 Points)

Evaluators will assess and assign values for the Contractor's.

- Assurance of liaison with the Departmental Representative and as necessary, members of the project advisory team,
- Commitment to turn around times,
- Overall organization of the project.

APPENDIX "D"
ADDITIONAL CONDITIONS
AND
GENERAL INSTRUCTIONS

ENVIRONMENT CANADA APPENDIX "D"

ADDITIONAL CONDITIONS WHICH FORM A PART OF THIS CONTRACT

1. Environment Canada (DOE) at its North Vancouver office will provide working space for the Contractor so that he or she has convenient access to reports and publications held by DOE, and to DOE officers, during the period the Contractor needs this access. DOE does not intend this period to be lengthened to include drafting the report. DOE cannot provide any long distance, facsimile or photocopying services, and nor will DOE provide access to a computer except where as agreed with the Departmental Representative, the Contractor needs such access to use any DOE electronic data base.

2. DOE has a large collection of reports and publications on marine effects of mining effluents, as well as field notes and analyses which have not been included in published reports. DOE officers who have studied marine environmental effects will discuss their work with the Contractor. In September 1995, DOE completed a small program of grab sampling over mine tailings deposited in Alice Arm, and DOE will provide results for this work to the Contractor during the term of the contract.

Appendix "D"

GENERAL INSTRUCTIONS

Contract Number

GC1 Interpretation

1.1 In the contract,

1.1.1 "contract" means the contract documents referred to in the Articles of Agreement;

1.1.2 "invention" means any new and useful art, process, machine, manufacture of composition of matter, or any new and useful improvement thereof;

1.1.3 "Minister" includes a person acting for, or if the office is vacant, in place of the Minister and the Minister's successors in the office, and the Minister's or their lawful deputy and any of the Ministers or their representatives appointed for the purpose of the contract;

1.1.4 "work", unless otherwise expressed in the contract, means everything that is necessary to be done, furnished or delivered by the Contractor to perform the Contractor's obligations under the contract;

1.1.5 "Departmental Representative" means the officer or employee of Her Majesty who is designated by the Articles of Agreement and includes a person authorized by the Departmental Representative to perform any of the Departmental Representative's functions under the contract;

1.1.6 "prototypes" includes models, patterns and samples;

1.1.7 "technical documentation" means designs, reports, photographs, drawings, plans, specifications, computer, software, surveys, calculations and other data, information and material collected, computed, drawn or produced, including computer printouts.

GC 2 Successors and Assigns

2.1 The contract shall enure to be benefit of and be binding upon the parties hereto and their lawful heirs, executors, administrators, successors and assigns.

GC 3 Assignment

3.1 The contract shall not be assigned in whole or in part by the Contractor without the prior written consent of the Minister and any assignment made without that consent is void and of no effect.

3.2 No assignment of the contract shall relieve the Contractor from any obligation under the contract of imposo any liability upon Her Majesty or the Minister.

GC 4 Time of the Essence

4.1 Time is of the essence of the contract.

4.2 Any delay by the Contractor in performing the Contractor's obligations under the contract which is caused by an event beyond the control of the Contractor, and which could not have been avoided by the Contractor without incurring unreasonable cost through the use of work-around plans including alternative sources or other means, constitutes an excusable delay. Events may include, but are not restricted to: acts of God, acts of Her Majesty, acts of local or provincial governments, fires, floods, epidemics, quarantine restrictions, strikes or labour unrest, freight embargoes and unusually severe weather.

4.3 The Contractor shall give notice to the Minister immediately after the occurrence of the event that causes the excusable delay. The notice shall state the cause and circumstances of the delay and indicate the portion of the work affected by the delay. When requested to do so by the Departmental Representative, the Contractor shall deliver a description in a form satisfactory to the Minister, of work-around plans including alternative sources and any other means that the Contractor will utilize to overcome the delay and endeavour to prevent any further delay. Upon approval in writing by the Minister of the work-around plans and use all reasonable means to recover any time lost as a result of the excusable delay.

4.4 Unless the Contractor complies with the notice requirements set forth in the contract, any delay that would constitute an excusable delay shall be deemed not to be an excusable delay.

4.5 Notwithstanding that the Contractor has complied with the requirements of **GC4.3**, Her Majesty may exercise any right of termination contained in **GC8**.

GC 5 Liability and Indemnification

5.1 The Contractor shall indemnify and save harmless Her Majesty and the Minister from and against all claims, losses, damages, costs, expenses, actions and other proceedings, made, sustained, brought, prosecuted, threatened to be brought or prosecuted, in any manner based upon, occasioned by or attributable to any injury to or death of a person or damage to or loss of property arising from any wilful or negligent act, omission or delay on the part of the Contractor, the Contractor's servants or agents in performing the work or as a result of the work.

