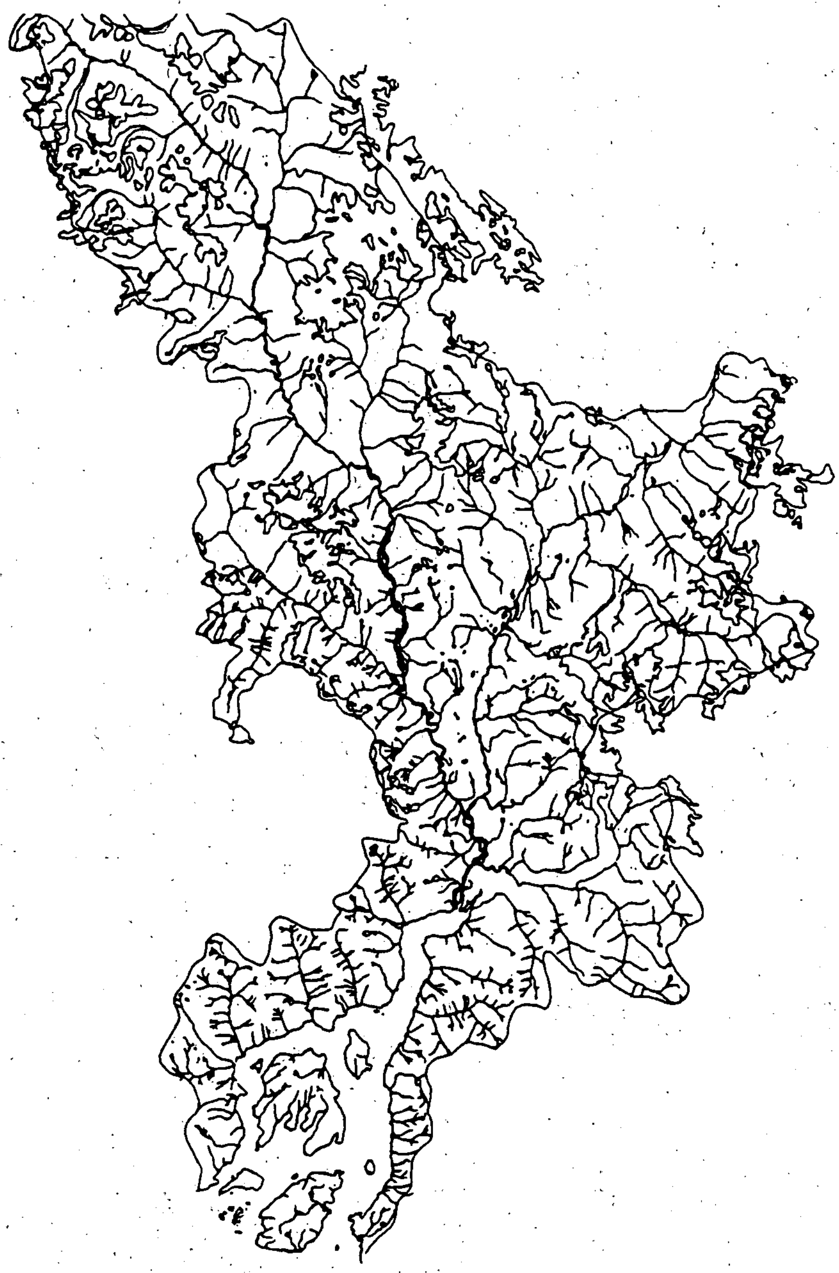
HOWE SOUND ENVIRONMENTAL SCIENCE WORKSHOP



September 30-October 3
1991
Bowen Island, B.C.

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Brian Clarke	B.C. Ministry of Environment, 10334 152A St, Surrey, B.C
Walt Cretney	Fisheries and Oceans, P.O. Box 6000, Sidney, B.C.
Colin Levings	Fisheries and Oceans, 4160 Marine Drive, West Vancouver
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Howe Sound Environmental Science Workshop
Program Outline

October 1, 1991

MORNING SESSION:

Welcome and Opening Remarks	0900-0915
Hamilton Pond Jackson/Steyn	0915-1000
Discussion	1000-1030
COFFEE	1030-1050
Deans Stronach et.al McLaren/Cretney	1050-1135
Discussion	1135-1200
LUNCH	1200-1300

AFTERNOON SESSION:

Swain/Moore Lucey et.al	1300-1330
Discussion	1330-1350
Hickin Jordan	1350-1420
Discussion	1420-1445
COFFEE	1445-1505
Harding Marliave Levings/Riddell	1505-1550
Discussion	1550-1620
Dwernychuk Drysdale/Pedersen	1620-1650
Discussion	1650-1710
DINNER	1800

EVENING SESSION:

Poster Presentations (cash bar)	1930-2130

Bovis et al, Brooks, Broughton, Brugman, Cretney et al, Jackson, Matysek & Sibbick, Pharo & Levings, Prior & Bornhold, Rempel, Stronach, Wilson

October 2

A full day field trip by charter boat (the 72 foot *Eloquent*) around Howe Sound will feature on site discussion of the paper mills (stops to be negotiated), Squamish estuary and harbour front, Britannia Mine, and landslides and debris flows and efforts at mitigation along Squamish Highway. Technical presentations will be made at points of interest.

DINNER	1800

EVENING:

Bill Rees, Keynote Speaker	1930

October 3

MORNING SESSION:

Stockner Whitehead Reid/Brand	0900-0945
Discussion	0945-1015
COFFEE	1015-1035
Nuszdorfer Seip/Savard	1035-1105
Discussion	1105-1125
Nassichuk Huston	1125-1155
Discussion	1155-1215
LUNCH	1215-1315

AFTERNOON SESSION:

Plenary Session Dunn	1315-1345
General discussion, recommendations.	1345-1600

CONTENTS

ABSTRACTS

FOR ORAL, POSTER &FIELD PRESENTATIONS

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Neoplasia and Biomarkers in Fish and Bivalves, Collected near Pulpmills

D.G. Brand, c/o Department of Biology, University of Victoria
P.O. Box 1700, Victoria, B.C. V8W 2Y2

Sublethal toxicity tests make it possible to detect incipient effects on fish and shellfish and aids in the estimation of threshold concentrations for various pollutants. Multidisciplinary efforts, often those in which pathology is allied with biochemistry, is an effective approach for documenting exposure to and evaluating the effects of pollutant stress. Our research is concerned with the examination of the impact of pulp mill effluents on marine benthic organisms by measuring a suite of selected stress responses. Three British Columbian pulp mills were surveyed. Two species of flatfish (*Parophrys vetulus* and *Hippoglossoides elassodon*) and deposit-feeding bivalves (*Yoldia thraciaeformis* and *Macoma calcarea*) were collected. Samples were examined histopathologically for idiopathic lesions and biochemically for the induction of MFO enzymes and metallothioneins. Preliminary results have revealed a 20% prevalence of idiopathic liver lesions in flatfish, the presence of fused and stunted gill lamellae, and the induction of MFO enzymes and metallothioneins. This bioindicator approach can serve as an early warning signal and give insight into causal relationships between stressors and effects resulting from a complexly contaminated marine environment.

Aspects of Postglacial Sediment Supply to Squamish River

G.R. Brooks, Department of Geography, Simon Fraser University
Burnaby, B.C. V5A 1S6 POSTER

Recent work has focused upon two major components of the postglacial sediment supply to Squamish River: mass movement from Mt. Caley, and the reworking of glacial deposits.
Mt. Caley is the largest Quaternary volcano in the central portion of the Garibaldi Volcanic Belt. Stratigraphic work examining debris avalanche and backwater deposits along the bottom of Squamish Valley reveal a long chronology of debris avalanches and river impoundments attributed to debris avalanches. This chronology began with a massive collapse of the Mt. Caley volcanic cone ~4800 years BP which generated the largest of the debris avalanches (~2 x 10^8 m^3). Subsequent debris avalanches have been smaller (up to ~2 x 10^7 m^3), but have occurred regularly up to the present day. These debris avalanches and related secondary debris flows form an episodic sediment supply to Squamish River. The present unstable character of the Mt. Caley cone suggests that they will continue to supply the river in the future.

Extensive incised valley fill deposits in the five major tributary valleys identify the occurrence of a major sediment transfer into the trunk valley. The valley fill deposits relate to the Fraser Glaciation and consist of ice-contact glaciofluvial, and glacio-lacustrine, deposits. Radiocarbon dating of fluvial terraces excavated into the valley fills indicates that the incision generally ceased thousands of years ago, with the most representative date being ~4150 years BP from Ashlu Valley. The volume of material involved varies considerably between valleys (6 x 10^6 to 3.6 x 10^8 m^3), reflecting local valley morphology and late Quaternary history. The incision of the valley fills is believed to represent the primary source of the reworked component of paraglacial sedimentation.

The reworked and mass-movement components of the sediment supply condition the contemporary morphology of Squamish River and also control the present position and rate of advance of Squamish Delta.

Assessment and Control of ARD, From Britannia Mine Site

Linda M. Broughton, Division Head - ARD, Steffen Robertson and Kirsten (B.C.) Inc., #800 - 580 Hornby Street,
Vancouver, B.C.V6C 3B6 POSTER

The decommissioned Britannia Mine is located at Britannia Beach approximately 48 km north of the city of Vancouver, on the east shore of Howe Sound. The underground and open pit mine was operated by the Britannia Mining and Smelting Company Ltd. from 1905 to 1963 at which time it was purchased and operated by Anaconda Mining Company until shutdown in 1974. During operation, approximately 45 million tonnes of ore were processed for recovery of copper and lesser amounts of silver, zinc and gold.

Acid rock drainage containing elevated acidity and metal levels has issued from the Britannia Site since the operational period, discharging into Britannia Creek and Howe Sound. In 1972, in an attempt to improve drainage quality from the site, acidic mine water was diverted within the mine workings for treatment in a copper cementation plant prior to discharge at depth to Howe Sound. Recent investigations however have indicated that contaminated water is again draining directly into Jane Creek and then into Britannia Creek and ultimately into Howe Sound.

We recently completed an investigation of ARD from the Britannia mine site for the B.C. AMD Task Force. An assessment of acid generation and the sources of contaminated drainage was conducted, and alternative options for control and remediation developed. Site water quality data was compiled in a Geographic Information System (GIS) with recent topographical data for graphical display of the sources of contaminated drainage, and the current physical nature of the site.

The Britannia site could provide a rather unique opportunity for research and investigation into ARD processes and control. The site is readily accessible by road with a long history of ARD potentially from all components of any mine site; open pits, underground, tailings, waste rock and construction materials. Consideration should be given to developing the site as a research facility, and also as an opportunity to disseminate information to the public regarding acid rock drainage and the measures that can be taken to assess and remediate these sites.

Glacier Water Input into Howe Sound from Garibaldi Lake Region

Melinda M. Brugman, National Hydrology Research Institute, 11 Innovation Boulevard, Saskatoon, Saskatchewan S7N 3H5 POSTER

The seasonal timing and volume of water input into the Howe Sound region is strongly modulated by the presence of glaciers, some of the largest of which occur in the Garibaldi Lake region. This paper treats the impact of Sentinel Glacier on the level of Garibaldi Lake and the downstream string of lakes and streams through which the water discharges. This study is important because glaciers make a large impact on the amount and timing of runoff generated, water stored enroute in lakes, and water discharged into Howe Sound from the Garibaldi Lake Basin, and because of the related hazard potential of large landslides at Barrier Dam and in vicinity of Rubble Creek. Generally the highest lake levels occur during late summer, and have been assumed to be due to glacier runoff, although lake levels should be highest near the time of maximum snow melt in late spring to early summer. This issue is examined using a simple surface runoff and lake-water storage model, that is coupled to a model of the local groundwater flow and glacier mass balance behaviour.

Glacier extents have dramatically reduced in the region since the 1920's and have apparently caused a reduction in summertime runoff into the lake. Average glacier water input into Howe Sound is estimated using Sentinel Glacier as an index basin for the other relevant glaciated areas. Future trends of glacier runoff into Howe Sound from the basin are projected for doubling of atmospheric CO_2 and attendant warming; these are compared to effects of possible return to "Little Ice-Age" conditions. Glacier water input is an important component of the water balance in Howe Sound, and may change significantly during the next century.

Spatial and Temporal Distributions of Dioxins in Subtidal Sediments from Howe Sound, B.C.

W.J. Cretney, N.F. Crewe, R.W. Macdonald, D.W. Paton,
Institute of Ocean Sciences, 9860 West Saanich Road,
Sidney, B.C. V8L 4B2 POSTER

Howe Sound, a fjord system contiguous with the Strait of Georgia, has two bleached-kraft mills at Woodfibre on the upper basin and Port Mellon on Thornbrough Channel. Subtidal surface sediments were collected at mid-channel at varying distances from both mill sites to look for trends in the PCDD and PCDF distributions. Sediment cores were collected and age-dated to examine the historical records of these compounds as well as those of PAHs, PCBs and other selected organics and metals. In surface sediments, the concentrations of PCDDs and PCDFs generally diminished with distance from the mill sites. In cores, 2,3,7,8 T4CDF, the H6CDDs and the H7CDDs were found to exhibit elevated concentrations dating from about the time of the introduction of chlorine bleaching of pulp. The O8CDD concentrations, however, were found to have been elevated for a period of time before that. These results and those from other congeners, organic compounds and the metals are consistent with a time-varying, mixed input of mill and combustion derived dioxins and furans.

Geochemical Behaviour of the Buried Britannia Mine, Tailings Deposit in Howe Sound, British Columbia

Karen Drysdale, Department of Geography, University of Victoria
Victoria, B.C. V8, and T.F. Pedersen, Department of Oceanography
University of British Columbia, Vancouver, B.C. V6T 1W5

The Anaconda Mine at Britannia Beach, B.C. operated for 75 years, dumping a tailings slurry enriched in copper, zinc, and lead into the restricted inner basin of nearby Howe Sound. We report here the extent of metal contamination still evident in the surface sediments of the sound (despite roughly 16 years of dilution by natural sediments) and the present reactivity of those tailings. Analysis of 150 surface and core samples from throughout the sound show that copper, zinc and lead are still enriched in sediments near the original mine outfall, though metal levels are considerably diluted relative to concentrations found shortly after the mine shut down. With distance from the mine site, metal levels rapidly decrease in surface sediments in both basins, approaching normal background levels for the area. Porewater analyses were undertaken in two cores to determine the redox conditions within the sediments, which in turn can determine the reactivity, or mobility, of trace metals. The inner basin, which is periodically hypoxic at depth due to restricted deep water circulation, has a compressed redox profile: the sediments are anoxic very close to the sediment/seawater interface. Dissolved Cu and Zn are enriched in surficial pore waters in both the inner and outer basins ([Cu] = 215 nM and 132 nM respectively; [Zn] = 32 μM and 1.6 μM, respectively) but decrease rapidly within the top 2-3 cm, indicating active removal at shallow depths. Dissolved interstitial Pb contents, in contrast, are universally low (<3nM). The absence of dissolved sulphides in porewaters (despite the presence of sulphate reduction) indicates that authigenic sulphides are precipitating in the deposits. Such reactions probably account for the depletion of dissolved trace metals at depth. The data strongly suggest that metal release from the buried tailings is effectively prevented by the existing diagenetic regime.

Organochlorines in the Marine Environment of Howe Sound

L.W. Dwernychuk, R.P.Bio., Hatfield Consultants Ltd.
201 - 1571 Bellevue Avenue, West Vancouver, B.C. V7V 1A6

Studies on the environmental effects of pulpmill activities in Howe Sound have been carried out by various groups since 1975. These studies addressed sediments, benthic/intertidal/pelagic organisms, plankton and water quality. These earlier programs were relatively inconsistent with respect to overall study design on both temporal and spatial scales. With increasing public and regulatory interest in bleached kraft pulpmill effluents, the Department of Fisheries and Oceans, Department of Environment and department of National Health and Welfare were involved in the collection/analyses of biological tissues from Howe Sound in 1988. The interpretation of data for specific organochlorine compounds during the 1988 programs resulted in a closure of the commercial harvest for shrimp, prawn and crab in portions of Howe Sound (November 1988). It was stated that these closures were implemented as a result of unacceptable levels of dioxins/furans found in consumable tissues.

Subsequent to the initial closure, Howe Sound Pulp and Paper Limited and Western Pulp Limited Partnership were issued directives from Environment Canada (Environmental Protection) in December 1988 to design and implement a baseline organochlorine survey. This study was conducted in January/February 1989 and focused on sediments and biological tissues. Subsequent to submission of data and a review by Department of National Health and Welfare, Department of Fisheries and Oceans extended closure boundaries in the Sound.

During 1990, a comprehensive monitoring program was initiated. This investigation examined effluent dispersion through dye tracer studies, contaminants in sediments and groundfish, AOX/chloroform at specific depths in the Sound, water quality profiles (pH, temperature, dissolved oxygen, salinity) from surface to near-bottom depths and community analyses on subtidal benthic macroinvertebrates. The two Howe Sound mills also conducted an additional crab program in September/October 1990. This study repeated sampling at previously targeted sites.

Pursuant to a further directive from Environment Canada and the Department of Fisheries and Oceans in February 1991, a Trend Monitoring Program was initiated in Howe Sound addressing dioxins/furans in tissues of crab, prawn and shrimp (in addition to select sediment locations); this program was targeted as an annual study to be performed during the February/March period to facilitate data comparability (site-specific and with other coastal regions).

This presentation will focus on organochlorines detected in certain ecological compartments within Howe Sound (ie., sediments and crab muscle and hepatopancreas tissues). The data review will encompass the time span of 1988 through 1991. It should be noted that at the time of abstract preparation, organochlorine analyses on recently collected sediments and crab tissues are in progress.

RGS: A Regional Environmental Survey?

P.F. Matysek and S. Sibbick, Geological Survey Branch, Environmental Geology Section, B.C. Ministry of Energy, Mines and Petroleum Resource 200-756 Fort Street, Victoria, B.C. V8V 1X4 POSTER

Since 1976, the British Columbia Geological Survey Branch, in cooperation with the Geological Survey of Canada, has conducted Regional Geochemical Surveys across the province to assess mineral potential and stimulate exploration in the mining sector. Samples of stream or lake sediment are collected from second order streams every ten square kilometres and analyzed for upwards of 30 elements such as copper, zinc, lead, antimony, arsenic, bismuth, cadmium, mercury and uranium. Water samples collected at each site are analyzed for uranium, fluorine and pH. During sample collection, the physical characteristics of each sample and the surrounding sample site are recorded. To date, over 1.3 million analytical determinations have been performed on 38,000 samples covering approximately sixty-five percent of British Columbia. Constituting one of the largest geochemical databases in the country, this high quality data is available both in digital and map format. In 1990, a survey in southeastern B.C. included analysis of waters for total concentrations of arsenic, cadmium, copper, lead and zinc sulphates. The Howe Sound drainage basin was surveyed in 1981 and 1989.

Regional Geochemical Surveys provide information on the composition of bedrock within drainage basins as well as information on the physical characteristics of the drainages themselves. Studies of RGS data have indicated that natural background concentrations of elements in sediments vary widely and are strongly dependent upon the underlying rock type.

Potential applications of the RGS dataset include its use as a baseline database to assist in the determination of acceptable levels of elements in lakes or streams. In addition, the RGS dataset can also aid in the identification of areas which contain abnormal levels of deleterious elements. Expertise in sampling techniques, analytical methods, quality control and data reduction procedures utilized and developed over the 15 year lifetime of the Regional Geochemical Survey will benefit environmental studies in British Columbia.

The Howe Sound Fjord: Geological and Geophysical: Evidence for its Origin and Quaternary Development

T.S. Hamilton, Pacific Geoscience Center, Geological Survey of Canada, P.O. Box 6000, Sidney, B.C. V8L 4B2

Marine seismic profiles and regional maps are used to identify Howe Sound's geology and sedimentary processes. The fjord incises the Coast Mountains about halfway from Georgia Strait to the Garibaldi Arc. The narrow reach from the Squamish River mouth to the Porteau Sill has depths to 285 m. Flow is confined to <55 m over the sill while lower Howe Sound has depths >245 m. Bedrock relief is great and sediment thickness locally exceeds 500 m. Despite regional lineations of 41° and 131° in the geology, gravity, magnetics and seismicity; no active faults are known.

Substrates include: modern sand to superhydrous silt, tailings and organic waste, glaciomarine turbidites, diamicts and various bedrock types. Rock is restricted to slopes over 30° and hills.

Layered reflectors and diffractors characterize proglacial turbidites (>17,000 B.P.), typically 150 to over 450 m thick. Variable offlap and lenticular deposits imply multiple ice lobes. Some strata suggest ice incursion from the south. Outcrop is restricted to the eroded fjord walls and floor. The top of this facies dips slightly from Porteau to Horseshoe Bay, possibly due to ongoing uplift in the Coast Mountains.

The Porteau Sill is one of the few fjord sills in western Canada that is a terminal moraine. Built on eroded glaciomarine deposits and bedrock it marks a stillstand or readvance during the last ice retreat. Its coarse sediment has an arcuate structure with bedding dips that steepen upsection to 28°.

In upper Howe Sound the main source of modern sediment is the Squamish River delta. This acoustically coarse and gassy sediment thins to <10 m along the basin axis. Seismic data shows that no significant Squamish sediment traverses the sill to the south.

Silt from the Fraser River plume enters via Queen Charlotte Channel to accumulate on the flat basin floor in water >200 m. Since deglaciation, this has formed a transparent to faintly laminated wedge shaped deposit which tapers from >90 m off Horseshoe Bay to about a metre on the Porteau Sill and is absent further north. From seismic character and correlation, the sedimentation rate is highest in southeast Howe Sound, and there it is still less than 7.5 mm/yr. The Fraser silts also thin to the west, and do not extend into the westernmost Howe Sound or Thornbrough Channel. The distribution of the Fraser silt resembles that of the peak velocities for the surface currents. The only modern sediments in western Howe Sound are small debris fans from high gradient streams and local reworked lags.

In addition to the 2 main sediment sources restricted to the lower (Fraser) and upper (Squamish) Howe Sound, are local sources from erosion of unconsolidated sediment and from industry such as tailings, mills and outfalls. The low sedimentation rates in many parts of this fjord, imply that pollutants are not being buried or diluted and are likely to persist.

Overview of the Marine Ecosystem of Howe Sound

Lee E. Harding, Environmental Protection, Pacific and Yukon Region
Environment Canada, 224 West Esplanade Avenue,
West Vancouver, B.C. V7M 3H7

The upper Howe Sound basin is a true fjord, approximately 290 metres at the deepest point, bounded by the Squamish River estuary and a shallow sill (61 m) near Anvil Island. The waters of the upper basin are strongly influenced by salinity, temperature and current changes associated with freshwater input. A pronounced stratification occurs during freshet (May to September) of the Squamish River and extensive silt loading and turbidity result. Progressive density differences between water outside the sill and the water inside the sill, which entrains lower-density fresh water from the Squamish River, cause periodic renewal of bottom water in the inner basin.

Throughout upper Howe Sound, the impact of turbidity from the Squamish River reduces primary productivity during freshet. Turbidity from the Fraser River plume also intrudes into the outer basin. However, the light attenuation properties of bleached kraft pulp mill effluent (BKME) are the major cause of reduced phytoplankton productivity near Woodfibre. Under certain conditions, nutrient enrichment from the effluent can enhance productivity if light conditions are suitable.

Surface dissolved oxygen (DO) is strongly influenced by the Squamish River flow. The stratification created during freshet dilutes and disperses effluent discharged at the surface. The effects of tides, winds and currents also lessen the impact of BKME. Poor flushing and exchange because of restricted subsurface flow over the sill results in progressive hypoxia. Renewal occurs approximately every three years. Extremely low DO (<1.0 mg/l) is typical of the deep basin in between renewals.

The Squamish Estuary is a detrital-based community, with considerable production of plant biomass by rooted emergents providing a carbohydrate base for detritivores, which in turn nourish secondary consumers an so on. Salmon and steelhead rear in the estuary and migrate up the river, providing seasonal fare for eagles and other scavengers and predators.

Biological communities (intertidal and subtidal) are greatly modified near the two pulpmills, and on tailings deposits from the abandoned mine at Britannia. The Squamish Estuary was extensively restructured, reducing freshwater-saltwater mixing with consequent effects on marsh vegetation, and altering sediment deposition patterns. Mercury contamination from a chlor-alkali plant in Squamish, and dioxin/furan contamination from the two pulpmills have caused fisheries closures (the latter still in effect). Contamination with copper from the mine can be observed in mussels and oysters.

An Overview Squamish Basin Research at Simon Fraser University

Ted Hickin, Department of Geography, Simon Fraser University
Burnaby, B.C. V5A 1S6

From 1977 Ted Hickin and his graduate students in the Department of Geography at Simon Fraser University have been conducting research into the geomorphology, sedimentology, and morphodynamics of Squamish River and its floodplain. Results of these studies are contained in two M.Sc. theses and a Ph.D. thesis and in ten papers published in various research journals. Work continues and several additional papers are forthcoming.

Individual studies on Squamish River include an examination of mean flow structure in bends of the lower meandering reach (Hickin, 1978), the origin, morphology, and stratigraphy of 'concave-bank benches' in the meandering reach (Hickin, 1979), the role of vegetation in conditioning process and form of the channel (Hickin, 1984), the downstream gradation of particle sizes in the river bed and bars (Gary Brierley, 1984 and Brierley and Hickin, 1985), an inventory of channel changes derived from sequential aerial photography (Henry Sichingabula, 1986), the geomorphic impact of the October 1984 flood on channel planform (Hickin and Henry Sichingabula, 1987), the contemporary sediment flux to Howe Sound (Hickin, 1988), suspended sediment concentration and calibre in relation to surface-flow structure in Squamish estuary (Ken Rood and Hickin, 1989), a comprehensive inventory of the sediment and internal structures of Squamish River floodplain (Brierley, 1989), and the Holocene sediment budget of Squamish Basin, particularly sediment supply (Greg Brooks and Hickin).

Other related work includes studies of wetland environments and aquatic plants on Squamish Delta (Ian Hutchinson and Susan Smythe, 1986, 1989).

Work continues on detailing the Holocene geological history of Squamish Basin and its link to the behaviour and morphology of Squamish River (Greg Brooks) and further work on the estuary flow and sediment transport dynamics is in progress (Hickin, Ken Rood, and others).

Volcanism in the Howe Sound Drainage Basin: Hazards from the Garibaldi Volcanic Belt

Catherine J. Hickson, Cordilleran Division, Geological Survey of Canada
100 West Pender Street, Vancouver, B.C. V6B 1R8 FIELD TRIP

The Howe Sound Drainage Basin is part of the geologically dynamic west coast of North America; the result of subduction of the Juan de Fuca Plate off Vancouver Island. As a consequence of subduction, the region is subject to volcanism and earthquakes. A chain of volcanoes extend northward from California (the Cascade Volcanoes) into British Columbia where they are referred to as the Garibaldi Volcanic Belt (GVB). The GVB consists of three major strato-volcanoes; Mount Garibaldi (just north of Squamish), Mount Cayley (25 km west of Whistler) and Mount Meager (just north of the drainage divide) and other smaller, less voluminous centres.

Volcanism in the GVB started some 3 million years ago and eruptions have continued into the Holocene Epoch. The most recent well documented event, a plinian eruption from Mount Meager, about 2300 years ago, blocked the Lillooet River and spread ash across southern B.C. into Alberta. It has been recently suggested that some postglacial landslides and debris flows may have been volcanically triggered, if true, it would indicate the belt is more active than presently thought. Hot springs are found at both Mount Cayley and Mount Meager. The geological record of lava flows and volcanic debris suggests that both basaltic eruptions, and infrequent violent explosive eruptions, may both occur in the future. Small basaltic eruptions may have little or no warning; explosive eruptions usually have associated earth tremors that will be detected on the regional seismic network. Subduction continues and with it, the potential for future volcanic eruptions.

A continuing hazard in the GVB is posed by the extreme relief of many vent areas and the unstable nature of volcanic deposits. Landslides and debris flows from these volcanoes pose a very real threat. Landslides from Mount Cayley (Dusty Creek slide) and the "Barrier" blocked the Squamish and Cheakamus rivers during the 1800's. Debris flows originating on steep volcanic slopes have much greater run out distances than those generated in nonvolcanic areas. When human development is pushed into these drainages, this hazardous aspect of the volcanoes must be taken into consideration during planning.

Health Hazard Assessment of Dioxins and Furans

B.L. Huston, Chief, Chemical Evaluation Division, Bureau of Chemical Safety
Food Directorate, Health Protection Branch, Health and Welfare

Health hazard assessment is made up of two major components, an exposure assessment and a toxicity assessment. The toxicity assessment of dioxins is based on studies carried out in laboratory animals with the most toxic dioxin congener 2,3,7,8-terachlorodibenzodioxin (2,3,7,8-TCDD) as well as comparative studies with the other dioxin and furan congeners. The toxicity of the other dioxin and furan congeners is normalized to the toxicity of 2,3,7,8-TCDD through the use of toxicity equivalence factors. Based on all the toxicity information available, a Tolerable Daily Intake (TDI) of 10 pg/kgbw/day total dioxin equivalents has been estimated. For purposes of calculating exposure, consumption of fish and shellfish muscle as well as crab hepatopancreas have been estimated from various sources including the Nutrition Canada Survey, USA surveys, and anecdotal data. Based on these data, it is estimated that for eaters of fish and shellfish muscle the average consumption is 40g/day while for eaters of crab hepatopancreas the average consumption is 20g/day. Using these criteria, it has been determined that consumption of crab hepatopancreas from crabs caught in certain areas in Howe Sound would result in intakes of total dioxin toxic equivalents much in excess of the tolerable intake for these substances. Hence recommendations have been made to not consume crab hepatopancreas from these sites.

The Weather and Climates of Howe Sound

Peter L. Jackson and Douw G. Steyn, Atmospheric Science Programme,
Department of Geography, The University of British Columbia

Howe Sound is a steep walled channel oriented perpendicular to, and dissecting, a substantial northern hemisphere topographic barrier (the Coast Mountains). As such, it (as well as the other fjords along the coast) links the elevated interior plateau of Central British Columbia with the coast. These topographic factors result in fascinating local modifications to the regional climate and weather. In order to illustrate this, and build a picture of the weather and climates of Howe Sound, topographic modifications of the five main synoptic weather types of British Columbia defined by Suckling (1977) will be examined.

The most singular meteorological phenomenon encountered in Howe Sound (and all of the fjords of British Columbia and Alaska) is the locally named Squamish wind. These winds occur in Howe Sound mainly in winter (in Suckling's (1977) "Land High" synoptic type) when an intense anticyclone building over Alaska and the Yukon Territory moves southward. The coastal mountains act as a partial barrier, separating the cold, dense air associated with the anticyclone from the warmer, less dense maritime air mass. This density difference results in a strong cross coastal pressure gradient, and often very strong winds through gaps (such as Howe Sound) in the mountains. A field study of the Squamish winds in Howe Sound will be presented with numerical modelling results from that study. The results show the winds to be a strongly forced (by both synoptic conditions and topography) meso-scale phenomenon with considerable diurnal and spatial variability.

(This contribution is designed to be presented orally, and will be accompanied by a short (6 minute) video representation of modelled winds in Howe Sound during a Squamish wind event).

Salmonid Habitats and Production in Howe Sound and its Drainage Basin: Status of Current Knowledge

C.D. Levings, West Vancouver Laboratory, and B.Riddell, Pacific Biological Station, Fisheries and Oceans Canada

This paper synthesizes existing knowledge of habitat and population ecology of salmonids in Howe Sound. Spawning and rearing habitats of salmonids in the Squamish River basin have been modified by hydroelectric developments, logging, dyke construction and some sewage pollution. The rearing habitats in the Squamish estuary have been modified by port construction and major portions of the wetlands have been permanently lost. Foreshore rearing habitats further seaward in the Sound have been affected in localized areas by disposal of mine tailings, pulp mill effluent, and log storage. Catches of salmonids are significantly reduced from historical levels. Overfishing and habitat factors are implicated as reasons for the decreased production.

Mass Movement and Sediment Yield in the Howe Sound Drainage Basin: The Significance of Industrial Development

Peter Jordan, Forest Sciences Section, Vancouver Forest Region
B.C. Ministry of Forests, 4595 Canada Way, Burnaby, B.C. V5G 4L9

Landslides and debris flows are widespread natural processes in the Howe Sound drainage basin, as in all mountainous regions, and are responsible for much of the sediment entering river systems and the ocean. An important question for resource management is the extent to which industrial development, especially logging, has increased the sediment yield.

The watersheds of the upper Squamish River and several of its tributaries, which are extensively glacierized and include Quaternary volcanic centres, have very high sediment yields. Additional contributions of sediment from industrial activity are likely to be negligible. However, other watersheds have low natural sediment yields, which in some cases may be significantly increased by mass movement and erosion related to logging or other development. The Squamish River dominates sediment inputs to Howe Sound. Increased sediment input from other sources is probably not significant to the sediment budget of the sound as a whole; however, it may be very important locally for streams or estuaries with valuable aquatic habitat or which are used for water supply.

The Mamquam River does not have extensive natural sediment sources, compared with other parts of the Squamish basin, but logging covers much of its watershed. Numerous landslides and debris flows during heavy rainstorms in 1990 illustrate the importance of logging roads and clearcuts as sediment sources, and show that mass movement may be delayed for several decades following logging. Mashiter Creek displays some evidence of an increase in sediment yield following logging, and a subsequent decrease a few decades later. In Britannia Creek, and possibly Furry Creek, mass movement directly or indirectly related to mining has substantially increased the sediment yield. Mass movement and soil erosion resulting from pipeline construction in 1990 have been significant as sediment sources in several watersheds.

Impact on Pristine Mountain Rivers of Waste Waters From Remotely Located, but Recreationally Accelerated, Wilderness Development

W.P. Lucey, B. Moore, A.P. Austin, B. Jeffs, and K. Congdon, Department of Biology, University of Victoria, Victoria, B.C. V8W 2Y2

A three year field study, in experimental streams, quantified the nutrient contribution of sewage effluent from the recreational community of Whistler to the Cheakamus River, British Columbia, with particular reference to phosphorus. Fisheries and aesthetics are adversely affected at algal biomass values exceeding 2500 ug/cm^2; it was experimentally determined that this would likely occur given an increased river level of ortho P of 2.0 ug/L. The latter is equivalent to an increased sewage effluent discharge of 5339 to 5884 m^2/day, based upon optimal phosphorus stripping within the community's sewage treatment plant. The revealed river's limited nutrient assimilative capacity, in view of the proposed new development, resulted in Whistler community developing a Liquid Waste Management Plan which would effect sewage effluent discharge into the adjacent Squamish River. A subsequent stream-trough study is being conducted to assess how the effluent diversion would affect Squamish River water quality, especially with respect to the development of undesirable algal growth. The latter could potentially adversely affect fisheries spawning and rearing habitat.

Environmental Monitoring through Natural History Research

Jeffrey B. Marliave, Vancouver Aquarium, P.O. Box 3232, Vancouver, B.C. V6B 3X8

Documentation of newly observed natural history phenomena is the primary goal of Vancouver Aquarium research in Howe Sound. Ancillary to that goal, however, is the desire to provide a basis for future comparisons, a continuum of baseline data on marine life in Howe Sound. Emphasis has been on early life history of marine fishes and shrimps, but those life stages are ephemeral, with expected interannual and long-term fluctuations. To balance this emphasis on planktonic larval forms, projects also have been initiated for monitoring larger, more long-lived forms such as harbour seals, intertidal starfish and glass sponges.

Accomplishments to date from ichthyoplankton surveys include disproof of the assumption of planktonic drift dispersal for larval rocky shoreline fishes, demonstration of larval polymorphisms, new taxonomic descriptions of larval fishes and discovery of late larval distribution of Pacific whiting. Beds of *Agarum* kelp have been identified as juvenile nursery habitat for spot prawns, and year-class fluctuations have been documented. Censusing of harbour seals at Popham Island has included photographic identification of individuals and monitoring seasonal changes in sex and age structure of the colony. Studies of seasonal movements of *Pisaster* starfish and growth rates of hexactinellid sponges provide monitoring of more stable populations of benthic life. Long-term commitment to these projects will provide a basis for gauging changes which may occur in the quality of Howe Sound as a habitat for marine life.

