CASE STUDIES OF SUBMARINE TAILINGS DISPOSAL: VOLUME 1 - NORTH AMERICAN EXAMPLES

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VOLUME 1 - NORTH AMERICAN EXAMPLES

A Report Resulting from a Cooperative Agreement
with the University of British Columbia

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Frontispiece: The engineered tailings outfalls at Island Copper mine. The operating outfall is at the left with seawater mix tank and tailings pipeline connected underwater. The original, now standby, outfall on the right has a smaller seawater mix tank and the tailings discharge directly to it from the pipeline on the catwalk.

Editors' Preface

This two volume report summarizes global experience with Submarine Tailings Discharge (STD) as an option for coastal mines in reducing the environmental problems implicit in tailings disposal.

Our intent is to conclude Volume II with a development of a set of Screening Criteria for appraising STD. The criteria will be useful for mine developers and regulatory agents in appraising the validity of STD at new sites, or for environmental upgrading at existing mines.

To some extent the technical screening criteria are already obvious: (1) submarine topography allowing tailings deposition below the euphotic zone by an appropriately engineered deep outfall, (2) virtually no risk of tailings resuspension and upwelling, and (3) other resources such as fisheries either not affected, or only slightly so (and recoverable or replaceable by alternatives after mine closure). These criteria will be developed in more detail after we have documented the remaining relevant case histories in Volume II.

Volume I (this volume) covers the four best documented relevant case histories. They happen to all be from North America: two from Alaska and two from Canada. All the chapter authors have personal experience with one or more of the cases.

Volume II will provide other relevant case histories. They are largely from other countries. We currently expect Volume II to include the Misima gold mine in Papua New Guinea, and the Black Angel lead-zinc mine in Greenland. We will document new developments or proposals for STD in Peru, Turkey and Fiji. We will provide some documentation from coastal mines that did not use STD, but where our screening criteria indicate that STD could have avoided the environmental impacts generated. We will provide a second chapter on Island Copper Mine, Canada, as the continuously ongoing monitoring there is, once again, entering a novel phase useful at other sites: predicting recovery following mine closure (expected in 1996), and planning appropriate monitoring to check the predictions.

We have had a number of editorial difficulties in preparing this Volume. They mainly involve units of measurement, definitions and abbreviations.

For units of measurement, in our texts we use the metric system, except where we are quoting measurements from original documents. Where Tables and Figures are reformatted we keep the original units, otherwise conversions produce silly values (3 feet for instance needs to be converted to 0.9 meters). A set of Conversion Constants follows this Preface.

Our main problem with definitions occurs with the word "contamination". We use it to mean chemical or microbiological environmental impact, and not physical impact such as benthic smothering by those tailings which are chemically inert. This distinction allows us to distinguish in an environmental context between various, chemically different, kinds of tailings. Some tailings such as those from lead-zinc mines might have a high risk of generating contamination, whereas others have far less risk.

Finally STD (Submarine Tailings Discharge) has a synonym. At Island Copper Mine, STD has been used in many of the annual reports to mean standard deviation. We have left this abbreviation in the republished Island Copper figures, as we see no ambiguity in the context.

Conversions Constants

foot	x	0.3048	=	meters
yard	x	0.9144	=	meters
fathom	x	1.8288	=	meters
cubic foot	x	0.02831	=	cubic meters
ton (short)			=	2,000 lbs
	x	907.18	=	kilograms
	x	0.90718	=	tonnes (metric)
lbs/ton	x	500	=	milligrams/kilogram or ppm

CASE STUDIES OF SUBMARINE TAILINGS DISPOSAL:
VOLUME I - NORTH AMERICAN EXAMPLES

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Abstract

This report details four case histories of Submarine Tailings Disposal (STD) from Canada and Alaska. STD involves relatively new technology to ensure that tailings are deposited below resuspension depth in chemically-unreactive low-oxygen deposits. Previous discharge systems to rivers and beaches were environmentally unsatisfactory as they did not achieve this environmental objective.

This report presents, for each case history, descriptions of the ore body and the milling process, the wastes produced, the engineered tailings outfalls and data demonstrating the levels of environmental impact.

At Island Copper Mine, Canada, the STD system with both its positive and negative aspects is the best documented anywhere. A comprehensive monitoring program has been in place since 1970 prior to operations which started in 1971. Monitoring is scheduled to continue through to closure, expected in 1996, and possibly afterwards. Essentially, STD can deposit tailings to the seabed of a fjord in a way that does not contaminate either the overlying water column or the seabed, and does allow local commercial fisheries (salmon and crabs) to continue. Where active tailings deposition and localized resuspension smothers benthos and causes turbidity there is no indication of impact on primary biological production, and natural recolonization restores a productive ecosystem within one to two years.

The other case studies include the Kitsault molybdenum mine, near the Canadian - Alaskan border, the WestGold marine placer dredging operation near Nome, Alaska, and the proposed Quartz Hill molybdenum mine near Ketchikan.

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Dr. Poling is Professor of Mineral Process Engineering at the University of British Columbia. He has acted as an environmental and process advisor to BHPs Island Copper Mine since 1971 and for Jordan River Mine and the Quartz Hill Mine proposal. At present he coordinates the Island Copper Mine Environmental Advisory Committee dealing with submarine tailing disposal, waste rock disposal and closure planning. He has authored several articles on submarine disposal and serves on several joint industry-government-academic committees dealing with mine environmental protection and land reclamation.

D.V. Ellis, Ph.D., R.P.Bio.

Dr. Ellis is Professor of Biology at the University of Victoria in Canada, and a Registered Professional Biologist. He has acted as an environmental consultant for Island Copper Mine since 1972, for Wesfrob iron mine, Polaris and Black Angel lead-zinc mines, Bougainville and Marcopper copper mines and the Quartz Hill Development. He edited the multi-authored books *Marine Tailings Disposal* in 1982 and *Pacific Salmon; Management for People* in 1978. He is the author of the 1989 book *Environments at Risk: Case Histories of Impact Assessment*, about half of which are cases from the mining industry. He is the author of many articles in refereed professional journals, and is on the Editorial Board of the international journal *Marine Pollution Bulletin.*

C.A. Pelletier, B.Sc.

Mr. Pelletier, President of Rescan Consultants Inc., has an extensive background in the chemical/metallurgical/environmental aspects of precious metals, base metals, potash and coal mining developments. His experience in submarine tailings disposal is very extensive. Environmental auditing, risk analysis and hazardous site investigations are also areas of particular expertise. Mr. Pelletier has over twenty years of experience in industry and consulting which qualifies him to provide technical advice and guidance for resource development projects on an international basis.

C. Hesse, P. Eng.

Formerly Vice-President, Engineering for U.S. Borax & Chemical Corporation, Christian Hesse currently acts as a consultant to the minerals industry. While with U.S. Borax, he served as Project Manager of the Quartz Hill Project from April 1981 through June 1990, managing Borax's detailed feasibility evaluation completed during that period. Other executive assignments have included a Nevada heap-leach silver mine, design and construction of the world's largest boric acid plant and management of potash projects in Canada and England.

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EXECUTIVE SUMMARY

This report reviews four case histories of Submarine Tailings Disposal (STD) from Canada and Alaska. STD involves technology to ensure that tailings are deposited at depth in chemically unreactive low oxygen environments. Previous discharge systems to rivers and beaches were environmentally unsatisfactory as they did not achieve this environmental objective.

This report presents for each case history descriptions of the ore body and the milling process, the wastes produced, the engineered tailings outfalls, and data demonstrating the levels of environmental impact.

At Island Copper Mine, Canada, the STD system is the best documented anywhere. Both positive and negative aspects of the technology are demonstrated. A comprehensive monitoring program has been in place since 1970 prior to operations which started in 1971. Monitoring is scheduled to continue through to closure expected in 1996, and possibly afterwards. Essentially, STD can deposit tailings to the seabed of a fjord in a way that does not contaminate either the overlying water column or the seabed, and does allow local commercial fisheries (salmon and crabs) to continue. Where active tailings deposition, and localized resuspension, smothers benthos and causes turbidity there is no indication of impact on primary biological production, and natural recolonisation restores a productive ecosystem within one to two years.

The Kitsault molybdenum mine, near the Canadian-Alaskan border was redeveloped in the late 1970s. Substantial environmental impact assessments were undertaken prior to and during operations. The results indicated that the mine could utilize STD and thereby deposit its tailings deep in a silled fjord. In so doing there would be little environmental impact, without loss of significant fishery resources. An appropriately designed and located outfall was built and operated to specifications from 1981 - 1982, although rapidly improving monitoring technology detected previously unsuspected minor deviations from predicted plume flow and dispersal. The mine closed in 1982 when a fall in molybdenum prices made it uneconomical. Subsequent post-closure monitoring of the only habitat of concern, the sea-bed, showed some recovery of the benthos one year after closure, and thereafter naturally derived widely spread changes in both tailings and non-tailings areas.

At the WestGold marine placer dredging operation near Nome, Alaska, a substantial monitoring program was implemented to address local concerns expressed during an initial public review process. The monitoring data provided unique information on the effectiveness of the discharge controls, and on the rate of recovery of the seabed impacted first by dredging and secondly by re-deposition of tailings. Effectively, in sandy areas the benthos had recovered within three years to a community of organisms similar to that at control sampling stations. Cobble dredged areas recolonized more slowly in the four

years after mining, test stations, although with a productive benthos, could still be distinguished from control areas.

At the proposed Quartz Hill molybdenum mine in SE Alaska near Ketchikan, the marine environmental studies over almost ten years, represented a state-of-the-art environmental impact assessment designed to meet requirements of regulatory agencies in the USA. A number of predictive models were developed, and these in association with Best Professional Judgments indicated that STD in the preferred fjord receiving area would have similar effects to those at Island Copper Mine and Kitsault.

This report is the first of two volumes reviewing case histories of STD. The second volume will review existing or planned systems from around the world, including examples from South America, Papua New Guinea, the Black Sea and Greenland. It is expected that the complete set of case histories will allow the development of screening criteria for appraisal of STD systems at new mines. These criteria will be presented at the conclusion of volume II.

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1.0 INTRODUCTION (by G. Poling & D. Ellis)

1.1 Submarine Tailings Disposal

Coastal mines in the past, over many hundreds of years, have inevitably discharged their mill tailings to the sea. The environmental impacts of such riverine, estuarine, and beach discharges are obvious, and generally unacceptable in today's industrial societies.

Submarine Tailings Disposal (STD) in contrast involves technology whereby mill tailings are discharged through an engineered outfall at a location and depth selected to minimize environmental impacts. Such STD systems have been in operation since 1971 in Canada, and others are operating or are in planning around the world.

These STD systems also incorporate advanced preliminary assessment work, and comprehensive monitoring requirements to predict and then document actual levels of impact.

STD as described here does not include discharge to a beach or river, or even via a simple pipeline or flume system into shallow sea water. These are no longer environmentally acceptable means of disposing of mill tailings.

The Alaska Field Operations Center of the U.S. Bureau of Mines has recently completed an overview of the technical, regulatory and economic aspects of STD (Baer *et al.* 1992). Part of the incentive for the overview was to evaluate whether STD offers a viable alternative to land disposal, particularly along the Alaskan coast where fjord topography, storm rainfall, earthquake risk and salmon spawning streams severely limit choices of suitable safe, land sites having minimal impacts. The mining industry in the USA is currently unable to use STD due to an Environmental Protection Agency interpretation of the Clean Water Act (Baer *et al.* 1992).

A co-operative agreement has been made with the University of British Columbia, Vancouver, Canada, to document cases of STD from around the world. At the completion of this two volume project, criteria will be presented to assist in the screening of prospects for STD in Alaska. It is anticipated that current developments using Geographical Information Systems (GIS) combined with Expert Systems will soon allow such criteria to be applied routinely by developers and regulatory agencies.

Following this Introduction, Chapter 2 of this report provides a general summary of mining and milling processes, and the generation of mining wastes.

1.2 Environmental Concerns

It is now known that STD in such locations as British Columbia and Alaska can offer several physico-chemical advantages over terrestrial disposal particularly in terms of long term physical stability and security of the deposit. The most recent generalized reviews are included in Ellis (1989). STD also minimizes the possibility of oxidative releases of residual heavy metals due to the low availability of oxygen within submerged deposits (Pedersen *et al.* 1991). In spite of these advantages, there is a wide range of legitimate concerns which must be satisfied before regulatory and public approval can be expected. These concerns include:

- potential physical and biological impacts during the discharge and sedimentation of tailings solids, *i.e.* possible burial of benthic organisms and modification of marine food webs, effects of ingestion of tailings solids by the organisms, and prospects of bioaccumulation of trace metals, and their biomagnification up the food chain;
- physical stability of tailings deposits; prospects of resuspension contributing turbidity and contaminated interstitial waters to the sea water column; and
- prospects for recolonization of the tailings deposits, or overlying natural deposits following mine closure; potential for remediative actions equivalent to bioengineered reclamation at land tailings impoundments.

It is now possible to provide generalized answers to these concerns, and to indicate the situations under which STD is an environmentally sound option for disposal of mine tailings. These answers are provided by several existing case histories with 5-21 years of pre-discharge surveys, mill operation, discharge monitoring and/or post-closure assessment.

In contrast to the generalized conclusions, if answers to the concerns at a particular site indicate that there will be substantial degradation of the marine receiving environment, then STD is not the solution at that site to the problem of mill tailings disposal.

1.3 Case Histories

This report reviews the major case histories from British Columbia and Alaska. The cases concern primarily low-grade metalliferous tailings. A second report will document other experience from around the world (South America; Papua New Guinea; the Black Sea; and Greenland) and will include data from higher grade, more massive type sulphide deposits.

Two of the case studies reviewed in this report are particularly important, both in amount of information provided and their proximity to Alaska. One is the Island Copper Mine of BHP Minerals (Canada) Ltd. This mine has operated continuously since 1971 at the north end of Vancouver Island (Figure 1-1). Island Copper Mine was required to undertake a substantial marine monitoring program since before discharge started, and has had to report results annually to the regulatory agencies.

The second case is the Kitsault mine owned by AMAX of Canada Ltd. located at the head of Alice Arm on the British Columbian coast (Figure 1-1). The mine has been closed since 1982, but some post-closure monitoring has been maintained.

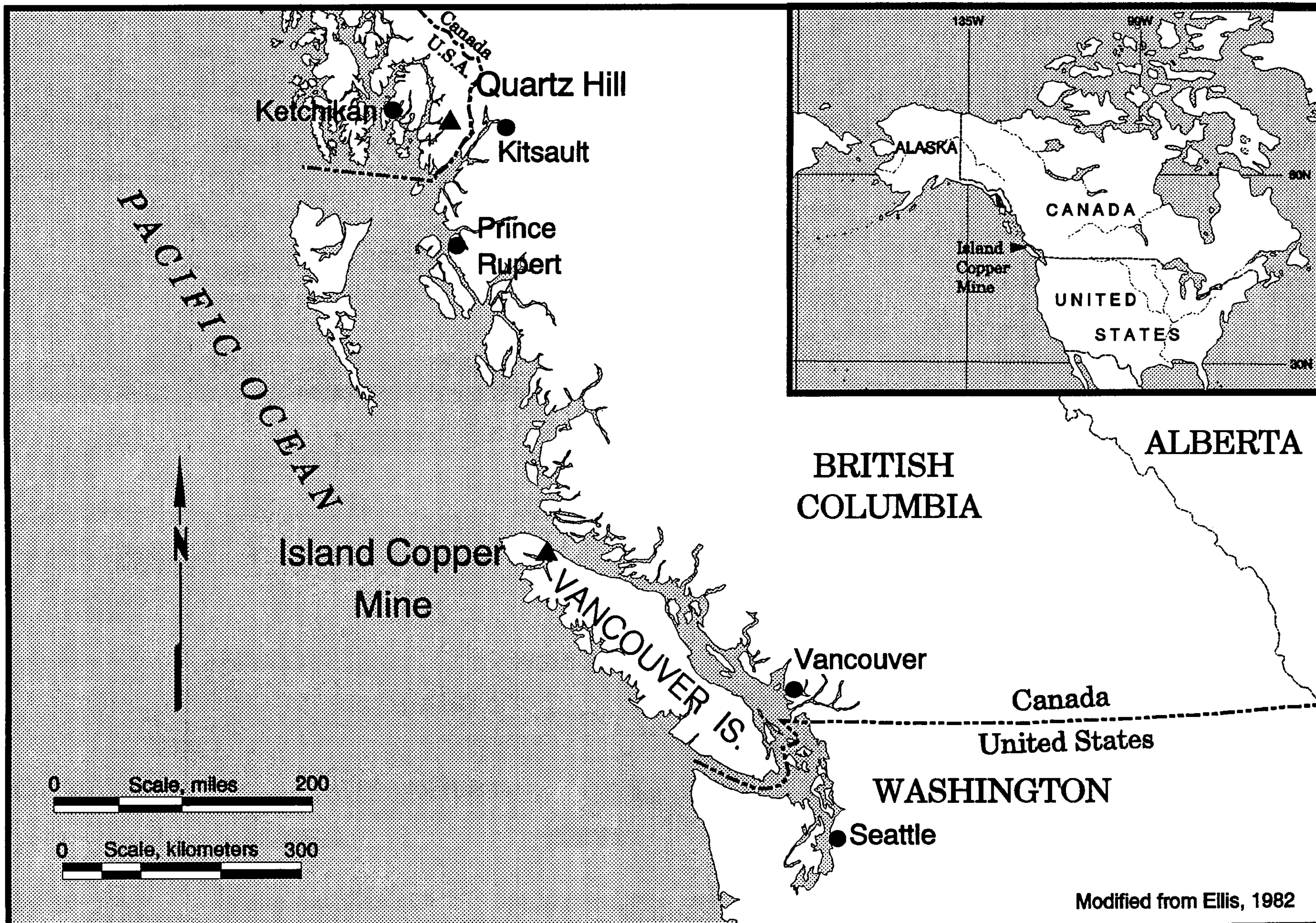


Figure 1.1 - Location of Island Copper, Kitsault and Quartz Hill Mines.

Both these Canadian mines opened and operated under close public and regulatory scrutiny. Each mine generated considerable public interest and controversy, and had to meet substantive environmental monitoring requirements. Numerous reports are available for public access. We provide an extensive list of references for both.

Island Copper Mine (Chapter 3) opened in 1971 after a year of baseline surveys and a lengthy public hearing. The case now provides more than 20 years of essentially continuous operation where between 30,000 and 60,000 tons per day of mill tailings solids have been discharged at approximately 50 metres depth into a fjord, Rupert Inlet. The marine environmental data bank produced by two decades of monitoring is enormous. Scientists and engineers from around the world, from government, industry and universities, have utilized the data for purposes of environmental review, development of predictive risk models, and other purposes. Many of the results have been published in the peer-reviewed international journals and reference books of science and engineering, *e.g.* Ellis *et al.* (1991), Pedersen (1985) and Poling (1982). Island Copper mine will probably close in 1996. Formal closure plans are now being prepared, and it is to expected that some environmental monitoring will continue after closure, thus documenting any continuing impact on the marine ecosystem.

The Kitsault STD system (Chapter 4) operated only during 1981 and 1982 as a re-opened mine (B.C. Molybdenum). The tailings had been previously discharged to a river, from which they flowed into the sea. Marine monitoring was intensive preceding and during mine operation. Monitoring routines have been continued on a reduced scale since the closure (due to low molybdenum prices in 1982). There have been several intensive assessments, particularly of the seabed by government agencies since closure (*e.g.* Burd and Brinkhurst 1990).

There are two other case histories in this report. The WestGold marine placer gold dredge operation (Chapter 5) while relatively short (1985-1990) provides unique information on impact and recovery of a shallow, gently sloping, high energy, near shore seabed from dredging and tailings discharge, *i.e.* re deposition of deposits after dredging and mineral processing (Gardner 1992).

At the proposed Quartz Hill molybdenum mine, U.S. Borax undertook comprehensive assessments of projected environmental impacts of STD in both possible receiving fjords (Chapter 6). The property is now owned by COMINCO Ltd. and while the project is on hold, the case shows the type and extent of engineering and environmental work undertaken to meet regulatory requirements in the USA (Ellis 1989; Hesse and Reim 1993).

2.0 MINING/MILLING PROCESSES AND WASTE GENERATION
(by G. Poling and C. Pelletier)

2.1 Introduction

Mining and mineral processing operations generally occur as tandem processes at the site of an ore body. A few ore bodies can still be mined and ore shipped directly without any beneficiation. Several industrial minerals such as gravel and limestone are common examples. Most ores require upgrading and hence mined ore is processed physically to produce marketable concentrates and a waste product - mill tailings. Some tailings might leach toxins while others might be very inert and closely duplicate the kind of natural erosion sediments typically contained in a major river. For example the Fraser River system in British Columbia carries 50 million tons of sediments to the Pacific Ocean each year. Estimates are that 20 billion tons of riverine sediments deposit in the worlds oceans each year (Holeman 1968). Hydroelectric dams on many other west-coast North America rivers retain so much of their natural river sediment that several ocean beaches become impoverished of sand in the summer. In several instances off-shore sands are dredged and deposited hydraulically to nourish and maintain sandy beaches.

A detailed knowledge of the physical and chemical characteristics of mill tailings is essential to predict its inert or potentially toxic nature. Both solids and liquid components require characterization.

2.2 Characteristics of Mill Tailings

2.2.1 Solids Components

Minerals in ore bodies can range from highly soluble salts such as sylvite (KCl), to slightly soluble compounds, such as malachite [Cu_2CO_3 $Cu(OH)_2$] to highly insoluble materials, such as chalcopyrite ($CuFeS_2$) or silica (SiO_2). In addition, the solid phase might require only coarse crushing to "liberate" the valuable minerals in an ore for physical separation, or extremely fine grinding might be needed. Thus the waste tailings can range from gravel size material to extremely fine silt or clay size particles. These sorts of characteristics dramatically affect both the physical behaviors and chemical stabilities of the solid phases in a marine environment.

Mineralogies can be critical in determining the suitability of tailings for marine disposal since heavy metal components vary dramatically in both abundances and in potential toxicities. Hence tailings containing significant cadmium, mercury, arsenic, lead, beryllium or chromium undoubtedly cause more concern than tailings containing only silicon, aluminium and oxygen (silicates and aluminium silicates). To assist in placing the composition of mill tailings in perspective, Table 2-1 shows average abundances of elements in various crystal rock types and in surface river waters (Berkman 1976).

Table 2-1
Average Abundance of Selected Minor Elements in the Earth's Crust[1, 2, 3]

Element	Earth's Crust	Ultra-mafic	Basalt	Grano-diorite	Granite	Shale	Lime-stone	Soil	River Water
Ag	0.07	0.06	0.1	0.07	0.04	0.05	1	0.1	0.3
As	1.8	1	2	2	1.5	15	2.5	1-50	2
Au	0.004	0.005	0.004	0.004	0.004	0.004	0.005	--	0.002
B	10	5	5	20	15	100	10	2-100	10
Ba	425	2	250	500	600	700	100	100-3000	10
Be	2.8	--	0.5	2	5	3	1	6	--
Bi	0.17	0.02	0.15	--	0.1	0.18	--	--	--
Br	2.5	1	3.6	--	2.9	4	6.2	--	20
Cd	0.2	--	0.2	0.2	0.2	0.2	0.1	1	--
Ce	60	8	35	40	46	50	10	--	0.06
Cl	130	85	60	--	165	180	150	--	7800
Co	25	150	50	10	1	20	4	1-40	0.2
Cr	100	2000	200	20	4	100	10	5-1000	1
Cs	3	--	1	2	5	5	--	6	0.02
Cu	55	10	100	30	10	50	15	2-100	7
Dy	3	0.59	3	3.2	0.5	5	0.4	--	0.05
Er	2.8	0.36	1.69	4.8	0.2	2	0.5	--	0.05
Eu	1.2	0.16	1.27	1.2	--	1	--	--	0.07
F	625	100	400	--	735	740	330	--	100
Ga	15	1	12	18	18	20	0.06	15	0.09
Gd	5.4	0.65	4.7	7.4	2	6	0.6	--	0.04
Ge	1.5	1	1.5	1	1.5	1.5	0.1	1	--
Hf	3	0.5	2	2	4	3	0.5	--	--
Hg	0.08	--	0.08	0.08	0.08	0.5	0.05	0.03	0.007
Ho	1.2	0.14	0.64	1.6	0.07	1	0.1	--	0.01
I	0.5	0.5	0.5	--	0.5	2.2	1.2	--	7
In	0.1	0.01	0.1	0.1	0.1	0.1	0.02	--	--
Ir	0.0004	--	--	--	--	--	--	--	--
La	30	3.3	10.5	36	25	20	6	--	0.2
Li	20	--	10	25	30	60	20	5-200	3
Lu	0.50	0.064	0.20	--	0.01	0.5	--	--	0.008
Mn	950	1300	2200	1200	500	850	1100	850	7
Mo	1.5	0.3	1	1	2	3	1	2	1
Nb	20	15	20	20	20	20	--	--	--
Nd	28	3.4	17.8	26	18	24	3	--	0.2
Ni	75	2000	150	20	0.5	70	12	5-500	0.3

(continued)

Table 2-1
Average Abundance of Selected Minor Elements in the Earth's Crust[1, 2, 3]

Element	Earth's Crust	Ultra-mafic	Basalt	Grano-diorite	Granite	Shale	Lime-stone	Soil	River Water
Os	0.0004	--	--	--	--	--	--	--	--
Pb	12.5	0.1	5	15	20	20	8	2-200	3
Pd	0.004	0.02	0.02	--	0.002	--	--	--	--
Pr	8.2	1.02	3.9	8.5	4.6	6	1	--	0.003
Pt	0.002	0.02	0.02	--	0.008	--	--	--	--
Rb	90	--	30	120	150	140	5	20-500	1
Rc	0.0005	--	0.0005	--	0.0005	--	--	--	--
Rh	0.0004	--	--	--	--	--	--	--	--
Ru	0.0004	--	--	--	--	--	--	--	--
Sb	0.2	0.1	0.2	0.2	0.2	1	--	5	1
Sc	16	10	38	10	5	15	5	--	0.004
Se	0.05	--	0.05	--	0.05	0.6	0.08	0.2	0.2
Sm	6	0.57	4.2	6.8	3	6	0.8	--	0.03
Sn	2	0.5	1	2	3	4	4	10	--
Sr	375	1	465	450	285	300	500	50-1000	50
Ta	2	1	0.5	2	3.5	2	--	--	--
Tb	0.9	0.088	0.63	1.3	0.05	1	--	--	0.008
Te	0.001	0.001	0.001	0.001	0.001	0.01	--	--	--
Th	10	0.003	2.2	10	17	12	2	13	0.1
Ti	5700	3000	9000	8000	2300	4600	400	5000	3
Tl	0.45	0.05	0.1	0.5	0.75	0.3	--	0.1	--
Tm	0.48	0.053	0.21	0.5	--	0.2	0.1	--	0.009
U	2.7	0.001	0.6	3	4.8	4	2	1	0.4
V	135	50	250	100	20	130	15	20-500	0.9
W	1.5	0.5	1	2	2	2	0.5	--	0.03
Y	30	--	25	30	40	25	15	--	0.7
Yb	3	0.43	1.11	3.6	0.06	3	0.1	--	0.05
Zn	70	50	100	60	40	100	25	10-300	20
Zr	165	50	150	140	180	160	20	30	--

1/ From Levinson, 1974, by permission.
2/ All values in ppm except those for river water which are ppb.
3/ Dashes (--) indicate no data are available.

Tailings from relatively low-grade porphyry copper deposits located adjacent to a coastal inlet might closely duplicate natural sediments already lying at the bottom of an inlet. Table 2-2 provides typical chemical and mineralogical compositions of BHP Minerals, Island Copper Mine tailings and natural sediments in Rupert Inlet prior to submarine tailings deposition. With the exception of elevated copper and molybdenum levels (from unrecovered chalcopyrite and molybdenite minerals) in the mill tailings the two types of solids compositions are nearly identical. This is to be expected since the tailings result from the processing of an adjacent copper-molybdenum ore body after recovering from 80-90% of these two metals in the concentrator on-site. The natural sediments would have resulted from several thousands of years of erosion of this same country rock adjacent to Rupert Inlet. Thus the tailings and the natural sediment are closely related mineralogically.

In contrast to tailings from low grade porphyry deposits, those derived from the processing of massive sulphide ore bodies might present a different level of concern. For example, Table 2-3 presents data on the nature of ore, concentrate and tailings at the Greenex A/s Black Angel Mine in Greenland (Fish 1974; Mikkelborg 1974; Asmund *et al.* 1991). Although the majority (85-95%) of the lead and zinc contained in the ore were recovered as concentrates, these tailings still contained several thousand ppm of lead and zinc in the solid phase. Table 2-3 also shows that these massive sulphide tailings were composed of nearly 25% metal suphide (mostly pyrite, FeS_2). Assuring the physical and chemical stability of these tailings as a sediment becomes more crucial than with the much lower heavy metal content tailings cited above in Table 2-2. Massive sulphide particulate might present the prospect of electrochemical galvanic couples contributing to oxidation processes and chemical instabilities of the solid phases present. Thus the need for testwork demonstrating chemical stability of submarine tailings solid components becomes even more crucial in the case of massive sulphide ores.

2.2.1.1 Chemical Stability of Tailings as Marine Sediments

Marine sediments exhibit chemical zonation with depth which reflects the integrated effects of physical, microbiological and chemical processes occurring therein. Figure 2-1 shows zonations typical of both marine and lacustrine sediments (Pedersen and Pelletier 1989). Note that oxygen levels will generally be depleted rapidly below the sediment-water interface. Under anoxic conditions metal sulphides become the stable dominant solid authigenic phase. Thus most trace metals which might be present initially within pore water should precipitate as solid sulphide phases within the sediments. Table 2-4 shows equilibrium solubility constants for mono-sulphides, oxides and hydroxides, carbonates and hydroxide carbonates. Note that the solubilities of metal sulphides are several orders of magnitude less than the other forms. Thus anoxia is particularly important to stabilize heavy metal compounds as solids in marine sediments. Co-deposition or post-deposition of organic detritus with or on top of the tailings sediments will also promote oxygen depletion. This, of course, presupposes that the sediments remain physically stable and are not subject to substantial resuspension.

Table 2-2

Typical Chemical and Mineralogical Composition of Tailings Solids and Natural Sediments in Rupert Inlet, B.C.[1]

Element or Oxide *etc.*	Content of Sediments A Tailings	B Natural	Ratio A:B	Mineral Species	Tailings Content
SiO_2	62			Quartz	50-70%
Al_2O_3	14			Feldspar	2-20%
Ca,K,Na & Mg				Biotite and	
Oxides	10			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		
Elements	**ppm**	**ppm**			
Cu	700	44	16:1	Chalcopyrite	0.2%
Mn	650	640	1:1	Mn Oxides	n.d.[2]
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	Aresenopyrite	n.d.
Cd	3	2	3:2	In sphalerite	n.d.
Hg	0.03	0.06	1:2	Cinnabar	$>4x10^{-6}\%$

1/ Reprinted from Poling (1972).
2/ n.d. = not determined.

Table 2-3

Typical Chemical and Mineralogical Composition of Tailings Solids from the Black Angel Mill

Element	Major Mineral Species	Metal Content, ppm: Ore	Concentrate	Tailings	In Tailings Tons/day
Pb	PbS	30,000-70,000	680,000-700,000	2,500	7
Zn	ZnS	150,000-200,000	580,000-590,000	5,000	14
Fe	FeS_2	200,000 FeS_2		~250,000	700
Cd	CdS			50	0.14
	Tremolite			} 750,000	
	Marble				
	Talc				
Tailings slurry					2,800 (solids)

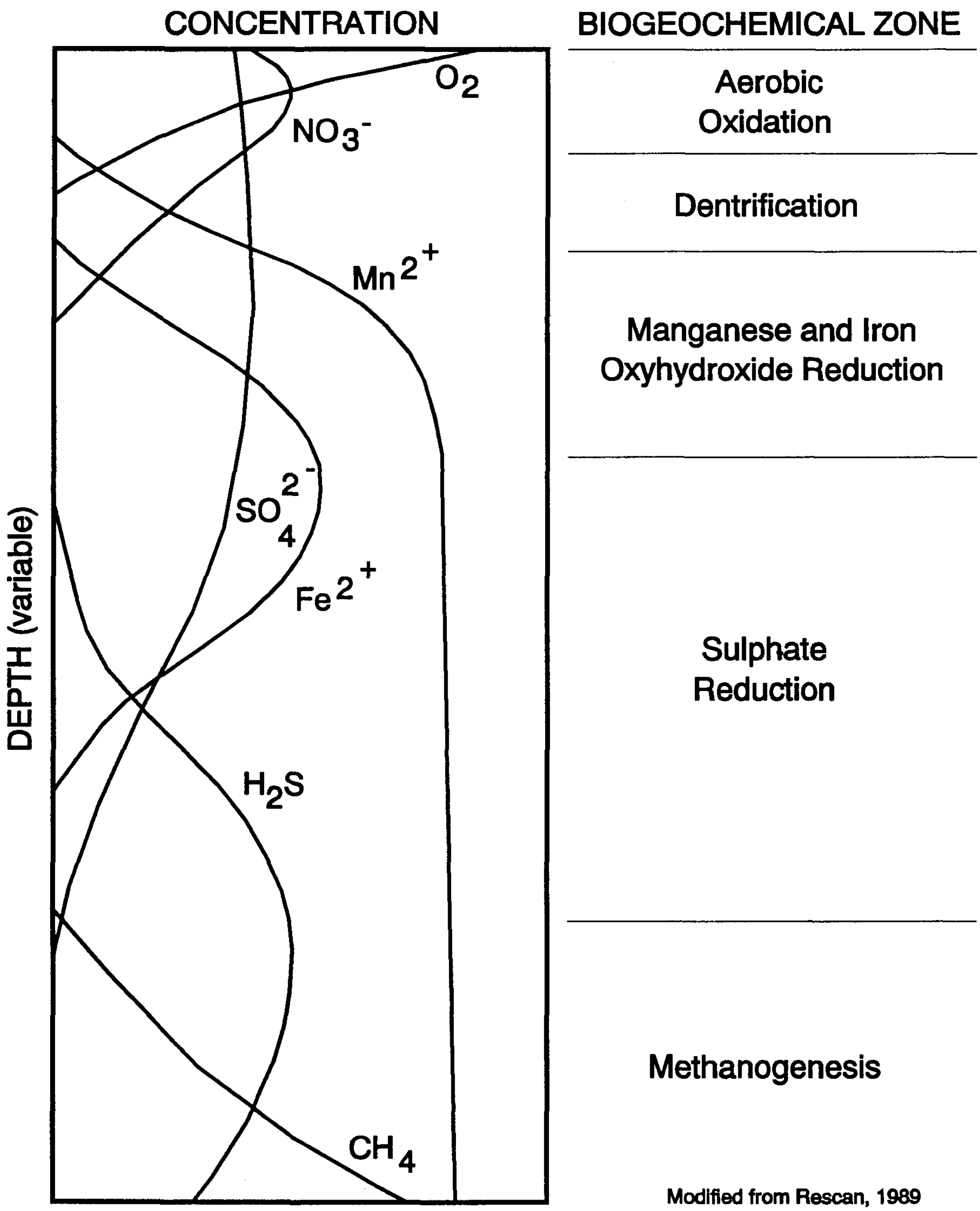
Source: Asmund (1991).

2.2.1.2 Physical Behaviour of Tailings in Marine Environment

The density and size distribution of tailings dramatically affect their sedimentation characteristics and their eventual dispositions in a marine receiving environment. Higher density, coarser solids settle faster and limit the areal extent of the spread of tailings over the ocean floor or fjord bottom. Enhanced settling rates also minimize the chance of upwelling or resuspension to create undesirable turbid conditions in the upper-euphotic zone of the water column. For reference, Table 2-5 shows settling velocities of quartz spheres in water. Coarse solids also minimize the surface area exposed per unit weight of tailings solids and thereby slows oxidative release of heavy metal ions.

Although individual fine particles settle at almost insignificant velocities, as shown in Table 2-5, their aggregation into clusters (coagules or flocs) can dramatically enhance these velocities. Typical flotation mill tailings will contain from 5-25% weight of solids finer than 10 µm. As individual particles these so-called "slimes" fractions would typically take over 30 minutes to settle 10 cm. They would readily be swept up in ocean currents and carried up to create euphotic zone turbidity or spread widely through the receiving environment.

Tailings are often pre-treated with coagulants (*i.e.* hydrated lime $Ca(OH)_2$) or synthetic flocculent (*i.e.* high molecular weight polyacrylamide chemicals which act as bridging or "glueing" chemicals) in thickeners prior to discharge to the marine environment. This pretreatment aggregates the fine fractions with the coarser fractions in tailings to enhance dramatically overall settling velocities. In addition, admixing seawater with the tailings



Schematic distribution of biogeochemically important molecules and ions in interstitial waters in sediments showing the zonation typically observed in marine and lacustrine sediments. This distribution will stretch or compress in response to changing physical, chemical and biological conditions.

Figure 2.1 - Schematic distribution of biogeochemically important species in interstitial waters in sediments (Pedersen 1985).

Table 2-4
Constants for Selected Solubility Equilibria of Selected Sulphides, Oxides, Hydroxides, Carbonates and Hydroxy-Carbonates

Sulphides	**log K, 25°C, I = 0**
$MnS(s) - Mn^{2+} + S^{2-}$	-13.5
$FeS(s) = Fe^{2+} + S^{2-}$	-18.1
$ZnS(s) = Zn^{2+} + S^{2-}$	-24.7
$CdS(s) - Cd^{2+} + S^{2-}$	-27.0
$CuS(s) = Cu^{2+} + S^{2-}$	-36.1
$PbS(s) = Pb^{2+} + S^{2-}$	-27.5
$HgS(s) = Hg^{2+} + S^{2-}$	-52.7
Oxides and Hydroxides	
α-$FeOOH(s) + 3 H^+ = Fe^{3+} 2H_2O$	$^*K_{sO} = 0.5$
(am) $FeOOH(s) + 3 H^+ = Fe^{3+} 2H_2O$	$^*K_{sO} = 2.5$
$ZnO + 2 H^+ = Zn^{2+} 2H_2O$	$^*K_{sO} = 11.14$
(am) $ZN(OH)_2 + 2H^+ = Zn^{2+} 2H_2O$	$^*K_{sO} = 12.45$
$CuO(s) + 2 H^+ = Cu^{2+} + H_2O$	$^*K_{sO} = 7.65$
Carbonates and Hydroxide Carbonates	
$Zn(OH)_{1.2}(CO_3)_{0.4}(s) = 2 H^+ = Zn^{2+} + 1.6H_2O + 0.4 CO_2(g)$	$^*K_{psO} = 9.8$
$ZnCO_3(s) + 2 H^+ = Zn^{2+} + H_2O + CO_2(g)$	$^*K_{psO} = 7.95$
$Cu(OH)(CO_3)_{0.5}(s) + 2 H^+ = Cu^{2+} + 3/2H_2O + 1/2 CO_2(g)$	$^*K_{psO} = 6.49$
$PbCO_3(s) = Pb^{2+} + CO_3^{2-}$	$K_{sO} = -13.1$
$CdCO_3(s) + 2 H^+ = Cd^{2+} + H_2O + CO_2$	$^*K_{psO} = 6.44$
$MnCO_3(3) = Mn^{2+} + CO_3^{2-}$	$K_{sO} = -10.4$

Source: Stumm and Morgan (1981).

(solids and residual fresh water components) causes coagulation and agglomeration of tailings. Seawater reduces the electrostatic "repulsive" charges (zeta potential[1]) on the solids to near zero, thereby enabling ever present "attractive" Van der Waals forces to predominate and cause particle aggregation.

Figure 2-2 shows how the zeta potentials[1] of typical siliceous and alumino silicate mill tailings and reference minusil silica (-5 μm) react to increasing salinity, as reflected by solution specific conductance. This figure shows that seawater promotes coagulation (zeta potential -10 to 0 to +12 mV). Figure 2-3 gives strong visual evidence for the coagulating action and enhanced settling of both natural and artificial seawater as compared to fresh water (Poling 1973).

[1]Zeta potential is a measure of the effective surface charge that a solid particle suspended in water carries. High negative or positive zeta potential can impart a high degree of dispersion to a mineral suspension.

Table 2-5

Settling Velocity of Quartz Spheres in Distilled Water at 20°C

	Diameter		Settling Velocity		Time to Fall 10 cm				Settling Velocity
	mm	microns	Stokes' Law	Wadell	Days	Hours	Min	Sec	m/day
Boulder	256	256,000	--	--	--	--	--	--	--
Cobble	64	64,000	--	--	--	--	--	--	--
Pebble	4	4,000	--	--	--	--	--	--	--
Granule	2	2,000	--	--	--	--	--	--	--
Very coarse sand	1	1,000	(89.2 cm/sec)	16.0 cm/sec	--	--	--	0.6	--
Coarse sand	1/2	500	(22.3 cm/sec)	7.7 cm/sec	--	--	--	1.2	--
Medium sand	1/4	250	(5.58 cm/sec)	3.4 cm/sec	--	--	--	2.7	--
Fine sand	1/8	12.5	(1.39 cm/sec)	1.2 cm/sec	--	--	--	8.3	1040
Very fine sand	1/16	62.5	3482 microns/sec	--	--	--	--	29	301
Silt	1/32	31.2	870	--	--	--	1	55	75.2
	1/64	15.6	218	--	--	--	7	40	18.8
	1/128	7.8	54.4	--	--	--	30	38	4.7
	1/256	3.9	13.6	--	--	2	2	32	1.2
Clay	1/512	1.95	3.4	--	--	8	10	--	0.3
	1/1024	0.98	0.85	--	1	8	41	--	0.074
	1/2048	0.49	0.21	--	5	10	42	--	0.018
	1/2096	0.25	0.052	--	21	18	50	--	0.004
	1/8192	0.12	0.013	--	87	3	19	--	0.001

Source: Sverdrup, Johnson, Fleming (1942).

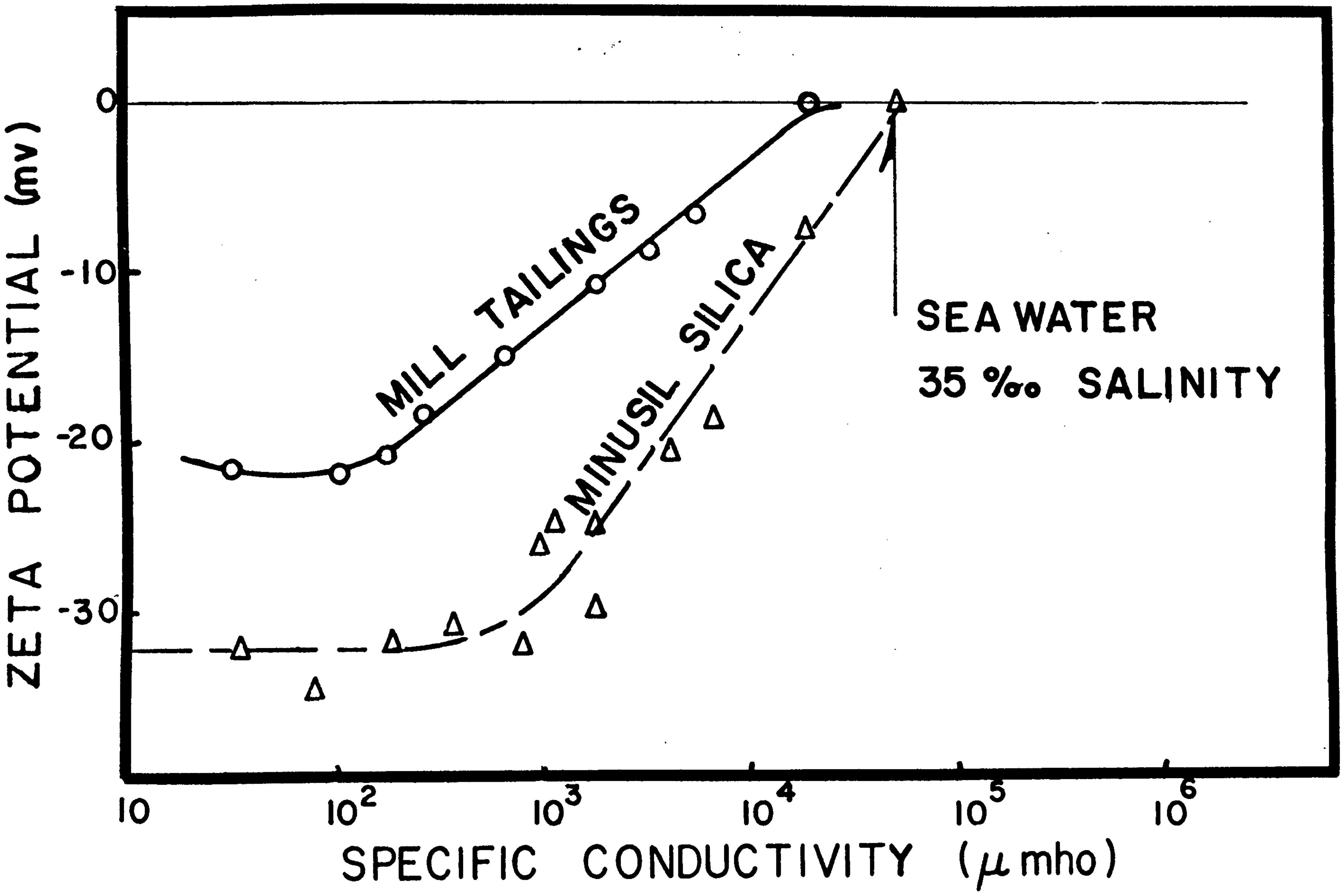


Figure 2-2 EFFECT OF SEAWATER ADDITION ON ζ POTENTIAL

(Poling 1973)

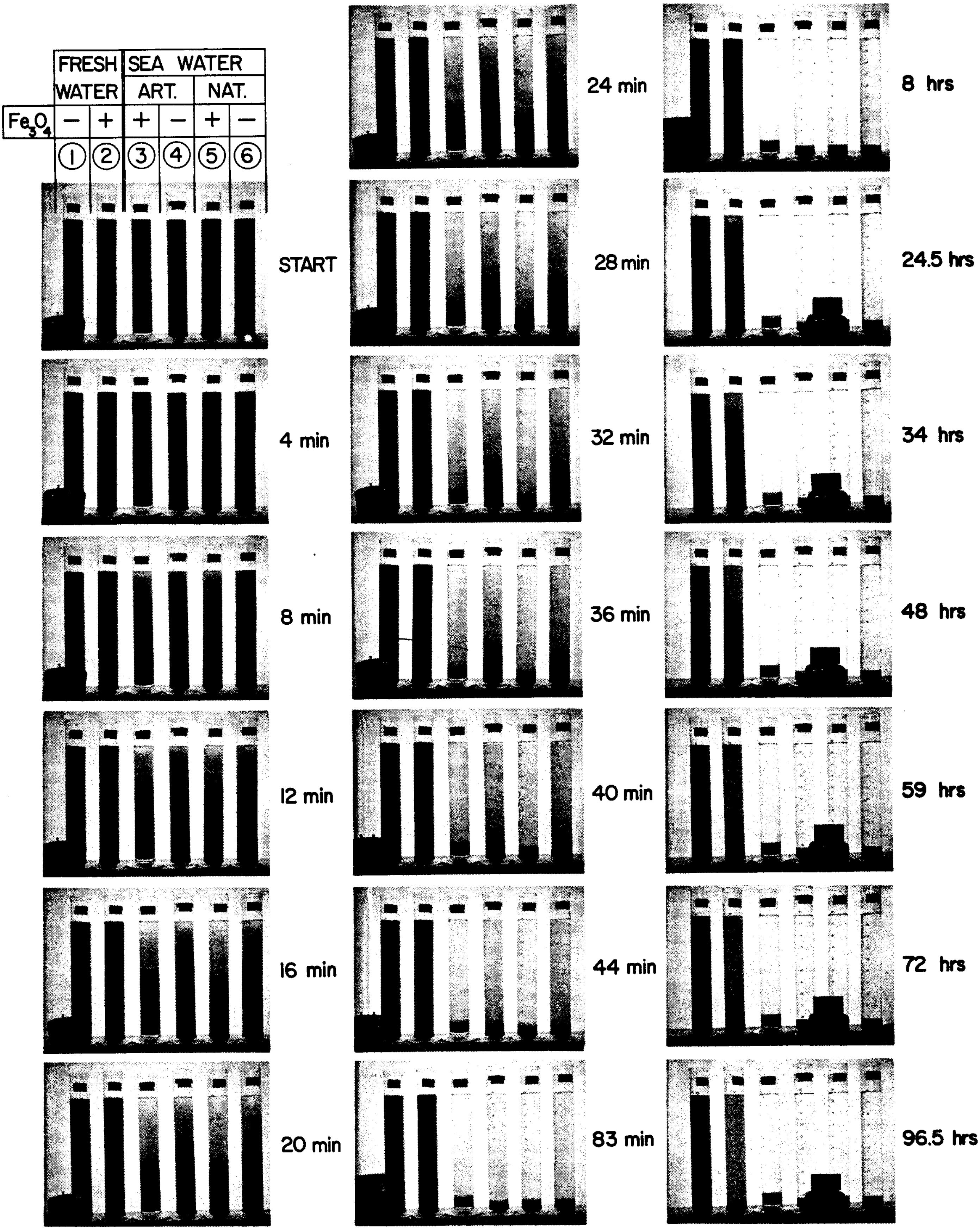


Figure 2-3 Settling of tailings (6% solids) in fresh and in sea waters (Poling 1973).

In well-engineered submarine tailings disposal systems, the mill tailings are thickened (to enable reclamation of clarified fresh process waters and to improve sedimentation characteristics of tailings solids) often to 40-60% solids by weight, admixed with seawater and discharged via pipe line at depth (>40 m). Admixing the seawater @ 1:1 to 5:1 seawater: tailings ratios enhance aggregation of fines as described above, and perhaps more importantly, reduces temperature and density differences between the slurry carrier fluid and the receiving seawater. This reduces chances of creating a "buoyant plume" of lower density fresh water component of the tailings discharge slurry. Such a buoyant plume of fresh water emanating from the main tailings flow would invariably carry with it high levels of tailings "fines" which would generate rising clouds of turbid water.

Upon discharge, well coagulated, seawater admixed, tailings flow downslope largely as a coherent density current along the existing sea-floor water interface. The slurry-seawater tailings mix would typically emerge at the pipe terminus having a specific gravity of 1.1 to 1.4 (substantially higher than the receiving seawater) at a velocity of 4-12 ft/sec. The discharge would increase in diameter as it moves away from the terminus by admixing in additional seawater. As the plume dilutes, coarse, high density solids will rapidly settle out of the plume onto the sea floor in this “near field” region. Deltas and submarine channels will be formed and the density/turbidity flow will possibly meander between levees for several hundred metres downslope as at Island Copper Mine, Chapter 3 (Hay 1982; Quartz Hill 1987).

At the Island Copper Mine, the near field channels had an average axial slope of 2.2° for nearly 1 km decreasing to a 1° slope over a "middle reach" of ≈ 2 km followed by a "lower reach" of ≈ 0.5° axial slope. Figure 2-4 shows this sedimentation behaviour (as of 1976) at the Island Copper Mine (Hay 1982). At various times in the lifespan of this disposal system, the depositional regime cycled periodically back and forth between a "meandering channel" and an "apron" type system. Periodic failures of the leveed walls by slumping produced periodic surge-type turbidity currents in the lower reach. This surging appeared to carry coarser tailings farther to depth than would otherwise have resulted from steady state type of flow. The surging probably also serves to clean away sediment build up in the vicinity of the outfall terminus.

Figure 2-5 shows a schematic of sediment transport and depositional regimes envisaged for the Quartz Hill, Alaska silled fjord system (Quartz Hill 1987). This figure summarizes some of the concepts described above.

2.2.2 Liquid Components

The freshwater component in the mill tailings would contain some residual milling chemicals in addition to potential leached elements or constituents dissolved from the solid phase. Each mineral processing system can be highly unique and needs careful evaluation as to potential impacts on a receiving water system. Table 2-6 lists milling chemicals used by the Island Copper Mine (in 1980) and their estimated distribution among mill products.

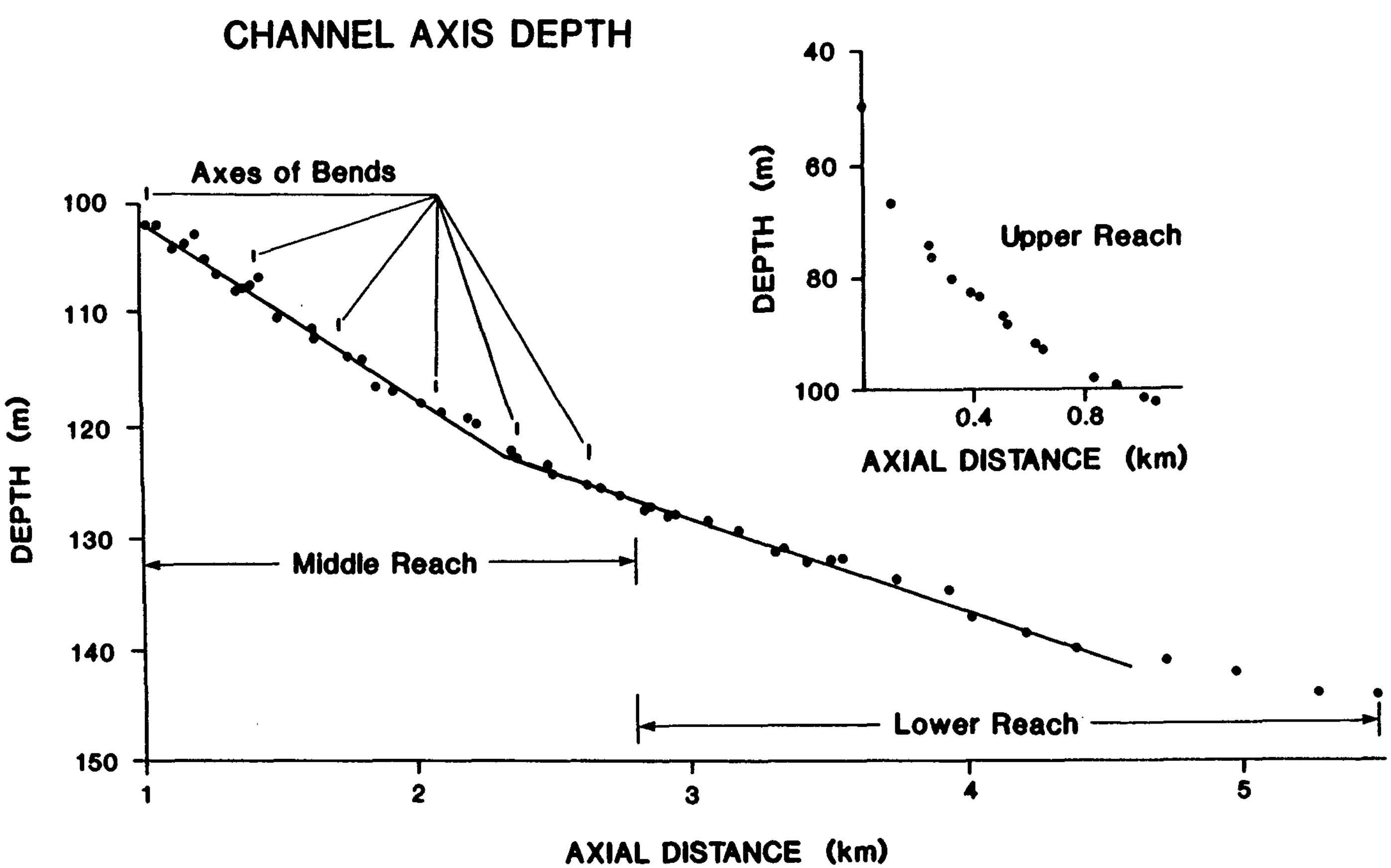


Figure 2.4 - Depth of November 1976 fjord channel axis at Rupert Inlet as a function of long-channel distance (Hay 1972).

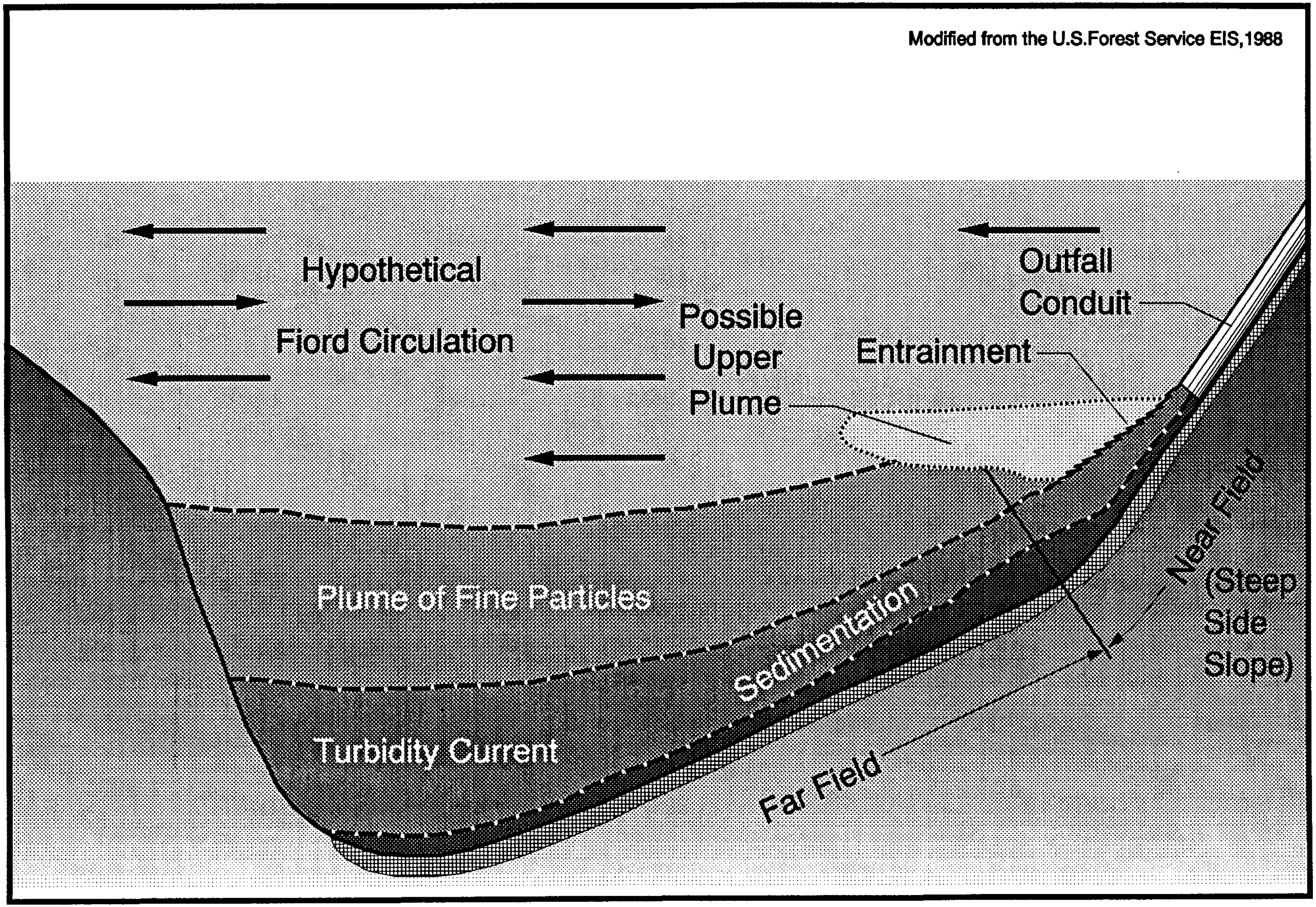


Figure 2.5 - Schematic of sediment transport and depositioned regime envisaged for Quartz Hill.

Table 2-6
Milling Chemicals Used by Island Copper and Their Environmental Considerations

Reagent Type and Name	Chemical Composition	Amount Added Lb/ton Ore	Approx. Factional Distributions in Mill Products: Adsorbed on Solids: In Mineral Concentrates	Adsorbed on Solids: In Tailings	In Liquid: Fraction In Tailings	In Liquid: Fraction Volatilized
Xanthate-collector	$C_5H_{11}OCSSK$	0.005	>1/2	<1/4	<1/2	~0
Aerofroth 71R-frother	C_6-C_9 alcohol	0.05	<1/4	<1/4	>1/2	<1/2
Dowfroth SA-1012 frother	Polypropylene glycol	0.004	<1/4	<1/4	>1/2	~0
Lime-coagulant and pH regulator	CaO	1.3	<1/4	<1/4	>1/2	~0
Cyanide-depressant	NaCN	0.04	>1/4	>1/4	~1/4	<1/4
Hydrosulphide-depressant	NaSH	0.22	>1/2	<1/4	<1/4	<1/4
Exfoam 635 froth suppressant		0.013	<1/4	<1/4	>1/2	~0
Aerodri 100-drying agent	Sulpho-succinic acid	0.008	>1/2	<1/4	<1/4	~0
Alchem 8863-flocculent	Polyacrylamide	0.046	<1/4	>1/2	~0	~0
Alfloc 84046-flocculent	Polyacrylamide	0.046	<1/4	>1/2	~0	~0

Table 2-7 shows proposed milling chemicals for the Quartz Hill mine and their expected concentrations in the near field discharge plume.

A compilation of reagents used in mineral processing has been published recently by K. R. Suttill (Suttill 1991). Toxicities of most milling chemicals have been evaluated by Hawley in a report published in 1972 by the Ontario Ministry of the Environment (Hawley 1972).

Apart from a few acutely toxic reagents, such as cyanides and hydrosulphides, most milling chemicals have low acute toxicity. Since most are organic compounds, some concerns about biological oxygen demand of any residuals can persist. Testwork to demonstrate low impact from projected BOD might be in order. In addition, bioassays of all milling chemicals should be known to prove they are not toxic before they are tested or used in any plant using submarine tailings disposal.

Based on the editors' 21 years of research at the Island Copper Mine there have been no significant environmental impacts from residual milling chemicals reaching Rupert Inlet. Accidental spills of neat chemicals during transport to or storage at the mine site probably pose more hazard than the small residual reagents present in most mill tailings. Fail safe design to prevent accidental spills should be part of any approved design plan.

2.3 Conclusion

Tailings characteristics and processes that generate them vary widely and are often unique to each ore body being mined and processed. Many mines produce concentrates and tailings (for disposal) that are chemically inert. Gravity separation plants (such as WestGold's Alaskan gold dredge) generally use no milling chemicals and sometimes only remove a small fraction as valuable mineral component prior to delivering essentially unaltered tailings as sediment back to the sea floor.

At the other extreme, a massive sulphide ore body perhaps with significant oxidized heavy metal content might cause high levels of concern over potential release of toxic heavy metal species. Gold cyanidation plants with significant residual cyanide levels in the mill tailings are of obvious concern. Each proposal must be considered in detail.

Table 2-7

Predicted Milling Reagent Concentrations in the Near Field Discharge Plume

(Based on predictions for Quartz Hill Project)

Reagent[1]	Percent In Dissolved Phase of Effluent	Usage Lb/Short Ton Ore[1]	Concentration In Effluent (mg/L)	Biodegradability	Worst Case Before Inner Basin is Filled mg/L[2]	Worst Case After Inner Basin is Full mg/L[3]
Dowfroth 25 or	100	0.0003	1.20	No [4]	0.027	0.067
ALFOL6	100	0.045	18.05	Readily [5]	0.40	1.003
MIBC (=C_5 alcohol)	100	0.088	35.30	Readily [4]	0.784	1.960
Fuel Oil		0.634	0.01[6]	No	<0.001	0.001
Stepanfloat 85L	100	0.011	4.41	Expected degree unknown [7]	0.098	0.246
Sodium Silicate and/or	100	0.063	25.27	No	0.562	1.404
CMC–7	50 [8]	0.045	9.02	With difficulty [4]	0.200	0.501
Nokes	5[9]	0.054	10.83	No	0.0243	0.061
Resultant H_2S concentration				No	0.019	0.049
M502 or SF330[10]	50[8]	0.199	39.91	Expected degree unknown [7]	0.887	2.218
	50[8]	0.010	2.00	Expected degree unknown [7]	0.045	0.112
Lime	100	0.134	53.74	No	1.195	2.986
Aerodri	50 [8]	0.0002	0.04	Expected degree unknown [7]	0.001	0.002

1/ U.S. Borax (1984b) and Project Description.
2/ Diluted 2:1 in mixing box and 14:1 at a distance of 100 m from the outfall.
3/ Diluted 2:1 in mixing box and 5:1 at a distance of 50 m from outfall..
4/ Read and Manser (1975,p. 246).
5/ U.S. Borax (1984c).
6/ U.S. Borax (1983a, p. 8-40).
7/ Most organic compounds are expected to undergo some biodegradation, however specific testing of biodegradability of this reagent was not available
8/ Approximately half of the organic reagents would remain in the tailings discharge (U.S. Borax 1983; CATOA Appendix E, p. 16). For the worst case, reagents accompanying the tailings are assumed to remain dissolved.
9/ Assumes 95 percent converted to H_3PO_4 and H_2S. H_2S is the toxic component of concern, therefore, resultant H_2S concentrations are presented for a pH . 8 (see Appendix G, Table 15-3).
10/ These application rates may be much higher than will actually be required as other types of flocculents will be tested (Poling 1984).

Source: U.S.D.A. Forest Service (1988).