5.2 The Contractor shall indemnify Her Majesty and the Minister from all costs, charges and expenses whatsoever that Her Majesty sustains or incurs in or about all claims, actions, suits and proceedings for the use of the invention claimed in a patent, or infringement or alleged infringement of any patent or any registered industrial design or any copyright resulting from the performance of the Contractor's obligations under the contract, and in respect of the use of or disposal by Her Majesty of anything furnished pursuant to the contract.

5.3 The Contractor's liability to indemnify or reimburse Her Majesty under the contract shall not affect or prejudice Her Majesty from exercising any other rights under law.

5.4 It is understood and agreed by the parties hereto, that Her Majesty will not be liable for claims in respect of death, disease, illness, injury or disability which may be suffered by employees or agents employed by the Contractor due to their negligence in carrying out the services described in "Appendix A".

5.5 It is further understood and agreed by the parties hereto, that the Contractor shall be liable for any damages to or loss of Her Majesty's property occasioned by or attributable to the Contractor's employees or agents in carrying out the services in "Appendix A".

GC 6 Notices

6.1 Where in the contract any notice, request, direction, or other communication is required to be given or made by either party, it shall be in writing and is effective if delivered in person, sent by registered mail, by telegram, telex or by facsimile addressed to the party for whom it is intended at the address mentioned in the contract and any notice, request, direction or other communication shall be deemed to have been given if by registered mail, when the postal receipt is acknowledged by the other party; by telegram, when transmitted by the carrier: and, by telex or facsimile, when transmitted. The address of either party may be changed by notice in the manner set out in this provision.

GC 7 Canadian Labour and Materials

7.1 The Contractor shall use Canadian labour and material in the performance of the work to the full extent to which they are procurable, consistent with proper economy and the expeditious carrying out the work.

GC 8 Termination or Suspension

8.1 The Minister may, by giving notice to the Contractor, terminate or suspend the work with respect to all or any part or parts of the work not completed.

8.2 All work completed by the Contractor to the satisfaction of Her Majesty in accordance with the provisions of the contract and, for all work not completed before the giving of such notice. Her Majesty shall pay the Contractor's costs as determined under the provisions of the contract and, in addition, an amount representing a fair and reasonable fee in respect of such work.

8.3 In addition to the amount which the Contractor shall be paid under GC8.2, the Contractor shall be reimbursed for the Contractor's cost and incidental to the cancellation of obligations incurred by the Contractor pursuant to such notice and obligations incurred by or to which the Contractor is subject with respect to the work.

8.4 Payment and reimbursement under the provisions of GC8 shall be made only to the extent that it is established to the satisfaction of the Minister that the costs and expenses were actually incurred by the Contractor and that the same are fair actually incurred by the Contractor and that the same are fair and reasonable and are properly attributable to the termination or suspension of the work or the part thereof so terminated.

8.5 The Contractor shall not be entitled to be reimbursed any amount which, taken together with any amounts paid or becoming due to the Contractor under the contract, exceeds the contract price applicable to the work or the particular part thereof.

8.6 The Contractor shall have no claim for damages, compensation, loss of profit, allowance or otherwise by reason of or directly or indirectly arising out of any action taken or notice given by the Minister under the provisions of GC8 except as expressly provided therein.

GC 9 Termination Due to Default of Contractor

9.1 Her Majesty may, by notice to the Contractor, terminate the whole or any part of the work if:

(i) the Contractor becomes bankrupt or insolvent, or a receiving order is made against the Contractor, or an assignment is made for the benefit of creditors, or if an order is made or resolution passed for the winding up of the Contractor, or if the Contractor takes the benefit of any statute for the time being in force relating to bankrupt or insolvent debtors, or

(ii) the Contractor fails to perform any of the Contractor's obligations under the contract, or, in the Minister's view, so fails to make progress as to endanger performance of the contract in accordance with its terms.

9.2 In the event that Her Majesty terminates the work in whole or in part under GC9.1, Her Majesty may arrange, upon such terms and conditions and in such matter as Her Majesty deems appropriate, for the work to be completed that was so terminated, and the Contractor shall be liable to Her Majesty for any excess costs relating to the completion of the work.

9.3 Upon termination of the work under GC9.1, the Minister may require the Contractor to deliver and transfer title to Her Majesty, in the manner and to the extent directed by the Minister, any finished work which has not been delivered and accepted prior to such termination and any materials or work-in-process which the Contractor has specifically acquired or produced for the fulfilment of the contract. Her Majesty shall pay the Contractor for all such finished work delivered pursuant to such direction and accepted by Her Majesty, the cost to the Contractor of such work plus the proportionate part of any fee fixed by the said contract and shall pay or reimburse the Contractor the fair and reasonable cost to the Contractor of all materials or work-in-process delivered to Her Majesty pursuant to such direction. Her Majesty may withhold from the amounts due to the Contractor such sums as the Minister determines to be necessary to protect her Majesty against excess costs for the completion of the work.