The Sediment Transport Regime of Howe Sound: Implications to the Dispersal of Contaminants

Patrick McLaren, GeoSea Consulting Ltd., Fulford Harbour, B.C. V0S 1C0 and
Walt Cretney, Ocean Chemistry, Institute of Ocean Sciences
Pacific Geoscience Centre, 9860 West Saanich Road, Sidney, B.C. V8L 4B2

This study, instigated by the Ocean Chemistry Division, was designed to undertake a sediment trend analysis in order to determine the relationship between particle-associated contaminants and the natural sediment transport regime. A sediment trend analysis is a technique developed by GeoSea which uses the relative changes in grain-size distributions to assess: (1) the net patterns of sediment transport; (2) the relative probability of each size of material being moved, and; (3) areas of erosion, dynamic equilibrium, accretion and total deposition.

The above information may be used to predict the transport behaviour of contaminants such as heavy metals, dioxins and hydrocarbons according to the following rules: (1) contaminant loadings (in the sediments) decrease rapidly along high energy transport paths where sediments coarsen in the direction of transport; (2) there is no net increase or decrease of contaminant loadings when sediments are in dynamic equilibrium; (3) contaminants increase along transport pathways undergoing net accretion, and; (4) the greatest contaminant concentrations are found in environments of total deposition (ie. once a contaminated particle is deposited, there is no further transport).

For this study, 300 grab samples were analyzed for their complete grain-size distributions. The results of the sediment trend analysis showed that upper Howe Sound (between Squamish and the sill at Porteau Cove) is an environment of total deposition dominated by the Squamish River outflow. Over the sill, transport is also in a down-fjord direction; however, many sample sequences showed slight net erosion. A clockwise flow was determined in Thornbrough and Ramillies Channels, where total deposition is occurring.

The analysis showed that, with the exception of the sill, the fjord bottoms are a sink for contaminants. Once deposited, they will remain and become buried in the sediment. This finding is supported by repeat surveys of the mercury content contained in the sediments of upper Howe Sound. Because the environment is one of total deposition, contaminant "hotspots" will have a defined relationship with specific sources, rather than to a concentration build-up along transport pathways.

Dioxin Mediated Shellfish Closures in Howe Sound

M.D. Nassichuk, Habitat Management Division, Fisheries and Oceans Canada
555 West Hastings Street, Vancouver, B.C. V6B 5G3

In early 1988, a monitoring program was initiated to document the presence and concentration of dioxins and furans in aquatic organisms near British Columbia pulp and paper mills. Preliminary data on dioxins and furans in selected finfish and shellfish from Howe Sound indicated that elevated levels of certain dioxin and furan congeners were present in prawns and in the hepatonpancreas (digestive gland) of Dungeness crab. Subsequent and more intensive monitoring led to the closure, in November 1988, of a portion of Howe Sound near the Port Mellon and Woodfibre pulp mills to all harvesting of prawn, shrimp and crab. In June 1989, the shrimp and crab closure to all user groups was expanded to include an additional part of the Sound in the vicinity of Keats Island and all of Howe Sound was closed to commercial crab fishing. A consumption advisory was also issued recommending that the hepatopancreas of crab taken from that portion of Howe Sound open to recreational or Native harvesting, not be consumed. Monitoring of aquatic organisms in Howe Sound is continuing and results obtained will be used to determine when areas closed t o fishing can be reopened.

Forest Ecosystems in Watersheds draining into Howe Sound

F.C. Nuszdorfer, Ecologist, Ministry of Forests
4595 Canada Way, Burnaby, B.C. V5

The watersheds of the rivers (Cheakamus, Elaho, Mamquam and Squamish), and streams that form part o f the Howe Sound system encompass an area of approximately 463,000 ha and extend from sea level to 2678 m at the peak of Garibaldi Mountain. Three of the 14 biogeoclimatic zones of British Columbia occur in these watersheds. The Coastal Western Hemlock zone predominates. The Mountain Hemlock and Alpine Tundra zones are also found.

Some of the major upland forested ecosystem associations that are present are: Western Hemlock - *Amabilis* Fir - Blueberry, Western Hemlock - Flat Moss, Douglas-fir - Salal, Douglas-fir - Western Hemlock - Falsebox, Mountain Hemlock - *Amabilis* Fir - Blueberry. On floodplains Sitka Spruce - Salmonberry, Black Cottonwood - Red-osier Dogwood and Black Cottonwood - Willow are the major forested ecosystem associations present. The ecosystems in the area have soil moisture regimes ranging from very dry to wet. Soil nutrient regimes tend to be very poor to medium due to the dominance of the granitic bedrock that was the parent material of many of the soils of the area.

Two ecological reserves have been established in the watersheds of the Howe Sound system: ER 69, Ba ynes Island - black cottonwood ecosystems on an island of the Squamish River (71 ha) and ER 48, Bowen Island - ecosystems representative of the drier maritime part of the CWH zone (397 ha). Parks also offer some protection o f ecosystems (e.g. the montane and subalpine ecosystems of Garibaldi Provincial Park - 53,000 ha in the area).

The forests of the area provide habitat for a wide variety of species; influence the quantity and quality of w ater that reaches streams and rivers, affecting drinking water, anadromous and resident fish and other species; provide a scenic view for travellers to destinations such as Squamish, Whistler, Pemberton and the interior of the Province; provide a recreational experience for many; stabilize soils on slopes; release oxygen and are a sink for carbon dioxide. In addition, lower elevation forests have provided substantial timber for the forest industry and are expected to continue to provide it, albeit at reduced levels, in the future.

The Ministry of Forests research in the area is testing different genotypes of species, methods of controlling unwanted species, tree response to application of fertilizer, and characterizing forest ecosystems.

Physical Oceanography of Howe Sound, B.C.

S. Pond, Department of Oceanography, University of British Columbia
Vancouver, B.C. V6T 1W5

Howe Sound is a British Columbia fjord which empties into the Strait of Georgia. There is a sill of 70 m depth about 17 km from the head. Beyond the sill the width increases from about 3.5 km to 20 km at the entrance. The outer triangular basin has many islands and an average depth of about 200 m. It is freely connected to the Strait and, except for the influence of the estuarine circulation of the upper region in the upper few metres, is oceanographically part of the Strait of Georgia. Inside the sill the width is a roughly constant 2.5 km; the channel is somewhat sinuous; the inner basin has a maximum depth of almost 300 m.

The Squamish River flows in at the head and has an average annual discharge of 242 m^3/s, one of the larger outflows into a fjord in British Columbia. The runoff is seasonally modulated with a peak in late spring which is two or so times the annual average. This fresh water input causes a lower density layer of a few metres thickness and drives an outflowing surface current of a few centimetres per second. There is an estuarine return flow below of comparable magnitude. The tides also produce currents of a few centimetres per second. The tidal currents show considerable variation in amplitude and phase with depth indicating that internal tides are generated at the sill. Wind driven currents in the upper layer have amplitudes of tens of centimetres per second and totally dominate the near surface currents. There are substantial lateral variations in the near surface currents and in the estuarine return flow.

The deep water inside the sill is fairly homogenous and usually has fairly low oxygen levels. Partial or total replacements occur from time to time raising oxygen and density values. Replacements to the bottom occur in late fall or early winter at intervals of one to three or four years. Replacements to intermediate depths occur more often and sometimes occur during freshet in late spring (or other times associated with short high rainfall periods) as well as i n the late fall-early winter period.

Sea Floor Sediment Transport Processes: Howe Sound, British Columbia

David B. Prior and Brian D. Bornhold, Pacific Geoscience Centre
Geological Survey of Canada, 9860 West Saanich Road, Sidney, B.C. V8L 4B2 **POSTER**

High resolution acoustic surveys of the sea floor in Howe Sound reveal a variety of high energy sedimentary processes, that create distinctive bottom topography and near-surface sediment distributions. Interpretation of side scan sonar and subbottom profiler data indicate that very energetic underwater processes such as landslides, debris flows and turbidity currents distribute sediment within the sound.

At the front of the Squamish Delta, the river distributary channels feed offshore channels, incised into the subaqueous slopes and carry coarse sediment. Associated features such as flute marks and arcuate sea floor scarps suggest a combination of turbidity currents and shallow sliding.

Slope instability has been documented at the Wood Fibre fan delta, where dramatic changes in nearshore bathymetry accompanied damage to the jetties. The underwater slopes of the dan delta are cut by chutes, scarps and rotated blocks leading downslope to debris aprons arranged around the base of the fan wedge.

Subaerial floods, debris torrents and debris flows feed sediment to the shoreline of the sound at various locations, including Britannia Beach and M Creek. Offshore Britannia Beach there are coarse-grained sediment splays that trend downslope to a large area where intricate patterns of intersecting scarps bound sediment blocks displaced by shallow translational sliding. Further downslope there are hummocky, blocky debris accumulations marking the down-fjord limit of the landslide activity. Off M Creek and other similar high relief catchments along the eastern flank of the sound there is evidence of sediment dispersal away from the shoreline by debris avalanching down the steep underwater slopes, forming distinct debris lobes, and sand and gravel splays.

Wildlife Diversity in Old Growth Forests, and Managed Stands

Dale Seip and Jean-Pierre Savard, B.C. Ministry of Forests
4595 Canada Way, Burnaby, B.C. V5

1. We have completed 2 years of research comparing wildlife diversity and abundance in Coastal Western Hemlock old growth stands (>250 years), 40-80 year old second growth stands and clearcuts. Study sites include the Queen Charlotte islands, southern Vancouver Island and the lower mainland.
2. Many species such as chipmunks, long-tailed voles, orange-crowned warblers, juncos and song sparrows are most abundant in clearcuts.
3. Numerous species live primarily in forests but are equally abundant in old growth and 40-80 year old second growth stands (eg. shrewmoles, flying squirrels, red-backed voles, western flycatchers, Townsend's warbler, golden-crowned kinglets, Ensatina salamanders).
4. Most bird species that require snags for feeding and nesting live in both old-growth and second-growth forest but are more abundant in old growth because of the greater abundance of snags (eg. sapsuckers, brown creepers, nuthatches).
5. Two species that appear to nest almost exclusively in old growth forests are the marbled murrelet and the spotted owl.

Implications:

- the greatest abundance and diversity of wildlife will occur in areas that provide a good mixture of habitat t ypes including clearcuts, second-growth coniferous forests, old-growth forests and hardwood stands.
- second-growth forests can provide habitat for most of the wildlife species that live in old-growth forests if they are managed to ensure that they contain abundant snags, decaying logs and gaps in the canopy to allow shrub growth.
- There are some species such as the spotted owl which live almost exclusively in old-growth forests and sufficient amounts of old-growth habitat must be protected if they are to be maintained.

The Phytoplankton Ecology of Howe Sound

J.G. Stockner, Canada Fisheries & Oceans, West Vancouver Laboratory
4160 Marine Drive, West Vancouver, B.C. V7V 1N6

The production, distribution and abundance of phytoplankton in Howe Sound were studied from 1972 to 19 78. Results of this 6 year field study coupled with laboratory bioassay experiments revealed a very heterogenous population distribution with considerable spacial, temporal and interannual variability. Greatest population abundances and highest daily and annual rates of carbon production were in the seaward boundaries of the Sound contiguous with the Strait of Georgia where average annual values often were >350 gC/m^2/yr. The least productive regions of the Sound were off the Squamish River delta and in waters adjacent to the pulp mills and Britannia copper mine where values were typically <50 gC/m^2/yr. Severe light attenuation in surface waters of the Sound extending from Squamish to Anvil Island and caused by turbid, glacial Squamish River and stained pulp mill effluent discharges, were thought to be the major factors limiting rates of primary production in Howe Sound. Strong seaward flushing of the surface layer and stable stratification from May to October with summer declines in available nitrate-nitrogen also influenced phytoplankton dynamics in certain regions of the Sound. An annual spring diatom 'bloom' is a common, dominant feature in all coastal B.C. fjords. In Howe Sound it usually commenced in April just off the Squamish delta and moved progressively seaward down the Sound over about a 3-4 week period. But in some years it was restricted and/or eliminated by poor spring weather conditions or early Squamish River discharge which influenced the production dynamics of the Sound. Autumn blooms were common in the seaward boundary waters but not in other regions of the Sound where turbidity and hydrographic conditions either prevented or dampened the autumnal response. Some possible effects of removal of perturbations or addition of nutrients to the surface layer of the Sound will be discussed relative to the maintenance of a productive and 'healthy' plankton community in Howe Sound.

Hydrodynamic and Sedimentation Modelling in Howe Sound

J.A. Stronach and A.J. Webb, Seaconsult Marine Research Ltd. 820-1200 West 73rd. St. Vancouver, B.C. V6P 6G5, and T.S. Murty and W.J. Cretney, Institute of Ocean Sciences, P.O. Box 6000, Sidney, B.C. V8L 4B2

A high resolution, three-dimensional hydrodynamic model of Howe Sound has been developed. This model employs a horizontal grid spacing of 390 m, and uses 8 levels in the vertical. It calculates the 3 components of velocity, as well as time-varying density fields. The model is forced at its open boundaries by a larger model of the Strait of Georgia, using a 1.95 km resolution, by surface wind stress, and by Squamish River flow. The verification of the m odel will be briefly discussed, as well as significant flow features.

The velocity fields from the hydrodynamic model are used to drive a sediment transport model, which is currently under development. The purpose of this model is to simulate the horizontal advection of fine particulate material as it sinks to the sea floor, with particular reference to variations induced by the different sinking rates associated with different grain sizes. Settling rates for source materials will be determined by both literature reviews and by laboratory experiments. The model results will be compared with recent measurements of the spatial variability of grain size distributions of seafloor sediments in Howe Sound.

Waste water discharges to Howe Sound and their apparent significance

L.G. Swain, B.C. Ministry of Environment, 765 Broughton St. Victoria, B.C. V8V 1X5, and B. Moore, B.C. Ministry of Environment, 15326 103A Ave., Surrey, B.C. V3R 7A2

The B.C Ministry of Environment is presently preparing a water quality assessment for Howe Sound. Integral parts of the water quality assessment are to document water uses of, and waste water discharges to, Howe Sound. This paper will present an overview of water uses of Howe Sound, including recreation, boating, and use by aquatic life. Waste water discharges to Howe Sound will be identified, including the well known pulp and paper discharges. Some ambient water quality impacts which have been noted as a result of these discharges will be documented.

Dioxins and Furans in Cormorant Eggs and Tissues of Diving Ducks Collected in Howe Sound

P. Whitehead, J. Elliott and R. Norstrom, Canadian Wildlife Service
Pacific and Yukon Region, Environment Canada, Delta, B.C. V4

Since 1977, the Canadian Wildlife Service has monitored several persistent environmental contaminants in the eggs of Great Blue Herons nesting in the Strait of Georgia. The goal of the program is to provide information o n industrial contamination of estuaries and intertidal mudflats in the Strait, and possible implications for the health of resident birds. In 1982, a method for measuring dioxin (PCDD) and furan (PCDF) residues in eggs was developed, and became part of the monitoring protocol. The first eggs analyzed were collected from a colony near the Fraser River estuary and contained elevated levels of some 2378- substituted congeners. Levels of 2378-TCDD, the most toxic isomer were high enough to be embryotoxic in a sensitive species. In 1987, chlorine bleaching of pulp was identified as the probable source of the PCDD/Fs in the Strait. Recently the Canadian Wildlife Service began collecting Double-crested cormorant eggs from Christie Islet in Howe Sound. Levels of 60 ng/kg of 2378-TCDD, 107 ng/kg of 1378-PnCDD and 237 ng/kg of 123678-HxCDD were found in 1988. The following year, 2378-TCDD had fallen to 30 ng/kg, while higher chlorinated congeners were less than 1/5 1988 levels. In 1990 levels were almost unchanged from 1989. In addition, samples of several species of over-wintering diving ducks were collected near the Port Mellon mill in early spring, 1990. Liver and muscle tissue of all the ducks contained PCDD/Fs. Fish-eating species were the most contaminated followed by benthivores and herbivores. Western grebe, for example, contained 46 ng/kg of 2378-TCDD, 29 ng/kg of 12378-PnCDD, 77 ng/kg of 123678-HxCDD and 109 ng/kg of 2378-TCDF. These data show the value of fish-eating birds as indicators of environmental quality.

Howe Sound Pulp and Paper Modernization

Ron Wilson, Howe Sound Pulp & Paper Limited
Port Mellon, B.C. V0N 2S0 <u>POSTER</u>

In June of 1990 the first portions of the newly modernized Howe Sound Pulp and Paper complex started up, signalling a new era in environmental performance for the complex. When the decision to modernize the plant was made in 1987, one of the overriding design guidelines was to utilize the most advanced technology available to minimize the plants impact on the receiving environment. The best possible technology was incorporated into the design, including the first oxygen delignification plant in British Columbia as well the ability to bleach pulp using only oxygen and chlorine dioxide. An oxygen based secondary treatment system for the liquid effluent started up in September of 1990 and coupled with primary and secondary clarification has brought effluent discharges down well under permitted levels. The complex also has the most restrictive permit levels in the province for the discharge of AOX and current discharges are well within permit levels. Overall discharges to Howe Sound have decreased by over 70% despite an increase in pulp production and the installation of a new newsprint machine.

The marine component of the Howe Sound environmental system thus includes episodic, near-bottom, geological processes that determine sediment distribution in the sound, involving dispersal for long distances away from stream and river mouth sources. High discharge from the surrounding drainage basins is accompanied by low retention of the sediment at the coastline. Sediment is remobilized and bypasses the nearshore areas, introducing large volumes of coarse sediment to the basin floor. Beneath the apparently tranquil surface of the sound there are high energy events which affect the stability of nearshore engineering structures and which should be considered in environmental land use planning of the coastline and sea floor.

Western Pulp's Squamish Operation

W. Rempel, Technical and Environmental Services, Western Pulp Limited Partnership, P.O. Box 5000, Squamish, B.C. V0N 3G0

A brief history of the Woodfibre pulp mill will be presented as well as a description of the mill as it exists to day. The marine activity associated with the complex will be described. Effluent discharge characteristics and loadings to Howe Sound will be reviewed. A similar overview of air emissions will be given together with comments on ambient air quality analysis in upper Howe Sound. The presentation will conclude with a description of projects underway to further reduce the environmental impact of this operation on Howe Sound.

* **DRAFT COPY, Sept. 29/91**: This is a draft copy. A revised final copy will be distributed at public meetings in late October and November. We are soliciting input that will improve the accuracy and completeness of this Guidebook. If you can assist us, **please FAX additional contributions, corrections or comments by October 15** to: Bob Turner FAX # 666-1124 (phone 666-4852).

FIELD GUIDEBOOK

LOWER HOWE SOUND WATERSHED

edited and written by

Bob Turner[1]

with contributions by

Tracey Feeney[1], Linda Broughton [2], Bernie Claus[3], Brian Clarke[4], John Clague[1], Bob Forbes[4], Lee Harding[3], Cathie Hickson[1], Brian Ricketts[1], Tim Turner[5] and Doug Halliwell[1]

[1]Geological Survey of Canada, 100 W. Pender St., Vancouver, B.C. V6B 1R8
[2]Steffen Robertson and Kirsten (B.C.) Inc., Suite 800, 580 Hornby St., Vancouver, B.C. V6E 2Y3
[3]Environment Canada, 224 West Esplanade, North Vancouver, B.C. V7M 3H7
[4]B. C. Environment, 10334 152A St., Surrey, B.C. V3R 7P8
[5]Turner and Turner Consultants, RR4, S19, C53, Gibsons, B.C. VON 1V0

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PART I
HOWE SOUND WATERSHED: AN OVERVIEW

INTRODUCTION

The Howe Sound watershed is an area of approximately 4000 km^2 (463,000 ha) within the southern Coast Mountains just northwest of the Vancouver metropolitan area (Figure 1). The term "Howe Sound watershed" is used here to include Howe Sound as well as the the landmass drained by streams flowing into Howe Sound. The Squamish River system drains over 90% of the watershed; other streams include the Mamquam River and small rivers and streams draining the eastern and western shores of Howe Sound (Figure 3). The Howe Sound watershed probably bears more human impact than any other watershed in the Coast Mountains watershed and therefore it provides an opportunity to better understand how humans impact coastal British Columbia's natural system. The marine, land and atmospheric ecosystems of the Howe Sound watershed are affected by coastal communities, major pulp mills, a chemical plant, important road and rail links, past mining activity, flow control on rivers, active forest harvesting, and a major port facility. The Howe Sound basin also supports an important fisheries and has significant recreational use.

This guidebook focuses on the southernmost part of the Howe Sound watershed; that is the waters of Howe Sound and immediately adjacent lands.

PHYSIOGRAPHY

The southern Coast Mountains of southwestern British Columbia are separated from the lowlands of Georgia Strait to the southwest by a clearly defined front. Mountains along this front rise to about 1200 m but peaks farther inland reach progressively greater heights (Figures 2 and 4). In the vicinity of Squamish, the summits of the Tantalus Range reach 2500 m while near the upper part of the watershed, elevations of some peaks are over 2800m.

Howe Sound is a complex sound-fiord system within the outer Coast Mountains. Howe Sound is 42 km in length, has a maximum width of 35 km and its mouth lies just northwest of the city of Vancouver and the delta of the Fraser River (Figure 2). The sound consists of a complex of U-shaped submarine valleys with deep basins, steep sides and submerged sills (Figure 5). Adjacent to the sound are glacially sculpted steep forested ridges and craggy peaks 1250 to 2100 m in elevation. Howe Sound is divided by a submerged ridge or sill north of Anvil Island (inner sill) that has a maximum depth of 70 m (Figure 5). North of the inner sill is a narrow fjord (inner basin); to the south is an island-strewn sound (outer basin) as much as 22 km wide. The inner basin is a true fiord, a narrow, U-shaped trough approximately 3 km wide and 15 km long and up to 325 m depth. The Squamish River, which drains an area of 3636 km^2, flows into the north end of the inner basin across an elongate delta.

South of the inner sill, the fjord flares out into three U-shaped troughs (Thornborough, Ramilles and Montagu channels) with depths of up to 250 m. The eastern side of the outer basin is a deep north-south channel 2 to 6 km wide (Montagu Channel, Queen Charlotte Channel) adjacent to an abrupt mountain wall 1200 to 1650 m high with short, steep drainages. The western two thirds of the outer basin has numerous islands and narrower channels with shallower water depths. The largest islands in the sound, Gambier, Bowen and Anvil, have a rugged topography and summit peaks with elevations between 600 and 850 m. The mountainous western side of the sound is dissected by large southerly trending valleys of Potlach Creek, McNab Creek and Rainy River.

A discontinuous sill (outer sill) extends across the mouth of Howe Sound with maximum depths of 100 m except in Queen Charlotte Channel where it has been breached to a depth of 245 m (Figure 5). In

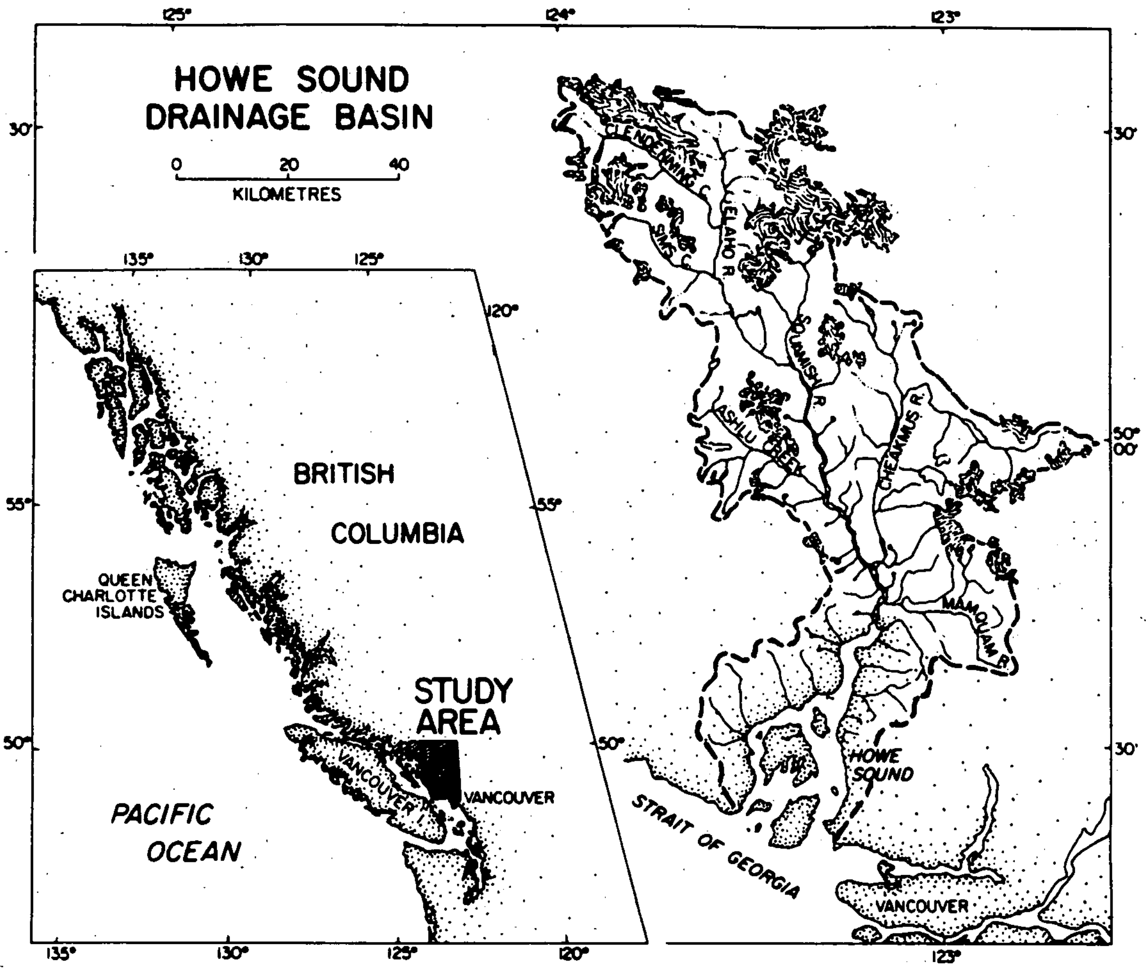


Figure 1 The Howe Sound watershed (Sivitsky and MacDonald, 1981).

Figure 2 Topographic map of the southern Howe Sound area.

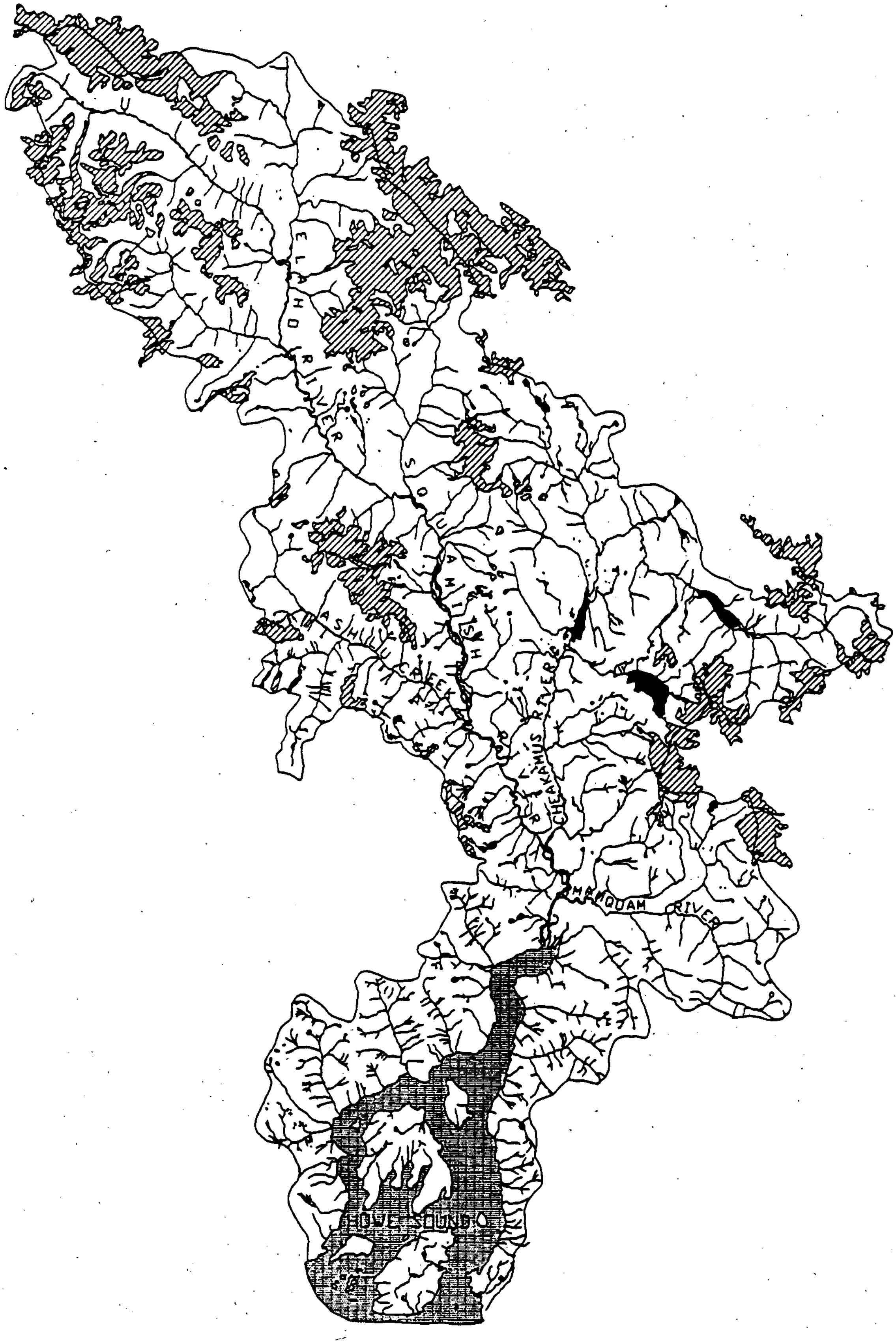


Figure 3 The Howe Sound watershed with major streams, lakes (dark shading) and ice fields (diagonal pattern). By T. Feeney from NTS map base.

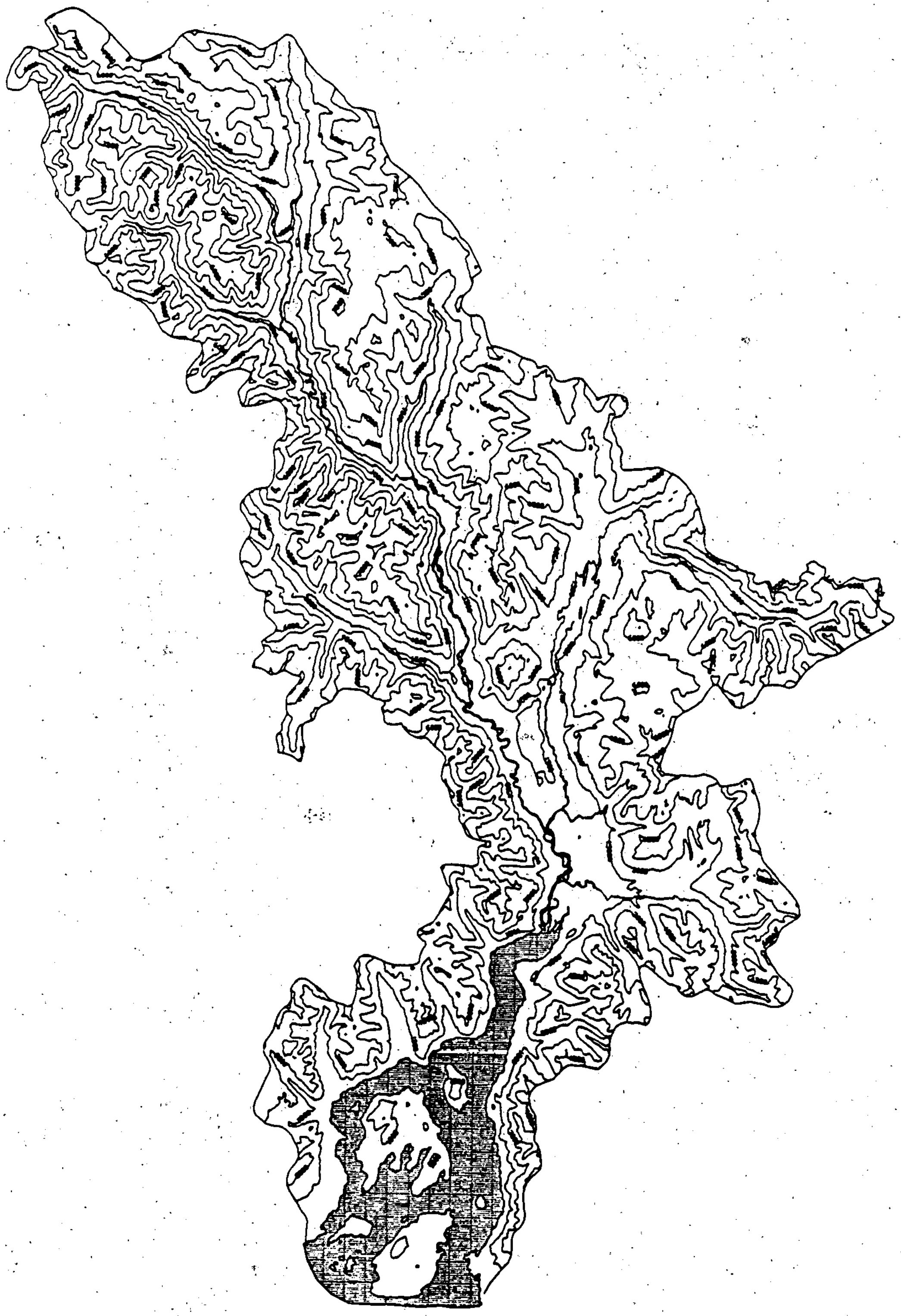


Figure 4 Topographic map of the Howe Sound watershed. By T. Feeney from NTS map base.

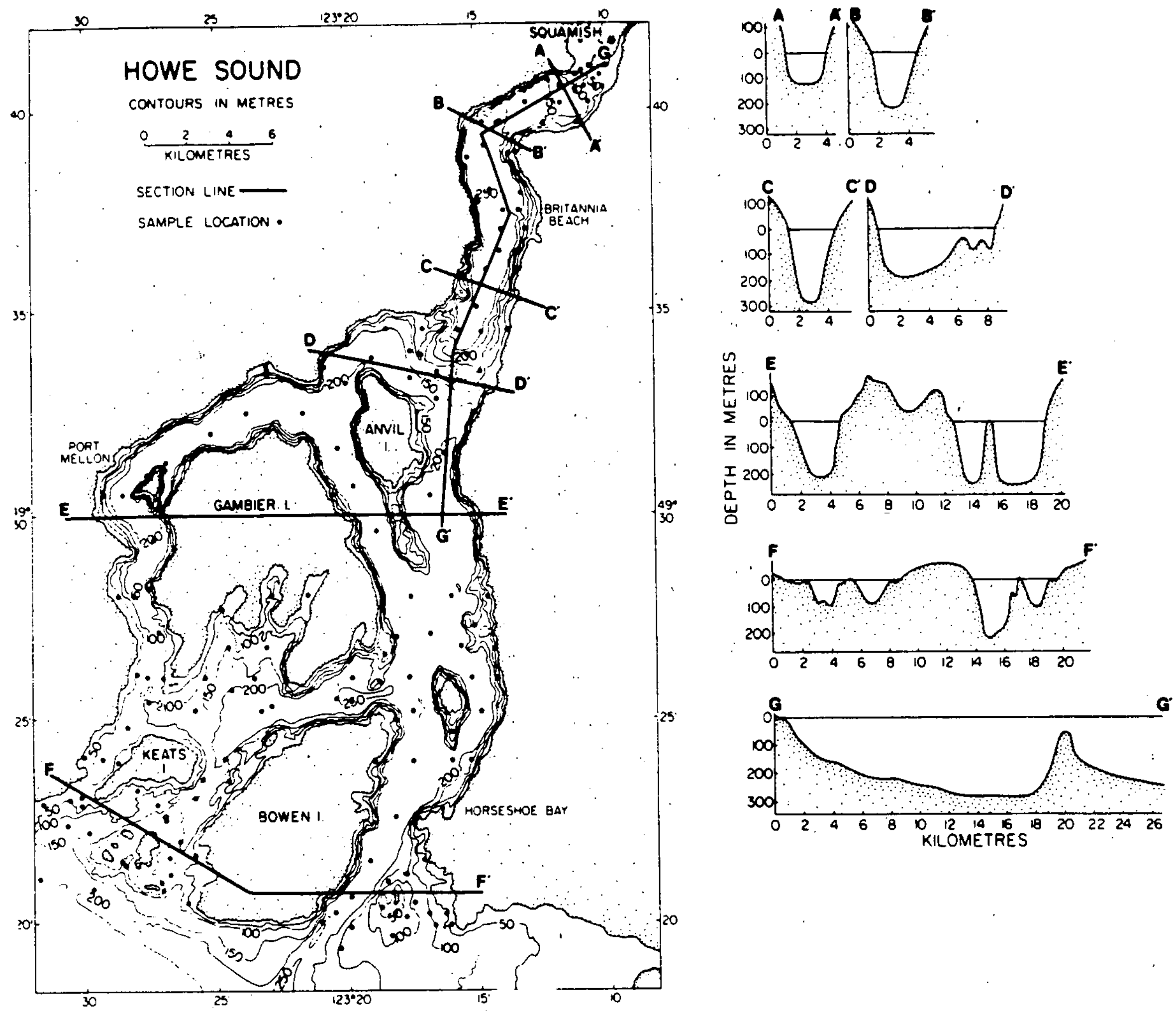


Figure 5 Bathymetric chart of Howe Sound with lines of bathymetric profiles (From Syvitsky and MacDonald, 1981).