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3.0 ISLAND COPPER MINE, CANADA (by T. Pedersen, D. Ellis, G. Poling & C. Pelletier)

3.1 Introduction

In 1968, Utah Mines Ltd. announced plans to develop a large open pit copper-molybdenum mine on the north shore of Rupert Inlet, one of the reaches of Quatsino Sound on northern Vancouver Island (Figure 1-1 and 3-1). The company commenced investigations of the feasibility of submarine disposal of tailings in April 1968, and carried out bathymetric surveys of the inlet, studies of the settling characteristics of the tailings, and bioassay tests of effluent from a pilot plant operation. Consideration was given to the potential effects of tailings on the aquatic flora and fauna in the Rupert Inlet, to design, engineering, and siting of the outfall, and to the physical oceanography of the basin (Utah Mines Ltd. 1969). In 1971, the company was granted formal permission to discharge mill tailings and waste rock into the inlet following discussions with the then Department of Fisheries of the Government of Canada and a public inquiry requested by the Pollution Control Board of the Province of British Columbia (Table 3-1). Construction of the Island Copper Mine was completed in 1971, and the first concentrates were produced in September of that year (BHP-Utah Mines 1987).

The Island Copper deposit is a low-grade chalcopyrite-and molybdenite-bearing porphyry averaging ~0.5 wt.% Cu and ~0.02 wt.% Mo. The ore is hosted by andesitic pyroclastic rocks and a complexly brecciated and altered quartz-feldspar porphyry dyke. The mine initially processed about 33,000 metric tonnes per day (mtpd) of ore; as of the spring of 1992, the daily throughput was about 55,000 mtpd. Between startup and June 1992, about 310 million tonnes of tailings have been discharged by STD into the adjacent Rupert Inlet. Closure is anticipated in 1996 upon exhaustion of the orebody. Waste rock has been deposited along the northern margin of the inlet since 1971, resulting in the addition of more than 260 ha of land to the foreshore (Plate 3-1).

Under the terms of the discharge permit issued by the British Columbia Waste Management Branch (see Section 3.6.4), the mine has been required to maintain a comprehensive marine monitoring program and to make the results public through annual reports. The program is supervised by an independent advisory body consisting of several professors from the Universities of British Columbia and Victoria, as well as an environmental consultant. The program is extensive and has been modified several times since data collection commenced in 1970, prior to the opening of the mine. A voluminous body of information spanning some 20 years is now available. In concert with a suite of data generated by independent, university- and government-based, research, the monitoring results permit a rigorous evaluation to be made of the short to long-term impact of the mine on the local inlet system. Both the continuity and the breadth of the available information are unparalleled by any other marine tailings disposal operation.

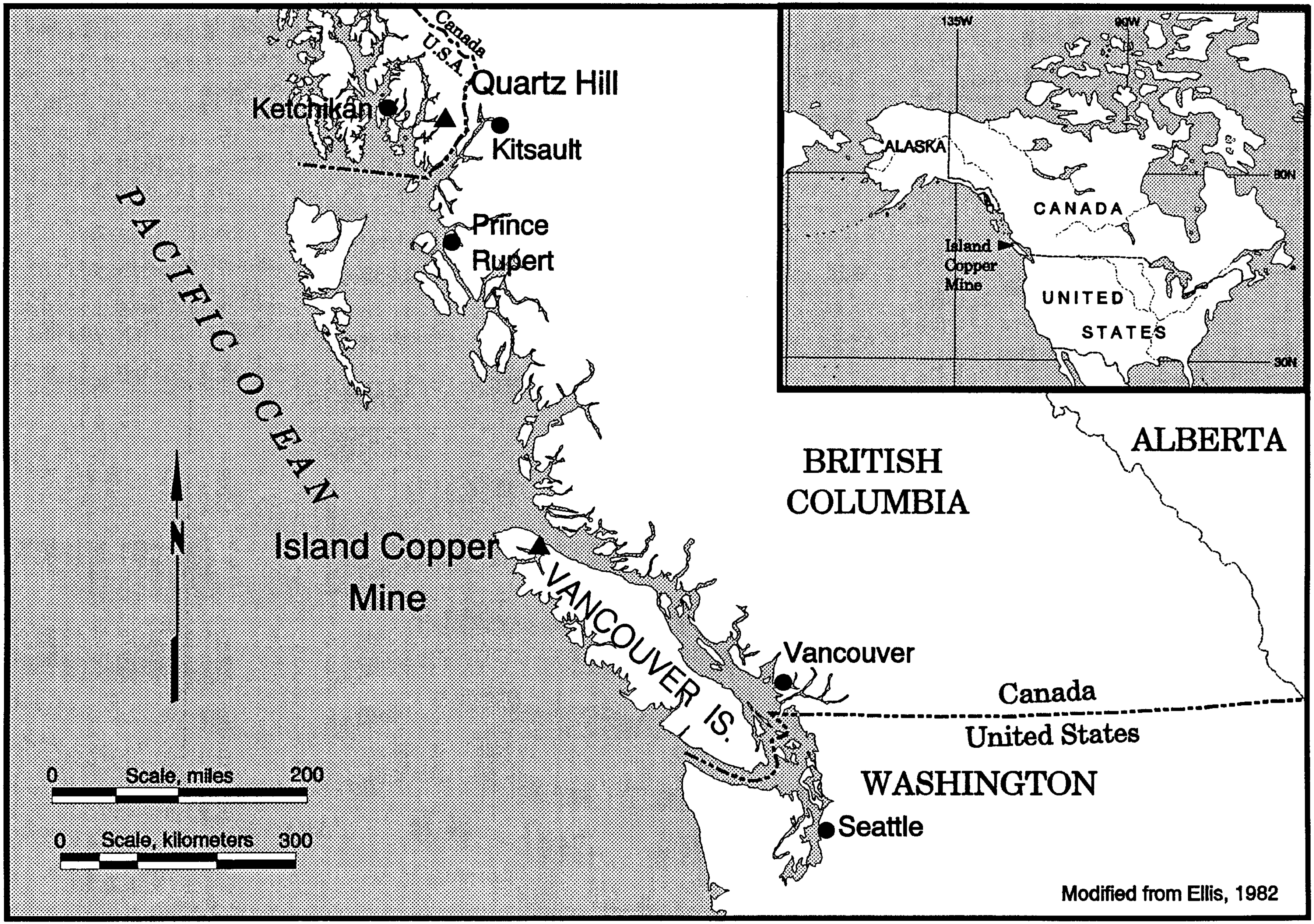


Figure 3.1 - Location of Island Copper Mine on the west coast of Canada.

Table 3-1
Timing of EIA Events at Island Copper Mine

1968	Preliminary feasibility studies started.
1969	Application for waste discharge permit based on engineering designs and literature search of oceanographic information.
	Request from government for more environmental information.
	Start of oceanographic data gathering.
1970	Public hearing on discharge permit.
1971	Discharge permit granted with effluent controls and EIA requirements.
	EIA program redesigned and initiated by the mine, but under supervision by a university group of marine scientists and mining engineers.
	Mine operational October 1971.
1978	Government inquiry into the mine's tailings discharge system and environmental impact.
	University supervisory group re-organized, starts to meet regularly at six month intervals.
1980	Inquiry results released - no changes in tailings discharge system, nor EIA requirements.
1990	Mine initiated Closure Plan for an expected 1996 closure.

Plate 3-1. - Island Copper Minesite on Rupet Inlet (BHP-Utah 1991).

3.2 Composition of the Orebody

The Island Copper deposit lies in the upper portion of the Bonanza Volcanic Formation and is hosted by andesitic pyroclastic rocks and a complexly brecciated and altered quartz-feldspar porphyry dyke. The principal ore minerals are chalcopyrite and molybdenite which occur as fracture fillings and smears on fractures and slips. The mean mill head grade through mid-1987 was 0.435% Cu and 0.017% Mo (BHP-Utah 1987). The mineral assemblage of the gangue (Poling 1982) is dominated by quartz (50-70%), feldspar (2-20%) and biotite and chlorite (5-10%). Magnetite is present at concentrations on the order of 2-4%, as is calcite (~2.5%). Sulphide minerals identified in the ore body include pyrite (3%), chalcopyrite (~1.5%), sphalerite (0.02%), molybdenite (0.02%), bornite, and galena (0.01%). The chalcopyrite contains approximately 90% of the copper in the ore, and the molybdenite about 60% of the Mo present in the feed to the mill.

3.3 The Milling Process and Characteristics of the Effluent

The milling circuit at Island Copper includes primary grinding with six semi-autogenous mills, secondary grinding with four ball mills, and rougher flotation with 300 ft^3 ($8.5m^3$) Wemco cells. First cleaning is accomplished with Outokumpu cells, and second and third cleaning with Agitair cells. Mill process reagents and their consumption rates on treated material and tailings solids are listed in Table 3-2.

Tailings remaining at the end of the concentrating process are thickened in two 114 m diameter thickeners to about 45% solids by weight. The slurry flows by gravity to a mixing chamber where it is typically mixed with twice the volume of seawater and discharged through the outfall at about 40 m depth. The solids consist largely of silt-sized aluminosilicate particles (about 60% is <63 µm in diameter) with average copper and molybdenum contents of 700 and 40 ppm respectively (also see Chapter 2, Table 2-2).

3.4 Other Resources and Uses

3.4.1 Effluent

A summary of the characteristics of recent effluent is presented in Table 3-3. Note that all parameters met the permit objectives for the period reported in Table 3-3 with the exception of Mo. Figures 3-2 to 3-10 summarize the mean annual variations of a suite of key parameters in the Island Copper effluent. Several features are noteworthy: (a) dissolved cyanide (Weak Acid Dissociable method) was below the level of detection (5 ppb) in all samples in 1990 (Figure 3-5); (b) dissolved copper remained in the range observed since 1984 (6 to 10 ppb) which is well below the permit limit of 50 ppb (Figure 3-7); (c) dissolved molybdenum concentrations continued an upward trend which began in 1985 (Figure 3-8) – this was attributed in 1990 to the processing of stockpiled, oxidized, marginal ore, as suggested by Figure 3-9 in which dissolved molybdenum concentrations in the final effluent are compared with the proportion of marginal ore processed during the

Table 3-2
Typical Mill Process Reagents Used at the Island Copper Concentrator

Reagents	Total Consumption (lbs)	Mineral Feedstock (tons)	Consumption Rate on Treated Material (lb/tons)	Consumption Rate on Tailings Solids (lbs/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)	6,440	1,581,996	0.004	0.0003
Molybdenum Circuit				
Arylene M-60 (Dioctyl Sodium Sulfosuccinate)	8,129	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	1,399	47.1	0.0033
Gold Leach				
Soda Ash	25,210	112,792	0.22	0.0013
Hydrogen Peroxide	28,155	2,669	10.5	0.0014
Sodium Cyanide	45,616	2,511	1802	0.0023
Activated Carbon	2,205	1,689	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**

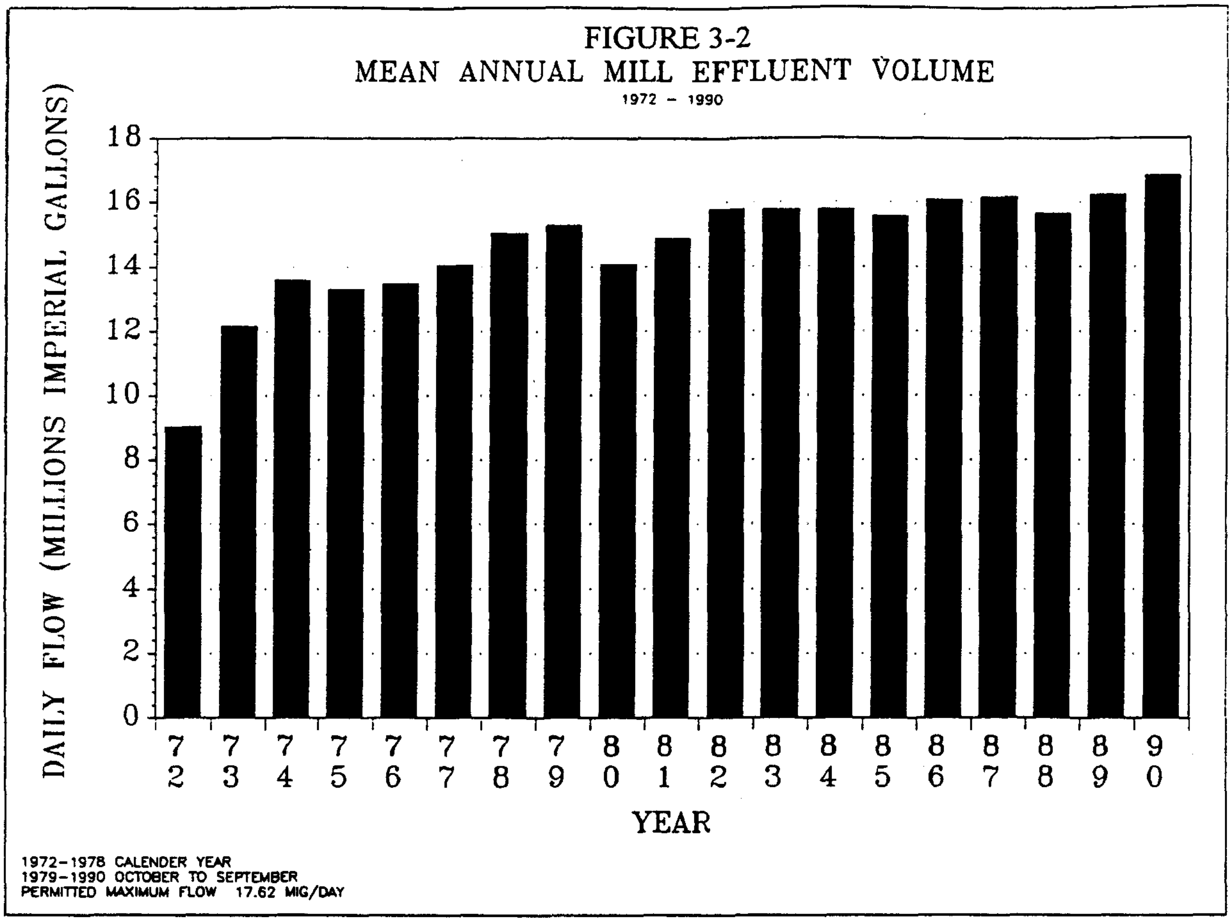
Source: BHP-Utah (1991)

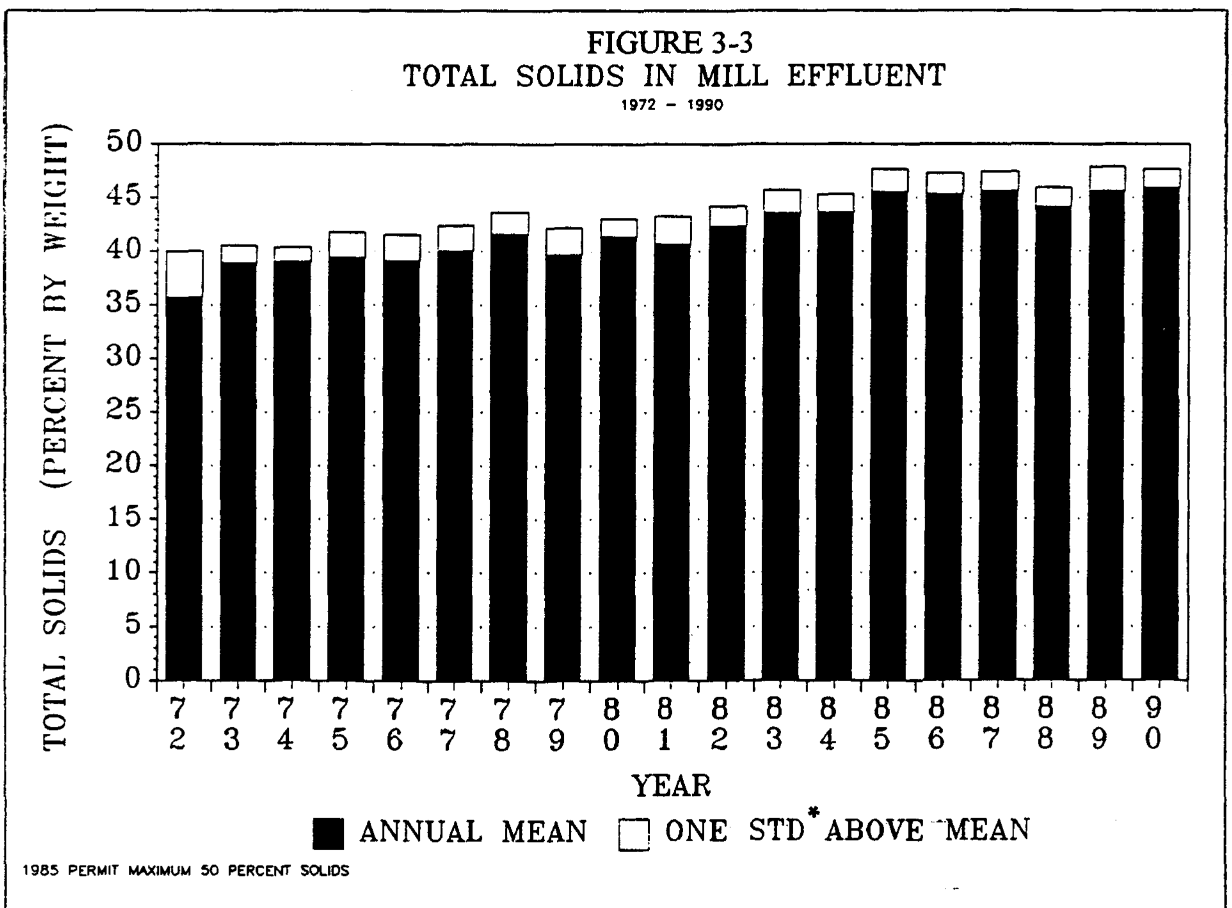
Table 3-3
Summary of Physical and Chemical Analysis of Effluent from the Island Copper Mine
October 1989 to September 1990

Parameter	Unit	n	Mean	Standard Deviation	Min.	Max.	Permit or Prov Objectives
Daily Volume	10^6 Gallons	365	16.87	--	6.4	20.1	17.62/24.21[1]
Daily Volume	(m^3)	365	75,670	--	28,900	86,820	80,100/110,100*
% Solids	% by Weight	52	45.9	1.6	42.6	49.1	50
Temperature	°C	52	24.6	4.9	15.4	32.8	None
pH		52	10.3	0.3	9.6	10.8	7.5-11.5
Diss. Arsenic	µg/L	52	19	10	5.8	48	100
Diss. Cadmium	µg/L	52	<0.1	--	<0.1	0.1	5
Diss. Copper	µg/L	52	7.9	5.2	3.2	30	50
Cyanide (WAD)	µg/L	52	<10	--	<10	<10	100
Diss. Lead	µg/L	52	2.1	1.1	1.0	4.5	50
Diss. Manganese	µg/L	52	2.1	0.6	0.9	3.5	100-1000[2]
Total Mercury	µg/L	52	<0.1	--	<0.1	0.2	1
Diss. Molybdenum	µg/L	52	377	134	190	670	500
Diss. Zinc	µg/L	52	6.3	4.1	2.1	20	200-1000[2]

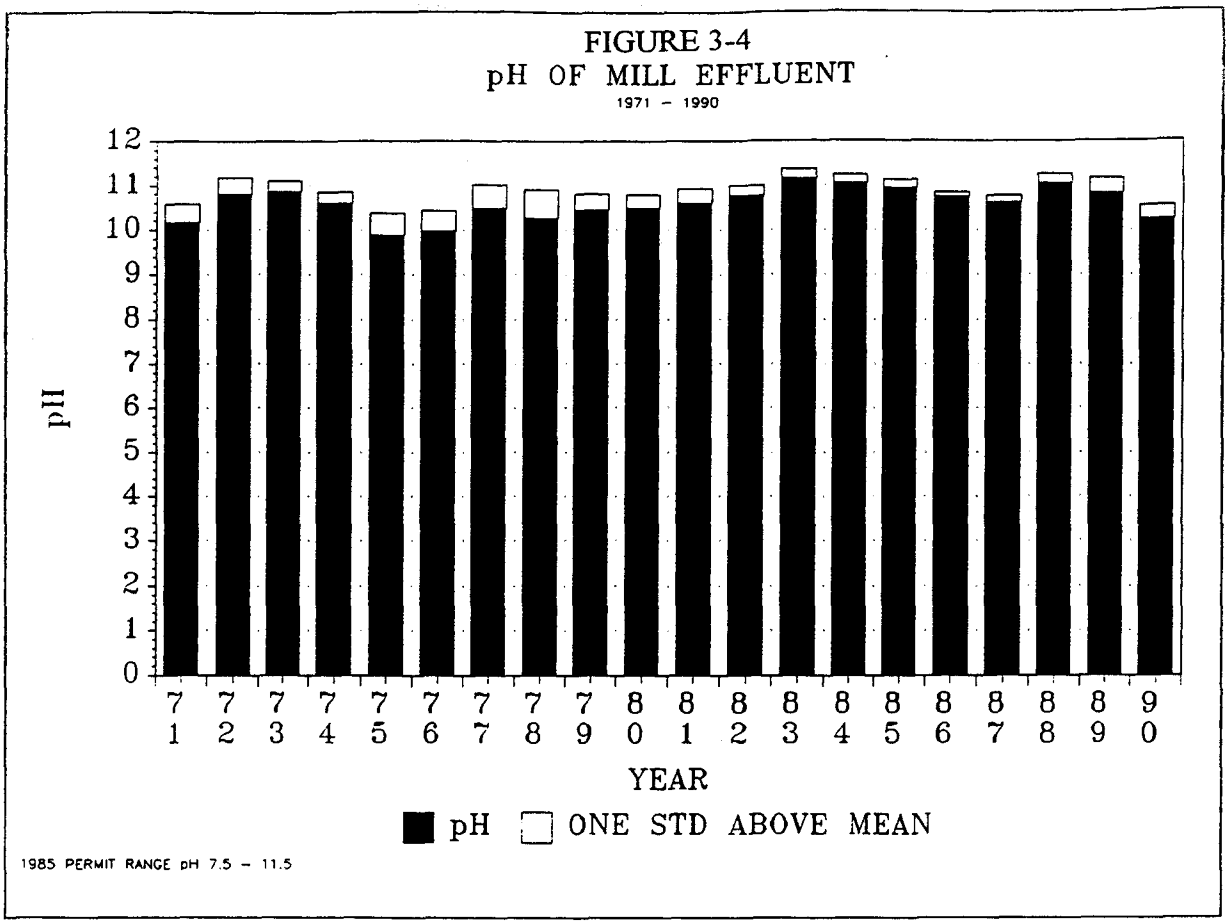
1/ Permit Objectives for Volume:
Annual Daily Mean Volume = 17.62 x 10^6 gallons or 80,100 m^3
Daily Maximum Volume = 24.21 x 10^6 gallons or 110,100 m^3
2/ Provincial Objective (unmarked values are permit objective).

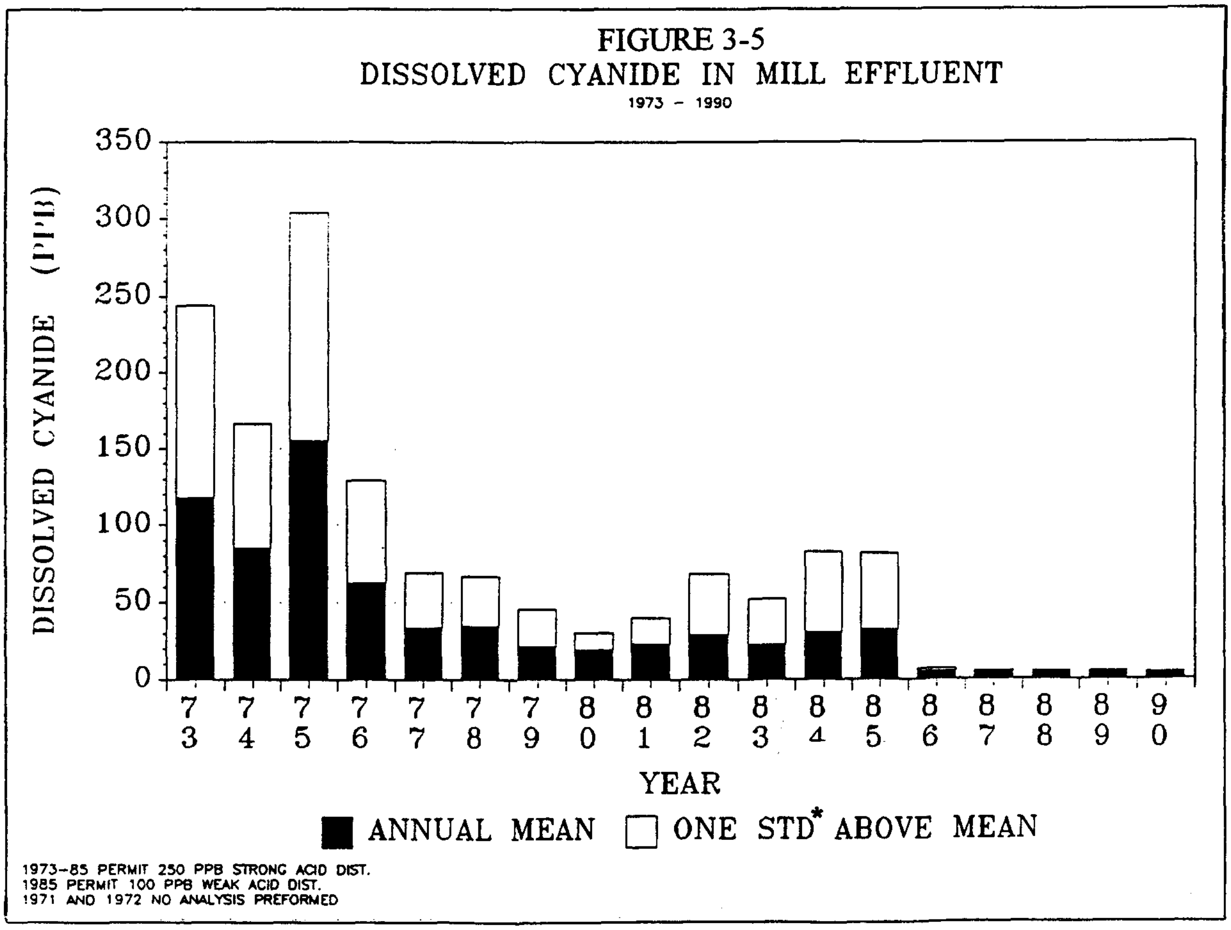
Source: BHP-Utah (1991)



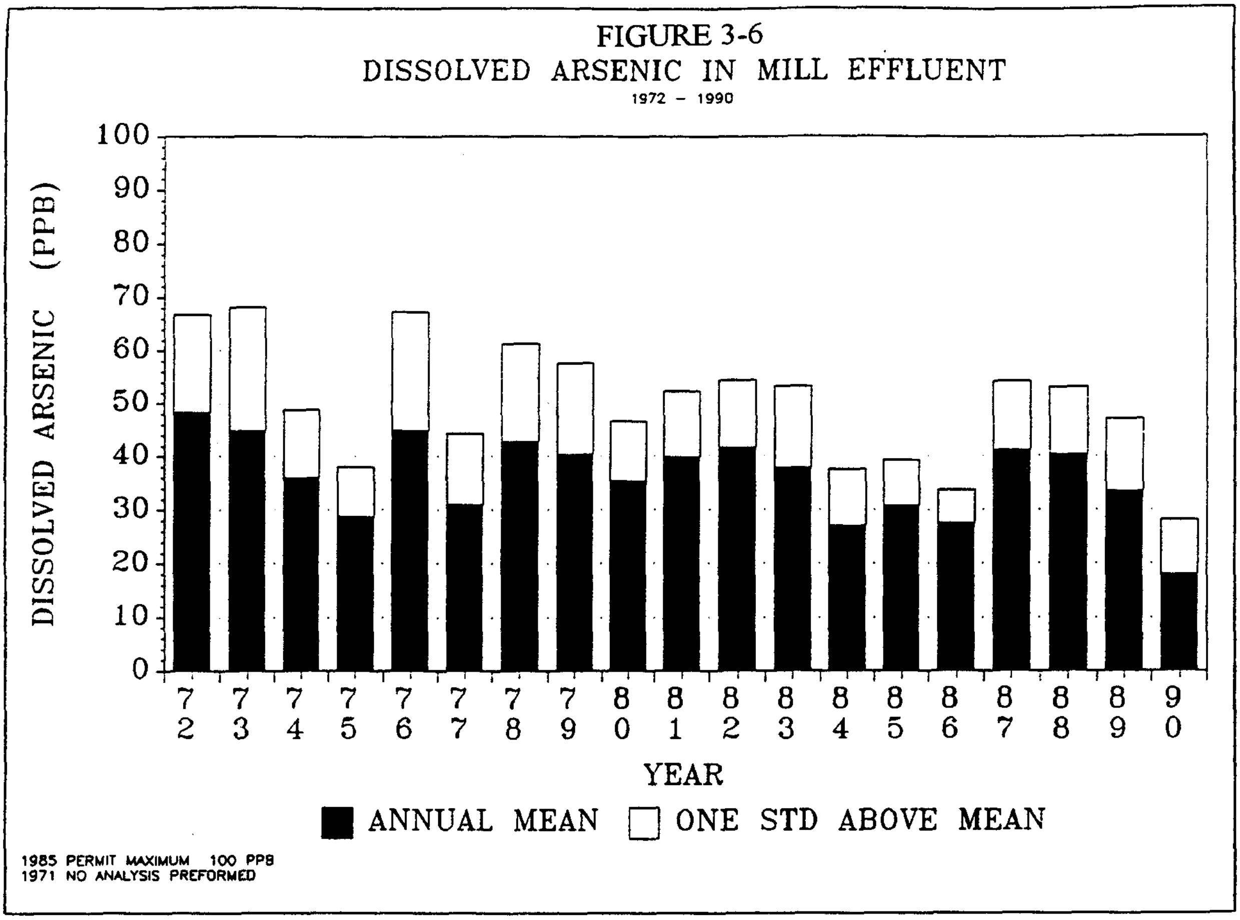


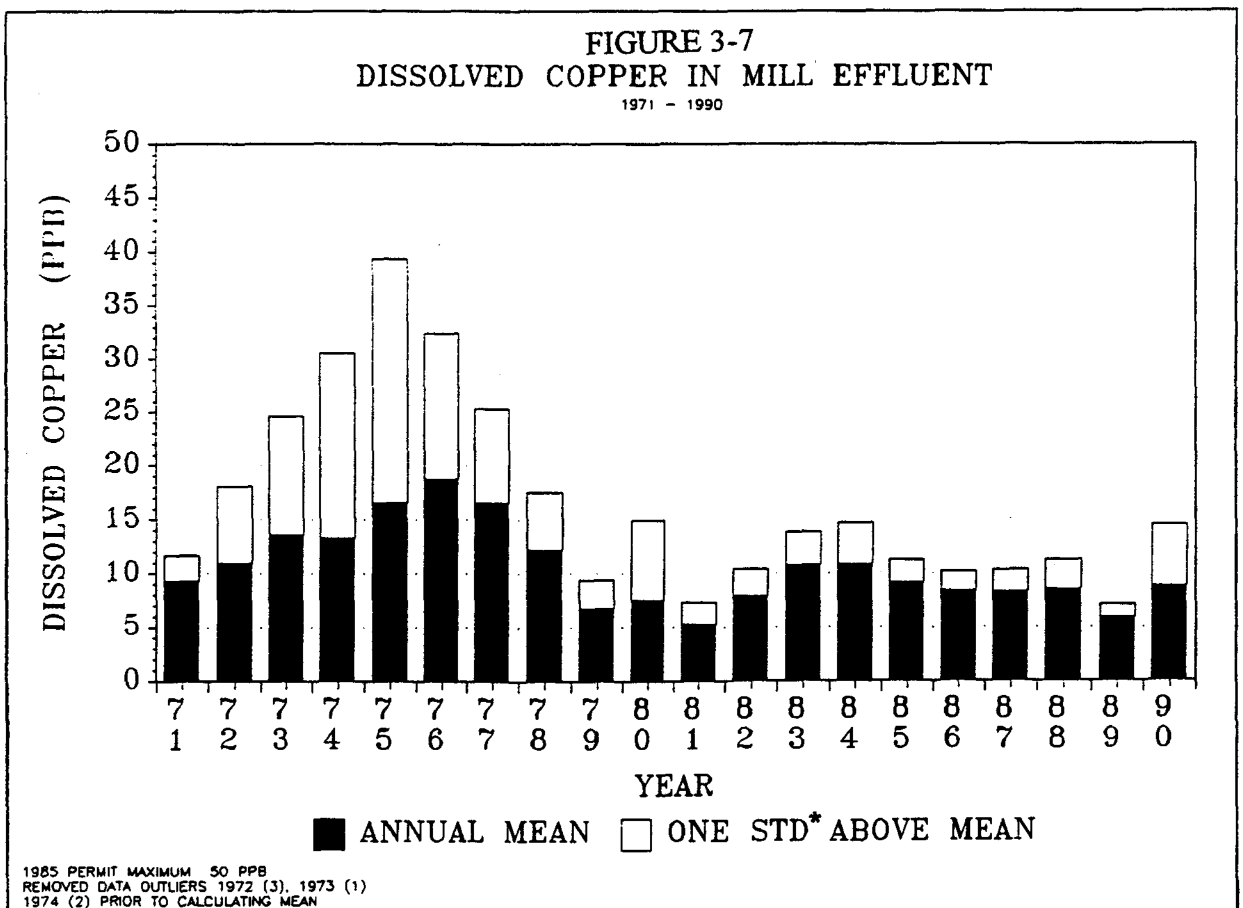
***STD = Standard Deviation in Island Copper Mine Data.**
(Source: BHP-Utah 1991)



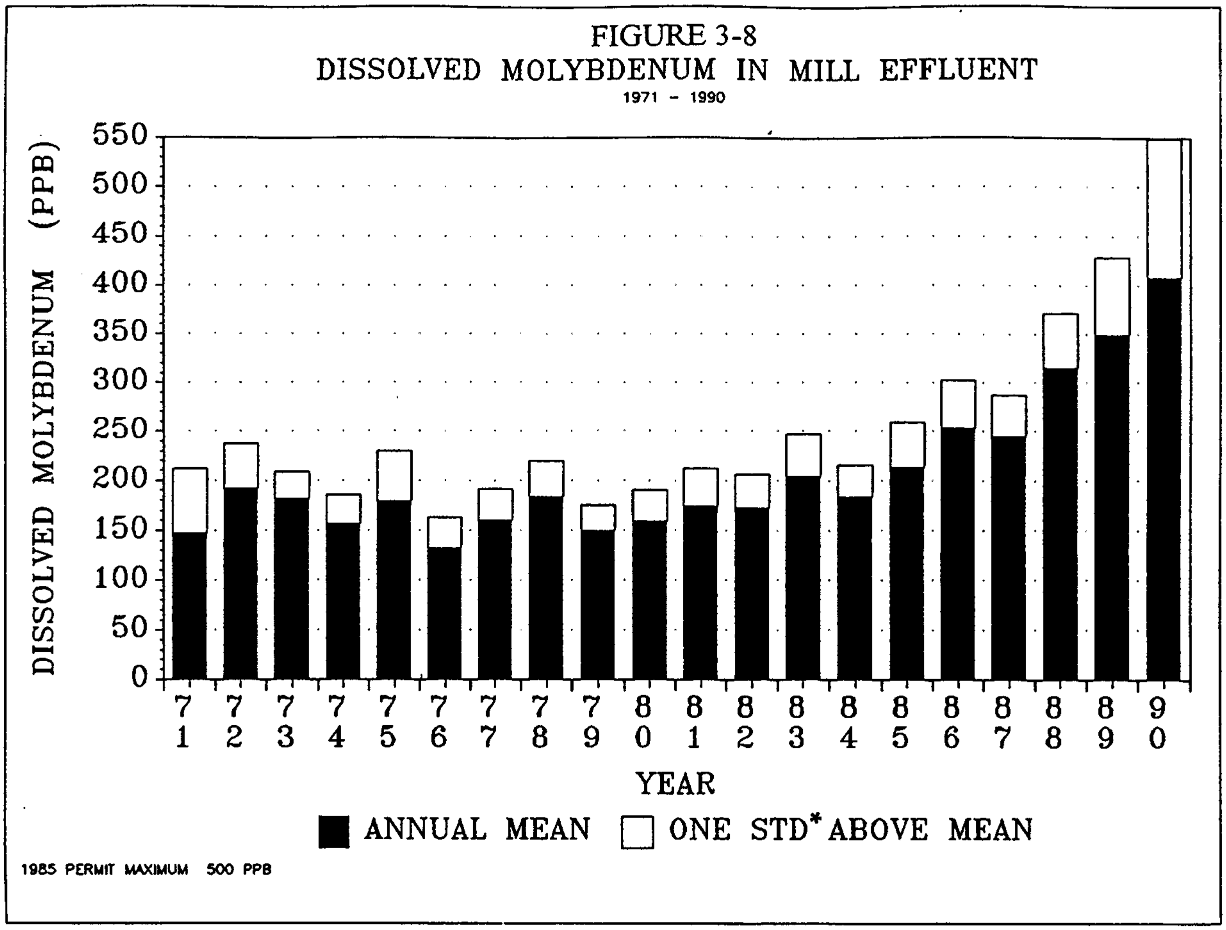


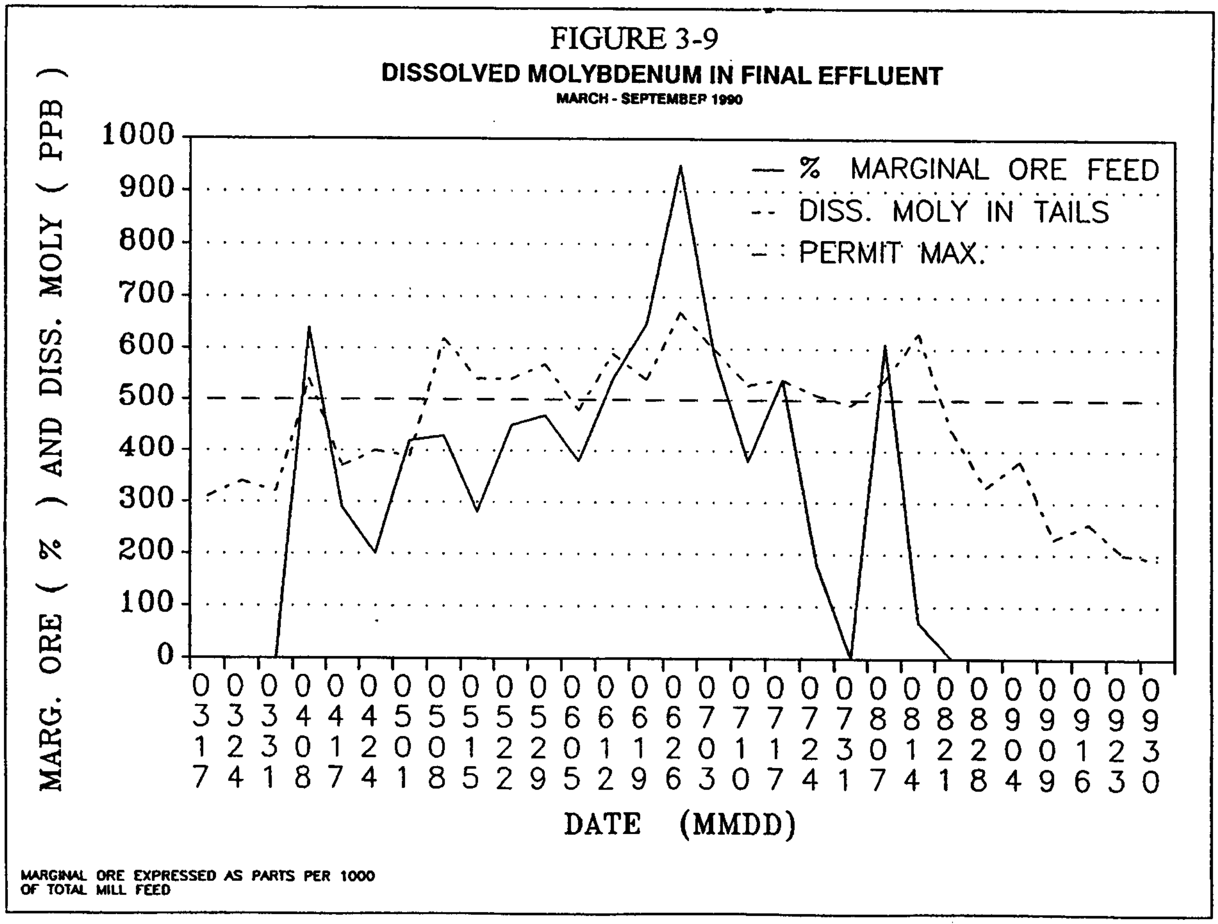
***STD = Standard Deviation in Island Copper Mine Data.**
(Source: BHP-Utah 1991)



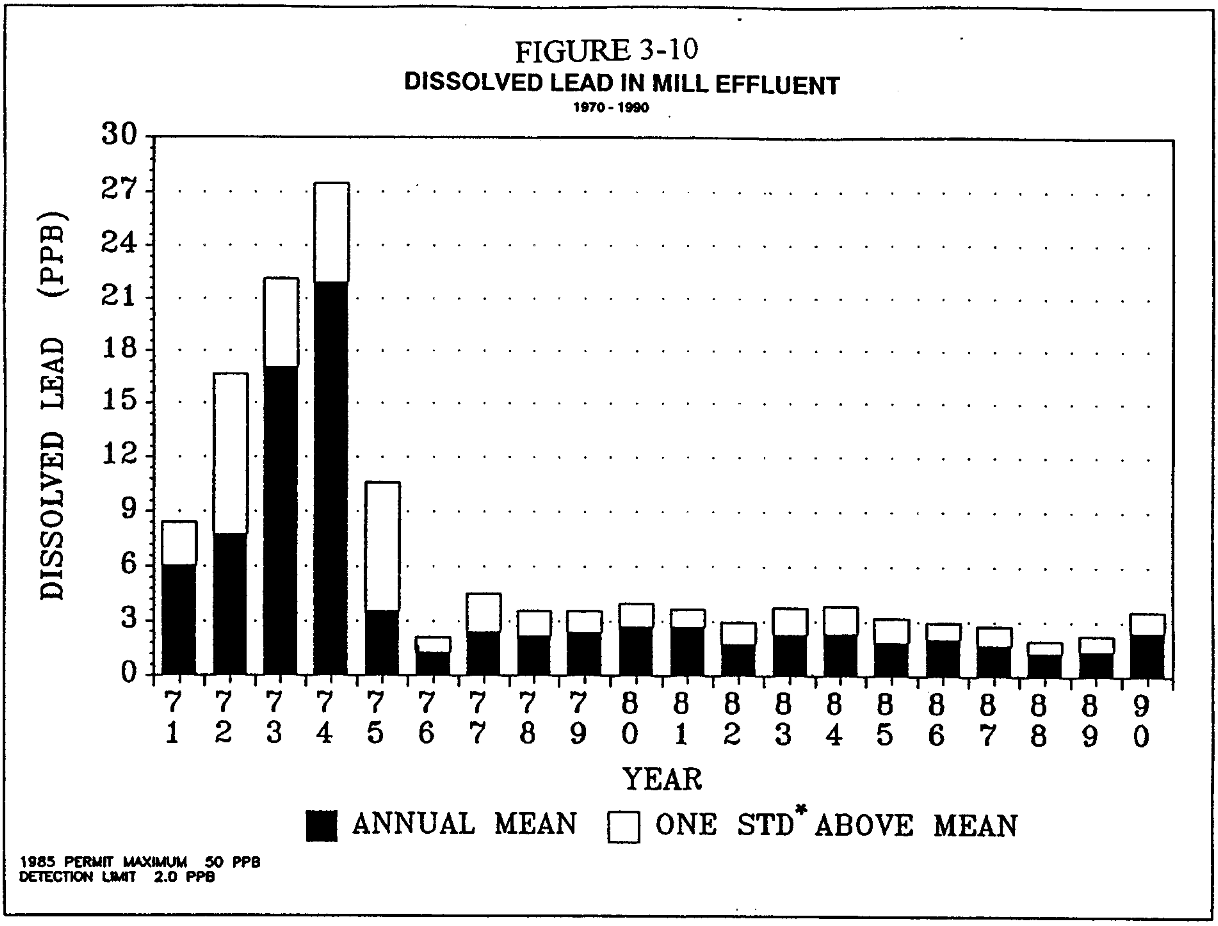


***STD = Standard Deviation in Island Copper Mine Data.**
(Source: BHP-Utah 1991)





***STD = Standard Deviation in Island Copper Mine Data. (Source: BHP-Utah 1991)**



***STD = Standard Deviation in Island Copper Mine Data.**
(Source: BHP-Utah 1991)

reporting period, the figure shows a clear relationship between the two (note that marginal ore is expressed as parts per thousand of total mill feed); and (d) dissolved lead was near or below the detection limit as has been the case since 1976 (Figure 3-10). Dissolved cadmium and total mercury remained below their limits of detection (0.1 ppb for both elements) during 1990 (Table 3-3), as has consistently been the case for at least the last 10 years, according to the Annual Assessment Reports dating back to 1981. Dissolved manganese and dissolved zinc are not covered by the discharge permit; both remained well below provincial objectives in 1990 (Table 3-3) as has been the case in previous years.

3.4.2 Waste Rock Dump Characteristics and Impacts

Under the terms of a foreshore lease, waste rock has been dumped along a 3.5 km stretch of the north shore of Rupert Inlet since the mine commenced operation in 1971, and has created some 260 ha of new land (Plate 3-1). While the dump was developing, the leading edge prograded into deep water (50-90 m) over previously-discharged tailings. This resulted in dump instability and failure with the debris being spread across the floor of the inlet towards the south shore (Island Copper 1988).

Concern that the progressive eastward advancement of the dump would have a deleterious effect on crab habitat has not been borne out by extensive catch data collected over 20 years (see Section 3.6.4). The range of sampling stations for crabs is shown in Figure 3.11.

The development of acid rock drainage in terrestrial waste dumps at Island Copper during the 1980s heightened concern about the release of dissolved heavy metals into Rupert Inlet. From 1987 to the summer of 1990, the majority of the acid seepage was collected and conducted to a Settling/Treatment Pond and Exfiltration Pond. Both the pH and metals levels in the drainages vary seasonally with higher values in the fall and winter, apparently reflecting a flushing effect during the winter rains.

Up to the summer of 1990, the collected drainages were allowed to dissipate into the beach dump, where they were diluted as a result of slow tidally-driven mixing within the submerged portion of the dump. The effect of this disposal on the metals concentrations in proximal inlet waters, plus the potential influence of oxidation of sulphide minerals within the beach dump waste rock itself, has been monitored approximately bimonthly for several years at three stations established directly off the face of the dump (Stations X, Y and Z; Figure 3-12) Dissolved copper and zinc values have been quite variable (BHP-Utah 1991; Table 3-4) but on average have been higher than the mean (time-averaged) concentrations measured in surface waters near the centre of the basin (BHP-Utah 1991; Table 3-5) south of the mine site (Station A; Figure 3-13). The contrast between the two data sets in part reflects the sampling strategy. All samples off the face of the beach dump were collected during the last hour of an ebb tide during the time when water in the dump was draining into the inlet. A 24-hour study conducted in April 1990 to determine if the metal concentration at the dump face varied with tidal phase showed that the zinc concentration

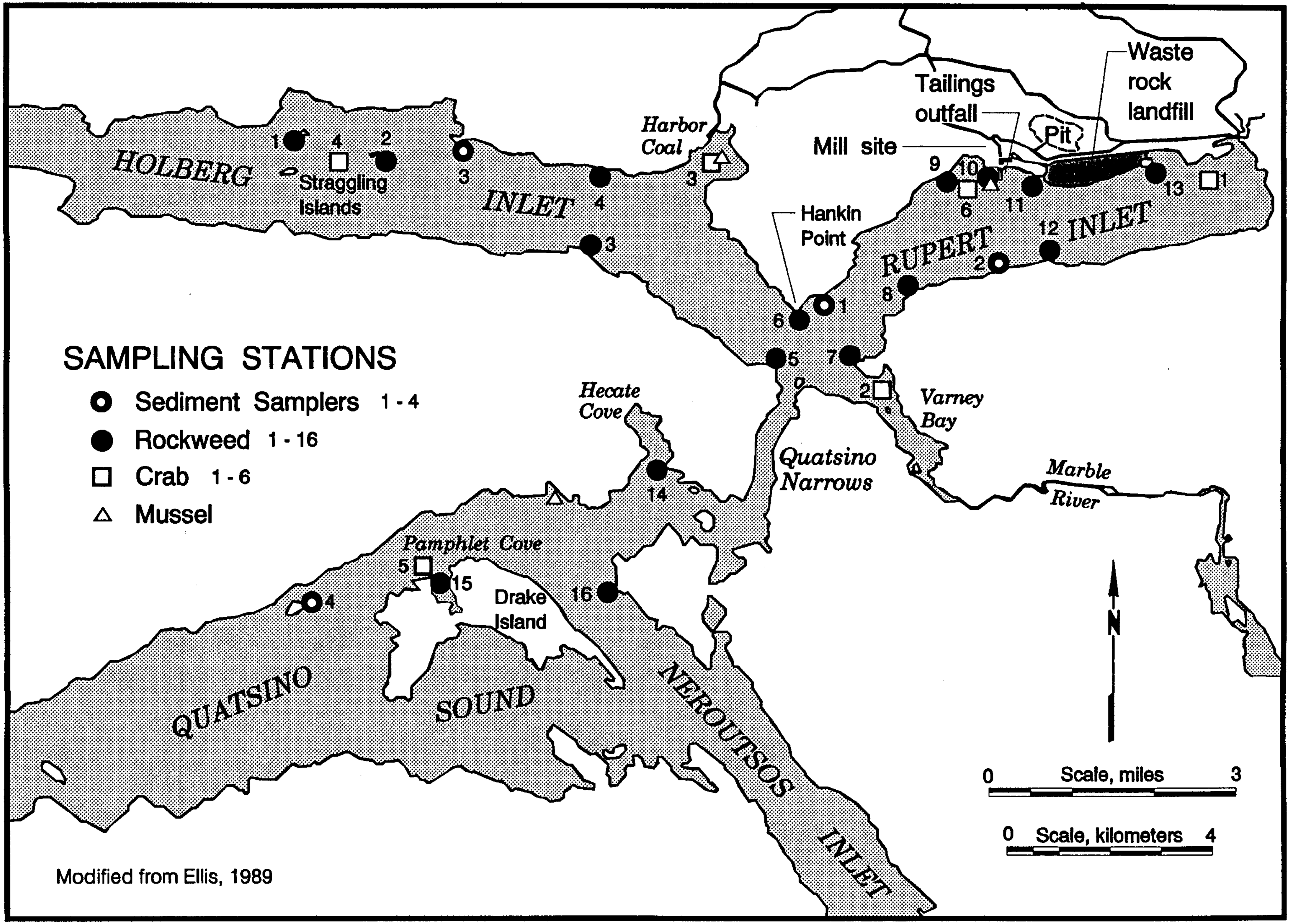


Figure 3.11 - Map showing positions of sampling stations for the crab fishery and selected other parameters.

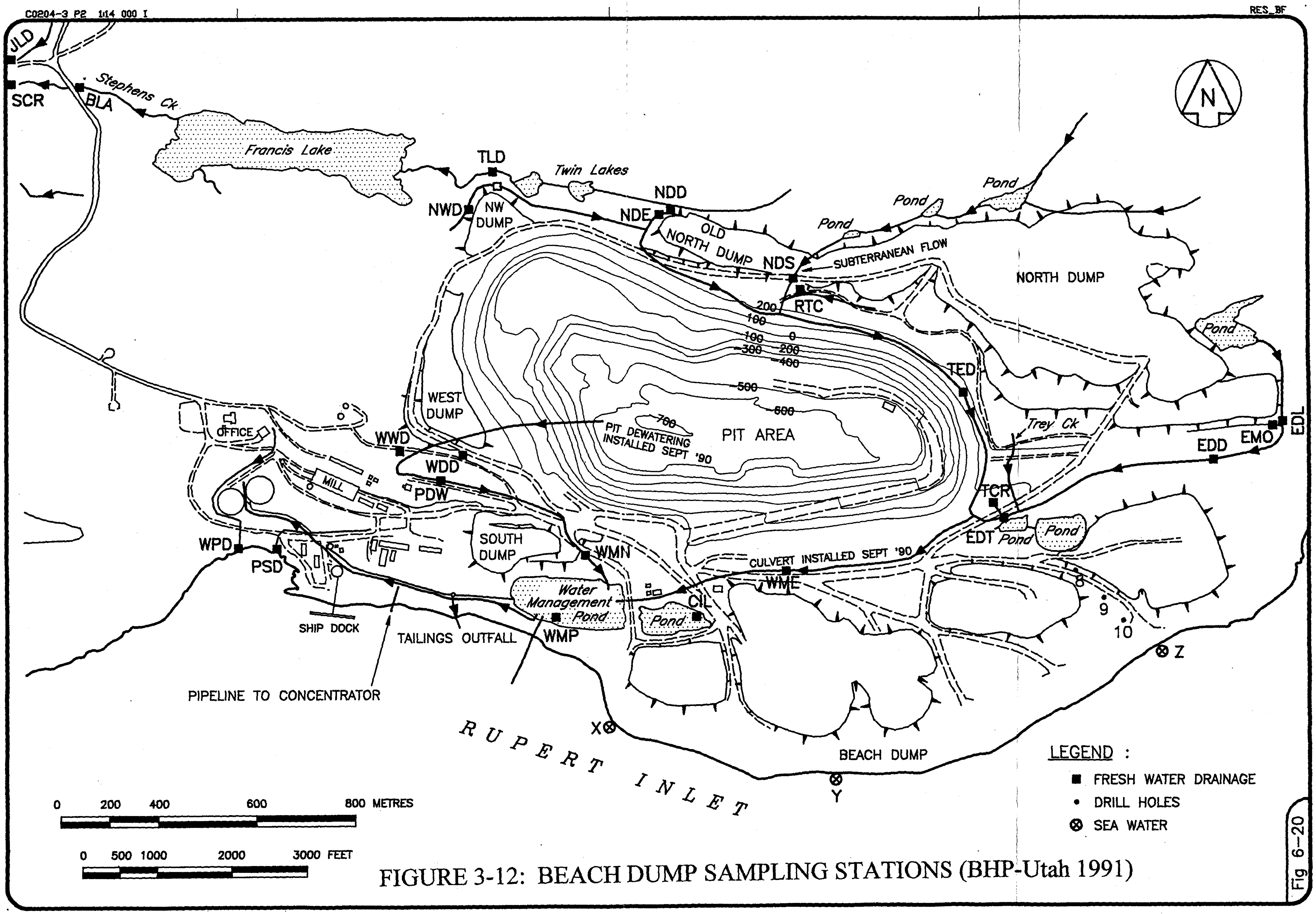


FIGURE 3-12: BEACH DUMP SAMPLING STATIONS (BHP-Utah 1991)

Table 3-4

Dissolved Metals in Seawater off the Beach Dump (µg/L)[1]

Year	n	Station X (Narrow Island) mean	min	max	n	Station Y (Mid Dump) mean	min	max	n	Station Z (Red Island) mean	min	max	Grand Mean
Dissolved Zinc													
1985	9	4.4	1.6	9.8	9	3.2	1.8	4.7	8	6.6	2.5	15.5	4.7
1986	9	8.9	2.0	26	9	8.0	3.2	21.0	9	29.0	3.7	150.0	15.3
1987	12	4.5	1.3	8.9	12	5.3	0.8	9.5	12	5.7	2.1	8.9	5.2
1988	9	9.7	2.8	32	9	6.5	3.1	10.0	9	7.4	2.0	24.0	7.9
1989	18	9.6	2.9	28	18	10.3	3.0	25.0	18	12.5	2.5	40.0	10.8
1990	18	7.3	2.4	29	18	10.0	3.5	45.0	18	9.2	3.6	230	8.8 ± 7.0
1991	21	11.2	3.2	24	21	11.4	2.8	33.0	21	10.8	3.2	38.0	11.1 ± 6.7
Dissolved Copper													
1985	9	4.9	2.2	11.7	9	4.3	2.3	9.3	8	5.7	2.4	10.1	5.0
1986	9	3.2	1.7	4.8	9	3.3	1.8	5.0	9	4.6	2.7	18.0	3.7
1987	12	2.5	1.0	3.7	12	2.1	0.7	4.6	12	2.4	1.1	3.8	2.3
1988	9	5.0	1.6	12.8	9	3.3	2.2	7.6	9	4.5	1.3	8.1	4.3
1989	18	4.5	1.3	9.2	18	3.9	1.6	9.7	18	4.3	1.6	14.0	4.2
1990	18	3.4	2.0	9.3	18	3.9	1.9	10.0	18	3.3	1.6	10.0	3.6 ± 1.9
1991	21	3.9	2.0	7.3	21	3.7	2.0	5.8	21	2.8	1.8	4.7	3.5 ± 1.2

1/ Refer to Figure 3-12.

Source: BHP-Utah (1991)

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Table 3-5

Dissolved Metals at Station A[1,2]

	Copper			Manganese			Zinc		
	Mean		Std. Dev.	Mean		Std. Dev.	Mean		Std. Dev
1977	1.97	±	0.45	6.30	±	5.83	–		–
1978	1.77	±	0.44	6.19	±	2.80	3.33	±	1.16
1979	1.83	±	0.52	4.61	±	2.64	2.37	±	1.40
1980	2.40	±	1.09	6.57	±	1.97	5.23	±	4.24
1981	1.88	±	0.30	7.68	±	2.53	3.51	±	2.10
1982	1.94	±	0.57	5.73	±	1.79	5.41	±	2.01
1983	2.40	±	0.37	4.40	±	1.46	2.09	±	0.59
1984	2.49	±	0.67	4.09	±	1.21	2.41	±	1.63
1985	2.32	±	0.29	2.85	±	0.87	1.93	±	0.62
1986	2.08	±	0.68	3.62	±	1.18	3.13	±	2.50
1987	1.62	±	0.42	3.08	±	1.08	1.71	±	0.99
1988	1.93	±	0.36	3.48	±	1.23	2.17	±	1.20
1989	2.55	±	0.63	5.83	±	1.38	3.54	±	1.53
1990[3]	1.93	±	0.39	3.56	±	1.35	2.96	±	1.43

1/ Concentration given as mean ± standard deviation (µg/L) with N = 16.
2/ See Figure 3-13 for location of Station A.
3/ Current calendar year results include only January - September, N = 12.

Source: BHP-Utah (1991).

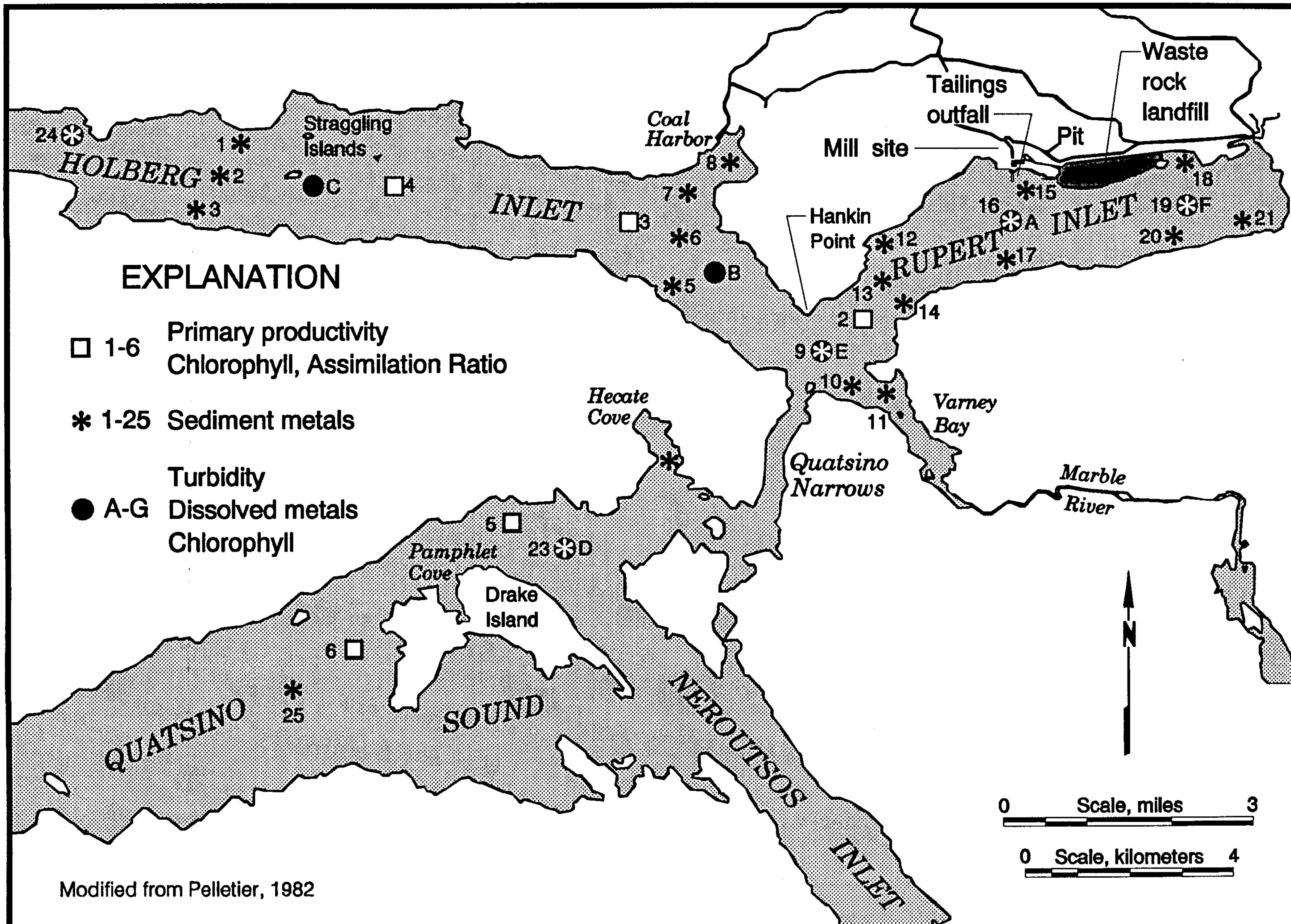


Figure 3.13 - Rupert Inlet and adjacent fjords with selected monitoring stations.

decreases during a flood tide and increases as the tide ebbs (Figure 3-14; BHP-Utah 1991). The existing monitoring scheme therefore records maximum values for Zn off the face of the dump.

Dissolved metals in seepage taken from test drill holes in the beach dump exceeded provincial objectives and were likely to continue doing so. The mine therefore constructed a water management system in the summer of 1990. The land dump drainages are now carried to a Water Management Pond southwest of the open pit (Figure 3-12). When the water in the pond meets objectives it is allowed to exfiltrate through the beach dump. When water quality is unacceptable, the water is pumped to the mill for use as process water.

Mean annual concentrations of Cu, Mn and Zn compiled from data collected at five stations in the Rupert-Holberg-Quatsino system (Figure 3-13) since 1977 show that the ambient levels of all three metals remained essentially unchanged through 1990. Figures 3-15 to 3-20 (BHP-Utah 1991) summarize the mean concentrations at Station A in the centre of Rupert Inlet and the distal Station D located outside the Rupert-Holberg basin in Quatsino Sound (Figure 3-13).

3.5 Tailings Disposal System

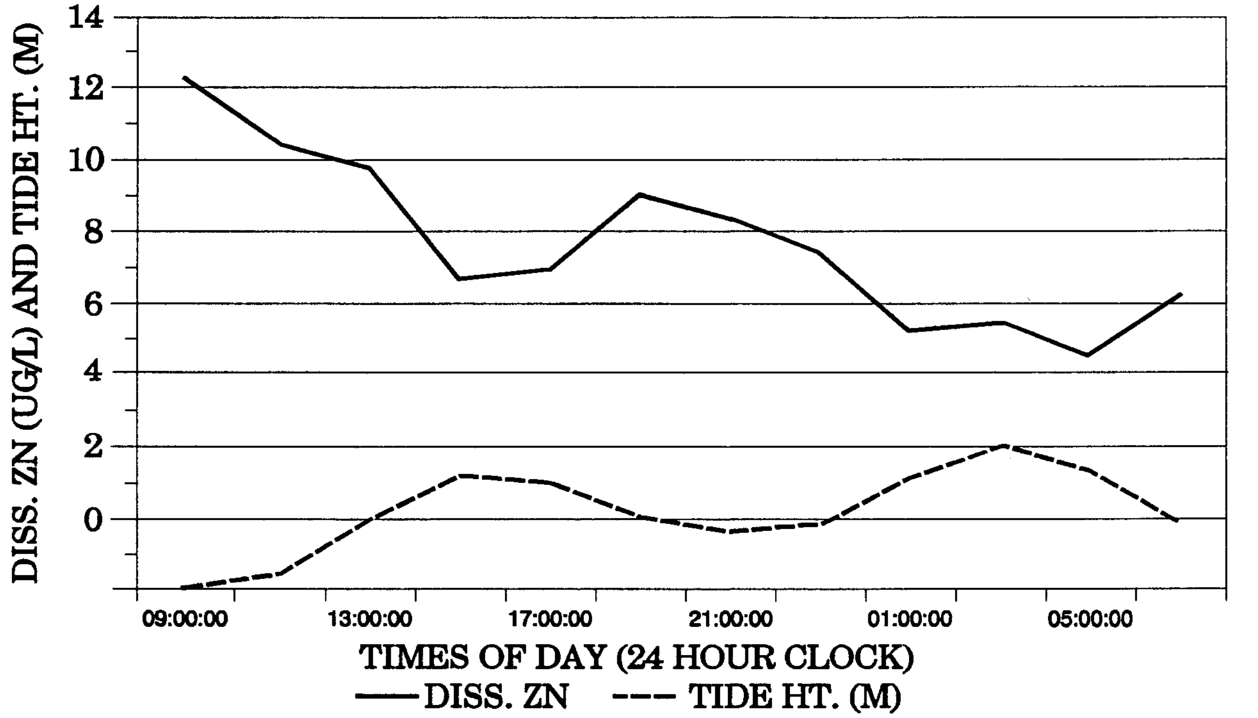
Island Copper Mine designed and installed the first STD system in 1970-71. It consisted of a tailing line discharging to an open seawater mix chamber. A seawater intake line originated at 20 m depth, and provided a self-maintaining flow mixing with the tailings slurry, with subsequent gravity flow to the outfall discharge point at 50 m depth. In 1974 the original outfall was converted to standby use as a redesigned and enlarged system became operational (See Frontispiece). In this, the tailings line discharged the slurry below the surface of the seawater mix chamber, minimized air entrainment, and allowed deaeration of the slurry.