9.4 The Contractor shall not be entitled to be reimbursed any amount which, taken together with any amounts paid for becoming due to the Contractor under the contract, exceeds the contract price applicable to the work or the particular part thereof.

9.5 If, after the Minister issues a notice of termination under GC9.1, it is determined by the Minister that the default of the Contractor is due to causes beyond the control of the Contractor, such notice of termination shall be deemed to have been issued pursuant to GC8.1 and the rights and obligations of the parties hereto shall be governed by GC8.

GC 10 Records to be kept by Contractor

10.1 The Contractor shall keep proper accounts and records of the cost of the work and of all expenditures or commitments made by the Contractor including the invoices, receipts and vouchers, which shall at reasonable times be open to audit and inspection by the authorized representatives of the Minister who may make copies and take extracts therefrom.

10.2 The Contractor shall afford facilities for audit and inspection and shall furnish the authorized representatives of the Minister with such information as the Minister or they may from time to time require with reference to the documents referred to herein.

10.3 The Contractor shall not dispose of the documents referred to herein without the written consent of the Minister, but shall preserve and keep them available for audit and inspection for such period of time as any specified elsewhere in the contract or, in the absence of such specification, for a period of two years following completion of the work.

GC 11 Ownership of Intellectual and Other Property Including Copyright

11.1 Technical documentation and prototypes produced by the Contractor in the performance of the work under the contract shall vest in and remain the property of Her Majesty, and the Contractor shall account fully to the Minister in respect of the foregoing in such manner as the Minister shall direct.

11.2 Technical documentation shall contain the following copyright notice:

(c) HER MAJESTY THE QUEEN IN RIGHT OF CANADA (YEAR) as represented by the Minister of the Environment

11.3 Technical information and inventions conceived or developed or first actually reduced to practice in performing the work under the contract shall be the property of Her Majesty any articles or things embodying such technical information and inventions.

GC 12 Conflict of Interest

12.1 The Contractor declares that the Contractor has no pecuniary interest in the business of any third party that would cause a conflict of interest or seem to cause a conflict of interest in carrying out the work. Should such an interest be acquired during the life of the contract, the Contractor shall declare it immediately to the Departmental Representative.

12.2 It is a term of the contract:

(1) that no former public office holder who is not in compliance with the post-employment provisions of the Conflict of Interest and Post-Employment Code for Public Office Holders shall derive a direct benefit from this contract;

(2) that during the term of the contract any persons engaged in the course of carrying out this contract shall conduct themselves in compliance with the principles of the Conflict of Interest and Post-Employment Code for Public Office Holders. Should an interest be acquired during the life of the contract that would cause a conflict of interest or seem to cause a departure from the principles, the Contractor shall declare it immediately to the Departmental Representative.

GC 13 Contractor Status

13.1 This is a contract for the performance of a service and the Contractor is engaged under the contract as an independent contractor for the sole purpose of providing a service. Neither the Contractor nor any of the Contractor's personnel is engaged by the contract as an employee, servant or agent of Her Majesty. The Contractor agrees to be solely responsible for any and all payments and/or deductions required to be made including those required for Canada or Quebec Pension Plans, Unemployment Insurance, Workmen's Compensation, or Income Tax.

GC 14 Warranty by Contractor

14.1 The Contractor warrants that the Contractor is competent to perform the work required under the contract in that the Contractor has the necessary qualifications including the knowledge, skill and ability to perform the work.

14.2 The Contractor warrants that the Contractor shall provide a quality of service at least equal to that which contractors generally would expect of a competent contractor in a like situation.

GC 15 Member of House of Commons

15.1 No member of the House of Commons shall be admitted to any share or part of this contract or to any benefit to arise therefrom.

GC 16 Amendments

16.1 No amendment of the contract nor waiver of any of the terms and provisions shall be deemed valid unless effected by a written amendment.

GC 17 Entire Agreement

17.1 The Contract constitutes the entire agreement between the parties with respect to the subject matter of the contract and supersedes all previous negotiations, communications and other agreements relating to it unless they are incorporated be reference in the contract.

GC 18 Criminal Code Prohibitions

18.1 Conviction under Section 121, 124 and 418 of the Criminal Code denies the capacity to contract with the Crown, unless the Governor Council under section 748(3) has restored (in whole or in part) this capacity to the individual or the individual has been granted a pardon.