Shoal Channel near Gibsons this sill is less than 5 m deep. The smaller Grace-Langdale sill with a maximum depths of 90m extends from the southern tip of Gambier Island (Grace Island) to Langdale.

CLIMATE

At the latitude of British Columbia, the dominant atmospheric movement is eastward. The Pacific Ocean acts as an immense reservoir of heat and moisture and consequently the southern coast of BC has a relative lack of sunshine, moderate temperatures year round and heavy precipitation in the winter. Moist air masses and cyclonic storms generated over the northern Pacific Ocean move inland and encounter north-trending mountain ranges. These weather systems drop considerable moisture as rain or, at higher elevations, as snow, when air is forced up the west-facing slopes of the Coast Mountains. Annual precipitation amounts for Point Atkinson, Port Mellon, Squamish and Whistler are approximately 1250, 3300, 2250 and 1415 mm respectively (Figure 6). These mountains also block the westward passage of frigid continental Arctic air masses from reaching the coast during the winter. The mean annual range of temperature (i.e. the mean temperature of the warmest month minus that of the coldest month) in the outer coastal area is the smallest in Canada at 10°C.

The Howe Sound area is influenced by the rainshadow effect of the Vancouver Island Ranges. The outer islands of Howe Sound have a climate approaching the Mediterranean type in that summers are normally dry and warm with a high number of hours with bright sunshine. However, at higher elevations in the coastal mountains transition takes place to moderate rainy climates and then colder, snowy climates. Mean temperatures decline 5°C for every 1000 m increase in elevation. Summers become cool and short. Heavy snowpacks form in the winter and linger into mid-summer. In the extreme glaciers and icefields cover the highest elevations.

Winter Large amounts of precipitation fall during winter cyclonic storms. Precipitation amounts increase markedly with elevation and snowline commonly ranges from 500 to 1500m. Air temperatures are moderated by maritime air masses and vary much less on the coast than farther inland. Winter frontal disturbances are commonly preceded by gale-force southeasterly winds that are funneled into strong upchannel winds in Howe Sound (Thomson, 1981). Also common in the winter are strong down channel winds or "Squamishes". As in other coastal inlets, Squamishes occur when cold, dense Arctic air flows seaward along river valleys from the interior uplands, and such Squamish winds are often triggered by the passage of a low-pressure system down the outer coast of British Columbia. In Howe Sound, these winds blow down the inner basin and along the eastern side of the outer basin.

Summer During the summer, the Howe Sound area comes under the influence of a large semi-permanent Pacific anticyclone or high pressure centre which expands northward up the British Columbia coast, greatly diminishing the frequency and intensity of Pacific storms and coastal precipitation. There are spells of fair weather with infrequent convective storms. During this period, the wind pattern is dominated by land and sea breezes related to the differential heating of the land and sea (diurnal winds)(Thomson, 1981). From about midnight to 9 A.M., a gentle breeze blows from the north (land breeze). With the onset of daytime heating of the land, winds shift to a sea breezes from the south that strengthen in the afternoon and tend to die off about sunset. These diurnal winds are strongest where confined by topography (e.g. inner basin, east side of the outer basin) and are most prevelent during clear sunny weather. Larger scale atmospheric conditions such as the passage of weak fronts or strong westerly flow from the Pacific modify these diurnal winds.

HYDROLOGY

The Squamish River, along with its major tributaries the Elaho, Cheakamus and Mamquam rivers, drains an area of 3636 km^2. This river system is fed by glacial meltwater, which peaks in July-August, lessor snow melt which peaks in June, and rainstorms which peak in the fall (Hoos and Vold, 1975). Maximum discharge of around 760 m^3/s occurs in early summer while late winter flows are typically only 10% of maximum flow (Figure 7). Flood events up to 2100 m^3/s can occur in the fall related to sudden thaws and heavy rainfall, and have combined with strong winds and high tides to cause damaging

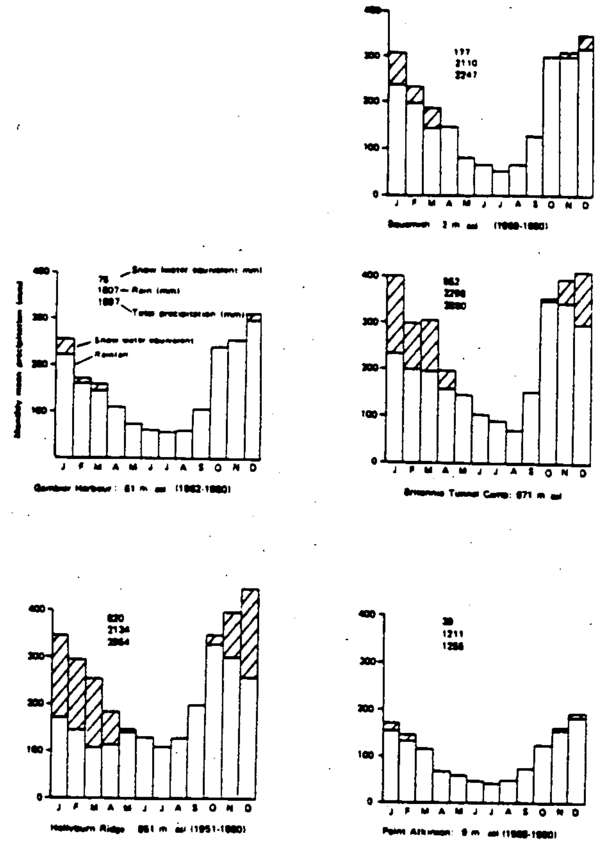


Figure 6 Monthly mean precipitation for 5 selected stations in the Howe Sound region (from Jackson and others, 1985).

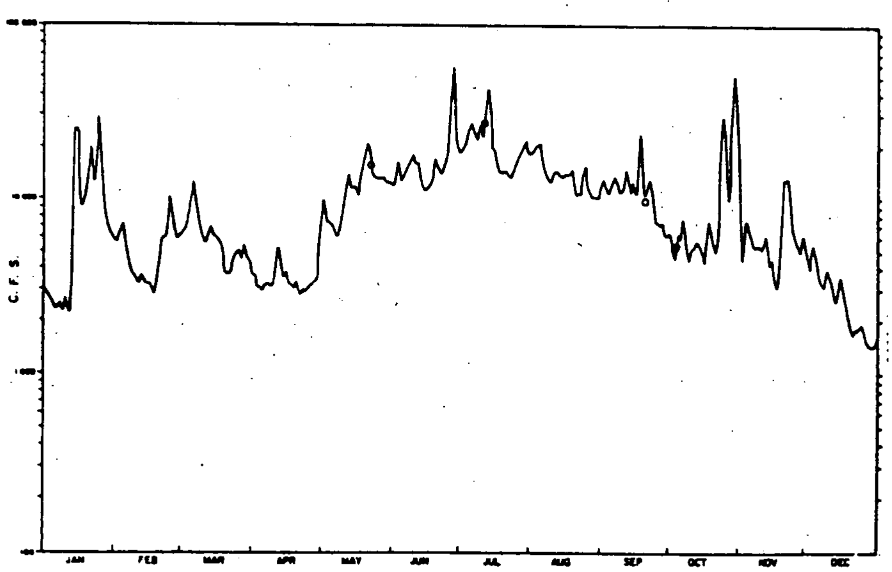


Figure 7 Discharge hydrograph, Squamish River (from Hoos and Vold,1975)

	Parameter	Mean Level
(1)	Discharge (cfs)	8,600
(2)	Temp. (^{o}C)	8.45
(3)	pH	6.9
(4)	Turbidity (Jackson units)	14.38
(5)	Total dissolved solids (Calcd. mg/l)	23.64
(6)	Total hardness ($CaCO_3$ mg/l)	10.89
(7)	Dissolved calcium (Ca mg/l)	4.16
(8)	Dissolved magnesium (Calcd. mg/l)	0.39
(9)	Dissolved potassium (K mg/l)	0.61
(10)	Dissolved sodium (Na mg/l)	1.61
(11)	Total alkalinity ($CaC0_3$ mg/l)	7.75
(12)	Bicarbonate (Calcd. HCO_3 mg/l)	11.64
(13)	Dissolved chloride (Cl mg/l)	1.59
(14)	Dissolved fluoride (F mg/l)	0.08
(15)	Reactive silica ($Si0_2$ mg/l)	5.83
(16)	Dissolved sulphate ($S0_4$ mg/l)	5
(17)	Dissolved nitrogen (NO_3, NO_2, N mg/l)	0.04
(18)	Dissolved phosphorus (Ortho, PO_4, P mg/l)	0.003 *
(19)	Total phosphate (PO_4 mg/l)	0.018
(20)	Total inorganic phosphorus (inorg. PO_4 mg/l)	0.004 *
(21)	Dissolved iron (Fe mg/l)	0.03

Figure 8 Summary of water quality parameters of the Squamish River measured at Brackendale from 1968 to 1974 (from Hoos and Vold, 1975).

flood events on the Squamish delta. Devastating floods occurred in 1921, 1937, 1940 and 1949. The Mamquam can also flood during spring freshet as a result of heavy runoff and abundant log jams in the channel (Stathers, 1958). The town of Squamish was regularily flooded with nearly five feet of water every 16 years, and to a lessor degree every seven years prior to the building of the retaining dyke (Waldichuck, 1972).

The Squamish River has an average gradient of 6.2 feet per mile. Stretches of slower moving waters within a smooth sinuous channel are separated by straighter intervals of fast flow and rapids below the confluences of major tributaries. The Cheakamus and Mamquam rivers, which are steeper and carry greater sediment loads, form sediment build-ups where they enter the Squamish causing a "step" in the main river flow. The eventual site of deposition of sediment is the estuary and the delta front is advancing about 7 m per year (Hoos and Vold, 1975).

Streamflow has been monitored since 1914 for the Cheakamus River, 1957 for the Squamish River, 1966 for the Mamquam River and 1972 for the Stawamus River (Hoos and Vold, 1975). Water quality at the Brackendale station has been monitored since 1968; pH values are nearly neutral, temperature ranges from 3°C to 17°C, nutrient values are low with silica values much higher than magnesium, potassium and sodium (Figure 8). Periods of extremely low flow may correlate with elevated total dissolved solids. Total carbonate alkalinity is low (<20 mg $CaCO_3$/l) and these waters are poorly buffered and therefore highly susceptible to pH changes (Cliff and Stockner, 1973).

GEOLOGY

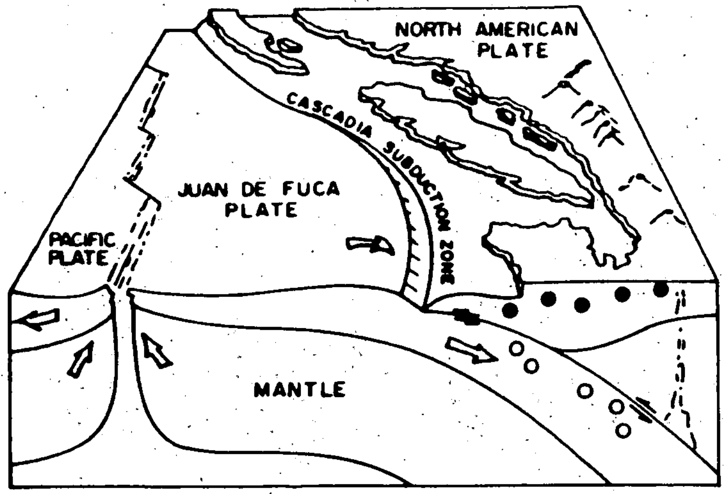
Modern geologic setting

The modern geologic regime in southern British Columbia reflects the differing movements of crustal plates that underlie the continental margin and adjacent Pacific Ocean (Figure 11). North of Vancouver Island, the two largest plates (North America, Pacific) are separated by the Queen Charlotte fault (Keen and Hyndman, 1979). To the south, two smaller plates (Explorer, Juan de Fuca) occur between the North American and Pacific plates. Spreading ridges (areas of ocean crust formation) offset by fracture zones ("transform faults") separate these smaller plates from the Pacific plate to the west. The Juan de Fuca plate descends and underrides the North American plate along a convergent margin (" Cascadia subduction zone"). Partial melting of the descending Juan de Fuca plate gives rise to a line of active volcanoes (Cascade volcanic chain) parallel to but inland from the continental margin (Riddihough and Hyndman, 1976) (Figure 10). Earthquakes are associated with faults separating the crustal plates. Historic seismic activity includes large magnitude earthquakes (magnitude >8) along the Queen Charlotte fault; moderate (magnitude 6-7+) earthquakes below Vancouver Island and Strait of Georgia, and small earthquakes along spreading ridges and related offsetting faults (transform faults)(Milne et al., 1978). Although large magnitude earthquakes have not been recorded from the Cascadia subduction zone during the last 300 years, submerged marshes and forest in coastal Washington and Oregon record sudden subsidence events 300, 1700 and 3100 years ago (Atwater and Yamaguchi, 1991). These subsidence events, which in some cases were accompanied by tsumamis, are interpreted to be manifistations of great earthquakes centered in the Cascadia subduction zone.

The Howe Sound region lies within the North American plate above the subducting Juan de Fuca plate. The volcanoes of the Garabaldi volcanic belt, the northern extension of the Cascade volcanic belt are reminders of this ongoing subduction process. The present makeup of the rock and sediment substrate of the Howe Sound region includes metamorphic and granitic bedrock, remains of volcanoes formed in the past 2 million years, sediments related to glaciation that ended 10,000 years ago, and modern sediments that postdate glacier retreat and continue to accumulate today.

Granitic and metamorphic bedrock

Granitic rocks form about 80% of the southwestern Coast Mountains with the bulk of the remainder being metamorphosed volcanic and sedimentary rocks (Figure 9; Roddick, 1965; Roddick and Woodsworth, 1979; Monger, 1990). Granitic rocks are predominantly Middle to Late Jurassic (175-140



o Earthquakes in the plunging ocean plate
● Earthquakes in the overlying continental plate
Note: none recorded on the subduction interface

Figure 9 Schematic view of plate tectonic setting of southwestern British Columbia and northwestern Washington illustrating crust formation at ocean ridges, subduction of ocean crust under the continental margin, and associated earthquakes and volcanoes (from Robinson, 1991).

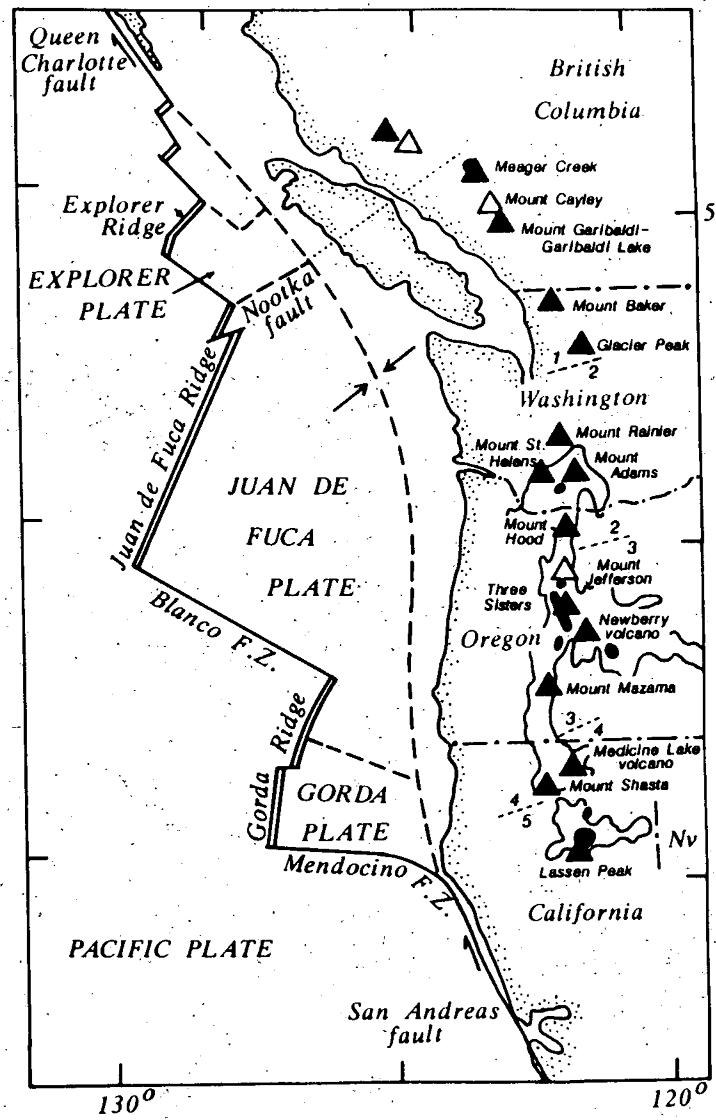


Figure 10 Map of Cascade volcanic arc and its relation to major plate-tectonic features. Dashed line parallel to coast is the subduction zone and boundary between Juan de Fuca and North American plates, arrows show direction of convergence. Dotted line is extrapolation of Nootka fault. Triangles are major Quaternary volcanic centres; filled ones were active in the last 15,000 years. Small filled areas are zones of post-15,000 year basaltic volcanoes. The northern portion of the Cascade volcanic arc is the Garibaldi volcanic belt of southwestern British Columbia (from Scott, 1990).

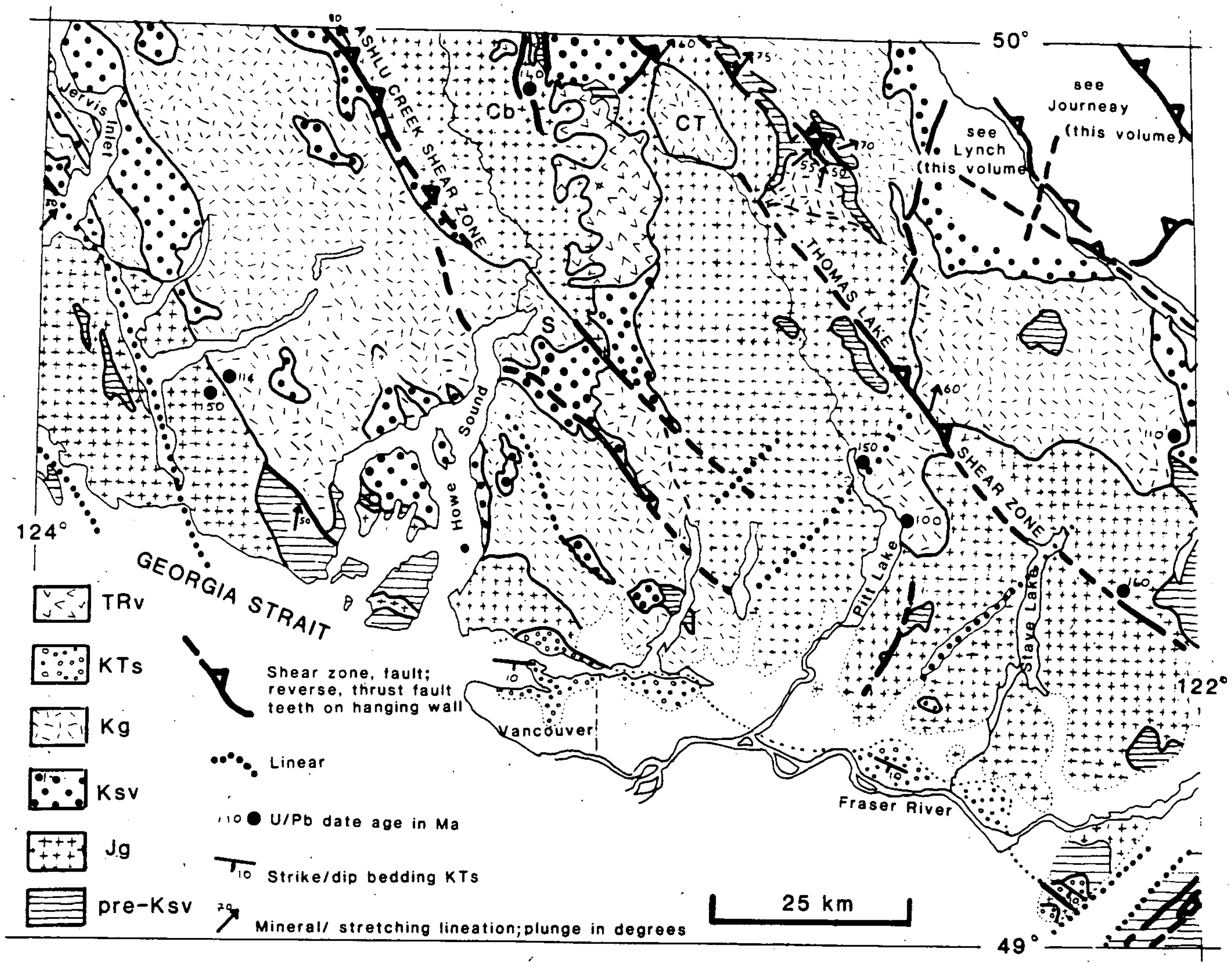


Figure 11 Simplified geological map of the Vancouver map area (92G) (from Monger, 1990). This area includes the southern portion of the Howe Sound watershed. Rock types identified in the legend include granitic rocks of Middle and Late Jurassic age (Jg) and Lower to mid-Cretaceous age (Kg), metamorphosed rocks of Lower to Middle Jurassic age (pre-Ksv) and Cretaceous age (Ksv), sedimentary rocks of Cretaceous and Tertiary age (KTs), and Tertiary to Recent volcanic rocks of the Garabaldi volcanic belt (TRv).

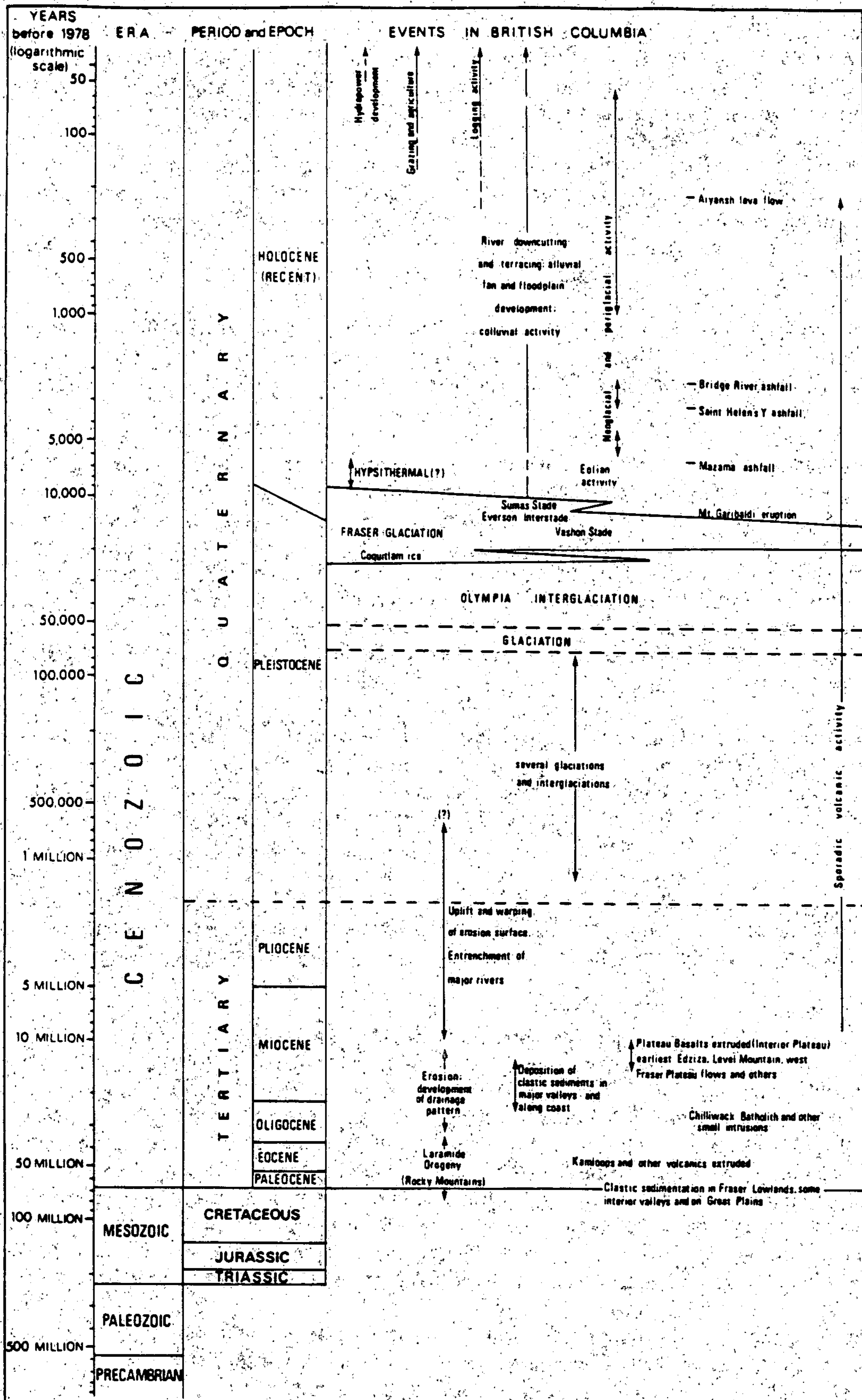


Figure 12 Geologic time scale (Table 1.3.2, Soil Landscapes of BC).

million years) or Early to mid-Cretaceous age (114-100 million years) (Monger, 1990) (Figure 12). Jurassic granitic rocks are dominant southwest of a major shear zone running northwest from the Stawamus-Indian River to Ashlu Creek; Cretaceous granitic rocks are abundant to the northeast. Metamorphosed volcanic and sedimentary rocks range in age from Jurassic to Cretaceous age and are metamorphosed to a greenschist grade (ie. metamorphic minerals include albite, chlorite, epidote, calcite). Northwest trending, northeast dipping shear zones that extend tens of kilometers along strike and range in width up to 2 km cut granitic and metamorphic rocks. These shear zones displace the northeast side up relative to the southwest. Such shear zones extend from Ashlu Creek to the Stawamus River-Indian River valley, and occur in the Britannia and Garibaldi areas (Monger, 1990). The Ashlu Creek shear zone is dated as between 140 and 100 million years (Monger, 1990).

Fission track studies suggest that about 2 km of uplift has occurred in the last 10 million years to form the present Coast Ranges (Parrish, 1983). It is likely that major stream valleys that cut the Coast Mountains predated this uplift, and that uplift caused streams to deeply incise their valleys (Clague and others, 1987).

Granitic rocks are composed of interlocking large grains of durable minerals such as quartz, feldspar and hornblende that result in a cohesive fabric. As a result intrusive rocks are resistant to weathering and slopes on these rocks tend to be steep and topography rugged. Spectacular glacier-carved intrusive rocks such as the Chieftain at Squamish have survived the last 10,000 years with little modification. Joints (fractures) tend to be widely spaced in intrusive rocks and consequently mechanical breakdown tends to produce extremely coarses rubble on colluvial slopes. The span of post-glacial time is too short to have allowed significant chemical weathering. However the least stable minerals such as olivine, pyroxene and calcic feldspar are susceptible to chemical attack and crystals of quartz and potash and sodic feldspar can be released to form a sandy or gritty residue.

Metamorphosed volcanic and sedimentary rocks occur in northwest-trending belts. Metavolcanic rocks are often less resistant to mechanical weathering than intrusive rocks due to finer grain size, greater abundance of platy minerals causing cleavage in the rock, and higher density of joints. Theses rocks tend to be green in colour, fine-grained and include volcanic rocks of intermediate silica content (andesite and dacite). Metavolcanic rocks are composed of Ca, Mg and Fe bearing aluminosilicate minerals (plagioclase, orthoclase, biotite, hornblende, chlorite, epidote), quartz and calcite with variable amounts of trace Cu, Zn, Pb, and Ag. The Britannia Cu-Zn-Pb mine occurs within Gambier Group volcanic rocks. Numerous small Cu deposits also occur within volcanic rocks on Bowen Island. Where faulted or altered to clay-rich compositions, metavolcanic rocks can be very unstable (e.g. Magnesia Creek area).

Garibaldi volcanic belt

The uplifted and eroded intrusive and metamorphic rocks of the southern Coast Range are locally mantled by Quaternary volcanic rocks of the Garibaldi volcanic belt (Mathews, 1958; Mathews and Souther, 1987; Hickson, 1990). This north-trending belt of volcanic rocks consists of about 32 volcanic edifices in the southern Coast Mountains including Mount Garabaldi, Mount Cayley and Meager Mountain (Figure 10). The Garabaldi volcanic belt is a northward continuation and less active component of the Cascade Volcanoes, a line of volcanoes that extend from Lassen Peak in northern California to Mount Baker just south of the Canadian border. These volcanoes originate due to the subduction and partial melting of ocean crust under the western margin of North America. The convergence angle of the oceanic plates changes along this zone of subduction effecting the vigor of volcanism inland. The northern segment of the belt, extending north from Glacier Peak, Washington, is the least active segment.

Much of this belt lies within the Howe Sound watershed. Unlike the large stratavolcanoes of the Cascade belt, the Garibaldi centers are more numerous but much smaller. Only Mt. Garibaldi, Mt. Cayley and Meager Mountain rise above the level of summits developed on older rocks. Rocks of the Garibaldi volcanic group are basalt, andesite and rhyodacite. Basaltic lavas are mostly extruded on valley bottoms (e.g. Brandywine Falls area) while andesites and dacites compose the higher and larger volcanic edifices (e.g. Mt. Garabaldi). Radiometric dates range from 2.7 million years ago to 2400 years ago. There

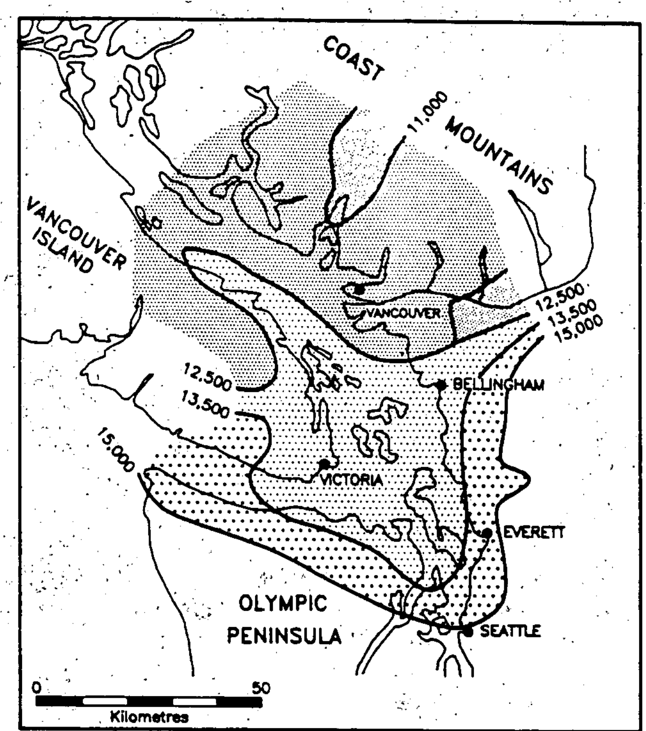


Figure 13 Decay of the Cordilleran Ice Sheet in southern British Columbia and northern Washington during the terminal phase of the Fraser Glaciation. Approximate positions of glacier margins are shown for 15,000, 13,500, 12,500 and 10, 000 years before present (Armstrong, 1990).

appears to have been a concentration of eruptive activity at the closing stages of the last glaciation (15,000 to 11,000 years ago) and a paucity since (Mathews, 1958). Isostatic uplift associated with ice removal may have triggered this volcanic activity.

Pleistocene Glaciation

Several times during the past two million years ("Pleistocene Epoch") large parts of the Canadian Cordillera were covered by a complex of interconnected glaciers collectively known as the Cordilleran Ice Sheet. In western British Columbia, ice streamed down valleys in the coastal mountains and covered large areas of the continental shelf. The last major glaciation in southwestern British Columbia ("Fraser" or "Late Wisconsin") occurred between about 25,000 and 10,000 years ago. Ice from the Coast Mountains and Vancouver Island coalesced to flow south along the depression of the present Strait of Georgia into the Puget Lowland (Armstrong et al., 1965; Waitt and Thorson, 1983). The south-trending valleys of the Squamish and Cheakamus rivers and Howe Sound were a major outlet for the Cordilleran Ice Sheet. These tributary valleys were scoured to a U-shaped cross-profile, and mountainous topography was overrun by ice to about 1500-2000 m elevation, producing rounded peaks and ridges. The cirques, horns and comb ridges of Sky Pilot, the Tantalus Range and peaks to the north indicate these areas stood above the ice sheet surface.

At the close of the Fraser Glaciation, the western marine margin of the Cordilleran Ice Sheet became unstable, probably due to sea level rise (Blaise et al., 1990). The British Columbia continental shelf was rapidly deglaciated as the ice sheet calved back to fiord mouths and coastal embayments (Figure 13). Ice retreat within Howe Sound probably proceeded slowly and melting of the ice surface ("downwasting") was a relatively more important process. Deglaciation was likely punctated by glacier stillstands and readvances. A submarine sill, which reaches to within 35 m of sealevel, extends across Howe Sound from Porteau Cove to the Defense Islands. This may record a glacier stillstand at this abrupt constriction in the fiord, or a late-glacial readvance (Mathews, 1968). Relicts of this great ice sheet such as the Pemberton ice field west of Whistler still cover high parts of the Coast Ranges.

Ice sheet growth caused depression of the underlying crust ("isostatic depression"); the amount of the depression varied from region to region in relation to the thickness of the covering ice. Elevated glaciomarine sediments and shoreline features in the Vancouver area show that isostatic depression in that area exceeded 200m during the Fraser Glaciation (Clague, 1981). Studies of former sea level positions (Clague et al., 1982) indicate that most of British Columbia coastal zone experienced rapid isotstatic uplift at the close of the last glaciation causing a relative fall of sea level. Delta deposits perched high on the mountain side near Magnesia Creek north of Lions Bay are evidence of a shoreline 150 m higher than present. Most crustal rebound was completed by about 9,000 BP (Clague et al., 1982).