In 1989, a new outfall line and seawater intakes were installed. The earlier continuous down-slope flow pattern established near the outfall had changed and tailings were accumulating within 400 m of the discharge point before periodically sloughing away. This appeared to be due to gradient reduction of the seabed by encroachment of submerged apron of the shoreline waste rock dump.

The tailings slurry turns southwest after discharge and flows by gravity down-inlet. The deepest part of the fjord at the confluence of Rupert and Holberg Inlets, and Quatsino Narrows is the principle locus of accumulation (Figure 3-13), and some 40 meters thickness of tailings have now accumulated there.

Chemical analyses of heavy metals in sediments indicates that measurable quantities of tailings occur in surface sediments in Quatsino Sound and for some distance up Holberg Inlet (Figure 3-21). In Hecate Cove, for example, the presence of tailings has been defined chemically since 1976; visual identification of the deposits has been possible only since 1987. Tailings are now visually obvious in Hecate Cove to a depth of about 10 cm (BHP-

FIGURE 3-14
24 HOUR STUDY OF DISSOLVED ZINC OFF THE FACE OF THE BEACH DUMP (APRIL 26 - 27, 1990)



(Source: BHP-Utah 1991)

FIGURE 3-15
DISSOLVED COPPER IN SEAWATER AT STN. A
1977 - 1990

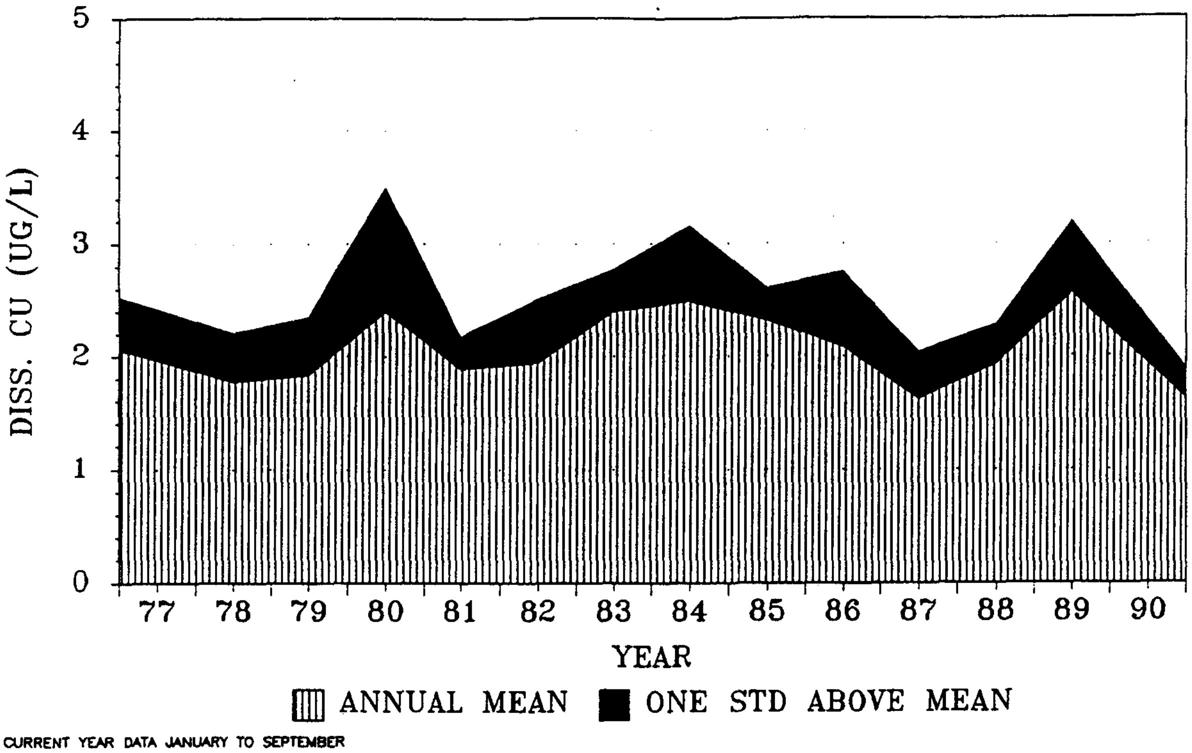
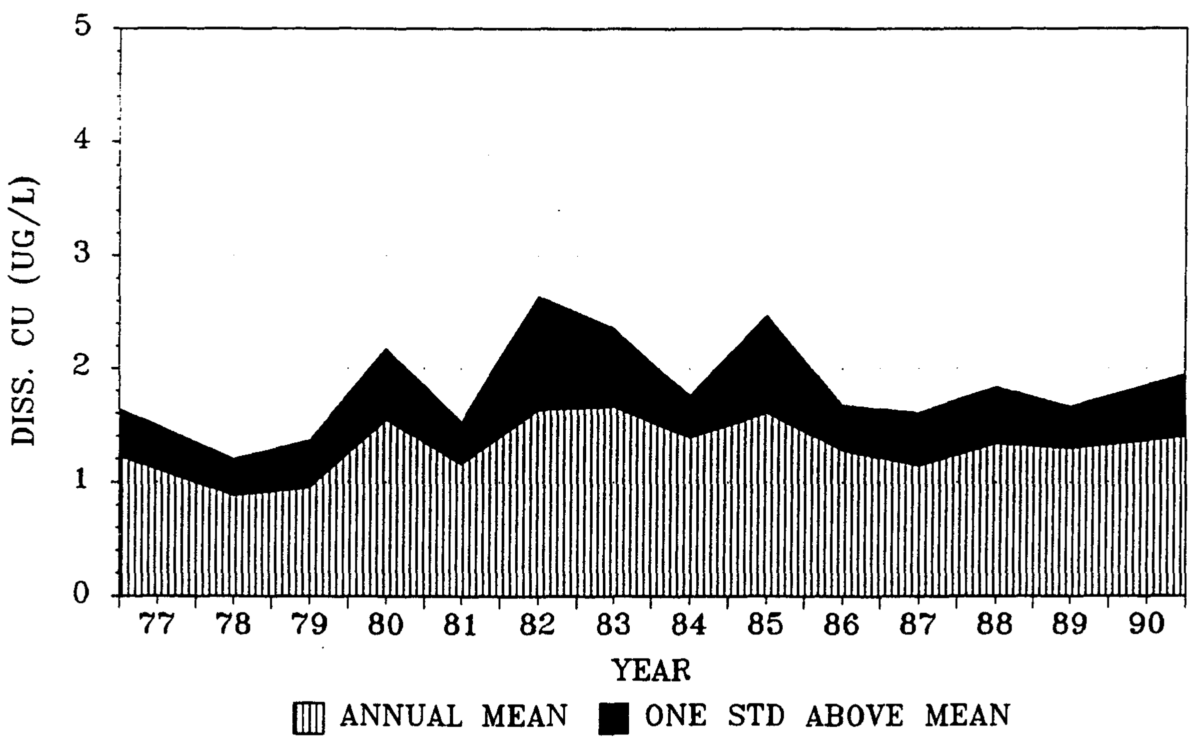


FIGURE 3-16
DISSOLVED COPPER IN SEAWATER AT STN. D
1977 -1990



(Source: BHP-Utah 1991)

FIGURE 3-17
DISSOLVED MANGANESE IN SEAWATER AT STN.A
1977 - 1990

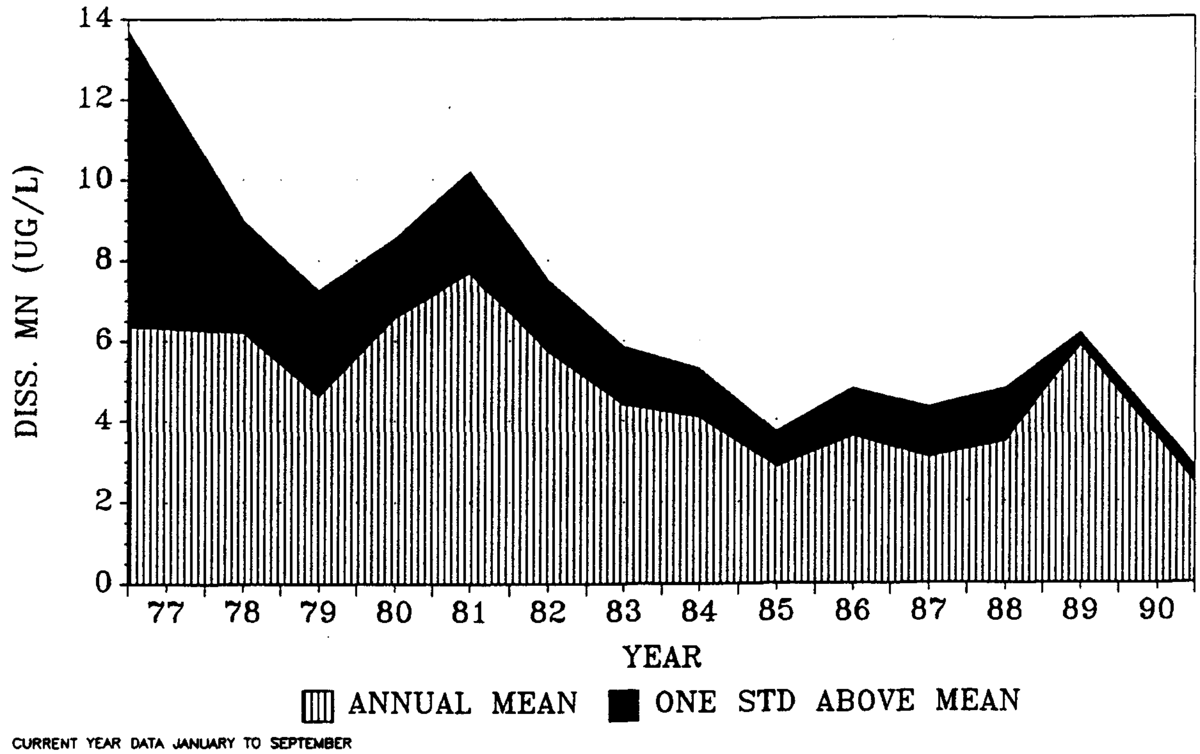
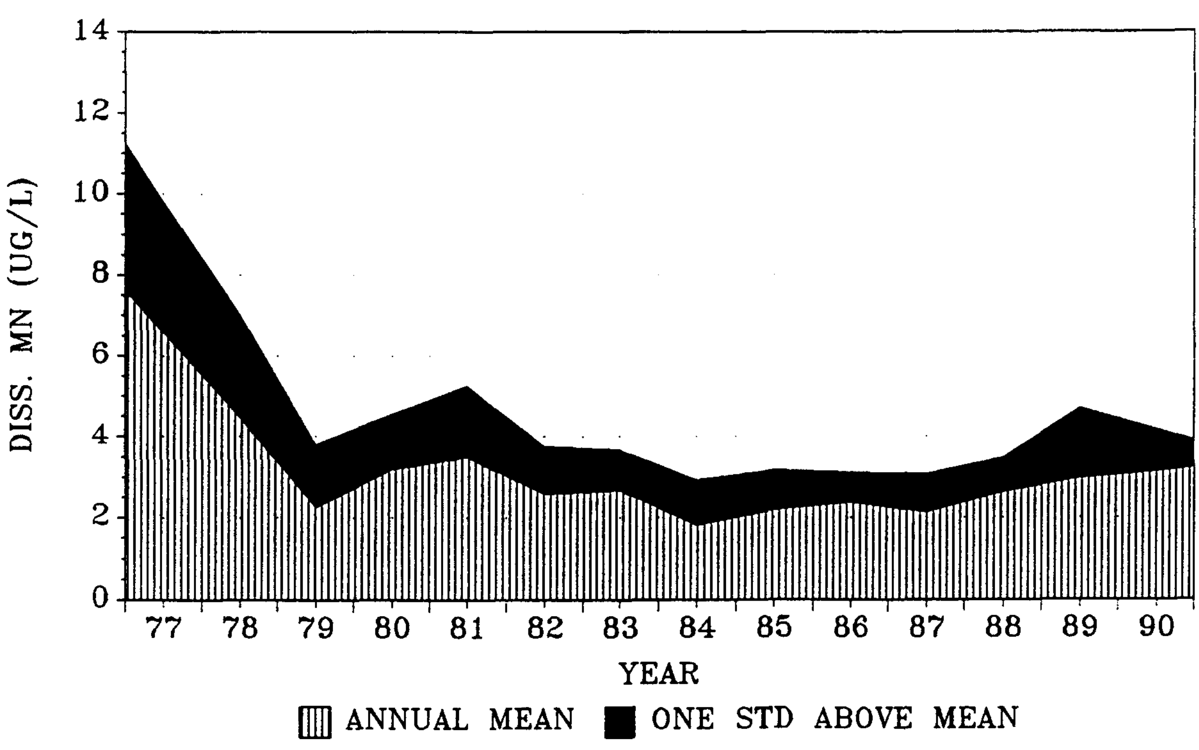
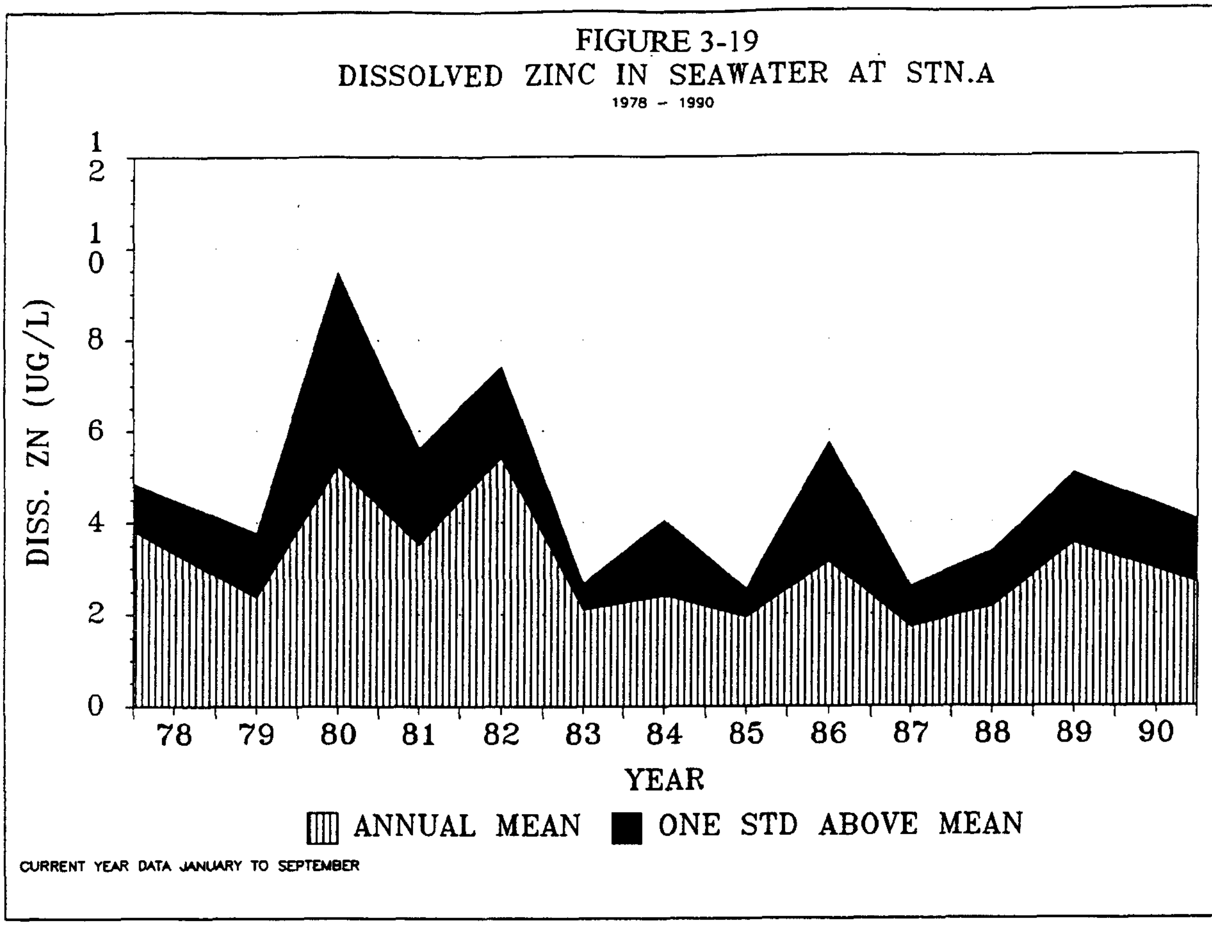
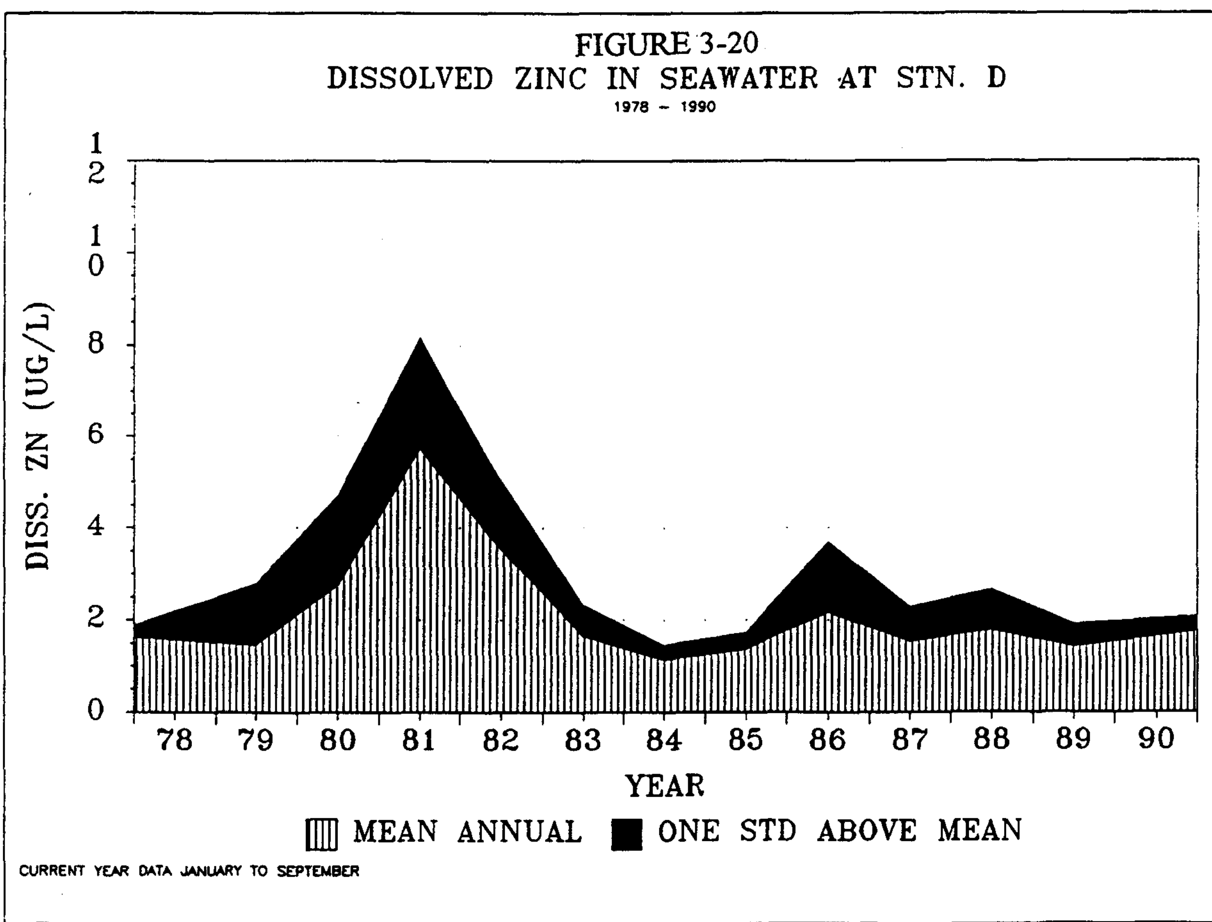


FIGURE 3-18
DISSOLVED MANGANESE IN SEAWATER AT STN.D
1977 - 1990



(Source: BHP-Utah 1991)

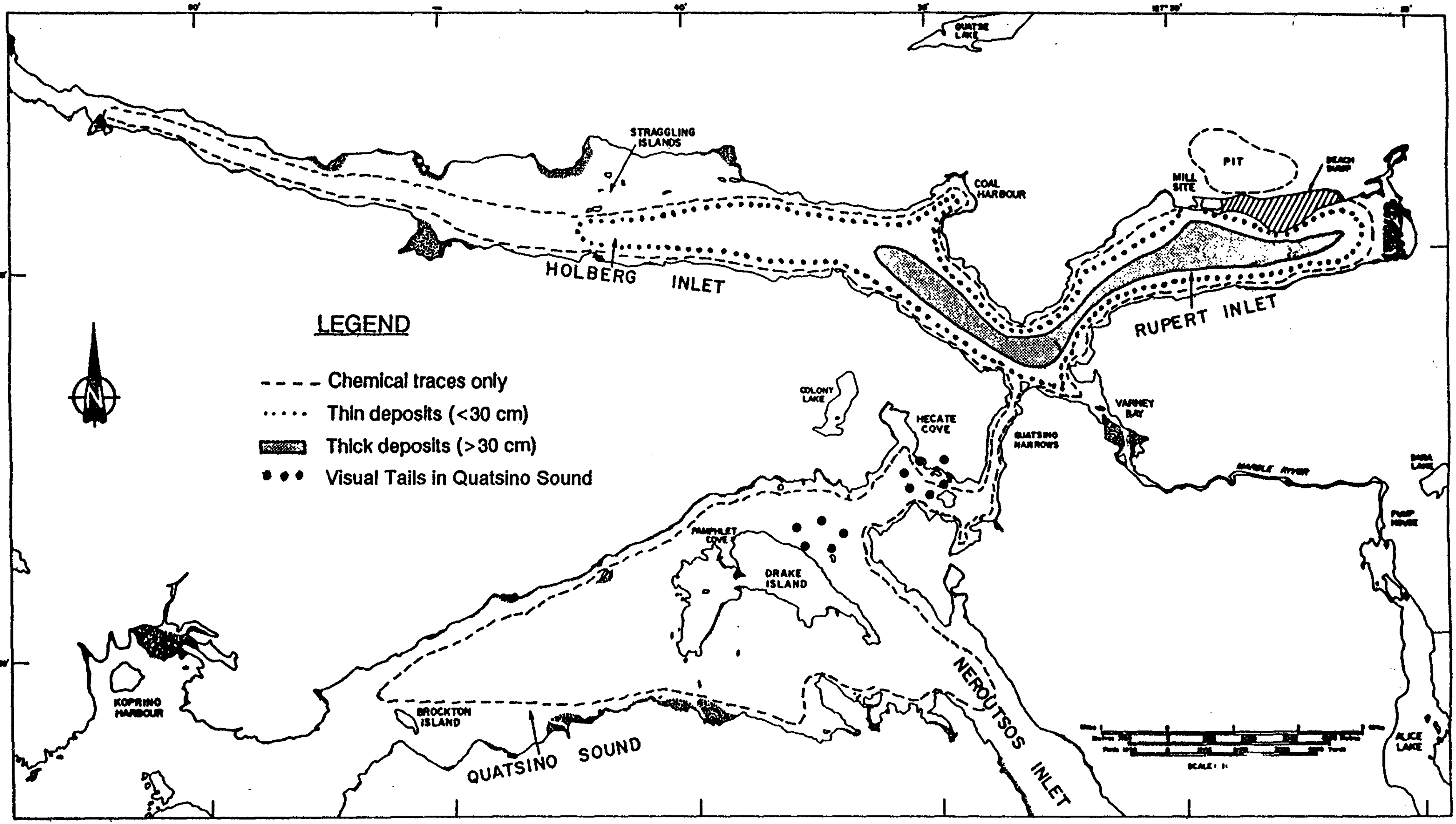




(Source: BHP-Utah 1991)

Island Copper Submarine Tailings Monitoring Program

Figure 3-21 Tailings Distribution to 1991



(Source: BHP-Utah 1991)

Utah 1991), where they occur intermixed with natural organic-rich sediments. As demonstrated later in Section 3.6.4.2, there have been no impacts on benthos in these distal areas despite the detectable increase in tailings accumulation.

3.6 The Environmental Situation

3.6.1 Bathymetry, Physical Oceanography and Resuspension

Rupert Inlet is 10 km long, on average ~1.8 km wide (Figure 3-13) and ranged in depth prior to tailings disposal from about 110 m in the axial channel immediately south of the mine site to ~165 m at the deepest location directly south of Hankin Point (Figure 3-22). Adjoining Holberg Inlet (Figure 3-13) is ~34 km long, ~1.3 km wide on average, and shallower, the mean axial channel depth being about 80 m. The two fjords are connected to the Pacific Ocean via Quatsino Sound through Quatsino Narrows, a long, narrow and very turbulent, shallow (18 meter deep sill depth) tidal channel (Figure 3-13). The water column is generally well-mixed (Drinkwater and Osborn 1975) by tidal currents and turbulence, particularly near the confluence of the two fjords at Quatsino Narrows. The principal river affecting the water properties of the Rupert-Holberg basin is the Marble River, which flows into Rupert Inlet near the junction with Holberg and Quatsino Narrows. This discharge location contrasts with the typical B.C. fjord in which the freshwater enters near the head.

Time-series temperature, salinity and dissolved oxygen data collected by Drinkwater and Osborn in 1971 and 1972 showed that a relatively homogeneous water body exists in the Rupert-Holberg basin below 30 m depth. Comparison with data for other fjords (Pickard 1963) indicates that the water properties of most British Columbian inlets are not as uniform as those in the Rupert-Holberg system (Drinkwater and Osborn 1975). Oxygen contents in the deep water vary seasonally being generally 3-4 mg/L in summer (about 55-70% saturation) and up to ~5.5 mg/L in winter. The near-uniformity of the oxygen content throughout the deep water column implies frequent mixing. The lower summertime values may reflect an influx of low/O_2 water from the Pacific Ocean into Quatsino Sound during upwelling episodes as well as increased oxygen demand in deep waters following the spring phytoplankton bloom (Drinkwater and Osborn 1975).

Tailings are discharged to Rupert Inlet via a submerged pipe 1.07 m in diameter at a depth of about 40 m as a slurry of solids, freshwater and seawater in the respective ratio 1:4:5 parts by volume (Hay 1982). Time-series seismic and echo-sounding profiles and side-scan sonar information defined a leveed submarine channel in Rupert Inlet for the first time in 1974, three years after startup (Hay 1982). At that time, the channel started close to the outfall, ran southerly down-slope and across the inlet before hooking to the west to follow the axial trend of the basin toward Hankin Point. The presence of the channel and its well-developed flanking levees was particularly well illustrated by bathymetric (echo-sounding) data collected in November 1976 (Figure 3-23). Hay (1982) noted that levees in the proximal zone near the outfall are steep-walled and are sites of rapid deposition characterized by non-cohesive sands and silts. These features appear to be the area of

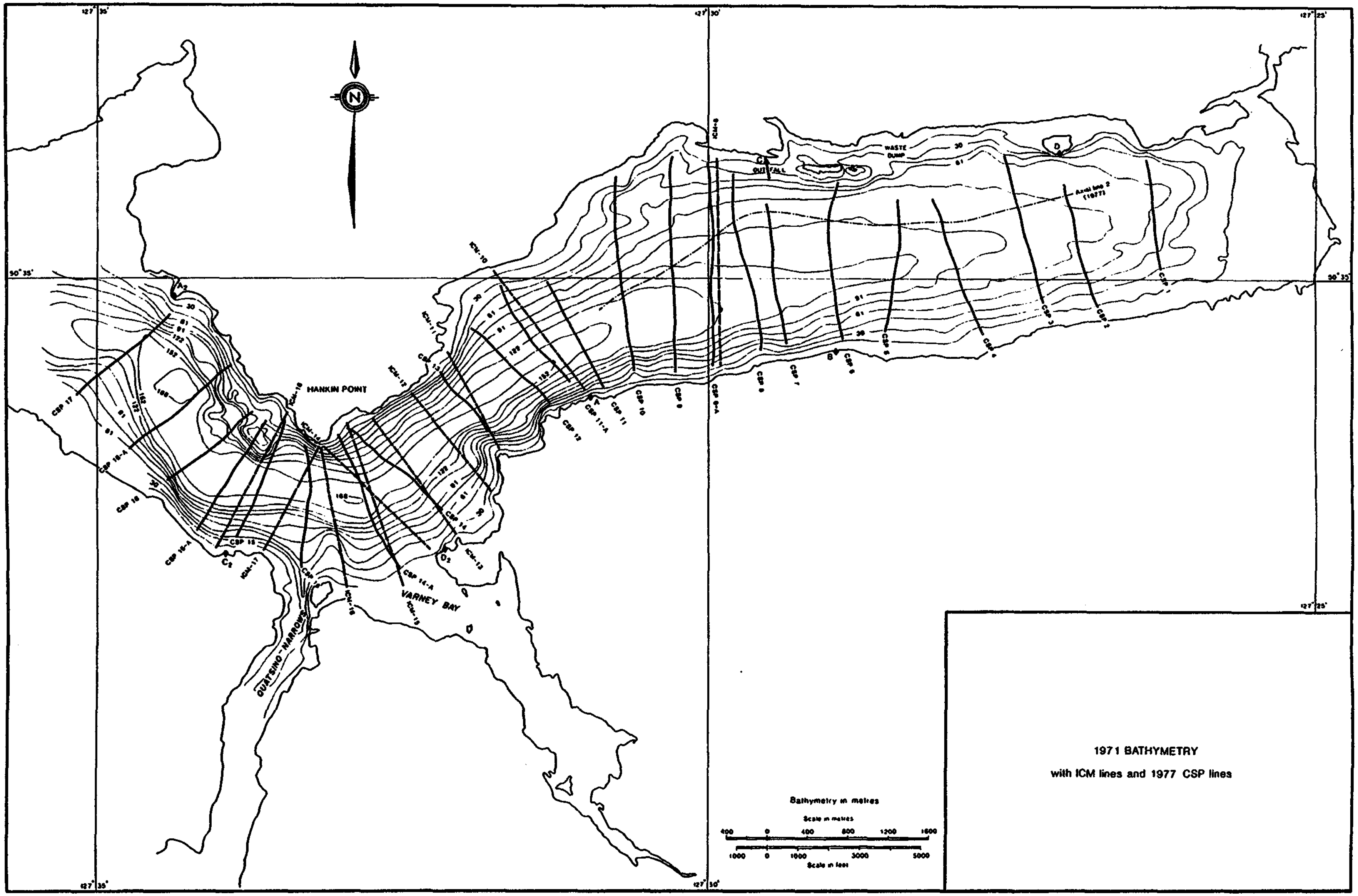


Figure 3-22 Pre-mine bathymetry in Rupert Inlet. Locations of seismic reflection lines (CSP) and the mine's echo-sounding lines (ICM) are also shown. (Source: Pelletier 1982)

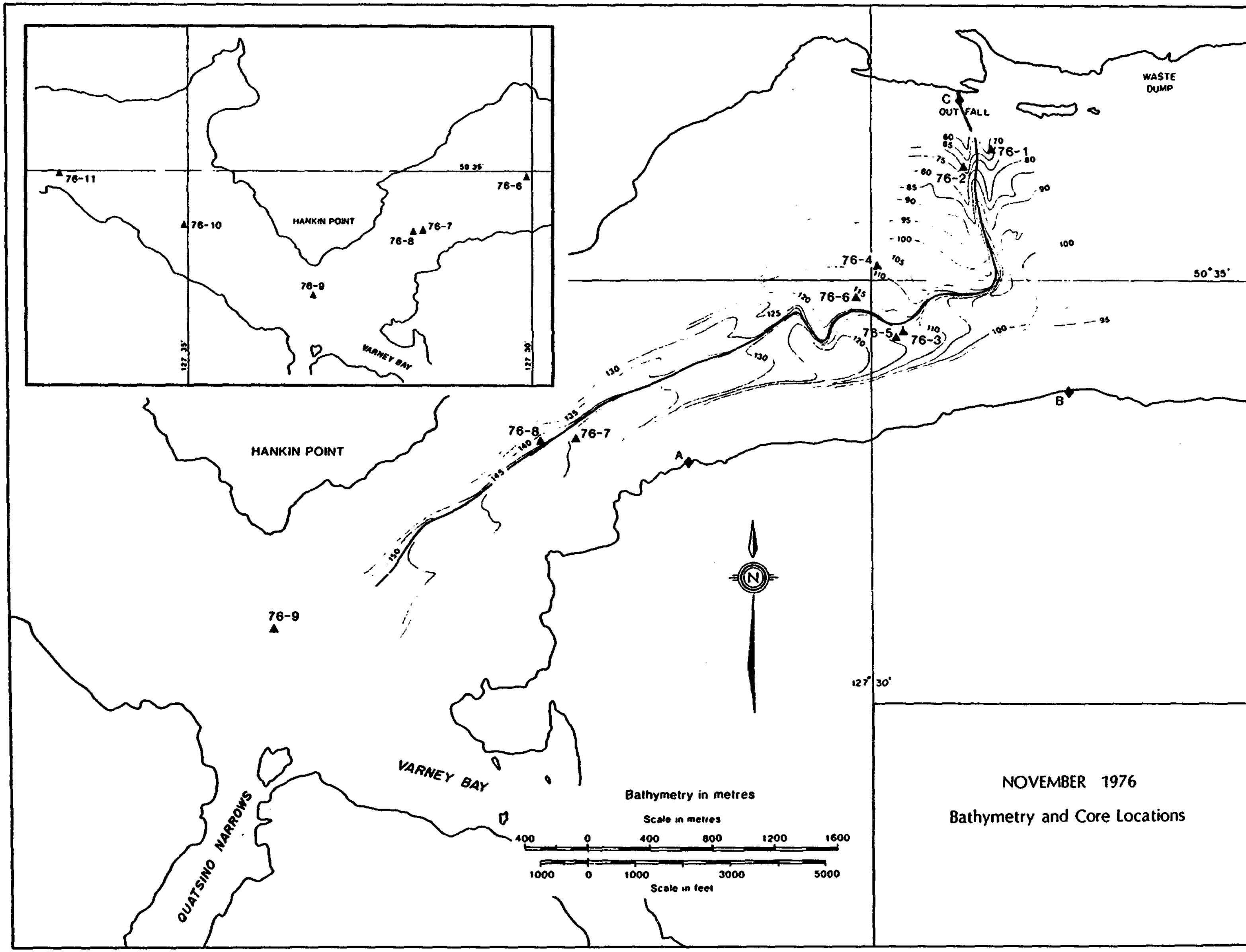


Figure 3-23 Core locations and bathymetry, November 1976 (Source: BHP Utah 1987)

origin of slump-generated turbidity currents which deposit turbidities on levees in the middle and lower reaches.

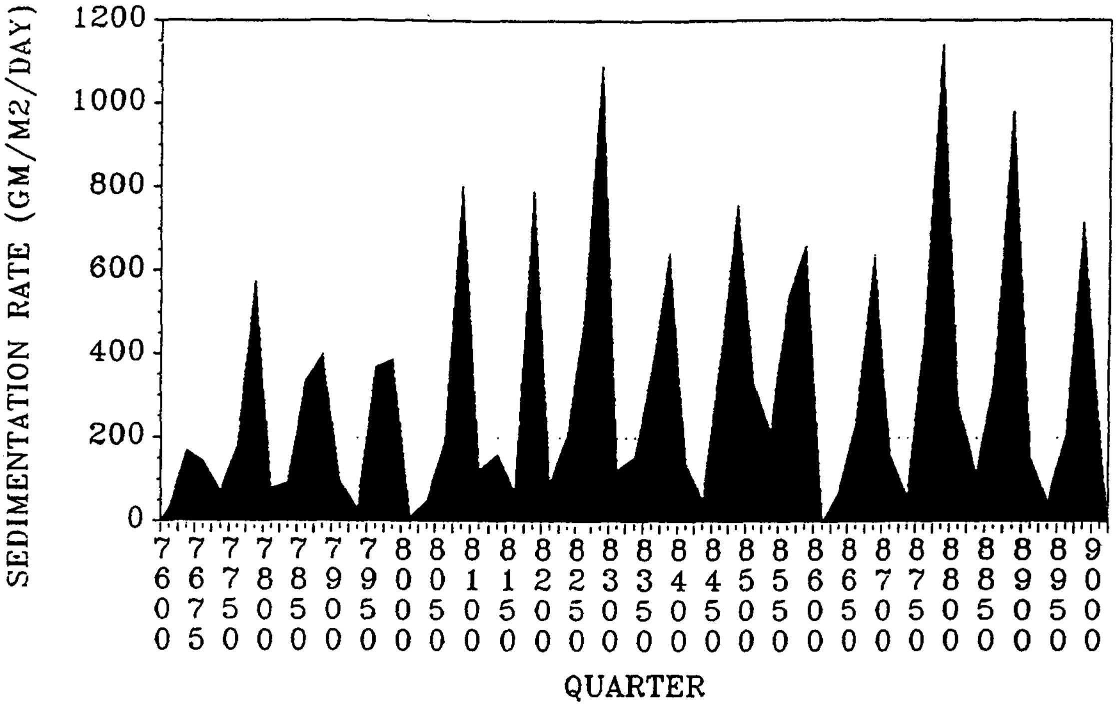
The submarine channel in Rupert Inlet has two important consequences (Hay 1982): (a) because lateral divergence of the tails is constrained, the velocity and excess density of the continuous flow are maintained to greater distances and depths – deposition near the outfall is therefore reduced; and (b) because the levees are subject to intermittent failure, sporadic surge-type turbidity currents will transport material down the relatively flat floor of an inlet to greater distances than would otherwise be the case. Although such phenomena may prove to be advantageous in terms of outfall performance by dispersing the tailings further from the source, under certain circumstances such distal transport may have unforeseen effects.

In the case of the Rupert-Holberg fjord system, resuspension of tailings to the surface has occurred repeatedly during each year since the spring of 1972 in the vicinity of Hankin Point. Two major influences conspire to foster the resuspension. First, tidal exchange through the constricted Quatsino Narrows is exceptionally turbulent and is manifested by high current velocities. Second, during the spring and summer, upwelling off the coast of northern Vancouver Island brings to the surface relatively cold, dense water, which is transported into Quatsino Sound on the tide. During flood tides, this well-mixed water plunges downward as a jet after crossing the Quatsino Narrows sill. Depending on the density contrast between the incoming and resident waters, the jet may penetrate to the bottom south of Hankin Point before being deflected surface ward after colliding with the fjord wall on the north side of the confluence. The momentum of the jet plus associated physical displacement can carry deep waters containing resuspended tailings to the surface. Such resuspension is most pronounced during spring tides when upwelling is significant off the coast, and when the density of the water resident in Rupert Inlet has been lowered by precipitation and runoff, particularly after the fall and winter (Drinkwater and Osborn 1975). The resuspension is exacerbated by the distal transport of tailings via turbidity current flow to the Hankin Point area.

As of 1990, the tidally-dominated circulation off Hankin Point was continuing to resuspend tailings, most of which have settled out in the shallow waters around Hankin Point. However, some material is transported through Quatsino Narrows on the ebb tide and settles out around Hecate Cove. The seasonality of sediment accumulation in shallow water near shore at Hankin Point (Figure 3-24; BHP-Utah 1991) illustrates the strong influence of summer upwelling off Vancouver Island. The highest settling rate during the 15 years prior to 1990 was observed in September, 1987.

The mean depth of Rupert Inlet along the mid channel has been decreasing by roughly two meters per year (BHP-Utah 1987). By closure in 1996, the thickness of the tailings in the central trough of the fjord will be about 50 m; the mean mid-channel depth of the fjord will have been reduced from the pre-mine depth of 145 m to about 96 m.

FIGURE 3-24
INSITU SEDIMENTATION RATE
AT HANKIN PT. 1976 - 1990



(Source: BHP-Utah 1991)

Resuspension and dispersal of tailings over broad areas in Rupert and Holberg inlets, and to a lesser extent in Quatsino Sound, were unforeseen in the original planning for the submarine disposal program. The tailings were expected to flow from the outfall as a continuous density current, settling progressively down-inlet. Although the density flow was expected to reach the deepest part of the inlet south of Hankin Point, it was thought that the deposition would occur at a depth below about 120 m, "...in a zone of vertical stability well below any significant influence from tidal effects coming through the Narrows." (Utah Mines 1969). This prediction appears to have arisen from an inadequate appreciation of the controls on deep-water renewal in the Rupert-Holberg inlet system. This example underscores the need for detailed, site-specific physical oceanographic surveys and modelling studies to be carried out prior to the selection of particular sites for submarine discharge.

3.6.2 Post-Depositional Stability

Two aspects of the post-depositional (diagenetic) chemical behaviour of both tailings and natural sediments in the Rupert-Holberg basin have been considered in detail previously (Pedersen 1984; 1985): *i.e.* benthic nutrient regeneration and remobilization of metals. Both studies used interstitial water and solid-phase measurements made on a trio of cores raised from the basin in 1980. The cores represented three different sedimentary facies including natural sediments in upper Holberg Inlet (core HOL 14; Figure 3-25), rapidly-accumulating tailings collected from the presumably stable flank of the deposit slightly down-inlet from the original outfall (core RUP 3), and slowly accumulating tailings overlying natural deposits near the head of Rupert Inlet (core RUP 1).

Profiles of dissolved nutrients (ammonia and phosphate) in the three cores are shown in Figure 3-26. Ammonia and phosphate are clearly regenerated from organic matter in the natural sediments (HOL 14; Figure 3-25) in a typical stoichometric molar N:P ratio of 10. However, no phosphate regeneration is observed in either tailings-bearing core, despite the presence of significant concentrations of dissolved ammonia. Pedersen (1984) attributed the phosphate deficiency to the precipitation in situ of carbonate fluorapatite. Supersaturation of the tailings pore waters with respect to this phase appears to be fostered by the addition of lime during milling of the ore and in the thickeners; continuing dissolution of this additive following deposition of the solids on the inlet floor promotes supersaturation of the apatite phase by driving up the pH and the calcium concentration in the pore waters (Figure 3-27).

The removal of phosphate from pore waters in the submerged Island Copper tailings appears to eliminate any regenerative flux of phosphorus from the sediments to the overlying water. Although such regeneration can be important to the nutrient budgets of many coastal water bodies (see for example Fisher *et al.* 1982), it does not appear to be a factor in Rupert Inlet where the phosphate budget appears to be dominated by the tidally-promoted advection of nutrients into the fjord. Nevertheless, the potential for phosphate consumption by submerged tailings should be taken into account in the planning of future STD operations.

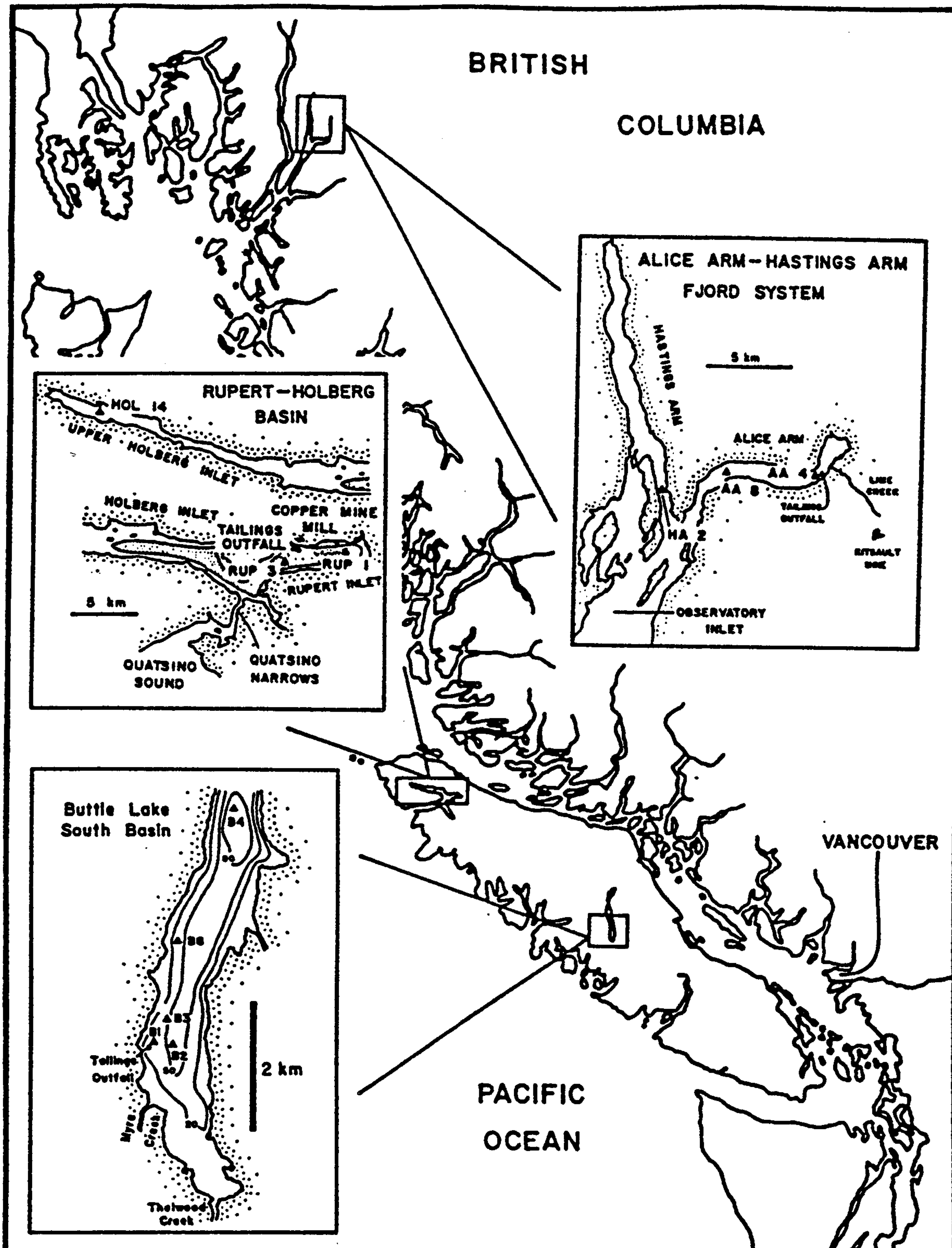


Figure 3-25 Location map showing sites of tailings deposition and core locations (*insets*). The *shaded zone* in the Rupert Holberg Basin inset shows the approximate distribution of tailings in the area in 1980. (Source: Pedersen and Losher 1988)

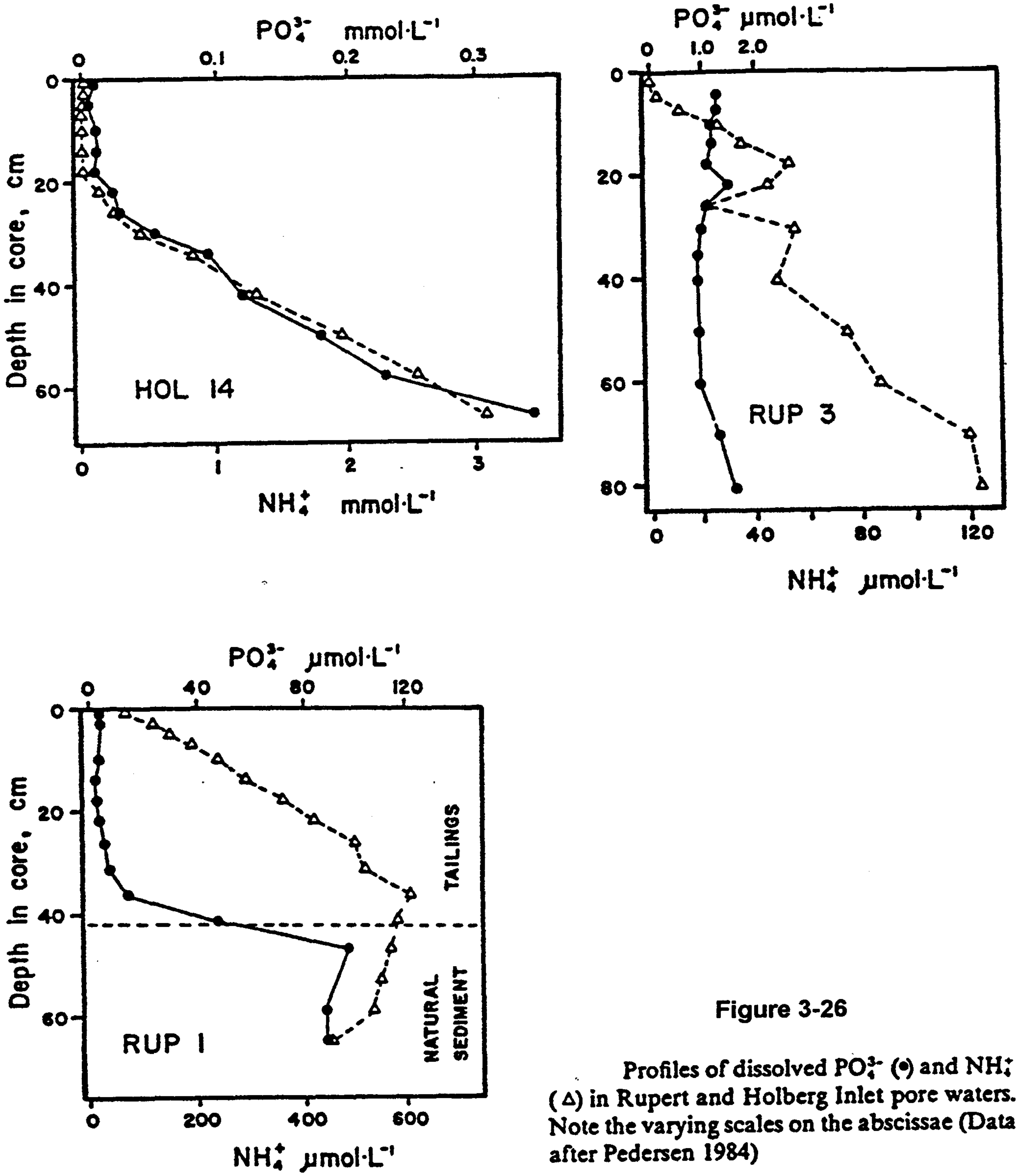


Figure 3-26

Profiles of dissolved PO_4^{3-} (•) and NH_4^+ (Δ) in Rupert and Holberg Inlet pore waters. Note the varying scales on the abscissae (Data after Pedersen 1984)

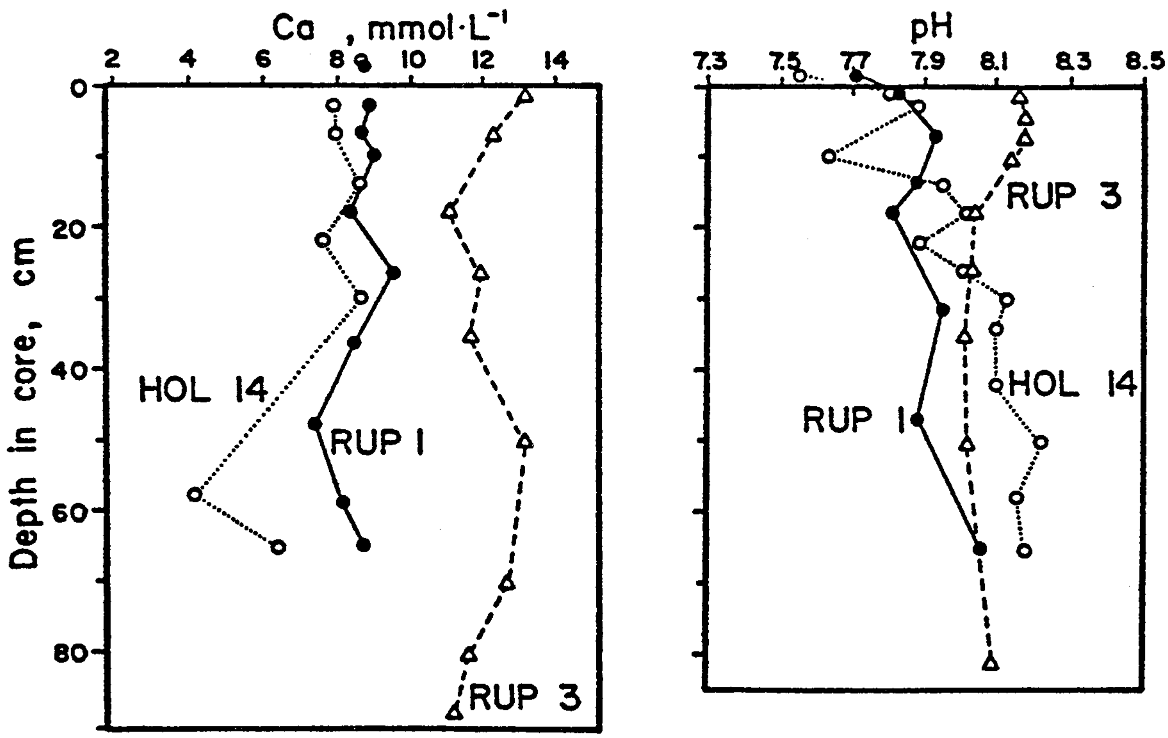


Figure 3-27 Dissolved Ca and pH data in tailings and natural sediments in the Rupert-Holberg Basin (Pedersen 1984).

Pedersen (1985) showed that the distribution of dissolved copper in surface sediments was similar at three sites examined in the Rupert-Holberg basin (Figure 3-28). The dissolved Cu concentration decreased at depth in the deposits, strongly in the natural sediments (HOL 14; Figure 3-25) and less so in the tailings. It was suggested by Pedersen (1985) that these distributions reflected control by three factors: (a) release to solution from a labile copper-bearing phase at or near the sediment-water interface; (b) release to solution by freshly-deposited tailings, possibly as a result of oxidation at the exposed sediment surface which is more likely to be a factor in areas with a slow accumulation rate; and (c) precipitation of authigenic sulphides at depth. Pedersen (1985) noted that the magnitudes of the copper enrichments in surficial pore waters in the tailings were similar to or less than concentrations observed in natural sediments collected from unpolluted environments (*e.g.* Heggie 1983). Therefore, at the time of sampling in 1980, the tailings in Rupert Inlet were not supporting a benthic flux of Cu to inlet waters greater than the evasion of the metal from most natural coastal sediments.

The dissolved molybdenum content in tailings pore waters in 1980 was enriched in the rapidly-accumulating deposits (RUP 3) by a factor of six over normal sea water, and in the slowly-accumulating facies by a factor of two (Figure 3-28). In contrast, lower concentrations were observed in the natural sediments (HOL 14), where consumption of the element with depth was attributed to the precipitation of authigenic molybdenum sulphide. The profiles indicated that the tailings were releasing Mo to the overlying water in 1980 to an extent not witnessed in natural deposits. The efflux was thought to be supported by the dissolution of MoO_3, a soluble oxidation product of molybdenite which can form during the atmospheric weathering of molybdenite-bearing ore (Chander and Fuerstenau 1972). Pedersen (1985) calculated that the incremental addition of the benthic efflux of Mo to the dissolved molybdenum inventory in Rupert Inlet is extremely small (<0.002% at steady-state). This insignificant impact is partly a reflection of the relatively short residence time of water in the basin, calculated by Drinkwater and Osborn (1975) to be on average 13 days. It should also be noted that Mo occurs naturally at relatively high concentrations in seawater (~11 parts per billion) as the oxyanion MoO_4^{2-}, which is essentially a biounavailable species.

It has been reported that the distribution of dissolved arsenic species in pore waters from the Rupert-Holberg-Quatsino system. As it is toxic to biota, and because the element occurs in oxic seawater as arsenate (AsO_4^{3-}), which is isoelectronic with phosphate, it is readily assimilated. Arsenopyrite is a trace constituent in the Island Copper ore (Poling (1982) reported 5 ppm As in the tailings), and the study allowed the extent of arsenic release from these deposits to be determined. The total dissolved As content in interstitial water extracted from tailings surface samples in each of the three years from 1981 to 1983 was very low (<6 ppb). Much higher concentrations characterized surficial pore waters extracted from natural sediments in upper Holberg Inlet and Quatsino Sound, where levels exceeding 30 ppb were observed. The dissolved As contents correlated well with dissolved phosphate measured in the same samples (r = 0.75, n = 12) suggesting that the arsenic distribution in the Rupert-Holberg-Quatsino system is controlled by natural biogeochemical cycling, and is not influenced by the tailings distribution.

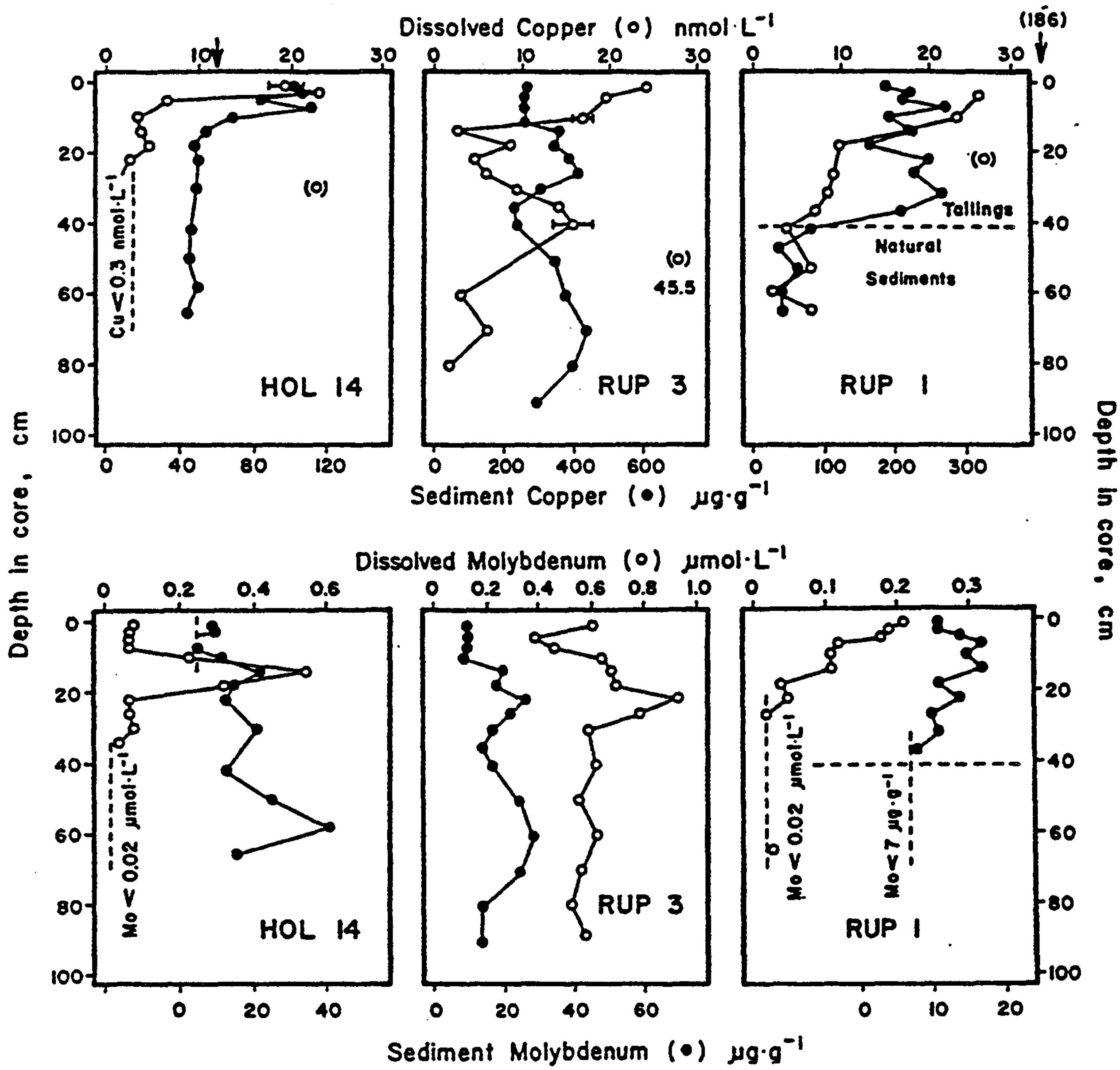


Figure 3-28 **Profiles of solid-phase and dissolved copper and molybdenum in Rupert-Holberg sediments and pore waters (After Pedersen 1985).** ***Vertical lines*** **represent analytical detection limits. Note the varying scales on the abscissae.**

3.6.3 Preliminary Environmental Information

3.6.3.1 Major Resources and Uses

The major fishery resource present in the area at the time of mine development was the stock of several species of Pacific salmon. A then estimated 10,000 salmon return from the sea annually through the Rupert/Holberg inlets and spawn in the inflowing streams and rivers (Ellis and Jewsbury 1974). Hence several million young salmon annually will use the inlets as nursery area and/or highway to the offshore growing areas. This salmon resource was only occasionally fished commercially in the inlets by regulation, but primarily contributed to the near shore regional fishery. There was also an accompanying recreational fishery.

Other fishery potential was little used commercially and is not well documented. It is to be expected that a variety of other fish, crustacea, and bivalve molluscs were used by local residents.

There had been a whaling station at Coal Harbour nearby in the 1950s, but this was closed with little prospect of the whale fishery ever being revived.

Otherwise the major resource was forestry, which was heavily utilized, with small and large logging operations scattered around the two inlets.

One coastal mine had previously operated: Yreka in the adjacent Neroutsos Inlet. Other mines had been located inland, hence there was potential for other mineral prospects.

There were a number of native American reserves scattered around the inlets, and these drew on the local fishery and land resources for subsistence living, for traditional purposes, and in some cases as commercial fishermen. A few commercial fishermen lived in the inlets.

3.6.3.2 Preliminary Community Concerns

Many concerns were expressed prior to and at the public hearing in 1969. They included trace metal contamination, the general concern that mining was an environmentally unclean industry, and resistance to marine disposal of industrial wastes due to unknowns about waste impacts in the sea. There were many applications by interest groups to formally protest at the hearings, but only four were selected as having the proper legal standing. This in itself exaggerated the controversy (Lucas and Moore 1973), which became a substantial media event.

In 1969, with so many environmental unknowns, application of contemporary appraisal concepts, might have denied the permit: public resistance to the mine was very strong although there was significant local support.

The hostile opinions were defused to some extent by the monitoring requirement of the permit under supervision of an independent university group. Nevertheless controversy continued through the 1970s, until a regulatory agency inquiry in 1978 (Waldichuk and Buchanan 1980; Buchanan 1982) confirmed the conclusions from the routine monitoring: *i.e.* that STD was preferred over land tailings disposal, that the environmental impact of STD was slight, tolerable (after 10 years), and almost certainly recoverable after mine closure.

3.6.4 The Monitoring Program

Island Copper was required by the terms of its tailings discharge permit to monitor a substantial number of parameters. These are listed in Table 3-6 for 1990 (see Pelletier 1982 for an earlier version). Each parameter has an extensive set of sampling stations; diagrammed in the annual environmental reports, *e.g.* BHP-Utah (1991), with earlier versions in Ellis (1989) and Pelletier (1982). Many of the sampling stations are shown in Figures 3-1 and 3.2.

3.6.4.1 Fisheries

Pacific salmon and Dungeness crabs are fished commercially in Rupert and Holberg Inlets, at times regulated by the Canada Department of Fisheries and Oceans. Stock estimates and catch figures for these two major fisheries are kept by the regulatory agency. They are in a form which does not distinguish the stocks in the Rupert/Holberg inlets from other inlets, other than very crude estimates of numbers of salmon in some of the spawning streams each fall.

Accordingly, Island Copper monitors Dungeness crab by its own test trap fishery. Sampling station positions are shown in Figure 3-11 and fishery results in Table 3-7 and Figures 3-29 to 3-31. The trap catch in Rupert Inlet (with heavy tailings deposits) has fluctuated showing an initial decline to 1974 after mine start-up in 1971, then an increase through 1975-1980, then another low 1981-1989, and in 1990 appeared to be increasing again. Catches from Holberg Inlet (with little tailings) show slight variations on these changes, whereas Quatsino Sound (the tailings-free reference site) normally has lesser catches (from natural causes).

The size frequencies have differed in the three inlets since 1981. In the Rupert/Holberg inlets the modal size of trapped crabs has been relatively large at 14-16 centimeters body width with the exception of a few years (1984 and 1987-9 in Rupert Inlet, and 1988-9 in Holberg Inlet). Quatsino Sound shows more irregular size frequencies, and usually smaller crabs.

The figures in combination are suggestive of a pattern of irregular stock overfishing followed by recoveries. There is no sign of a consistent reduction of catch in Rupert Inlet due to the mine tailing discharge.