APPENDIX "E"

SUPPLEMENTARY INSTRUCTIONS

Appendix "E"

Supplementary Conditions

Contract Number

1.0 Haitian Condition

1.1 The Contractor represents and warrants that, to his/her knowledge, the goods or services provided pursuant to this contract are neither of Haitian origin nor from majority-owned (51% of the voting rights) Haitian companies located outside Haiti.

1.2 Any breach of this representation and warranty shall entitle the Minister to terminate this contract for default and to recover from the Contractor any loss or damages resulting therefrom.

2.0 Sales Tax

2.1 The Contractor shall not invoice or collect any Ad Valorem Sales Tax levied by the Province in which the goods or taxable services are delivered to federal Government Departments under authority of the following Provincial Sales Tax Licenses:

Newfoundland	32243-0-09
Prince Edward Island	OP-10000-250
Nova Scotia	U84-00-03172-3
New Brunswick	P87-60-01648
Quebec	Q-398-SS-3921-1-P
Ontario	11708174G
Manitoba	390516-0
British Columbia	005521

2.2 In all other provinces, Provincial Sales Taxes do not apply to goods or taxable services delivered to Federal Government Departments or Agencies under this contract.

2.3 The Contractor is not relieved of any obligation to pay Provincial Sales Taxes on goods or taxable services which the Contractor uses or consumes in the performance of this contract.

3.0 Certification – Contingency Fees

3.1 The Contractor certifies that it has not directly or indirectly pay or agreed to pay and covenants that it will not directly or indirectly pay a contingency fee for the solicitation, negotiation or obtaining of any contract to any person other than an employee acting in the normal course of the employee's duties.

3.2 All accounts and records pertaining to payments of fees or other compensation for the solicitation, obtaining or negotiation of the contract shall be subject to the Accounts and Audit provisions of the resulting contract.

3.3 If the Contractor certifies falsely under this section or is in default of the obligations contained therein, the Minister may either terminate the contract for default provisions of the contract or recover from the Contractor by way of reduction to the contract price or otherwise the full amount of the contingency fee.

3.4 In this section:

"contingency fee" means any payment or other compensation that is contingent upon or is calculated upon the basis of a degree of success in solicitating or obtaining a government contract or negotiating the whole or any part of its terms.

"employee" means a person with whom the Contractor has an employer/employee relationship.

"person" includes an individual or group of individuals, a corporation, a partnership, an organization and an association and, without restricting the generality of the foregoing, includes any individual who is required to file a return with the Registrar pursuant to section 5 of the Lobbyist Registration Act R. S. 1985 c.44 (4th Supplement) as the same may be amended from time to time.

APPENDIX II

EXCERPTS FROM THE
DRAFT PROGRESS REPORT ON

THE EFFECTS OF METAL MINE EFFLUENT ON THE MARINE ENVIRONMENT:
BIBLIOGRAPHIC DATABASE, MINE SUMMARIES AND TRENDS

1.0 INTRODUCTION

1.1 Background and Purpose of Report

The general purpose of this report was to highlite the information available to date on Canadian metal mine effluent discharges to marine waters and promote discussion of additional information that should be included for review, particularly for a case study.

More specifically, the purpose of the progress report was to provide: i) an outline of the methods used in the reviews of relevant mining projects, ii) an inventory of reports (database) relevant to the 12 mines listed by Environment Canada (See Figure 1), iii) the summaries of information available to date for each mine, iv) a brief interpretive discussion of the effects noted at each mine, and v) the necessary information and interpretion to select a case study for the next phase of this project (i.e., AQUAMIN Case Study).

In conducting the work to date, numerous reports for twelve sites were examined, and it was necessary to limit the level of detailed analysis in order to develop an appreciation for the big picture in short period of time. The next task of this project entailed a debate (internal and external) of the findings and selection of a preferred site for a more *detailed* analysis under the AQUAMIN framework.

2.0 INFORMATION SOURCES, DATABASE DEVELOPMENT AND EXTRACTION FORMS

2.1 Information Sources and Database Development

The majority of information and reports used in this assessment was obtained from the Environment Canada library in North Vancouver. Additional sources included:

1. Robert McCandless (EC)
2. Robie MacDonald (IOS)
3. Wayne Knapp (DFO)
4. Darcy Goyette (EC)
5. Bruce Fallis (DFO)
6. Tim Parsons (UBC)
7. Gordon Ford (BCE - Victoria)

8. Shelley Thibaudeau (WB, NWT)
9. Neil Matheson (BCE - Surrey)
10. Mark Love (BCE - Smithers)
11. John Goyman (Nanisivik Mine)
12. Deirdre Reily (Cominco)
13. John Knapp (Cominco)
14. H. Tays (Falconbridge)
15. Ian Horne (BHP Minerals)

These people provided information, reports or lists of reports that were later retrieved from either the UBC or SFU libraries. In addition, the AQUAMIN database was searched for information relevant to the marine environment.