Glacial sediments

A variable thickness of unconsolidated sediments underlies most of the forested bottoms and lower slopes of valleys within the Howe Sound watershed. These sediments were deposited during and since the Fraser Glaciation. Till, and glaciofluvial, glaciolacustrine and glaciomarine sediments were largely deposited during ice retreat. Till was deposited directly from glacier ice and is probably the most extensive glacial sediment. It is highly variable in composition and texture, and is characterized by compact nature, wide range of particle sizes (boulder, pebble, sand, silt and clay), and absence of layering (stratification). Sandy tills are permeable whereas clay tills tend to be poorly drained. Glaciofluvial sands and gravels were deposited by meltwater from glaciers and are typically well sorted, stratified and very well drained. Such sediments may occur as terraced ice margin deposits ("kame terraces") or broad sheets on valley bottoms downslope from the glacier front ("proglacial outwash"). Glaciomarine materials also were deposited during deglaciation when sea level was relatively higher than at present. Gravelly fan deltas, now perched high on mountain slopes, date to this time (e.g. Magnesia Creek). Unsorted pebbly and silty clays represent marine accumulations of particles released from melting ice. As sea level fell, emergent marine sediment was worked over by wave action to form a thin covering of beach sands and gravels.

Post-glacial and modern sediments

Throughout post-glacial time ("Holocene Epoch"), colluvial materials have accumulated on or at the foot of slopes and are probably the most widespread surficial material in the Howe Sound watershed. Glacial sediments were commonly eroded by changing river regimes causing stepped terraces on valley floors and sides. Fluvial, lacustrine and organic sediments have been deposited on valley floors.

A wide range of sediment types occur on the floor of Howe Sound (Figure 14). Coarser sediments (sandy mud, gravelly mud, muddy sand) originate from reworked Pleistocene deposits on sills, shallower platforms and near shorelines, and from mountain creeks (Mathews and Murray, 1966; Syvitski and Macdonald, 1982). Shallow water areas have low to zero net deposition because of tidal current winnowing. Deep basins on the other hand act as sediment traps. Fine muds accumulate in the deep areas the outer basin whereas sedimentation rates are higher and sediments coarser (silts and sandy silts) in the northern part of the inner basin due to sediment influx from the Squamish River. Sediment slumping and gravity flows are more common in the inner basin because of the high sediment loading on steep delta and fiord wall slopes (Prior and others, 1981). Tongues of sandy mine tailings, traceable some 2 km downslope from Britannia Beach, likely were emplaced by sediment gravity flow processes (Prior and Bornhold, 1986).

The major minerals in Howe Sound sediments include feldspar, quartz, mica, Mg-chamosite, amphibole, tourmaline and smectite (Syvitski and Macdonald, 1982). Quartz, tourmaline and smectite occur dominantly in the coarse fraction, and mica and chamosite in the fine fraction; feldspar and amphibole occur in all size fractions. Sediment from the Squamish River accounts for over 90 percent of recent Howe Sound deposition; other sediment sources include surface waters of the Fraser River, small creeks and rivers flowing into the sound, Pliestocene deposits reworked in shallow water areas, and mine tailings from the Britannia mine (Syvitski and Macdonald, 1982). Sediments in Howe Sound contain little organic carbon (Syvitski and Macdonald, 1982). North of the inner sill, carbon averages 0.6% while to the south in basins where sedimentation rates are lower it averages 1.5% (Figure 16). The coarser biogenic particles are dominated by diatom frustules, radiolarians, foraminifera, sponge spicules, dinoflagellate cysts, pollen and spores. Fecal pellets of planktonic zooplankton (e.g. euphausiids, copepods) are locally abundant in the inner basin. However, the correlation of organic and inorganic sedimentation rates in the inner basin suggests the organic matter is largely derived from the Squamish River (Syvitski and Murray, 1981).

Near-shore tailings dumped from the Cu-Zn Britannia mine have been reworked by wave activity and dispersed up and down the fjord from the mine site. A distinct copper anomaly is widespread within the inner basin (Drysdale, 1990; Syvitsky and MacDonald, 1982) (Figures 18 and 19). Suspended tailings leave also leave the upper basin over the inner sill via the outflowing Squamish River plume based on a distinct copper anomaly (>100 ppm Cu) in 1980 that extended from Watts Point and Britannia Beach through Montagu Channel, Ramilles Channel and Thornborough Channel as far as Port Mellon (Figure 18). Tailings have also moved down slope into the inner basin via sediment gravity flows of slumped material. High amounts of nickel (>40ppm) occur in sediments at the mouth of Howe Sound, in the eastern outer basin as far north as Anvil Island, and in Collingwood Channel (Figure 20). This provides a sensitive indicator of Fraser River sediment in Howe Sound (Syvitski and Macdonald, 1982). Mercury is elevated in sediments affected by pulp mill effluent (Thompson and MCComas, 1973).

SOILS

Soils in the Howe Sound areas are predominantly podzolic in character, highly leached, acidic and reddish brown in colour (Armstrong, 1961; Dept. Environment., 1973; Valentine and others, 1978). Mineral soils have three major horizons. An upper A horizon often includes a surface organic layer and underlying layer where removal of materials has occurred by solution, suspension or erosion (Figure 22). The B horizon is a zone where materials derived from the A horizon (i.e. clays, organic material, iron and aluminum) accumulate. The lower C horizon is weakly modified parent material. Organic parent materials occur where plant material is produced faster than it is decomposed. Commonly this occurs

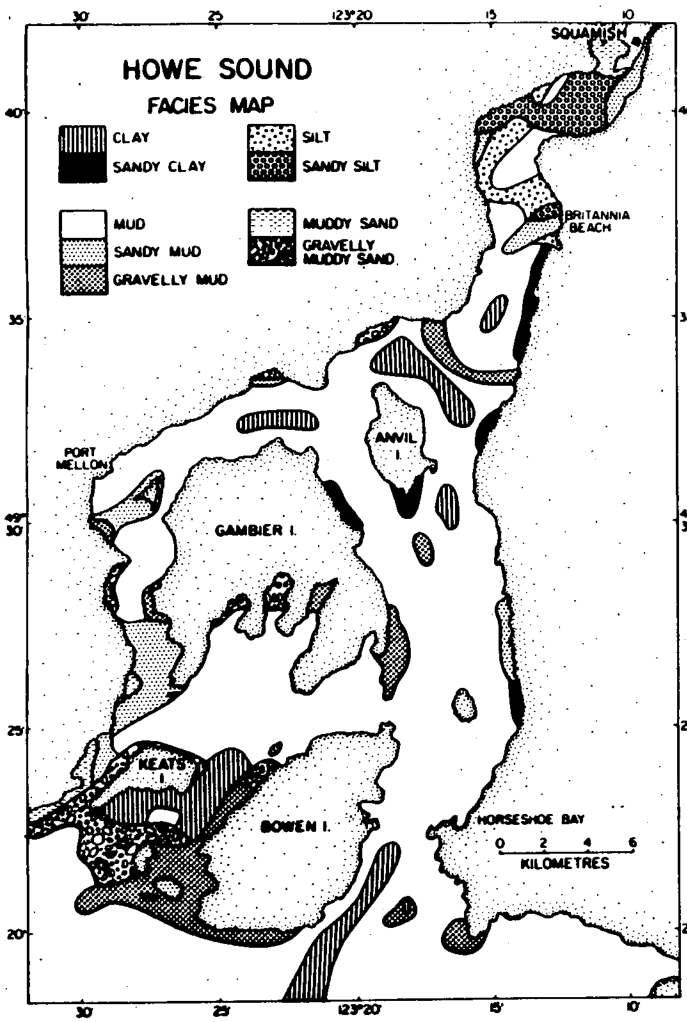


Figure 14 Recent marine sediments, Howe Sound (Syvitsky and MacDonald,1982).

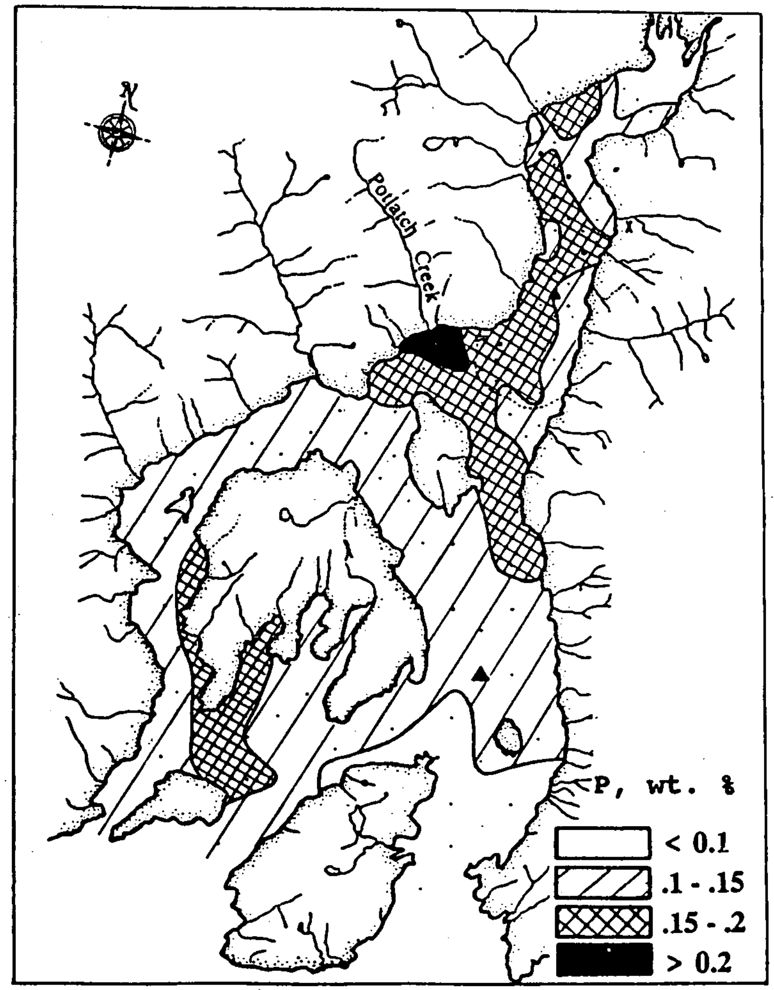


Figure 15. Phosphorus (weight %) in surface sediments from Howe Sound, May 1987 (from Drysdale, 1990).

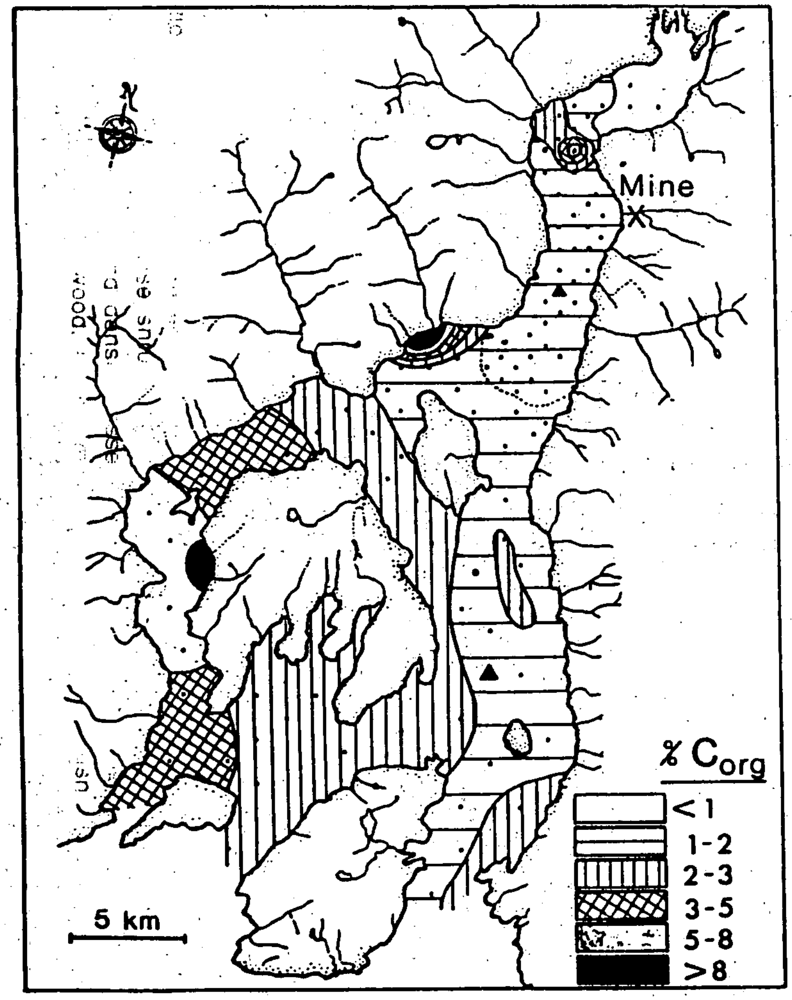


Figure 16 Organic carbon (% dry weight) in surface sediments from Howe Sound, May 1987 (from Drysdale, 1990).

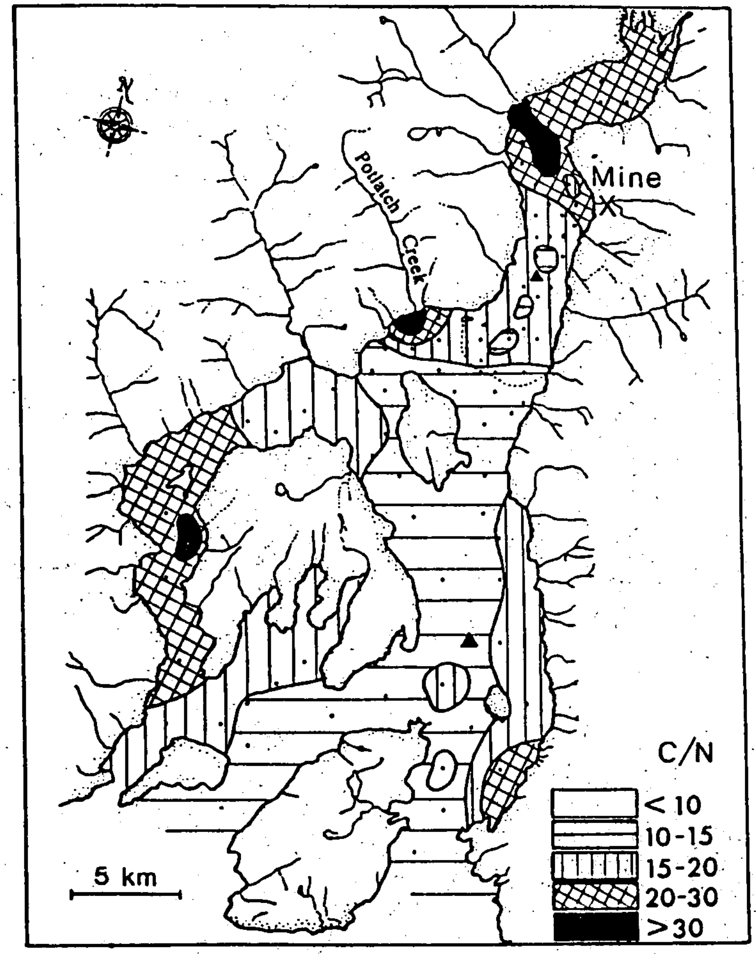


Figure 17. Organic carbon to nitrogen ratios (weight ratios) in surface sediments from Howe Sound, May 1987 (from Drysdale, 1990).

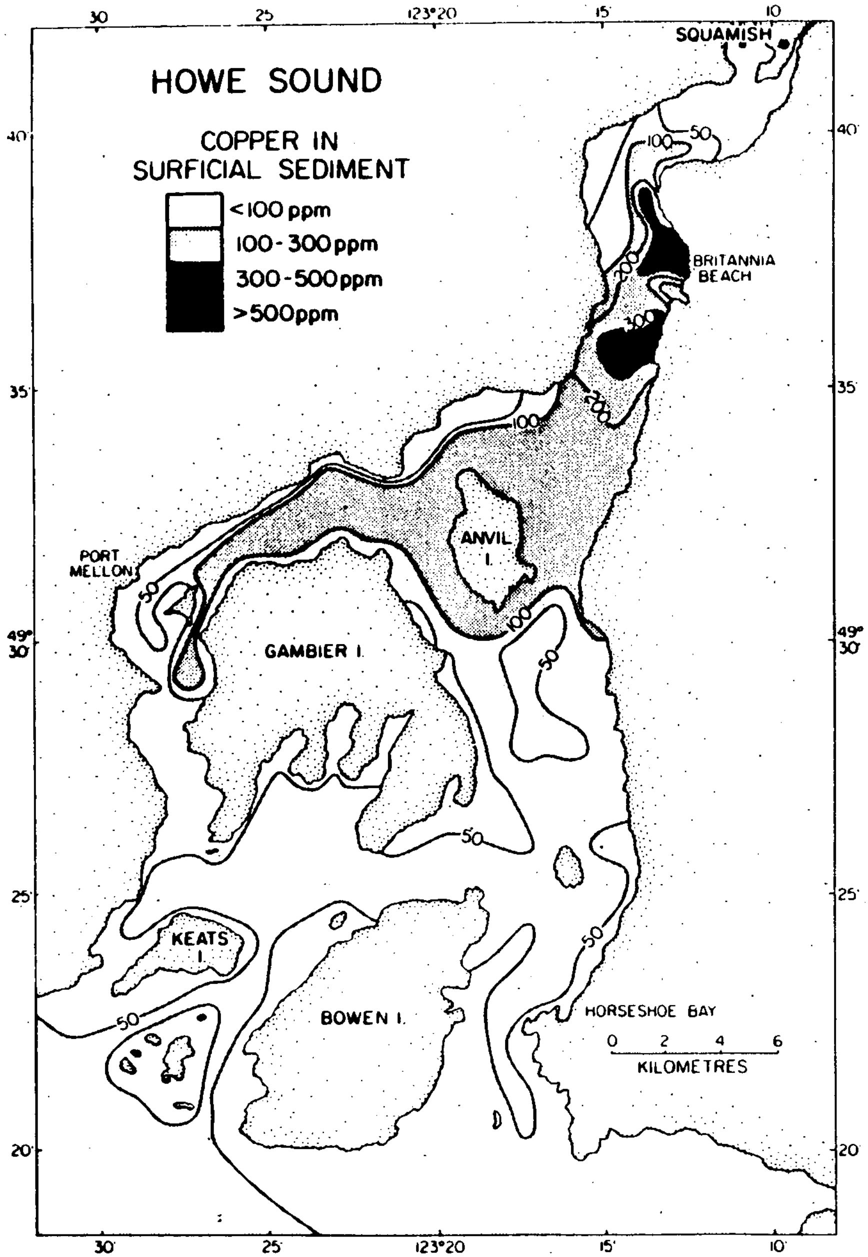


Figure 18. Distribution of copper in surface sediments from Howe Sound (from Syvitsky and MacDonald, 1982).

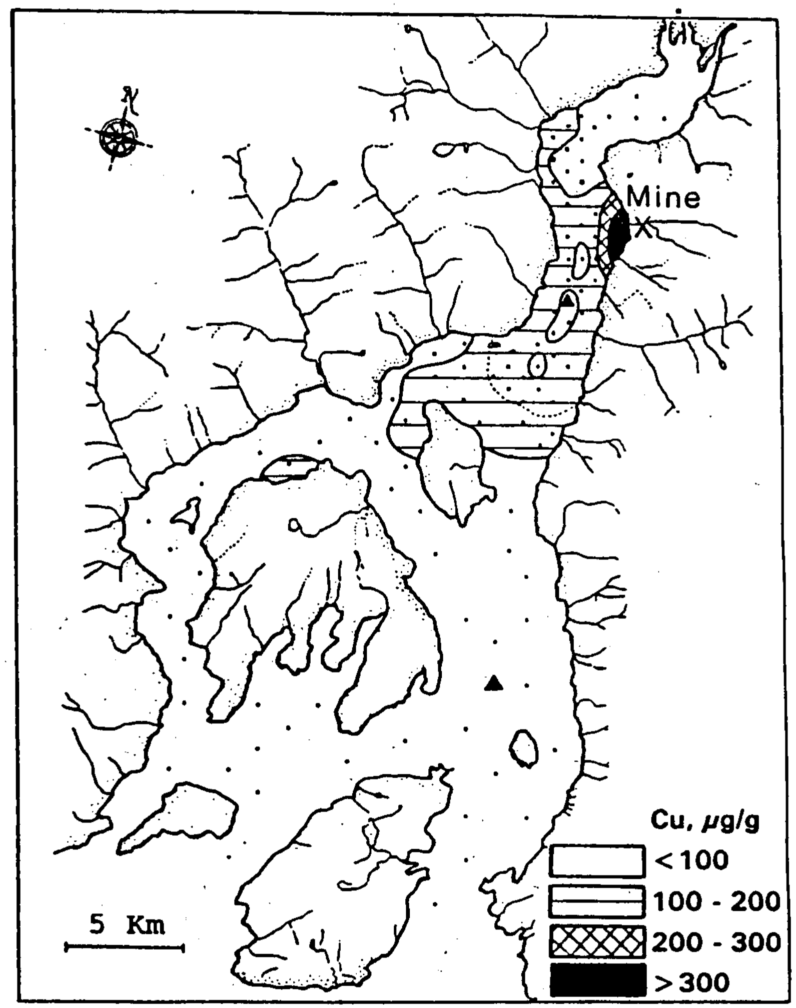


Figure 19 Distribution of copper in surface sediments from Howe Sound (Drysdale, 1990).

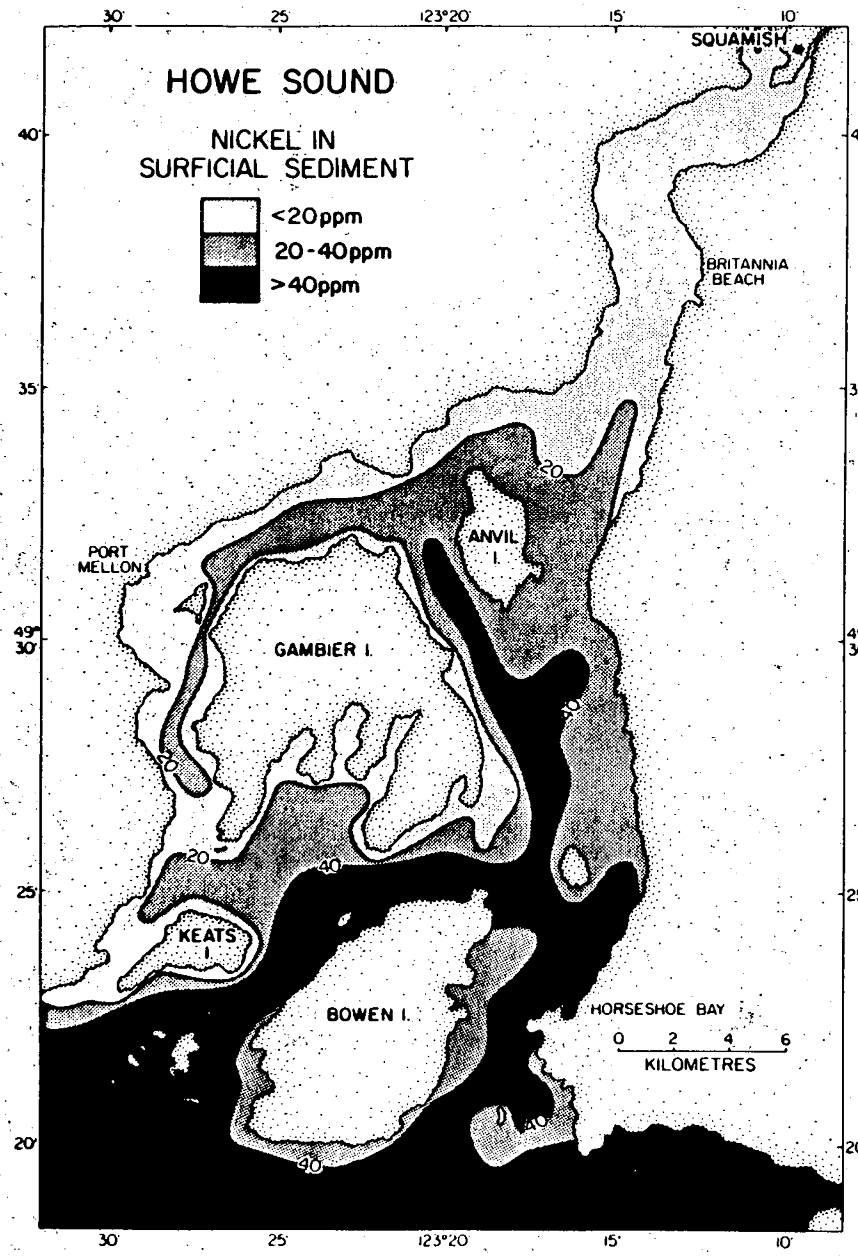


Figure 20. Distribution of nickel in surface sediments from Howe Sound (from Syvitsky and MacDonald, 1982).

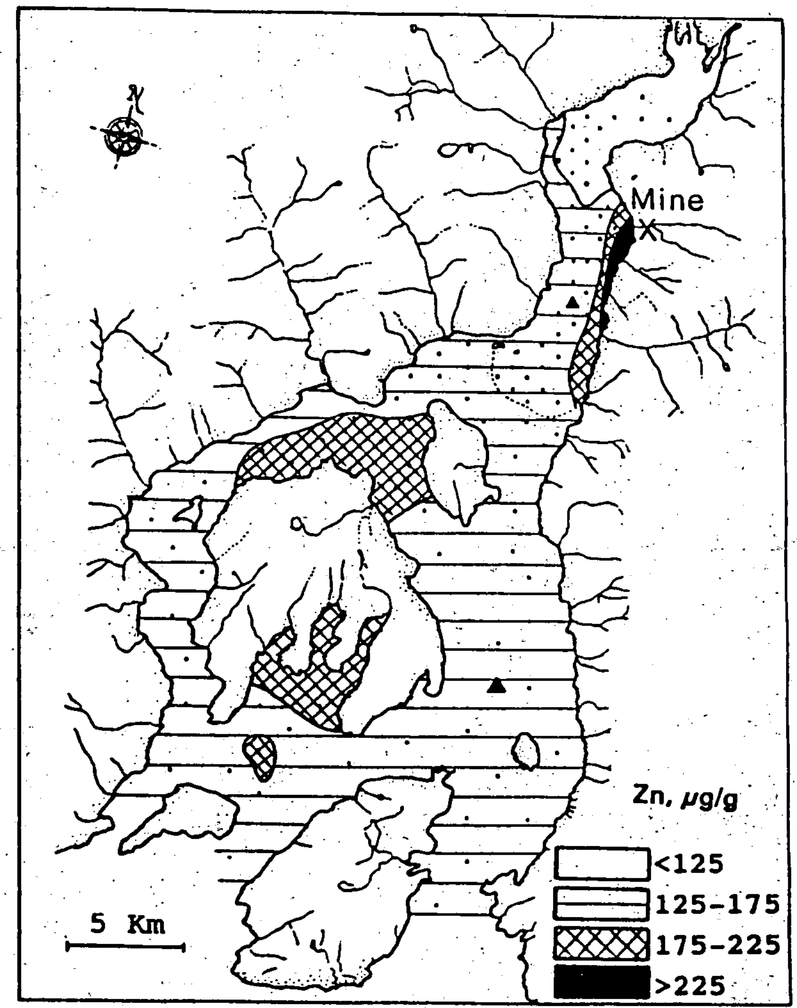


Figure 21. Distribution of zinc in surface sediments from Howe Sound, May 1987 (from Drysdale, 1990).

where the water table is at the surface and anaerobic conditions limit biological decomposition, or in cold regions where biologic decomposition is also limited.

Intensely leached soils (Podzols):

Most of the soils in the Howe Sound drainage basin reflect the abundance of water moving through the soil during the year causing intense chemical and biological transformations in the upper horizons. Organic matter is decomposed and primary minerals are broken down releasing iron and aluminum. The accumulation of organic matter, iron and aluminum in the B horizon is the distinguishing characteristic of these soils, known as podzolic soils. Podzolic soils are distinctive by a black organic litter layer on the surface; an underlying light grey silica sand/silt horizon (Ae layer) leached of organic matter, iron and alumium; and a distinct reddish brown layer enriched with organic matter, iron and aluminum that becomes more yellowish with depth. Compact cemented horizons ("pans") often occur within glacial till deposits two to four feet below the soil surface and commonly restrict root penetration and permeability.

Within the Howe Sound area, two types of podzol soils can be distinguished based on the relative amounts of organic matter and iron plus aluminum that have accumulated in the upper B horizon. Humo-Ferric Podzol soils are developed under dryer confir forests at lower elevations and on southwestern slopes underlain by glacial till or colluvium. These soils are distinguished by the accumulation of iron and aluminum but only little organic matter in the B horizon. Ferro-Humic Podzol soils tend to occur below more humid and cooler conifer forests (often with a thick ground cover of moss) at higher elevations. In these soils organic matter as well as iron and aluminum accumulate in the B horizon.

Organic Soils

Organic soils composed mainly of organic matter form where accumulation of organic matter exceeds the rate of decomposition by microorganisms and macro soil fauna. This commonly occurs under highly saturated conditions that limit oxygen availability, where organic accumulation rates are very high, and where low temperatures limit biologic decomposition processes. In the Howe Sound watershed, acidic organic soils composed of peat moss form in in poorly drained depressions that were lakes immediately following glaciation and have infilled with vegetation. On upper mountain slopes under dense forests where surficial materials are thin or absent, large amounts of needles, twigs, wood and bark can accumulate over very thin soils or directly on bedrock. Decomposition of this material is slow and a thick spongy organic surface layer (Folisol) forms. Such organic soils are associated with intensely leached podzol soils developed on thicker surficial materials. Organic soils may also occur at high elevations where cold temperatures limit organic decomposition.

Immature soils (Brunisols and Regosols)

Immature soils develop where soil forming processes are restricted due to lack of soil moisture, long winters and low temperatures, coarse texture (e.g. sands and gravels) or geological youth of recently deposited parent material (e.g. flood plain sediments, colluvium). Two important immature soil types occur within Howe Sound watershed: Brunisols in the drier outermost parts of Howe Sound area, and Regosolic soils in the high mountain areas.

Brunisolic soils (Dystric Brunisols) occur in the driest parts of the watershed such as the lower elevations on the Sunshine Coast, the islands of Howe Sound, and from Horseshoe Bay to Lions Bay on the east side of the sound. These soils are recognized by a weakly developed B horizon that is browner or more reddish than the underlying parent material. The immature nature of these soils is due to low soil moisture during the summer months that limits biologic activity and hence chemical weathering. Active processes in these soils include leaching of soluable salts and carbonates, weathering of the mineral fraction to form hydrated iron and aluminum oxides, and development of soil texture. In the Howe Sound area these soils tend to have only a thin layer of organic accumulation (Ah layer) and a soil pH of less than 5.5.

Such immature soils are also developed on fluvioglacial sands and gravels elsewhere in the watershed because of the lack of fine reactive components that make this sediment somewhat chemically

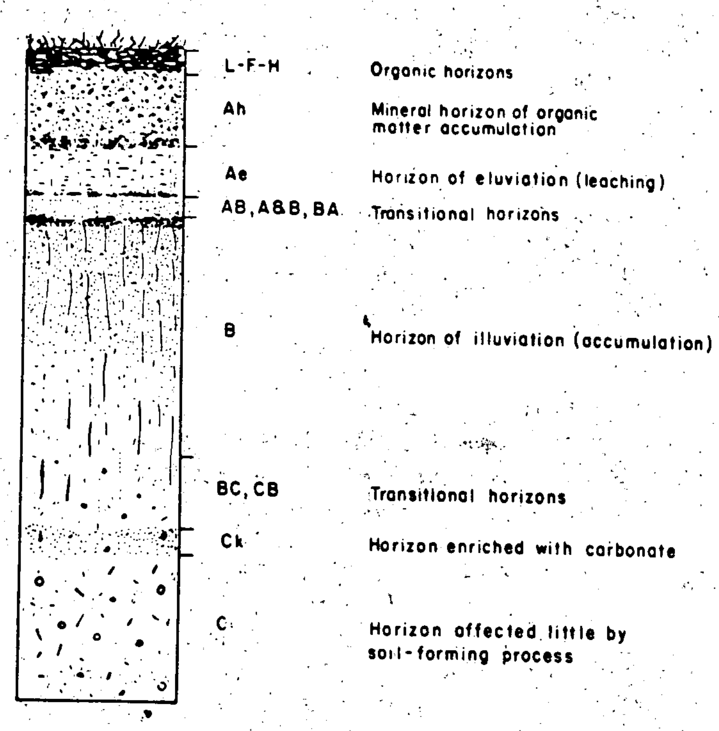


Figure 22. Common horizons in a mineral soil profile (Fig. 2.2.2 Valentine et al., 1978).

inert. Low water-holding capacity, and sparse vegetation on these sands and gravels also limit soil development. Immature soils are also found on very young but fertile alluvium along the floodplain of the Squamish River. These soils are subject to periodic flooding and fluctuating watertables.

Above tree line, well-vegetated alpine meadow soils generally have a dark-coloured surface horizon due to the predominance of sedge and grass vegetation. Higher up but below the snowline there are large expanses of rock debris with little vegetation. Frost action continually disrupts the surface materials and cold temperatures limit rates of chemical and microbiological reactions resulting in only weak development of soil horizons.

FOREST ECOSYSTEM

Vegetation

The Howe Sound watershed cuts transversely across the topographic grain of the Coast Mountains and ranges in elevation from sea level to over 3000 m. The vegetation within the Howe Sound watershed changes with elevation from wet maritime forest to subalpine forests to alpine tundra. The outermost islands and shores of Howe Sound lie within the influence of the rainshadow of Vancouver Island causing a drier maritime forest. There is also some rainshadow effect by the outer Coast Ranges on the interior part of the watershed. Consequently the watershed may be divided into four biogeoclimatic zones, large geographic areas with broadly homogeneous climates (Figure 23). Such areas have characteristic webs of energy flow, nutrient cycling and patterns of vegetation and soil. They are often named for the climax species of trees shrub, herb or mosses within the biogeoclimatic region. The four biogeoclimatic zones within the Howe Sound watershed are Coastal Douglas Fir, Coastal Western Hemlock, Mountain Hemlock and Alpine tundra (Figure 23) .

Drier maritime forests (Coastal Douglas Fir zone)

The Coastal Douglas Fir zone, the driest climate area in Howe Sound watershed, occurs only on the lower (<150m) southwest-facing slopes of Bowen, Keats, Gambier Island and other outer islands in Howe Sound, and in the Gibsons-Langdale area (Nuszdorfer and others, 1985)(Figure 23). The rainshadow effect of Vancouver Island coupled with southern exposure results in very dry conditions during the summer. Forests, with the exception of old growth in Lighthouse Park, have regenerated after logging near the turn of the century. Douglas Fir is the most common tree species and can regenerate under the mature and partially open canopy. Western red cedar, grand fir, arbutus, western flowering dogwood, red alder and bigleaf maple are common in this zone (Nuzsdorfer and others, 1991). The understory often includes a dense shrub layer of salal, Oregon grape, red huckleberry, roses and salmonberry, and underlying Indian-plum, vanilla-leaf, sword fern, starflower, and mosses. Rocky sites with very dry soil moisture regimes are dominated by arbutus and Douglas Fir with understories dominated by spring wildflowers such as camas, sea blush, shootingstar, and blue-eyed Mary, and by shrubs such as ocean spray and common snowberry.