Table 3-6

Outline of the Environmental Control Monitoring Program 1990 at Island Copper Mine

Program Description	Frequency	Objective
I MILL EFFLUENT		
a) Chemical		
i) From weekly compositions of daily samples (2 grabs/day, 7 days/week) of mill effluent entering discharge mix tank, determine pH, % solids, dissolved As, CN, Cd, Cu, Mn, Mo, Pb and Zn, Total Hg (decanted sample) and temperature	Daily samples analyzed weekly	Monitor physical and chemical characteristics of the effluent
b) Physical		
ii) Measure flow rate of effluent discharged into Rupert Inlet (m^3/day)	Daily	Monitor effluent flow
iii) Measure tons of solids discharged into Rupert Inlet (t/d)	Daily	
c) Bioassay		
From a decanted sample of mill effluent entering the discharge mix tank determine toxicity to fish (96 hour LC_{50})	Monthly	Monitor effluent for toxicity
II PIT DEWATERING		
a) Physical		
Measure flow rate of pit water discharged to a settling pond. (m^3/day)	Daily	Monitor pit dewatering flow
b) Chemical		
Collect samples of settling pond inflow for temperature, total dissolved solids, total suspended solids, pH, turbidity, hardness dissolved oxygen, sulfate, nitrate, alkalinity, calcium, magnesium, total As, Cu, Hg and Zn, dissolved As, Cd, Cu, Fe, Mn, Mo, Pb, and Zn.	Quarterly (Dec, Mar, June & September)	Monitor chemical characteristics of pit water
c) Bioassay on Ex-Filtration Pond		
Determine toxicity to fish (96 hr LC_{50})	Nov 1989 Jan 1990 April 1990 June 1990	Monitor effluent for toxicity

(continued)

Table 3-6
Outline of the Environmental Control Monitoring Program 1990 at Island Copper Mine

Program Description	Frequency	Objective
III SURFACE WATER ANALYSIS		
a) Chemical		
At Francis (Bay) Lake, East Drainage Ditch, 1080 Perimeter Ditch, North Dump Drainage and Marble River. Collect surface water samples for temperature, total dissolved solids, total suspended solids, pH, turbidity hardness, dissolved oxygen, sulfate, nitrate, alkalinity, calcium, magnesium, total As, Cu, Hg, and Zn. Dissolved As, Cd, Cu, Fe, Mn, Mo, Pb and Zn.	Quarterly (Dec, Mar, June & September)	Monitor chemical characteristics of surface waters
IV PHYSICAL MONITORING OF THE MARINE ENVIRONMENT		
a) Seawater Sampling		
At 7 stations (A-G) analyze for temperature, salinity, turbidity, and surface transparency.	Monthly	Monitor the physical characteristics of seawater
b) Suspended Sediment Distribution		
i) Water column		
At 5 stations (A,B,D,E,F) collect samples in profile for turbidity and total suspended solids measurements.	Quarterly (Dec, Mar, June & September)	Delineate suspended sediments and the turbidity cloud in the water column
ii) Suspended Sediment Settling Traps		
At 4 stations (2 depths per station) collect settling solids	Quarterly (Dec, Mar, June & September)	Monitor the settling rate of suspended solids
c) Bottom Sediment Distribution		
i) Bottom Coring		
Coring at 24 stations where tailings are 60 cm deep. Log and measure tailings thickness on the bottom	Annually (March)	Visually determine tailings distribution

(continued)

Table 3-6
Outline of the Environmental Control Monitoring Program 1990 at Island Copper Mine

Program Description	Frequency	Objective
Five station cores to be sectioned and each section to be analyzed for copy, molybdenum and zinc.	Annually (March)	Determine history of tailings sedimentation
ii) Bottom Sediment Grab		
At 24 stations (to include stations 2, 6, 11, 19, 23, 24, 28, 30) collect sediment surface sample for analysis of copper, molybdenum and zinc	Annually (March)	Chemically delineate tailings distribution
iii) Echo Sounding		
Bottom profile at 18 transects	Annually (March)	Physically delineate tailings distribution
V CHEMICAL MONITORING OF THE MARINE ENVIRONMENT		
a) Seawater Sampling		
At 7 stations (A-G), analyze for dissolved oxygen	Monthly	Monitor chemical characteristics of seawater
At 7 stations (A-G), analyze for pH and alkalinity	Monthly (April - Oct)	Monitor chemical characteristics of seawater affecting phytoplankton productivity
At 5 stations (A,B,C,D,E), analyze for dissolved copper molybdenum, zinc, manganese, arsenic and mercury	Quarterly (Dec, Mar, June & September)	Monitor heavy metals in seawater
VI BIOLOGICAL MONITORING OF THE MARINE ENVIRONMENT		
a) Phytoplankton		
i) Euphotic Depth Survey		
At 7 stations (A-G) measure light attenuation and scatter at depth.	Monthly (April - October)	Record light attenuation in water column

(continued)

Table 3-6
Outline of the Environmental Control Monitoring Program 1990 at Island Copper Mine

Program Description	Frequency	Objective
ii) Chlorophyll *a*		
At 7 stations (A-G) at 6 depths each, collect samples for chlorophyll a analysis	Monthly (April-October)	Monitor phytoplankton biomass
iii) Phytoplankton		
At 7 stations (A-G) collect a composite water sample from surface to 5 m	Weekly (April-October)	Monitor population for dynamics
b) Zooplánkton		
At 4 stations (A-D) conduct 3 horizontal tows and 1 vertical haul for quantitative analysis of density and diversity.	Semi-annually (March, Sept)	Monitor population dynamics
c) Periphyton		
At 16 sites, artificial substrates are monitored for growth of settling organisms and inorganic deposits	Bi-monthly (Mar-Sept)	Monitor settling flora and fauna in intertidal zones
d) Benthic In-Fauna		
At 24 stations collect 3 replicate samples for quantitative density and diversity	Annually (Sept)	Monitor population dynamics
e) *Cancer* sp.		
At 6 stations, two traps each, capture crabs to determine sex, length, weight and body condition	Quarterly (Dec, Mar, June & September)	Monitor population dynamics
VII TISSUE METAL MONITORING OF THE MARINE ENVIRONMENT		
Flora		
a) *Fucus*		
At 16 stations collect samples for analysis of CU, Mo, Zn, Cd, As and Hg	Annually (June)	Monitor metal content of *Fucus*

(continued)

Table 3-6
Outline of the Environmental Control Monitoring Program 1990 at Island Copper Mine

Program Description	Frequency	Objective
b) *Zostera*		
At 16 stations collect samples for analysis of Cu, Mo, Pb, Zn, Cd, As and Hg	Annually (June)	Monitor metal content of *Zostera*
Fauna		
a) Intertidal Bivalves		
i) Clams		
At 9 sites, collect 4 marker species, identify, weigh, measure and analyze for Cu, Mo, Pb, Zn, Cd, As, and HG	Annually (June)	Monitor metal contents of clams
ii) Mussels		
At 3 sites (Utah dock, Coal Harbour & Quatsino) collect *Mytilus edulis* weigh, measure and analyze for Cu, Mo, Pb, Zn, Cd, As and Hg.	Quarterly (Dec, Mar, June & September)	Monitor metal constant of *Mytilus edulis*
At 2 sites (Port Hardy & Winter Harbour) collect *Mytilus edulis,* weigh, measure and analyze for Cu, Mo, Pb, Zn, Cd, As and Hg	Annually (June)	Monitor metal content of *Mytilus edulis*
b) Benthic Epifauna		
i) *Cancer magister*		
At 6 sites in the population study retain 3 samples and analyze for Cu, Mo, Pb, Zn, Cd, As and Hg	Quarterly (Dec, Mar, June & September)	Monitor metal content of *Cancer magister*
c) Zooplankton		
From samples collected at 4 stations in the population study, analyze an unsorted sample and euphausiids for Cu, Mo, Pb, Zn, Cd, As and Hg	Semi-Annually (March & Sept)	Monitor metal content of zooplankton

Source: BHP-Utah (1991)

Table 3-7
Crab Catch Summary 1970 - 1990
(Mean Catch/Trap for 18-hour Set)

Year	Holberg	Quatsino Sound	Rupert Inlet
1970	19.5	24.5	22.8
1971	21.2	18.9	18.5
1972	14.9	13.8	11.5
1973	23.8	6.8	13.1
1974	22.8	9.8	19.4
1975	41.0	8.3	34.6
1976	30.8	16.8	28.2
1977	34.7	2.9	25.4
1978	31.4	15.3	24.6
1979	38.4	14.4	35.1
1980	27.3	4.9	25.5
1981	26.0	6.3	21.3
1982	22.4	4.6	19.4
1983	26.1	7.3	20.2
1984	20.9	6.4	14.5
1985	19.8	4.5	16.1
1986	21.2	4.9	11.2
1987	23.9	9.8	17.3
1988	26.3	6.5	15.4
1989	18.7	5.0	5.0
1990	18.5	4.1	16.9
Mean	25.2 ± 6.8	9.3 ± 5.8	19.8 ± 7.4

Source: BHP Utah (1991)

FIGURE 3-29

SIZE FREQUENCY OF CRABS - HOLBERG INLET

1981 - 1990

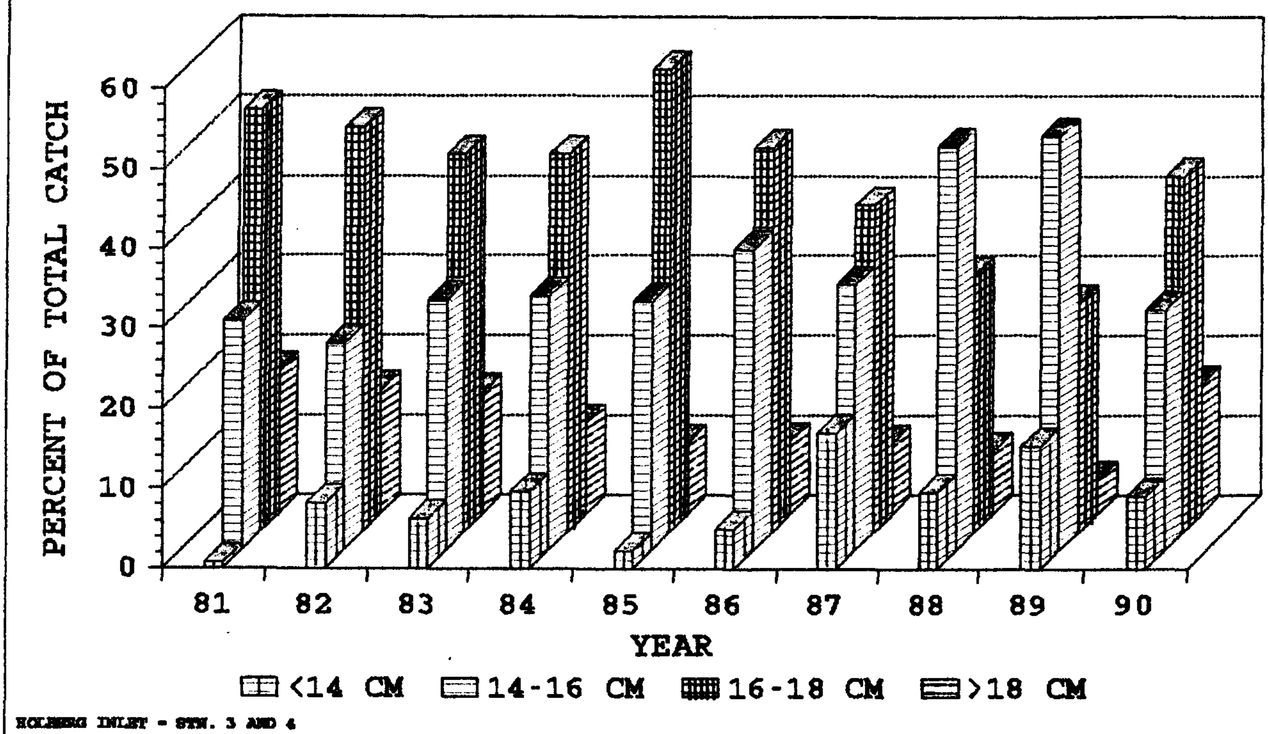
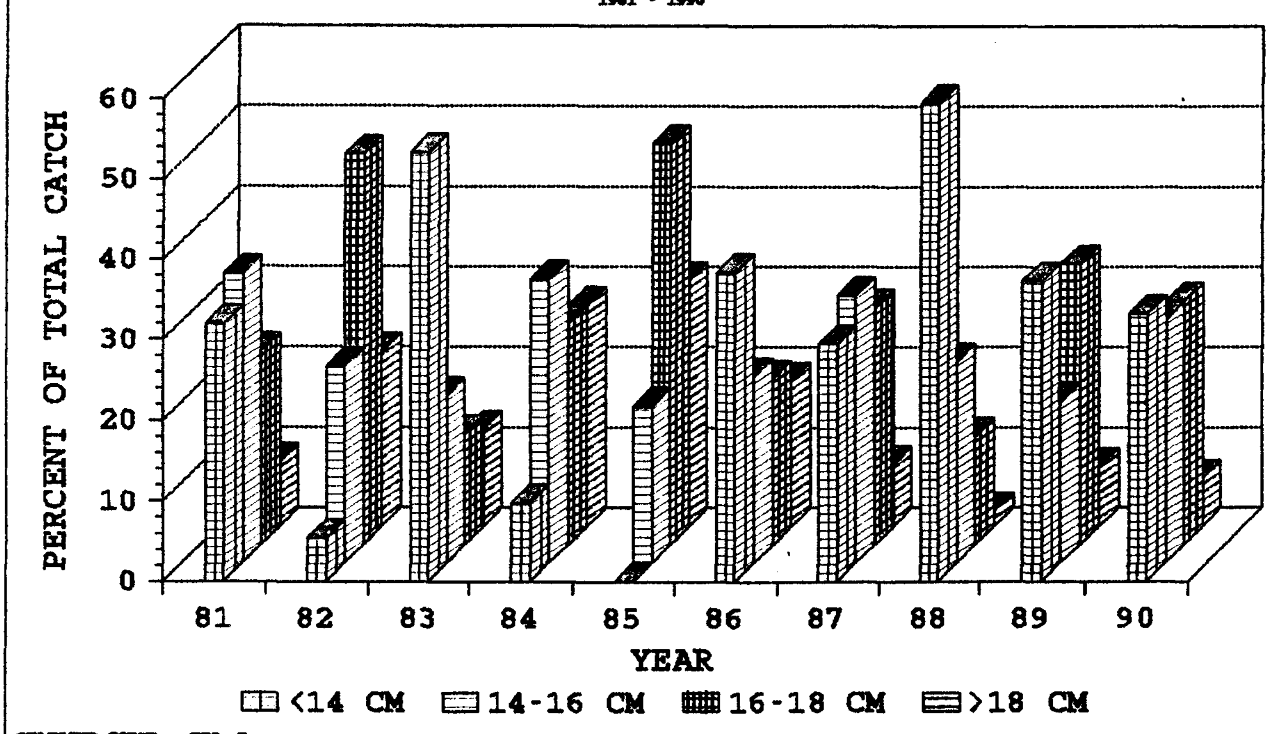


FIGURE 3-30

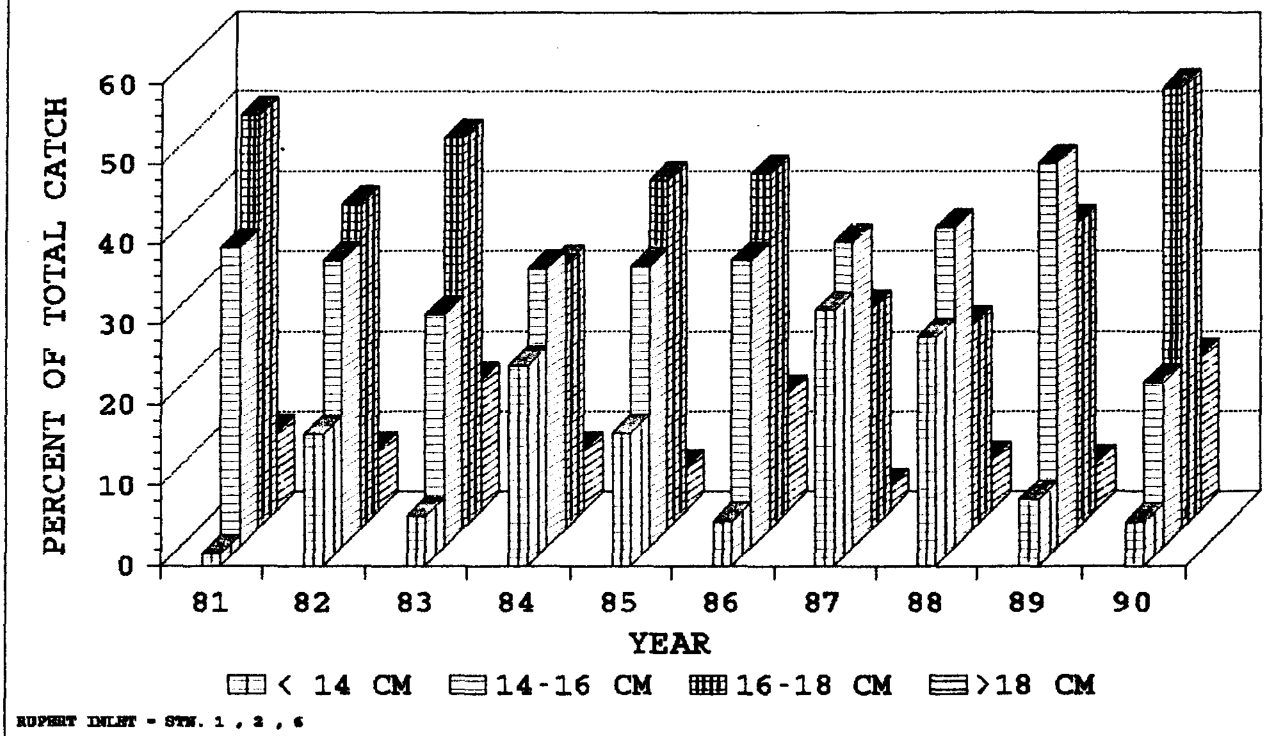
SIZE FREQUENCY OF CRABS - QUATSINO SOUND

1981 - 1990



(Source: BHP-Utah 1991).

FIGURE 3-31
SIZE FREQUENCY OF CRABS - RUPERT INLET
1981 - 1990



(Source: BHP-Utah 1991)

3.6.4.2 The Aquatic Ecosystem

Marine Benthos

The most extensive sampling of the aquatic ecosystem is of mud-bottom benthos. Tailings being fine grained, after deposition become a mud-bottom, similar in grain specifications to fine deep fjord deposits. At Island Copper the benthic sampling stations are located with those for sediment metal analyses (Figure 3-13). The set of 26 stations (Stations 1-25, plus Station B), sampled in triplicate annually, mostly since 1970 prior to mine operation, provides a time-series of benthos surveys unique in duration, spatial extent and replication. In addition, aiding consistency in species biodiversity assessment, the scientist responsible for the species identifications has been with the project almost from the start.

Tables 3-8, 3-9 and 3-10 show summary population and environment statistics for 1990 divided into samplings stations from thick, little and no tailings. A number of conclusions can be drawn from the 1990 survey. Data are now available from the 1991 and 1992 surveys, and generally support the conclusions in 1990. The benthos analytical procedures are currently being updated by database and GIS developments, and the availability of new statistical packages, including significance testing.

Conclusions from the 1990 surveys are as follows. A stock of benthos is present at all thick tailings stations (Table 3-8). They tend to have lower biodiversity (5-35 species) and fewer organisms in total (down to $80/m^2$) than other stations whether with lesser or no tailings (Tables 3-9 and 3-10). Direct evidence of benthos is available from submersible surveys (Ellis and Heim 1985). Figure 3-32 shows benthos holes through a thin layer of tailings, as seen from a submersible port.

The similarity analysis conducted on the 1990 survey clustered thick tailings stations together, and separated them from lesser and no tailings stations (Figures 3-33 and 3-34). There are statistically significant differences between some stations, or clusters. Station 15 near the outfall was an impoverished outlying station, different from all others due to its low biodiversity. The cluster of all remaining thick tailings stations included three designated as Little Tailings by the arbitrary criterion of 27+ centimeters thickness. These stations, 19, 2 and 4 had thicknesses of 18, 2.5 and 21 centimeters respectively. The remaining major cluster included no Thick Tailings stations, but all the remaining Little and No Tailings stations. This last point is important. It appears that the benthos under a regime of light tailings deposition (about 10 centimeters or less in 20 years) cannot be distinguished from benthos where tailings are either not present or can only be detected by slight increases in copper level of the deposits current.

This general pattern of benthic distribution was established within a few years after discharge started (Ellis and Hoover 1990; Ellis *et al.* 1991). An independent test of the speed of recolonization after benthic smothering by thick rapidly depositing tailings using

Table 3-8
Benthos Population Data from Stations with Thick Tailings

	Station #								
	15	**16**	**17**	**14**	**13**	**9**	**B**	**6**	**5**
Distance from outfall (km)	0.25	0.75	1.75	3.0	3.0	5.0	6.5	7.0	7.25
Tailings thickness (cm)	>60	>60	>60	>60	>60	>60	>60	45+	27
Water depth (m)	46	76	87	75	117	134	147	138	128
No. organisms/m^2	80	1393	1493	5773	2140	10500	2713	2546	1653
No. taxa/3 samples	5	8	15	35	14	32	27	28	28
Pielou Index	0.68	0.47	0.57	0.51	0.14	0.18	0.53	0.60	0.71
Other indices									
Keefe-Bergersen	0.57	0.55	0.67	0.71	0.12	0.20	0.72	0.78	0.86
Shannon	1.58	1.43	2.24	2.61	0.54	0.92	2.53	2.92	3.41
Margaleff	1.61	1.31	2.59	5.03	2.25	4.21	4.33	4.54	4.90
Numerically dominant species (no./m^2)									
Diphyes sp.	53								
Cossura pygodactylata		787	773					553	280
Lumbrineris luti				2860					440
Capitella capitata					2007	9360	1180		
Pista cristata								940	280
Nephtys cornuta							740		

Note: **Numerically dominant species are the most abundant species which together add to more than 50% of the total no. organisms per m^2.**

Source: **BHP-Utah (1991)**

Table 3-9
Benthos Population Data from Stations in 1990 with Little or Sparse Tailings

	Station #								
	12	**19**	**20**	**10**	**7**	**4**	**22**	**23**	**2**
Distance from outfall (km)	3.0	3.5	3.5	5.0	6.5	8.75	8.75	11.5	15.75
Tailings thickness (cm)	9	18	10	15	10	21	9.5	3.0	2.5
Water depth (m)	24	75	39	28	28.5	117.5	23.5	118	100
No. organisms/m^2	11180	1600	8220	14313	11706	3133	18280	19286	3873
No.taxa/3 samples	64	15	49	70	85	32	120	154	34
Pielou Index	0.64	0.63	0.59	0.37	0.57	0.63	0.65	0.72	0.63
Other indices									
Keefe-Bergersen	0.86	0.76	0.79	0.51	0.81	0.80	0.87	0.93	0.84
Shannon	3.84	2.49	3.35	2.32	3.70	3.17	4.52	5.23	3.23
Margaleff	8.49	2.55	6.74	8.99	11.24	5.04	15.03	19.20	5.18
Numerically dominant species (no./m^2)									
Axinopsida serricata	3527		3440	9913	4660	947	5933		827
Euchone incolor	1073		627						
Lumbrineris luti	1027				1047			667	
Heteromastus filobranchus		593							
Cossura pygodactylata		380							747
Chaetozone setosa			663				1053		
Chaetozone spinosa					667		860		
Nephtys cornuta						960			973
Polydora socialis							833		
Leptochelia dubia							773		
Campylapis canaliculata								3733	
Nematoda indet.								1700	
Mediomastus sp.								1547	
Galathowenia oculata								940	
Euclymeninae maldanids								873	
Rhepoxynium sp.								733	

Note: **Numerically dominant species are the most abundant species which together add to more than 50% of the total no. of organisms per m^2.**

Source: BHP-Utah (1991)

Table 3-10
Benthos Population Data from Stations With No Tailings

	Station #						
	21	11	8	1	3	25	24
Distance from outfall (km)	4.5	5.0	5.75	15.5	16.0	18.0	19.0
Water depth (m)	9	20	25	22	76.5	178	75
No. organisms/m^2	20153	14893	12600	28666	1673	10120	4140
No. taxa/3 samples	101	77	73	124	24	100	58
Pielou Index	0.55	0.64	0.53	0.71	0.62	0.68	0.70
Other indices							
Keefe-Bergersen	0.78	0.85	0.77	0.94	0.78	0.89	0.90
Shannon	3.66	4.05	3.32	4.95	2.88	4.53	4.14
Margaleff	12.48	9.86	9.54	14.70	4.16	13.52	8.86
Numerically dominant species (no./m^2)							
Axinopsida serricata	8900	5240	2560	2760	553	2780	1007
Lumbrineris luti		1887			1127		
Tharyx multifilis		1407					
Tharyx sp.		827					
Lafoea sp.			5273				
Nematoda indet.				4687			
Prionospio cirrifera				2113			320
Mediomastus sp.				1513			
Euclymeninae maldanids				1460			
Polydora socialis				1360			
Nephtys cornuta					520		420
Yoldia sp. *immat.*						1073	
Cylindroleberididae indet.						773	
Cossura pygodactylata						687	
Paraonella spinifera							407

Note: **Numerically dominant species are the most abundant species which together add to more than 50% of the total no. organisms per m^2.**

Source: BHP-Utah (1991)

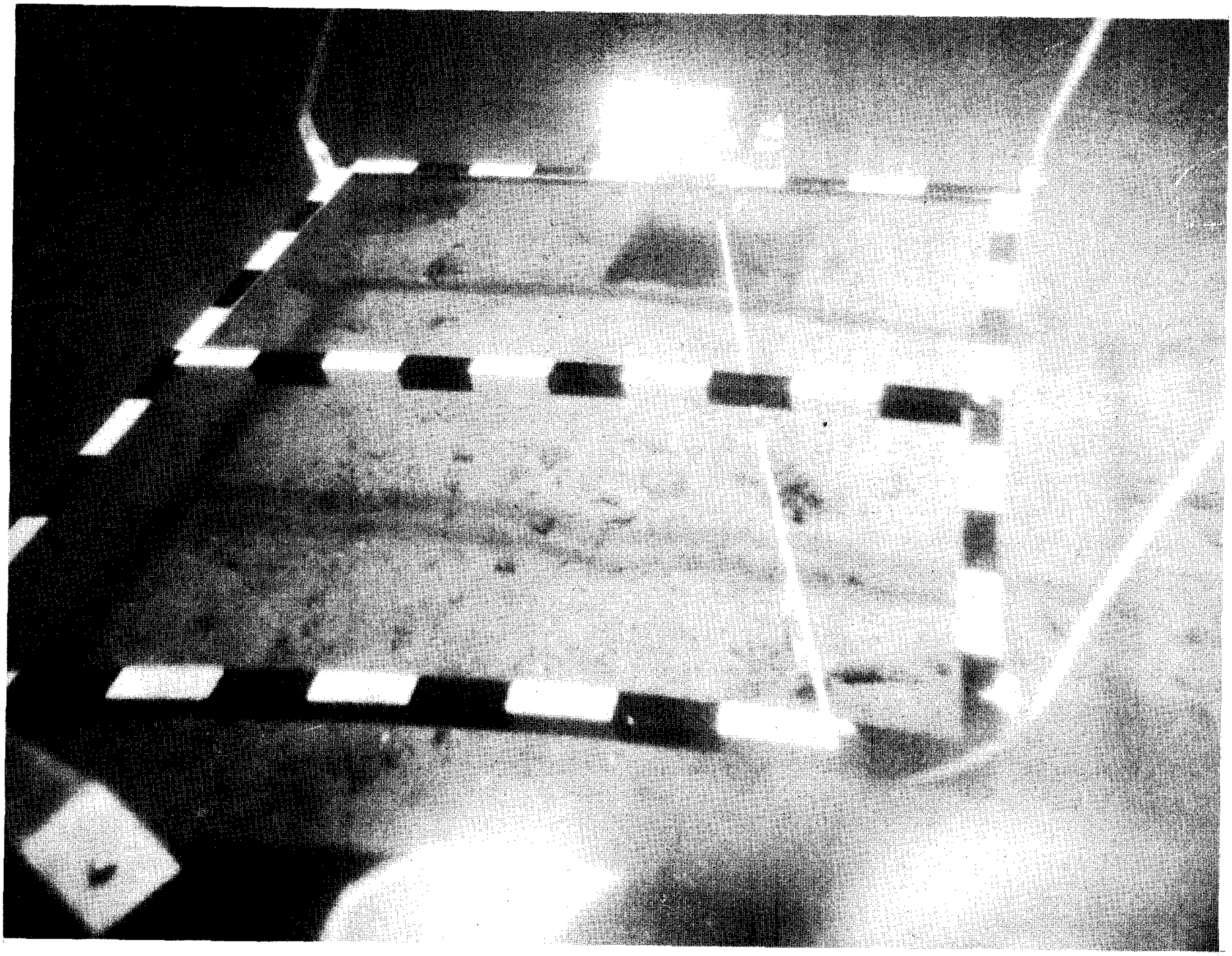
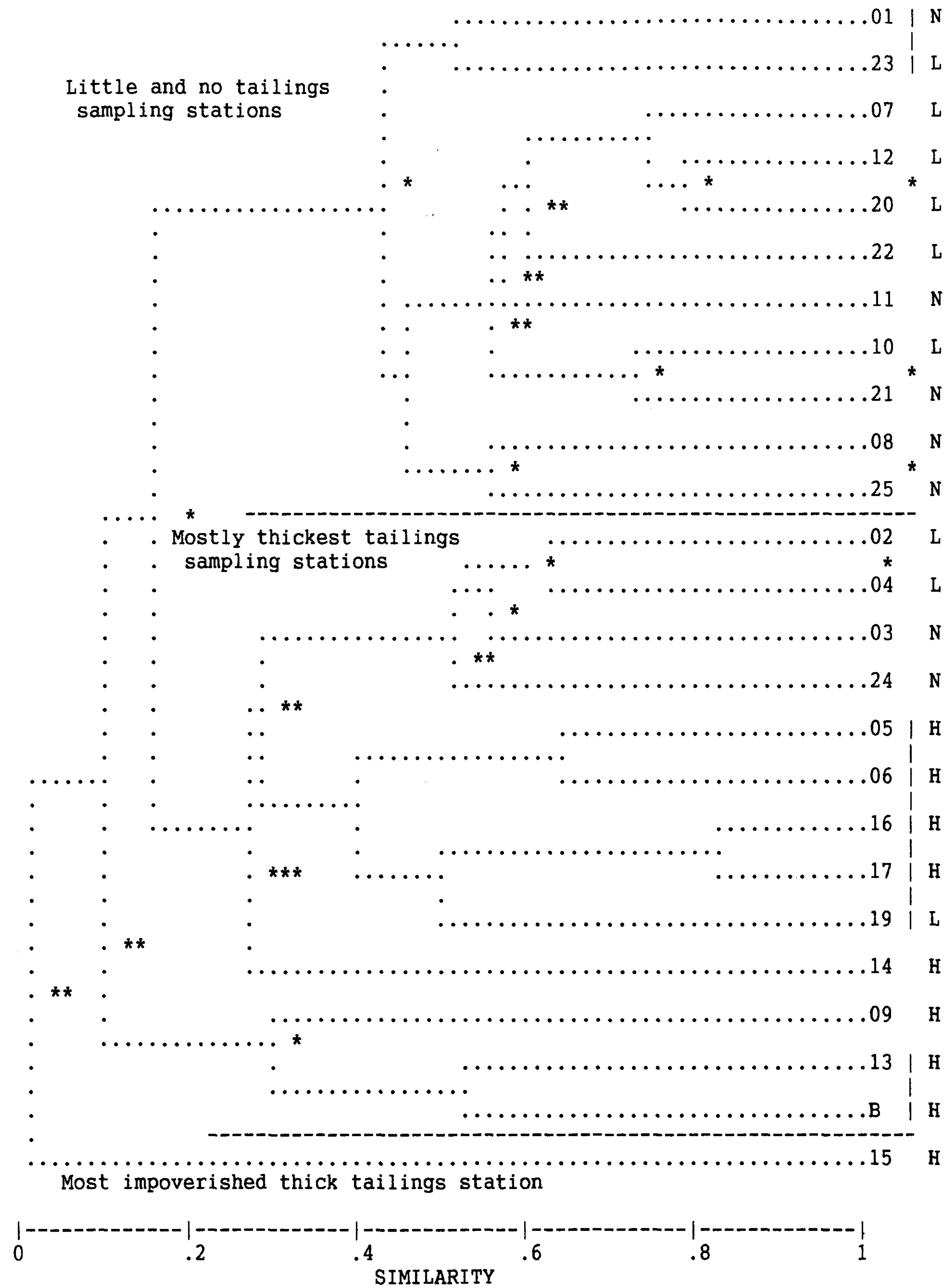


Figure 3-32. - Tailings and benthos in Rupert Inlet as seen from submersible.

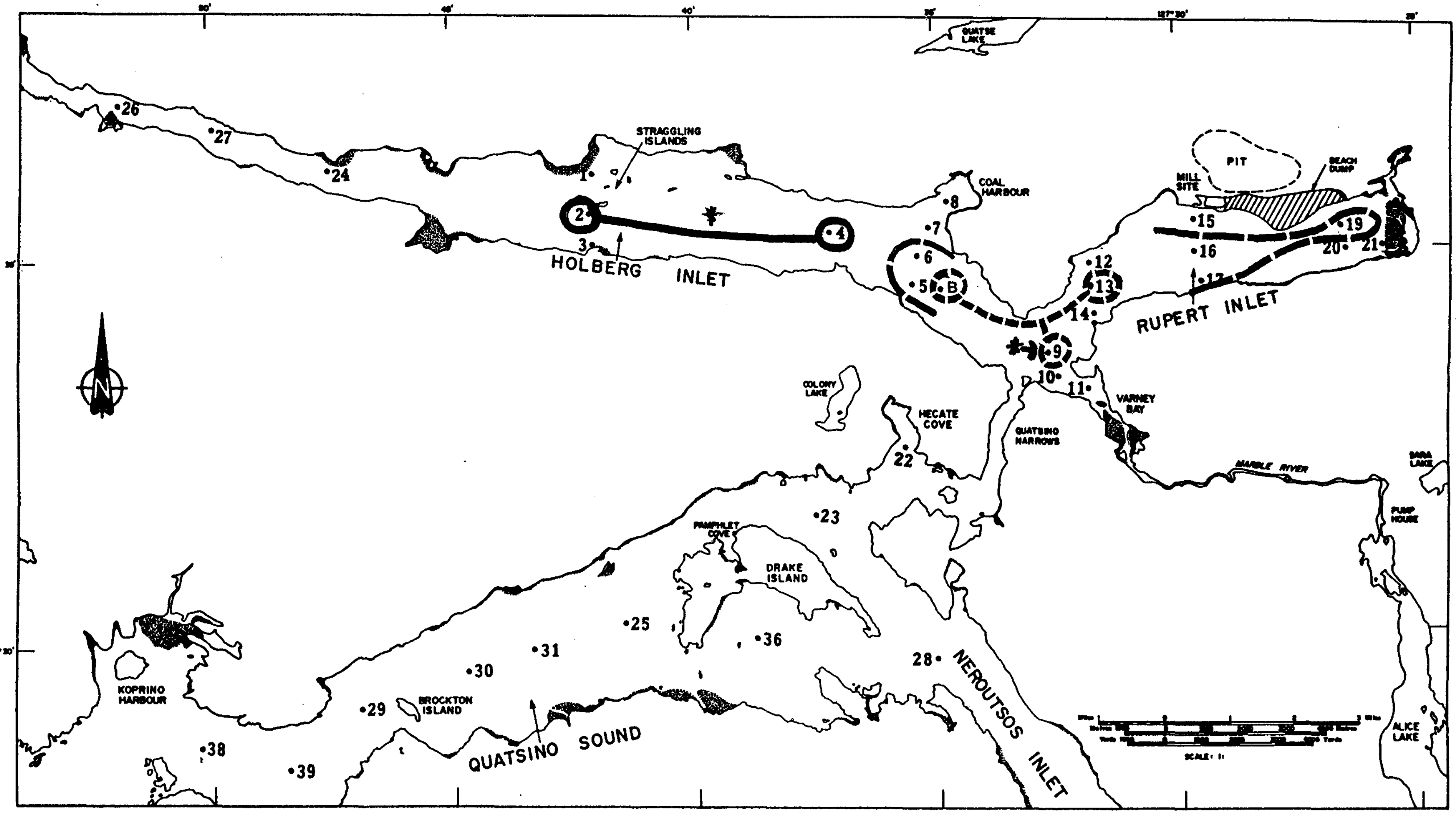


* P<0.05, ** P<0.01, ***P<0.001, | Stations not significantly different

Figure 3-33 Similarity dendrogram for all stations, minimum species (96) and not log n transformed data.

FIGURE 3-34 **Consensus cluster map grouping similar (least different) stations on tailings.**

*** indicates significant differences**



(Source: BHP-Utah 1991)

experimental boxes (Taylor 1986) showed an extensive population re-appearing within twelve months (Figure 3-35), although the species differed from control boxes and those present at the sampling stations nearby (Figure 3-36).

In summary, tailings deposits support benthos. There can be a diverse and abundant fauna present, and this appears to be able to colonize within 1-2 years of deposits settling and stabilizing. In addition, benthic populations on tailings deposits of a few centimeters thickness appear not to be different from those at similar depths without tailings. These conclusions are being re-examined annually with each year's data and newly available analytical systems, with the intent of predicting benthic changes following mine closure.

Other Aquatic Stocks

Table 3-6 includes the variety of aquatic stocks that are monitored annually by Island Copper. Population figures are reported annually. Essentially there is no suggestion from the data that any of these stocks shows reduction spatially or temporally related to the mine tailings discharge, other than mud-bottom benthos under rapidly depositing or unstable tailings.

Tissue Metal Contamination

Table 3-6 includes the stocks which have been monitored for contamination by a suite of trace metals established in 1970. Figures 3-37 and 3-38 show the maximum elevations of trace metal in Rupert Inlet closest to the mine. Results for most stocks either provide no suggestion of trace metal contamination, or are ambiguous, *i.e.* no clear evidence due to population variability. The exceptions are the blue mussel on the Utah (BHP) dock pilings. This is the concentrate loadout facility and the area has some fugitive dusting and spillage problems. The common rockweed (*Fucus*) shows raised levels of zinc near the mine; this is taken as due to an inability to wash all particulate off the plant.

3.6.4.3 Other Resources

There have been suggestions that water extraction for the mine from an important salmon spawning river (The Marble River; see Figure 3-13) might contribute to salmon spawning losses (*e.g.* Waldichuk and Buchanan 1980; Buchanan 1982). Although this has not been demonstrated, Island Copper has co-operated in the establishment and operation of a salmon hatchery there since 1982.

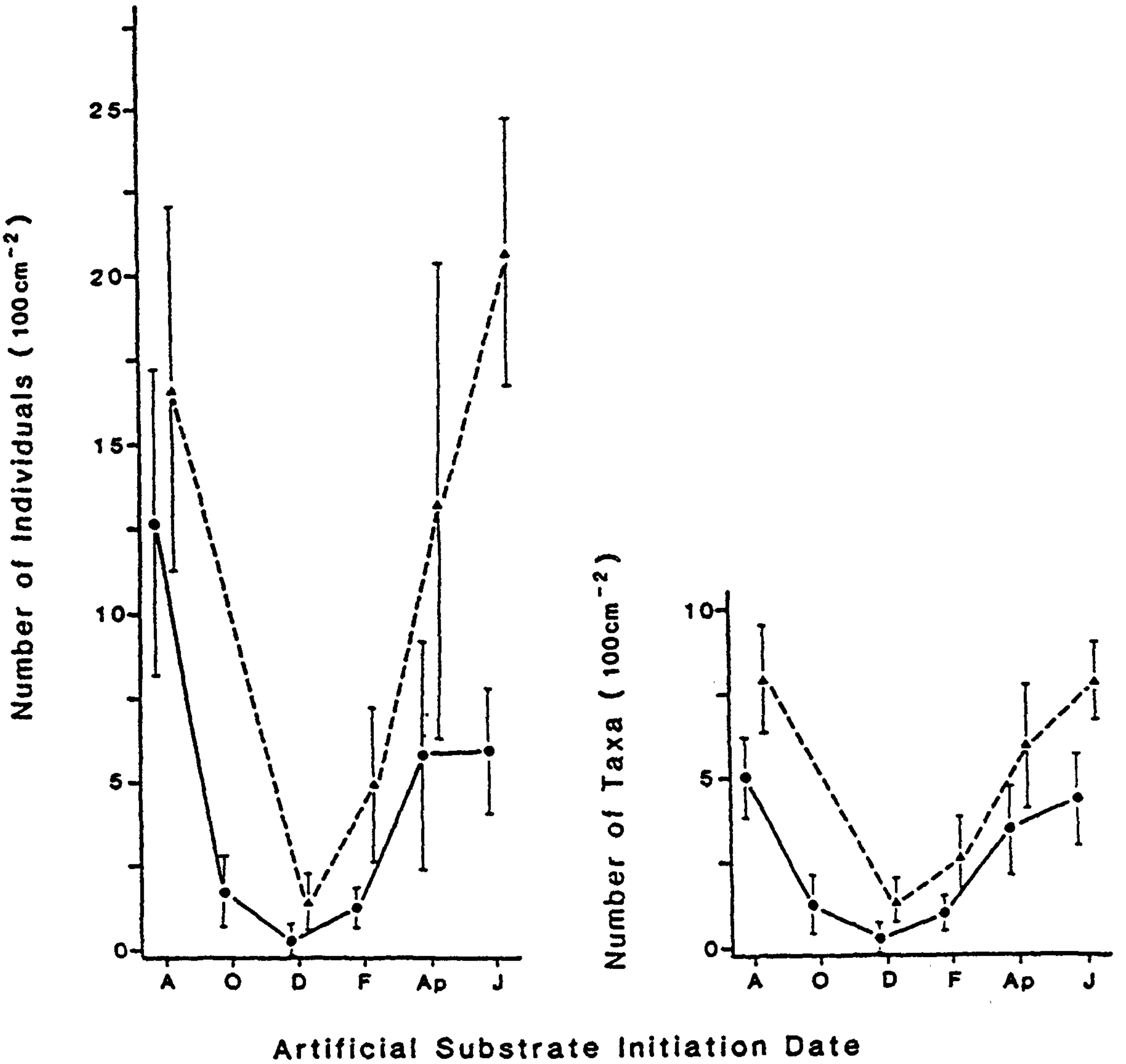


Figure 3-35 Succession of benthos in artificial substrate boxes from August through July (Taylor 1986). Diverse and abundant benthos settled each summer.

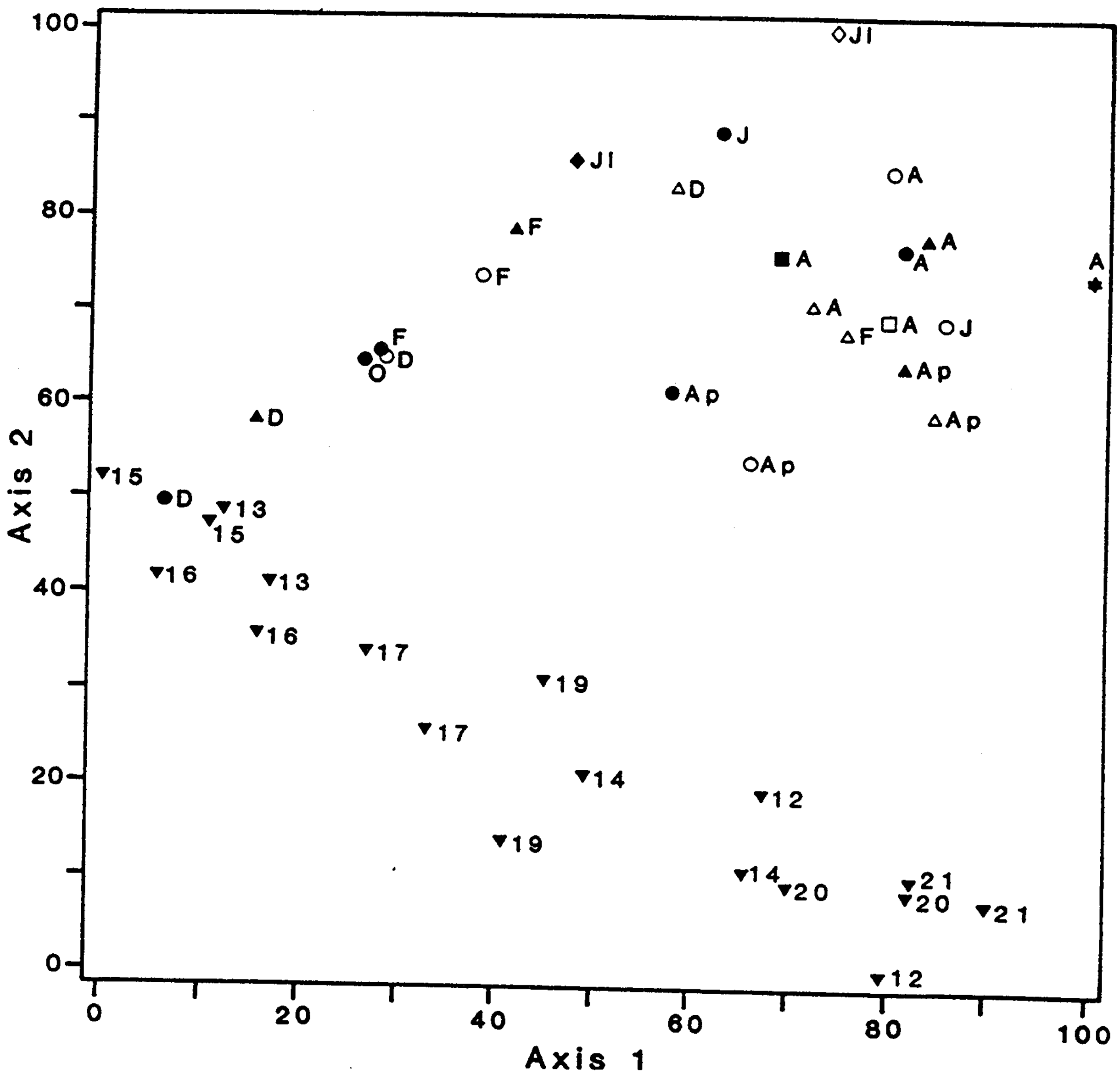


Figure 3-36 An analysis of species associations recolonising tailings on the seabed in Rupert Inlet (▼), and in artificial substrate boxes (Taylor 1986).

FIGURE 3-37
BLUE MUSSEL TISSUE COPPER
1981 - 1990

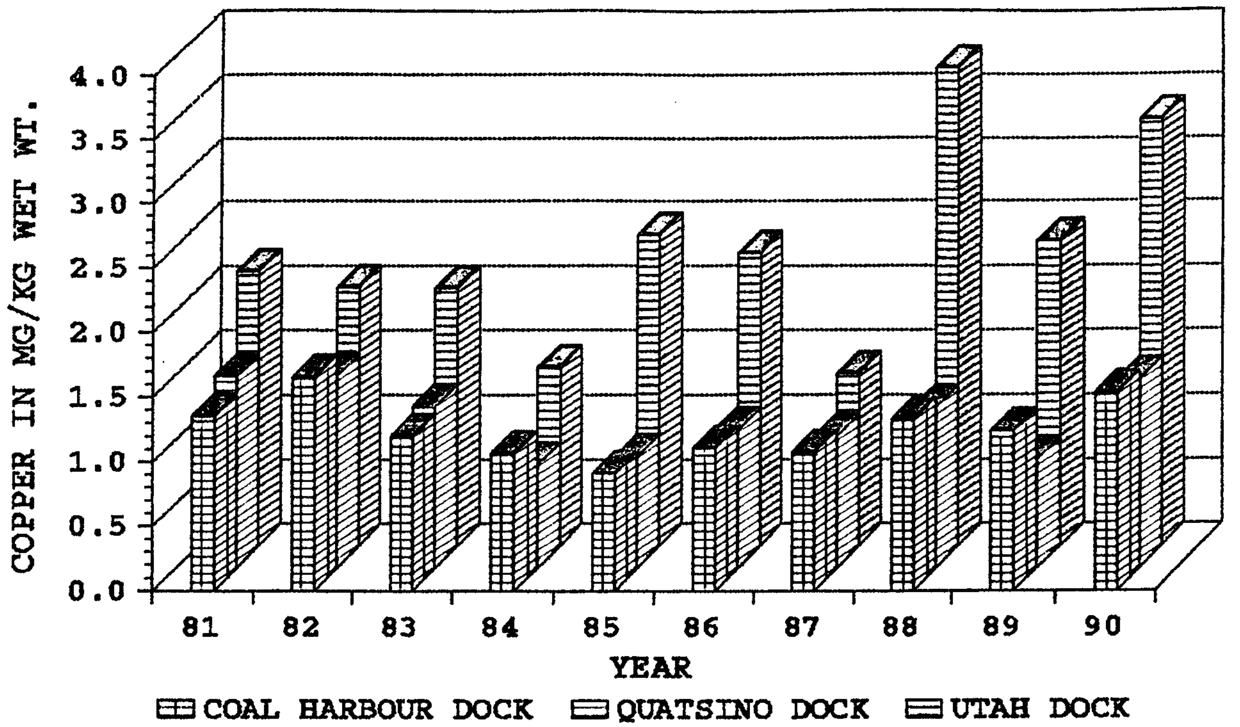
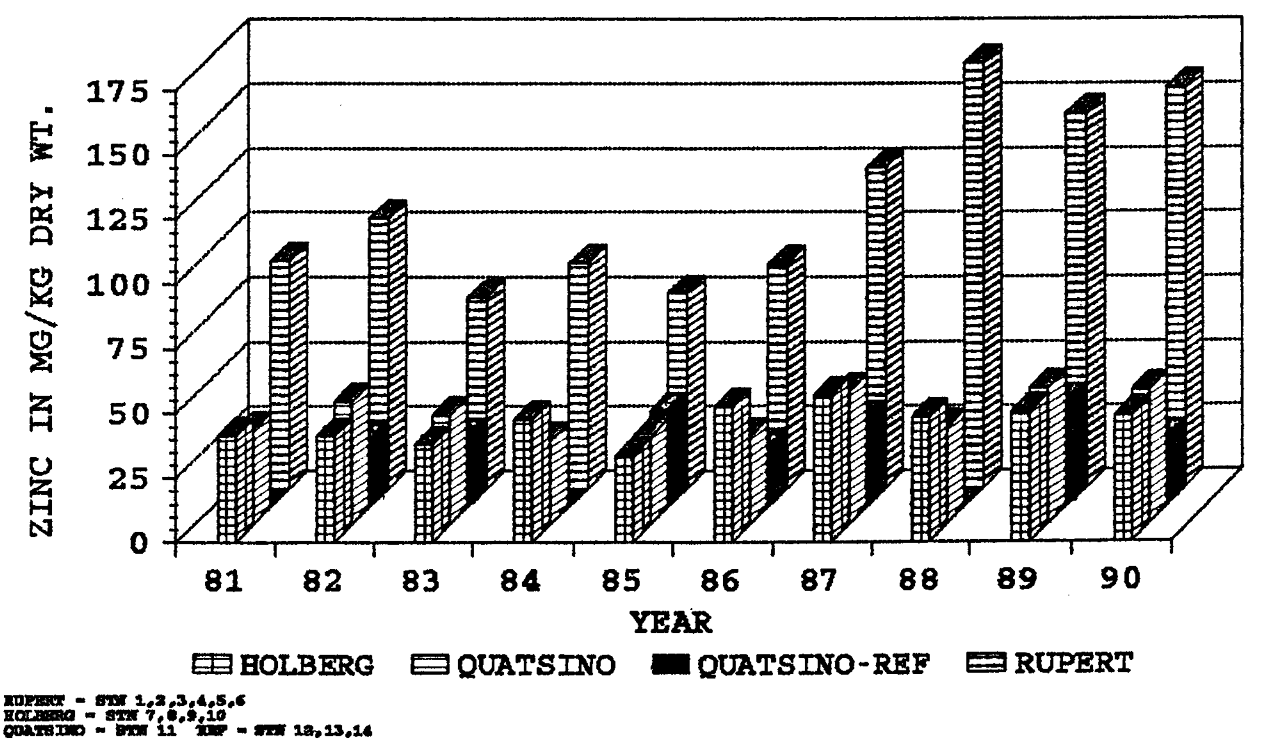


FIGURE 3-38
MEAN FUCUS TISSUE ZINC CONC.
1981 - 1990



(Source: BHP-Utah 1991)

3.7 Community Involvement

The development of Island Copper mine caused considerable controversy in the early 1970s. This has been reviewed by Lucas and Moore (1973) two of the partisans at the time. There has been little further review although there is information in Dorsey and Martin (1986), and Jones (1975). A short later review was included in Ellis (1989), Ch. 11, Fact-Finding and Social Input.

3.8 Conclusion

The STD operation at the Island Copper Mine is clearly the best-documented example of positive aspects of such technology. This example also demonstrates that unexpected aspects such as irregular upwelling events can cause sporadic surface turbidity. As a result of comprehensive monitoring now spanning 22 years and ancillary studies of the chemical behaviour of the tailings following deposition, it is now recognized that STD can produce deposits that do not contaminate the overlying water column and permit commercial fisheries (*i.e.* for Pacific salmon and Dungeness crabs) to be maintained in the receiving basin. There is no evidence that either the major regional fishery based on migrating stocks of Pacific salmon or the crabbing have been deleteriously affected by the Island Copper submarine tailings disposal. The only major ecosystem compartment to be impacted, the benthos, can support a diverse and abundant fauna on tailings. Losses in regions of high tailing sedimentation rates, such as occur close to the tailing outfall, have been shown to rehabilitate within one to two years.

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4.0 KITSAULT MOLYBDENUM MINE, CANADA (by T. Pedersen, D. Ellis, G. Poling & C. Pelletier)

4.1 Introduction

The Kitsault mine re-development in northern British Columbia (Figure 4-1, and see Figure 1-1) was initiated in the early 1970s. This followed prior mine operation from 1967 to 1972; with stream disposal of tailings (Table 4-1). This was soon after the then controversial development and 1971 opening of Island Copper mine (Chapter 3), and soon after it became technically apparent that the novel, and then unique, sea-water mixing outfall was successful in discharging the tailings coherently to depth. The Kitsault mine opened in 1981; and closed in 1982 when a fall in molybdenum prices made it uneconomical.

Table 4-1

Kitsault Mine History

1972-1976	B.C. Molybdenum mine at Kitsault.
1974	EIA started for mine redevelopment.
1975	Application for STD permit.
1977	New Federal government regulations effectively prohibit STD by limiting concentration of suspended solids in mine waste discharges.
1979	Federal government regulations developed site-specifically for Kitsault, and allow STD. Permit for STD issued.
1980	Native concerns publicized.
1981	Mine operational.
	Public Inquiry held.
1982	Mine closes; for economic reasons.
1983-1991	Extended post-closure monitoring and EIA.

The importance of this case is that (1) the mine was brought into operation using STD during a period of considerable public opposition to mining in general and to STD in particular, (2) recently introduced Federal regulations had effectively banned further use of STD in Canada and site-specific regulations were required to permit it at Kitsault, (3)

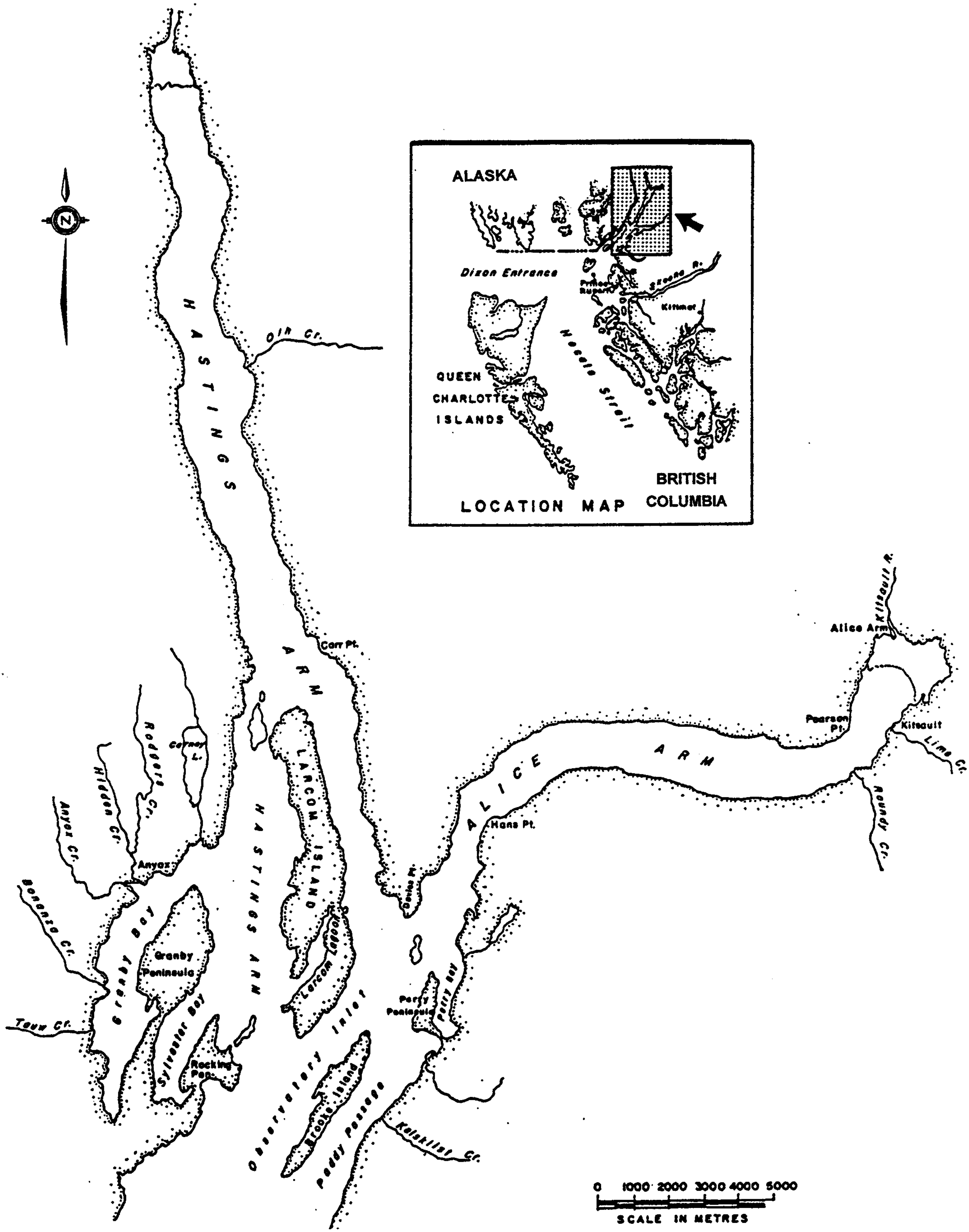


Figure 4-1 Location map of Alice Arm and Hastings Arm.

STD was again shown to work technically, and (4) the first marine post-closure assessments were made.

The mine development also reflected the state of EIA at the time, in that considerable oceanographic investigation was made (Littlepage 1978), but there was virtually no social impact assessment. The mining company apparently underestimated the extent and intensity of opposition, particularly by a native tribe (Nishga) with a long history of forcefully claiming their traditional rights (Ellis 1982).

The first environmental investigations were reported by Littlepage (1978). They were substantially expanded by both mine and federal government agencies in 1980 and 1981. In 1981, public and media clamour provoked a Federal Government Inquiry as the mine opened. The Inquiry reports (Burling *et al.* 1981; 1983) summarized the environmental information, accepted STD as the tailing disposal method, and recommended additional controls and impact assessments. A series of post-closure studies were reported through to 1991 (see Section 4.6.4; Amax 1981).

4.2 Composition of the Orebody

Kitsault ore consists of molybdenite-bearing quartz monzonite porphyry, quartz diorite and alaskite, and the mineralogy of the tailings reflects this: quartz and K-feldspar dominate while plagioclase, biotite and occasionally hornblende are minor constituents (Losher 1985). Clay minerals are essentially absent from the tailings with the exception of 10 Angstrom diameter mica which occurs in very low concentrations. Losher (1985) identified biotite, sphalerite and pyrite in heavy mineral concentrates from deposited tailings. The heavy mineral fraction amounted to a few per cent of the samples.

4.3 Mineral Processing

The ore was crushed and ground to a fine sand; 60-70% passed a 150 µm sieve and about 20% was <50 µm in size. Molybdenite was extracted from ore by froth flotation with a recovery of 85-95%. Reagents added during the milling included collector oils (140 ppm), complex alcohol frothers (45 ppm), P_2S_5 depressant (70 ppm), NaOH (60 ppm) and lime (a pyrite depressant). Roughly 50% of the collector oils and frothers ended up in the tailings discharge, with about 1/3 of that being in the liquid fraction and the remainder adsorbed on particle surfaces (Burling *et al.* 1981).

4.4 Waste Discharge Characteristics

The tailings left the mill in a freshwater slurry averaging 34% solids by weight. Mo, Pb and Zn contents in the solids averaged 95, 52 and 314 ppm respectively. In comparison, natural (Nass River) sediments typically host 2.5, 10 and 122 ppm, respectively. The tails were also enriched in Cd (~9 ppm) relative to the ~1 ppm characteristic of most uncontaminated coastal sediments. Cd, Pb and Zn tended to be concentrated in the finer grain-size fractions of the tailings (Burling *et al.* 1981). Dissolved metals levels in the liquid fraction of the tailings discharge were less than the limits stipulated in the 1978 Canadian guidelines for drinking water quality except for Mn, which was ~100 ppb, twice the limit for drinking water. Burling *et al.* (1981) noted that the published limit for Mn was determined not for health but for aesthetic reasons since manganese in high concentrations tends to discolor drinking water. Dissolved As, Cd, Pb, Hg and Ni contents in the tailings water were less than Canadian objectives pertaining to aquatic life, except for Hg which occurred in the liquid fraction at a concentration similar to the objective (0.2 ppb).

Monthly LD_{50} toxicity tests using the neat liquid fraction of the tailings showed consistent survival, indicating that the tailings were not acutely toxic to fish.

4.5 The Tailings Disposal System

Tailing slurry is piped (0.7 m diameter) and cascaded in drop tanks down the steep slope from the concentrator to the deaeration chamber mostly submerged just offshore at a depth of 10 metres in Alice Arm. Dilution sea water from 20 metres depth is drawn into the vertical cylindrical chamber via a course rock pile intake filter and 0.9 m diameter pipe. This sea water dilution in the ratio of from 2:1 to 6:1 serves to eliminate both temperature variations between the slurry carrier fluid and the marine receiving water and density differences. The sea water dilution also promotes coagulation of the tailing solids and enhances settling velocities (Poling 1973). Tests indicated that a 2:1 seawater dilution increased settling velocity of the Kitsault tailings by approximately four times (from 0.11 m/hr in freshwater to 0.49 m/hr in the tailings + seawater) (Claggett 1981).

Admixing sea water enhances the coherency of the tailing plume and increases settling velocities, both of which are beneficial in preventing fines from the tailings plume contributing to increased turbidity in the upper euphotic zone of the inlet. The mix tank is designed to inject the tailings into the tank and provide sufficient residence time therein to deaerate the tailings. This can be particularly important in submarine disposal of tailings containing residual sulphide particles. Otherwise, air bubbles engulfed in the slurry, particularly in a cascading drop-tank pipeline system, such as used at Kitsault, could lead to "flotation" of the sulphides to the inlet surface after discharge at depth.

From the deaeration tank the outfall pipe (0.9 m diameter) was directed across the inlet following the bottom slope. The pipe dropped 40 m over its 110 m length. At the final discharge point 50 m, the diluted tailings slurry had an average specific gravity of ~1.06 indicating a dilution of approximated 4:1 was achieved (Burling *et al.* 1981).

As described in Section 4.6.1 and 4.6.2, the expected coherency and settling of the Kitsault tailing plume along the sloping bottom of Alice Arm was achieved by 92-98% of the tailing solids. A secondary tailing plume formed between depth of 65 and 125 m and extended down inlet as much as 5 km (see Figure 5-2, Burling *et al.* 1981). Some improvements in the outfall system (reduction in dilution ratios) to reduce discharge velocity of the tailing jet were subsequently made which reduced the significance of this secondary plume (Burling *et al.* 1983). A variable orifice was installed in the seawater intake pipe in March 1982. This allowed the dilution ratio to be reduced to 3.5:1 while the concentrator treated 12,000 TPD. This lowered dilution ratio apparently improved the integrity of the tailing plume. Reduced velocity at discharge would also have reduced the scouring resuspension of pre-deposited tailings on the bottom near the outfall. An early recommendation to deepen the outfall to 100 m (Burling *et al.* 1981) was later rescinded based on engineering studies by AMAX showing insignificant environmental benefits (Burling *et al.* 1983). In their 1983 report, the independent review panel recommended that the outfall not be extended at its present location. Instead, they recommended that the mining company investigate redirecting the outfall slightly down inlet rather than straight across the inlet. In such a revised installation, a deeper outfall was also recommended with the location selected to maximize integrity of the primary downslope tailing plume (Burling *et al.* 1983).

It should also be underlined that the review panels 1981 conclusion that the secondary cloud of turbidity was a tailings "cloud" was found to be premature. Re-examinations of transmissometry profiles made before the mines start-up shows that such an intermediate turbidity cloud existed before tailings were discharged. The tailings might have only intensified an already existing natural feature in the water column (Burling *et al.* 1983).

These results simply re-emphasize the necessity of detailed pre-operational physical/chemical monitoring programs to prevent such misinterpretations of STD impacts.

4.6 The Environmental Situation

4.6.1 Bathymetry

Alice Arm and Hastings Arm are the landward termini of the Portland Canal-Observatory Inlet system in northwestern B.C. (Figure 4-1) which stretches some 110 km inland from the Pacific Ocean. A complex of shallow sills (Figure 4-2) ranging in depth from 20 to 51 m separates the arms from Observatory Inlet, but does not seriously constrain the tidal exchange of water within the inlet system. The entrance to Alice Arm is restricted by a sill 20 m deep; the 2-km wide fjord extends from the sill 19 km toward the east, and reaches a maximum depth of 386 m. A relatively flat axial trough of average depth 380 m characterizes the fjord between Roundy Creek and Hans Point (Figure 4-2).