All reports received were entered into a marine mining effects database in "In Magic". The reports were keyworded and sorted by mine. More than three hundred records have been entered into the bibliographic database on the effects of metal mining effluent on the marine environment. The subject mines for this study were developed and in production during different timeframes from 1905 to 1995. Some mines operated over longer time periods than others and/or extracted significantly more ore than others. Consequently, the amount of information available differs significantly from one mine to the next. Figure 3 outlines the number of reports that were available for each mine (at the time this report was in preparation).

2.2 Development of Mine-Specific Summary Extraction Form

A standardized form was developed by Golder to extract and summarize the information available in the reports discussed above. This was considered necessary to guide the information extraction process to ensure that a consistent level of effort was used throughout the information extraction and summary process. The forms were developed by the project team and were reviewed and approved by Environment Canada. All the information available for one mine was condensed and summarized onto one form.

The following outlines the headings used in the extraction forms:

1. General Information (e.g. Mine name, location, landscape).

2. Contaminant Source Characterization: (e.g. process volume, metals produced, mining method, extraction process, method of waste discharge, particle size distribution of tailings, other chemical sources).

3. Relevant Physical Oceanographic Processes (e.g. tidal current, surface currents, estuarine currents, deep water renewal events, coastal upwelling, wave exposure, measurements, stratification, pre- and post operations seafloor characteristics, ocean transport studies).

4. Chemical Oceanographic Fate & Transport Processes (e.g. sediment analyses, sediment porewater analyses, water column analyses, chemical speciation - dissolved and bottom sediments, primary exposure media).

5. Receptor/Habitat Characterization (e.g. potential habitat effected - intertidal, subtidal, photic, euphotic; receptors exposed - phytoplankton, zooplankton, benthic invertebrates, demersal fish, pelagic fish, macrophytes, marine mammals).

6. Reported Biological Effects (e.g. tests conducted - lab, field; effects reported - organism level - tissue metal content, toxicity studies, pathology; population level - elimination of benthic community, decreased abundance).

3.0 OVERVIEW OF TRENDS AND RECOMMENDATIONS FOR CASE STUDY

Data Quality

Several trends have become evident in this preliminary review of reports on the effects of metal mine effluents on the marine environment. Large differences exist in the availability of data, with larger volumes of information being available for mines currently in operation or recently closed (See Figure 2). For this review, large amounts of information were available for Island Copper and Kitsault (Figure 3). Indications from the Northwest Territories Water Board are that a great deal of information is also available for Nanisivik and Polaris in the form of mine-sponsored monitoring reports, however, these reports were not available at the time of this review. Given the timeframe of operation of the Britannia mine, a relatively large amount of information was available. This may be related to the proximity to Vancouver and associated research facilities and the extent of bioeffects related to the mine.

Data Quality

This trend of increased data quantity available for the operating or recently closed mines was repeated for data quality. Bioeffects data for Island Copper and the Kitsault mines was rated 'good', while the available data for all the older mines was rated either 'fair', 'poor' or 'non-existent'. The quality of bioeffects data for Nanisivik and Polaris was judged to be 'good', based on discussions with the NWT Water Board.

The quality of chemical oceanographic information was also generally poor for the mines with the older mines have less information than the newer mines. An exception to this was Britannia mine, an older mine for which the chemical oceanographic information was rated 'good'. A similar 'good' rating was given to Island Copper with Kitsault receiving only a 'fair-to-good' rating. The chemical oceanographic information for all other mines was either 'fair', 'poor' or 'non-existent'.

Generally, the quality of physical oceanographic information for the twelve mine sites was of poorer quality than the chemical oceanographic information. Only the physical oceanographic data for the Kitsault mine was rated 'good'. Anyox is shown with a 'good' rating as well, however, this was by virtue of the proximity of Anyox to Kitsault and the prospect of shared data. There are five mines for which there are no physical oceanographic data available.

Promalgation of Mine Regulations and Data Availability

The trend of data availability and timeframe of mine operation can also be related to the timeframe of mine regulations in BC and Canada. The first mine regulations were adopted in the 1970s, at the time that the Island Copper mine was in the early stages of operation and before AMAX re-opened the Kitsault mine. All other mines that were discharging to the marine environment were either closed or nearing the end of the operation period. Nanisivik, which opened in 1976 and Polaris, which opened in 1981 were subject to mine regulations and are considered to have, by the NWT Water Board, good monitoring programs.