Wet maritime forests (Coastal Western Hemlock zone)

The Coastal Western Hemlock zone dominates the lower elevations in the Howe Sound watershed. This zone oCCupies lower slopes from sea level up to 800 or 1000 m elevation adjacent to Howe Sound and in the valleys of the Squamish River system (Nuszdorfer and others, 1985)(Figure 23). Areally, this is the most extensive biogeoclimatic zone in the watershed. Western Hemlock dominates the forest canopy with dense understories of salal, huckleberries, devel's club, ferns, foamflowers, and a thick moss layer (Pojar and others, 1991a). Western red cedar (lower elevations) and yellow cedar (higher elevations) are common seral species with red alder pioneering heavily disturbed sites. At higher elevations amabilis fir occurs with hemlock as a climax species. In drier areas Douglas Fir is a common seral species with an dense shrub-dominated understories of salal, falsebox, false azalea, huckleberry, vanilla-leaf, sword fern, and dense mosses. Floodplains such as along the Squamish River often have Sitka spruce, black cottonwood, bigleaf maple, red alder, and a lush shrub cover of red-osier dogwood,

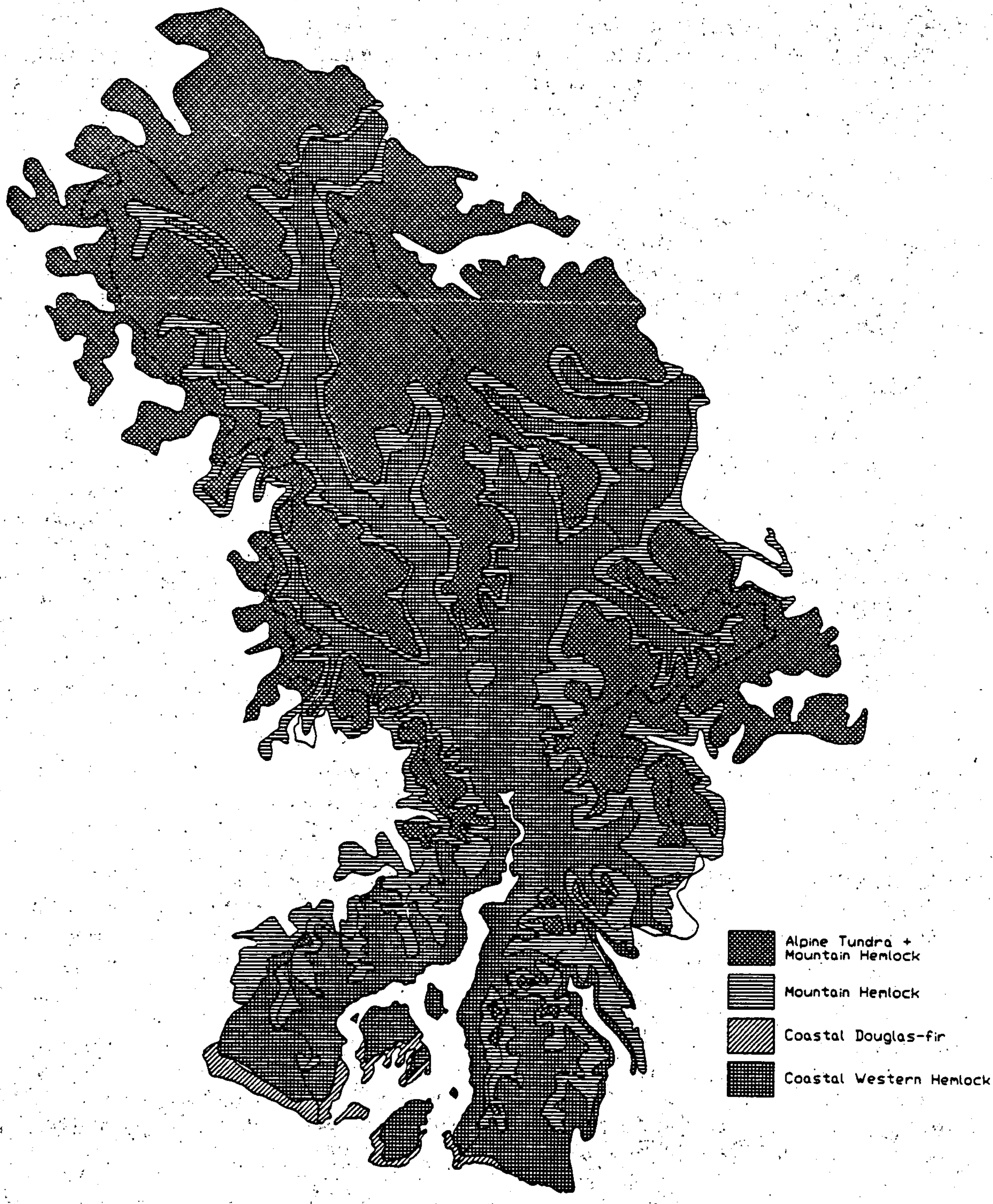


Figure 23 Biogeoclimatic map of the Howe Sound watershed (by T. Feeney from data in Nuzsdorfer and others, 1985).

salmonberry, and ferns. Avalanche chutes are densely covered with Sitka alder and moisture-loving herbs.

<u>Subalpine forests (Mountain Hemlock zone)</u>

The Mountain Hemlock zone is the subalpine zone above the Coastal Western Hemlock zone. In the Howe Sound watershed , the Mountain Hemlock zone typically lies between 800 and 1000m elevation (Figure 23). This subalpine zone covers the upper mountain slopes of the ranges adjacent to Howe Sound, but in the higher mountainous area north of Squamish the subalpine occurs as a thin belt on valley slopes above lower forests and below extensive alpine uplands (Nuszdorfer and others, 1985). The lower part of this zone is a dense forest of mountain hemlock, amabilis fir and yellow cedar with western hemlock, western red cedar and Douglas fir (Pojar and others, 1991b). Understories include white-flowered rhododendron, false azalea, blueberries, and thick mosses. At upper elevations tree growth becomes progressively poorer due to shorter growing season, increased duration of snow cover and cooler temperatures, and forests become discontinuous and are intermixed with wet and dry meadow vegetation. The Mountain Hemlock zone has little forestry value due to the short growing season.

<u>Alpine Tundra zone</u>

The alpine tundra zone occurs on high mountains throughout the Howe Sound watershed. In the lower mountainous areas adjacent to Howe Sound, alpine tundra is limited to small isolated areas around the highest peaks (e.g. SkyPilot Mtn., Tetrahedron Peak) whereas in the higher mountainous interior of the watershed alpine tundra covers large upland areas flanking icefields and rocky peaks (e.g. Pemberton icefield area, Garabaldi Lake area) (Figure 23). Scattered pockets of mountain-heather or meadow vegetation occur in this area of rock and glaciers. Alpine vegetation is dominated by shrubs, herbs, bryophytes, and lichens (Pojar and Stewart, 1991). Prostrate woody plants form a dwarf scrub that is widespread (e.g. (heather, kinnikinnick, willow). Alpine grass meadows are restricted to drier areas on south-facing slopes or ridges, or some seepage or snowbed ecosystems (e.g fescue, wheatgrass, sedge). Herb meadows of broad-leaved forbs are common at lower elevations in well-drained sites with deep soils, in seepage areas or along streams (e.g. lupine, groundsel, daisy, buttercup, hellebore, paintbrush, pasqueflowers). Stunted (krummholz) subalpine fir, Engelmann spruce, white spruce and mountain hemlock occur at lower elevations. A few species of lichens and mosses thrive up to the upper limits of vegetation and occur over bedrock, in boulderfields or as vegetation stripes on patterned ground.

Fauna

<u>Maritime forests and shores</u>

The Coastal Western Hemlock zone has great diversity and abundance of animal habitats (Pojar and others, 1991a). Black tailed deer and black bear are the most common large mammals. The thick forest canopy intercepts snow while the litterfall of arboreal lichens and needles provides winter forage for Black-tailed deer. Mountain goat descend to forested rocky cliff areas in winter. Many species of birds, such as owl, flicker, woodpecker, flycatcher, jay, raven, chickadee, nutch, wren and thrust use the conifer forests because of the presence of other birds, rodents, bark and wood-boring insects, and conifer seeds. Because of the damp litter on the floor of mature forests, there are many species of amphibian such as salamander, toads and frogs. Garter snakes are widespread. Clearcut areas with suCCulent regrowth creates an abundance of forage for deer and bear, and habitat for grouse, pidgeon, woodpecker, robin, thrust, waxwing and finch.

Salmon and trout spawn in many large and small rivers, and most of their young spend some time in these streams. These fish support a wide range of predators including black and grizzly bear, river otter, mink, merganser, goldeneye, eagle and gulls. The lower Squamish and Cheakamus river support a very large resident population of Bald Eagle. The nutrient-rich, protected waters of the Squamish estuary provide shelter for over-wintering waterbirds such as diving and da31ling ducks, swan, grebes, scoters, and gulls.

Low, near-tidal islets among the outer islands of Howe Sound are important haul-out areas for harbor seal. Small, rocky coastal islands such as Pam rocks and Christie Islets provide good protection from predators and nesting habitat for colony-nesting marine birds such as gulls, guillemot and cormorant. Harbour seals and northern sea lions occur among the outer islands.

Subalpine areas

The steep and rugged topography, and long, cool, wet winters with heavy snow cover result in few species and low population densities. Deer, black and grizzly bear, and mountain goat tend to use open areas such as avalanche chutes, southfacing rock outcrops and talus slopes, and subalpine parklands (Pojar and others, 1991b). Birds such as owl, nutcracker, raven, flicker, woodpecker, chickadee, nuthatch, kinglet and warbler that eat wood- or bark-boring insects, conifer seeds, other birds and mammals find habitat in old growth stands. Reptiles are lacking and amphibians are rare.

Alpine tundra areas:

Wildlife species diversity and density are low in the alpine tundra due to the harsh climate. Snowpack is exceptionally thick in the winter and does not melt away until well into summer. Mountain goat are common but commonly descend to lower elevations in the winter. Summer species include deer foraging in lower elevation meadows, and golden eagle, ptarmigan, marmot and wolverine (Pojar and Stewart, 1991).

Big Game

text by Bob Forbes, Fish and Wildlife Branch, B.C. Environment

Big game occurrence in the Howe Sound watershed can be summarized as follows:

Black bear: ubiquitous occurrence, slight seasonal altitudinal migrations. Population estimated at 250 animals. Excellent habitat availability, largely as the result of early successional stages provided through logging. Current habitat availability not impacted by human development. Not thought to occur on many of the islands of Howe Sound.

Blacktail deer: Ubiquitous, including islands of Howe Sound. Migrates elevationally in response to weaterh conditions (mainly snow). Species is managed conservatively in terms of hunting harvest (ie. much of area is private land where public access is not permitted, antlerless seasons permitted on islands only). Hunting harvest is not limiting deer populations in this area. Population estimate is 1200-1500 animals.

Cougar: Occurs in low numbers (approximately 20 animals) throughout the area, usually associated with presence of prey species (normally deer).

Coyote: current population estimate is 150 animals, distributed throughout the area. Can utilize a wide variety of habitats, does best in diverse habitats, and is very opportunistic.. Coyote does well in habitat types within Howe Sound watershed.

Elk: There are rumors of relict population oin McNab Creek and Woodfibre Creek valleys. These may be remnants of a translocated population established in McNab Creek in 1933. Population was thought to have been extirpated by overhunting and winter range alienation. Excellent habitat availability on Sechelt side of Howe Sound, largely as the result of early successional stages provided by logging and powerline development.

Moose: Approximately 30 animals occur in the Elaho River valley. Winter range is restricted to approximately 450 acres of riparian habitat on Elaho River Summer range is extensive and not limiting. Currently managed for non-consumptive use. Population is the furthest southwest extension of species in B.C.

Mountain goat: Mountain goat inhabit alpine areas in summer and lower elevation , SW facing rock bluffs inwinter. There has been much habitat loss through logging several decades ago but recent loss has been minimal. Although there were overharvests of local goat populations in the 1950's and 1960's, conservative harvests have been in place for several years. Populations are estimated as: the height of land between Howe Sound and Capilano watersheds (15 animals); Mt. Wrottsley, Woodfiber Creek, McNab Creek, Rainy River areas (25 animals) and Squamish drainage (50 animals).

Wolf: Occurs in low numbers in the northern part of the watershed. Population estimate is 10 animals. Occurrence and abundance is primarily prey driven. The species continues to suffer losses through human control, most of which is largely illegal.

Freshwater fisheries

text by Brian Clarke, B.C. Environment

The fisheries potential of Howe sound's rivers and creeks is limited due to high gradients, extreme flow variation, low temperatures and nutrients and habitat loss due to industry and urbanization. Smaller creeks support runs of cutthroat, chum and coho salmon while larger streams support salmon as well as Dolly Varden char, lamprey, sculpin and stickleback. Lakes of the area were originally barren but stocking programs since the 1930's have spread rainbow and cutthroat throught most of the areas lakes, including alpine waters.

The Squamish River system has significant populations of steelhead, coho, chum and chinook salmon. Sockeye and cutthroat salmon and Dolly Varden char are found in smaller numbers. Chum, coho and chinook populations are augmented in large numbers by the Tenderfoot Hatchery on the Cheakamus River. While some stocking of steelhead fry occurs in the tributary headwaters, steelhead of the Squamish watershed are managed primarily as a wild stock with recreational catch and release regulations and habitat protection used to maintain the stock. Steelhead, coho, chinook, cutthroat and Dolly Varden all utilize the freshwater tributaries and side channels of the Squamish River for periods of 1 to 5 years before migrating to the estuary and ocean. The most critical habitat in the watershed are the many small side-channels and ground water seepage channels found on the valley floor. While these habitats represent only 6% of the upper river they are ressponsible for over 60% of the salmonid production.

OCEANOGRAPHY OF HOWE SOUND

Howe Sound is an estuarine system with a marine environment strongly influenced by fresh water input from the Squamish River system, and to a lessor extent, the Fraser River. (Thomson, 1981). Squamish River runoff progresses seaward as a turbid brackish surface jet about 10m thick that widens and becomes progressively more saline as it advances seaward and mixes with underlying seawater. The strength of this chalky looking, silty jet is greatest in the summer when runoff is highest, and weakens during low winter flow. Large back eddys develop adjacent to the jet at the head of the sound near the Squamish delta, Woodfibre and Britannia whereas at Porteau Cove the flow is everywhere down the sound (Buckley, 1977) (Figure 24). Southerly winds in the inner basin can reverse the flow of the jet for short periods of time, particularily during periods of low runoff.

There is little known about general circulation among the islands of the outer sound. It is likely that currents are weaker, more variable and have more eddy-like structure than those within the inner basin due to the competing dynamic forces of the Squamish and Fraser River discharges, greater width of the basin allowing transverse (E-W) current directions to become important, divergence and convergence of currents around the numerous islands, and rougher bottom topography (Figure 5) (Syvitski and Macdonald, 1982; Thomson, 1981). During the maximum flood (freshet) of the Fraser River in June, brackish surface waters flow up the eastern channel (Tabata, 1972). The surface jet of the Squamish River may enter the outer sound either east of Anvil Island (Montagu Channel) or to the west via Ramilles or Thornborough channels. The distribution of clay sized mica from the Squamish River, and Cu and Zn from the Britannia mine area supports the divergence of the Squamish River jet around Anvil and Gambier Islands (Syvitski and Macdonald, 1982). Strong southerly winds or inflow of Fraser River waters may force the jet to the western route, while high discharge from the Squamish River, northerlies or weak southerly winds encourage the jet along the eastern margin of the sound (Syvitski and Macdonald, 1982; Thomson, 1981). This south moving jet can be deflected to the west through Collingwood Channel by a northerly inflow of Fraser River water up Queen Charlotte channel.

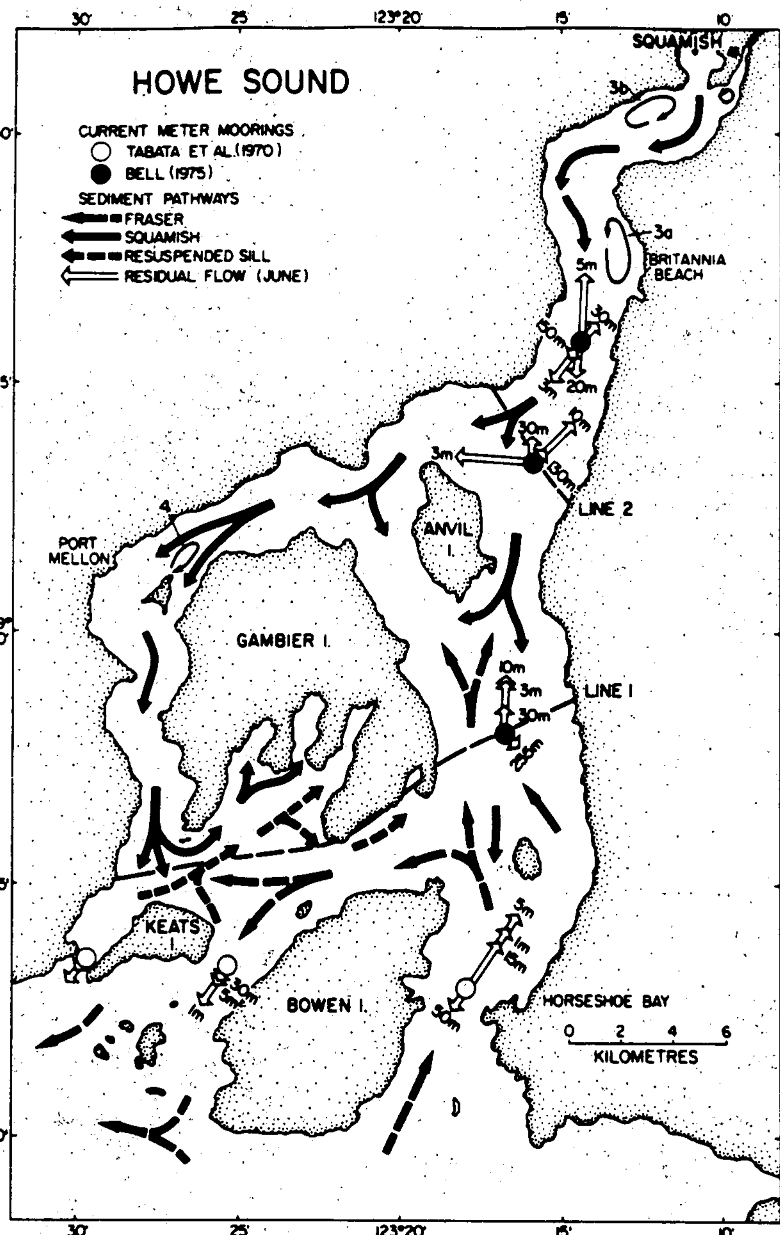


Figure 24. Major sediment dispersion pathways and residual currents (based on current meter moorings) for Howe Sound. Fraser sediment is obvious south of line 1 but negligible north of line 2. Areas 3a and 3b are surface-water gyres under which the bottom sediment contains abundant biogenic pellets. The length of the arrow of residual current velocities represent relative current speed (from Syvitski and MacDonald, 1981).

During high summer discharge of the Squamish River, the salinity of the jet is about 15 parts per thousand in the Porteau Cove area while salinities at the mouth of the sound are comparable with the Strait of Georgia (29-31 parts per thousand) (Thomson, 1981). There is a slow drift of deeper seawater up the sound to compensate for the loss of seawater to the overlying surface jet. Below 50 m depth, the salinity ranges from 29-31 ppt throughout the year (Thomson, 1981). The Porteau sill tends to impede this deep counter flow leading to oxygen depletion in the deep waters of the inner basin (Bell, 1973; Levings, 1980). However, strengthened overflow of the sill by deep waters of the outerbasin may be triggered by a very strong surface jet related to the coincidence of Squamish winds with high river discharge. This winter incursion of oxygenated deep waters is critical to marine organisms living below the sill height. Whenever such refreshening events are delayed too long, oxygen depletion leads to widespread depletion of benthic organisms (Levings and McDaniel, 1980).

There is very little known about deep water circulation in the outer sound. North-flowing surface brackish waters from the Fraser River eventually become the subsurface current that flows into the upper basin (Syvitski and Macdonald, 1982). Given the deep straight channel along the eastern side of the sound (Montagu and Queen Charlotte Channels), it is likely that the deep waters in this area are well mixed with marine waters of the Strait of Georgia. Because of the irregular nature of channels within the numerous islands of the western side of the sound, and the presence of sills between Gibsons and Bowen Island and Langdale and the southwest corner of Gambier Island, it is likely that deeper circulation in this area is less effective.

Howe Sound has mixed, predominantly semidiurnal tides (Thomson, 1981). At both Squamish and Point Atkinson, the mean tidal range is 3.2 m and the large tide range is 4.9 m. Times of high and low tide are usuallly only a few minutes behind Point Atkinson, though this delay can be inceased or decreased respectively by Squamish winds and southerly winds. During the summer months, the outflow of brackish Squamish river water is to strengthen the ebb and weaken the flood tides.

MARINE ECOSYSTEM OF HOWE SOUND

text by Lee E. Harding, Environment Canada

Howe Sound has been the subject of several planning studies during the past two decades: The Burrard Inlet - Howe Sound Area Planning Study by Environment Canada in 1973, a Howe Sound Overview Study by the B.C. Environment and Land Use Committee Secretariat in 1980 and a federal-provincial Squamish Estuary Management Plan, completed in 1982. These planning initiatives have been supported by numerous scientific environmental studies. This overview summarizes some of the key physical and biological features of Howe Sound as they relate to functioning of the marine ecosystem.

Oceanography

The upper House Sound basin is a true fjord, approximately 290 metres at the deepest point, bounded by the Squamish River estuary to the north and a shallow sill (61 m) near Anvil Island to the southwest. The sill inhibits regular flushing of the upper basin. The waters of the upper basin are strongly influenced by salinity, temperature and current changes associated with freshwater input. A pronounced stratification occurs during freshet (May to September) of the Squamish River and extensive silt loading and turbidity result. Progressive density differences between water outside the sill and the water inside the sill, which entrains lower-density fresh water from the Squamish River, cause periodic renewal of bottom water in the inner basin.

Primary Productivity

Plant biomass is produced in two principal areas: production by phytoplankton in the euphotic zone of the surface waters of the Sound, and production by marsh plants in the Squamish River Estuary. Throughout upper Howe Sound, the impact of turbidity from the Squamish River reduces primary productivity during freshet (Stockner and Cliff, 1973). Turbidity from the Fraser River plume also intrudes into the outer basin. However, the light attenuation properties of bleached kraft pulp mill effluent (BKME) near Woodfibre were shown to be the major cause of reduced phytoplankton productivity

(Stockner et al., 1975). Under certain conditions, nutrient enrichment from the effluent can enhance productivity if light conditions are suitable (Stockner and Costella, 1976).

The Squamish Estuary is a detrital-based community, with considerable production of plant biomass by rooted emergents providing a carbohydrate base for detritivores, which in turn nourish secondary consumers and so on (see Hoos and Vold, 1974). Salmon and steelhead rear in the estuary and migrate up the river, providing seasonal fare for eagles and other scavengers and predators. The Squamish Estuary has been extensively restructured by training dikes, dredging, filling, and other industrial activities. These have reduced freshwater-saltwater mixing with consequent effects on marsh vegetation, and altered sediment deposition patterns. Extensive use of intertidal areas for log storage has further reduced productivity.

Dissolved Oxygen

Surface dissolved oxygen (DO) is strongly influenced by the Squamish River flow. The stratification created during freshet aids in dilution and dispersion of effluent discharged at the surface. The effects of tides, winds and currents also lessen the impact of bleached kraft mill effluent (BKME). Poor flushing and exchange because of restricted subsurface flow over the sill can result in a progressively hypoxic environment. Renewal occurs approximately every three years (Giovando, 1972; Bell, 1974). Extremely low DO (< 1.0 mg/l) is typical of the deep basin between renewal events.

Benthic Communities

Shallow subtidal epibenthic communities in the upper basin include brachiopods, nudibranchs, numerous crab species, shrimp, tubeworms, anemones, sea cucumbers etc., typical of sheltered, west coast inlets (McDaniel, 1973). Trawls in deeper water have produced prawns, ratfish, walleye pollock, several sole species eelpouts, deepsea smelt, prickleback, sculpin, Pacific cod, northern lampfish and various shark species, numerous bivalve and gastropod molluscs, polychaete annelids, echinoderms and an ascidian chordate (Harbo and Birtwell, 1978, Levings, 1980; Levings and McDaniel, 1980); McDaniel et al., 1978).

The presence of pulp mill fibre beds at Woodfibre and, to a lesser extent at Thornborough Channel, locally reduces or eliminates infaunal communities (McGreer, 1984). Benthic biota are also scarce or absent on the old mine tailings from the abandoned mine at Britannia Beach (Goyette, 1975).

Intertidal Communities

The usual mix of nemerteans oligochaetes, chironomid larvae, amphipods, isopods, barnacles, crabs, snails, clams, mussels, oysters, urchins, sea stars etc. occurs in intertidal coumunities except near the two pulpmills (c.f. Levings and McDaniel, 1976) and other modified shorelines such as wharves and marinas.

Industrial Impacts

Biological communities (intertidal and subtidal) are greatly modified near the two pulpmills, and on tailings deposits from a mine, which has been closed for many years, at Britannia. Mussels and oysters have increasing levels of heavy metals (especially copper) with proximity to the Britannia mine (Goyette, 1975). Mercury from the chlor-alkali plant occurred at high enough levels to force closure of some fisheries during the early 1970's until more stringent regulations brought these levels down. More recently, dioxins have been found in fish, crustacean shellfish and waterfowl, indicating uptake through the food chain. More research is needed to determine if these contaminants have had any influence on the complex marine ecosystems of the Sound.

Conclusions regarding marine ecosystem

Overall, the Sound can be characterized has having some natural limitations on productivity, owing to the natural turbidity in surface waters, the naturally hypoxic and occasionally anoxic deep waters of the inner basin, and the steep rocky shorelines. Productivity has been further reduced by restructuring and industrial use of the Squamish Estuary, and by habitat damage near the two pulp mills and the abandoned mine. However, the remaining productivity of the Squamish Estuary, and the areas of good habitat and well-oxygenated waters near the outer sound support well-developed, productive and stable biological communities. It is not known if industrial contaminants have any impact on the complex marine ecosystem.

FISHERIES

Salmonids

The Howe Sound drainage basin contains 17 salmon spawning streams (not including tributaries to the Squamish River) and 80 km of spawning grounds, 85% of which are found in the Squamish-Stawamus River systems (Knapp and Cairns, 1978). McNab Creek and Port Mellon area streams each have 3 km of spawning grounds, and outer Howe Sound streams collectively have 4 miles (Knapp and Cairns, 1978). Howe Sound river systems contain steelhead, Dolly Varden (char) and five types of Pacific salmon: coho, chum, pink, chinook and a small sockeye population. Chum and odd-year pink stocks, the major harvest outside the Sound, are taken by net fisheries in Strait of Georgia, Johnstone Strait and Juan de Fuca Strait. Based on escapement data (visual estimates of fish returning to spawn) since 1970, chinook and coho stocks have decreased, pink stocks have increased, chum stocks have increased significantly and steelhead stocks have varied depending on stream (pers. comm. C. Levings, 1991).

The Squamish-Stawamus River systems produce 95-100% of the salmon escapements to the Howe Sound drainage basin (Knapp and Cairns, 1978). The timing of adult salmonid migration into Howe Sound from the Pacific ranges from spring for steelhead to mid summer for chinook, early fall for pinks and coho, and late fall for chums (Figure 25). Peak spawning periods for salmon range from late August to late November. Residence of juvenile salmon in rivers varies between species (Hoos and Vold, 1975). Juvenile pink salmon leave freshwater immediately after emergence in early spring and are out of the estuary by mid-April. Juvenile coho and chinook spend up to a year in fresh water and are in the estuary from April to August. Chum salmon juveniles are present in the estuary from early April until July. Primary production in marshlands and intertidal areas of the Squamish estuary is critical to salmonid juveniles. Benthic algae and sedges (grass-like plants) provide food for amphipods and other benthic invertebrates which are preyed upon by fish.

Howe Sound was closed to commercial fishery in 1969 and it presently supports an important sport fishery. Tidal sport fishery for coho and chinook is concentrated in the early months of the year near Horseshoe Bay, the southeastern part of the Sound and Thornborough Channel. However, the sport fishery for chinook in the upper Howe Sound is vastly decreased. The streams of the Squamish river system support and important sport fishery for coho, chinook and steelhead.

Salmon stocks, particularily chinook, have been negatively impacted by overfishing of stocks, development of the Squamish estuary (the critical rearing area for juvenile salmon), loss of freshwater habitat due to construction of the Daisy Lake dam on the Cheakamus River, and logging in the upper watersheds (C. Levings, pers. comm., 1991). Landfilling, dredging, dumping of industrial and municipal effluents and storage of log booms diminish or degrade rearing habitat in the Squamish estuary. Salmonid production has probably been adversely affected by logging in upper watersheds of the Squamish River system which has increased flooding and resulting in destruction of spawning nests in the river gravels (redds)(Knapp and Cairns, 1978). For example, in 1973, floods destoyed 30 to 50% of coho and chum salmon spawn and up to 25% of pink and chinook spawn. In 1975, floods destroyed 80% of pink and chinook spawn (Knapp and Cairns, 1978).

Other commercial fish and invertebrate species

Herring spawn occurs during mid-March in Howe Sound (Knapp and Cairns, 1978). Egg deposition normally occurs within the shallow intertidal area where the eggs adhere to kelp, rockweed, eelgrass, rocks and other stable substrate. Present spawning areas are limited to Keats Island and the Gibsons area, and Long Bay of Gambier Island (Figure 26). Historical spawning areas in Mamquam channel at Squamish have been lost due to landfilling and log storage. A commercial gillnet herring fishery was active at the head of the Sound during the 1960's.

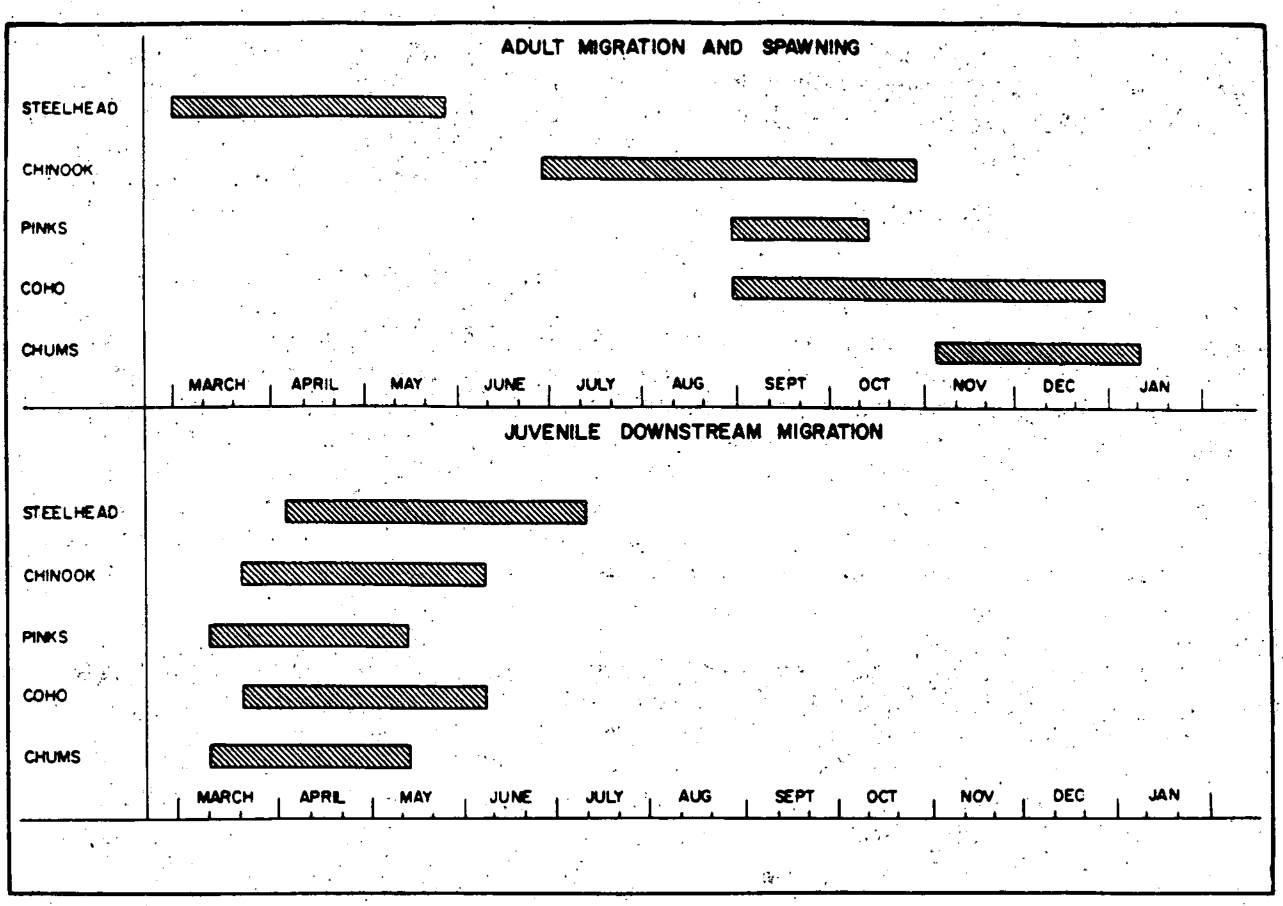


Figure 25 Timing of adult and juvenile migrations in the Cheakamus River (from Knapp and Cairns, 1978).

Commercial shellfish harvesting in upper Howe Sound was closed in 1970 due to mercury contamination. A significant shrimp fishery existed in this area prior to the closure (Knapp and Cairns, 1978). Significant shrimp populations exist off Grace and Gambier Islands (Figure 26). Significant populations of crab exist in the Sound but are not sufficient to support a commercial fishery. Mollusc fisheries ceased in Howe Sound about 1960. Oysters on Gambier Island contain high levels of zinc and copper, possibly related to contamination from Britannia mine. Northwestern Thornborough Channel is an important oyster and clam area (Figure 26) (Hoos and Vold, 1975).

Industrial and recreational use have adversely affected subtidal and coastal habitats of Howe Sound. Levings and McDaniel (1976) investigated the impact of industrial development on invertebrates along Howe Sound beaches and conclude that decreases in abundance and species composition occur adjacent to activities such as log storage, bleached kraft mill effluent discharge, copper leachates from mine activity, inorganic solid wastes such as mine tailings or gravel washings, municipal sewage discharge, disposal of organic solid wastes (wood chips, fibres), and shoreline construction of docks, causeways, and ferry terminals (Figure. Subtidal benthos are also effected. Long term log storage and dumping activities have resulted localized massive buildups of sunken logs and wood debris that blanket the natural substrate and support only a few species of invertebrates (MacDaniel, 1983). Thick layers of tailings on the bottom adjacent to the abandoned Britannia mine have not been colonized by benthic organisms.

Industrial development has adversely affected herring stocks in Howe Sound and has significantly reduced the herring spawning area (Knapp and Cairns, 1978). Herring spawning areas have been impacted by landfilling and log storage which resulted in loss of spawning substrate (Knapp and Cairns, 1978). Herring kills have been noted in Mamquam channel of the Squamish estuary, possibly due to low dissolved oxygen levels or hydrogen sulphide evolving from wood debris (Hoos and Vold, 1975) or spills of pentachlorophenol from sawmills.