Unlike the Rupert-Holberg basin (Chapter 3), the principal input of freshwater in Alice Arm is the Kitsault River at the head of the inlet (Figure 4-1). Thus, the general circulation is best described as being the classical fjord-type two layer flow, at least in the summer when high runoff into the arm results in a marked horizontal stratification. In contrast, low runoff in the winter drastically changes the characteristics of the water column: the thermocline vanishes, and salinity can be constant throughout. At this time stability is low, and deep water renewal is most likely to occur. Krauel (1981) notes that at least partial renewal of the deep water occurs every winter in the fjord.

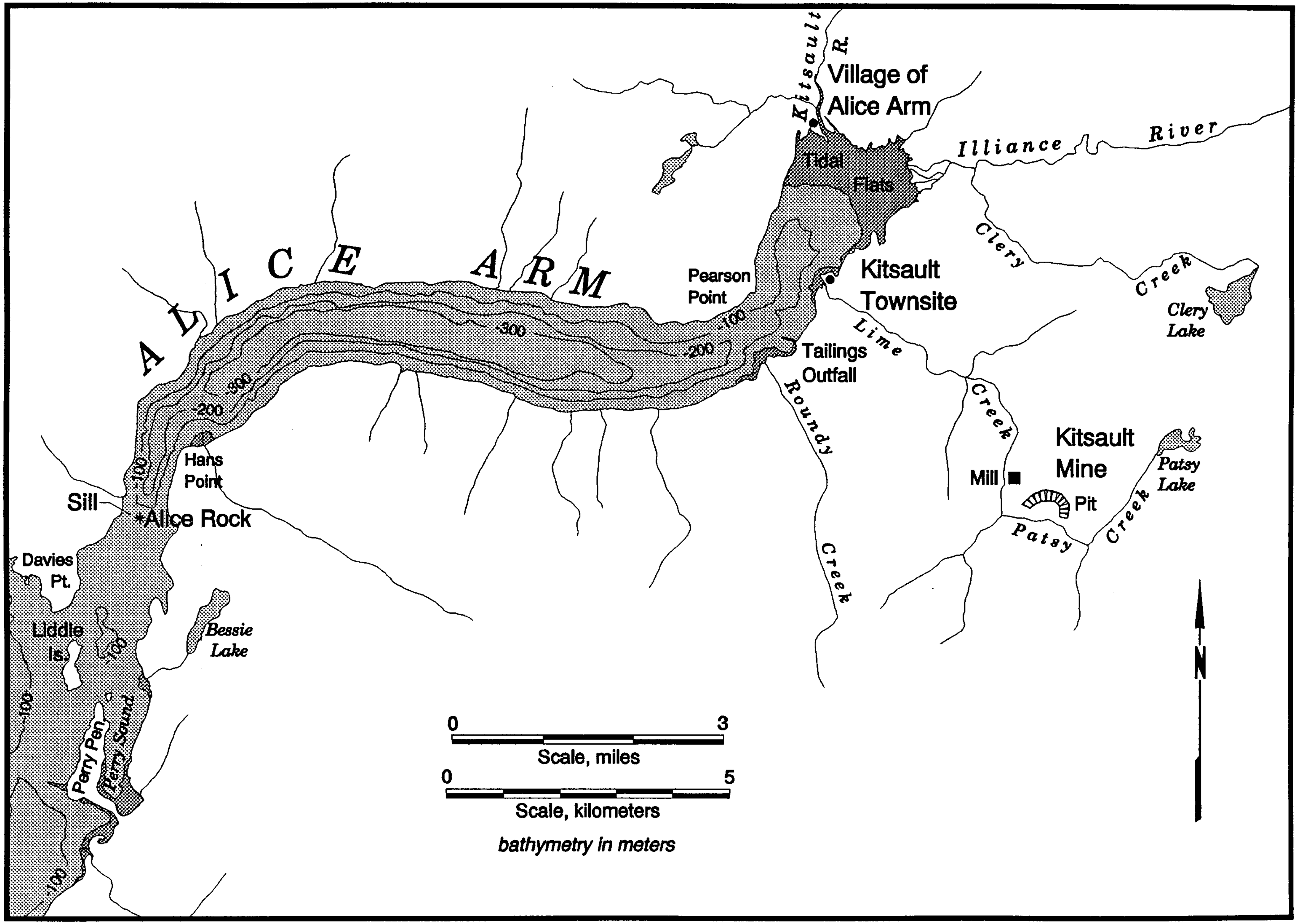


Figure 4.2 - Bathymetry of Alice Arm.

Dissolved oxygen levels in Alice Arm are typically high throughout the water column, being between 60 and 70% saturation; concentrations <50% saturation have never been observed (Littlepage 1978; Krauel 1981). These high values provide another indication that deep water renewal occurs almost every year.

The intrusion of denser water into Alice Arm over the sill in winter can be associated with penetration to considerable depths. Krauel (1981) observed that on one occasion the momentum of a gravity flow of incoming water caused it to overshoot its equilibrium depth (estimated to have been 150 m) mix down and entrain and displace water to a depth of at least 200 m. By analogy with other fjords (see for example, Farmer 1982) tidal exchange across the 20 m-deep sill at the entrance to Alice Arm could be expected to induce marked turbulence to depths exceeding 100 m via the penetration of hydraulic jumps. The breaking of internal waves progressively away from the sill can also foster the propagation of turbulence laterally for considerable distances.

The tailings slurry from the mill is deaerated and mixed with seawater (Plate 4-1) in a submerged tank at about 10 m depth just off the southern shore of Alice Arm. The design dilution ratios of 2:1 to 6:1 (seawater to tailings slurry) were intended to produce a final effluent of specific gravity ~1.06 for discharge as a jet at a depth of 50 m. Pre-operational predictions (Western Canada Hydraulic Laboratories 1976, cited in Burling *et al.* 1981) noted that "Even if...over half the tailings solids would settle out of the effluent plume, its density would continue to be greater than that of the seawater and hence the plume would continue to descend to the bottom of the inlet." Some larger particles were expected to accumulate on the bottom between 50 and 100 m depth and the remainder would flow as a turbidity current initially down-slope across the inlet, before turning westward to follow the inlet axis toward the deepest portion of the basin.

Measurements made during an early stage of operation defined an unexpected feature: although the density flow down slope generally behaved as predicted, a discrete and unanticipated turbid layer formed between depths of about 65 and 125 m and stretched down inlet as much as 5 km (Burling *et al.* 1981). The layer contained an estimated 2-8% of the daily tailings discharge (Burling *et al.* 1983) and appeared to form via separation of a lower density suspension from the main density flow near the outfall. Sediment trap data and chemical analyses subsequently confirmed that the turbid layer also contained a component of suspended particulates derived from natural fluvial input at the head of the fjord and mid-depth lateral transport down inlet. Improvements to the outfall design made in 1982 to lower the dilution rate in the mixing tank appeared to reduce the loading of tails in the upper turbid layer (Burling *et al.* 1983). A schematic of suspended sediment distribution related to the tails discharge, based on sediment trap data, is shown in Figures 4-3 and 4-4. Note that no tailings were observed in the water column above 250-300 m depth in the central section of Alice Arm. Inspection of monthly sediment trap data collected at stations EE and FF showed that the deep inflow associated with renewal of the bottom waters during winter did not resuspend or cause uplift of suspended tailings

Plate 4-1. - The engineered outfall for STD at Kitsault. The pipeline on the right is seen descending to the seawater mix tank (reached by catwalk) on the left. (Photo by D. Ellis)

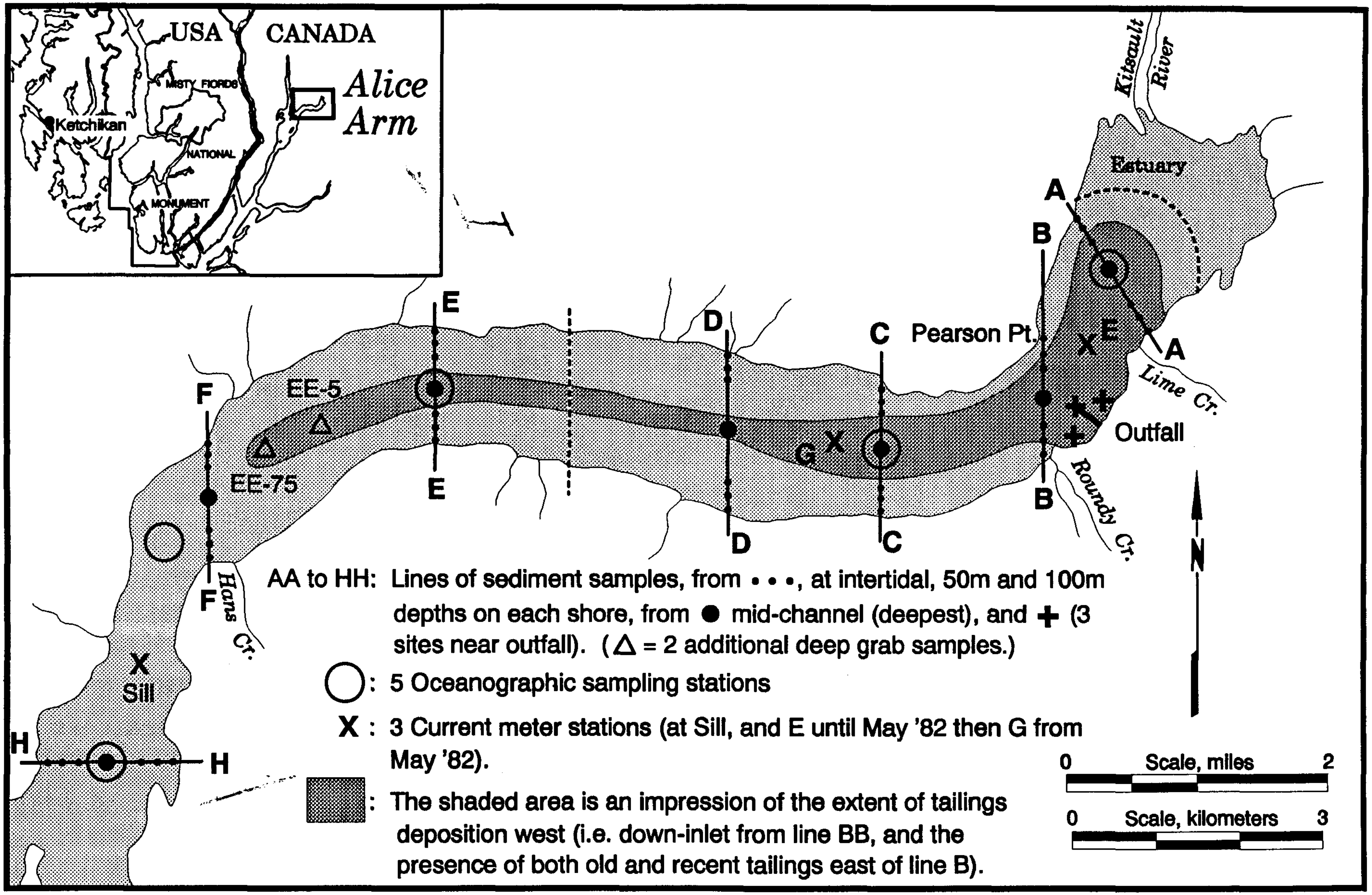
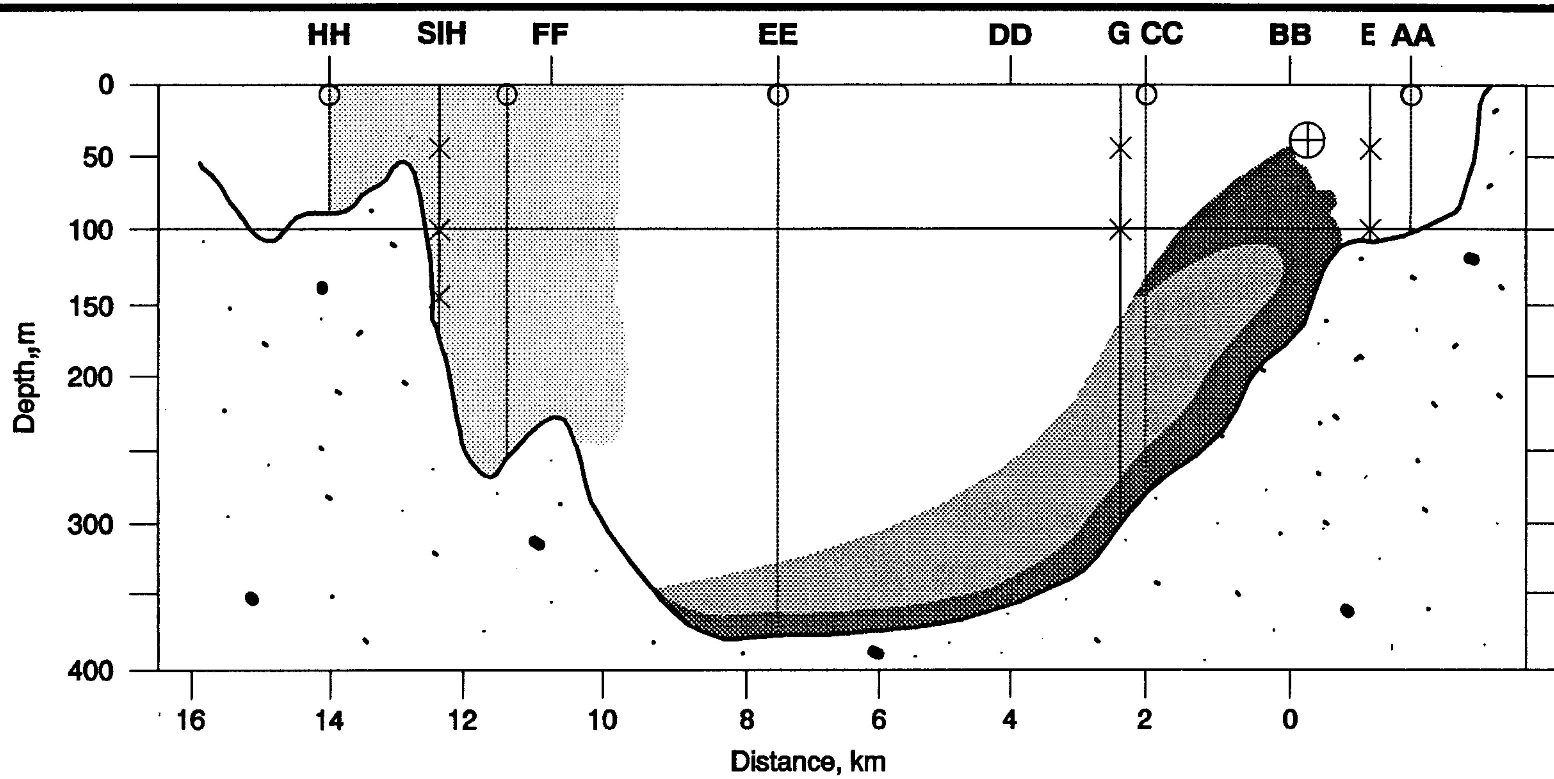


Figure 4.3 - Plan of tailings dispersal in Alice Arm showing location of sampling transects.



Indicates the depth of the outfall. Distances are measured roughly from this position.

Some sampling positions (see Fig. 1) are indicated along the top. Lines AA to HH denote both grab and suspended sediment sampling lines. X marks meter sites.

Shading is an impression of suspended sediment in the dominant turbidity flow (see Chapter 7) from the outfall: this of course starts across the inlet mainly along the bottom towards the trough.

Indicates stirring of natural sediments by tides near the sill and occasional contribution of sediments from Hans Creek (near FF).

Figure 4.4 - Profile of tailings dispersal in Alice Arm showing location of sampling transects.

in the vicinity (Burling *et al.* 1983). This result stands in contrast to the experience at the Island Copper Mine in Rupert Inlet, where the local physical oceanographic conditions are quite different.

The Kitsault tailings solids are characterized chemically by significant (see Section 4.4) Cd, Pb, Zn and Mo contents (Burling *et al.* 1983). Prior to the start of submarine disposal in the spring of 1981, the highest concentrations of these elements were found in the intertidal zone of the south shore close to Lime Creek, implying that tailings from the previous B.C. Molybdenum operation must have settled in that area after being carried to the shore by the creek. No other intertidal sites in the fjord showed evidence of raised metals levels. Metals analyses made on a suite of cores from Alice Arm prior to startup in 1981 showed that the B.C. Molybdenum tailings were dispersed along the deep trough of the inlet, extending from Section AA (Figure 4-3) to at least EE. Because these tailings were injected at the surface via the Lime Creek flow, the data suggested that shallow currents must have been responsible for the dispersion.

By August 1982, sixteen months after the Amax operation began, high Cd, Mo and Pb concentrations in sediments in the fjord showed that active tailings deposition was occurring below 100 m depth in the area just west of line AA down inlet to line EE (Figures 4-3 and 4-4). Arsenic concentrations in surface sediments fell, reflecting As-depletion in the tailings relative to natural sediments. Very low Cd, Pb and Mo levels prevailed in surface deposits at line FF and westwards (Burling *et al.* 1983) indicating that tailings deposition was limited to the area east of line FF.

4.6.2 Post Depositional Sketches

During the monitored period April 1981 to October 1982, dissolved metals levels in the tails discharge water were consistently low with the exceptions of Mo and occasionally Mn, and it was clear that solubilization of tailings solids in the mill process water was small or negligible. High concentrations of dissolved Mo in the discharge (typically 1500 ppb, some 150 times the concentration in seawater) were probably derived from oxidation of some MoS_2 to MoO_3 in the milling circuit; MoO_3 is quite soluble in water (Chander and Fuerstenau 1972). Molybdenum was not considered to be a deleterious substance under the terms of the federal discharge regulations for the Kitsault operation. This reflects two factors: (a) Mo occurs in seawater at ambient pH levels as the oxyanion MoO_4^{2-}, which is not a bioavailable species; and (b) the element is present in relatively high concentrations in seawater (~11 ppb), which is partly a reflection of the lack of bioreactivity of the oxyanion.

The low density (<5 mg/L), mid-depth (65-125 m) turbid plume in the vicinity of the outfall which persisted during the operation of the mine extended some 2.5 to 5 km down inlet, and included some suspended natural sediments apparently derived from fluvial inputs at the head of the inlet. There was no evidence of deleterious effects from this "cloud". Dissolved Cd, Pb and Zn in the water column showed negligible elevations (in the parts per trillion range) in upper Alice Arm. However, lead isotope ratio studies

(Stukas 1981) showed that dissolved lead in the water column was derived from Pb in the Kitsault orebody.

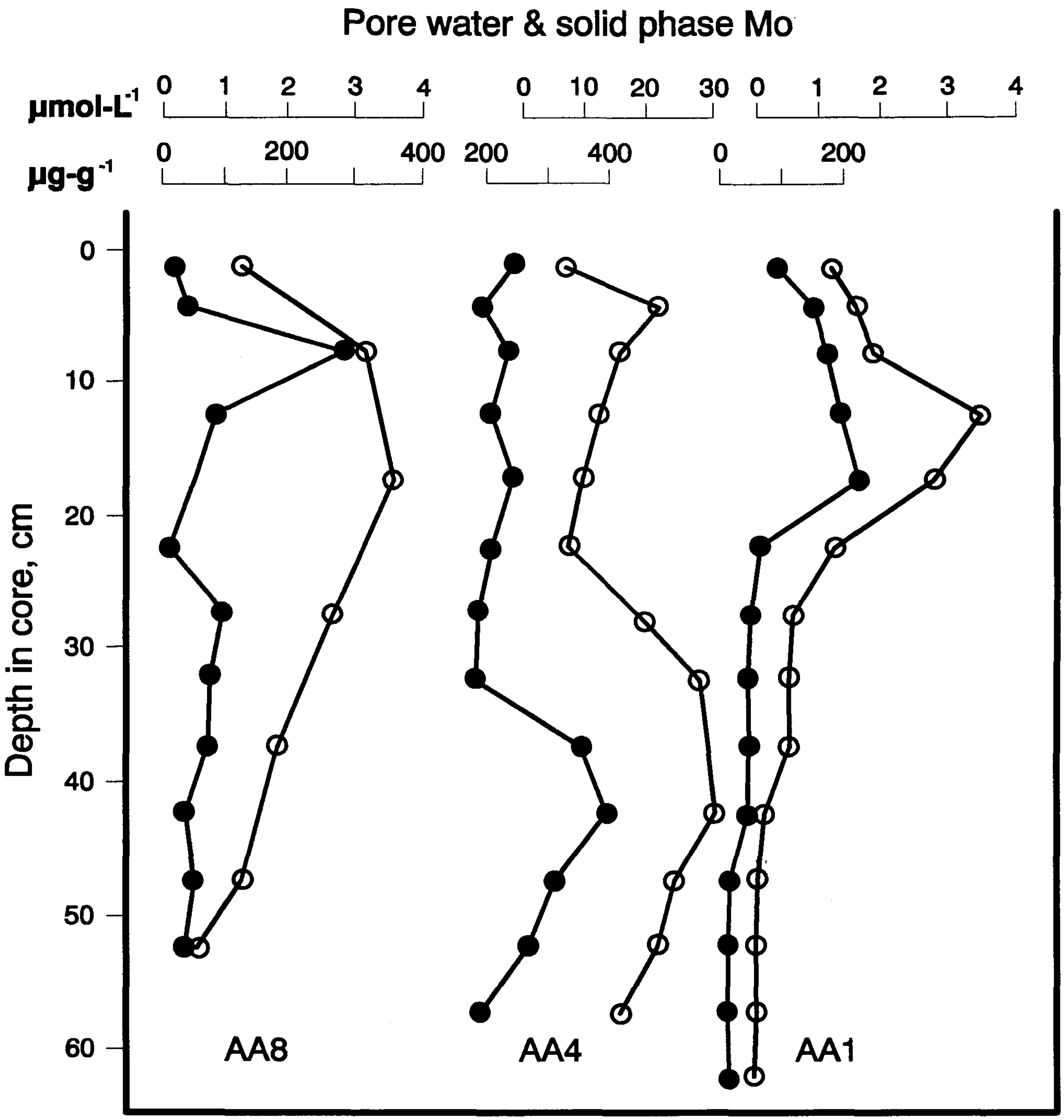
Losher (1985) used interstitial water measurements in concert with solid-phase analyses from a suite of cores collected from Alice Arm in 1983 to assess the post-depositional (diagenetic) behaviour of Mo in the tailings on the fjord floor. The presence of dissolved Fe enrichments at relatively shallow depths in the pore waters indicated that the zero oxygen boundary in the deposits occurred within the upper several centimeters. However, the dissolved Mo distributions in the deposits appeared to be insensitive to the presence or absence of O_2 (as indicated by the Fe^{2+} data). Dissolved Mo concentrations were very high in the pore waters (Plate 4-1), reaching 30 mmol L-1 (~3000 ppb), some 30 times the concentration in the overlying seawater. Comparison of the Mo levels in pore waters with the solid-phase content (Figure 4-5) showed a strong correlation. Losher (1985) interpreted the covariance to represent dissolution of MoO_3 (which is independent of redox state) and enhanced addition of Mo to pore water where the Mo content in the solid-phase was high.

The unique relationship between the solid and dissolved distributions was not only a function of dissolution from tailings particles but also reflected the high sedimentation rate of the tailings. The length of time for diffusion to operate over length scales of a few decimeters is on the order of 10-20 years; because the Alice Arm tailings had accumulated at a rate an order of magnitude faster, there had been insufficient elapsed time between deposition and subsequent sampling to allow diffusion to smooth the dissolved Mo profiles and obscure the relationship shown in Figure 4-4 (Pedersen and Losher 1988). The high Mo concentrations in shallow pore waters will clearly support an efflux of the element from the deposited tailings to the overlying waters. Losher (1985) calculated that flux would supply an upper limit of ~1500 kg of Mo to Alice Arm waters annually, which amounts to ~4% of the inventory of dissolved Mo in the inlet. This contribution will undoubtedly diminish with time as the tails become progressively covered with natural sediments.

4.6.3 Preliminary Environmental Information

The Kitsault documentation reflects the time of its development, the early 1970s, in that the major document (Burling *et al.* 1981) says virtually nothing about fisheries and other socio-economic concerns. Burling *et al.* (1981) is the report of a public inquiry, but an inquiry aimed at technical (meaning STD) issues. The requirement to protect economically important and native food fisheries (see Table 4-2) was not taken as authority to assess their extent, utilization and value prior to predicting the scale of any losses.

Nevertheless in hindsight sufficient reconnaissance-level information was available for a resource conflict appraisal. There is a commercial fishing fleet out of Prince Rupert and other towns in the general area. The fishery consists of Pacific salmon, halibut and king crabs, plus others of importance to the natives, *e.g.* eulachon.



Solid phase and dissolved molybdenum in three molybdenite-bearing tailings cores from Alice Arm. Open circles = Dissolved Mo; Filled circles = solid-phase Mo.
(Note the varying scales for the pore water profiles)
(Source: Pedersen & Losher, 1988)

Figure 4.5 - Solid phase and dissolved molybdenum in cores from Alice Arm.

Table 4-2

Terms of Reference for the 1981 Public Inquiry into the Kitsault Mine

1. To examine and advise on the adequacy of the Alice Arm Tailings Deposit Regulations for protecting economically important fisheries resources and native food fisheries of Alice Arm and environs.
2. To examine and advise on whether planned tailings deposit practices are likely to meet the terms and conditions of the Regulations.
3. To assess the planned monitoring program, to determine whether it will be adequate to detect violations of the terms of the Regulations or impacts upon fish and fish habitat, and to recommend necessary improvements.
4. To consult with interested agencies and parties knowledgeable about the issue.
5. To examine and recommend any alternative tailings disposal methods which would significantly reduce or preclude hazards to the fisheries resources.
6. To recommend further courses of action in the future which in the opinion of the panel may be necessary to address the issue.
7. To prepare two reports: as soon as possible an interim report recommending any action deemed important for protecting the public interest, and a final report by July 1, 1981.

Source: Burling *et al.* (1981).

There is a strong native presence in the area, with a long history of asserting their traditional rights, although they did not do so publicly in this matter until several years after the development started (Ellis 1982). It appears that the mine developers proceeded for several years without making the most appropriate community contacts due to taking over a prior operation which had only recently closed down.

The area had previously been explored and mined extensively, with the existence even of a smelter nearby for a time at Anyox (Loudon 1973). The nearby residents were used to there being mining operations in the area, and there must have been considerable local support for restarting the mine with an environmentally upgraded operation.

The Kitsault case provides an interesting example of what can be called the concept of an environmental "fatal flaw", *i.e.* a problem perceived as so serious and unresolvable that the development should not proceed. If there had been an environmental appraisal in the mid-1970s of the mine reopening, soon after the original mine closed, it is likely that no such "fatal flaw" would have been perceived by local residents used to the previous mine operation. However by 1980, the native Indian community had effectively made an appraisal in their own context. They saw an incompatibility with their interests, and in conjunction with influential church-based environmental groups (Ellis 1982) used their well-established protest procedures to draw attention to their concerns. The result was a public inquiry, and a temporary closure.

4.6.4 The Monitoring Program

The initial monitoring program (Table 4-3) was set on September 17, 1979, by the provincial Pollution Control Branch, and was based on both provincial and federal government requirements. There have been annual reports of the data as required by the terms of the monitoring program.

Table 4-3

Summarized Monitoring Program for the Kitsault Mine*

1. Mill tailings flow. Volume of slurry and average daily quantity of tailings solids discharged. Frequency - weekly.
2. Mill tailings composition. pH, selected dissolved trace metals, total mercury and suspended solids. Frequency - monthly.
3. Mill tailings toxicity. Acute toxicity by TLm - 96 hr using rainbow trout. Frequency - monthly.
4. Suspended tailings distribution. Transmissometer surveys to 100 m depth. Frequency - annually, 3rd calendar quarterly.
5. Fine tailings distribution. Bottom sediment surveys with selected trace metal analyses.
6. Coarse tailings distribution. Echo sounding surveys and mapping of coarse mill tailings distribution. Frequency - every three years.
7. Heavy metal bioaccumulation in mussels (*Mytilus edulis*). Tissue analyses of selected trace metals. Frequency - annually.
8. Heavy metal bioaccumulation in clams (*Yoldia thraciaeformis*). Tissue analyses of selected trace metals. Frequency - annually.
9. Heavy metal bioaccumulation in shrimp (*Pandalus borealis*). Tissue analyses of selected trace metals. Frequency - annually.

*** Dated September 17, 1979.**

After closure, the mine has continued some monitoring, and the area has been subject to detailed EIA of specific components of the ecosystem.

There is no comprehensive document reviewing impacts on the aquatic ecosystem and fisheries, although there are sets of documents on some components of the marine system, as a comparative summary of Kitsault, Island Copper and Wesfrob Iron Mine (Harding 1983).

The water column community has had some assessment. There was little impact (Anderson 1986; Mackas and Anderson 1986). The crab fishery was also investigated (Jewett *et al.* 1985; Sloan 1985; Sloan and Robinson 1985). No impact was documented. There was minor trace metal bioaccumulation in mussels and clams.

The marine benthos has been assessed in much detail (Kathman *et al.* 1983; 1984), and the data set used for several follow-ups developing new benthic statistical analytical techniques (Burd 1991) and comparing STD impacts between cases (Ellis and Hoover 1990). Note that this was not a requirement of the initial monitoring program. Note also that relevant investigations of benthic recovery after the prior operations, conducted by environmental consultants for the mine (Ellis 1974; Goddard 1975; O'Connell and Byers 1977), were largely ignored by the later government investigators. The statistical techniques of the time (1974 - 1977) suggested that recovery was well advanced 2-3 years after the 1967-72 operations ceased. It was a further 10 years before this early determination of rapid recolonizing of benthos on mine tailings was confirmed elsewhere, *i.e.* at Island Copper Mine - see Chapter 3.

Benthic sampling in 1982, 1983 and 1986 at similar stations showed progressive changes. In 1982 during mining, the benthic losses from STD were measured by a limited required monitoring program (Kathman *et al.* 1983). Government-funded post-closure sampling in 1983 (Kathman *et al.* 1984), 1986 (Brinkhurst *et al.* 1987), and 1989 (Burd and Brinkhurst 1990) showed some recovery a year after closure, and changes in both Test and Reference sampling station populations by 1986. These conclusions were supported by more advanced inferential statistical analyses five years later (Burd 1991).

It was noticeable that although the speed of benthic recovery, *i.e.* about a year, was similar to that at Island Copper Mine (Chapter 3) the species concerned were almost totally different (Ellis and Hoover 1990). There appears to be a great diversity of benthic opportunist species which can colonize a seabed smothered by mechanically favourable and non-contaminating deposits such as tailings.

There was also some investigation of trace metal dynamics in the benthic and fishery ecosystem, but little indication of bioaccumulation (Thompson *et al.* 1986; Reid 1984; Farrel and Nassichuk 1984).

The effectiveness of the government assessment program was also reviewed (Rambold and Stucchi 1983).

4.7 Community Involvement

Although the government inquiry, held as the mine opened, and the mine company documents say little about community involvement and concerns, nevertheless there is some record. Newspaper articles during the inquiry provide some information. Also there is an individual day-by-day report on the inquiry (Ellis 1981) which documents presentations, as well as assembling the media accounts.

Two well informed local residents presented information to the inquiry about the regional fishery resources, as used both commercially and by the native community. They documented that fishable stocks were present but did not contradict the mining company documentation of little actual use of the stocks in the immediate vicinity of the mine and its STD. The king crab fishery in the STD area had been started after the mining redevelopment was substantially on its way to permitting, and was already declining prior to operations.

The native community had held its own inquiry just prior to the formal government inquiry, and had brought in an environmental expert to comment. Any formal record of the native meeting has not been obtained for this report, but the newspaper accounts at the time indicate that there was little informative interchange between the two meetings (Ellis 1981).

As the inquiry progressed, simultaneous government monitoring was interpreted by some as meaning that the mine was in contravention of its STD permit. Media-reported political pressure by a cabinet minister caused the mine to voluntarily close down (Ellis 1982). A few days later the government monitoring was reported as incorrectly interpreted and the mine re-opened. The incident reflects considerable media interest in the events at the time, and also the consequences of such media reporting.

4.8 Conclusion

The Kitsault molybdenum mine as redeveloped in the late 1970s, undertook environmental impact assessments reflecting the technical (as contrasted to social) concerns of the times prior to operations. The results indicated that the mine could utilize STD and thereby deposit its tailings deep in a silled fjord. In so doing there would be little environmental impact, without loss of significant fishery resources. An appropriately designed and located outfall was built and operated to specifications from 1981 - 1982, although rapidly improving monitoring technology detected previously unsuspected minor deviations from predicted plume flow and dispersal The mine closed in 1982 when a fall in molybdenum prices made it uneconomical. Post-closure monitoring of the sea-bed showed some recovery of the benthos one year after closure, and thereafter showed changes in benthos indistinguishable between tailings and non-tailings areas.

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5.0 WESTGOLD PLACER MINE, ALASKA (by D. Ellis)

5.1 Introduction

A marine placer mine known as WestGold was operated off Nome, Alaska, from 1985-90 (Figure 5-1). As a placer mine, the operations were substantially different from those described in the other case histories, but the case is relevant to STD in general. WestGold was a dredge-based operation with a floating mill (Figure 5-2), mechanical processing (10,000 to 21,000 yd^3/day) of the dredged gravel, and disposal of tailings back to the seabed by discharge below the dredge, *i.e.* a form of STD. The BIMA dredge operated in water depths ranging from 4.8 to 21 metres. Typical tailing discharge rates were 20,000 to 30,000 gpm.

The case history is informative in several ways. First, a required and very intensive monitoring program demonstrated the process of benthic recolonisation of the seabed after dredging and tailings discharge. The impact and recolonisation documented is relevant to the prospect of STD on open wave-exposed coasts, for which there is otherwise little information from the USA.

Second, and perhaps most important of WestGold's generalized importance to STD, is that the development was initiated and the mine was brought into operation under U.S. environmental controls during the 1980s. This was within the time that the Quartz Hill development (Chapter 6) spent 15 years and more than $100,000,000 while unsuccessfully seeking its various permits. Some differences between the two developments are readily apparent. It is relevant to development of the STD Criteria to ask why was mining, with inevitable STD, accepted without much controversy at WestGold but not at Quartz Hill? Was it just because WestGold was a placer operation returning tailings to an already dredged seabed. Were there procedures followed by the mine and the regulatory agency at WestGold which met the social issues more effectively? Did the conservation action of creating a National Monument within a wilderness area surrounding the mine site exaggerate social concerns and responses more strongly than at the WestGold development.

How the case history can be used has been demonstrated in a report by Ellis (1990) on implications for placer dredging operations in Canada.

The development and operations have been described and summarized in many annual and conference reports. The annual reports provide detailed information (Rusanowski *et al.* (1987), and Jewett *et al.* (1991) are the first and last of these, respectively). Summaries are given by Rusanowski (1989); Rusanowski and MacCay (1990) and Ellis (1990). Timing is shown in Table 5-1. Figure 5-3 shows the leases and annual (summer) dredge sites. The dredging season is limited by ice to less than 6 months each year from late May, at the earliest, to November.

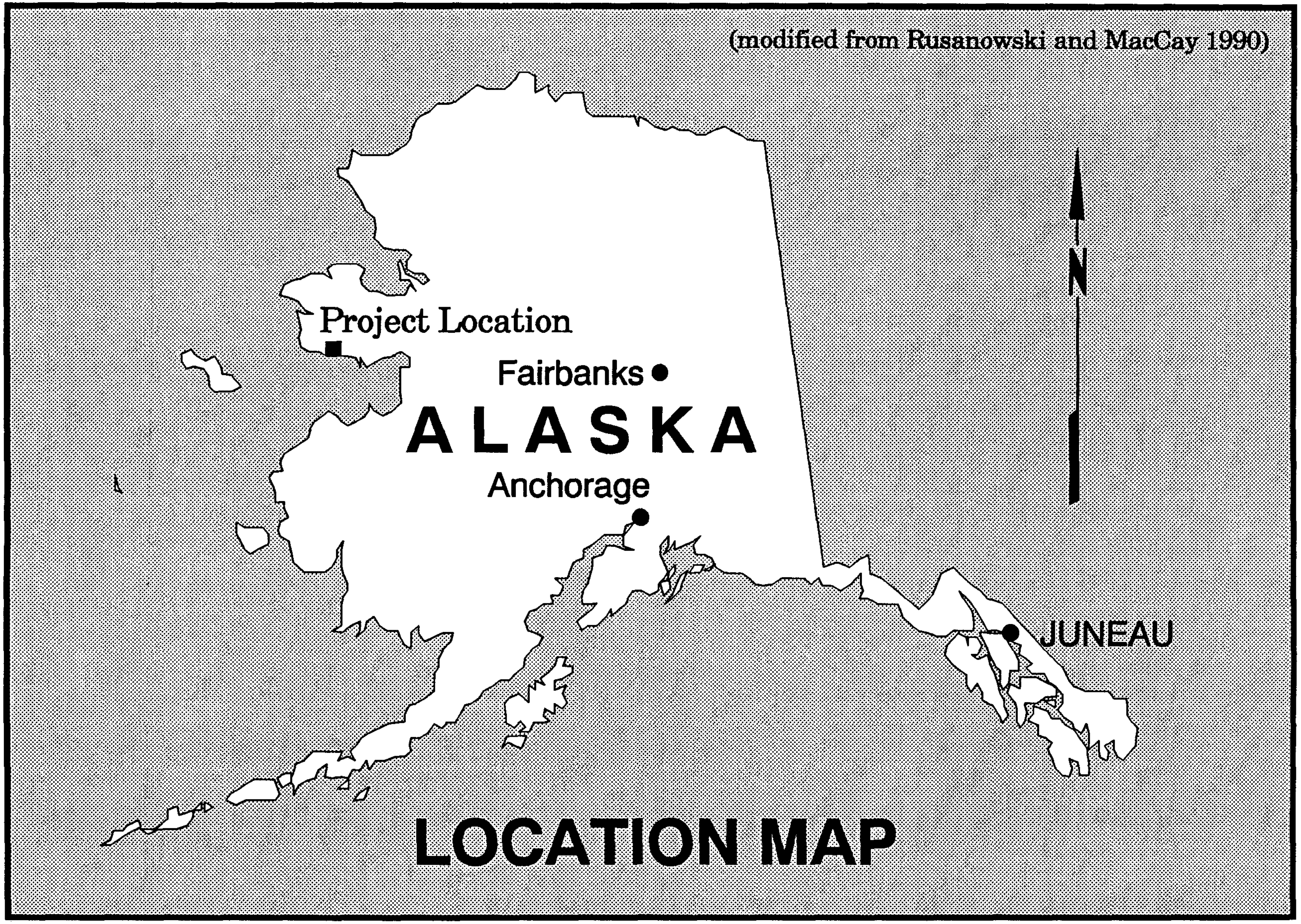


Figure 5.1 - Location of WestGold's operation in Alaska.

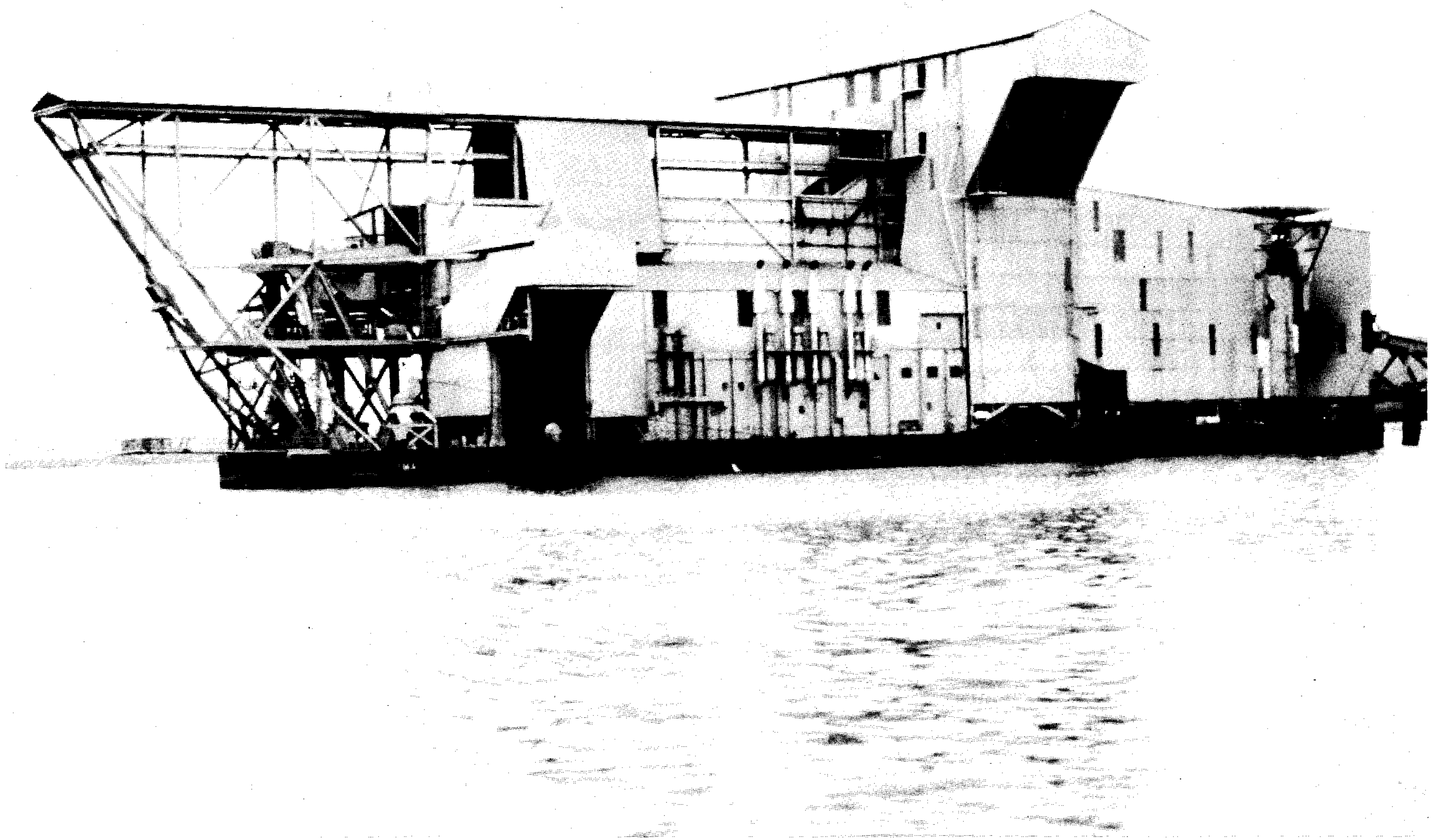


Figure 5-2. - View of the BIMA mining vessel on location near Nome, Alaska.

Table 5-1

Timing of Major Events at WestGold

1962	Shell Oil Company issued first prospecting permits, and initiated drilling.
1967-68	US Bureau of Mines surveyed using drills, geophysical methods and surface sediment sampling.
1984	Permitting initiated.
1985	Permit issued (AK-004319-2) and operations started using a clamshell bucket dredge.
	Quarterly Meetings of Project Review committee initiated.
1986	First Annual Report (for 1985 operations) issued.
	BIMA bucket-line dredge in operation.
1988	Intensive turbidity plume monitoring program initiated, after subsequent outfall pipes damaged in storm.
1990	Operations terminated September 20.
1991	Final Annual Report issued, with post-operational monitoring.
	Required Completion Report in preparation designating post-mining environmental studies.

This case history provides information on seabed recovery from ecosystem disturbance induced not only by tailings deposition and resuspension, but also by the even more impacting prior dredging, *i.e.* removal of deposits and their contained organisms.

5.2 Composition of the Ore

The sea bottom sediments excavated by the BIMA bucket line dredge were comprised of cobble or sand substrates and averaged approximately: 24% gravel (>2.0 mm diameter); 61% sand (2 - 0.0625 mm); 14% silt (0.0625 - 0.0039 mm) and less than 0.5% clay (<0.0039 mm). Levels of arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc in the bottom sediments to be mined were very near background levels from other areas in Norton Sound.

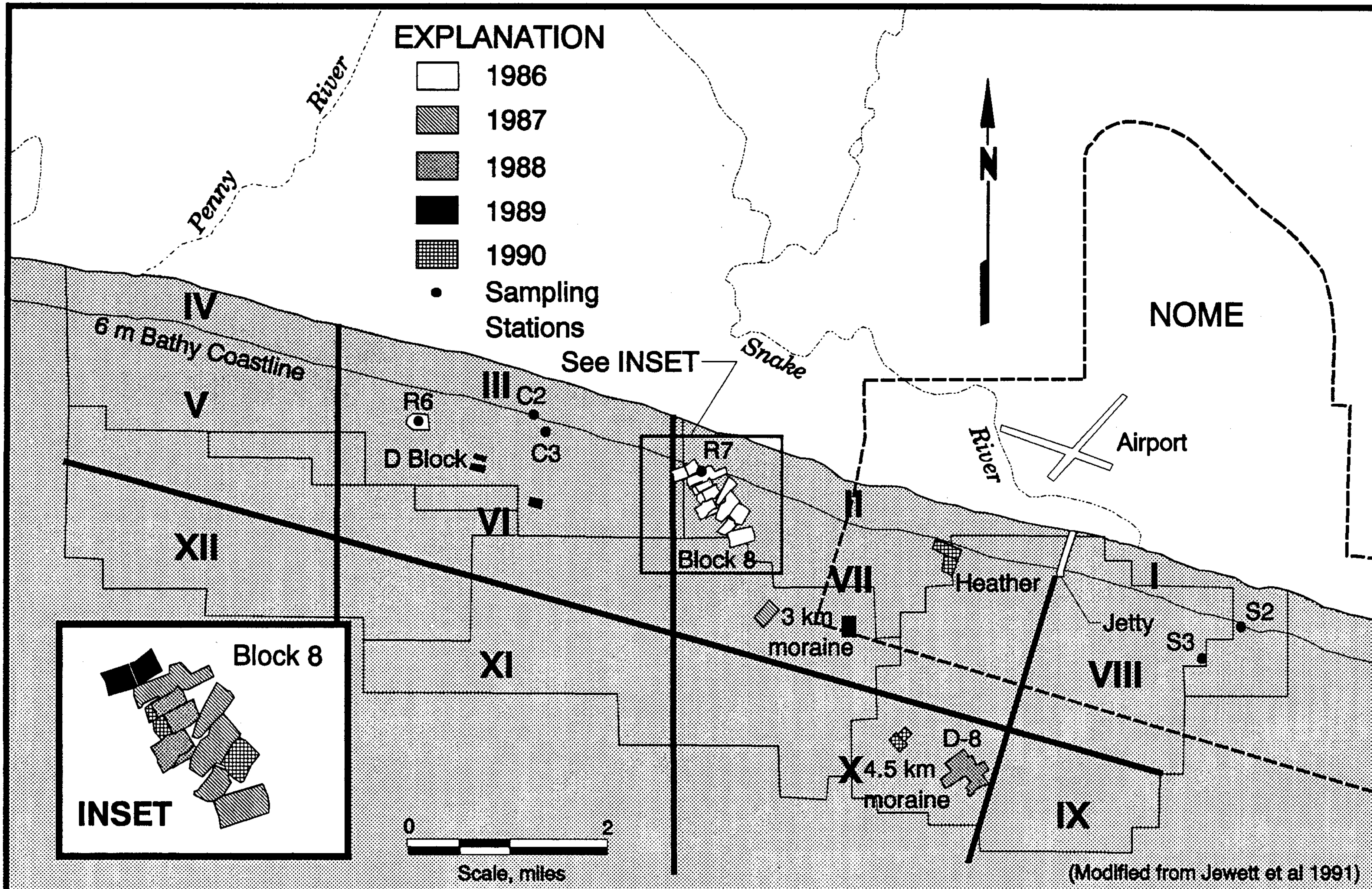


Figure 5.3 - Location of WestGold's leases, and annual dredging operations within the leases.

5.3 Mineral Processing

Mining leases covered an area from about 1.6 km east of Nome to about 16 km to the west and extended approximately 4 km seaward. The lease blocks covered ~ 21,750 acres. Mining began in 1985 using a crane operated clamshell bucket from a barge on a experimental basis. In 1986, one of the worlds largest bucket line dredges, the BIMA (see Figure 5-2) was installed to continue this off-shore mining. This dredge is 160 m long, 45 m wide and 45 m high and has a bucket ladder 88 m long with 134 buckets each of 0.85 m^3 capacity. The dredge is capable of digging to a depth of 45 m and can excavate nearly 46,000 m^3 of sediment each day. The water discharge associated with this mining rate was ~ 48 MGD.

On board the dredge, advantage was taken of the fact that particulate gold is typically seven times as dense as the majority of the other minerals (such as quartz and feldspar) contained in the submarine sediments to effect a simple physical "gravity" separation. In essence, only the minute amount of particulate gold was removed, without use of any chemical reagents, and the sediments and sea water were returned essentially unaltered to the sea bed to again become sediments.

5.4 Waste Discharge Characteristics

The waste discharge constraints and their monitoring were set by National Pollutant Discharge Elimination System (NPDES) Permit No. AK-004319-2 issued by the U.S. Environmental Protection Agency (EPA). Variability from time to time was allowed, subject to application to, and approval by, the EPA. There was also a requirement for WestGold to submit a plan of study for the environmental monitoring program by January 31 each year. WestGold had to submit results of the environmental monitoring to EPA by December 31 each year.

The permit was a very substantial document and was changed several times *e.g.* when the BIMA dredge was brought into use. Major constraints were compliance to < 25NTU (turbidity) units above background at a 500 meter radius from the point of discharge. Maximum trace metal levels were also specified at a 100 meter radius "mixing" zone boundary. The permit also required WestGold to discharge tailings at the sea floor, and to submit monthly discharge monitoring reports. The sea floor discharge requirement was subsequently changed after the outfall pipes were damaged in a storm and the consequent near surface discharge seemed to produce less turbidity in this relatively shallow water.

An example of the waste discharge characteristics required in the last year of operations, 1990, and the monitoring required to quality control the discharge, is given in Tables 5-2 and 5-3. The combined water and effluent results were reported, without comment on the effluent specifically, in Appendix E of the 1990 Annual Report (Tables E-2 and E-3, and a series of bar diagrams for each metal, Jewett *et al.* 1991).

Table 5-2
Example of WestGold's Waste Discharge Permit and Effluent Monitoring Requirement 1990

Process Tailings Launders (Discharge 003)

1. The combined discharge of the process tailings launders shall be limited and monitored by the Permittee as specified below:

Effluent Characteristics	Discharge Limitations		Monitoring Requirements	
	Average	Maximum	Sampling Method and Frequency	Monthly Reporting Values
Flow (MGD)	35	45	Estimate: 3 times per day	Average monthly: maximum daily
Settleable Solids small fraction (m^3/hr)	--	413	Grab: 3 times per day	Average monthly: maximum
Suspended Solids (mg/L)[1]	15,000	30,000	Grab: 3 times per day	Average monthly: maximum
Arsenic (µg/L)[2,3]	234	1,242	Grab: 2 times per week	Average monthly: maximum
Cadmium (µg/L)[2,3]	167.4	774	Grab: 2 times per week	Average monthly: maximum
Copper (µg/L)[2,3]	52.2	52.2	Grab: 2 times per week	Average monthly: maximum
Lead (µg/L)[2,3]	100.8	2,520	Grab: 2 times per week	Average monthly: maximum
Mercury (µg/L)[2,3]	0.45	37.8	Grab: 2 times per week	Average monthly: maximum
Nickel (µg/L)[2,3]	149.4	1.350	Grab: 2 times per week	Average monthly: maximum
Zinc (µg/L)[2,3]	1,548	1,710	Grab: 2 times per week	Average monthly: maximum

1/ Suspended solids is defined herein as the combination of clay and silt particles.

2/ Metal concentrations shall be measured and reported as both total recoverable and total dissolved metals. EPA may reduce the monitoring requirements after the development of a substantial, reliable record of metals concentrations in the discharge plume.

3/ Total recoverable and total dissolved metals shall be measured in accordance with EPA-approved methods which meet the requirements of 40 CFR Part 136 to achieve detection limits for (or at least) As (1 µg/L), Cd (1 µg/L), Pb (1 µg/L), Hg (0.05 µg/L), Ni (1 µg/L) and Zn (8.6 µg/L).

2. There shall be no discharge of dredge material from the tailings process launder to waters of less than 8 m depth at MLLW.

3. The average daily discharge of process tailings shall not exceed 10% solids, of which no more than 15% shall be silts and clays.

Table 5-3

Example of WestGold's Waste Discharge Permit and Effluent Monitoring Requirement 1990

Gold Table Sluice Tailings Launder (Discharge 004)

1. The discharge shall be limited and monitored by the Permittee as specified below:

Effluent Characteristics	Discharge Limitations		Monitoring Requirements	
	Average	Maximum	Sampling Method and Frequency	Monthly Reporting Values
Flow (MGD)	--	0.34	Estimate: daily	Average monthly: maximum daily
Suspended Solids (mg/L)	15,000	30,000	Grab: daily	Average monthly: maximum
Copper (μg/L)[1,2]	52.2	52.2	Grab: 2 times per week	Average monthly: maximum
Mercury (μg/L)[1,2]	0.45	37.8	Grab: 2 times per week	Average monthly: maximum

1/ Metal concentrations shall be measured and reported as both total recoverable and total dissolved metals. EPA may reduce the monitoring requirements after the development of a substantial, reliable record of metals concentrations in the discharge plume.

2/ Total recoverable and total dissolved metals shall be measured in accordance with EPA-approved methods which meet the requirements of 40 CFR Part 136 to achieve detection limited for (of at least) Cu (1 μg/l), and Hg (0.05 μg/l).

It should be noted that waste discharge constraints were set as a condition of the mining permit, with a very substantial monitoring and reporting requirement. The two sets of requirements together ensured that the mine minimized chemical and physical impact on the sea-water, with resultant benefits to the biological populations.

The mine experienced considerable difficulty in applying the required analytical technique for mercury, the trace metal of most environmental concern. This continued through to 1989, and was a result of the technique for very low mercury being developed for analyses in fresh water rather than sea-water with its mixture of dissolved salts. The difficulties were recognized by the regulatory agency through a substantial correspondence. They reflect technical difficulties which arise in monitoring the very low contaminant concentrations which now occupy the attention of regulatory agencies.

5.5 Tailings Disposal System

Tailings were finally discharged from the dredge-mill plant through two pipes of 51 cm diameter, extending 1.5 m below the sea surface. This was the product of a major project modelling effluent dispersal from various configurations, and designed to predict that water quality parameters remained within permit limitations (Rusanowksi 1990). The project included field verification of the water quality predictions. The model also allowed environmental and operational predictions of the occurrence of excursions beyond permit requirements.

The configuration adopted generated least water turbidity either by eddy formation at the point of discharge, or by sediment scour and resuspension from impact of the descending tailings jet on the seabed. The pipe width used minimized air entrainment. The pipes were maintained to ensure consistent operation.

It should be noted, that as with STD from coastal mines, careful outfall design and location is important. Design and location can increase the coherence of the tailings slurry during its descent to the seabed, and minimize re-suspension of tailings already deposited, hence water turbidity and biological impact.

5.6 The Environmental Situation

5.6.1 Bathymetry

Bathymetry of the Nome area in Norton Sound is shown in Figure 5-4 drafted from NOAA chart No. 16200. Off Nome and throughout Norton Sound there is a wide submarine shelf undulating through 5-15 fathoms depth. Inshore the slope increases so that the five fathom depth contour is about one mile from the shoreline. The coast is exposed in all directions, and the fetch for winds is enormous in the southwest extending to the Aleutian Islands.

More detailed bathymetry based on side-scanning sonar surveys reveals the dredge footprints and subsequent smoothing of the dredge/tailings deposit surfaces (see Jewett *et al.* 1991) (Figure 5-5).

5.6.2 Post Depositional Sketches

Resuspension of tailings has not been as much an issue at WestGold as effective deposition and minimization of the tailing plume after discharge. The dredging itself creates very substantial physical disturbance, including removal of habitat and water turbidity. This is followed by discharge and settling of coarse and fine tailings fractions from the dredge, and then smoothing of the dredge footprint by wave action and resettlement of sediments (Figure 5-5).

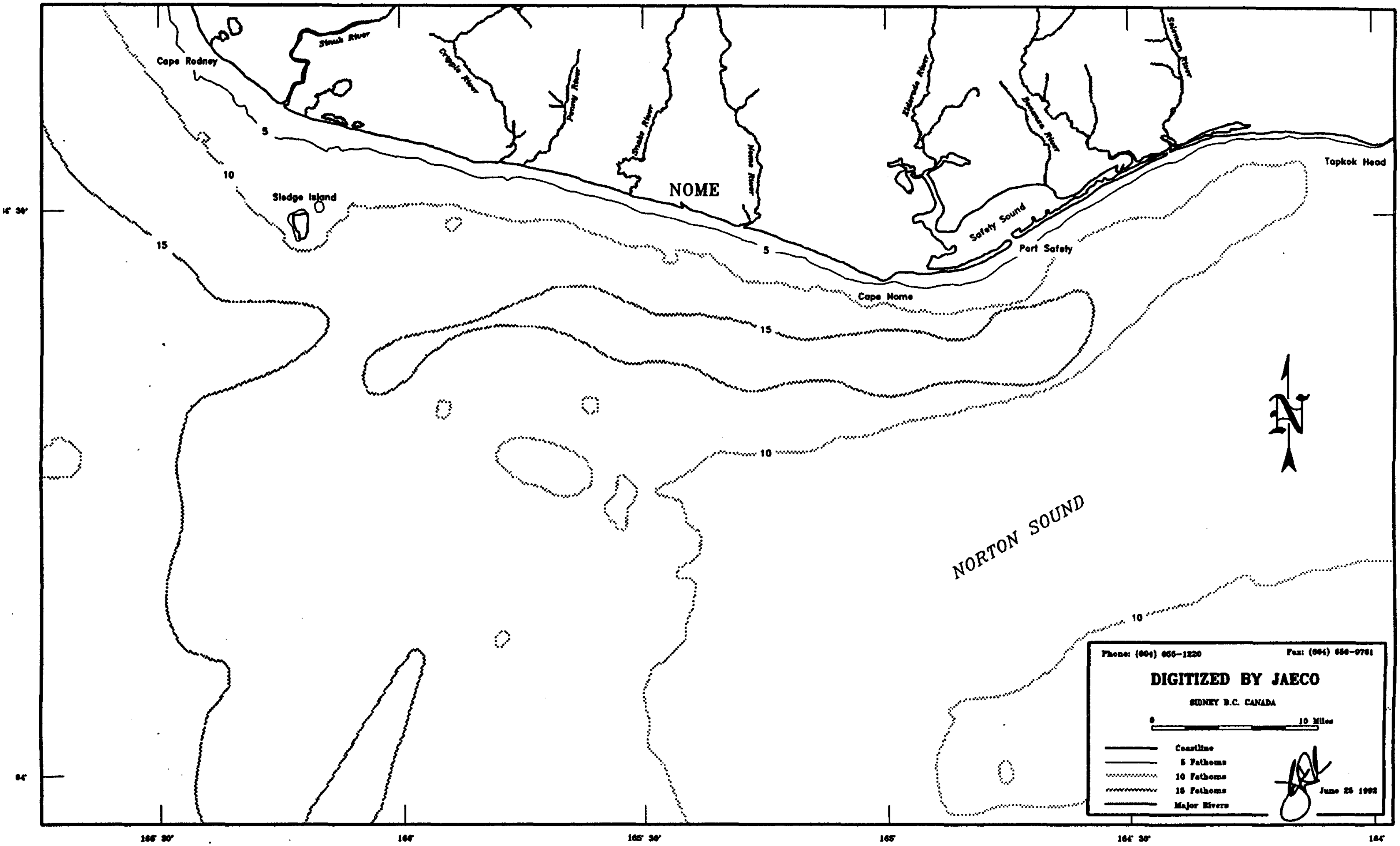
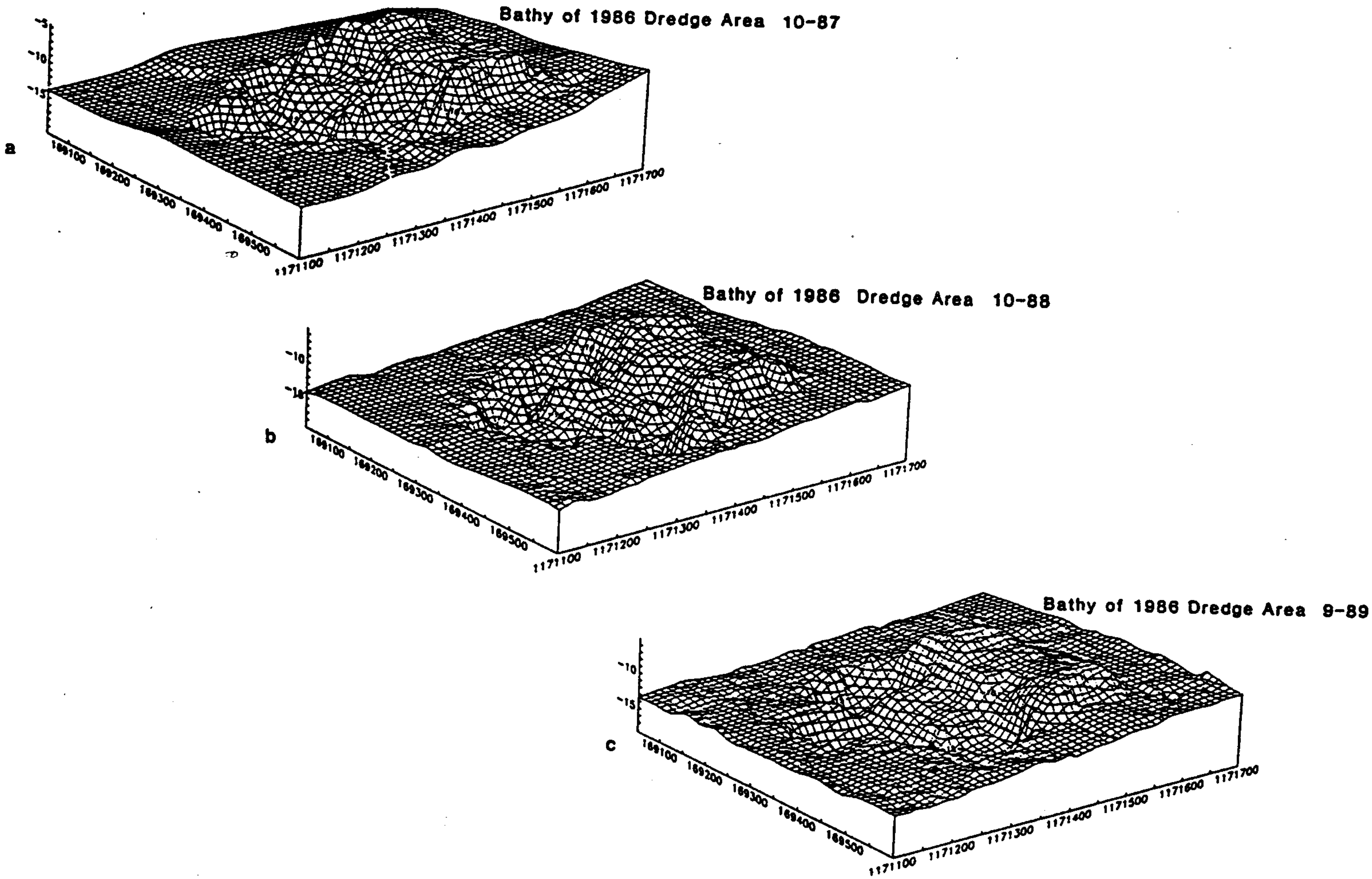


Figure 5-4 Bathymetry of Sound off Nome (from NOAA Chart No. 6200).



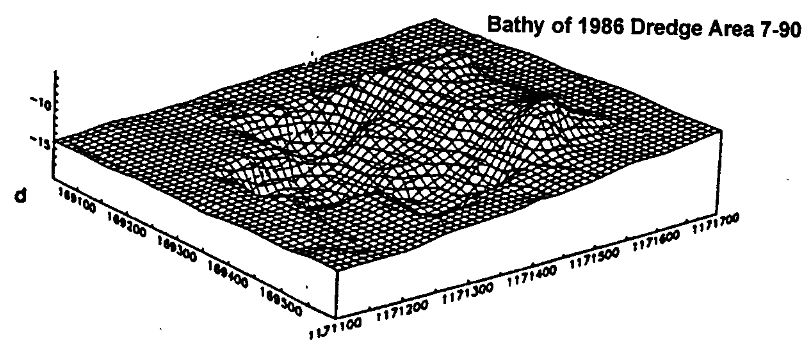


Figure 5-5

Three-dimensional representation of bathymetry of 1986 Dredge Area during (a) October 1987, (b) October 1988, (c) September 1989, (d) July 1990. The two horizontal axes (in meters) correspond to the WestGold coordinate positioning system. The vertical axis scale (in meters) is 10 times the horizontal to exaggerate relief. (Source: Jewett *et al.* 1991).

There has been a continuing concern that the dredging operations could mobilize sinks of mercury dispersed from prior beach gold mining. The concern over mercury derives from dredging operations, not tailing dispersal and resuspension.

5.6.3 Preliminary Environmental Information

Two public hearings were held in 1985 and they defined issues of local and regional concern. Norton Sound supports fisheries for cod, salmon, herring, clams, shrimp, crabs and seals. Crabs particularly might be affected by the seabed disturbance. Local residents, many of them Eskimo, had a traditional stake in local resources and were concerned about loss of resource habitat, loss of accessibility to fishing areas, and losses of stocks driven away from the area by the mining operation. A major concern was with public health from the risk of mercury release due to dredging of a seabed previously contaminated by beach gold mining. This in turn could lead to new contamination of seafoods, already suspected of bearing high mercury loadings. There was also concern for turbidity levels and its effects on fishery stocks, and on inadequate environmental knowledge such as crab stock recovery from disturbance. There was concern for fuel spills, and for a repeat of the prior exploitive history of mining in the region. After the mine was closed would the city of Nome be left to resolve any derived social problems without adequate tax benefits from the mine? During mining operations would local labour be hired, and would there be adequate local benefits?