4.0 RECOMMENDATIONS FOR AQUAMIN CASE STUDY

Although this review of the available data is not considered to be exhaustive, it was considered adequate to highlight the data gaps. Generally, the data are considered to be inadequate to assess the effects of older mines on the marine environment. In addition, much has been learned in the way of environmental stewardship since the older operations have closed, and it is unlikely these older practices would be considered in a contemporary setting. The quality of data for the newer mines shows a dramatic improvement, with overall good ratings of the data for Island Copper and Kitsault. These two mines are also good examples of contemporary submarine tailing disposal operations. Thus, these two sites were considered to be candidates for the case study. For the two arctic mines, Polaris and Nanisivik, the information databases are promising as case studies, although they represent unique operations which may not have wide applicability (e.g. natural coastal impoundments) and do not discharge *directly* to the marine environment.

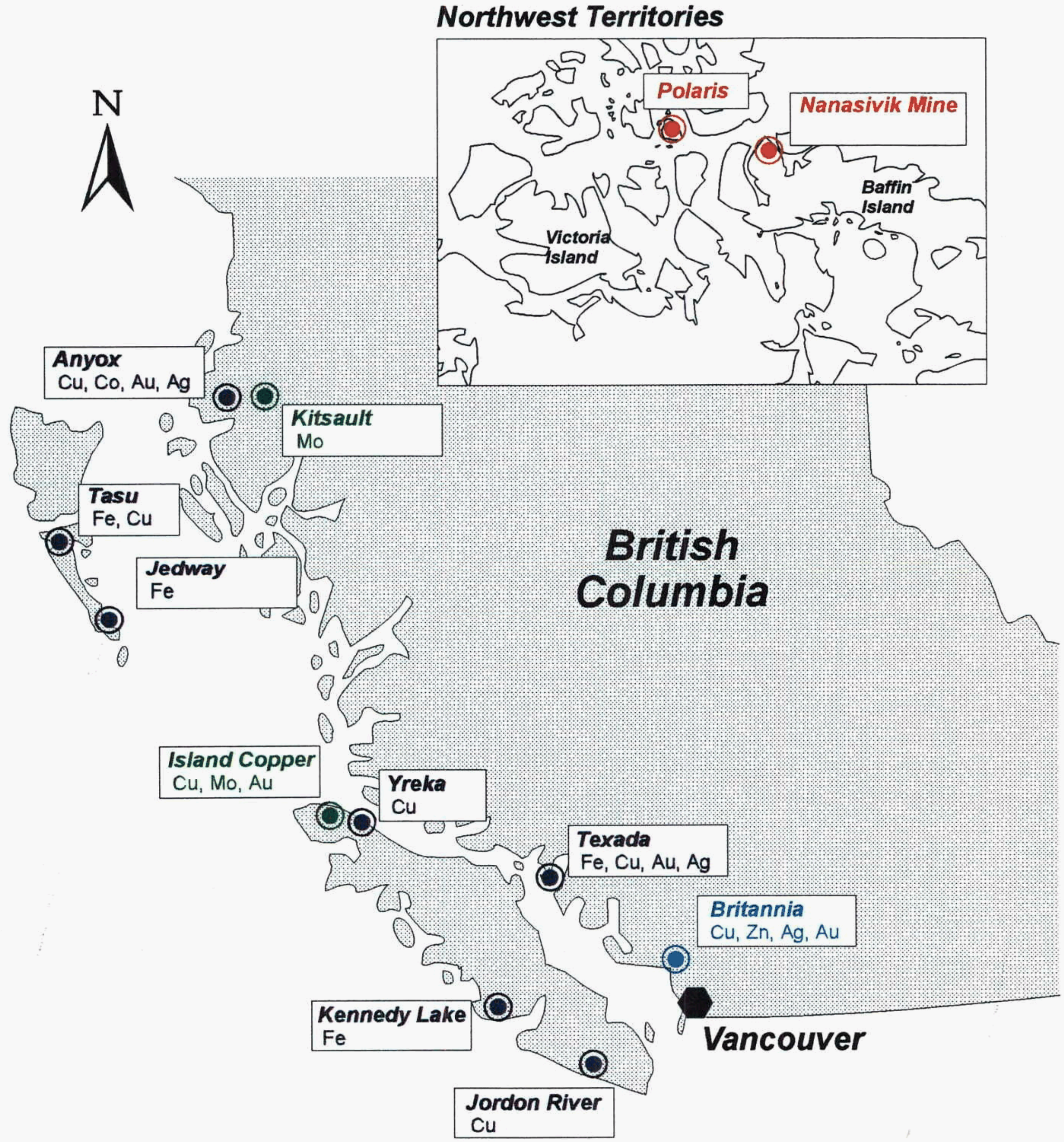
The Kitsault mine was considered to be a good candidate for the case study since a large volume of monitoring data exists from diverse sources (industry, government and academia), the receiving environment is representative of Canadian coastal mines and the mining operation was relatively recent, thereby representative of relatively current mining practices.