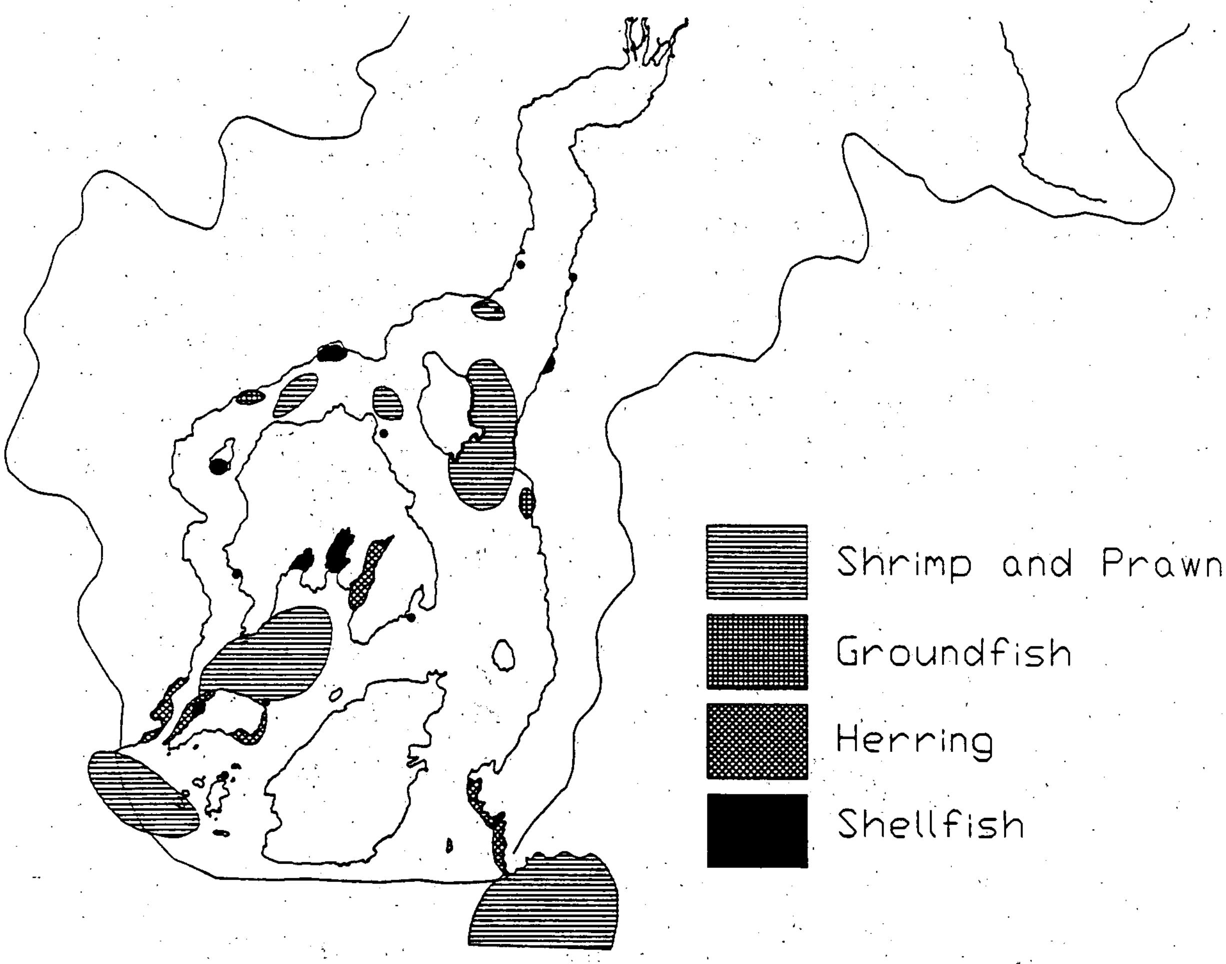


Figure 26 Distribution of shellfish and crustaceans in Howe Sound (by T. Feeney from data in Environment and Land Use Committee Secretariat, 1980).

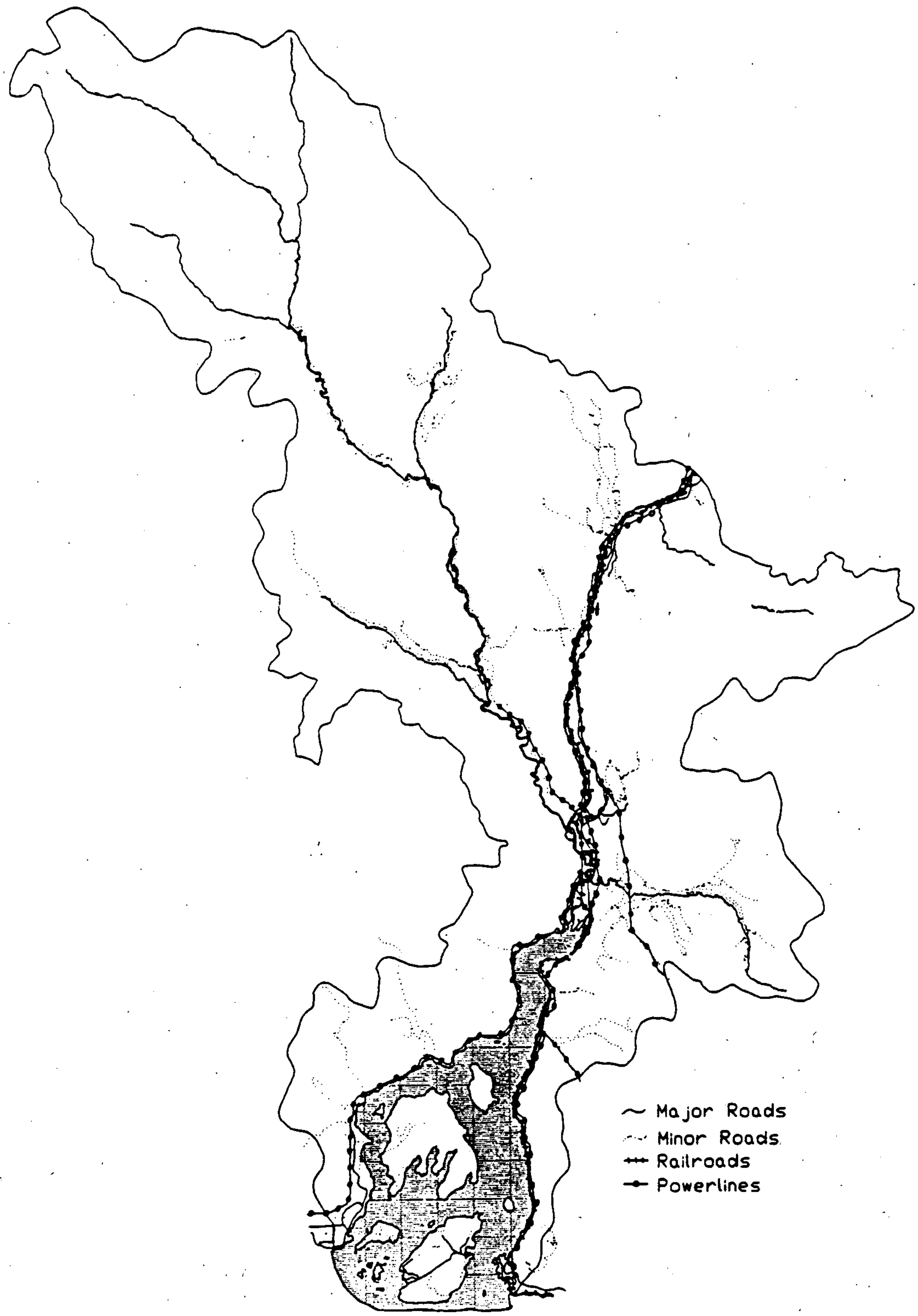


Figure 27 Roads, rail lines and power lines within the Howe Sound watershed (by T. Feeney based on data on NTS maps).

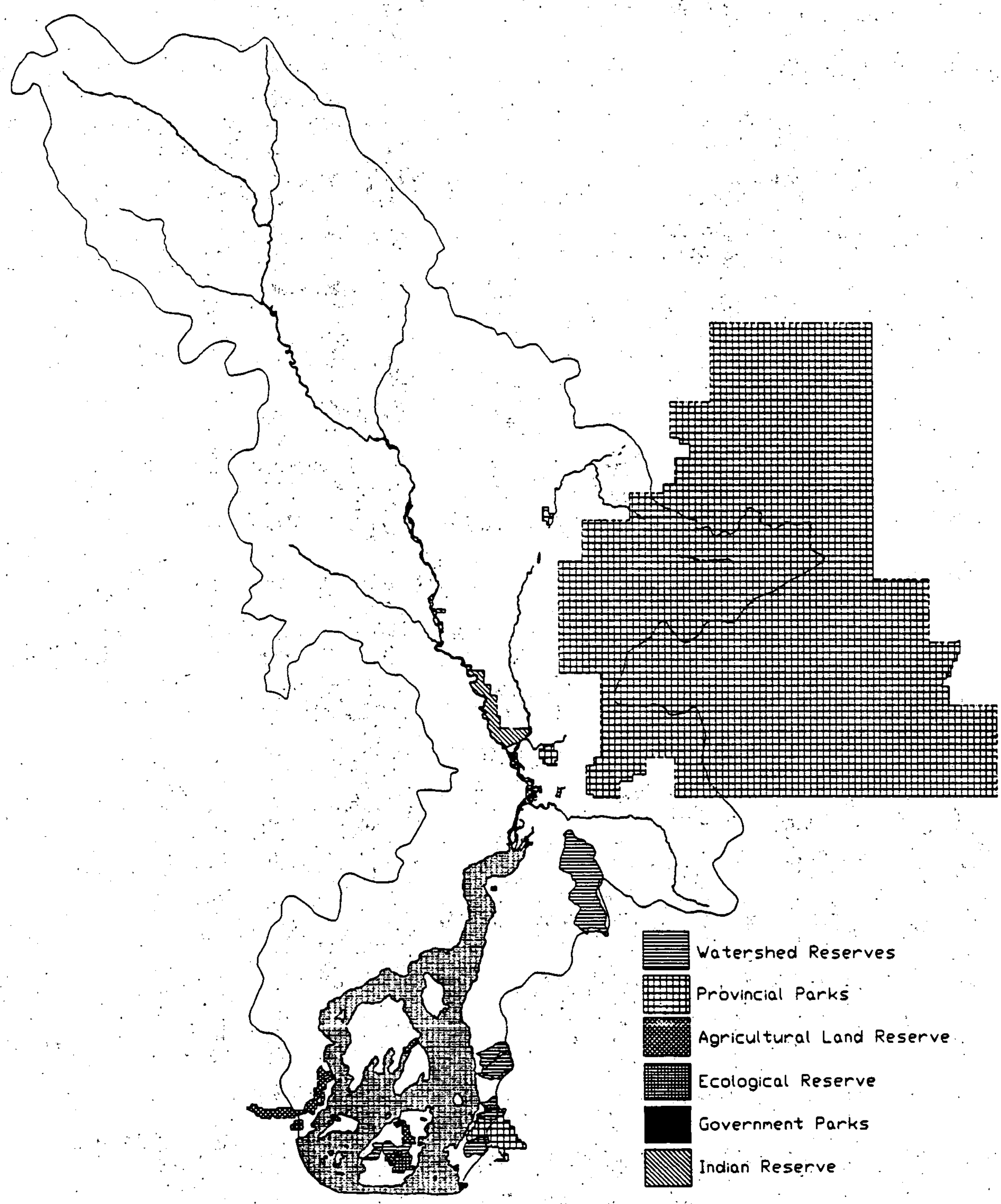


Figure 28 Special status lands in Howe Sound watershed (by T. Feeney from data in Environment and Land Use Committee Secretariat, 1980).

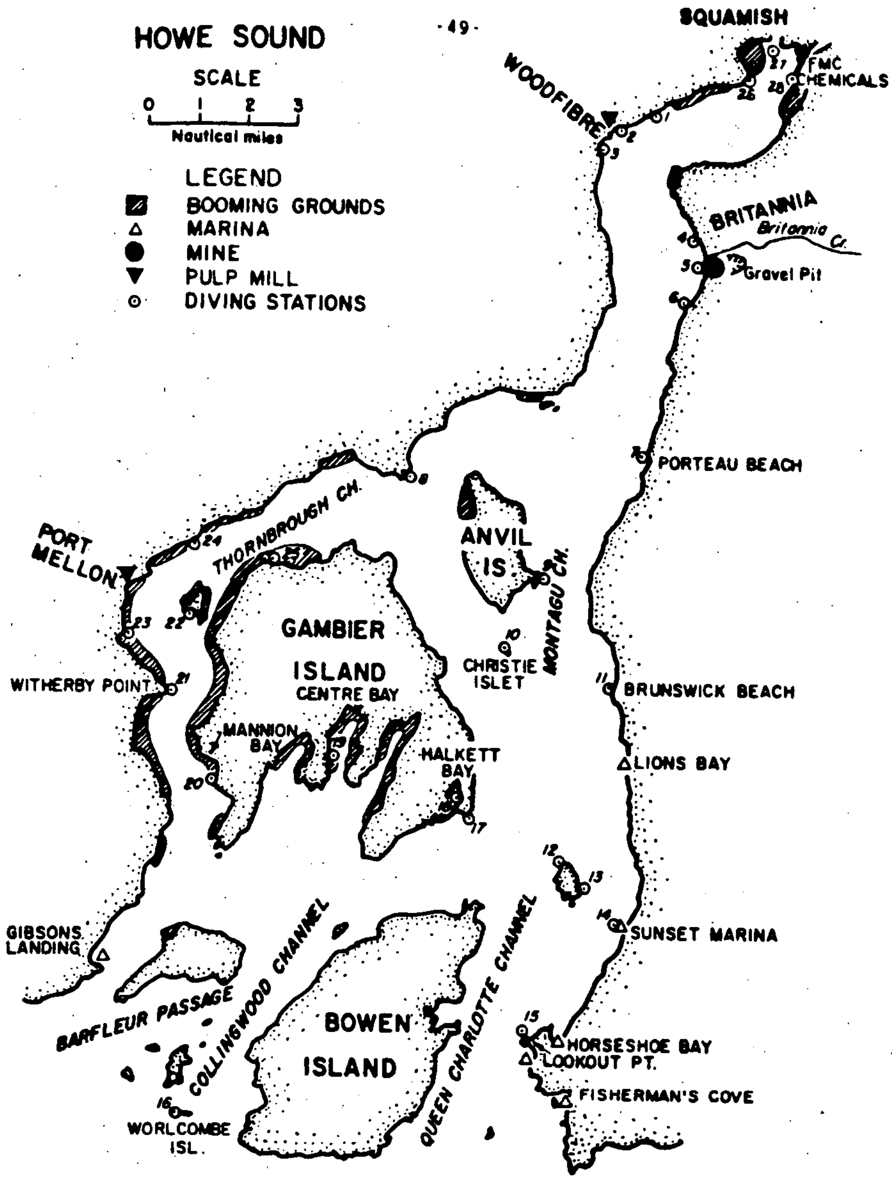


Figure 29 Sources of solid waste in Howe Sound (from McDaniel, 1973).

PART II

GUIDE FOR HOWE SOUND FIELD TRIP
BOWEN ISLAND TO SQUAMISH AND RETURN

Route: Begin at Snug Cove on Bowen Island, cross Queen Charlotte Channel to Lions Bay area (Figure 30).

STOP #1: DEBRIS TORRENT HAZARD, LIONS BAY AREA
Leader: Lionel Jackson, Geological Survey of Canada

The eastern shore of Howe Sound south of Brunswick Point is a remarkably steep mountain wall (Figure 31). Drainages along this mountain wall are short and steep, and drainage basins south of Brunswick Point are very small (Figures 31 and 32). Further north, drainages are somewhat larger and the mountain front less steep. From Brunswick Point south to Charles Creek, less resistant metamorphic rocks underlie the lower slopes while cliff forming granitic rocks form the upper slopes and peaks. A mixture of rock, till and colluvium is found in headwater regions. Fans or cones of fluvial and colluvial debris have been constructed in the lower parts of drainages since glacier ice retreat 10,000 years ago. Because of the steep shore of Howe Sound, the shallower slopes on these cones have been favoured sites for residential construction (e.g. lower Lions Bay village). Alluvial cones and fans constructed prior to full isostatic rebound of the land following deglaciation were uplifted and eroded (Clague and others, 1982); an example is the uplifted alluvial deposits of Magnesia Creek exposed along the highway above Brunswick just north of Lions Bay.

Channelized debris flows ("debris torrents") in steep drainages along the east side of Howe Sound have caused costly damage to Highway 99 and various settlements along its route (Jackson et al., 1985). A debris torrent is a moving mass of rock fragments, soil, and mud with very high water content that develops within the confines of a steep channel. A debris torrent may originate as a slide from adjacent hillslopes which enter a steep channel and move downstream, or by the mobilization of debris within a steep channel (Figure 33). As the debris torrent moves downstream, it incorporates organic debris, trees, soil, and channel sediments (sand, gravel, boulders) from the channel, often scouring the channel to bedrock. As the debris torrent looses momentum on a flattening slope, deposition of a tangled mass of vegetation debris in a matrix of sediment and fine organic material occurs.

Following completion of the railway and highway in 1958 from Horseshoe Bay to Squamish, records have been kept of floods and debris torrents large enough to disrupt road and rail traffic. Debris torrents in the Howe Sound area are associated with heavy precipitation during the autumn and early winter (Figure 35). Thirty five flood and debris torrent events have occurred in 15 of the 26 creeks between Britannia Beach and Horseshoe Bay (Figures 32 and 35). About half the events have been debris torrents, all but one were restricted to 9 creeks south of Brunswick Point (Jackson and others, 1985). This may reflect several factors: the steeper nature of drainages, the occurrence of more erodable metamorphic bedrock in at least parts of drainages, and the more northerly orientation of the mountain front which increases the effect of forced lift of air masses over the mountains causing more intense rainfall.

The frequency of debris flows is significantly higher on logged slopes versus unlogged slopes. The highest incidence of slope failure occurs several years after logging when root systems of cut trees start to break down decreasing the strength of the slope soils, and before new growth root systems are developed. Clear cuts and associated logging roads occur in the drainages of Harvey and Alberta Creeks. It is likely that a significant amount of the debris in the the destructive debris torrent of February, 1983

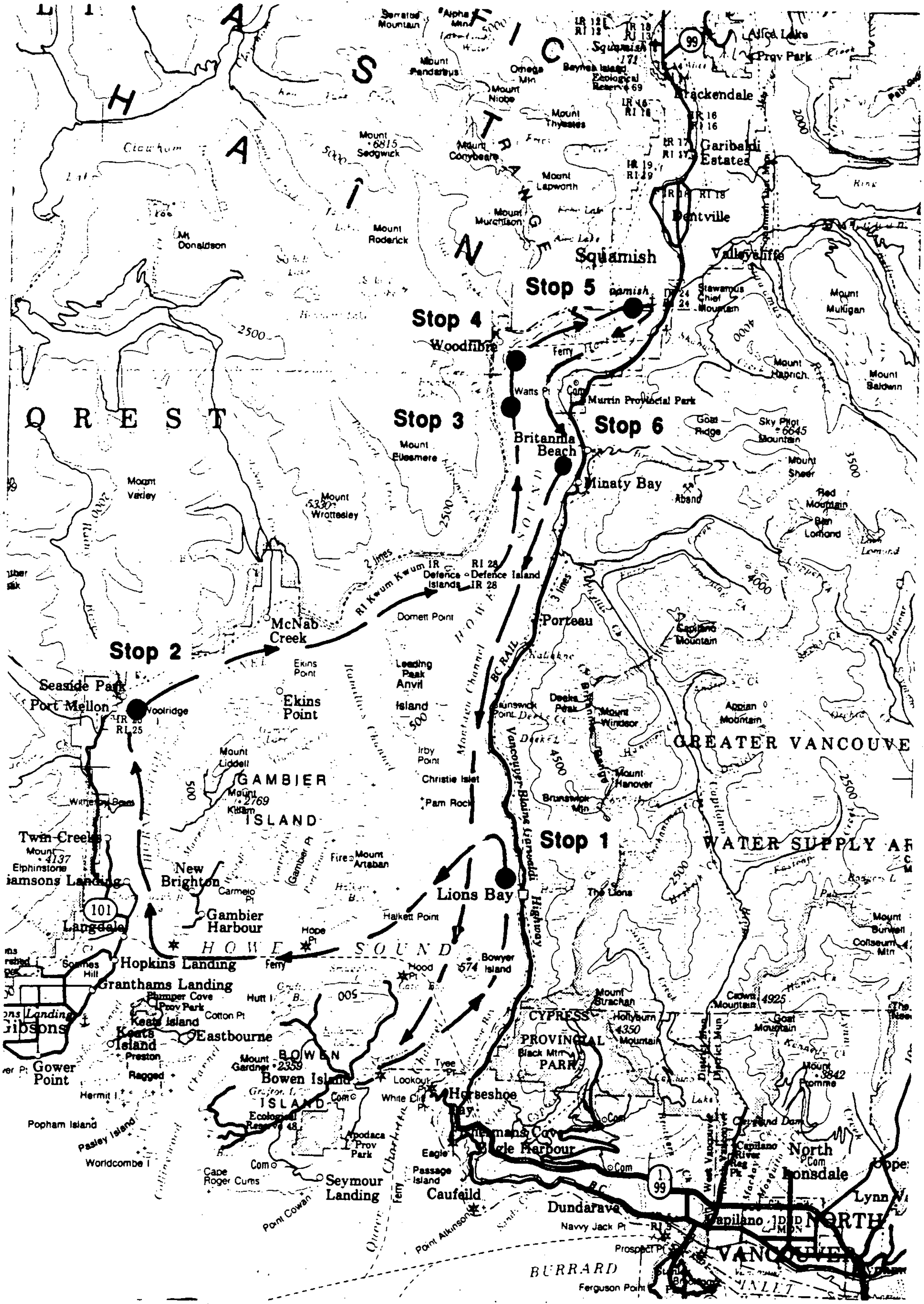


Figure 30 Topographic map of Howe Sound showing route of field trip.

1:50,000

Contour interval 50 feet.

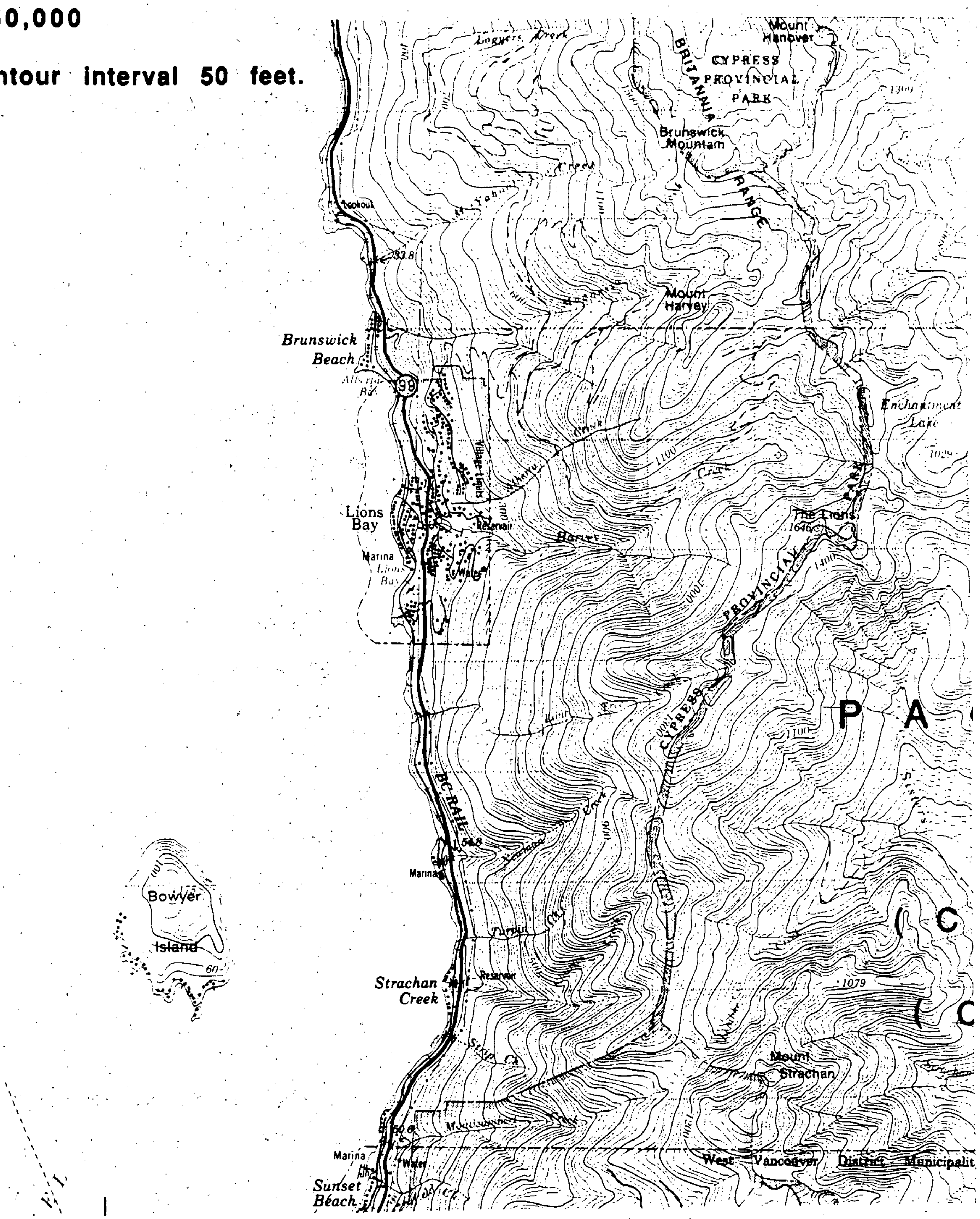


Figure 31. Topographic map of Lions Bay area. Map is 1;50,000 scale and contour interval is 50 feet.

Basin	Drainage area (km²)	Source elevation of channel (m)	Length (m)	Average gradients basin	Average gradients fan	% basin logged (30 yrs)	200 yr flood[2] (m³/s)	Design debris torrent (m³)	Debris torrents in 25 yrs	Hazard[4] rating
Disbrow	1.3	1170	2875	32°	12°	0	24	18,000	No	3
Sclufield	0.4	920	1600	30°	17°	0	8.6	6,000	1	3
Charles	1.8	1220	2550	27°	16°	1	32	29,000	6	4
Harvey	7.0	1300	5250	14°	9°	22	107	62,500	No	2
Alberta	1.2	1220	2626	27°	14°	0[3]	23	15,500	2	3
Magnesia	4.7	1440	4650	19°	10°	32	76	44,500	2	4
M	3.8	1470	3500	28°	8°	38	62	41,500	1	3
Britannia	28.5	1110	8425	3-11°	3.5°	13	268	n/a	No	0

Figure 32 Summary of data for selected stream drainages between Horseshoe Bay and Britannia (from Thurber Consultants, 1983). [2] Design estimate. [3] Some "bootleg" logging was carried out during road construction across the basin. Hazard rating refers to probability of debris torrent occurrence: 4 = very high; 3 = high; 2 = moderately high; 1 = low; 0 = no risk.

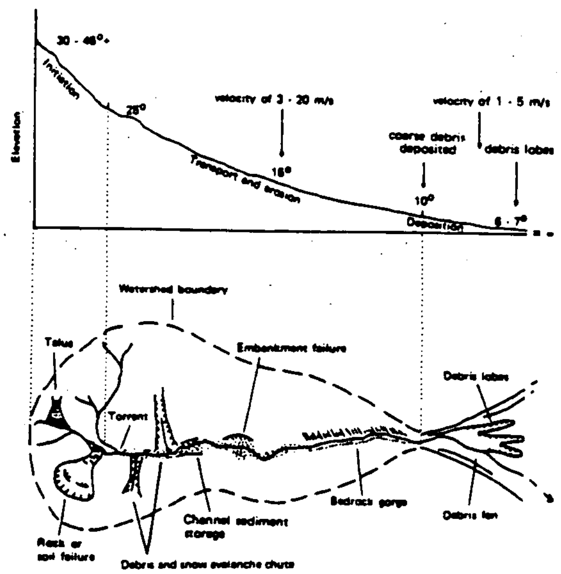


Figure 33 Schematic plan view and profile of a typical debris torrent in coastal British Columbia (from Jackson and others, 1985).

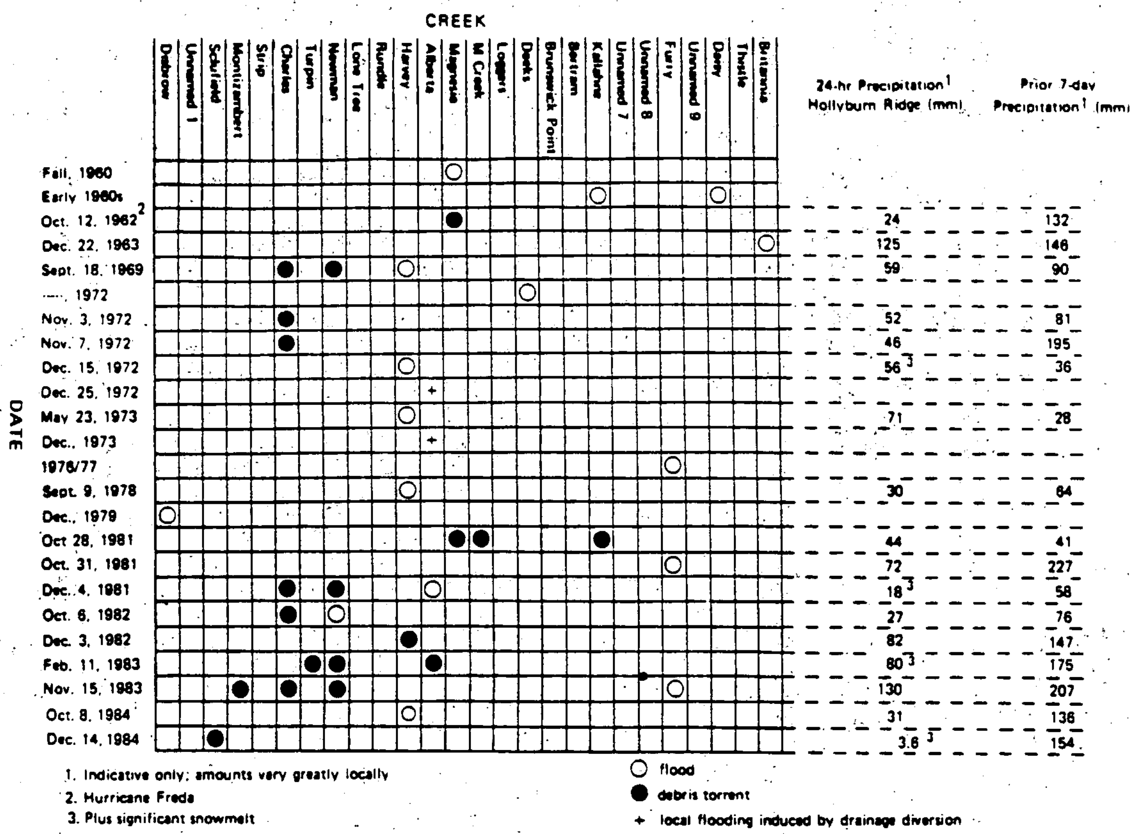


Figure 34 Occurrence of recorded debris torrent events in stream channels between Horseshoe Bay and Britannia (from Jackson and others, 1985).

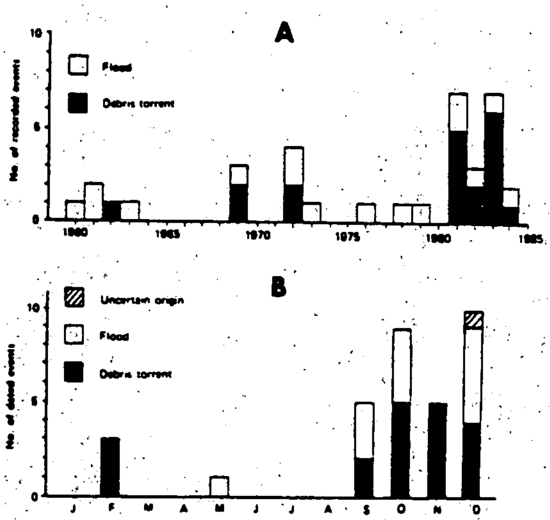
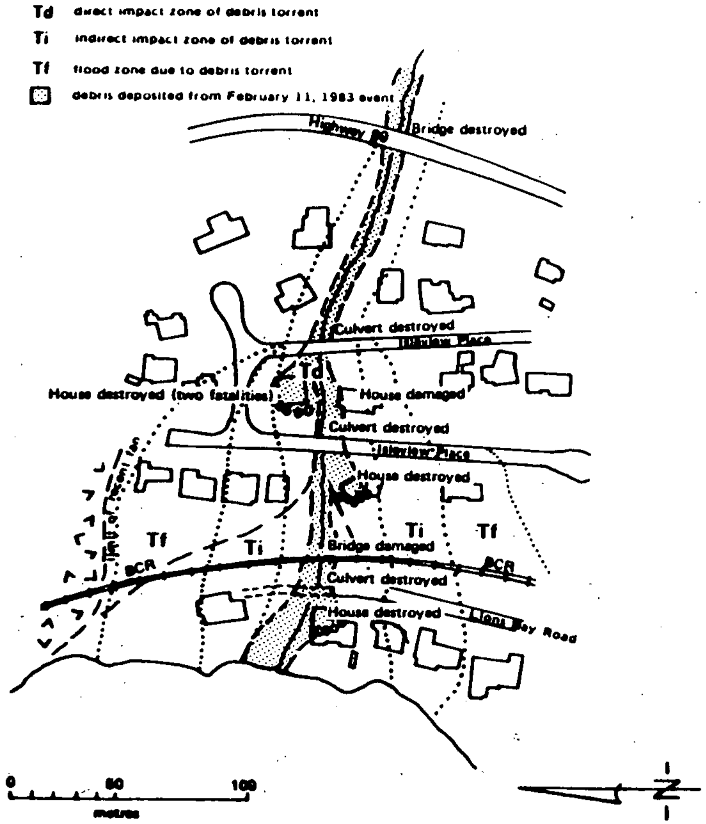
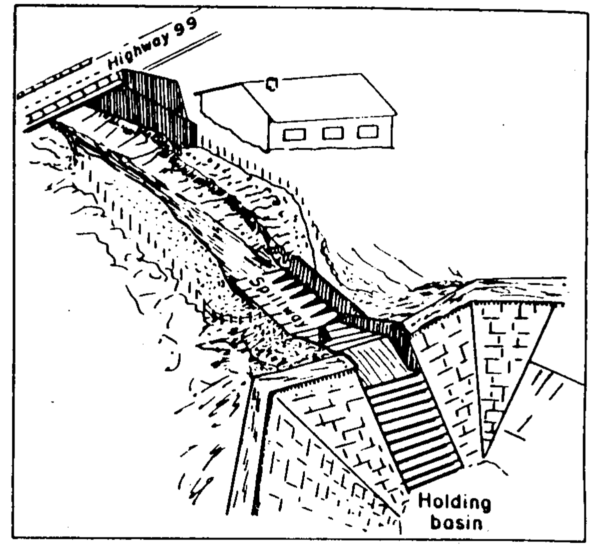


Figure 35 Frequency and type of events in stream channels between Horseshoe Bay and Britannia: (A) by year from 1960 to 1984 ; and (B) by month from 1901 to 1984 (from Jackson and others, 1985).





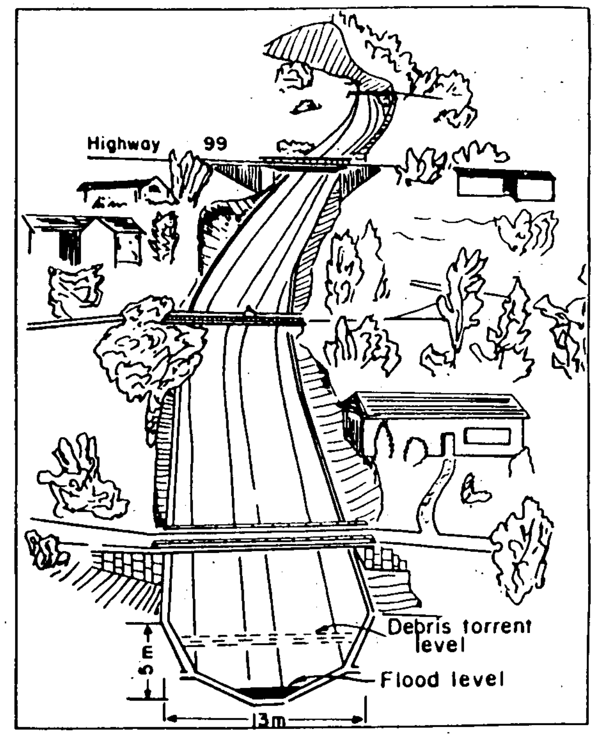


Figure 36 (Upper left) Map of the lower part of Lions Bay village showing impact of February 11, 1983 debris torrent in lowermost Alberta Creek (from Thurber Consultants, 1983).

Figure 37 (Upper right) Concrete block catch basin (foreground) and spillway (looking downstream) on Harvey Creek, designed to stop and pond debris flows and prevent damage to the village of Lions Bay (Armstrong, 1990).

Figure 38 Concrete-lined channel of Alberta Creek through the community of Lions Bay, designed to allow debris torrent clear passage through the residential area to the sea (Armstrong, 1990).

on Alberta Creek was derived from the area where a logging road crosses Alberta Creek at the 610m elevation (Jackson et al, 1985).