The concerns raised by the community and the regulatory agencies were met by specific stipulations for more information about the various items based on monitoring demands specified in the permit. In addition, a Project Review Committee was formed which met quarterly with a major review in January each year to address matters raised in the draft Annual Report. The Committee included local interest groups such as the Nome Eskimo Community (The Kawerak Inc.), the Bering Straits Native Corporation, the Eskimo-Walrus Commission, the Bering Sea Fishermens' Association, the City of Nome, the Trustees for Alaska, the Bering Straits Coastal Resources Management Program, as well as local, state and federal regulatory agencies. Accordingly, there was no substantial community objection, nor any perceived fatal flaw which should stop the development as planned at the time.

5.6.4 The Monitoring Program

The one fishery species monitored in detail was the red king crab (*Paralithodes camtschatica*). It was found that crabs move locally over distances which will allow them to transfer between dredged or undredged areas. Their movements prior to dredging were apparently random. Crabs are fished from both dredged and undredged areas, with more competition by boats for fishing sites in the dredged than the undredged areas after mining started.

Feeding habits of the crabs at dredged and undredged sites appeared not to differ.

Crab monitoring was scheduled to be discontinued in 1991 due to satisfaction that the feeding studies were adequate, but also due to the technical impossibility of obtaining clearer results on crab movements relative to dredged and undredged sites.

Sandy dredged areas had recolonized at Stn. R6 (see Figure 5-3) to a community similar to that of control benthic stations at similar depths three years after mining (1989). The return of bivalve mollusks was a major part of the recovery. In 1990, there were fewer mollusks at both test and control sites, reflecting the high level of natural variability that occurs; and confounds monitoring and its interpretation.

Cobble dredged areas appeared to be recolonizing more slowly, in that four years after mining (1990) test stations were not yet similar to control stations. However, between-station variability was higher than at the sandy sites. This between-station variability complicates the recovery studies.

Jewett *et al.* (1991) report:

"The extreme physical disturbance of dredging causes significant alteration of benthic invertebrate communities."

"Recolonization of these disturbed communities appears to begin immediately after dredging stops."

"Recovery of these communities to their original structure may not occur; instead a somewhat different assemblage of the original species may result"

"Recolonization of the dredged areas with comparable density, biomass and number of taxa to control sites may require 3 to 4 years for sand substrate and 5 or more years for cobble substrate."

"Recolonized dredged areas may have altered community structure but functionally are similar to the original communities."

There has been some indication that red king crab may accumulate arsenic and nickel, and indications also that the crabs might be able to purge themselves of nickel and chromium when molting their shells. Some of the crab feed-stock species showed erratic elevations of trace metals at the test sites, and in some cases reductions. These variations illustrate the technical difficulty of reaching clear conclusions with the known variability of trace metal tissue levels. The variability is derived both from analytical procedures and biology of the species available for testing.

Specifically, there has been no evidence for contamination effects particularly from the main element of concern; mercury.

5.7 Community Involvement

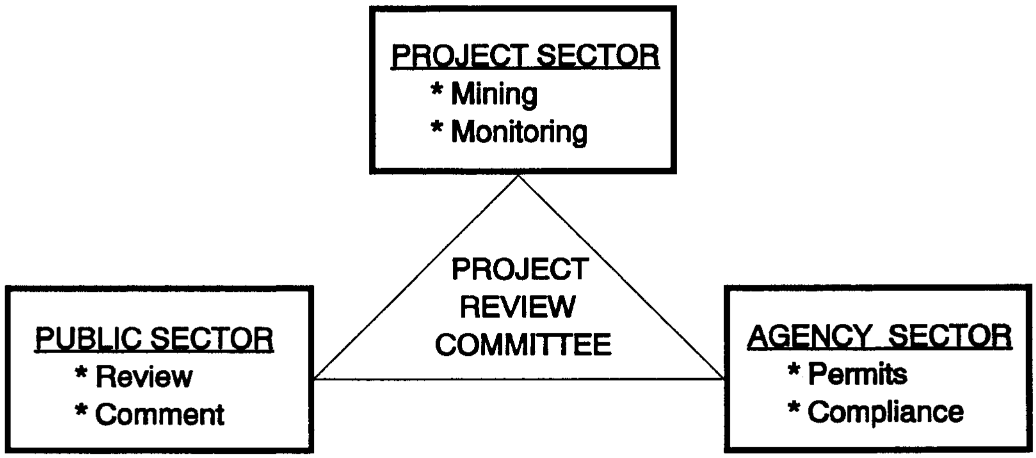
There has been very substantial community involvement in WestGold's operations ever since the initial public hearings in 1985 (Gardner 1992). Formation of a Project Review Committee formalized this involvement. The Committee, structured as shown in Table 5-4 and Figure 5-6, met quarterly. There was a major review meeting in January each year following submission of the draft annual report to the regulatory agency.

Table 5-4

Groups Represented on the Nome Offshore Placer Project Review Committee

Project Groups	Federal Agencies	State Agencies	Regional/Local Regulatory and Special Interest Groups
• WestGold	• U.S. Environmental Protection	• Department of Environmental Conservation	• None Eskimo Community
• ENSR	• U.S. Army Corps of Engineers	• Department of Fish and Game	• Kawerak, Inc.
• Engineering Hydraulics, Inc.	• U.S. Fish and Wildlife Service	• Department of Natural Resources	• Bering Straits Native Corporation
• University of Alaska Fairbanks, Institute of Marine Science	• National Marine Fisheries Service	• Division of Governmental Coordination	• Eskimo Walrus Commission
• Meacham and Associates			• Bering Sea Fishermen's Association
			• City of Nome
			• Trustees for Alaska
			• Bering Straits Coastal Resources Management Program

The meeting was organized and chaired by the mine or its environmental consultants, and provided opportunity for questions and answers. Minutes of the annual review meeting



* Information transfer.
* Forum for on-going interaction between all parties.
* Progress reports.
* Data presentation/interpretation.
* Problem solving Think Tank.
* Issue development.

(Source: Rusonowski and Gardner, 1989)

Figure 5.6 - Organization of Nome Offshore Placer Project Review Committee.

were included in the Annual Report for each year as finally distributed. Minutes of other quarterly meetings were distributed to attendees and others who were on a mailing list to receive copies.

WestGold responded to the early concerns by emphasizing and publicizing local benefits by their employment practices and training programs. Table 5-5 from Rusanowski and MacCay (1990) gives the employment statistics 1986-89 divided by local, state and out-of-state labour. Approximately $8-10 million dollars was injected in the local economy annually (Table 5-6), 42% in local wages.

Table 5-5
Employment Statistics at WestGold

WestGold Employment Statistics								
	1986		1987		1988		1989	
	(No.)	(%)	(No.)	(%)	(No.)	(%)	(No.)	(%)
Workforce (No.)	66	--	124	--	128	--	116	--
Local Hire	42	64	71	57	101	79	78	67
Alaska Hire	47	71	80	64	110	86	88	76
Out of State	19	29	44	35	18	14	28	24

Source: Rusanowski and MacCay (1990).

Table 5-6
Annual Payroll

Hourly Wages	$3,400,000
Services	$1,400,000
Office Salaries	$1,200,000
Local Vendors	$1,200,000
Local Construction Contractors	$600,000
Rents	$400,000
Miscellaneous	$100,000

Source: Rusanowski and MacCay (1990).

5.8 Conclusions

At WestGold there was an early appraisal through the medium of two public hearings during the permitting process. The mine and regulatory agencies accepted the concerns expressed. They adapted the mining plan, particularly the environmental quality control (monitoring) plans to address specifically these reasonable local concerns. From these hearings, a broadly based Project Review Committee was established. This met regularly (quarterly) with ample documentation and opportunity for discussion. The mine regarded this Committee as an essential part of good public relations.

The mining permit specified waste discharge controls and environmental impact limits for the topics of local concern. These included the effluent, the seabed and its organisms (especially the red king crab a biological resource of major importance to community), sea-water turbidity, and bioaccumulation of trace metals (especially mercury). The results of these effective controls and their monitoring were all documented annually and made publicly available.

The impact on the fishery species of most concern, the red king crab, was so negligible that monitoring was scheduled to be discontinued in 1991. Sandy dredged areas generally were recovered within three years of mining, but coarser cobble areas were still recovering four years after dredging. Tailings deposition appeared not to be a major factor compared to dredging impact.

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6.0 QUARTZ HILL MOLYBDENUM DEVELOPMENT
(by C. Hesse, D. Ellis and C. Pelletier)

6.1 Introduction

Quartz Hill was the first mine proposal in the USA for which STD was considered seriously as an option for disposal of mine wastes. The case provides details how STD was actually considered by the regulatory agencies and the public in the 1970s and 1980s, and the procedures that the mine developers followed then to answer environmental questions and attempt to obtain necessary permits.

A summary of the proposed development is given by the Abstract of the required Final Environmental Impact Statement (U.S.D.A. Forest Services 1988).

"U.S. Borax & Chemical Corporation has proposed constructing and operating a nominal 80,000 ton-per-day molybdenum mine and processing facility at the Quartz Hill site, 45 miles east of Ketchikan, Alaska....The mine development project would consist of an open pit mine, waste rock disposal areas, ore crushing and transport, a concentrator, tailings transport and disposal, employee housing and support facilities such as roads, water supply, wastewater treatment, and power supply..."

A review of the environmental actions taken by the developer, U.S. Borax, over STD is provided in Appendix A. The timing of the development is shown in Table 6-1 and the location in Alaska in Figures 1-1 and 6-1.

Table 6-1
Timing of the Quartz Hill Development

1974	U.S. Borax discovers the ore body.
1975	Environmental data-collecting started.
1977	Preliminary mine feasibility formally appraised.
1978	Mine site included in a National Monument by Presidential Action. Environmental data collecting expanded to a comprehensive EIA.
1980	Misty Fjords National Monument established by ANILCA (Alaska National Interest Lands Conservation Act), all but 152,610 acres (the Quartz Hill project site) designated a Wilderness.
1982-83	Access road permitted and built, and bulk samples removed.
1983-84	Environmental data collecting phased down.
1988	Final EIS (FEIS) completed by U.S. Department of Agriculture (U.S.D.A.) Forest Service.
1990	Permit for tailings discharge into Wilson Arm/Smeaton Bay denied by the Environmental Protection Agency (EPA).
1991	U.S. Borax sold its interests to Cominco Ltd.

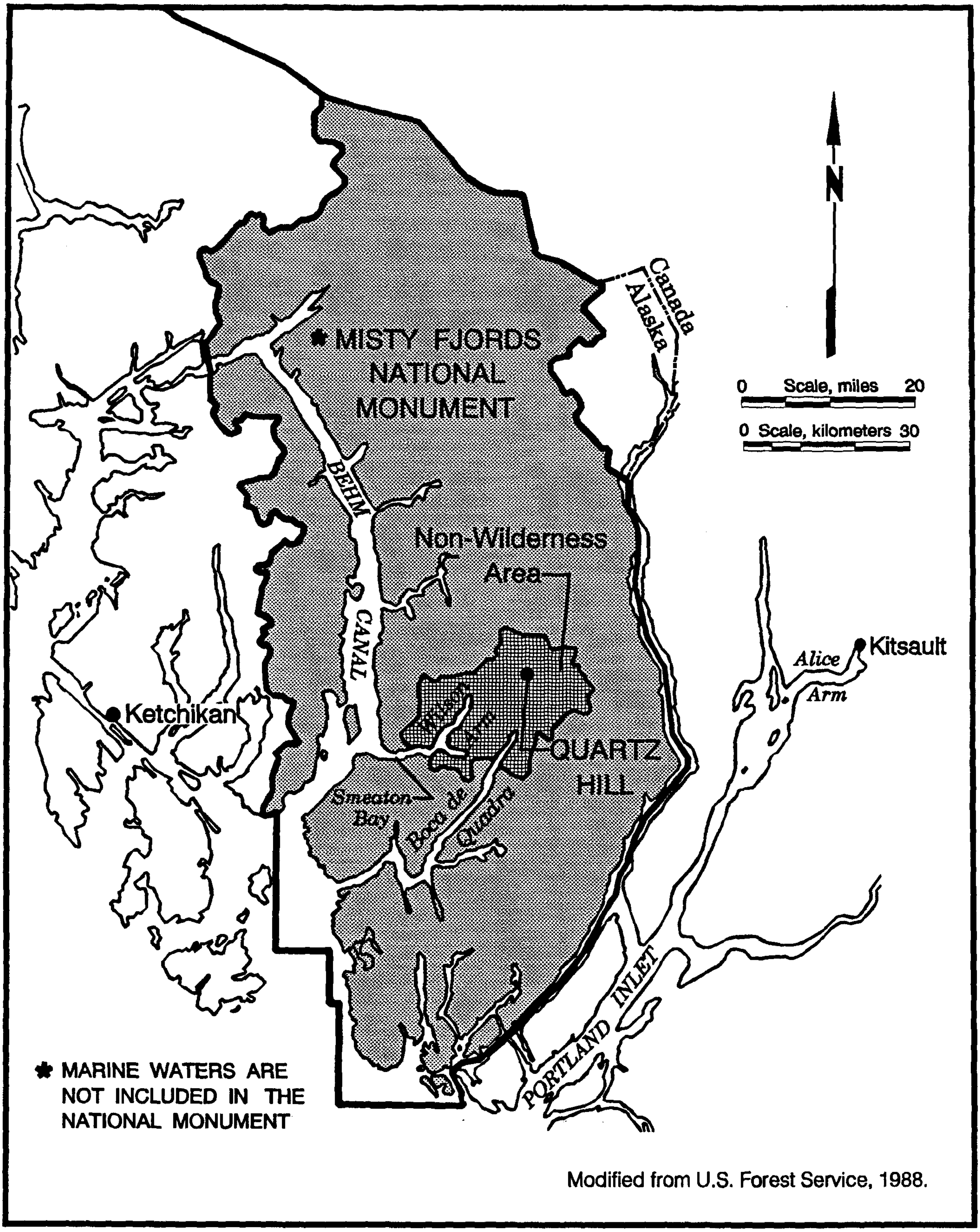

Figure 6- 1. - Location of Quartz Hill Molybdenum Deposit.

U.S. Borax discovered the ore-body in 1974. By 1976 the company had acquired property rights and announced their discovery. By 1977 the company had undertaken initial environmental data-gathering, and prepared a preliminary feasibility study. Procedures then became complex as in 1978 the area was included in a National Monument (Misty Fjords) established by a Presidential Action, and subsequently by the Alaska National Interest Lands Conservation Act (ANILCA) of 1980. However a development area of 152,610 acres surrounding the mine site was specifically excluded from the designated Wilderness Area of the National Monument. The seabed and water in fjords and channels are not part of the National Monument, but belong to the state.

By 1978 U.S. Borax had initiated extensive environmental impact assessments. The fjord Boca de Quadra was initially emphasized for STD, but the alternative Smeaton Bay/Wilson Arm was later added for detailed environmental studies.

During 1982/83 the EIAs were utilized for the permitting procedures needed for an access road. The road was to allow bulk sampling so that milling procedures could be tested, and waste discharges characterized. Legal action was taken by interest groups, and appeals lodged against formal decisions.

In 1983-84 the EIAs were phased down, and the final permitting phase initiated. The formal EIS was completed in 1988 and distributed to all persons and groups that requested a copy. Permitting deliberations and legal actions continued until 1990 when the permit was formally denied. A final appeal was considered, but was not initiated. U.S. Borax sold their interests in 1991 to Cominco Ltd., which has not taken public action since.

In 1988 the cost consequences to the developer of this 15-year unsuccessful permitting process, generated through changing property status, and environmental action, were summarized as follows (Ellis 1989):

"By 1982, U.S. Borax had spent about $60,000,000 [of an originally estimated $400,000,000 (U.S. Borax 1984)] on development (Reim 1983). About $12,000,000 were on the environmental work. By 1984 $100,000,000 had been invested with the permits not yet near (U.S. Borax 1985). About 20% of this was on the environmental work and permitting (U.S. Borax 1987). The estimate of total capital investment needed has now risen to almost 1 billion dollars (U.S. Borax 1987). The time taken for permitting has significantly added to the costs and capital projections (Reim *et al.* 1988)."

By 1990, at the time of U.S. Borax's sale of its interest, with more than $100,000,000 invested, approximately $25,000,000 was spent on the environmental work (C. Hesse, verbal communication).

Quartz Hill is thus an important case, not just for STD, but in the history of environmental management in general, and mining development particularly. Part of its importance is that it documents actions during the two decades (1970s/1980s) when environmental controls and public awareness were developing. The case clearly shows the extent of EIAs required by US controls, and to meet public concerns, of the time. More important, the case is one of the very few to show the cost consequences of the actions taken.

STD was an important part of the mine plan, and much of the environmental action was directed at the proposed STD. Details are provided in Appendix A.

6.2 Composition of the Orebody

The Quartz Hill mineral deposit is located at an altitude of 1400 to 2700 ft, about five miles east of the end of Wilson Arm fjord, and an equal distance north of the end of Boca de Quadra fjord. Although there is no close-by human habitation, the area is considered environmentally sensitive because of its location within the National Monument and because the streams flowing into the two adjacent fjords support commercially important salmon runs. The Wilson/Blossom River system is considered particularly important in this regard.

The terrain is mountainous, with steep, glacially scoured, narrow valleys. There is little flat land for siting facilities. Climate is of the typical west-coast marine type, with annual precipitation in the order of 150 inches, infrequent sunshine and little measurable net evaporation. Snowfall in the upper altitudes of the site measures 400 to 800 inches annually. The area supports some populations of waterfowl, black and brown bears, wolves, mountain goats, and beaver; however, numbers of wildlife in the area of the mineral deposit are not high.

The mineral deposit is of the porphyry type, associated with a composite quartz monzonite stock of Tertiary age. The stock was intruded approximately 27 million years ago near the contact between a metamorphic complex and the Coast Range batholith. After, emplacement, the porphyry was shattered by magmatic forces and flooded with aqueous mineralizing solutions which emplaced molybdenite (MoS_2) with accompanying quartz in an interlacing stockwork of cracks and fine veinlets. Following mineralization, the area was intruded by several series of post-mineral dikes.

After discovery in the autumn of 1974, the deposit was explored between 1975 and 1983 with the drilling of more than 268,000 ft of core holes and the driving of over 4800 ft of adit into two sectors of the deposit. This work revealed a mineralized body of about 5000 by 7000 feet in plan with a depth of about 2000 feet, consisting of over 1.1 billion tons at a cutoff grade of 0.10 percent MoS_2. If the cutoff is dropped to 0.05% MoS_2, tonnage increases to almost 1.7 billion tons.

U.S. Borax proposed to mine this massive deposit by conventional open-pit methods using high-capacity equipment such as large diesel/electric trucks and shovels. Ore was to be crushed at the minesite and transported to a mill near Wilson Arm by means of conveyors in a 21,000 ft tunnel. Proposed mill throughput was to be 35,000 tons per day initially, building up to 70,000 tpd within four to six years. Peak daily production could reach 80,000 tpd, and it was this number that was chosen as a permitting target. Since the recoverable mineral, MoS_2, would average only about 0.145% of the millfeed, peak disposal of tailings could reach 79,900 dry tons per day but would average 69,900 tpd, or about 25 million tons per year. Mine life would be about 55 years.

U.S. Borax proposed that waste material from mining would be stockpiled in the mine area adjacent to the pit. There are no plans, nor is it practicable, to dispose of waste in the marine environment. At a cutoff of 0.10% MoS_2, volume of waste mined overall would approximate one ton of waste per ton of ore mined. Tests on acid producing potential have indicated that acid producing waste rocks can be blended in the waste pile with acid consuming rocks, to prevent formation of acid drainage in the dump.

The Quartz Hill ore is relatively fresh and unaltered. The ore-bearing rocks have a very simple mineralogy and consist principally (about 93%) of quartz and feldspars (aluminum silicates of sodium, potassium and calcium). Accessory minerals include the micas and other rock-forming minerals, zircon, stilbite, fluorite, rutile, clay minerals, pyrite, magnetite, hematite, ilmenite and others. The bulk of these are insoluble and most occur in very small amounts. Sulfides of metals other than molybdenum comprise only about one percent of the total.

Table 6-2 gives an early comparison of the chemical composition of Quartz Hill ore as compared to an average igneous rock in the earth's crust. It is to be noted that Quartz Hill rocks are higher in silica and lower in copper and other heavy metals than the average igneous rock, and thus can be compared favorably to the glacial silt from ground-up crystal rocks, which is transported to the sea seasonally in high quantities by many of the rivers along the western coast of North America.

In *Marine Tailings Disposal* (Snook 1982), J. Snook of Eastern Washington University, concluded that:

"...the ore rock is quite uniform in both its physical and chemical properties, which simplifies the predictability of waste materials and metal recovery. The ore lacks significant amounts of objectionable elements, which should eliminate most environmental concerns. It is evident from these facts that most of the problems involving tailings disposal will be concerned with the grain size and volume of the tailings to be handled."

Obviously, the chemical properties, soluble components and content of objectionable elements are important considerations in the determination of the suitability of STD in any given situation.

For comparative purposes Table 6-3 gives similar data obtained at a later time.

Table 6-2

Comparative Oxide and Elemental Percentages for Quartz Hill and "Average" Igneous Rock

	Quartz Hill	Igneous Rock
SiO_2	78.08	59.14
$A1_2O_3$	11.52	15.34
Fe_2O_3	0.29	3.08
FeO	0.59	3.80
MgO	0.24	3.49
CaO	0.39	5.08
Na_2	2.98	3.84
K_2O	5.09	3.13
Cu	0.018	0.003
W	0.0003	0.0002
Pb	0.001	0.002
Zn	0.0005 - 0.002	0.0065 - 0.0094
Sn	0.005	--
Au	0.00002	--
Ag	0.00002	--
Mo	0.15	0.0001

Source: Snook (1982).

6.3 Mineral Processing

After consideration of several possible millsites, the preferred location for the concentrator for processing the ore was selected to be on the north side of Tunnel Creek valley, on a 210 acre site about one mile east of the upper end of Wilson Arm. With crushing of the ore done at the mine, the site would include processing facilities for grinding, flotation, filtration and concentrate shipment, as well as thickeners for preparing the tailings slurry for transport to the tailings disposal site. A power plant, offices and camp for housing personnel would also be located there.

Figure 6-2 shows locations of project facilities for the development option designated as the Preferred Alternative in the Final EIS: Tunnel Creek concentrator site and STD in Wilson Arm. If the Boca de Quadra alternative were eventually selected and permitted for STD, tailings would be transported through a tunnel commencing at the south side of Tunnel Creek valley and exiting near tidewater at either the Middle or Inner Basin of Boca de Quadra.

Table 6-3
Ore Characterization

Component	Weight Percent[1]	Component	Weight Percent[1]
Chemical Balance		**Mineral Balance**	
Silicon dioxide (SiO_2)	76.92	Quartz	39.99
Aluminum oxide (Al_2O_3)	11.6	Feldspar (total)	52.62
Iron (total) (Fe)	1.69	Biotite	2.51
Magnesium oxide	0.96	Chlorite	2.51
Calcium oxide (CaO)	0.90	Amphibole	0.56
Sodium oxide (Na_2O)	3.15	Molybdenite (MoS_2)	0.362
Potassium oxide (K_2O)	4.56	Molybdite	0.001
Molybdenum (total) (Mo)	0.217	Pyrite[2] (FeS_2)	0.88
Molybdenum (oxides) (Mo_x)	0.001	Chalcopyrite ($CuFeS_2$)	0.026
Copper (Cu)	0.009	Galena	0.007
Lead (Pb)	0.006	Sphalerite (ZnS)	0.006
Zinc (Zn)	0.004	Magnetite[3]	0.91
Sulfur (S)	0.63	Calcite	1.18
Zirconium dioxide (ZrO_2)	0.01	Zircon	0.02
Carbon dioxide (CO_2)	0.52	Garnet[4]	Tr.
		Apatite[4]	Tr.
		Sphene[4]	Tr.
		Rutile[4]	Tr.
		Ilmenite[4]	Tr.
	101.18		101.57[5]

1/ These data are from the mini pilot plant circuit 6/23/83.
2/ Includes minor pyrrhotite (Fe_7S_8).
3/ Include hematite.
4/ Trace minerals not included in balance calculation.
5/ Balance has 0.44 percent excess Al_2O_3.

Source: U.S. Borax (1983b), in U.S.D.A. Forest Service (1988).

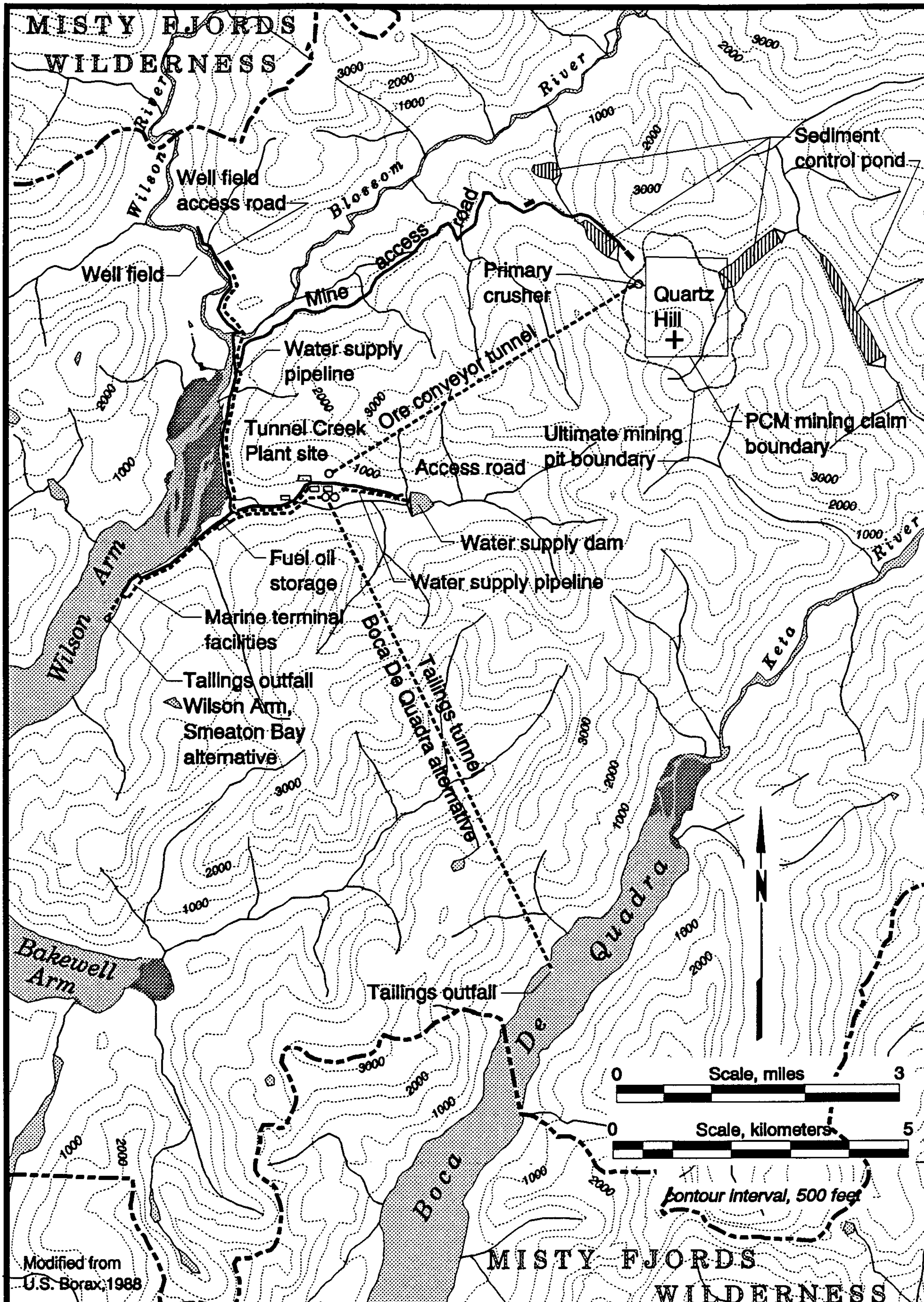

Figure 6.2 - Location of Facilities for Tunnel Creek Mill with Wilson Arm Tailings Disposal Alternative.

Figure 6-3 shows a block diagram of the concentrating process. At the concentrator, crushed ore from the mine at minus 8" would be received into a coarse ore stockpile from the ore conveyor in the tunnel from the mine. Initially, this would be ground with added water in a single semi-autogenous (SAG) grinding mill, operating in closed circuit with screens and a ballmill. It is anticipated that the initial design capacity of 35,000 dry tons per day would be doubled within the first five years of startup by adding a second identical line. Peak production at full capacity for short periods of time could reach 80,000 tpd.

The slurry of ground ore and water, at a solids fineness of about 80 percent minus 100 mesh, would then be passed to a series of flotation cells, where small amounts of reagents are added and air is bubbled through the mixture to promote frothing. The reagents added are frothers, collectors to promote adherence of the molybdenite to the air bubbles, and depressants to decrease the tendency of unwanted minerals to adhere to the air bubbles. The minor amounts of copper minerals present would be among those depressed, to improve the quality of the concentrate. The molybdenite-laden froth would be skimmed off the top of the cells and the waste material (or tailings) drawn from the bottom. In order to improve recovery and produce a high grade concentrate, the flotation process at Quartz Hill would be done in as many as ten stages, with regrind steps in between some of them.

The molybdenite concentrate, bearing most of the mill reagents, would be thickened and filtered to about 8 to 10% moisture. Recovered water would be recycled through the process. The concentrate would then be packaged and stored for shipment by barge to a refinery located elsewhere.

The tailings, or unwanted materials from the flotation separation process, would be thickened in large tanks to about 50% solids. Clear water overflow from the thickeners would be recycled through the plant. The thickened tailings slurry would then be directed to the tailings transport system to the disposal site, after the addition of other waste streams described in Subsection 6.4.1.

A description of the tailings transport systems to the alternative STD sites is given in Section 6.5.1.

6.4 Waste Discharge Characteristics

In 1983, representative samples of Quartz Hill ore types were removed from two adits driven into two separate locations on the orebody. The samples included all rock types that would appear in the millfeed and totaled about 4800 tons.

Pilot plant milling tests were conducted on composites of these samples by Hanna Mining Company's Research Center in Minnesota between September 1983 and February 1984, using methods that would model as closely as possible the actual processes and equipment types to be used in the prototype plant on site. The objectives of the pilot

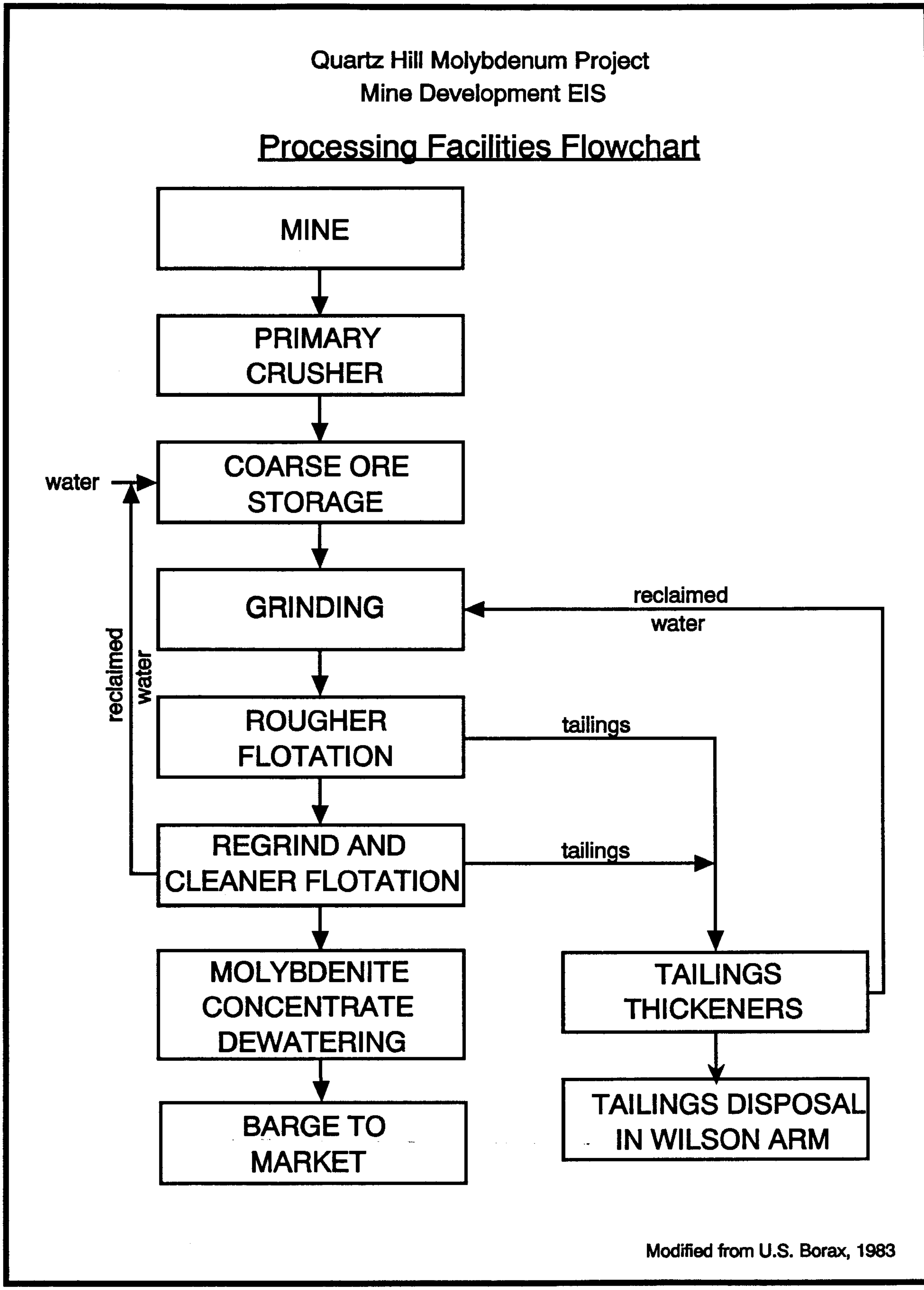

Figure 6.3 - Processing Facilities Flowchart.

plant tests included: (a) to obtain detail design information, (b) to establish the percent recovery (or adversely, the process losses), (c) to establish the optimum types of milling reagents and quantities to be used, (d) to characterize liquid and solid components of the tailings, (e) to obtain other technical and economic information needed for the project feasibility study and (f) to obtain representative samples of tailings for further study.

Much of the process information in the Final EIS (U.S.D.A. Forest Service 1988) was established during the pilot plant phase. Table 6-4, from the FEIS, shows the mill reagents usage established during the tests. Tables 6-5, 6-6 and 6-7 show, respectively, the characterizations of the tailings liquid phase, the solid phase, and the minor elements in the solid phase.

Table 6-4

Mill Reagent Use

Reagent[1]	Purpose	Usage[2] (lb/ton)	Usage (lb/day) for 80,000 ton/day
Lime	pH modifier	0.134	10,720
Sodium Silicate	gangue dispersant	0.063	5,040
Dowfroth 250[1]	frother	0.003	240
Methyl Isobutyl Carbinor (MIBC)	frother	0.088	7,040
Stepanfloat 85-L[2]	frother/dispersant for the collector	0.011	880
No. 2 Diesel Fuel Oil	molybdenite collector	0.634	50,720
Nokes Reagent[3]	depressant for Cu, Pb, Fe	0.054	4,320
M-502[4]	flocculant	0.199	15,920
Aerodri 100[5]	surfactant	0.0002	16

1/ During the pilot plant operations several reagents were tested to find suitable alternatives. It was found that MG700 could be replaced by M502 or SF330 (a cationic polyamine). Sodium silicate could be partially replaced by CMC-7 (carboxyl methyl cellulose). Dowfroth 250 could be replaced by ALFOL 6 (alcohol).
2/ From Bulk Sample Pilot Plant flotation testing from October 24 to 27, 1983. Based on fifty checks of reagent addition rates.
3/ Polypropylene methyl ether (Ch_3-$(O$-$C_3H_6)_x$-OH).
4/ Sodium fatty alcohol ether sulfate in alcohol-water solution.
5/ 43.5 percent phosphorus pentasulfide and 56.5 percent NaOH.

Source: U.S. Borax (1984a), in U.S.D.A. Forest Service (1988).

The potential toxicity of milling reagents was, needless to say, of concern. The reagents proposed are all typical of those used in other molybdenum concentrators and are similar

Table 6-5
Preliminary Tailings Thickener Effluent Characterization
Liquid Phase

Parameter[1]	Approximate Concentration (in Micrograms per Litre Unless Otherwise Noted)
pH (standard units)[2]	8.7
Temperature (F)[3]	51
Total dissolved solids mg/L[4]	160
Conductivity (mho/cm)[5]	256
Dissolved oxygen (mg/L)[5]	7
Total organic carbon (mg/L)[5,6]	13
Arsenic[7]	6.8
Cadmium[7]	15
Chromium[7]	34
Copper[7]	35
Iron[7]	1790
Lead[7]	120
Manganese[7]	330
Mercury[7]	1.2
Molybdenum[7] 1080	--
Nickel[7]	290
Selenium[7]	6.6
Silver[7]	7
Zinc[7]	77

1/ Prior to transport and mixing with seawater.
2/ pH value is from Bulk Sample Pilot Plant testing without lime addition (hourly tests for four days).
3/ Temperature is an engineering estimate of the tailings before mixing with seawater.
4/ Total dissolved solids was calculated from conductivity, based on 16 analyses of conductivity.
5/ Conductivity, dissolved oxygen, and total organic carbon values are from Bulk Sample Pilot Plant testing from October 24-27, 1983, dissolved oxygen based on 16 analyses.
6/ Total organic carbon is the parameter which indicates the amount of residual reagents. Value based on three analyses.
7/ From analyses of the tailings samples from Bulk Sample Pilot Plant Flotation testing from October 24 to 27, 1983. Number of samples for each parameter are As (32), Cd (32), Cr (29), Cu (53), Fe (17), Pb (32), Hg (32), Mo (32), Mn (19), Ni (32), Ag (32), Ni (32).

Note: The concentrator would produce about 3,780 tph (80,000 tpd) of solids and 3,700 tph of water from thickener underflow. No further treatment of this stream is planned after possible pH adjustment and flocculation. This characterization does not include washdown water, power plant wastewater, adit drainage water, runoff or others.

Source: U.S. Borax (1984a) with modifications by Stine (1984) and U.S. Borax (1984d) in U.S.D.A. Forest Service (1988).

Table 6-6
Preliminary Tailings Thickener Effluent Characterization
Solid Phase

Component	Tailings Concentration Weight Percent [1]
Chemical Balance	
Silicon dioxide (SiO_2)	77.0
Aluminum oxide ($A1_2O_3$)	11.4
Iron (total) (Fe)	1.2
Magnesium oxide (MgO)	0.3
Calcium oxide (Ca_2O)	0.5
Sodium oxide (Na_2O)	3.2
Potassium oxide (K_2O)	5.0
Carbon dioxide (CO_2)	0.4
Others [TiO_2 (titanium dioxide), P_2O_5 (phosphorus pentoxide), MnO_2 (manganese dioxide), and H_2O (water)]	0.5
Mineral Balance	**100.0**
Quartz	34
Feldspar (total)	60
Biotite	2
Chlorite	1
Molybdenite	0.02
Pyrite	1
Magnetite	0.7
Calcite	0.8
Others	0.48
	100.00

1/ Typical weight percents are from mine whole rock analyses and these mineralogical/chemical analyses of tailings samples.

Source: U.S. Borax (1984a) with modifications by Stine (1984), in U.S.D.A. Forest Service (1988).

Table 6-7

Concentration Tailings Characterization

Solid Phase, Minor Elements

Element	Concentration[1] (ppm)
Arsenic	10.9
Cadmium	2.4
Chromium	10
Copper	69
Lead	47
Mercury	0.05
Molybdenum	120
Manganese	462
Nickel	17.7
Selenium	0.10
Silver	0.13
Zinc	46

1/ From analysis of the tailings samples form Bulk Sample Pilot Plant flotation testing from October 24-27, 1983. Concentrations are based on one 24-hour composite analysis, ten one-hour composite analyses, and about four grab sample analyses.

Source: U.S. Borax (1984d), in U.S.D.A. Forest Service (1988).

to those employed at Island Copper Mines and the Kitsault Molybdenum Mine (see Chapters 3 and 4), both of which used STD. Thus, it could be said that the reagent types had been tested under field conditions. Most of the reagent quantities are removed with the concentrate and do not reach the tailings stream.

Nonetheless, the tailings from the pilot plant were tested for biological toxicity by means of acute, chronic and sublethal bioassays and bioaccumulation studies performed in 1984 by E.V.S. Consultants in North Vancouver (Mitchell *et al.* 1984). The following marine species and life history stages were used:

- crab (*Cancer magister*) zoea and juveniles
- mussel (*Mytilus edulis*) eggs, larvae and adults
- amphipod (*Rhepoxynius abronius*) adults
- clam (*Macoma balthica*) adults
- flatfish (*Citharichthys stigmaeus*) juveniles
- algae (*Dunaliella tertiolecta*)

Sublethal bioassays included growth of crab zoea and algae; development of crab zoea and mussel eggs and larvae; and, burrowing behavior of clams. Acute toxicity bioassays utilized mussel larvae, amphipods and crab zoea. Bioaccumulation tests utilized juvenile crabs, adult clams and juvenile flatfish.

The report by E.V.S. dated December 1984, stated the results to be as follows:

"The bioassay results confirmed the low acute toxic nature of the Quartz Hill mine tailings to be in the range of 86,000 - 197,000 mg/L (range of LC_{50} and EC_{50} values). Sublethal tailings concentrations of 7,500, 2,400 and 750 mg/L did not affect growth and development of crab zoea over a 30 d exposure period. The data suggested a trend to less successful development with increasing the low numbers of surviving larvae. Further, the tailings had no demonstrable effect on clam burrowing behavior during a 16 week exposure period. Quartz Hill mine tailings did not contribute to bioaccumulation of any metals in fish, clams or crabs over a 4 month exposure period.

The acute lethal toxicity of manganese and molybdenum was additive, and mussel larvae 48-h LC_{50}'s for manganese and molybdenum, singly or in combination, showed that these metals could account for only a very small proportion of the tailings toxicity. It is therefore probable that the observed low toxicity of Quartz Hill mine tailings is the result of a mass interaction of a number of constituents. The inability of the tailings to induce inhibitory sublethal effects is important for the assessment of long-term environmental impact, and shows that representative species and life history stages can survive, grow, and actively burrow in a mine tailings environment. The results of the sublethal bioassays confirm determinations from acute toxicity tests that Quartz Hill mine tailings have a relatively low toxicity."

6.4.1 Other Waste Discharges

Miscellaneous waste streams that would be added to the tailings slurry for disposal by STD include treated sewage washdown and runoff from the process plant, wharf and camp areas. The volume of effluent from the sewage treatment plant handling the process plant and camp was estimated at 85 gpm.

Volume of plant site runoff would, of course, depend on the rainfall pattern. Annual precipitation varies widely and for the years measured, averaged somewhat less than 150 inches per year. Plant runoff would be collected in a sedimentation pond prior to discharge, where treatment could be applied if necessary.

6.4.2 Discharge Controls Applicable

The tailings discharge would be required to meet conditions established by the National Pollutant Discharge Elimination System (NPDES) permit, issued under authority of the Clean Water Act by the Environmental Protection Agency (EPA). A determination by the State of Alaska of consistency with the standards of the Alaska Coastal Zone Management Act of 1977 is also required.

As previously mentioned, the NPDES permit was never finalized, but draft permits were issued at various times for both fjords; for Boca de Quadra in August 1984, and for Wilson Arm/Smeaton Bay in November 1988. These detailed the principle permit requirements, the foremost of which was that Alaska Water Quality Standards be met in the uppermost 100 meters of the water column, regarded by EPA as the depth of the productive zone which must be protected.

Of particular concern were the risks of suspended solids and the levels of dissolved copper. Containment in one fjord of all of the tailings from mining of the entire orebody presently identified, was also considered important. The draft NPDES permits contained provisions for monitoring the tailings deposition, water quality and biota to ensure that permit standards were being met and to provide early warning of developing conditions which might need correction.

The State, for its part, had concerns about the predictability of the tailings deposition and environmental effects, but in July 1987, agreed to support STD in Wilson Arm/Smeaton Bay subject to submission of a suitable monitoring program to detect any divergence from predictions or violations of water quality standards, and a contingency plan on what could be done to make corrections if the monitoring plan were to show that tailings deposition and environmental effects were varying significantly from the predictions in the EIS. Drafts of both plans were submitted to the State and EPA by U.S. Borax.

The EPA permit can be issued for a maximum period of five years. Thus, the permit would have to be renewed an additional ten times over the anticipated 55 year mine life. Each renewal would be based on the previous operating history and a review of permit compliance history and annual operating reports. EPA would have the regulatory power to enforce permit compliance during the life of the permit, and to deny renewal at the end of each permit period unless the operator could show that permit conditions would be met. The FEIS (U.S.D.A. Forest Service 1988) states:

"Depending on the results of the monitoring program, the permit for tailings disposal may be modified or even terminated if necessary prior to the completion of the design life of the project."

In addition, under provisions of ANILCA, the Secretary of Agriculture is empowered to order temporary suspension of any activity which he finds constitutes:

"...a threat of irreparable harm to anadromous fish, or other food fish populations or their habitat" (Public Law).

The Secretary's interests would be overseen by a Resource Advisory Group supervised by the Forest Service and constituted from regulatory and scientific personnel from the various State and Federal Agencies having a regulatory interest in the project together with representatives of the local communities.

These would be the principle regulatory controls over the STD operation.

6.5 The Tailing Disposal System

Because of the mountainous terrain, the paucity of suitable land sites and the high rainfall, STD seemed to project planners an attractive option from the start. This perception was encouraged by the apparently successful years of experience with STD at the Island Copper Mine in a comparable situation.

Discharge of mill tailings to a marine environment requires a NPDES permit in accordance with the Clean Water Act, issued by the EPA. New Source Performance Standards (NSPS) associated with the Clean Water Act require "new sources" to adhere to a zero discharge guideline; however, U.S. Borax applied for exclusion from this regulation on the grounds that it would be impossible due to excessive runoff. EPA granted this exemption on December 3, 1982, with the understanding that effluent limitations and permit conditions would be developed through the environmental reviews and permitting processes to come. EPA's review was conducted using the Ocean Discharge Criteria as a means to perform an environmental evaluation of estuarine and marine impacts using Best Professional Judgment (BPJ) (U.S.D.A. Forest Service 1998a).

An objective review of all tailings disposal modes was done by U.S. Borax in order to select the preferred alternative (U.S. Borax 1983) Consideration of all alternatives is required under Council of Environmental Quality rules governing preparation of an Environmental Impact Statement. The tailings disposal options including both land disposal and STD, were evaluated from the viewpoints of several different options for a mill site.

No land site within a reasonable distance of the possible mill sites was found which could store significantly more than about one-half of the expected tailings volume over the projected mine life. Thus, for land disposal, the use of two stream valleys would be required. Two rock-fill dams with eventual heights of 1000 ft and 780 ft would be needed, and 2700 acres of forest habitat would eventually be inundated. This option would also preclude use of one of the valleys as a mill site, which would eliminate the preferred site. Compliance with the "New Source" NPDES zero discharge limitation, which in Quartz Hill's case was a goal rather than a necessity, was judged infeasible because of the high volumes of natural runoff (U.S.D.A. Forest Service 1988). The relative risk of environmental damage from dam failure was also considered. Temporary land disposal with eventual backfill into the pit was eliminated as a viable option because of the shape of the Quartz Hill deposit, which would require that all sections of the pit be kept active until mining was virtually completed.

For these and other reasons including economics, land disposal for the Quartz Hill tailings was judged to be less desirable, from environmental, socioeconomic and economic points of view, than STD.

The STD options included ocean disposal by barge, as well as deposition in the nearby fjords, Wilson Arm/Smeaton Bay and Boca de Quadra. Ocean disposal was eliminated quickly because of engineering and operating problems and prohibitively high cost. This left, as the prime tailings disposal option, STD into one of the two fjords. Investigations concentrated on Boca de Quadra initially, but when later information indicated Wilson Arm/Smeaton Bay was a viable possibility, investigations there were brought up to a comparable level.

The choice between Wilson Arm/Smeaton Bay and Boca de Quadra has still not been resolved at the time of this writing. In the Final Environmental Impact Statement for the project issued in November 1988, it was stated that because of differing interpretations of the data, the Forest Service and EPA:

"...reached different conclusions regarding the preferred tailings disposal alternative: the Forest Service preferred Wilson Arm/Smeaton Bay, while the EPA preferred Boca de Quadra. Both agencies have reached agreement in this EIS that the risks of exceeding water quality criteria and the risks to marine life in either fjord are sufficiently small that tailings disposal can be permitted at either location."

The Forest Service agreed that there would be a slightly higher risk of adverse consequences to the marine environment by disposal in Wilson Arm/Smeaton Bay, but chose that fjord as the overall environmentally preferred alternative for socioeconomic reasons and because of lesser impacts to the Misty Fjords Wilderness.

Nevertheless, in June 1990 the EPA denied U.S. Borax's application for an NPDES permit for STD in Wilson Arm/Smeaton Bay, citing relatively greater risks of exceedance of water quality standards from dissolved copper and suspended solids in the upper 100 meters of the fjord. The question of the acceptability of Boca de Quadra was left open.

6.5.1 The Tailings Transport System

For the Wilson Arm/Smeaton Bay STD option, tailings would be transported to the outfall in Wilson Arm by two pipelines. The tailings slurry, consisting of 40 to 50% solids mixed with water from the processing plant, would flow from the two 400 ft diameter tailings thickeners by gravity, through control valves and to the mixing chamber at the edge of Wilson Arm, a distance of about 17,000 ft. Annual volume of solids discharged at full plant capacity would be about 25 million tons, with a daily peak of about 79,900 tons. Figure 6-4 indicates the route of the tailings pipeline to Wilson Arm.

The topography of Tunnel Creek valley provides a generally uniform slope from the mill elevation at about 500 ft elevation to tidewater. The tailings pipelines would consist of

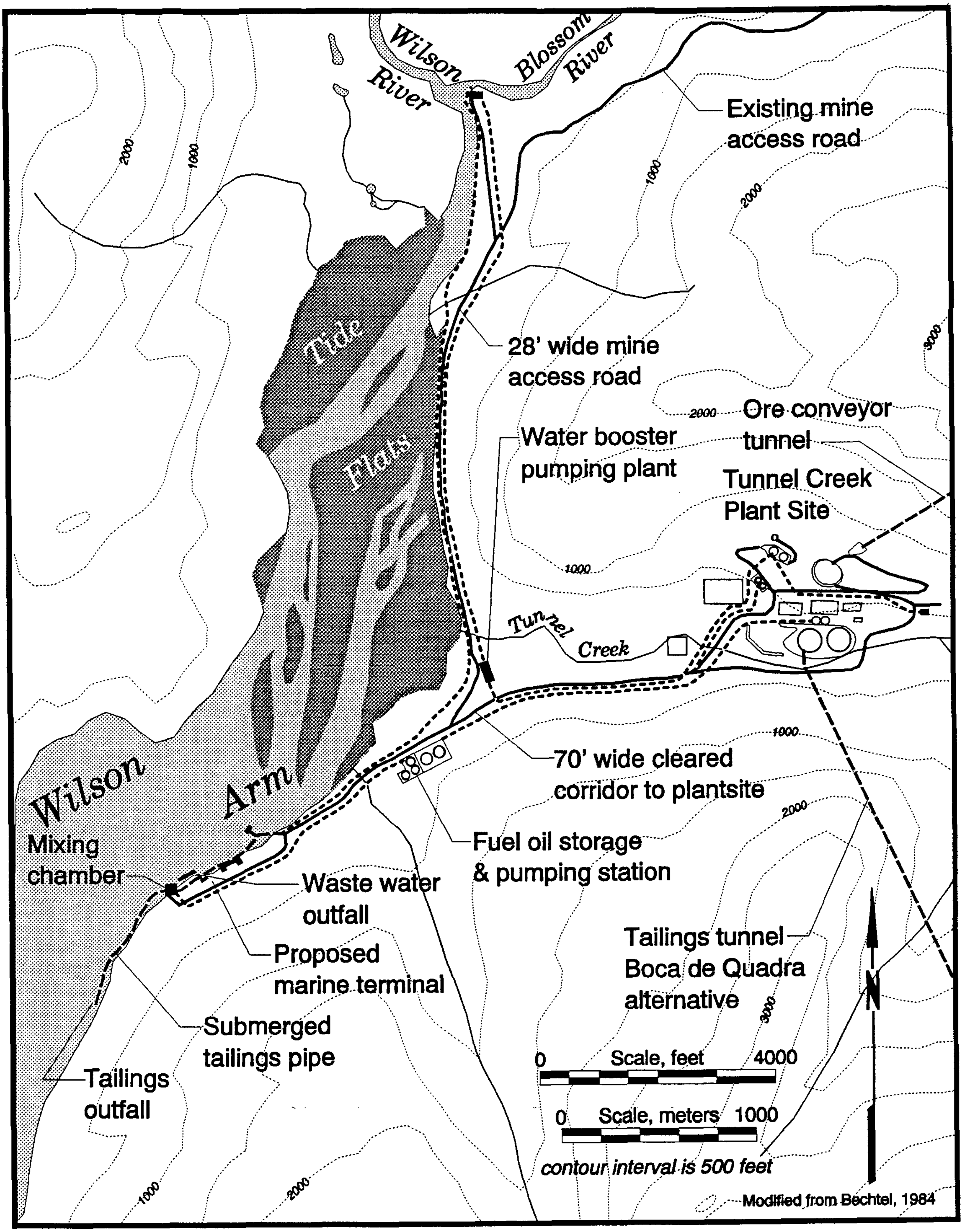

Figure 6.4 - Tailings Pipeline to Wilson Arm.

two 24" diameter high-density polyethylene pipes with couplings which would permit rotating individual pipe lengths periodically to equalize wear. At intervals along the line and particularly in areas of steeper slopes, "drop boxes" would be located to dissipate head and relieve internal pressure within the lines.

The pipes would be mounted on sleepers on a bench or berm cut into the uphill slope beside the access road on the south side of Tunnel Creek. The pipelines would be separated from the road surface by a six foot wide ditch leading to a retention pond in the wharf area. This would be designed to catch any spills from pipeline leaks. In addition the pipeline would be instrumented with pressure sensitive spill detection equipment which would close off the valves at the thickeners automatically in the event of a major leak. Figure 6-5 shows the pipeline arrangement with respect to the road. Any sections of the pipe which could not be guarded by a spill ditch would be enclosed in larger pipes.

About 3000 ft beyond the wharf, the tailings pipelines would lead into a 20 ft diameter vertical mixing chamber, set just off the shoreline of Wilson Arm, with its bottom about 35 ft below Mean Low Water (MLW) elevation. Figure 6-6 illustrates this arrangement.

The purpose of this chamber is to eliminate by means of baffles any air entrained in the tailings slurry and to mix the slurry with seawater in adjustable ratios of 1:1 to 1:4 (tailings:seawater). The seawater adjusts the specific gravity of the slurry to closer to that of seawater, which minimizes the possibility of a gravity separation between the fresh water carrier and the seawater host upon slurry discharge. This in turn promotes keeping the tailings stream down adjacent to the fjord bottom. The mixing chamber has a seawater intake pipe or ports equipped with screens to prevent entrainment of fish.

From the bottom of the mixing chamber, the tailings slurry/seawater mixture would be transported to the actual outfall point by means of a 48" diameter high-density polyethylene pipe pointing down-fjord, the end of which would be anchored to the steeply sloping fjord bottom. Depth of the outfall would be at least 150 ft.

The tailings slurry would have a pH range of 8 to 9, with a probable range of 8.5 to 9.0. Temperature would vary somewhat seasonally within the range of 48°F to 60°F. Size distribution is shown in Table 6-8. As previously mentioned, the tailings slurry would contain added waste streams consisting of washdown, drainage and treated sanitary sewage from the plant and wharf areas, but the volume would be negligible compared to the slurry volume. In addition to a minor portion of the mill reagents (the major portion goes with the concentrate), the tailings slurry could contain some quantities of lime added for pH adjustment, and minor amounts of polyacrylamide flocculating agents added to improve settling characteristics. Deposited density of the tailings in the fjord bottom would average 100 lbs/cubic foot, according to density tests conducted on the pilot plant tailings by the University of British Columbia (Rescan 1983).

For the *Boca de Quadra* STD option, the characteristics of the tailings, the discharge rates and the preferred plant-site in Tunnel Creek valley, as previously described, would remain the same. However, the tailings would have to be pumped from pump intakes at

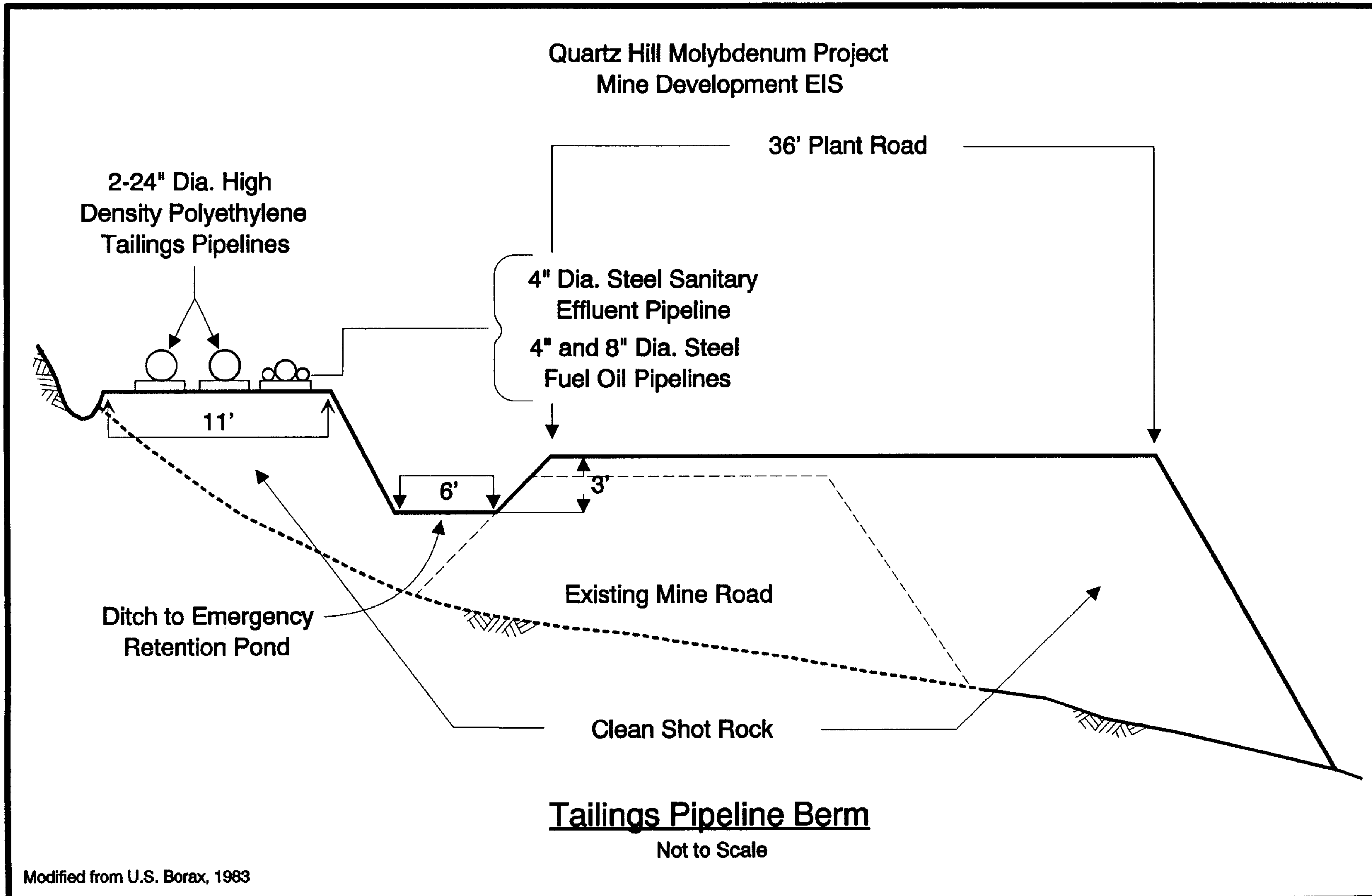

Figure 6.5 - Tailings Pipeline Berm.

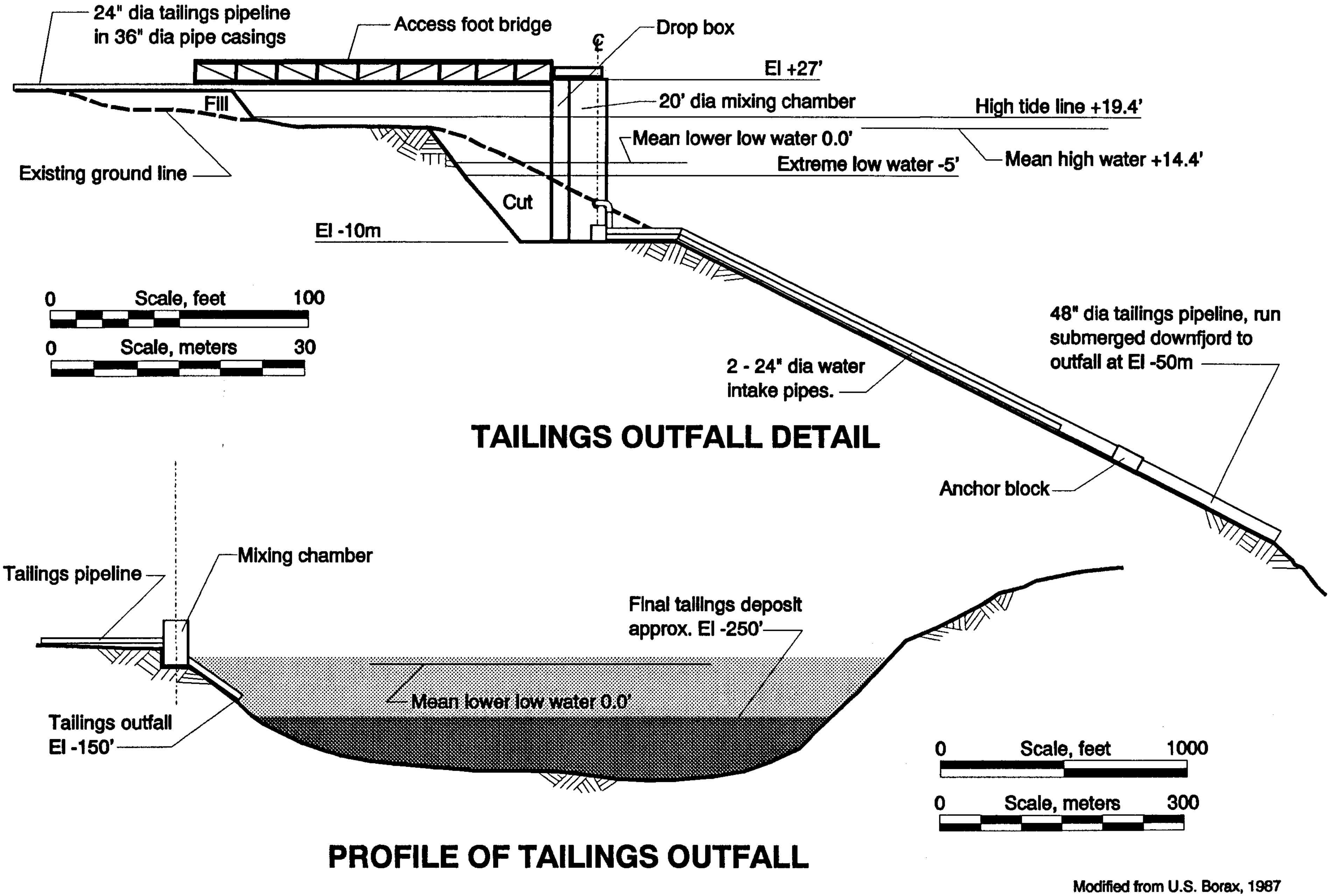

Figure 6.6 - Tailings disposal mixing.

Table 6-8
Concentrator Effluent
Tailings Particle Size Distribution

Upper Limits Microns	U.S. Standard Sieve Equivalent No.	Weight Percent Passing [1]
595	28	98.8
297	48	95.1
210	65	90.0
149	100	80.9
105	150	69.4
74	200	53.0
53	270	46.3
44	325	42.4
37	400	38.9
30	---	35.2
25	---	32.4
20	---	28.5
15	---	23.4
10	---	18.0
5	---	10.7

1/ From analysis of samples from the Bulk Sample Pilot Plant grinding tests on October 14, 15, and 18, November 30, December 1 and 19, 1983 (six tests). The grinding target for the concentrator is 20 percent plus 100 mesh (149 microns).

Source: U.S. Borax (1984a), in U.S.D.A. Forest Service (1988).

the bottom of the thickeners to the portal of a tunnel located on the south slope of Tunnel Creek valley at an elevation about 45 to 135 feet higher than the thickeners. From here, the tunnel would slope gradually to a point near tidewater at Boca de Quadra, so that the tailings could flow by gravity in a launder in the tunnel from the plant-side portal to the mixing chamber.

Since the final discharge location has not yet been chosen, the tunnel alignment and length is at present undetermined. The Final EIS describes two possible tailings disposal sub-options in Boca de Quadra; one discharging into the Inner Basin with eventual gravity overflow of the tailings on the fjord bottom to the Middle Basin, and the other discharging directly to the Middle Basin. Figure 6-7 shows the probable tunnel alignment for discharge to the Inner Basin. For Middle Basin discharge, the tunnel would exit at a point about one-half mile south of the sill.