Island Copper was also considered to be a good candidate for the case study since a large volume of monitoring data also exists for this mine, the receiving environment is also representative of coastal mines, it is a recent operation utilizing current mining practices, the mining operation occurred for 24 years allowing adequate time for effects to develop, and it has a substantial submarine tailings disposal.

The main deterrent to using the Kitsault mine for the case study compared to the Island Copper is that the Kitsault mine is complicated by two operating periods using different disposal technologies. In addition, the Kitsault mine under AMAX ownership operated for only slightly more than a year, prohibiting any analysis of trends. Furthermore, there are other sources of metals and stressors that may have caused bioeffects in the receiving environment (e.g. B.C. Molybdenum Kitsault, Anyox and the town of Kitsault).

For these reasons and based on the data available at this time, Island Copper was proposed to be the mine most suited to the case study.

R:\ENVIROS\952-1928\REPORTS\REPORT2\APXII.DOC



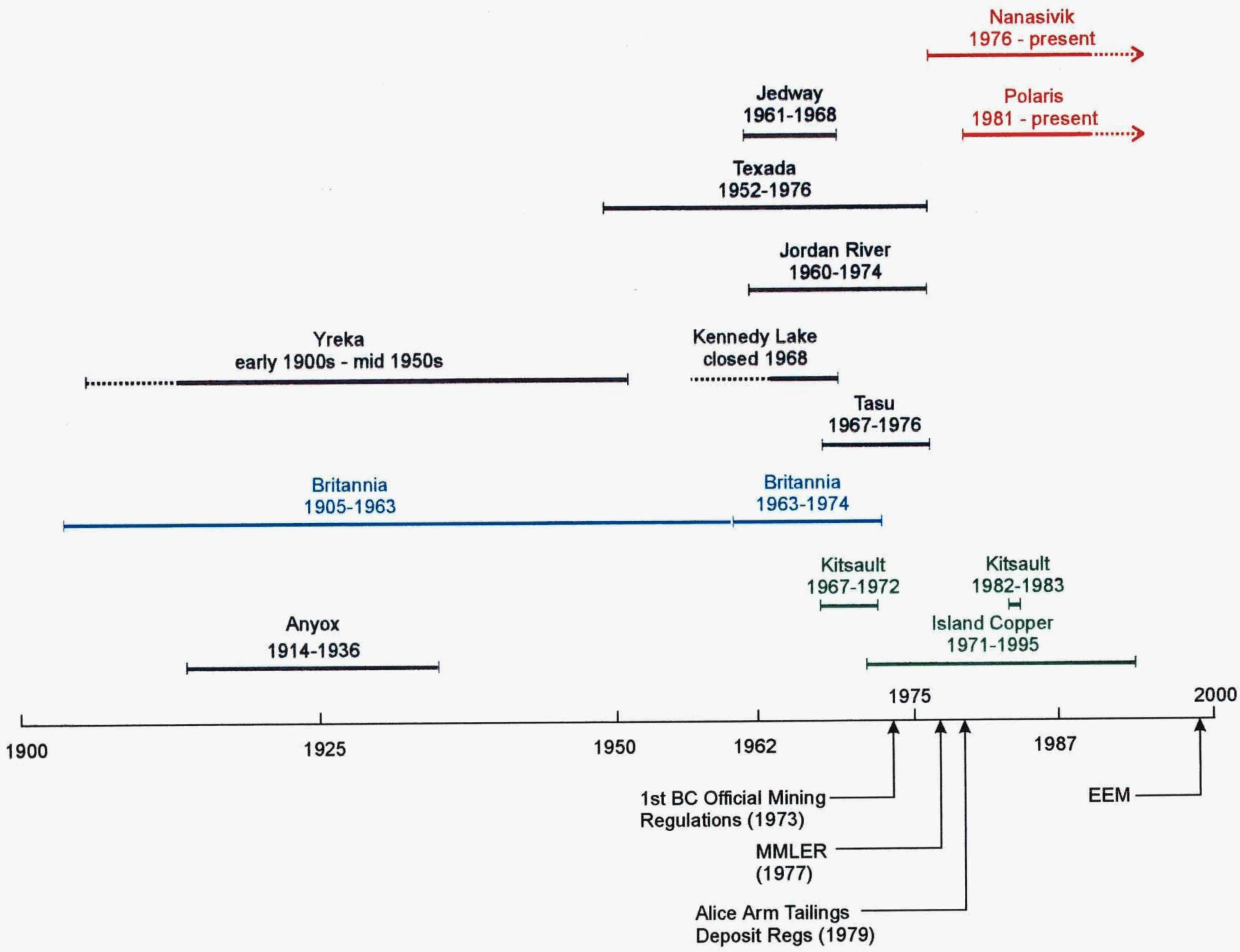
PROJECT NO. 952-1928 DRAWN BY: GG REVIEWED BY: PM DATE: JAN-19-96 FILE LOCATION: J:\9521928\0196MAP.CDR