Lions Bay area

The village of Lions Bay is built on and adjacent to a steep cone or fan of alluvium deposited by Harvey and Alberta creeks since the glacier retreat (Figure 4B). Residential development began in 1957 after the construction of Highway 99 and part of the village has been built on the shallower lower slopes of the fan surface. However, the same depostional processes that have built the alluvial fan put the community at risk. Major debris torrents occurred in both Alberta and Harvey Creeks during the 1930's. The catalyst for the construction of the control structures we see today was an event on February 11, 1983 that followed three days of heavy rain. A debris torrent descended Alberta Creek destroying the highway bridge, several village bridges, and five homes adjacent to the channel (Figure 36). The debris flow moved in a series of surges with flow velocities of 2 to 9 m/sec down Alberta Creek (slope ~16 degrees), transporting a total volume of 20,000m^3 of debris (Thurber Consultants, 1983). Log and boulder tongues were forced out of the channel and into residential neighbourhoods at bends and obstructions in the channel. These tongues froze after a few meters progress but nonetheless caused significant damage.

Protective Engineering structures

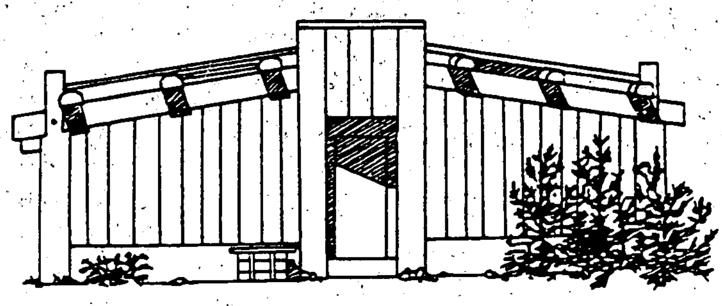
To mitigate debris torrent hazard, structures need to be built to stop and pond the debris torrent (ie. dam structure) before entering the vulnerable area, or to allow passage of the debris torrent safely through. Such required structures along Highway 99 were designed by Thurber Consultants and built by the Department of Highways from 1984 to 1989. An example of a dam and debris catch basin structure is upstream from Lions Bay on Harvey Creek (Figure 37). The catch basins are are designed to retain the "design torrent" (the debris torrent with a recurrence interval of 200 years), but allow normal floods to pass without trapping normal sediments. After the capture of a debris torrent, the material is excavated with bulldozer and truck so that the basin doesn't lose its capacity. The second strategy was used on Alberta Creek where a deep, straight walled channel with necessary clearance for bridges was built so that the torrent can pass through without obstacle (Figure 38). A large submarine storage basin area was dredged at the mouth of Alberta Creek so that debris would not backfill up the channel. The cost of these and other protective measures were: Alberta Creek, $8.6 million; Harvey Creek, $4.4 million; Charles Creek, $3.5 million, and Magnesia Creek, $3.1 million.

Route: Lions Bay to Port Mellon via channel south of Gambier Island and Thornborough Channel (Figure 30).

POINTS OF INTEREST

VANCOUVER AQUARIUM RESEARCH STATION, POPHAM ISLAND

The Vancouver Aquarium operates the Murray A. Newman Field Station for Howe Sound Research, located on Popham Island. Popham Island is a private nature refuge, exclusive aCCess being granted by lease to Aquarium research staff and their assistants. In addition to the caretaking protection of the island which this research arrangement provides, the natural history monitoring of Howe Sound marine life provides a data baseline which can provide for correct environmental assessments in the future. Vancouver Aquarium research is the only institutional commitment to a continuous research presence in Howe Sound, and has included the early life history of fish and shrimp, harbour seal censusing, glass sponge biology and starfish behavior. This research is priviately funded by tourism income, with no regular taxpayer support.



FISHERIES CLOSURES DUE TO ORGANOCHLORINE CONTAMINATION

In early 1988, the departments of Fisheries and Oceans, Environment, and Health and Welfare initiated a program testing for dioxins and furans in aquatic organisms near British Columbia pulp and paper mills (Nassichuck, 1991). Within Howe Sound, studies of selected finfish and shellfish recognized elevated levels of certain dioxin and furan congeners in prawns and the digestive gland (hepatonpancreas) of Dungeness crab. In December 1988, Howe Sound Pulp and Paper Limited and Western Pulp Limited Partnership were directed by Environment Canada to design and implement a a baseline organochlorine survey of sediments and biological tissures. Health and Welfare review of this data led to the closure by Fisheries and Oceans of all harvesting of prawn, shrimp and crab of portions of Howe Sound adjacent to Port Mellon and Woodfibre pulpmills. In June, 1989 the closure was expanded to those parts of the Sound near Keats Island and the entire Sound was closed to commercial crab fishing. An advisory was issued against consumption of the digestive gland of crab taken by recreational or native harvesting elsewhere in the Sound.

During 1990, a comprehensive monitoring program was undertaken to examine effluent dispersion through dye tracer studies, contaminants in sediments and ground fish, AOX/chloroform at specific depths in the Sound, water quality profiles (pH, temperature, dissolved oxygen,salinity) from surface to near-bottom depths and community analyses on subtidal benthic macroinvertebrates (Dwernychuk, 1989, 1991). A trend-monitoring program was started in 1991 to test the dioxin and furan content in crab, prawn and shrimp, and sediment at select sites on an annual basis during the months of February or March.

IMPACT OF LOG BOOMING, THORNBOROUGH CHANNEL

The waters of Howe Sound have long been used for the transport, sorting, booming and storage of logs. Howe Sound waters are the closest protected waters for logs destined to mills on the Fraser River and 30-40% of sawlogs cut on the B.C. coast pass through Howe Sound (Environment and Land Use Committee Secretariat, 1980). Logs are sorted, scaled and stored prior to transport to the mills. A peak in storage occurs in the autumn, when inventory is built up to supply the mills over the winter. During this period available booming areas are filled and some wood has to be temporarily stored at up-coast locations. Only 20% of the logs come from the Howe Sound area (Soo, Quadra and Vancouver P.S.Y.U.s)(Environment and Land Use Committee Secretariat, 1980).

Major log storage areas include shorelines of Thornborough channel (Longview to McNab Creek, Port Mellon to Williamsons Landing, Woolridge Island, Ekins Point to Grace Island on the Gambier shore), the 4 southern bays of Gambier Island, near Woodfibre, and Darrell Bay north to and including the Squamish estuary (Environment and Land Use Committee Secretariat, 1980). In 1980, approximately 110 log storage water-lot leases (issued by BC Ministry of Lands, Parks and Housing) covered some 947 hectares of foreshore and affected 40% of the beach shorelines in the Sound. This use is considered the capacity of Howe Sound by the Ministry of Forests (Environment and Land Use Committee Secretariat, 1980).

Log storage results in smothering and abrasion of sediment (Levings and McDaniel, 1976). Long term log storage and log dumping activities cause thick, local accumulations of sunken logs and wood debris which blankets the natural substrate. This organic refuse smothers indigenous benthic fauna and provides a substrate that few invertebrates colonize. High organic loading can depress the levels of dissolved oxygen and cause generation of hydrogen sulphide.

IMPACT OF KRAFT PULP MILLS

Kraft pulp mills discharge to the oceans large volumes of waste effluent that contains chemicals from the pulping and bleaching process, as well as wood fibers and other wood waste. Biological communities (intertidal, benthic and planktonic) are greatly modified near the two pulpmills in Howe Sound. The presence of pulp mill fibre beds at Woodfibre and, to a lesser extent at Thornborough Channel, locally reduces or eliminates infaunal communities (McGreer, 1984). Waste solids tend to smother bottom-dwelling organisms. Pollutant stress on organisms is evident from abnormal occurrence of liver

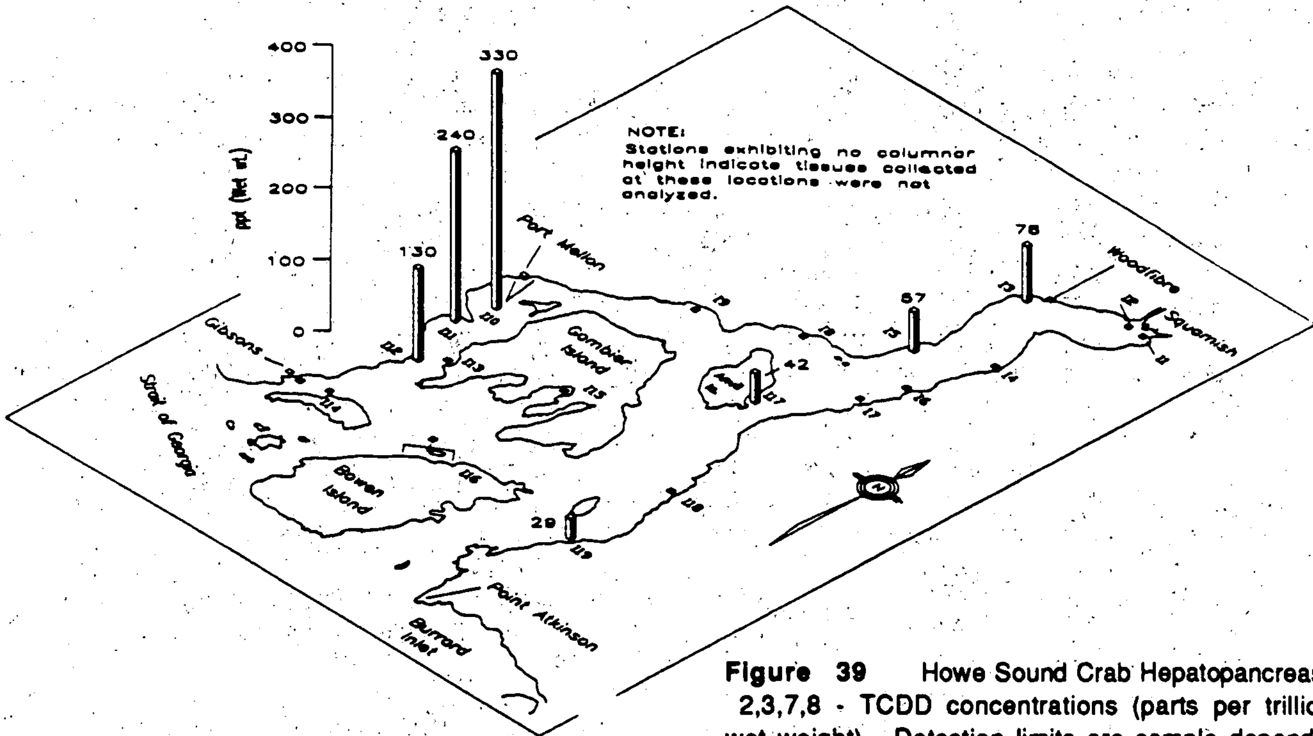


Figure 39 Howe Sound Crab Hepatopancreas: 2,3,7,8 - TCDD concentrations (parts per trillion; wet weight). Detection limits are sample dependent (Dwernychuk, 1989).

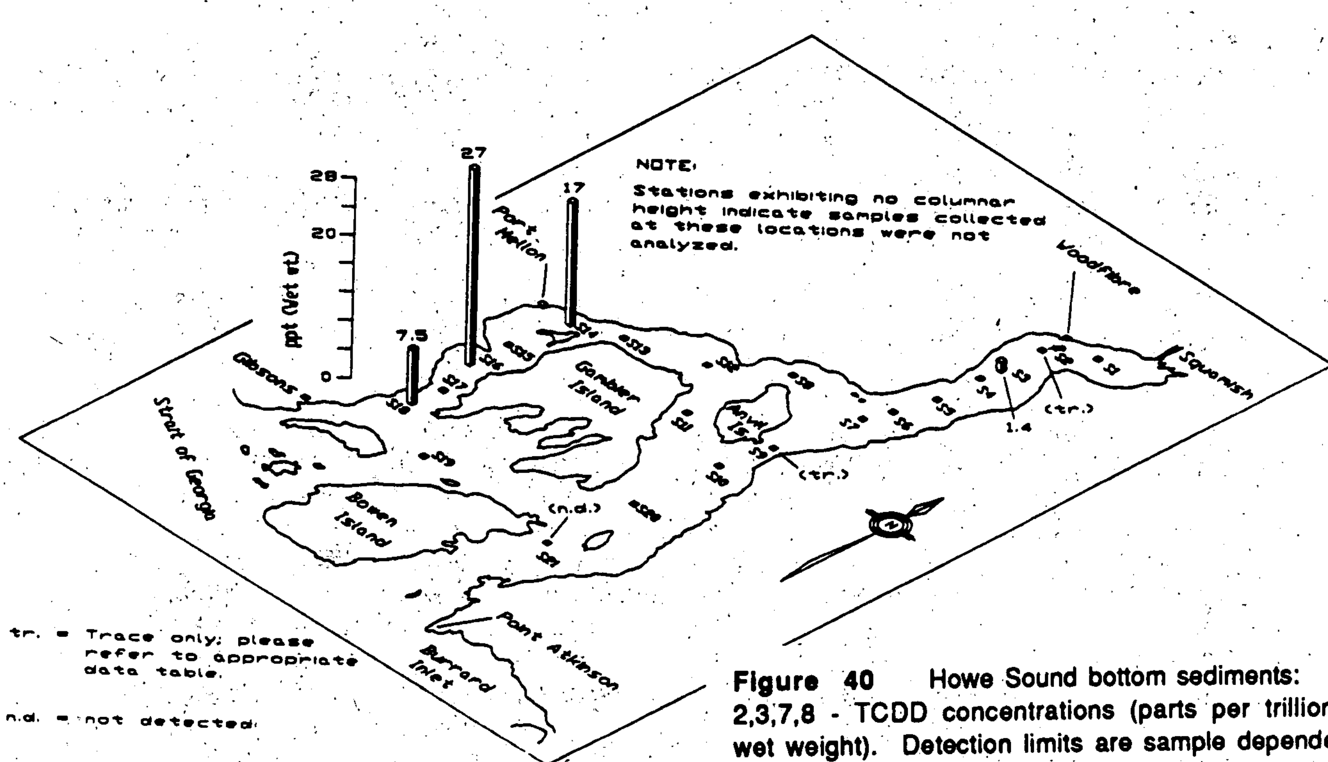


Figure 40 Howe Sound bottom sediments: 2,3,7,8 - TCDD concentrations (parts per trillion; wet weight). Detection limits are sample dependent (Dwernychuck, 1989).

lesions in flatfish and stunted and fused gill lamellae near some pulpmills (Brand, 1991). Microorganisms that breakdown this organic effluent (e.g. to wood sugars and hemicellulose) consume dissolved oxygen from seawater (ie. biological oxygen demand or BOD). This depletion of dissolved oxygen can adversely affect nearby marine plant and animal life, sometimes over significant areas (i.e. 0.3 to 10km^2). Impact of effluent can be reduced by decreasing the biological and chemical oxygen demand of effluent through secondary treatment.

Intertidal communities are also greatly reduced or eliminated near the two pulp mills (Levings and McDaniel, 1976). Impact of effluent on intertidal ecology has been reduced by extending outfalls into deeper water, and using diffusers to spread waste over wider areas. The dark colour of bleached kraft pulp mill effluent attenuates light and has been shown to be the major cause of reduced phytoplankton productivity near the Woodfibre mill (Stockner et al., 1975). Nutrients in effluent can enhance phytoplankton productivity under certain lighting conditions (Stockner and Costella, 1976). Bleached kraft mill effluent also contains synthetic chlorinated hydrocarbons such as dioxins and furans (Kay, 1989). Based on recent measurements, biological uptake of dioxins and furans results in significant contamination of the food chain including species of crab, prawn, shrimp, overwintering diving ducks (e.g. grebes) and cormorants (Whitehead, 1991; Dwernychuck, 1991).

The impact of bleached kraft mill effluent is influenced by the nature of circulation (and hence mixing and dilution rates) in the receiving environment. The proximity of the Woodfibre mill to the surface plume of the Squamish River assists in mixing of effluent discharged into the surface layer. Circulation is likely more restricted in Thornborough Channel given lessor winds and currents, and given that the sill extends from southwestern Gambier Island to Langdale.

STOP 2: HOWE SOUND PULP AND PAPER MILL, PORT MELLON

Leader: Ron Wilson, Howe Sound Pulp and Paper Ltd.

Howe Sound Pulp and Paper Ltd, built in 1908, is the oldest operating pulp mill in B.C. The mill sits on the delta deposits of the Rainy River on the west side of Thornborough Channel (Figures 30 and 41). The site was chosen for availablity of water from the Rainy River, sheltered harbour, and proximity to Vancouver. It began as a soda mill manufacturing wrapping paper from a blend of soda pulp (produced by cooking wood with a caustic soda solution) and waste paper. The mill converted to the kraft process within a very few years. Between 1908 and 1951, mill operations were erratic due to frequent shutdowns and changes of ownership. The mill was purchased in 1951 by Canfor who immediately launched a series of major upgrading, starting with a bleach plant. Between 1951 and 1988 the mill expanded in capacity from 40,000 tonnes/year of unbleached kraft to 220,000 tonnes/year of fully bleached kraft. In 1988 Canfor Corp. and Oji Paper Co. formed Howe Sound Pulp and Paper Limited (HSPP) and initiated a $CDN 1.14 billion program to expand the pulp mill to a capacity of 345,000 tonnes/year, to install a thermomechanical-based newsprint mill with a capacity of 200,000 tonnes/year, and to generate 85 mw of electrical power through co-generation. Howe Sound Pulp and Paper presently employs about 650 people.

Raw materials

Most of the mill's wood fibre supply comes from sawmills within the Vancouver area, with additional wood from the interior. Residual chips from sawmill operations, and whole log chips are the two types of raw material. With expansion the pulp mill uses approximately 16,800 to 18,000 cubic metres of chips a day (Canfor, 1990). Barges (Seaspan International Ltd.) of woodchips are loaded at millsites on the Fraser River and towed to the mill. At full production, the mill receives 4 to 6 barge-loads of chips a day (Canfor, 1990). The mill produces three types of pulp that utilize different raw materials: a blend of western hemlock and Douglas Fir (thick cell wall species) for a pulp with high tear strength and bulk, a coastal hemlock pulp of intermediate qualities, and a blend of coastal western red cedar with interior white spruce and lodgepole pine (thin cell wall species) for a pulp with low porosity and high softness and sheet smoothness (Canfor, 1989b). Water supply is from the Rainy River and augmented by mountain reservoir water during dry weather. Water quality is maintained during periods of high runoff through water treatment and a 5 million gallon reservoir at the mill site. Cogeneration of electrical power (completion date May 1991) involves utilizing steam from the recovery boiler, and from a wood waste (from sawmills in the Lower Mainland and Vancouver Island) and natural gas fired boiler (Cirrus Consultants, 1990).

Pulp Process

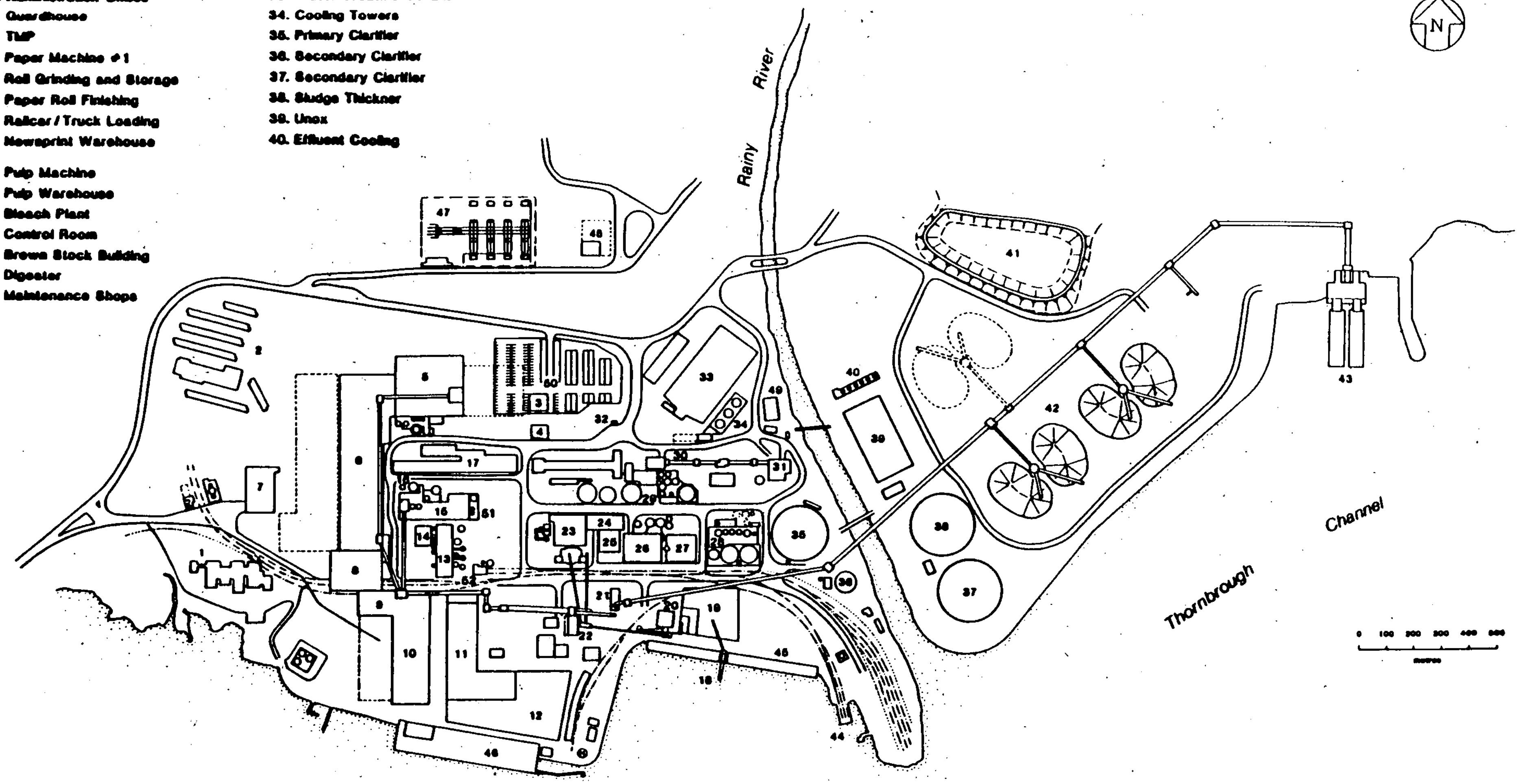
Chips are cooked in a digester to remove lignin, resins and fatty acids from fibres while leaving intact the long-chained cellulose molecules (delignification) (Figure 42). The two vessel Kamyr digester increases lignin removal (extended delignification) and therefore reduces chlorine required to remove lignin at the bleaching stage. Brownstock from the digester is washed (remove dissolved lignin and cooking chemicals from pulp), stripped of large uncooked pieces of wood ("knots") and screened of wood debris ("shives"). Brownstock is then mixed with a caustic solution and oxygen at 95^{o}C in two upflow towers to further remove lignin (oxygen delignification). The bleach plant creates a high brightness pulp by utilizing molecular chlorine and chlorine dioxide bleaching systems. The bleaching process has been changed from a chlorine only first bleach stage followed by one or more chlorine dioxide stages, to 50% substitution of chlorine by chlorine dioxide in the first stage. The present bleach plant has the ability to switch to 100% chlorine dioxide bleaching, and a flexibility to change to peroxide and oxygen bleach systems (Canfor, 1990b). Use of chlorine gives rise to chlorinated organics in the bleach effluent. The final stages of pulp production involve cleaning, forming and drying.

Effluent controls

The mill's fibre supply is spot tested for chlorophenol contamination (chlorophenol-based anti-sapstains as chlorophenols are known to create dioxins during the chlorination stage). HHSP no longer uses defoamers in the brownstock washers made from recycled oils as these have been found to contain unchlorinated dioxins and furans. Chlorine usage by the bleach plant has been decreased through higher levels (~50%) of chlorine dioxide substitution since installation of an chlorine dioxide generator in July 1989. In 1990, installation of a Kamyr digester to extend the delignification process and a Kamyr two-stage oxygen delignification process also reduce the level of chlorine used. Test results by British Columbia Research in September 1989 indicated that 2378-TCDD (dioxin) content was reduced to non-detectable levels in both pulp and effluent, compared with earlier levels of 14 parts per trillion in pulp and 400 parts per quadrillion in effluent. Levels of 2378-TCDF (furan) were reduced from 310 parts to 7.2 parts per trillion in pulp, and from 9400 parts to 88 parts per quadrillion in effluent (Canfor Ltd., 1989b).

A new secondary treatment system to reduce the biological oxygen demand (BOD) of effluent includes a primary clarifier (remove suspended solids), a high rate oxygen activated sludge system (UNOX) that uses bacteria to break down organic compounds in the mill's effluent, and secondary clarifiers (Figure 44)(Cirrus Consultants, 1990). Primary and secondary clarifier sludge is dewatered and incinerated in the wood waste boilers. Ash from the wood waste boilers is placed in HSPP landfill. Stormwater discharges from the solid waste landfill, chip and wood waste storage piles, heavy fuel oil and chemical storage dykes, and mill process equipment are diverted to the effluent treatment system. Wash, rinse and cooling water is recycled and reused in both the kraft and thermomechanical pulp mill, and there are spill containment systems within the plant and a 33,000 m^3 spill pond.

Reduced sulphur or non-condensible gases give kraft pulp mills their characteristic odour. A new low odour recovery boiler (Figure 43) is designed to reduce total reduced sulphur (TRS) emissions (Cirrus Consultants, 1990). Low volume, high concentration non-condensible gases will be incinerated in a new lime kiln (Figure 43) while high volume, low concentration non-condensible gases will be incinerated in a new wood waste and natural gas fired boiler (Cirrus Consultants, 1990). Total reduced sulphur (TRS) from other sources such as gases from the digester, blow tank, evaporators and brownstock washers will be reduced by combustion in the lime kiln or the power boilers. Particulate smoke from combustion processes will be reduced by electrostatic precipitators on the new recovery boiler, wood waste boiler and lime kiln.



1. Construction Offices
2. Thornbrough Camp
3. Administration Offices
4. Guardhouse
5. TMP
6. Paper Machine #1
7. Roll Grinding and Storage
8. Paper Roll Finishing
9. Railcar / Truck Loading
10. Newsprint Warehouse

11. Pulp Machine
12. Pulp Warehouse
13. Bleach Plant
14. Control Room
15. Brown Stock Building
16. Digester
17. Maintenance Shops

18. Wood Waste Unloading Facility
19. Wood Waste Reclaim
20. Bark Press Building

21. Chip Screening
22. Sludge Presses
23. Wood Waste Boiler
24. Turbo Generator Building
25. Electrical and Control
26. Recovery Boiler
27. Precipitators
28. Evaporators
29. Recausticizing
30. Lime Kiln

31. Lime Mud Filter Building
32. Propane Storage
33. Water Treatment Plant
34. Cooling Towers
35. Primary Clarifier
36. Secondary Clarifier
37. Secondary Clarifier
38. Sludge Thickner
39. Unox
40. Effluent Cooling

41. Spill Pond
42. Chip Storage
43. Chip Scow Unloading
44. Rail Barge Ramp
45. Wood Waste Barge Wharf
46. Deep Sea Wharf
47. Substation
48. O_2 Plant
49. Training Centre
50. Parking

51. O_2 Delignification
52. ClO_2 Generator

Figure 41 Map of the physical plant of the Howe Sound Pulp and Paper Port Mellon pulp and paper mill (from Cirrus Consultants, 1990).

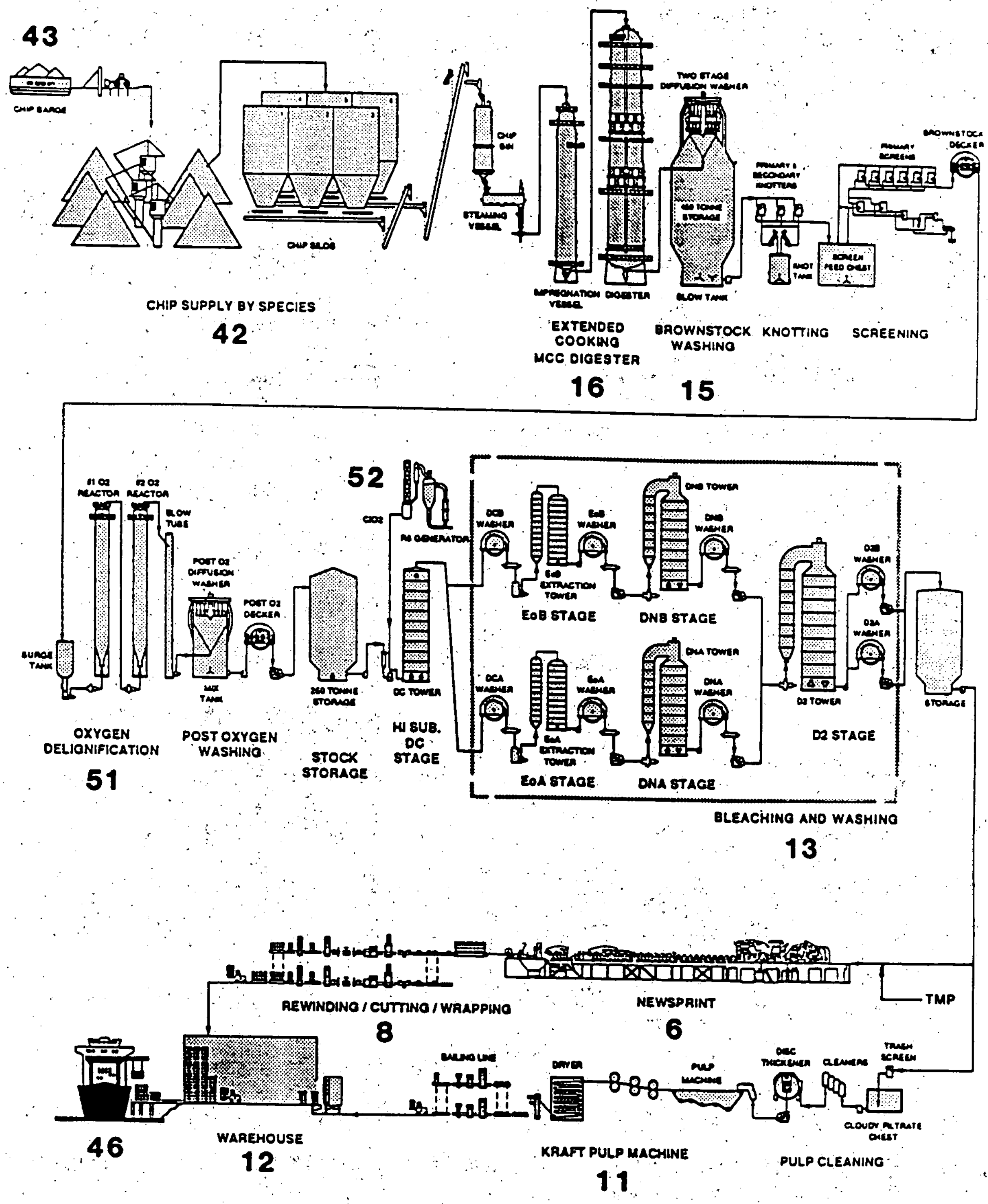


Figure 42 Schematic flow diagram of pulp cycle within Port Mellon pulp and paper mill. Numbers refer to location map in Figure 41 (from Cirrus Consultants, 1990).

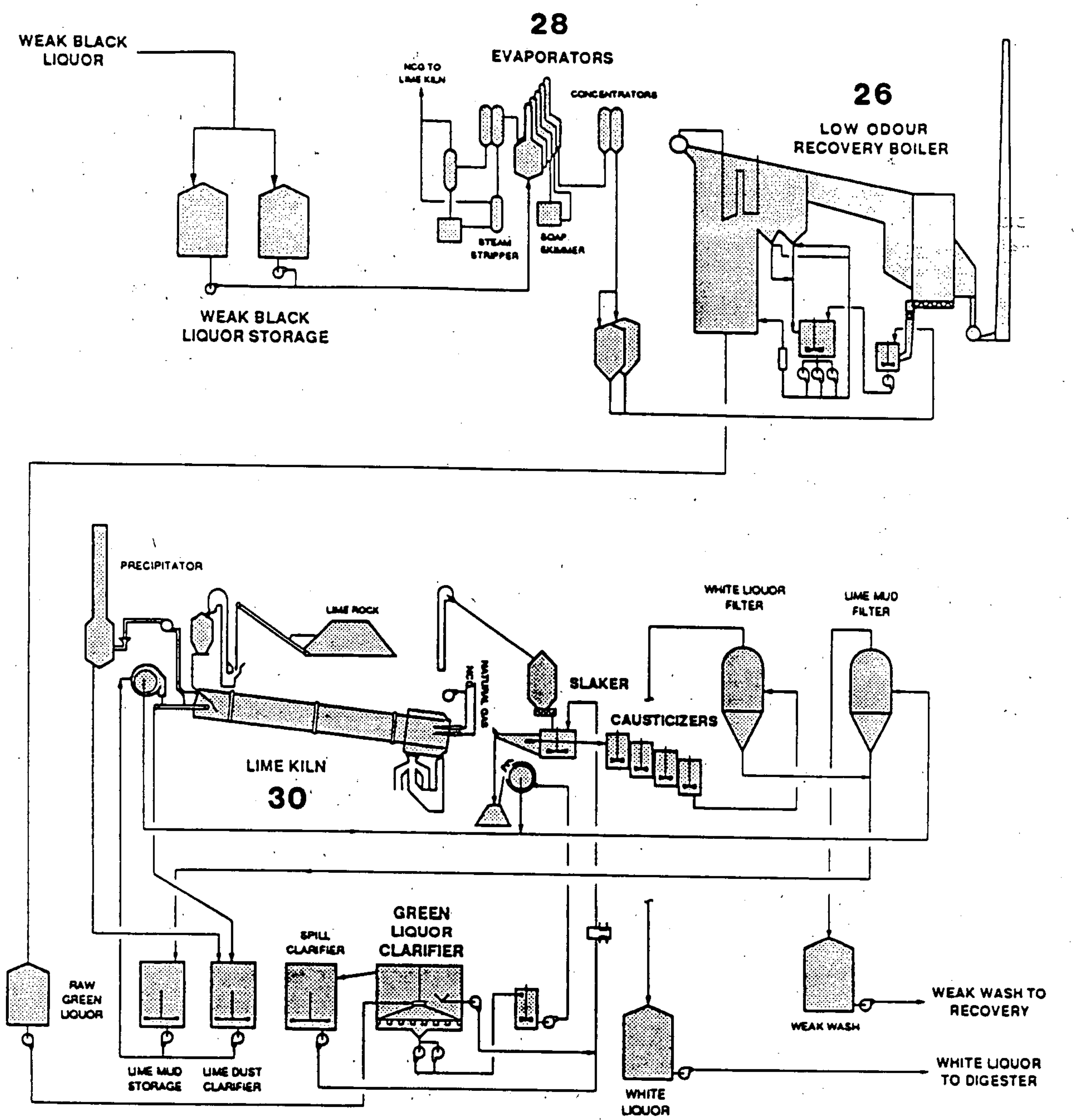


Figure 43 Schematic flow diagram of liquor cycle in new mill. Numbers refer to location map in Figure 41 (from Cirrus Consultants, 1990).