For Inner Basin discharge, the tunnel length would be 28,000 feet and for Middle Basin discharge about 44,000 feet. The tunnels in both cases would have a cross section of

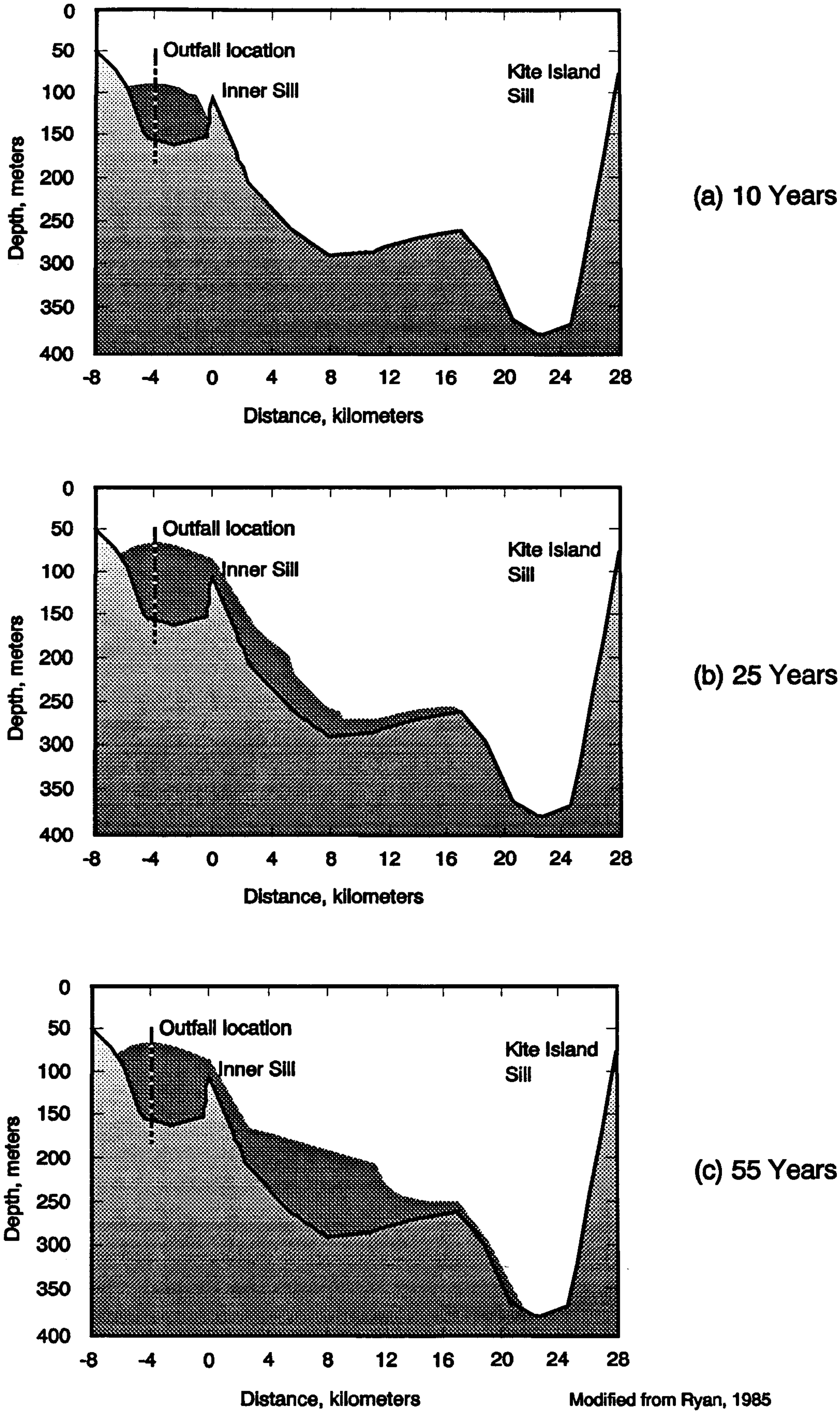

Figure 6.7 - Predicted deposition pattern in Boca de Quadra - Discharge to Inner Basin.

about 9 ft width by 11 ft height; or if bored, a diameter of about 11 ft. Most of the tunnel driving would be done from the Tunnel Creek end, as the excavated rock could be used there for site construction purposes. Since the Middle Basin tunnels exits in the Wilderness portion of the National Monument, disposal of excavated rock (and minimization of facilities) would be an important factor.

In both sub-options, the tunnels would be equipped for tailings transport with a concrete-lined or united open launder or ditch. The slope of the tunnel would be such as to minimize settling of solids. Ground water flows encountered during construction would be grouted off; however, temporary sedimentation ponds would be required at both ends to treat ground water flows before discharge. The tunnels would also be equipped with a roadway or light rail system for inspection and maintenance during operations.

At the discharge end, the tailings slurry in the launder would be channeled into two high-density polyethylene pipes to transport the slurry to the mixing chamber. Drop boxes would be positioned in the lines as necessary. The mixing tank would be designed and positioned near the Boca de Quadra shoreline in a manner similar to that described for Wilson Arm. The outfall line from the tank bottom would again be oriented with its end pointing down-fjord and would discharge at a minimum depth of 150 feet. Figures 6-8 and 6-9 show, for the Inner Basin sub-option, a general arrangement and a profile showing transport details. Layouts for the Middle Basin sub-option would generally be similar, except that no tailings would be deposited in the Inner Basin.

Besides the mixing chambers and associated structures, needed facilities at Boca de Quadra would include float plane and small boat docks, a helicopter landing pad, fuel tanks, a maintenance shed and minimal emergency housing facilities. In addition, a holding pond to receive spills would be required. This would have to be large enough to hold the entire volume of tailings in the tunnel, if a discharge interruption were required because of a leak in the downstream transport system.

6.6 The Environmental Situation

6.6.1 Bathymetry

The bathymetry and physical oceanography of Boca de Quadra and Smeaton Bay/Wilson Arm are described in the EIS (U.S.D.A. Forest Service 1988) and Appendix A. Both fjords are conkim sills.

In Boca de Quadra there are three sills (Figure 6-10), with minimum depths of 50 m, 75 m and 100 m respectively. Thus Boca de Quadra contains three basins. Depths are 150 m, 360 m and 360 m respectively. Each basin is irregular in longitudinal section, although tending to deepen from head to mouth, and each basin also shows in general a regular U-shaped cross-section. The two innermost basins were proposed for tailings discharge. With lengths of approximately seven and 33 miles respectively, their total below-sill volume is estimated at 100 and 4300 million m^3 (U.S.D.A. Forest Service

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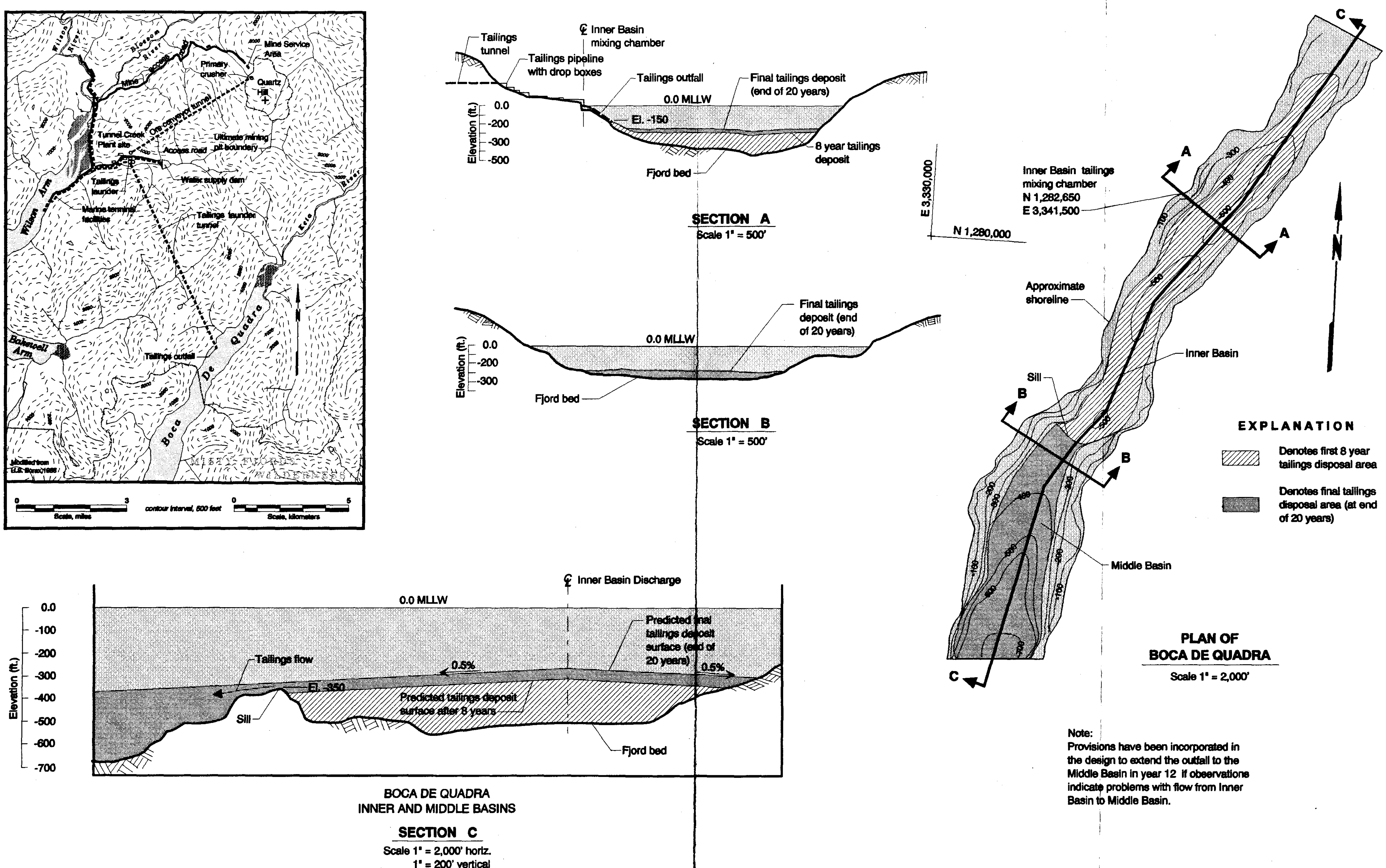

Figure 6.8 - Tailings disposal Boca de Quadra fjord, general arrangement - Plan and Section: Inner Basin Sub-Option.

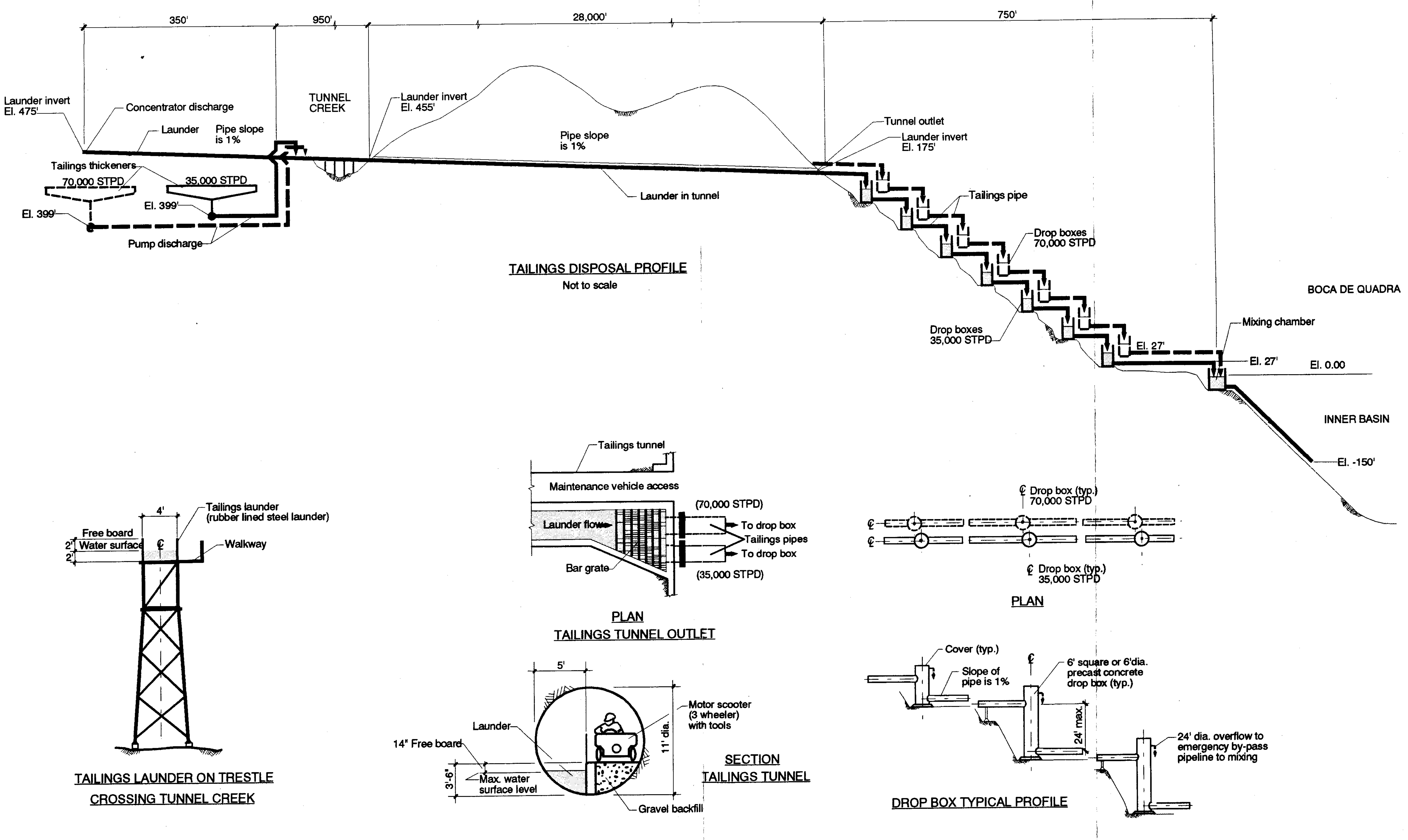

Figure 6.9 - Tailings Disposal Profile and Transport Details: Inner Basin Sub-Option.

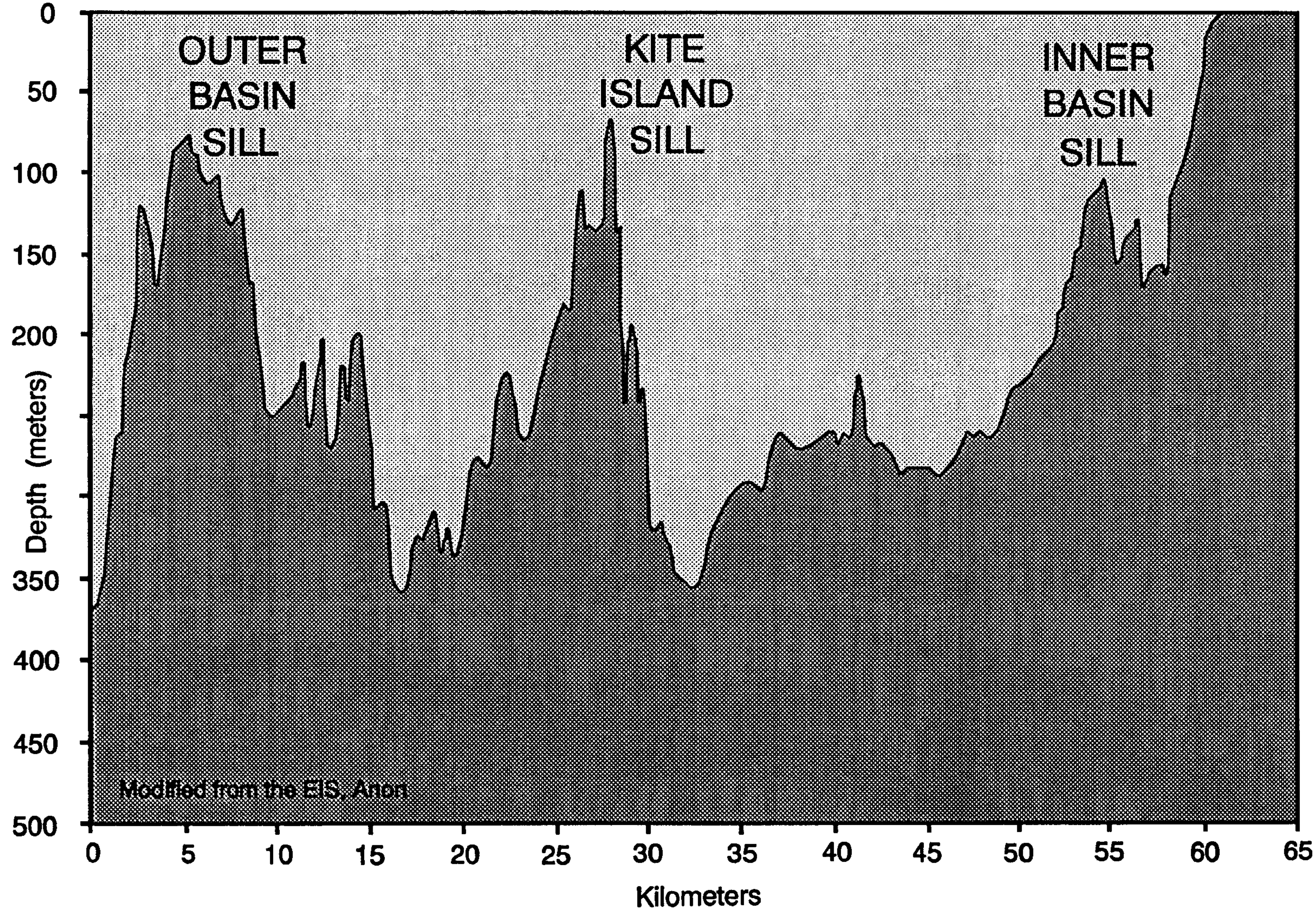

Figure 6.10 - Boce de Quadra longitudinal profile.

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1988; Ryan 1983). With tailings discharge to the inner basin, this would fill to sill depth and the balance overflow to the central basin (Table 6-9). The central basin could accept the total tailings discharge during the mine lifetime with little physical impact: a 15% reduction in total volume below sill depth.

Table 6-9

STD Options and Tailings Physical Impacts

Comparison of Impacts of Tailings Disposal in the Three Basin Alternatives with a Tunnel Creek Mill

	Disposal Basin Alternative		
Impact	Wilson Arm/ Smeaton Bay	Inner Basin Boca de Quadra	Direct to Boca de Quadra Middle Basin
Would change circulation of the discharge basin	Yes	Yes	No
Reduction in below-sill fjord volume	78%	100%	15%
Resulting fjord depth	75 to 100 m over about 30% of basin	80 to 100 m over about 100% of basin	More than 140 m over about 98% of basin
Change in resulting ecological community structure	To community of shallower depth	To community of shallower depth	No
Suspended tailings may reach near-surface waters	Possibly at sills	Possibly at sills	Possibly at sills

Source: U.S.D.A. Forest Service (1988).

The sill at the mouth of Smeaton Bay (Figure 6-11) is at 120 m depth. The interior basin has a maximum depth of 300 m. The head of Smeaton Bay is formed of two arms: Wilson Arm and Bakewell Arm. Both of these are relatively shallow (150 m), and with a gently sloping seabed to the final rise at the fjord-head river delta. The Smeaton Bay basin has a relatively uniform depth of about 250 m, although with irregularities in the outmost half. The basin length is 20 km, with below-sill volume of 777 million m^3. The tailings during the mine's lifetime would fill the basin to 75% of its below-sill volume (Table 6-9).

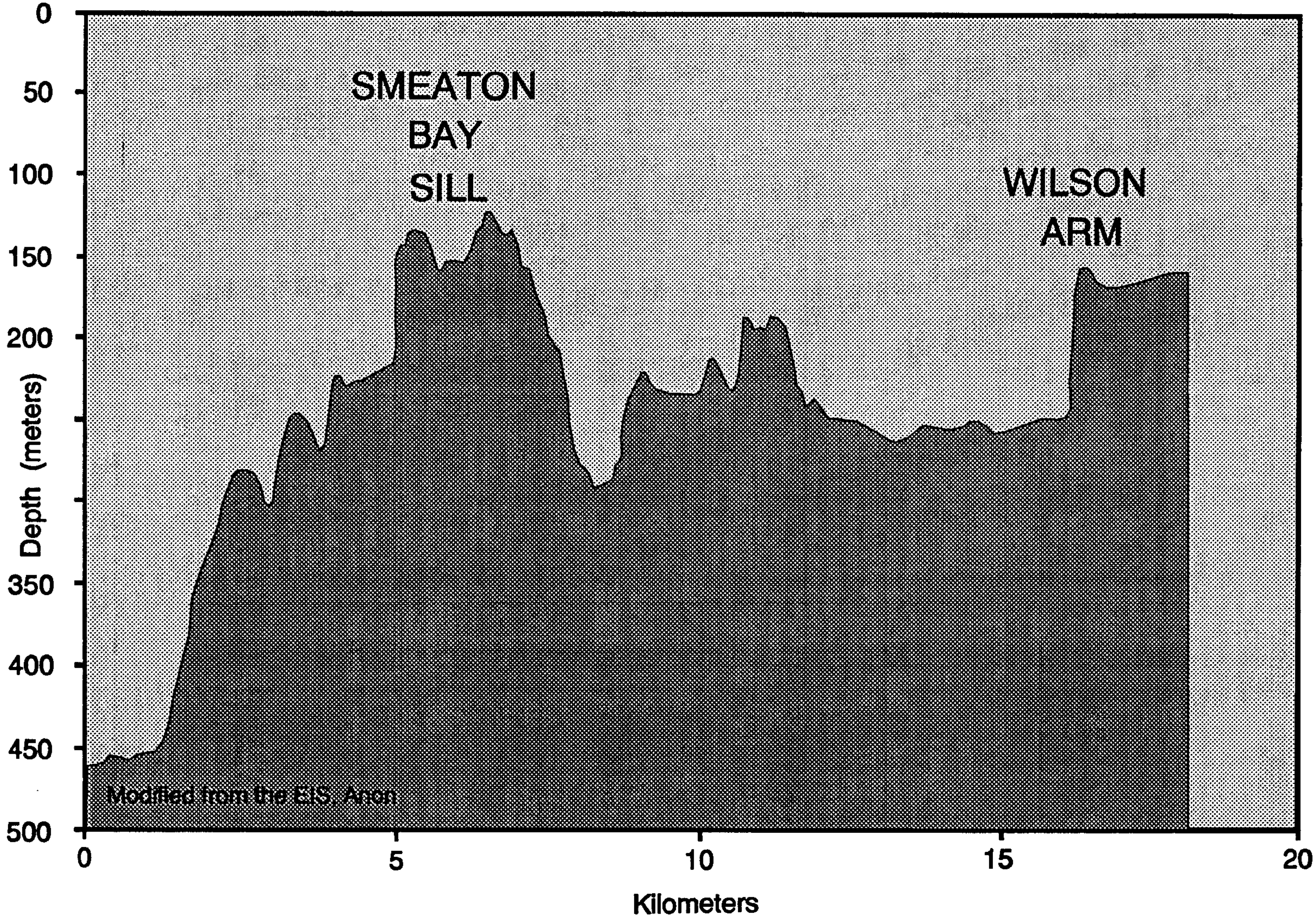

Figure 6.11 - Smeaton Bay/Wilson Arm longitudinal profile.

6.6.2 Resuspension Potential

The central basin of Boca de Quadra is subject in the summers of some years to deep water intrusions over the Kite Island sill (Figure 6-12). Modelling studies indicate that these have little energy for tailings resuspension, and that upwelling does not reach the surface. However, the modelling suggests that occasional tailings slumping and other forms of eddy induction might generate particle clouds which could be held in suspension and be detectable instrumentally. Such effects were even less likely in the innermost basin.

Smeaton Bay was also shown by modelling to have very little tailings resuspension potential (Figure 6-13).

6.6.3 Preliminary Environmental Information

Early reports identified major fishery and other concerns, and these were subsequently shown as correct (U.S.D.A. Forest Service 1988).

Both fjords are important for the commercial fishing industry of south-east Alaska. Rivers with extensive gravel beds functioning as spawning grounds for Pacific salmon discharge into both. The fjords therefore function as nursery areas (shallow water) for the juveniles during seaward migration each spring, and as highways for migrating adults returning to spawn in the fall. Adults use both shallow and deep water routes. There is, however, only rarely a salmon fishery located in either fjord.

Both fjords support other important fishery resources, ranging from Pacific herring spawning in early spring in shallow water, and Alaska king crabs on the deep seabed.

There is some recreational use of the fishery resources, largely from Alaskan residents, but also tourists.

The coastal land resources are small. There is some forestry and power generation potential. There is some wildlife (bears, goats, deer, *etc.*). The major biological resource using the coastal land ecosystem is waterfowl ranging from ducks and geese, through shorebirds, *etc.* There are both resident-nesting species, and spring and fall migrants. The bald eagle *(Haliaeetus leucocephalus)* exists in some numbers, and is a protected species.

6.6.4 Review of Environmental Impact Assessment Action

The Final Environmental Impact Statement (U.S.D.A. Forest Service 1988b) contains a 153-page record of the EIAs undertaken prior to permitting. It also contains a 314-page prediction of impacts based on those assessments and theoretical quantitative models judged appropriate. It is a very large document, reflecting the state of EIA and EIS in the USA in the late 1980's.

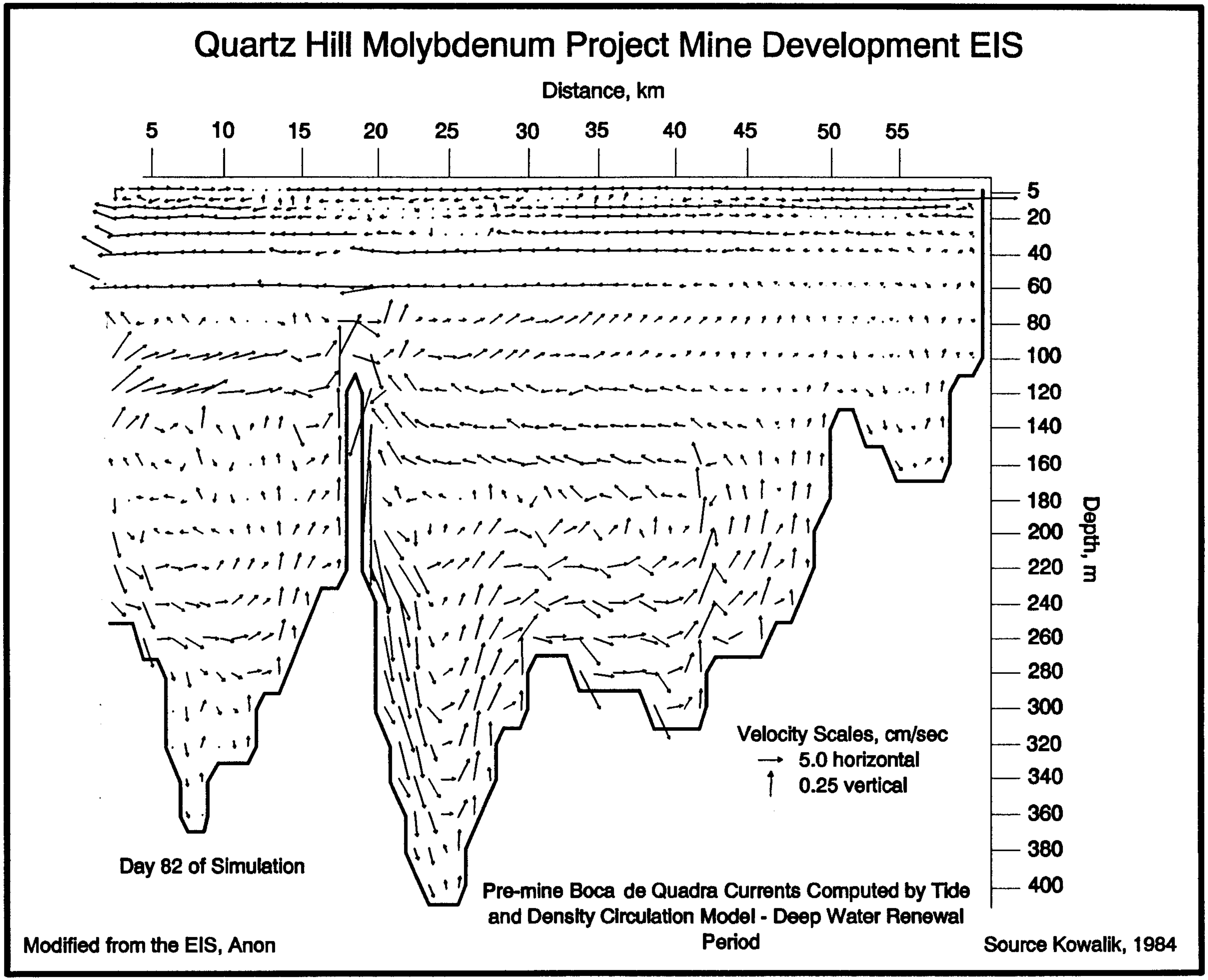

Figure 6.12 - Sub-surface currents, Boca de Quadra.

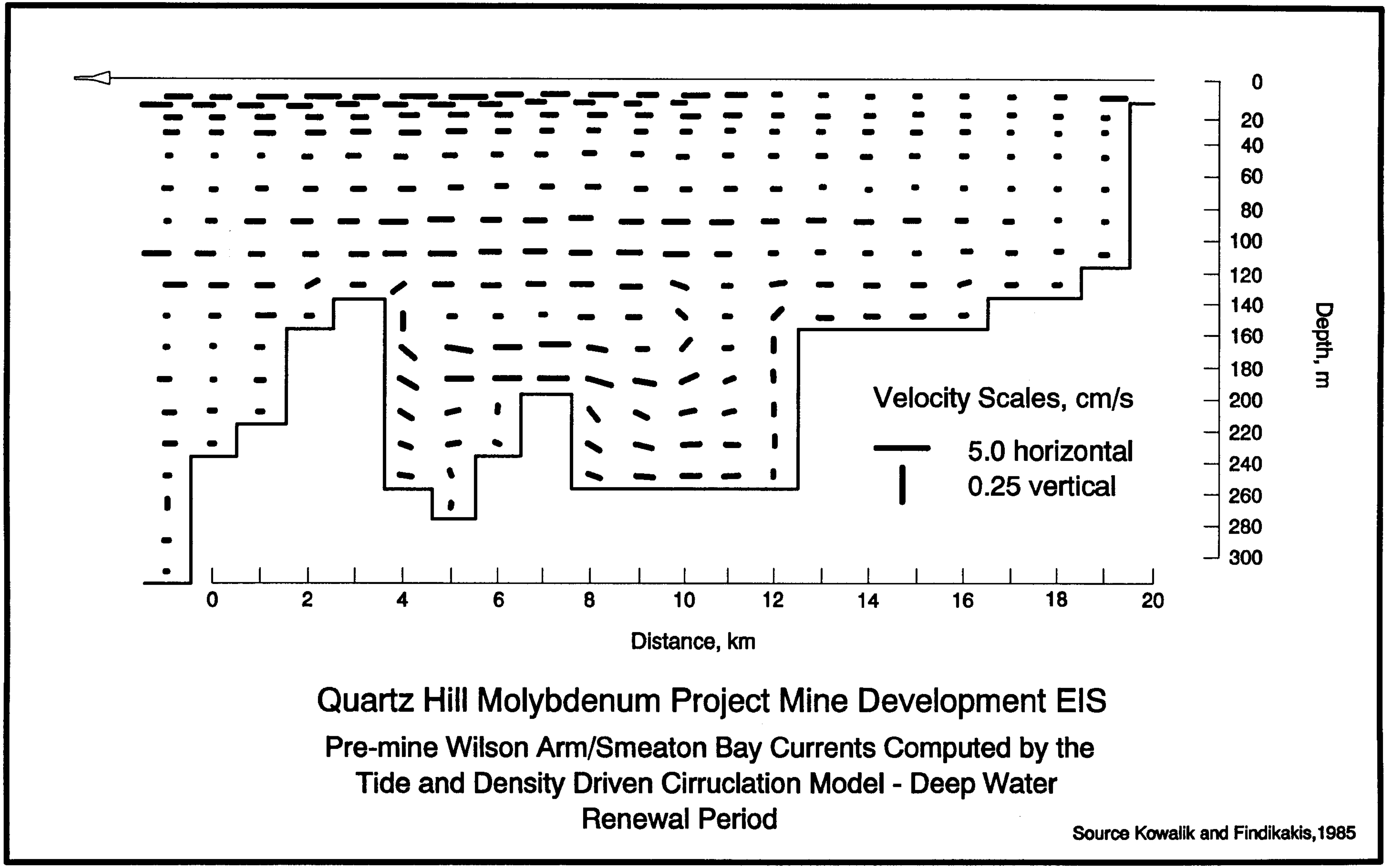

Figure 6.13 - Sub-surface currents, Smeaton Bay (Modified from the EIS, Anon).

Most of the information in this section is derived from the EIS, which should be consulted for more detail.

The preliminary statements about the importance of the fisheries in the two fjords were supported by the detailed EIAs. Table 6-10 provides details showing that up to 10% of the average Ketchikan area salmon harvest was from spawnings in rivers discharging to the two fjords.

The presence and biological timing of other fishery species are documented in Figure 6-14, although their regional importance could not be documented.

Impact from STD was predicted as follows:

"Migration of anadromous fish would not be affected, and all tailings impacts to salmon would be insignificant"

and:

"Potential habitat for herring would be occupied by tailings and/or suspended sediments to varying degrees depending on which basin receives the tailings."

Predicted loss of fisheries from the different options for STD is summarized in Table 6-11.

Impact from STD was stated as:

"Marine tailings disposal would impact marine ecology by burial of marine organisms and habitats, direct effects of suspended sediments, and possibly by toxicants present in the tailings. Burial of several important bottom dwelling species would occur in affected areas."

After recovery the benthos would form populations typical of shallower water.

Game and rare species, including the national emblem the bald eagle, are high profile biological resources. The EIS goes to the extent of documenting individual bald eagle nests in the Quartz Hill area (EIS Figure 3-40), and goat sightings 1980-1982 (EIS Figure 3-41).

The aquatic ecosystems were detailed by the various EIAs. The feed stocks of the various fishery species, and other aquatic-feeding resource species such as waterfowl, eagles, *etc.* are all documented (although non-quantitatively).

The economic base of the area taken as impacted by the development, *i.e.* the whole Ketchikan Gateway Borough (KGB), is documented in the EIS. Tables 6-12 and 6-13 show that the Ketchikan census area contains most of the regional population, with very little of the population (0.2%) involved with agriculture, forestry and fisheries.

Table 6-10

Salmon Production in the Quartz Hill Area

	Number of Fish					
	Wilson River	Blossom River	Keta River	Tunnel Creek	Aronitz Creek	Total
Pink						
Estimated Average Return	1,176,672	409,939	421,442	25,557	2,157	2,035,767
Estimated Average Harvest[2]	788,370	274,659	282,366	17,123	1,445	1,363,963
Percent of Average Area Harvest of Pink Salmon[3]	5.81	2.02	2.08	0.13	0.01	10.05
Chum						
Estimated Average Return	10,268	18,731	64,737	1,645	686	96,067
Estimated Average Harvest[4]	6,674	12,175	42,079	1,069	445	62,442
Percent of Average Area Harvest of Chum Salmon	1.11	2.02	6.98	0.18	0.07	10.36
Coho						
Estimated Average Return	5,520	14,925	7,230	166[6]	16[6]	27,587
Estimated Average Harvest[5]	4,200	11,940	5,784	133	13	22,070
Percent of Average Area Harvest of Coho Salmon	0.88	2.50	1.21	0.03	<0.01	4.63
Chinook						
Estimated Average Return	1,220	2,410	3,360	2[6]	1[6]	7,020
Estimated Average Harvest[7]	976	1,928	2,688	23	1	5,616
Percent of Average Area Harvest of Chinook Salmon	1.34	2.64	3.68	0.03	0.03	7.69
All Salmon						
Estimated Average Return	1,193,410	446,005	496,769	27,397	2,860	2,166,441
Estimated Average Harvest	800,220	300,702	332,917	18,348	1,904	1,454,091
Percent of Average Area Harvest of All Salmon	5.44	2.04	2.26	0.12	0.01	9.88

/ Computations based on data from Table 3-9 and methods used by ADF&G (1979, page 9).
/ Pink Salmon harvest is estimated to average 67 percent of total adult return (ADF&G 1979, Table 9).
/ Calculated as a propostion of the average Ketchikan area harvest (Appendix G, Table 3-1).
/ Chum salmon harvest is estimated to average 65 percent of total adult return (mean of 79 percent and 50 percent from ADF&G 1979, Table 12).
/ Coho salmon harvest is estimated to average 80 percent of total adult return (Gray 1983).
/ From Appendix G, Table 4-1.
/ Chinook salmon harvest is estimated to average 80 percent of total adult return (Kissner 1983).

ource: U.S.D.A. Forest Service (1988).

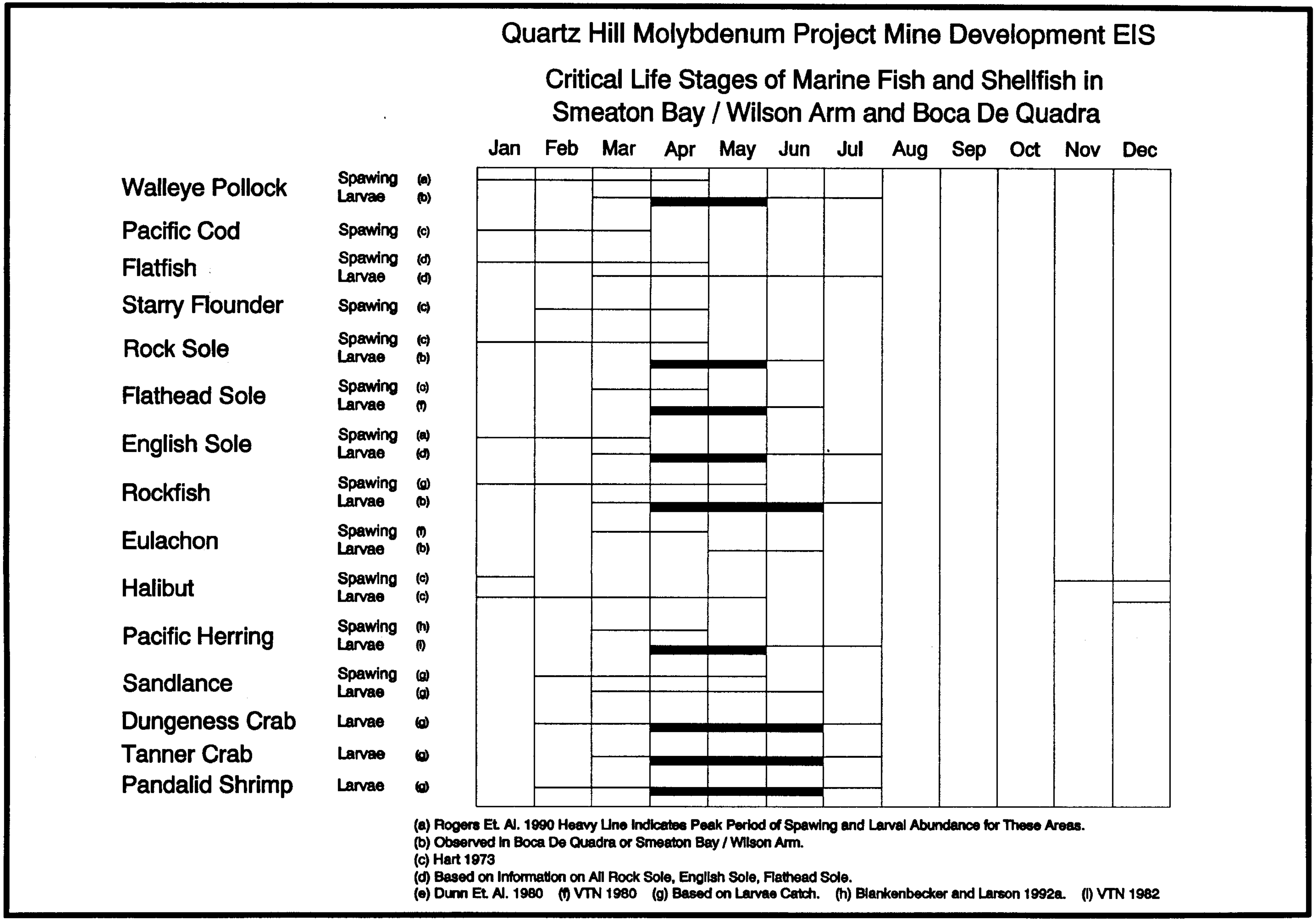

Figure 6.14 - Non-salmon fishery species and their seasonal timing (Modified from U.S.D.A. Forest Service, 1988).

Table 6-11

Estimated Fishery Losses from Various Forms of STD
Comparison of Impacts of Tailings Disposal
in the Three Basin Alternatives with a Tunnel Creek Mill

	Disposal Basin Alternative		
Impact	**Wilson Arm/ Smeaton Bay**	**Inner Basin Boca de Quadra**	**Direct to Boca de Quadra Middle Basin**
Tailings would impact salmon	No	No	No
Annualized loss of dungeness crab	960 kg	1,630 kg	660 kg
Annualized loss of pot shrimp	480 kg	740 kg	250 kg
Annualized loss of demersal fish	4,570 kg	7,070 kg	2,790 kg

Source: U.S.D.A. Forest Service (1988).

Land use within the Misty Fjords National Monument is also documented in the EIS. Use is now controlled by ANILCA, and most of the land is owned by the federal government. However there are some private landholdings, and about 1000 mine claims which have to be resolved. It should be noted that the seabed of the fjords and channels within the Monument area are not part of the National Monument, but belong to the State. The forest in the National Monument represents 14% of the region's total forest.
The EIS has surprisingly little about traditional native rights and uses, and what there is, is scattered. For example page 3-126 states:

"The number of Native (primarily Indian) people in the KGB in 1980 was 1,405, or 12.4% of the population."

Historically there had been two native groups (EIS p. 3-139) the Tsetsaut and the Sanyakan in the mining area, and there was some hostility between them which eventually caused the Tsetsaut to abandon the area.

Currently the City of Saxman has a 90% native population located in the City are the offices of the Cape Fox Corporation, the Native Corporation for the area. The local tribal governing body is the Organized Village of Saxman (EIS p. 3-134).

Table 6-12
Regional Population Data
Regional and Local Impact Areas
1970 - 1980

	1970	1980	Annual Average Percent Increase	Percent Growth Rate 1970-1980
Local Impact Area				
Ketchikan Census Subarea[1]	10,041	11,316	1.2	12.7
City of Ketchikan	6,994	7,198	0.3	3.0
Remainder of KGB	3,047	4,118	3.1	35.1
Remainder of Regional Impact Area				
Prince of Wales-Outer Ketchikan Census Area	3,782	3,822	0.1	1.1
Outer Kechikan Subarea	1,676	1,333	-2.3	-25.7
Prince of Wales Subarea	2,106	2,489	1.7	18.2
Wrangell-Petersburg Census Area[2]	4,920	6,167	2.3	25.3
Petersburg Subarea	N/A	3,804	N/A	
Wrangell Subarea	N/A	2,363	N/A	
Regional Impact Area Total	18,743	21,305	1.3	13.7
Southeast Alaska	42,565	53,794	2.4	26.3
State of Alaska	302,583	401,851	2.9	32.8

1/ The Ketchican Census Subarea has the same boundaries as the KGB.
2/ Not all of the Wrangell-Petersburg Census Area is within the regional impact area, but the cities of Wrangell and Petersburg are within the regional impact area and they accounted for over 80 percent of the Wrangell-Petersburg Census Area population in 1980.

Source: Alaska Department of Labour (1980), (1981a), and (1983a) in U.S.D.A. Forest Service (1988).

On pages 3-138 to 140 the EIS section 3-3-3 Cultural Resources summarizes the results of two archeological surveys. Twenty-one sites were located, five modern and in use, 11 modern abandoned, and five historic.

Table 6-13
Wage and Salary Employment by Industry
Ketchikan Gateway Borough 1982, 3rd Quarter - 1983, 2nd Quarter

Industry	Covered Employment	Percent of Total
Agriculture, Forestry, and Fisheries[1]	12	0.2
Mining	ND	--
Construction	330	5.6
Manufacturing	949	16.0
Transportation, Communications, and Utilities	483	8.1
Wholesale Trade	148	2.5
Retail Trade	1,007	17.0
Financial, Insurance, and Real Estate	206	3.5
Services	1,052	17.7
Government	1,693	28.5
Federal	334	--
State	545	--
Local	814	--
Miscellaneous	ND	--
TOTAL	**5,937**	**99.1[2]**

1/ Employers paying less than $20,000 per quarter in wages are not required to report number of employees.
2/ Mining and miscellaneous employment consists of 0.6 percent of total employment.

ND: Not reported due to disclosure.

Source: Alaska Department of Labour, Research and Analysis (1984) in U.S.D.A. Forest Service (1988).

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APPENDIX A - REVIEW OF SELECTED ENVIRONMENTAL ACTIONS AT QUARTZ HILL: OCEANOGRAPHIC SURVEYS AND IMPACT PREDICTIONS, COMMUNITY SURVEYS, PERMIT DECISIONS. (by C. HESSE)

The Quartz Hill molybdenum development provides the first example of a permit application with associated EIAs for STD in the USA. Due to the case's likely importance in future decisions about STD, this Appendix is provided to give more information than can be conveniently located in Chapter 6.

Since this Appendix was originally written, a further report titled "Regulatory Aspects of Submarine Tailings Disposal - The Quartz Hill Case History, has been distributed by the US Bureau of Mines (Hesse and Reim 1993).

References quoted are listed in the References section of the text.

A 1.0 Physical Oceanography of the Receiving Systems

The Bathymetries of Wilson Arm/Smeaton Bay and Boca de Quadra are described generally in Chapter 6. This subsection describes the oceanographic conditions in both fjords that relate to the expected behavior of the tailings after discharge, with some conclusions on the relative suitability of the three possible STD sites.

Oceanographic data were obtained on all three possible sites during over fifty cruises by oceanographic research vessels between the years 1978 and 1984, manned by scientists and researchers from the Institute of Marine Science, University of Alaska. The results are summarized in a number of reports by Burrell and Nebert (Burrell 1980-84; Nebert 1983). The quantity of data gathered and the intensity of the analysis make it probable that Wilson Arm/Smeaton Bay and Boca de Quadra are the most thoroughly environmentally evaluated fjord systems in the United States. In March 1984 and July 1985, the data were reviewed by Rescan Environmental Services Ltd. to produce assessments of the three STD alternative sites (Rescan 1982; 1984). The fjords were also assessed in the Best Professional Judgment Evaluation using the Ocean Discharge Criteria for mill tailings disposal from Quartz Hill published by EPA, which document was included in the Final EIS as Appendix S (U.S.D.A. Forest Service 1988a).

Both fjords are submerged, glacially scoured valleys with U-shaped cross-sections narrow enough so that after a short period of initial deposition, the tailings would occupy the entire width and could then be considered generally to be advancing only in the down-fjord direction. At all three locations, the outfall pipe would be anchored to the fjord wall in a down-fjord orientation, would be sloped at an angle of about minus 25 degrees and would discharge at a depth of at least 150 feet. The behavior of the tailings in the "near-field", described as extending 100 m from the tailings outfall, was predicted on the basis of physical modelling conducted for the project at the University of Iowa, and is outlined in Section A 1.1. Sedimentation behavior in the "far-field" was modeled mathematically for the project by Bechtel Inc. on behalf of the developers as described in Section A 1.2. Numerical models of fjord circulation, described in Section A 1.4, were devised by the University of Alaska and EPA; they were used to predict disposition of fines and the liquid fraction of the tailings discharge.

At Wilson Arm, the submarine topography descends rapidly from the silt delta at the mouth of the Wilson River, to a depth of about 350 ft at the outfall, located about 3500 ft from the Wilson River estuary (see Figure A-1).

The discharged tailings would be expected to flow easily down the wall of the fjord to the bottom of the fjord. After some initial backfilling toward the Wilson River delta, the tailings would flow in a density current southwesterly down the gently sloping fjord bottom, eventually spilling over into the 968 ft deep basin located at the point where Wilson Arm joins Smeaton Bay. Some years of discharge would be required to fill this basin to the point where there would be a further major advance of the tailings front over an intermediate sill. During this period there would be some backfilling of Bakewell Arm. The deposited tailings would move forward in a manner similar to an advancing river delta. Tailings would be carried down the fjord bottom in a meandering density current (described in Section A 1.2) over the already deposited tailings to the tailings front, standing at an angle of repose sloping down into deeper water. As material is deposited on the upper part of the slope by means of the settling of solids in the more quiescent waters, the upper slope steepens beyond the angle of repose and periodic slumping events move the front forward.

Near the end of the mine life, the tailings deposit would begin to climb the inward slope of the sill separating Smeaton Bay from Behm Canal, eventually reaching a level of 150 feet below the top of the sill, or approximately 570 feet below sea level. At the end of the mine's life, the fjord bottom would form a gradual slope (about 0.5%) upward from the deepest point at the sill toward the discharge point at a depth of about 250 feet. About 78% of the below-sill volume of Smeaton Bay would be filled with tailings. This assumes an average in-place density of the tailings deposit of 100 lb/ft^3 established by the UBC laboratory tests. Consolidation of the fjord bottom would likely continue for some time after deposition and there could be some minor redistribution of the sediments by bottom currents. If required by the permitting agencies, the height of deposited tailings at the discharge point could be kept below 100 m by moving the outfall down-fjord late in the mine's life. Figure A-2 shows cross sections of the tailings levels in Wilson Arm after 55 years of mine operation. Figure A-3 shows longitudinal sections. The below-sill volume of Wilson Arm/Smeaton Bay is 777 million m^3, according to Ryan (Ryan 1983).

During the EIS process, concern was expressed by some agency personnel and members of the public about the possibility of tailings fines escaping over the sill from Smeaton Bay into Behm Canal. The likelihood of this was investigated and reported in the Final EIS (U.S.D.A. Forest Service 1988a). The Forest Service's estimate, using data from a

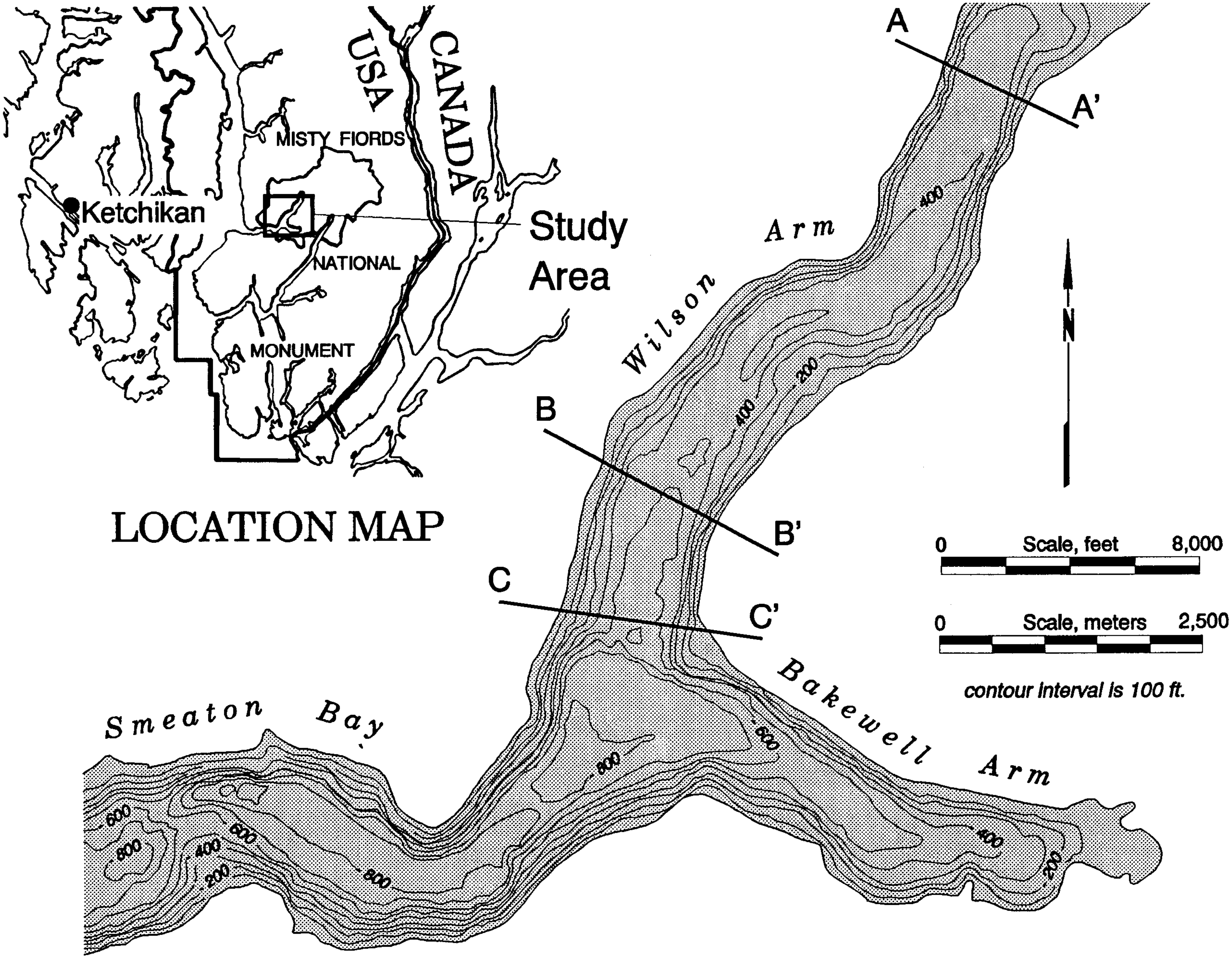


Figure A-1 - Bathymetry of Wilson Arm/Smeaton Bay.

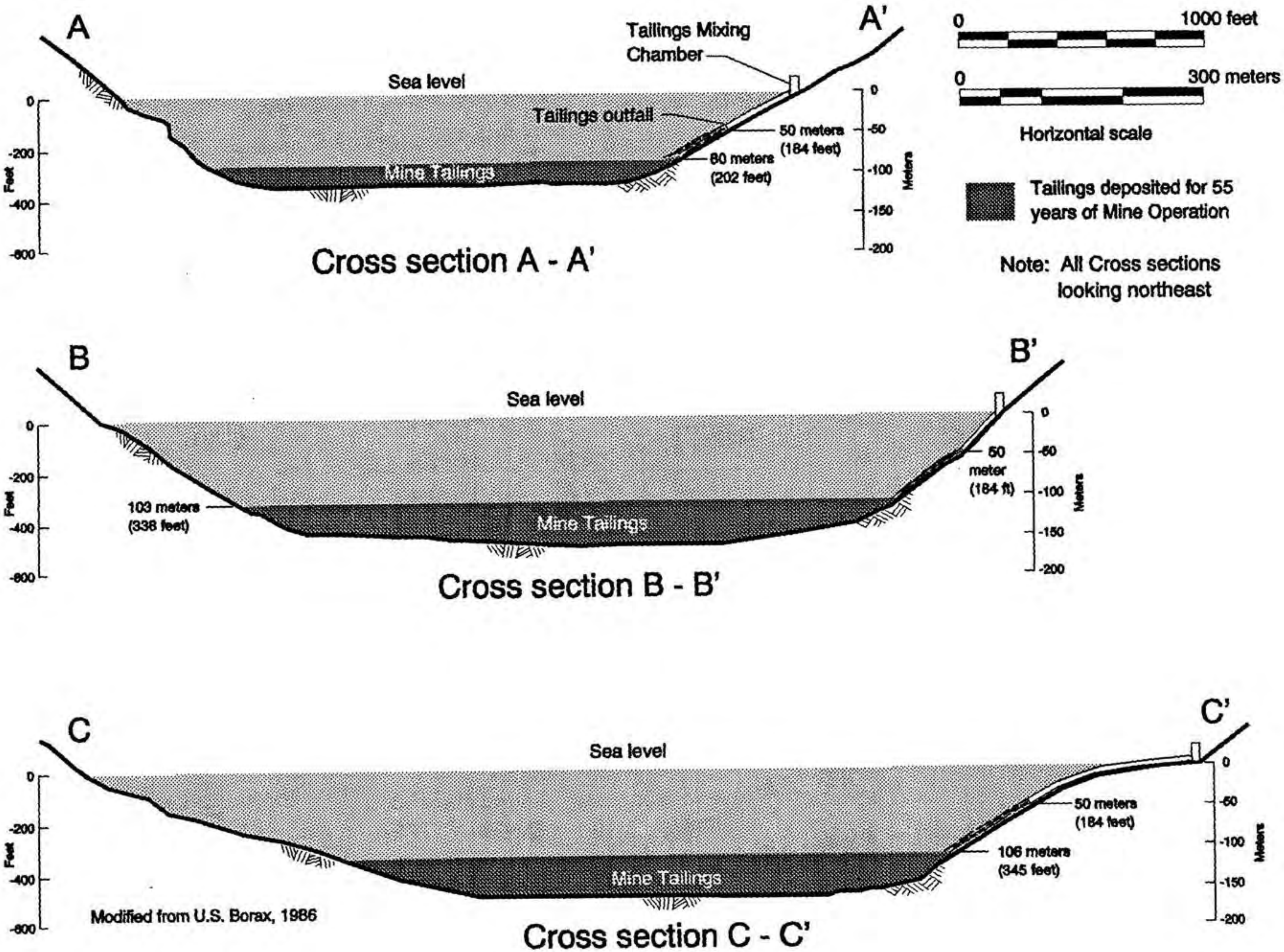
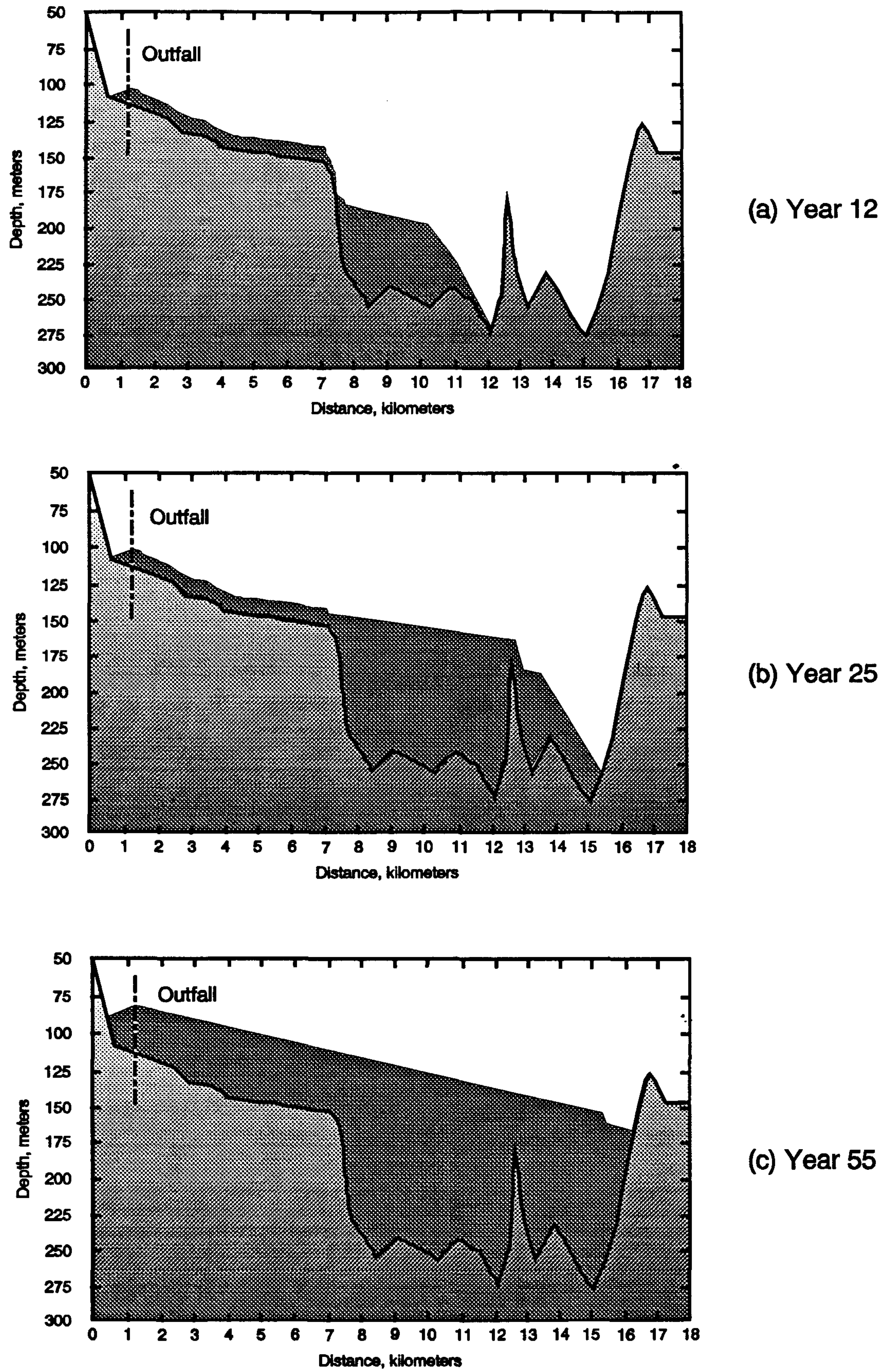


Figure A-2 - Cross sections of tailings deposited in Wilson Arm.



Modified from Envirosphere Co., 1985

Figure A-3 - Predicted tailings deposition in Smeaton Bay, Wilson Arm.

special field survey of the Island Copper Mine discharge, was 300,000 tons per year. This was double U.S. Borax's estimate. EPA, interpreting the same data differently, arrived at an estimate more than an order of magnitude higher. However, the consequences of fines escapement were viewed as negligible by the National Marine Fisheries Service, who in 1986 commented, in a letter to U.S. Borax (McVey 1986):

"...the National Marine Fisheries Service believes that additions to the flow of sediments along the bottom of Behm Canal resulting from the discharge of mine tailings into Wilson Arm would not likely result in a discernible impact to the fishery resources of Behm Canal."

At Boca de Quadra, for the Inner Basin sub-option, the tailings outfall would be located approximately two miles down fjord from the Keta River delta, or a little less than half way between the delta and the sill dividing the Inner and Middle Basins. At the outfall location, the Inner Basin is about 450 ft deep. As at Wilson Arm, the tailings would flow easily from the outfall to the centre of the basin cross-section, and there would be initial backfilling upstream toward the river delta. Before long, the predominant direction of tailings flow would be downstream toward the Middle Basin. Movement of the tailings front would occur through slumping events as described for Wilson Arm. For the first years of operation, tailings would be confined to the Inner Basin, except for carryover to the Middle Basin by tidal flushing and bottom currents. After 10 to 14 years of deposition, the 100 million m^3 below-sill volume of the Inner Basin would be filled and the density current would spill over into the much deeper Middle Basin (maximum depth of about 1200 feet). With a below-sill volume of 4300 million m^3, the Middle Basin is more than large enough to contain the 844 m^3 volume of tailings from the entire Quartz Hill orebody, and the tailings front would not approach the Kite Island sill until late in the mine's life. It is unlikely that any fines would be carried over this sill to the Outer Basin and far more unlikely that detectable fines would ever reach Behm Canal.

For the Middle Basin direct discharge sub-option, the tailings transport tunnel from the thickeners would emerge at a rocky promontory about one-half mile from the Inner Basin sill. Aside from cost considerations, this sub-option could have some advantages over discharge into the Inner Basin, in that the Inner Basin would not be directly impacted and the uncertainty of gravity flow of the tailings stream from the Inner Basin to the Middle Basin would no longer be of concern. A tunnel leading directly to the Middle Basin would be some three miles longer than a tunnel to the Inner Basin; thus this sub-option would be considerable more expensive. In addition, the tunnel portal would be located in the Wilderness portion of the National Monument, while that for the Inner Basin would be within the 152,610 acre non-Wilderness enclave. The previously mentioned facilities required at the tunnel portal would disturb up to about 20 acres. As with the Inner Basin sub-option, deposited tailings would encroach on the Kite Island sill only late in the mine's life and there would be little possibility of fines carryover into Behm Canal. Because of the greater depth of the Middle Basin, there would also be less possibility of suspended fines clouds appearing in the upper 100 meters of the water column. Upon completion of deposition in Year 55, the Middle Basin would be filled with tailings to only about 20 percent of its capacity. Figure 6-7 illustrates tailings deposition in Boca de Quadra for the Inner Basin sub-option.

In a 1985 letter summarizing its assessments of the three STD sites in 1984 and 1985, Rescan Environmental Services Ltd. stated that it could find no statistical significance between biological productivity of the Wilson Arm/Smeaton Bay system and the Boca de Quadra central basin (Rescan 1985). The Inner Basin, on the other hand, was found to have a slightly lower productivity than the other two basins. Thus, on ecological grounds, there was little to distinguish a preferred option. Similarly, based on available data there were no indications that resuspended material would circulate into the euphotic zone in any of the basins, but would remain below a depth of 60 meters. Rescan's conclusion was that Wilson Arm/Smeaton Bay is the preferred alternative for STD from the Quartz Hill project because:

"there is simply no environmental justification for selecting the far more costly Boca de Quadra options."

U.S. Borax estimated the cost differential (in 1984 dollars) between STD in Wilson Arm/Smeaton Bay and Boca de Quadra to be $59 million in capital cost, plus an additional $1.6 million per year in operating cost. When the financial cost of servicing the additional debt is added, this would equate to an additional production cost of 55 cents per pound of molybdenum.