Golder Associates

METAL MINES DISCHARGING TO THE MARINE ENVIRONMENT

Figure 1

PROJECT NO. 952-1928   DRAWN BY: GG   REVIEWED BY: PM   DATE: JAN-22-96   FILE LOCATION: J:\9521928\0196\TIMELINE.CDR

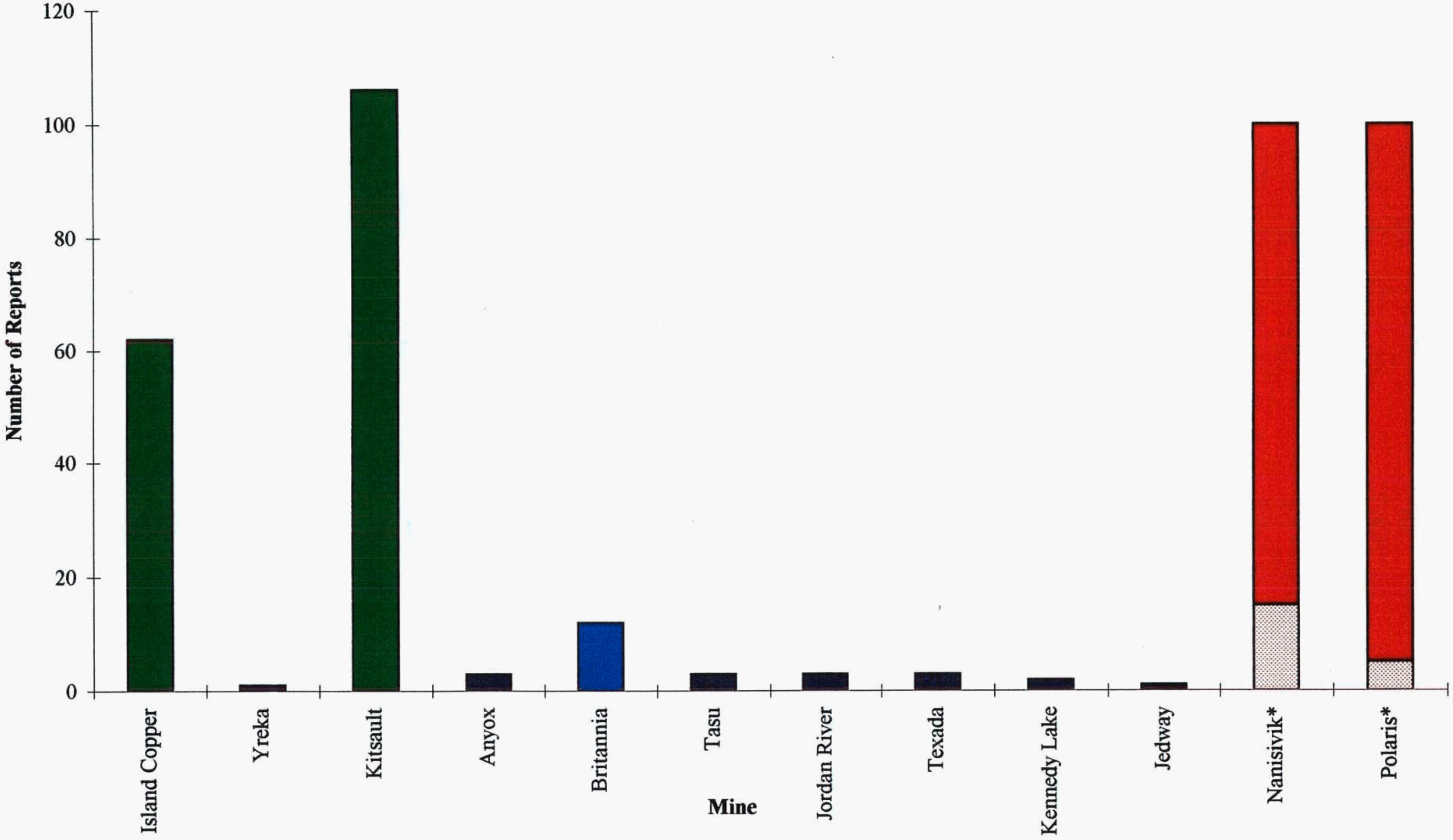


Golder Associates

TIME FRAME OF OPERATION OF SELECTED MINES

Figure 2

Figure 3
Quantity of Reports per Mine



*Note: reports are available for Nanisivik and Polaris at NWT Water Board