A 1.1 The Near-Field Tailings Disposal Model

In order to answer questions about the dispersal of tailings fines and the behavior of the tailings stream in the near-field region at the outfall, a physical model was constructed at the Institute of Hydraulic Research at the University of Iowa (Jain and Kennedy 1984). The near-field region is defined as extending 100 m (approximately 100 pipe diameters) from the end of the outfall pipe.

First, a literature search was done by Bechtel Inc. to find appropriate mathematical models and suitable validation data for the situation where tailings would be discharged at 50 m depth with the negatively buoyant plume flowing down the steep slope of the fjord wall. This search gave some indications of the degree of dilution of the tailings plume that could be expected at the edge of the near-field, but it was felt that a suitably designed physical model would provide further insight.

The model was constructed at a scale of 1/50 the size of the prototype outfall. The feed to be used for tests were tailings from the 1983-84 pilot plant runs of the Quartz Hill ore bulk samples. For convenience and logistics reasons, fresh water was to be used as the receiving medium. The feed material was screened to a size distribution which would achieve particle settling velocities which would compensate for errors introduced by model scale.

A description of the model operation, the tests run and a summary of the results is given in Appendix F of the Final EIS (U.S.D.A. Forest Service 1988a). The hinged sloping floor of the model was attached to a fresh water tank. Sediment was stirred vigorously in an adjacent mixing tank to give the desired premix ratio of tailings slurry to added water. The mixture was heated to achieve the same density differential between the discharged fluid and the receiving seawater in the fjord. A constant-rate pump discharged the mixture into the model through an outlet at floor level, corresponding to the tailings outfall anchored to the fjord bottom. A moveable instrument carriage collected water samples for sediment concentration determinations and temperature monitoring. Temperature differentials were interpreted to delineate the extent of the plume and provide estimates of its dilution. Still photographs and videos were taken of the plume and bottom sediment buildup. After each run, the tank was drained to allow measurements of the bottom sediment profile.

A total of 49 runs were made to investigate the effects, on the tailings plume and dilution, of:

- bottom slope, at angles of 5°, 12.5° and 25°;
- premixing, at ratios of 1:1, 1:2 and 1:4;
- exit jet velocities at 1.1, 2.5 and 4.5 m/s; and
- outlet diameters at 0.95 and 1.9 m.

The dominant influence was found to be the bottom slope. The plume behavior was influenced by bottom deposits and appeared to be unsteady, with three distinct flow types possible:

- *jet flow*, with deposition in a fan widening downstream from the outlet;
- *sheet flow*, where a crater forms around the outlet and acts as a hydraulic control, with the plume overflowing the edge; and
- *channel flow*, where a widening and deepening channel is scoured by the flow into previously deposited sediment.

The dilution of the plume at the edge of the near-field at 100 m was found to be dependent on flow type. Typical dilution values were 24 to 42 for jet flow, 9 to 16 for sheet flow and 5 to 9 for channel flow. Dilution values generally increased with increasing bottom slope angle.

One of the principal findings of the tests concerned the possible development of a "split plume" which had been observed occasionally at the Kitsault Molybdenum Mine. In this phenomenon, a separate cloud of suspended fines developed at an elevation higher than the main tailings stream on the fjord bottom. It was observed at depths between 200 and

360 ft and the average concentration in the plume was 3.6 mg/L (Burling *et al.* 1981). Some model tests were aimed at investigating whether a split plume forms when the plume is allowed to fall on the bottom from a raised outlet. None of the tests revealed such an occurrence, once air bubbles in the discharge were eliminated. The tailings plume in all cases was coherent and attached to the bottom in a thin layer which would scale up to 5 m thickness in a full size unit.

A 1.2 The Far-Field Sedimentation Model

To predict the dynamics and sediment deposition associated with the density current in the far-field, a numerical model was produced by Bechtel Civil and Minerals Inc. (Burling *et al.* 1981). Initial concentration of tailings in the sediment plume was chosen with reference to the dilutions predicted by the near-field model. In accord with observations at Rupert Inlet, it was assumed that the density current would be confined to a trapezoidal channel scoured into deposited tailings on the fjord bottom. The tailings particle size distribution was divided into several size fractions, each fraction was modeled separately and the results combined to predict net deposition along the fjord. Adaptations of the model were run for both Boca de Quadra and Wilson Arm/Smeaton Bay discharge locations. The outfall positions modeled were those described in earlier sections, but the model could also be run for other potential outfall locations.

Figure A-4 shows schematic cross-fjord and along-fjord sections which illustrate the transport and sedimentation actions in the fjords, as interpreted in the Final EIS. In the upper diagram, the density current is shown confined to a leveled channel which typically meanders across the top of the previously deposited tailings. This is consistent with observations at the Island Copper and Kitsault operations and with the findings of the near-field physical model. The "split plume" phenomenon is shown in the lower diagram, although as previously mentioned, it was not expected to occur with the Quartz Hill outfall conditions.

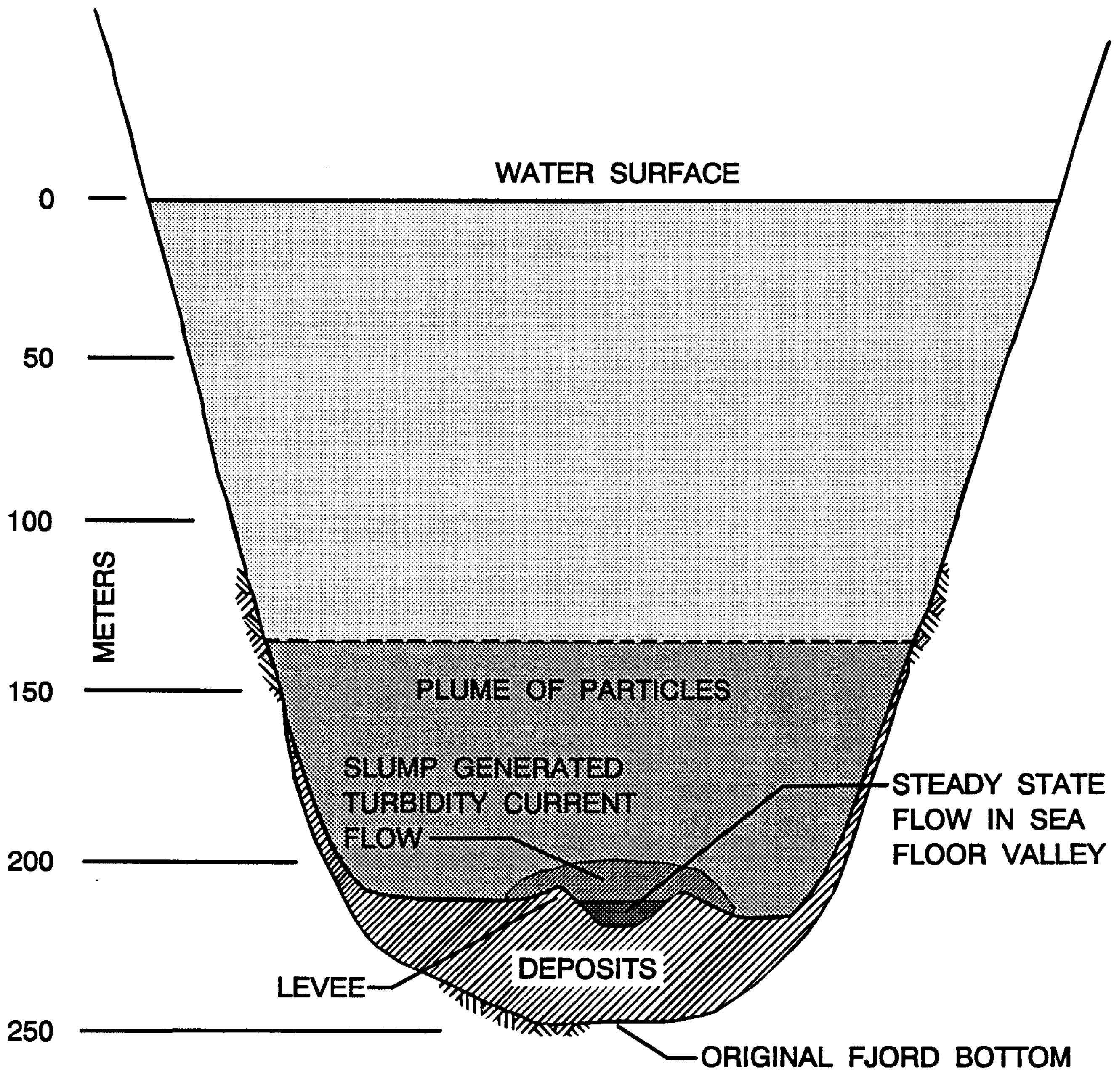
For the model, it was assumed that slumping and meandering of the leveed channel would distribute deposition evenly across the relatively narrow width of the fjord. Application of the model provided a time-dependent deposition thickness estimate for various positions along-fjord. Figures 6-2 and 6-3 in Section 6.3 illustrate the predictions for key years in Wilson Arm/Smeaton Bay and Boca de Quadra.

Before applying it to Quartz Hill, the validity of the model was calibrated against about ten years of data from the Island Copper Mines STD operation, where it was successfully able to predict the sediment thicknesses as actually in place. A fuller description of the model is provided in Appendix F of the Final EIS (Findikakis 1983; 1984; 1985).

A 1.3 Water Column Oceanography

On leaving the near-field, the tailings discharge flows as a "density current" along the floor of the fjord. Above the density current is a "turbidity plume". The definitions of

IDEALIZED CROSS-SECTION of SUBMARINE TAILINGS DISPOSAL in FJORD



Modified from Rescan, 1984

Not to scale

Figure A-4 - Schematic Cross-fjord section of tailings density current and sedimentation process.

these terms are important with respect to interpretation of the circulation models which were used to predict the likelihood of fines concentrations in the upper water column (see Section A 1.4). A density current may be defined as a mixture of tailings slurry and seawater perhaps 5 to 25 m in thickness, flowing in an aqueous medium and having a varying solids: liquid ratio depending on the relative distance from the bottom of the stream. The greatest solids: liquid (S/L) ratio is found near the bottom, which carries the coarsest particles. The top of the density current is marked by a fairly sharp break in the S/L ratio, above which is found the turbidity plume. This is a much broader band or cloud of suspended fines of 10 micron size or less, which varies from very turbid at the bottom to barely perceptible at the top. In addition to the differences in S/L ratio, the breakpoint between the density current and the superincumbent turbidity plume can also be detected and defined by the ability to transmit light; with the density current transmitting little to none, and the fines cloud transmitting ever greater amounts approaching the top. Here the solids concentration would be below 5 mg/L. In September 1983, a special survey of the Island Copper Mine tailings discharge was done in Rupert Inlet on behalf of the project by Rescan Environmental Services (Rescan 1983; 1984). Figure A-5, showing plots of suspended solids ratios and percent transmissivity, illustrates clearly the break between the density current and the turbidity plume. Table A-1 gives the solids concentrations at various depths for the two surveyed locations at 300 m and 1000 m downstream from the Island Copper outfall.

One of the concerns of the permitting agencies was whether significant amounts of fines from STD could appear in the upper water column, affecting photosynthesis and thus, fjord productivity. This is influenced by water column stratigraphy and vertical mixing, which undergo seasonal cycles. In the winter, stratification in the Quartz Hill fjords, as measured by salinity, is weak but still significant. With the approach of summer, denser waters from the Gulf of Alaska begin to enter the fjords over the outer sills and a deep water renewal process begins, accentuated by tidal action. During the summer, the renewed deep dense water is overlain by less dense, fresher waters. This process reaches a peak in Boca de Quadra in August-September, following which densities in the fjord basins begin to decrease. During the winter, vertical mixing takes place, tending to reduce stratification. The pycnocline, a level in the water column characterized by rapidly changing densities, tends to deepen and become less well defined. Tides provide the energy for this mixing action. However, deep water renewal in Boca de Quadra does not appear to be an annual event (Nebert 1983).

Boca de Quadra is a complex system, with three basins, three sills, and two sharp bends. Its circulation patterns are quite complex. Wilson Arm/Smeaton Bay is simpler, with only one basin and one sill. However, the fundamental circulation in both fjords is relatively similar and is dominated by the large tidal range (13 to 16 ft) strong vertical density gradients, and seasonal changes in the water structure outside the fjords. In Smeaton Bay, bottom water exchange appears to be more closely related to tides and storm events and occurs intermittently between April and October. Deep water renewal is more gradual and density gradients above outer sill levels are weaker than in Boca de Quadra.

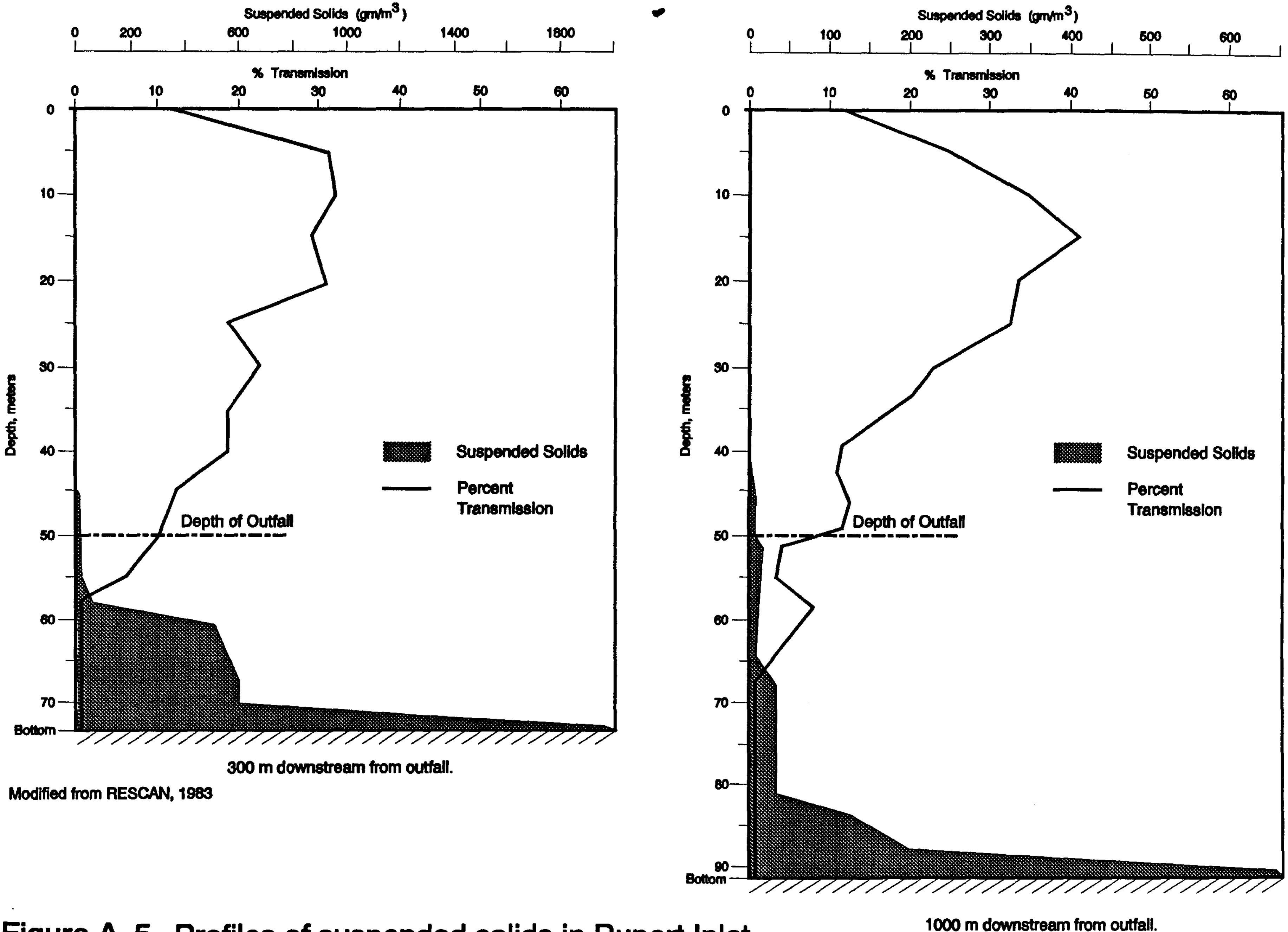


Figure A-5 - Profiles of suspended solids in Rupert Inlet.

Table A-1
Suspended Tailings Concentrations Downstream of Island Copper Discharge in Rupert Inlet, B.C.
(all concentrations in g/L)

Depth (m)	Depth Above the Bottom (m)	Concentration at 300 m	Depth (m)	Depth Above the Bottom (m)	Concentration at 1,000 m
45	28	0	43	48	0.0034
50	23	0.004	49	42	0.0045
55	18	0.012	55	36	0.0119
58	15	0.055	61	30	0.0071
61	12	0.50	67	24	0.0190
64	9	0.55	73	18	0.0150
67	6	0.60	79	12	0.0170
70	3	0.60	85	6	0.120
73	0	2.0	91	0	0.630

In both fjords, the upper water column is most stable during the June through October period. At that time, the pycnocline tends to separate the deep water renewal circulation from surface circulation, thus acting as a barrier to upward circulation and the movement of fines. The depth of the pycnocline at this time varies between 40 and 100 m (U.S.D.A. Forest Service 1988a).

The thickness of the euphotic zone, defined as the depth of light penetration in the upper water column, is another important consideration. A typical depth is 30 m but this also varies seasonally. In summer, light penetration of the upper waters may be inhibited by plankton blooms near surface. On the graphs in Figure A-5, the decrease in transmissivity exhibited in the upper 5-15 meters may be due to this phenomenon. It is important to note that the barrier to vertical circulation formed by the strong summer pycnocline is below the bottom of the euphotic zone.

A 1.4 Liquid Waste Fraction Dispersal (Circulation) Models

Two numerical models were produced in connection with the project, to synthesize the circulation patterns in Wilson Arm/Smeaton Bay and Boca de Quadra. These were used to predict dispersal of tailings fines and the liquid waste fraction of the tailings discharge, in order to determine effects of the discharge on marine water quality. The first model was devised by Kowalik at the University of Alaska (U.S.D.A. Forest Service 1988a). In an attempt to assess the ecological risks associated with STD in the fjords, a second model using a different approach was produced by the Environmental Protection Agency and used in EPA's Best Professional Judgment Evaluation (U.S. EPA 1988). Both models are described in Appendix F of the Final EIS.

In Kowalik's time-dependent, finite difference model, some of the principle assumptions were as follows:

- Separate runs were made for different stages of sediment deposition as predicted by the sedimentation model.
- Across-fjord variations in current, density and suspended sediment were ignored, for any given depth and position along the fjord.
- The geometry of the fjord cross-section was approximated by a rectangle. Side arms were treated as wider sections.
- There was no provision for modelling fresh water inflow, except at the head of the fjord.
- The effects of precipitation, surface heating and cooling, and evaporation were neglected.
- Suspended sediments were treated as not affecting the density structure.
- Suspended sediment values were assumed to be unaffected by deposition or scouring.

The model is driven by specified salinity structures at the mouth of the fjord, by wind stress at the surface, and optionally by the tides. The salinity is time-dependent based on monthly field observations. River inflow at the head of the fjord is an additional forcing agent. Suspended sediment concentration at the top of the density current on the fjord bottom is treated as a boundary condition, and the model predicts sediment transport in terms of percentages of the boundary value, which was assumed to be constant over the width of the fjord. A boundary value of 20 mg/L was chosen, based on the special surveys in Rupert Inlet (see Figure A-5).

Two simulations of the summer deep water renewal event were made, with and without tidal forcing. The initial condition was taken to be the June salinity structure at eight points along the fjord, obtained from field surveys. Salinity observations at the outer sill in July, August and September were interpolated to provide an open-boundary condition varying with time. Model predictions were checked against measurements within the fjord.

EPA's model was designed to provide ready assessment of the full range of natural variability possible in the fjord systems. It was devised using a stochastic approach to obtain a steady-state, finite difference statement of the conservation of suspended sediment in each cell of a rectangular grid similar to that used in the Kowalik model. A constant concentration of suspended tailings along the fjord bottom was applied as a boundary condition. For the deep water renewal and non-renewal seasons, circulation patterns were adopted conforming to available current meter measurements, using best judgments where data were sparse. Such patterns covered not only the present fjord topography but also those predicted by the sedimentation model for deposition years 20 and 55. The settling velocity chosen was that appropriate for the finest 10% of the tailings size spectrum, with a median diameter of five microns; all larger particles were assumed to be lost rapidly by deposition. Horizontal and vertical eddy diffusivities were treated as random variables with assumed probability distributions, as were some of the other unknown factors. The computer program solves for sediment content in each cell using a Monte Carlo procedure, to yield predictions of fine sediment and dissolved heavy metal concentrations in selected areas of the fjords.

The tabulated results from EPA's model suggested only a limited impact on the upper water column from STD. This conformed generally to the predictions of the Kowalik model. According to the Final EIS (U.S.D.A. Forest Service 1988a):

"the reversed estuarine circulation pattern observed in these fjords acts to inhibit the surfacing of sediment plumes, and represents a conservative choice from the point of view of risk assessment."

The major difference in the model results obtained by the University of Alaska and the Forest Service using Kowalik's model, and by EPA using its model, was introduced by the choice of the boundary value for suspended sediments along the fjord bottom, which for both models was the source of the suspended sediments. Using the input from the special survey of the Island Copper discharge in Rupert Inlet (Figure A-5 and Table A-1), the University of Alaska selected 20 mg/L as the typical concentration of suspended sediments at the boundary between the density current and the turbidity plume. Particles within the density current were regarded as not available for advection into the upper waters because the size of the particles were such that they would settle rapidly. From the same data, the Forest Service selected 40 mg/L and the EPA 600 mg/L. Since differences between the models themselves were apparently minor, EPA's results would be approximately 30 times those of the University of Alaska and 15 times those of the Forest Service. This would affect the conclusions of not only the predicted concentrations of suspended sediments, but also the diffusion of dissolved heavy metals.

A 1.5 Summary of Predicted Impacts

Among the many impacts predicted to occur from the submarine disposal of tailings from the project were the following: turning Wilson Arm/Smeaton Bay into a "shallow embayment" with resultant circulation changes and changes in bottom habitat, consequences from escapement of fines into Behm Canal, changes in fjord productivity from suspended sediments in the upper water column, loss of benthic organisms, fisheries impacts, toxicity to marine life from dissolved heavy metals, smothering effects from reduced dissolved oxygen and heavy sediment suspensions, bioaccumulation in the food webs of heavy metals, deposition of tailings in the estuaries, and the like. EPA, in its Final Draft, Ecological Risk Assessment of May 1988 (Kowalik 1984; 1985), determined that the agents that were:

"likely to cause harm are: 1) reagents, 2) settleable solids, 3) suspended sediments, and 4) metals (dissolved and particulate)."

The concerns were examined in depth separately by both the Forest Service and the EPA. Most of them proved upon examination to be of little or no consequence, or to have a very low likelihood of occurrence; however, the Forest Service and EPA, using the same basic information, viewed the risks somewhat differently.

The Summary of the Final EIS provides a good synopsis of the Forest Service's overall view of the impacts on the physical and biological environments predicted, in late 1988, from the disposal of tailings from the Quartz Hill project (U.S.D.A. Forest Service 1988a):

"With the proposed project, Wilson Arm/Smeaton Bay would be impacted by the submarine deposition of tailings. The below-sill depth would be about 78 percent filled and small concentrations of the tailings fines would flow over the outer sill and into Behm Canal. Impacts would change the fjord's bathymetry and circulation pattern, but no significant effects are expected in the upper waters. With the proposed project, all impacts would be in the Wilson Arm/Smeaton Bay basin and no impacts would extend to the Boca de Quadra basin. With tailings disposal into the inner basin of Boca de Quadra, the below-sill depth of the inner basin would be filled and much of the tailings would flow into the deep middle basin. Inner basin bathymetry and circulation would be substantially changed, but impacts to the upper waters are not expected. With middle basin disposal initially, impacts to the middle basin would be similar, but impacts to the inner basin would be reduced or eliminated. With Boca de Quadra disposal, no tailings impacts to Wilson Arm/Smeaton Bay would occur. On-land tailings would eliminate impacts to both fjords.

- The chemical oceanography of Boca de Quadra or Wilson Arm/Smeaton Bay, depending on the alternative, would be affected by the discharge of the mill tailings including solids, dissolved trace metals and milling reagents. Most impacts to the fjord's water quality would be in the near-field discharge plume and the turbidity plume, a layer near the bottom. Water quality impacts could include increased dissolved molybdenum and manganese concentrations, which would be of little consequence. On-land tailings disposal would eliminate chemical oceanographic impacts.

- Marine tailings disposal would impact marine ecology by burial of marine organisms and habitats, direct effects of suspended sediments, and possibly by toxicants present in tailings. Burial of several important bottom dwelling species would occur in affected areas. Potential habitat of herring would be occupied by tailings and/or suspended sediments to varying degrees depending on which basin receives the tailings. Migration of anadromous fish would not be affected, and all tailings impacts to salmon would be insignificant. On-land tailings disposal would eliminate most potential impacts to marine ecology."

The maximum impact of the project on the commercial fishing industry was estimated in the FEIS (U.S.D.A. Forest Service 1988a) to be only about $5,000 to $45,000 per year, depending on the alternative chosen. The higher losses were associated with on-land tailings disposal options because they would obliterate segments of some salmon streams. The lower losses were associated with tailings disposal methods (STD) that have only moderate impacts on salmon, bottomfish, and shellfish. The loss due to the project in the salmon fisheries was expected to be a "negligible proportion" of the whole.

Table A-2 shows estimated maximum annual value of losses of commercial fish and shellfish, by project development alternative.

EPA's Final Draft Ecological Risk Assessment (U.S. EPA 1988), written by Region 10 technical staff, predicted that:

"The loss of benthic organisms due to deposition of tailings would be approximately 4 times greater with the Wilson Arm/Smeaton Bay disposal option than with disposal in Boca de Quadra.

- Water quality degradation (exceedence of the water quality criterion for copper measured as extractable portion of the suspended solids) is to occur throughout the water column as a result of tailings discharge in either of the two fjords proposed as alternative disposal sites.

- As the project proceeds to the 55 year point, the concentration of suspended solids and concomitant copper will increase in the upper water column, presenting a higher probability of harm to pelagic organisms such as herring and salmon. The concentration of suspended solids and copper above 100 meters is higher for Smeaton Bay/Wilson Arm than for Boca de Quadra.

- Concentrations of extractable copper concentrations will exceed water quality standards over a large part of whichever fjord is chosen for the disposal site. In Boca de Quadra, the average concentration of suspended solids and copper are higher than they are in Smeaton Bay/Wilson Arm, but the potential impact upon biota may be greater in Smeaton Bay/Wilson Arm due to the fact that the high concentrations occur higher in the water column where there is likely to be more biological activity."

EPA concluded that:

"In Smeaton Bay/Wilson Arm, the discharge point is within 75-100 meters of the surface during the project's final stage. It is therefore, not surprising that the model predicts increasing impacts in the upper water column as time progresses—It is clear that the aquatic ecosystem in Smeaton Bay/Wilson Arm is less likely able to accommodate the

Table A-2
Estimated Maximum Annual Value of Commercial Fish and Shellfish Losses, by Alternative

		Value of Losses[1]			
Alternative	Option[2]	Salmon	Bottom-Fish	Shell-fish	Total
Tunnel Cr. Mill with Boca de Quadra Tailings Disposal and Commute Option	I	4,134	827	2,398	7,359
Tunnel Cr. Mill with Boca de Quadra Tailings Disposal, Upper Hill Creek Diversion, and Townsites	I	4,303	827	2,398	7,528
	II	4,303	218	484	5,005
	III	4,303	339	878	5,520
Tunnel Cr. Mill with Wilson Arm Tailings Disposal (the Proposed Project)		4,134	522	2,678	7,334
Beaver Cr. Mill with Boca de Quadra Tailings Disposal	I	4,696	827	2,398	7,921
	II	4,696	218	484	5,398
	III	4,696	339	878	5,913
Beaver Cr. Mill with Wilson Arm Tailings Disposal		4,696	522	2,678	7,896
Beaver Cr. Mill with On-Land Tailings Disposal		44,662	-	-	44,662
North Meadow Mill with Boca de Quadra Tailings Disposal	I	9,391	827	2,398	12,616
	II	9,391	218	484	10,093
	III	9,391	339	878	10,608
North Meadow Mill with On-Land Tailings Disposal		44,100	-	-	44,100

1/ All values equal the sum of values for aquatic environments affected. Values by species and environment are shown in Appendix G, Table 18-1. Environments affected by each alternative are shown in Appendix G, Tables 17-1a through 17-1h.

2/ See Appendix G, Table 17-1b.

Source: U.S.D.A. Forest Service (1988a).

introduction of the tailings material than middle basin Boca de Quadra. Due to this natural variation in the two fjords, it may be assumed that the impacts (reagent toxicity, other metal toxicity) which are not addressed in this quantitative statement of risk will also increase the risk estimate for both fjords. Since measurements of the other agents were not completed, and expert knowledge regarding impacts is limited, the expected increases in risk estimates are not included in this analysis."

In countering the concerns raised by EPA, U.S. Borax pointed out that in its opinion EPA's estimate of water quality degradation was unreasonably high because: (a) of the over-estimate in suspended solids dispersion because of misinterpretation of the bottom boundary condition value; (b) EPA had used its protocol of acid-extractable copper in the solids, rather than the biologically available portion of dissolved copper in the liquid fraction of the tailings; and (c) EPA's analysis was based on the copper content of the ore, rather than the tailings.

After careful evaluation of the dissolved copper content of the tailings effluent, U.S. Borax made a commitment that it would meet water quality standards at the outfall. It also offered to lower the outfall level to decrease the likelihood of impacts in the upper water column, and to move the outfall down-fjord late in the mine life, to keep deposited tailings below 100 meters.

A 2.0 Community Involvement

A 2.1 Public Participation

For better or worse, Quartz Hill was a high profile project in the public eye from the start. Located in a scenic and environmentally sensitive area close to a relatively small community, the project attracted much early attention. When the land surrounding the Quartz Hill discovery was withdrawn from economic activity by Presidential action in December 1978, U.S. Borax as the claim owner had to launch a lobbying campaign in Washington to preserve its right to develop the deposit. This attracted the attention of national environmental groups, who used Quartz Hill as a rallying cry for fund raising purposes. However, the Alaska National Interest Lands Conservation Act (ANILCA), signed into law on December 2, 1980, made special provision for development of the project, through the establishment of a 152,610 non-wilderness enclave around the mineral deposit. Public opinion soon became polarized. Local business groups and the vast majority of the local residents supported the project, but there was a small vociferous group that was opposed.

Official public participation in the project began with the application by U.S. Borax to the U.S.D.A. Forest Service for approval of an operating plan for mineral exploration and project development. It was determined that an EIS would be required. In accordance with the regulations implementing the National Environmental Policy Act (NEPA), the Forest Service as the lead agency provided for an early and open process to determine the scope of the issues to be addressed and to identify the significant project-related issues. This was accomplished in two ways: by forming an Interdisciplinary Team (IDT) composed of concerned federal and State of Alaska agency representatives, to whose meetings community representatives were sometimes invited; and by holding scooping meetings and public comment meetings at appropriate times during the development of the several Environmental Impact Statements required at various stages during the development of the project.

Table A-3 lists the major EIS's and other official documents in which the public had some impact (this table also illustrates the excessive length of time needed to permit the project).

Table A-3
Major Quartz Hill Development Documents

Public Date	Document	Required by
Jan. 1977	EIS, U.S. Borax Proposed Mining Access Road for Quartz Hill Project	NEPA
Sept. 1981	Mining Development Concepts Analysis Document (CAD)	ANILCA
July 1982	Final EIS, Road Access and Bulk Sampling at the U.S. Borax Quartz Hill Molybdenum Claims	ANILCA
Feb. 1983	Final EIS, U.S. Borax 1980-83 Operating Plan, Amendments 2, 3 & 4 for the Quartz Hill Molybdenum Claims	Court Order
Dec. 1983	EIS Preliminary Draft, Quartz Hill Molybdenum Project Mine Development	NEPA
July 1984	Draft Environmental Impact Statement, Quartz Hill Molybdenum Project Mine Development	NEPA
May 1987	Revised Draft EIS, Quartz Hill Molybdenum Project Mine Development	NEPA
Oct. 1988	Final EIS, Quartz Hill Molybdenum Project Mine Development	NEPA

Public meetings and public workshops were held at various times in direct connection with the Quartz Hill project development. In addition, there were opportunities for public comment on broader issues indirectly involving Quartz Hill, such as Tongass National Forest and Misty Fjords National Monument management plans. Meetings were also held by the Forest Service and U.S. Borax with community and special interest groups, and public opinion surveys were made (see succeeding sub-sections). Rarely, if ever, had the public had such ample opportunity to comment on a major mine development.

A 2.2 Opinion Surveys

In order to prepare to meet the socioeconomic issues which would arise in the local communities from the development of such a large project, U.S. Borax commissioned socioeconomic research and a public opinion survey. This was performed by Entercom Inc. in late 1981 and published in January 1982 (U.S.D.A. Forest Service 1988a). The survey consisted of a house-to-house sampling of residents of the Ketchikan Gateway Borough, including the City of Ketchikan, the Native American town of Saxman and environs.

The study detailed historical population growth of the local impact area and also ascertained preferences on local development and opinions regarding the project. Entercom's results were generally confirmed by other studies, such as Gee & Carssow's *A Thumbnail Sketch of Community Impacts on Ketchikan* (November 1981) and a survey conducted by the National Institute for Socioeconomic Research (NISR), for the Ketchikan Gateway Borough in 1983. This was an analysis of the social and economic effects resulting from the development and operation of the Quartz Hill molybdenum project. In 1982, Entercom also performed a focus group survey of native, fisherman and high school senior groups.

A 2.3 Community and Special Interest Groups

With a large projected capital expenditure and a location only about 45 air miles from Ketchikan, the project would obviously have a considerable impact on the community. The local impact area was defined as the Quartz Hill project site and the Ketchikan Gateway Borough (KGB), which is the major transportation, service and supply centre for the southern half of southeast Alaska. Population of KGB in 1980 was 11,300, with growth rate for the previous decade averaging 1.2 percent per year (U.S.D.A. Forest Service 1988).

The economy of the KGB is largely dependent on the harvesting and processing of timber and fish products, which have historically exhibited cyclical variations. Tourism has become an increasingly important basic industry and government is a predominant employment sector, accounting for 28.5% in 1982-83. Labor force, employment and unemployment trends were detailed by the Entercom and NISR studies of 1982 and 1983. Unemployment rate for the KGB labor force exceeded 12% in the early 1980's. For the Native American population, it was 2.4 times higher (Forest Service).

Initially, the project developers conceived that mine workers and their families would be housed in a new town to be constructed somewhere in the non-Wilderness enclave, and a number of potential townsites were investigated. In October 1983, however, U.S. Borax decided for environmental and cost reasons to house the workers in Ketchikan and commute them to the mine on a 7 day on - 7 day off basis. This decision met with local approval. Following the close of the public comment period on the Draft EIS, negotiations began as to how to control and mitigate impacts on the KGB communities. The City of Ketchikan, City of Saxman and Ketichikan Gateway Borough assigned their respective managers to a liaison committee composed of two Borough, two Ketchikan and one Saxman representative. U.S. Borax provided its Ketchikan Manager, backed up by its Vice President/Project Manager. An "Agreed Procedure" for discussions was signed by the Mayors and the President of U.S. Borax, along with a Memorandum of Understanding (MOU) (Entercom Inc. 1982) relating to the impact of the mine development upon the Ketchikan area communities.

Most special interest groups were represented indirectly in the negotiation process through the community representatives on the negotiation panel. The native population, centered in the City of Saxman, received direct representation. Native groups seemed generally in favor of the project because of its perceived economic benefit. Although the fishing industry was indirectly represented in community discussions, its interests in the project were more directly represented by a number of federal and State of Alaska agencies who either had permitting authority for the project or participated in the IDT. These included National Marine Fisheries Service, U.S. Fish and Wildlife, the Alaska Departments of Fish and Game, the Alaska Department of Environmental Conservation, and the Southern Southeast Regional Aquaculture Association. In addition, U.S. Borax held several direct meetings with fishermen and fishing trade organizations in order to outline and explain potential impacts of STD and other aspects of the project on the fisheries and enumerate the controls and mitigating measures available. These meetings, however, were poorly attended.

Periodic meetings of the community negotiating committee were held until it became clear that the project would be postponed indefinitely because of permitting delays and for market reasons. In the MOU, U.S. Borax had committed to giving the community a minimum of one year's advance notice prior to beginning mill and mine plant construction, to allow reasonable forecasting of community capital and program needs. U.S. Borax made a further commitment to re-estimate project impacts using a revised population/employment baseline before construction begins.

Although it was left until impacts become clearer to decide on the specific response to each issue, a table of possible mitigation measures was presented in the Final EIS (U.S.D.A. Forest Service 1988a), which commented that:

"MOU procedures and the commitment of the committee representatives provides a strong framework for mitigating impacts in a timely and mutually agreeable manner."

During the course of the project, regulatory approvals at various stages were appealed by certain national environmental organizations and/or their affiliates. The Record of Decision by the Regional Forester for the Final EIS was appealed in 1989 by the Sierra Club Legal Defense Fund. At the time of this writing, no official decision by the Chief Forester of the Forest Service has been made public.

A 3.0 The Permit Decisions

A 3.1 U.S.D.A. Forest Service

The Final EIS for the Quartz Hill project was published in November 1988 by the U.S. Department of Agriculture, Forest Service, with the Forest Service acting as lead agency and the EPA and Army Corps of Engineers acting as cooperating agencies. The intention was that all three agencies would use the FEIS as a platform for their permitting procedures.

The Record of Decision (ROD), published separately but at the same time as the FEIS and written in conjunction with the cooperating agencies, selected tailings disposal in Wilson Arm/Smeaton Bay as part of the "environmentally preferred" alternative. The ROD stated (U.S.D.A. Forest Service 1988):

"The environmentally preferred alternative for tailings disposal is marine disposal in Wilson Arm/Smeaton Bay. Impacts of the discharge will be evaluated through a monitoring program developed by EPA in conjunction with issuance of a National Pollution Discharge Elimination System (NPDES) permit for the tailings discharge. The monitoring is primarily intended to ensure that unreasonable or unanticipated degradation to the aquatic environment is not occurring. The NPDES permit will be designed to avoid exceeding water quality criteria outside the mixing zone for the discharge. Depending on the results of the monitoring program, the permit for tailings disposal may be modified or even terminated, if necessary, prior to the completion of the design life of the project.

There is a slightly higher risk of adverse consequences to the environment with tailings disposal in the Wilson-Smeaton basin than in the Boca de Quadra basin because the overall capacity to receive the tailings is less. Studies demonstrate, however, there is ample capacity, so the difference in risk is not significant. Coupling this with consideration of the impacts on Misty Fjords Wilderness from disposing of tailings in Boca de Quadra, the overall environmentally preferred alternative is disposal in Wilson/Smeaton Basin. Therefore, the preferred alternative is the environmentally preferred alternative."

The ROD went on to explain, as rationale for the selection:

"There is little difference in the environmental effects of tailings disposal in the marine environment between the Wilson Arm and Boca de Quadra fjords. The effect of disposal on anadromous fish, other food fish, and fish habitat is similar in both fjords.

The Wilson Arm alternative offers added advantages. First, the impacts of the mine development are confined to a single, smaller drainage. Second, it reduces the impacts on wilderness values since it is not necessary to construct facilities for tailings disposal in the Misty Fjords National Monument Wilderness as would be required if disposal were in the Boca de Quadra. Third, based on historic and projected molybdenum markets disposal in the Wilson Arm would result in greater community stability for Ketchikan and southeast Alaska. The frequency of mine shutdown will be less and the duration of shutdown would be shorter as a result of the difference in operating costs."

In detailing his decision in the ROD, the Regional Forester for Southeast Alaska stated that he would authorize approval of the U.S. Borax operating plan as described in the FEIS, subject to further mitigation measures; which with respect to tailings disposal, were outlined as:

"Mine tailings disposal will be allowed in the submarine environment of Wilson Arm/Smeaton Bay in accordance with the provisions of the NPDES permit to be issued by the Environmental Protection Agency. A comprehensive monitoring program will be required to provide early signals of tailing behavior so that comparisons to the predictive modeling can be made. Should it be discovered that tailings fill at a faster rate, behave in a detrimental manner, or cause unpredicted resource damage, changes will be needed. The changes could run the spectrum of reducing mine life to altering the tailings disposal site depending on the type and magnitude of variance from the predictive models."

Regarding the increase of permits by the cooperating agencies based on the FEIS, Section VIII of the ROD, "Determinations", stated as follows:

"The EPA will issue a draft National Pollution Discharge Elimination System (NPDES) permit for tailings disposal in Wilson Arm/Smeaton Bay for public review and comment in the immediate future. Following the review period the EPA will issue a final permit. The purpose of the NPDES permit is to ensure compliance with section 402 of the Clean Water Act. The permit will be designed to prevent unreasonable degradation of the marine environment. Section 403 (c) guidelines have been used to evaluate the proposed discharge and are documented in Appendix S of the FEIS."

The ROD also stated that Army Corps of Engineers would be issuing permits for the project under the Rivers and Harbors Act for work in or affecting navigable waters of the United States, and under Section 404 of the Clean Water Act, which provides for discharge of "dredged or fill material" in the waters of the United States.

The State of Alaska had in July 1987, offered to support STD in Wilson Arm/Smeaton Bay, provided that acceptable monitoring and contingency plans were developed. Thus, it appeared at this point that U.S. Borax had won the approval of the major permitting bodies.

A 3.2 The Environmental Protection Agency

In a letter dated December 6, 1988 to J. Michael Lunn, Forest Supervisor for USFS in Ketchikan, Robert S. Burd, Director of the Water Division of Region 10, EPA, stated:

"The Preferred Alternative as described in the FEIS is acceptable to EPA... Our position is that the projected risk does not preclude tailings disposal in either fjord, provided that appropriate environmental monitoring is conducted."

However, Mr. Burd's letter also stated that Boca de Quadra remained EPA's primary choice for STD for environmental reasons.

Early in 1990, the Regional Administrator for EPA's Region 10 in Seattle, who had attempted to balance environmental and socioeconomic factors in the choice of an STD site, left the Agency. Allegations made by employees of EPA Region 10 resulted in a Special Review by EPA's Office of the Inspector General of the Region's handling of air and water issues. The Inspector General's report, issued on May 3, 1990, (U.S.D.A. Forest Service 1988) found that the Regional Administrator's decision to approve a draft NPDES permit for the disposal of mine tailings into Wilson Arm/Smeaton Bay failed:

"...to adequately protect the environment... was not supportable based on available economic or scientific data...(and) was also contrary to the unanimous recommendations of the Water Division management and staff",

that Boca de Quadra was the environmentally preferred site. The report stated that:

"disposal of mine tailings into the Wilson Arm of Smeaton Bay fjord will turn the fjord into a bay. This has the potential to destroy a valuable salmon resource".

Consequently, on May 7, 1990 the Acting Regional Administrator of Region 10 issued a tentative denial of the NPDES application for STD into Wilson Arm/Smeaton Bay. Public hearings were held in Ketchikan and Juneau, Alaska, in June, 1990, followed by a public comment period which elicited 120 letters and a "petition in support of Borax Mine" with approximately 420 signatures. Nevertheless, the denial was confirmed by EPA on September 27, 1990 (Barton 1988).

The Final Decision of the Regional Administrator stated that EPA's earlier proposal to permit STD in Wilson Arm/Smeaton Bay was re-evaluated as a result of "several" public comments opposing the proposal. The comments were to the effect that the proposed discharge would impact the fisheries, benthic organisms and biologically significant upper water column of Smeaton Bay and violate Alaska water quality standards. In its re-evaluation, the EPA found that the "mixing zone", beyond which the likelihood of exceeding Alaska's water quality standards is small, would have to extend upward in the water column above the 100 m depth, which EPA had earlier arbitrarily defined as the important habitat for marine organisms which must be protected. The permit application was therefore denied on the basis that:

"The proposed discharge would significantly impact the existing beneficial uses of Wilson Arm/Smeaton Bay and exceed the water quality standards for sediment and copper."

No comment was made on the ultimate acceptability of Boca de Quadra as a STD site.

Although many questions could have been raised regarding EPA's interpretations of the data which led to this conclusion, U.S. Borax chose not to challenge EPA's decision at that time.

REFERENCES

Amax of Canada Ltd. 1981. *Environmental Monitoring Program, Annual Reports.*

Anderson, E.P. 1986. Lethal and sublethal effects of a molybdenum mine tailing on marine zooplankton: mortality, respiration, feeding and swimming behavior in Calanus marshallae, Metridia pacifica and Euphausia pacifica. *Marine Environment and Resources* 19:131-155.

Asmund, G., P. Johansen and B.W. Fallis. 1991. Disposal of mine wastes containing Pb and Zn near the ocean. *Chemistry and Ecology* 5:1-15.

Baer, R.L., G.E. Sherman and P.D. Plumb. 1992. *Submarine Disposal of Mill Tailings from Onland Sources - an Overview and Bibliography.* U.S. Dept. Int., Bureau of Mines OFR 89-92, 102 pp.

Barton, M.A. 1988. *Record of Decision for Quartz Hill Molybdenum Project Mine Development.* U.S.D.A. Forest Service. Juneau, Alaska. October 24, 1988.

Berkman, D.A. 1976. *Field Geologists Manual.* Australian Institute of Mining & Metallurgy, Parkville, Australia.

BHP-Utah Mines Ltd. 1987. *Notice of Work.* Unpublished internal document. 23 pp.

BHP-Utah Mines Ltd. 1991. *Island Copper Mine; 1990 Annual Environmental Assessment Report.* Volumes 1 and 2. Unpublished. (Available from B.C. Government, Ministry of Environment Lands & Parks).

Brinkhurst, R.O., B. Burd and R.D. Kathman. 1987. Benthic Studies in Alice Arm, B.C. during and following cessation of marine tailings disposal, 1982 and 1986. Can. Tech. Rep. Hydrogen. *Ocean Science* 89:45p.

Buchanan, R.J. 1982. A Government Inquiry into Mine Waste Disposal at Island Copper Mine. Chapter 7, pp 255-270, In *Marine Tailings Disposal.* Ellis, D.V. (Ed.), Ann Arbour Science.

Burd, B. and R.O. Brinkhurst. 1990. *Benthic Infaunal Survey of Alice Arm and Hastings Arm, British Columbia - October, 1989.* Canadian Data Report, Hydrography and Oceans Sciences No. 82, 23 pp.

Burd, B. 1991. *Qualitative and Orientative Studies of Benthic Communities in British Columbia Coastal Waters.* PhD Thesis, University Victoria, B.C.

Burling R.W., J.E. McInerney and W.K. Oldham. 1981. *A Technical Assessment of the Amax/Kitsault Molybdenum Mine Tailings Discharge to Alice Arm.* B.C. Report on Mining Fisheries and Oceans. Government of Canada, Ottawa. 154 pp.

Burling, R.W., J.E. McInerney and W.K. Oldham. 1983. *A Continuing Technical Assessment of the Amax/Kitsault Molybdenum Mine Tailings Discharge to Alice Arm.* B.C. Report for Minister, Department of Fisheries and Oceans. Canada. 145 pp.

Burrell, D.C. 1980-84. *Marine Environmental Studies in Roca de Quadra and Smeaton Bay.* Series of reports by the Institute of Marine Science, University of Alaska. May 1980, April 1981, May 1981, June 1981, April 1982, December 1983, and April 1984.

Chander, S. and D.W. Fuerstenau. 1972. On the natural floatability of molybdenite. *Trans American Institute of Mining Engineering* 252: 62- 69.

Claggett, F.G. 1981. *Size Distribution and Metal Analysis for AMAX Kitsault Tailings.* Environmental Protection Service Report.

Dorsey, A.H. and B.R. Martin. 1986. *Reaching Agreement in Impact Management: A Case Study of the Utah and Amax Mines.* Westwater Research Centre, University of British Columbia, Vancouver. 29 pp.

Drinkwater, K.F. and T.R. Osborn. 1975. The role of Tidal Mixing in Rupert and Holberg Inlets, Vancouver Island. *Limnol. Oceanogr.* 20: 518-528.

Dunne, P.T. 1990. Letter to Gordon L. Toll, Vice-President, U.S. Borax & Chemical Corp., September 27, 1990. Attaching Final Decision of the Regional Administrator of EPA - Region 10 to Deny the National Pollutant Discharge Elimination System (NPDES) Permit for Pacific Coast Molybdenum Company - Quartz Hill Project.

Ellis, D.V. and G.C. Jewsbury. 1974. *Turbidity Reviews III Pacific Salmon - Literature Survey and Population Data.* Report to Island Copper Mine 55 pp.

Ellis, D.V. and A.A. Jones. 1975. *Alice Arm Project: Review of Benthic Infauna Data.* University of Victoria Report 28 pp.

Ellis, D.V. (Ed). 1982. *Marine Tailings Disposal.* Ann Arbor Science, Ann Arbor, 368 pp.

Ellis, D.V. 1982. Kitsault, B.C. - Technical communication in a non-technical world. *Marine Pollution Bulletin* 13(3): 78-80.

Ellis, D.V. and C. Heim. 1985. Submersible surveys of Benthos near turbidity cloud. *Marine Pollution Bulletin,* 16 (5): 197-203.

Ellis, D.V. 1988. Case Histories of Coastal and Marine Mines. Ch 4 pp. 73-100 In *Chemistry and Biology of Solid Waste,* Springer, Berlin, 305 pp.

Ellis, D.V. 1989. *Environments at Risk: Case Histories of Impact Assessment.* Springer-Verlag, NY, 329 pp.

Ellis, D.V. 1990. *The Environmental Protection Program at the WestGold Marine Placer Mining Operation at Nome, Alaska; in the Context of Future Canadian Marine Placer Mining.* Report to Ocean Mining Division, Mineral Policy Sector, Energy Mines and Resources Canada. 31 pp.

Ellis, D.V. and P.M. Hoover. 1990. Benthos recolonizing mine tailings in British Columbia fjords. *Marine Mining* (9): 441-457.

Ellis, D.V. and P.M. Hoover. 1991. Benthos recolonizing mine tailings in British Columbia fjords. *Marine Mining* (9): 441-457

Ellis, D.V., Samoszynski, R. and A.A. Jones. 1991. Re-Analysis of Species Associational Data Using Bootstrap Significance Tests. *Water, Air and Soil Pollution.* 59: 347-358.

Entercom (Eds). 1982. *Ketchikan Gateway Borough Resident Survey.* Report prepared for U.S. Borax 18 pp.

Entercom Inc. 1982. *Ketchikan Gateway Borough Socioeconomic Impact Analysis Summary.* Denver, CO. September 1982.

Farmer, D.M. 1982. Summary: engineering and scientific principles. In *Marine Tailings Disposal,* D.V. Ellis (ed.). Ann Arbor Science. pp. 183-192.

Farrell, M.A. and M.D. Nassichuk. 1984. *Trace Metal Levels in Bivalves and Crabs from Alice Arm, Hastings Arm and Observatory Inlet, B.C.* Canada in Data Report on Fisheries and Aquatic Sciences, No. 467.

Findikakis, A.N. 1983. *Study of Submarine Tailings Disposal in Boca de Quadra - Appendix A: The Density Current/Sedimentation Mathematical Model.* Bechtel Civil and Minerals, Inc.

Findikakis, A.N. 1984. *Sedimentation Model Output 100 lbs/cu. ft. Case, Boca de Quadra.* Bechtel Civil and Minerals, Inc. October 1984.

Findikakis, A.N. 1985. *Study of Submarine Tailings Disposal in Wilson Arm/Smeaton Bay.* Technical Memorandum. Bechtel Civil and Minerals, Inc. March 1985.

Fish, R. 1974. Mining in Arctic Lands - The Black Angel Experience. *Canadian. Mining Journal* 8:24-29.

Fisher, T.R., P.R. Carlson and R.T. Barber. 1982. Sediment Nutrient Regeneration in Three North Carolina Estuaries. *Est. Coast. Shelf.* Sci. 14: 101- 116.

Gardner, L.A. 1992. *Regulatory Processes Associated with Metal-Mine Development in Alaska: A Case Study of the WestGold BIMA.* U.S. Dept. Int., Bureau of Mines OFR 88-92, 34 pp.

Goddard, J.M. 1975. *Oceanographic and Marine Biological Surveys in Alice Arm and Hastings Arm, B.C. (4). Benthic Infauna of Alice Arm and Hastings Arm, B.C.* Data Report to Dr. J.L. Littlepage. Dobrocky Seatech Ltd. 41 pp.

Harding, L. 1983. *Use of Fjords for Disposal of Mine Tailing.* Coastal Zone 1983. pp 32-51.

Hawley, J.R. 1972. *The Use, Characteristics and Toxicity of Mine-Mill Reagents of the Province of Ontario.* Ontario Ministry of Environment.

Hay, A.E. 1982. 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.

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

Hesse, C.A. and K.M. Reim. 1993. *Regulatory Aspects of Submarine Tailings Disposal in the Quartz Hill Case History.* U.S. Bureau of Mines, OFR 66-93, March, 1993.

Holeman, J.N. 1968. *Water Resource Research.* 4:737.

Island Copper Mine, Environmental Department. 1988. *Beach Waste Dump - Present and Future Impacts on Rupert Inlet.* Unpublished Internal Document, Unpaginated.

Jain, S.C. and J.F. Kennedy. 1984. *Near-Field Model Study of Mine-Tailings Discharge into a Fjord.* Institute of Hydraulic Research, The University of Iowa, September 1984.

Jewett, S.C., N.A. Sloan and D.A. Somerton. 1985. Size at sexual maturity and fecundity of the fjord-dwelling golden king crab Lithodes aequispina Benedict from northern British Columbia. *Journal of Crustacean Biology* 5(3): 377-385.

Jewett S.C., L.A. Gardner, P.C. Garvin and C.E. Sweeney. 1991. *Nome Offshore Placer Project, Final Annual Report 1990.* ENSR Consulting and Engineering Report for Western Gold Exploration and Mining Company. Nome, Alaska.

Jones, A.A. 1975. *The Role of Biologists in Pollution Control Branch Decision Making, with Particular Reference to the Ganges Harbour and Utah Mines Cases.* MPA Thesis, University of Victoria.

Kathman, R.D., R.O. Brinkhurst, R.E. Woods and D.C. Jeffries. 1983. Benthic studies in Alice Arm and Hastings Arm, B.C. in relation to mine tailings disposal. *Canadian Technical Report of Hydrology and Ocean Sciences* 22:30 pp.

Kathman, R.D., R.O. Brinkhurst, R.E. Woods and S.F. Cross. 1984. Benthic studies in Alice Arm, B.C. following cessation of mine tailings disposal. *Canadian Technical Report of Hydrology and Ocean Sciences* 37, 57 pp.

Kowalik, Z. 1984. *The Physical Oceanography of Boca de Quadra; Marine Environmental Studies in Boca de Quadra, Numerical Modeling of the Boca de Quadra Fjord.* Institute of Marine Science, University of Alaska.

Kowalik, Z. and A.N. Findikakis. 1985. *The Physical Oceanography of Wilson Arm/Smeaton By: The Numerical Modelling of Fjord Circulation and Submarine Disposal of Mine Tailings in Wilson Arm/Sneaton Bay, Southeast Alaska.* U.S. Borax and Chemical Corporation.

Krauel, D.P. 1981. *Deep Water Flow and Exchange Processes in Alice Arm, B.C.* Department of Fisheries and Oceans Contractor Report Series. 81(-4), 137 pp.

Levinson, A.A. 1974. *Introduction to Exploration Geochemistry.* Applied Publishing, Calgary.

Littlepage, J.L. 1978. *Oceanographic and Marine Biological Surveys, Alice Arm and Hastings Arm, B.C. 1974-1977.* Report to Climax Molybdenum Corp. of B.C. Ltd.

Losher, A.J. 1985. *The Geochemistry of Sediments and Mine Tailings in the Alice Arm Area.* M.Sc. Thesis, University of British Columbia, 189 pp.

Loudon, P. 1973. *The Town that Got Lost: The Story of Anyox, British Columbia.* Graves Publ., Sydney, B.C. 111 pp.

Lucas, A.R. and P.A. Moore. 1973. The Utah Controversy: A case study of public participation in pollution control. *Natural Resources Journal* 13(1): 36-75.

Mackas, D.L. and E.P. Anderson. 1986. Small-scale zooplankton community variability in a northern British Columbia fjord system. *Estuarine and Coastal Shelf Sciences* 22:115-142.

Martin, John C. 1990. *Special Review of EPA Region 10 Employee Allegations on the Region's Handling of Air and Water Issues.* Report No. Ega WGO-10-0022-0400015. EPA, Washington, DC. May 3, 1990.

McVey, Robert W. 1986. Director, Alaska Region, National Marine Fisheries Service. Letter to John Paulsen, U.S. Borax & Chemical Corp., July 22, 1986.

Mikkelborg, E. 1974. Looking Over the Black Angels' Shoulder. *Canadian Mining Journal* 8:30-36.

Mitchell, D.G. *et al.* 1984. *Report on Acute, Chronic and Sublethal Bioassays and Bioaccumulation Studies for the Quartz Hill Project, Southeast Alaska*, E.V.S. Consultants. Vancouver, B.C.

Nebert, D.L. and D.C. Burrell. 1982. *Marine Environmental Studies in Boca de Quadra and Smeaton Bay.* February 1981, Revised 1982.

Nebert, David L. 1983. *Physical Oceanography of Roca de Quadra, The Physical Oceanography of Smeaton Bay-Wilson Arm.* University of Alaska, Fairbanks. September 1983, February 1984, May 1985.

O'Connell G.W. and S. Byers. 1977. *Oceanographic and Marine Biological Surveys in Alice Arm and Hastings Arm, B.C., Features of the Intertidal and Subtidal Macrobiota of Alice Arm and Hastings Arm.* Dobrocky Seatech Ltd. Report for Dr. Littlepage. Alice Arm Survey, No. 2.

Pedersen, T.F. 1984. Interstitial Water Metabolite Chemistry in a Marine Mine Tailings Deposit, Rupert Inlet, B.C. *Canadian Journal Earth Science* 21: 1-9.

Pedersen, T.F. 1985. Early Diagenesis of Copper and Molybdenum in Mine Tailings and Natural Sediments in Rupert and Holberg Inlets, British Columbia. *Canadian Journal Earth Science* 22: 1474-1484.

Pedersen, T.F. and A.J. Losher. 1988. Diagenetic Processes in Aquatic Mine Tailings Deposits. pp 238-258. In *Chemistry and Biology of Solid Waste,* Salimons, W and U. Forstner. (Eds) Springer-Verlay. Berlin. 305 pp.

Pedersen, T. and C.A. Pelletier. 1989. *Subaqueous Disposal of Reactive Mine Wastes.* MEND, Ottawa.

Pedersen, T.F., B. Mueller, J.J. McNee and C.A. Pelletier. 1991. *Diagenetic Reactivity of Mine Tailings in Mesotrohic and Oligotrophic Lakes in Manitoba and British Columbia.* Proc. 2nd Int. Conf. on the Statement of Acidic Drainage, MEND, Montreal.

Pelletier, C. 1982. Environmental Data Handling and Long-term Trend Monitoring at Island Copper Mine. pp. 197-237, In *Marine Tailings Disposal*, Ellis D.V. (Ed) Ann Arbor Science.

Pickard, G.L. 1963. *Oceanographic Features of Inlets in the British Columbian Coast.* J. Fish. Res. Bd. Can. 20: 1109-1144.

Poling, G.W. 1973. Sedimentation of Mill Tailings in Freshwater and in Seawater. *Canadian Institute of Mining Bulletin* 66:97-102.

Poling, G.W. 1982. Characteristics of Mill Tailings and Their Behaviour in Marine Environments. In *Marine Tailings Disposal*, Ellis D.V. (Ed.) Ann Arbor Science.

Public Law 96-487, 96th Congress Alaska National Interest Lands Conservation Act. Section 505(b)5.

Quartz Hill Molybdenum Project. 1987. Revised Draft EIS. U.S. Dept. of Agriculture, Forest Service.

Rambold P.S. and D.J. Stucchi. 1983. An analysis of the Alice Arm crash program data - Summer 1981. *Canadian Technical Report of Hydrography and Ocean Science* 25, 66 pp.

Reid B.J. 1984. *Preliminary Laboratory Study of the Effects of Burial by Amax/Kitsault Mine Tailings on Marine Invertebrates (Microform).* Water Quality Unit, Habitat Management Division, Field Services Branch, Department of Fisheries and Oceans. 44 pp.

Reim K.M., F.A. Leonard and R.B. Ellingson. 1988. *Planning Considerations for Quartz Hill Mine, Southeast Alaska.* Report of Annual Meeting for Society of Mining Engineers. Jan 25-28, 1988. Phoenix, AR. 88-53, 9 pp.

Rescan Environmental Services Ltd. 1982. *Long Term Considerations in Environmental Impact Assessment for the Quartz Hill Submarine Tailing Disposal System.* Vancouver, B.C.

Rescan Environmental Services Ltd. 1983 and 1984. *Suspended Solids Survey of Rupert Inlet, B.C.* Vancouver, B.C.

Rescan Environmental Services Ltd. 1984. *Assessment of Three Submarine Disposal Site Alternatives for the Quartz Hill Molybdenum Project, Southeast Alaska.*

Rescan Environmental Services Ltd. 1985. Letter to J.C. Paulsen, U.S. Borax, October 9, 1985.

Rusanowski, P.C., L.A. Gardner and S.C. Jewett. 1987. *Nome Offshore Placer Project Annual Report - 1986.* Report to Inspiration Gold Inc. Nome, Alaska.

Rusanowski, P.C. 1989. Nome Offshore Placer Project, Issues and Answers -- A three Year Perspective. In *llth Annual Conference on Placer Mining, March 29-April 1, 1989.* Fairbanks, Alaska.

Rusanowski, P.C. and L.A. Gardner. 1989. *Nome Offshore Placer Project Synthesis Report.* 1988. Western Gold Exploration and Mining Company. Nome, Alaska. 38 pp.

Rusanowski, P.C. 1990. *BIMA Discharge Configuration Analysis Summary.* Westgold, August 15, 1990.

Rusanowski, P.C. and C.L. MacCay. 1990. *Nome Offshore Placer Project - 1989 Synthesis Report.* Western Gold Exploration and Mining Company. Nome, Alaska. 48 pp.

Ryan, P.J. 1983. *Study of Submarine Tailings Disposal in Wilson Arm/Smeaton Bay.* Bechtel Civil & Minerals, Inc. San Francisco, CA.

Sloan N.A. 1985 *Life history characteristics of fjord-dwelling golden king crabs* ***Lithodes aequispina***. Mar. Ecol. Prog. Ser. 22, 219-228.

Sloan, N.A. and S.M.C. Robinson. 1985. The effect of trap soak time on yields of the deep-water golden king crab (*Lithodes Aequispina Benedict*) in a northern British Columbia fjord. *Journal of Shellfish Research.* 5(1), 21-23.

Snook, J.R. 1982. Petrology and Petrography of the Quartz Hill Molybdenum Deposit. In *Marine Tailings Disposal, Ellis (Ed.).* Ann Arbor Science Publishers.

Stukas, V.J. 1981. *Distribution of Heavy Metals Derived from Mine Tailings in Alice Arm, British Columbia, Using Isotope Geochemistry.* Ocean Chemistry, Institute of Ocean Sciences. Sidney, B.C. Unpublished Report. 118 pp.

Stumm, W. and J.J. Morgan. 1981. *Aquatic Chemistry,* 2nd Ed., Wiley Inc. New York.

Suttill, K.R. 1991. A technical buyers guide to mining chemicals. *Engineering & Mining Journal* pp 23-34, August.

Sverdrup, H.U., M.W. Johnson and R.M. Fleming. 1942. *The Oceans.* Prentice Hall, Englewood Cliffs, N.J.

Taylor, L. 1986. *Marine Macrobenthic Colonization of Mine Tailings in Rupert Inlet, British Columbia.* M.Sc. Thesis, Univ. Victoria, 155 pp.

Thompson J.A.J., M.D. Nassichuk, D.W. Paton, B.J. Reid. and M.A. Farrell. 1986. Examination of tissue metal burdens and metal-binding proteins in the golden king crab. *Cananadian Technical Report of Fisheries and Aquatic Sciences* 1440:44 pp.

U.S. Borax. 1983. *Comparative Assessment of Tailings Disposal Alternatives.* December, 1983.

U.S. Borax (Eds). 1987. *The Decision Phase. An Investment in Alaska's Future. Quartz Hill Development Project.* 6th Ed. 12 pp.

U.S. Environmental Protection Agency. 1988. *Final Draft: Ecological Risk Assessment for Quartz Hill Molybdenum Mining Project.* May 1988.

U.S.D.A. Forest Service. 1988a. *Final Environmental Impact Statement for Quartz Hill Molybdenum Project Mine Development; Volume 1 and 2.* Tongass National Forest R10-MB-41a.

U.S.D.A. Forest Service. 1988b. *N.D. A BPJ Evaluation Using the Ocean Discharge Criteria for Mill Tailings Disposal from the Proposed Quartz Hill Molybdenum Mine.* Final; Region 10, Seattle, Washington.

Utah Mines Ltd. 1969. *Brief in Support of an Application Under the Pollution Control Act to Discharge Tailings into Rupert Inlet.* Unpublished Report. 14 pp. plus Appendices.

Waldichuk, M. and R.J. Buchanan. 1980. *Significance of Environmental Changes Due to Mine Waste Disposal in Rupert Inlet.* Fed/Prov./ Review of Mine Waste Disposal Problem in Rupert Inlet, BC. 56 pp.

Western Canada Hydraulic Laboratories Ltd. 1976. Report to Climax Molybdenum Corporation.