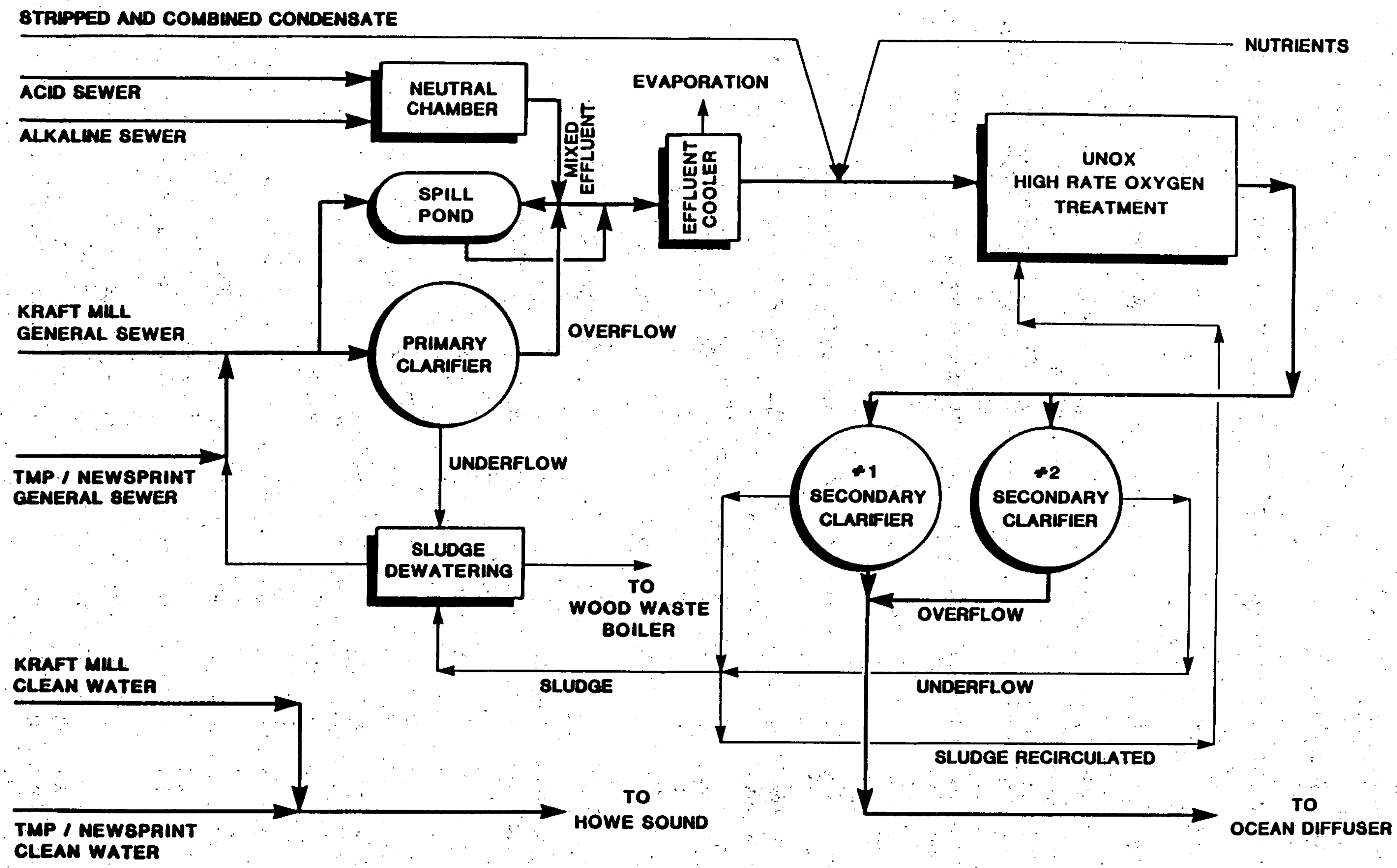


Figure 44 Schematic flow diagram of effluent treatment system in new mill (from Cirrus Consultants, 1990).

Route: North along Thornborough Channel and west side of Howe Sound to Watts Point (Figure 30).

POINTS OF INTEREST

PORTEAU SILL AND EFFECT ON CIRCULATION WITHIN THE INNER BASIN

A cresent-shaped submarine ridge or sill extend across Howe Sound at the mouth of the inner basin, a true fiord (Figure 5). The depth of the sill, which extends from Porteau Cove on the east side and is referred to here as the "Porteau sill", is between 13 to 61m. The Porteau sill separates deeper, flat bottomed basins to the north ("inner basin, average depth 280m) and south (average depth 240m). The sill is composed of glacial till (poorly sorted mud, sand and boulders) reflecting either a standstill of ice retreat at the head of the fiord, or during temporary readvance during the close of the Fraser glaciation (Mathews and Murray, 1966). The seafloor north and south of the sill is covered with greenish-grey silty muds with local deposits of coarser sediment derived from the margins of the fiord (Figure 14).

The Porteau sill inhibits regular the flushing of the deeper waters of the inner basin. The surface brackish flow of Squamish River water moves down the inner basin, entraining underlying seawater. A deep counter flow of seawater replaces these entrained waters. The Porteau sill tends to impede this deep counter flow leading to oxygen depletion in the deep waters of the inner basin (Bell, 1973; Levings, 1980). However, strengthened overflow of the sill by deep waters of the outerbasin may be triggered by a very strong surface jet related to the coincidence of Squamish winds with high river discharge. This winter incursion of oxygenated deep waters is critical to marine organisms living below the sill height. Whenever such refreshening events are delayed too long, oxygen depletion leads to widespread depletion of benthic organisms (Levings and McDaniel, 1980).

STOP 3: SLOPE AND VOLCANIC HAZARDS, MT. GARABALDI AND GARIBALDI VOLCANIC BELT

Leader: Cathie Hickson, Geological Survey of Canada

text by Cathie Hickson, Geological Survey of Canda, Vancouver

Along the axis of Howe Sound, several volcanic vents of the Garibaldi Volcanic Belt [GVB] are visible. The GVB is a continuation of the Cascade Volcanoes that extend northward from Lassen Peak in northern California to Mount Baker, just south of the Canadian border. These volcanoes originate due to subduction off the west coast of North America. The convergence angle of the plate changes along its trend, hence volcanism is more vigorous along some segments of the arc than others. The northern segment of the arc, extending north from Glacier Peak, Washington, is the least active segment.

In the Howe Sound region there are several volcanic vents which date from the end of the last glaciation or Fraser glaciation (approximately 18,000 to 11,500 years ago). These are Watts Point, along the east side of the Sound just south of the town of Squamish, and volcanic pinnacles, the tallest of which is known as Castle Rock, above the Squamish River on the west side of the Sound just above the town. Watts Point volcanic rocks erupted beneath glacial ice, hence on close examination the rock is intricately jointed where the lava quenched against the overlying ice. In some areas, screens of glacial debris can be seen enclosed within the rock. Castle Rock and the associated pinnacles are more problematic. They may represent remnants of `dykes' erupted into the ice during the waning stages of glaciation. After intrusion, the ice melted away, leaving the fairly fragile volcanic features seen today. W.H. Mathews however reports `agglutinate' (a red oxidized volcanic rock) near the base of the pinnacles, suggesting that the eruptions were at least in part subaerial - perhaps into a void in the glacier.

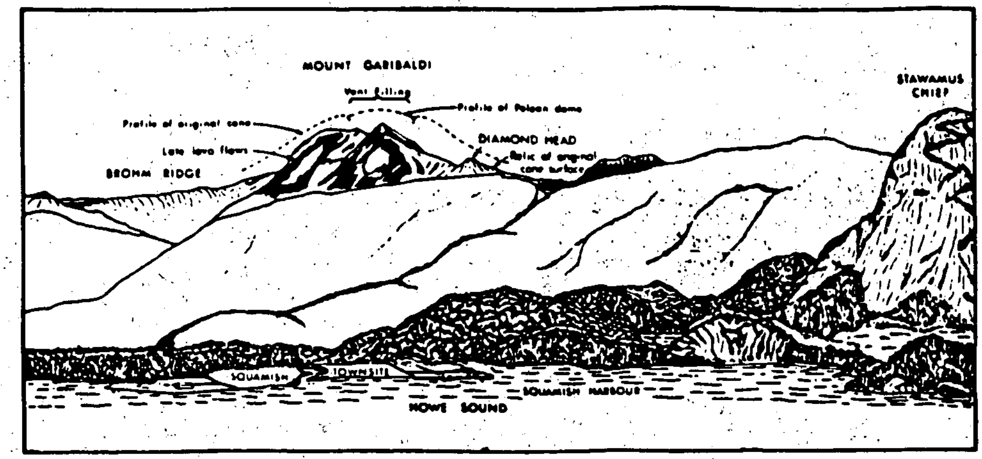


Figure 45 Mount Garabaldi volcano and granitic mountains of upper Howe Sound (from Mathews and Souther, 1987).

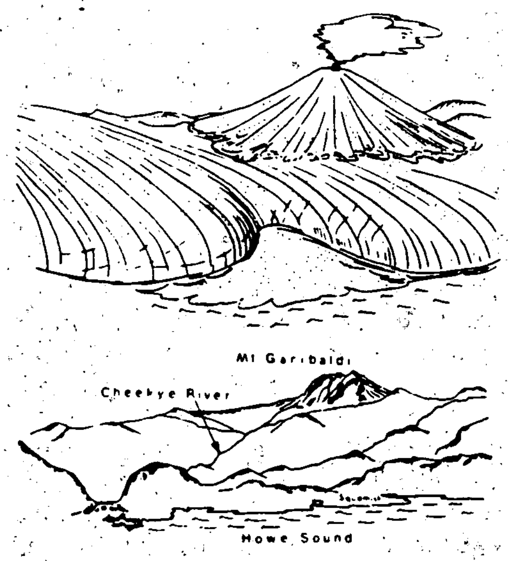


Figure 46 Top: Cartoon of late Pleistocene Mount Garabaldi erupting in contact with remnants of the Cordilleran ice sheet. Bottom: Panorama of the Mount Garibaldi massif (2670 m) and surrounding area as seen from Highway 99 south of Squamish (from Eisbacher, 1983).

Though of interest, neither of these volcanic feature pose any particular threat to the Sound. They do however remind us of the continuous magmatic processes the Sound is subject to. Mount Garibaldi is the closest major explosive vent to the Sound (Figure 45). It is one of the three major strato-volcanoes that make up the GVB. The edifice was built in several explosive (Pelean) phases during the waning stages of the last ice age. These explosions built blocky, unconsolidated material up around the vent area and out onto the surrounding sheet of thick glacial ice (Figure 46). As the ice receded the cone collapsed leaving the steep (600 m) front seen today. The faint layers seen in the steep face are the layers of ash and blocks, some blocks of which are up to 6 m in diameter. This material readily landslides in addition to contributing enormous amount of sediment to debris flows originating on the volcanoes slopes. This debris built up Cheekeye Fan and continues to contribute to debris flows and rock failures. The exact nature of the danger, and the recurrence interval, is now the focus of a detailed assessment commissioned by the Provincial Government and presently being carried out under contract.

Debris flows and landslides continue to pose a threat to downslope and downstream communities - hazard zonation is the only satisfactory solution to preventing losses in property and human lives. The near term threat of a volcanic eruption occurring is low. As near as can be determined, return eruption intervals for the Garibaldi Belt are very long - specific individual centres may never erupt again. However, there has been significant volcanism in the geologically recent past and subduction continues to the present day. Within the belt, volcanism has not been concentrated at individual stratovolcanoes as is the case to the south (e.g. Mt. Baker, Mt. Rainer), rather volcanism has occurred at centres that are closely spaced. Eruptions in the future may occur in close proximity to existing centres, but will probably not be coincident. Determining the details of the eruptive history of the Garibaldi Belt is a challenge that awaits further work.

Route: North to Woodfibre mill (Figure 30).

STOP 4: WOODFIBRE MILL, WESTERN PULP LIMITED PARTNERSHIP

Leader: Bill Rempel, Western Pulp Limited Partnership

Information taken from Western Pulp Limited Partnership publications unless otherwise noted.

The Woodfibre mill is located at the mouth of Mill Creek approximately 5 km from the head of Howe Sound on the western shore. Industrial activity, directed primarily at the production of wood pulp, has been continuous at the Woodfibre site since the beginning of the century. Following several years of sawmill operation, pulp production began in 1912 using an unbleached sulphite process. The mill was converted to a bleached sulphate (kraft) mill in 1961 under Rayonier Inc. Western Pulp Limited Partnership, formed in 1983 to finance moderization of the mill, is now wholly owned by Doman Industries. The modernization program of the mid 1980's included a new bleach plant, recovery boiler, lime kiln, new chip barge unloading facility, and associated equipment.

The Squamish mill produces 700 tonnes/day of bleach market kraft pulp. All of the fibre supply is in the form of residual chips from sawmills in the lower mainland and Vancouver Island area. The chemical reagents chlorine, sulphur dioxide and sulphuric acid are brought to the site by railcar. Caustic and R8 solution (chlorate) are delivered by barge. Oxygen, nitrogen and methanol are trucked. All pulp is fully bleached, and all is exported to the USA (15%), Asia (50%), Western Europe (25%) and 10% elsewhere. Three primary pulp grades are produced: SQH accounts for 77% of Western Pulp's production and utilizes 30% cedar chips, 30% fir, and 40% hemlock and balsam. SQXH accounts for 17% of production and utilizes 30% cedar, and 70% hemlock and balsam. SQC accounts for 4% of production and utilizes 65% cedar and 35% hemlock and balsam.

The mill uses a Dc Eo D E D bleach sequence with a minimum of 50% chlorine dioxide substitution in the chlorination stage. About one third of production is currently bleached without any molecular chlorine. In August 1991, the kiln and power boiler auxilary fuel was converted from oil to natural gas. The mill requires 17 megawatts of electrical power to operate. Two megawatts are generated from Cedar Creek, 3 from steam turbine generators, with B.C. Hydro supplying the remainder.

The oxygen activated sludge effluent treatment system currently under construction will come on line in autumn 1992. Negotiations are also underway with B.C.Hydro for a new wood waste power boiler with co-generation. This will reduce air emissions and make the mill self-sufficient in electricity. All of the new air emission sources of the modernization were designed to meet "Level A" emission guidlines. Effluent streams (some of which previously discharged into Mill Creek) are consolidated and after primary treatment they are discharged through a deep water diffuser 22 metres below low tide.

The Woodfibre mill's impact on Howe Sound Watershed can be summarized as follows:

<u>Effluent</u>
average volume - 65,000 cu. m/day,
suspended solids - 3 tonnes/day,
biological oxygen demand (BOD) - 17 tonnes/day, (2 tonnes/day by late 1992)
chlorinated organic compounds measured as adsorbable organic halogens -1.5 tonnes/day,

<u>Particulate emissions</u>
recovery boiler - 0.8 tonnes/day sodium sulphate and sodium chloride,
Lime kiln & dissolving tank combined - 0.4 tonnes/day, primarily Ca & Na carbonate.

<u>Wood waste</u>
Power boiler - 2.0 tonnes/day fly ash (0.5 tonnes/day with new boiler by 1994).

Based on a review in 1979, environmental impact of Woodfibre effluent discharges was interpreted to be confined to a localized area adjacent to the mill (Nelson, 1979). Good circulation and flushing of surface waters due to the Squamish River flow were interpreted as limiting impact. Study of invertebrate beach communities on a beach transect 375 m south of the Woodfibre sewer outfalls showed very depleted communities with only four invertebrate taxa recorded (nemerteans, oligochaetes, chironomid larvae, amphipod) while the beach area immediately adjacent to the mouth of Mill Creek under the docks was devoid of life (Levings and McDaniel, 1976). Installation of a submerged outfall and diffuser system discharging within the surface mixing zone was conducted to improve water quality and intertidal life near the mill.

STOP 5: SQUAMISH ESTUARY: IMPACT OF DEVELOPMENT

Leader: Colin Levings, Fisheries and Oceans , West Vancouver

The Squamish delta has been built by rapid sediment deposition as the velocity of the Squamish River current decreases upon entering Howe Sound . The delta has grown laterally and vertically by continued migrations or switching of channel position, and annual flooding of the delta surface during peak discharge (freshet). Advance of the delta began at the retreat of the last glaciation (Fraser Glaciation) 11,500 years ago and today the delta front is advancing seaward about 7 meters a year. At that rate, the delta will extend a kilometer further to the south in 120 years. Squamish River delta is less effected by wave energy than the Fraser delta due to it more protected location at the head of a fiord. Sands and silts are currently being deposited at the river mouth on the western side of the delta; the sediment is finer on the eastern side away from the river mouth. Continued slumping of oversteepened sediment on the submerged slope of the delta moves sediment to deeper water.

The town of Squamish has been inundated with nearly 1.5 m of water about once every 16 years since its founding, and to a lessor extent every 7 years (Thomson, 1981). Prior to 1921 the Mamquam River emptied directly into the ocean through what is now Mamquam Blind channel; a major flood in that year caused the the river to change course and flow into the Squamish River, 5 km from the sea.

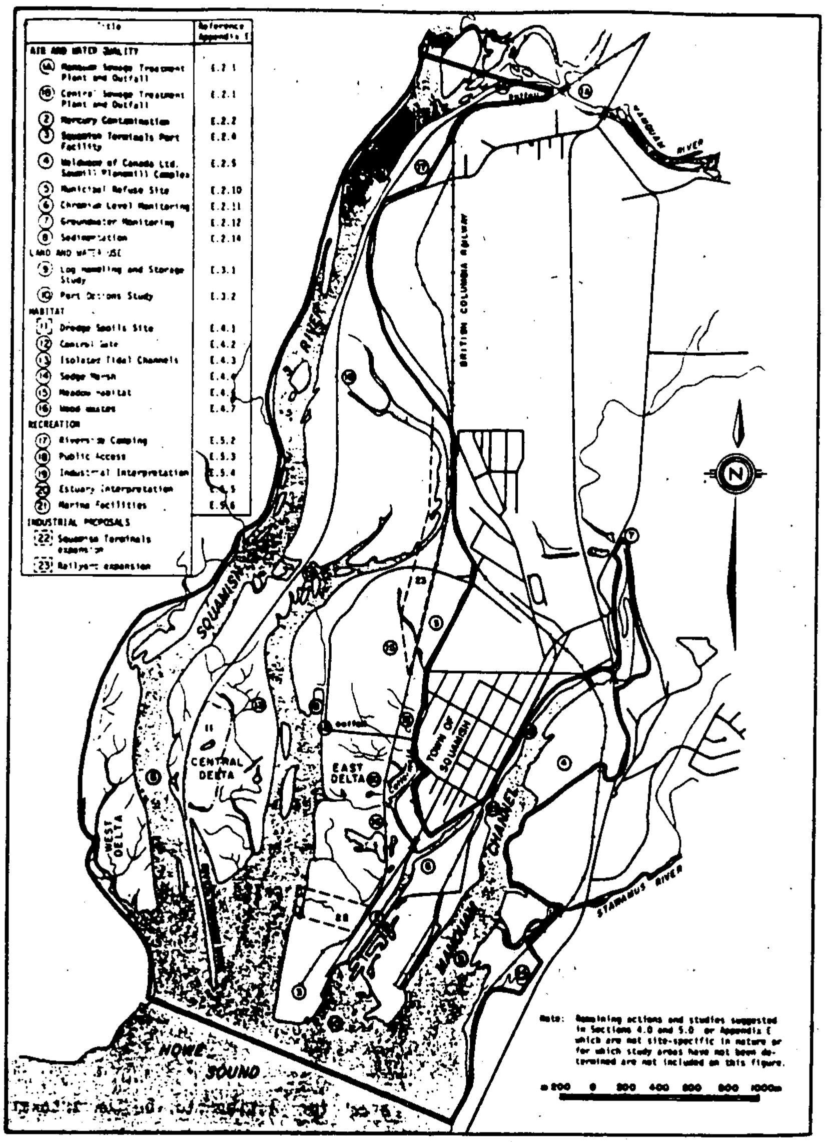


Figure 47 Map of Squamish estuary showing showing land use (Squamish Estuary Management Plan, 1982).

Dredging during the 1940's straightened the river's lower reach, and construction of a retaining dike in the early 1970's now confines the river to that course.

Vegetation on the delta is zoned seaward from (1) coniferous and deciduous forest above the high tide line (to the northwest), to (2) shrubs and grasses straddlling the high tide range, (3) intertidal sedges and rushes (to the west), and (4) lower intertidal benthic algae. Primary production in marshlands and intertidal areas of the Squamish estuary is critical to salmonid juveniles. Benthic algae and sedges (grass-like plants) provide food for amphipods and other benthic invertebrates which are preyed upon by fish.

Development on the outer delta

Much of the town of Squamish is built on the delta (Figure 47). The B. C. Forest Products Terminal, completed in 1971, and the FMC Chemicals plant, finished in 1965, have been built on reclaimed tidal flats and marsh along the front of the delta. Docking basins have been dredged adjacent to the B.C. Forest Products Terminal. Industrial development has made significant impact on the plant and animal habitats of the Squamish delta. Habitats have been lost due to emplacement of fill and dredge spoils, dredging of channels and port areas, log booming and resultant high organic (bark) sedimentation, dyking and diversion of fresh water. Of the 1200 acres of the delta, nearly 100 acres have been lost due to land filling and dyke construction. Log storage in Mamquam Channel has led to the accumulation of wood debris causing physical "smothering" of benthic organism and reductions in species diversity (Hoos and Vold, 1975).

The FMC chlor-alkali plant at Squamish uses the mercury cathode process, and discharged as much as 40 tonnes of mercury into Howe Sound between 1965 and 1970. In 1970, the shellfish fisheries was closed in Howe Sound from the Squamish delta to Porteau Cove due to elevated mercury levels (Harbo and Birtwell, 1978a). FMC installed more efficient mercury scrubbers, mercury discharge in water effluent decreased markedly resulting in lower levels of mercury in benthic organisms (Harbo and Birtwell, 1978b) and the fishing closure was dropped. Mercury levels in sediments near the FMC plant also decreased, possibly due to mechanical resuspension and transport due to tidal or river currents, or propeller wash from vessels using the facilitites (Thompson et al., 1980, p. 76).

Route: South to Britannia Beach (Figure 30).

STOP 5: BRITANNIA BEACH: ACID ROCK DRAINAGE, MARINE DISPOSAL OF TAILINGS, AND RECENT FLOOD DAMAGE

Leaders: Linda Broughton, Steffen, Robertson and Kirsten (B.C.) Ltd; Tom Pederson, Department of Oceanography, UBC; Karen Drysdale, Department of Geography, U. Victoria; and Bernie Claus, Environment Canada

Britannia mine site and acid rock drainage

text by Linda Broughton, Steffen, Robertson and Kirsten

The decommissioned Britannia Mine is located at Britannia Beach approximately 48 km north of the city of Vancouver, on the east side of Howe Sound. The underground and open pit mine was originally operated by the Britannia Mining and Smelting Company Ltd., from 1905 to 1963, at which time it was purchased and operated by Anaconda Mining Company until shutdown in 1974. During operation, approximately 45 million tonnes of ore were processed for recovery of copper and lesser amounts of zinc, silver, and gold. Tailings were deposited directly into Howe Sound through two intertidal outfalls located near the mouth of Britannia Creek.

It is said that a Doctor Forbes discovered the Britannia copper ore deposits while out deer hunting in the mountains not far north of Vancouver. That was 100 years ago. At that time, however, it was a

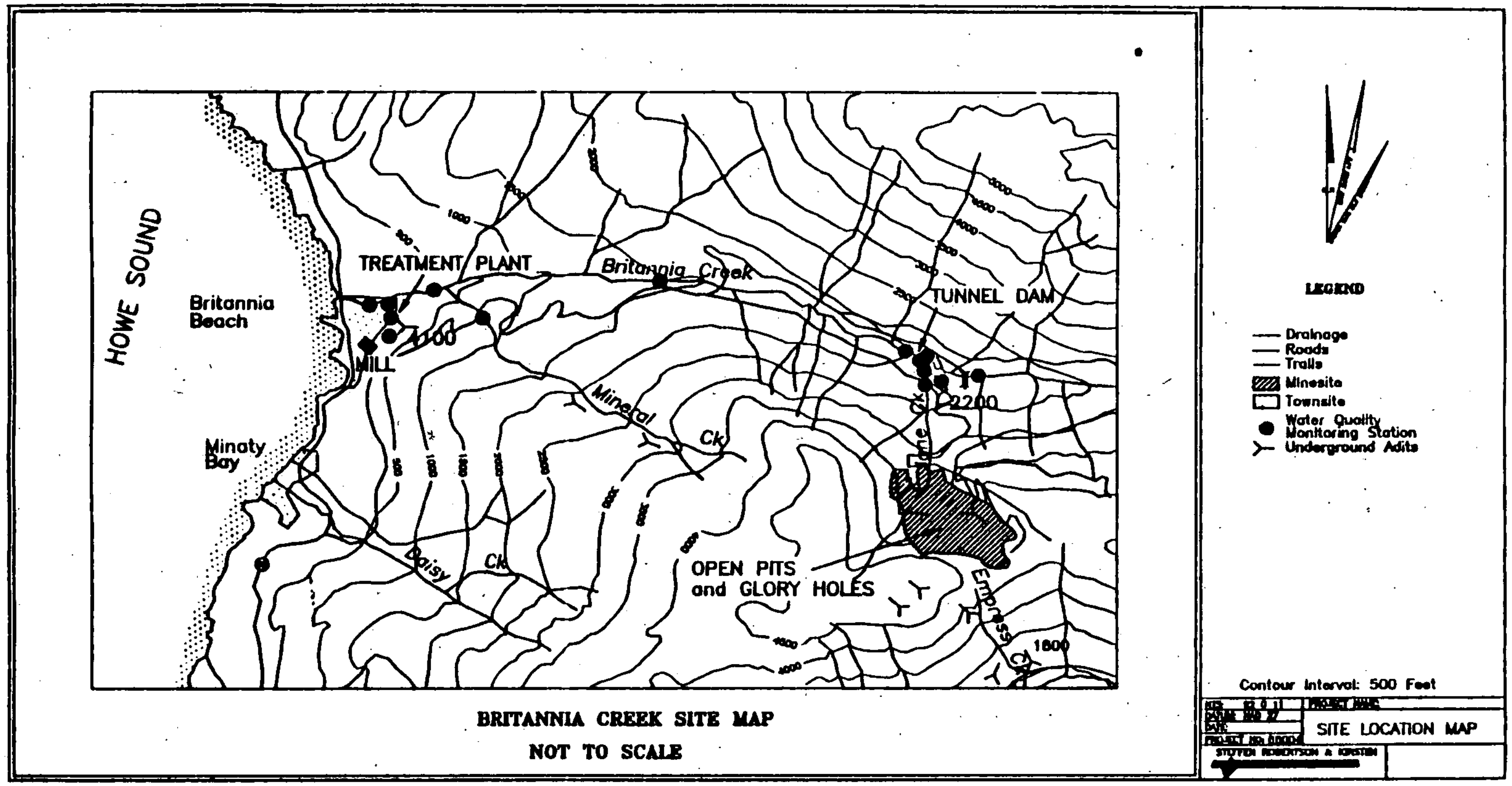


Figure 48 Map of Britannia mine area (from L. Broughton, Steffen Robertson and Kirsten).

remote area and nobody was too interested in his discovery. Ten years later Oliver Furry, a trapper, grubstaked by a Vancouver storekeeper, staked seven claims. This represented the nucleus around which the Britannia mine was built. Furry did 200 feet of cross-cut adit and drift work before selling out in 1898 for $10,000 to a fur-buying firm in Victoria. A year later a syndicate from Montana bought 7/10 of the property for $35,000. The mine went into production in the early 1900's and operated essentially continuously until closing in 1974. In its heyday Britannia was said to have been the largest copper producer in the British Empire.

Nowadays the mine is a museum, an interesting tourist stop alongside the beautiful fjordal Howe Sound. Many of the old stories and photographs - dating back to the early 1900's - show signs of the environmental problems which we are only recognizing today. Hobnailed boots lasted only a few months in the underground mine - the nails rusted away by the acidic mine waters. Silica was perceived to be the culprit at that time, producing acid waters by its so-called "vicious attack on pyrites in the rock." Concern for acid rock drainage has led the provincial government and the Acid Mine Drainage Task Force to commission SRK to study the site; to identify all of the sources and quantities of contaminated drainage, develop alternative remediation options for the entire site, and develop a focused monitoring and investigative program to select the appropriate remediation measures.

As shown on the site plan (Figure 48), the workings extend from the 4100 portal of Britannia Beach to the open pit, about 6 km up the Britannia creek valley. Note that the mine datum (0 feet elevation) is at about 4300 feet above sea level, so that the 2200 portal is at an elevation of about 2100 feet, while the 4100 portal is closer to sea level at an elevation of about 200 feet. Starting high up in the watershed, Britannia Creek flows past the mine workings collecting drainage from old adits, waste dumps and disturbed land, and discharges into the ocean in Howe Sound. Gloryholes at the top of the mountain funnel rain water through the extensive underground workings, flushing out acidity and dissolved metals that are also deposited in the Sound. Acid rock drainage containing elevated acidity and metal levels has issued periodically from the Britannia site since the operational period. During mine operation, drainage waters from the 2200 and 4100 levels were directed through two copper precipitation plants containing scrap iron, before discharging into Britannia Creek. In 1972, in an attempt to control drainage water from the site, acidic mine water was diverted within the mine workings to the 4100 level for treatment in the cementation plant prior to discharge.

The mine site extends far back into the hills and, with a history of acid rock drainage that seems to date back to the start of the mine, it will require a well planned, long-term remediation program. Meanwhile, short-term measures can be implemented to control the quality of water discharging into Howe Sound. The B.C. Ministries of Environment, and Energy, Mines and Petroleum Resources are continuing to lead investigations to evaluate the problem and institute effective control technology. In addition, the Britannia Mine provides an unique opportunity in B.C. to see the history of development of acid rock drainage. Valuable information for other, "younger", sites.

A note about acid rock drainage

Acid rock drainage is the contaminated drainage which results from the natural oxidation of sulphide minerals which are contained in rock, in the presence of air and water. The acidity and dissolved constituents of the resulting drainage depend on the nature and reactivity of the sulphides, the chemical constituents of the host rock and the physical and chemical controls limiting the rates of oxidation and leaching. As water flows away from the reaction site the drainage reacts with the rock and soil material with which it comes into contact, changing the pH and concentrations of the drainage.

Sulphide oxidation is a naturally occurring phenomenon and acidic springs and the characteristics "rust" coloured staining are often indicators of sulphide mineralization. Mining activities can aCCelerate the process by exposing mine wastes, tailings and mine workings which contain sufficient quantities of reactive sulphides to result in acid generation.

Geochemistry of marine mine tailings

For 75 years, the operations of the Britannia mine dumped an average of 1600 m3/day of tailings slurry enriched in iron, copper, zinc, lead, silver and gold (Ellis and Popham, 1983). Prior to 1927 the tailings were discharged into nearby Britannia Creek, but about 1927 an ocean outfall was constructed to discharge just below low tide (Drysdale, 1990). In addition, between 1925 and 1929 tailings were placed directly on the shoreline to reclaim land. Some of these tailings latter failed, slumping into deeper water. A plume of tailings extends from Watts Point to the north and southward to the sill near Porteau Cove (Figures 49 and 50) (Thompson and McComas, 1974). The waterfront and shallow marine area at Britannia Beach is highly disturbed by a history of submarine dumping of metal-rich mine tailings, metal-bearing acid mine drainage, sediment discharge from gravel washing operations, and rubble landfill of the water front during construction of the railway and dock facilities.

Mine tailing were discharged into Howe Sound from 1904 to 1974. The input of these metal-rich solid wastes has disrupted the ecology of the seabottom; scuba diving surveys indicate that the thick layer of mine tailings on the bottom adjacent to the Britannia mill had not been colonized by benthic organisms in 1973 (McDaniel, 1973).

A land fill project using mine tailings near the mouth of Britannia Creek between 1925 to 1929 was terminated when the fill became unstable on an oversteepened slope and slid seaward into deeper water. Cores taken a half mile offshore have intersected slumped mine tails rich in iron, copper and zinc (Mathews and Murray, 1966). Dispersal of copper from Britannia Beach has occurred throughout the upper part of Howe Sound (Fig. 13)

Britannia Beach Flood: 29-31 August 1991

text by Berni R. Claus, Environment Canada

Britannia Beach is located at the mouth of Britannia Creek about 7 km south of Squamish. The creek has a total watershed area of 28.5 sq. km and travels through a narrow canyon shortly before flowing over its alluvial fan to the ocean (Figure 51). The lower townsite built on the fan includes residences, offices, museum, gas station and stores. One railway bridge and two road bridges cross the creek in this area, and the recent flood washed out a smaller foot bridge.

Heavy rainfall caused severe flooding in the Howe Sound Basin between August 29th and 31th, 1991. The Squamish highway was blocked for 36 hours and initial damage estimates total $7 - $11 million for the Howe Sound Basin and Pemberton areas. The flooding at Britannia Beach was marked by the avulsion of Britannia Creek through the lower townsite, severe debris deposition and several million dollars damage. Flooding is not new to Britannia Beach. Damaging floods of Britannia Creek occurred in 1906, 1921, 1933 and on four occasions during the 1960's (Jackson et al., 1983). The October 21, 1921 flood followed 146 mm of rainfall in 24 hours. A flood surge caused by the failure of a railway embankment released a surge of water that destroyed half of the 170 houses in the settlement and washed some into Howe Sound. It is likely that activities related to the mine development such as logging in the watershed, logging debris in the creek channel, water supply dams and other interference with the stream channel, contributed to the disaster (Jackson et al., 1983). The five dams built on the creek are now completely or partly infilled with sediment. In 1989 one dam was purposely breached because of stability concerns, however, the breach was larger than expected causing a spectacular flood downstream.

The recent flooding was unusual in that it occurred in August. Preliminary data for August 1991 shows widespread precipitation with the heaviest rain falling between 29 and 30 September. The Squamish airport reported a 24 hour maximum of 103 mm, and Woodfibre 88 mm. By comparison the highest 24 hour rainfall for Squamish is 164 mm (November 10, 1990). Although the rains were heavy, the unusually wet August conditions most likely caused the exceptionally high runoff. When the August 29-30 rains came, the already saturated ground provided no attenuation. The warm temperatures precluded precipitation falling as snow, and almost all the precipitation became direct run-off. The heavy run off contributed to severe erosion and debris transport. After passing through the narrow canyon,

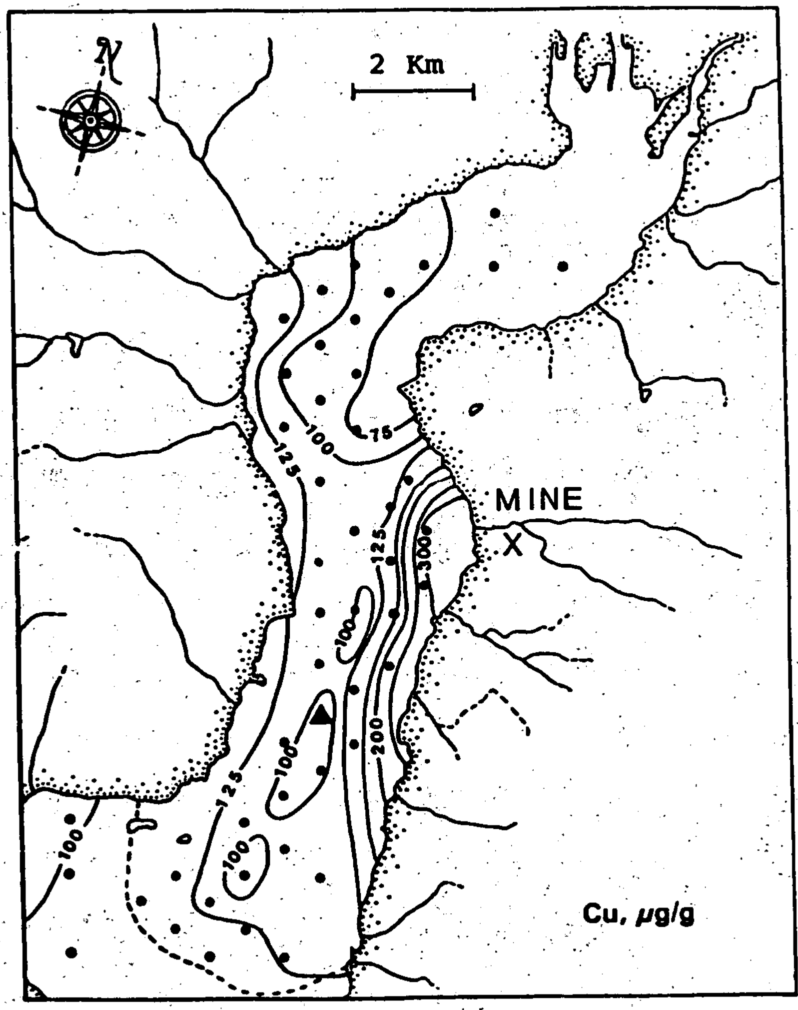


Figure 49: Copper distribution (ppm) in surface sediments of inner basin, Howe Sound, May, 1987 (from Drysdale, 1990).

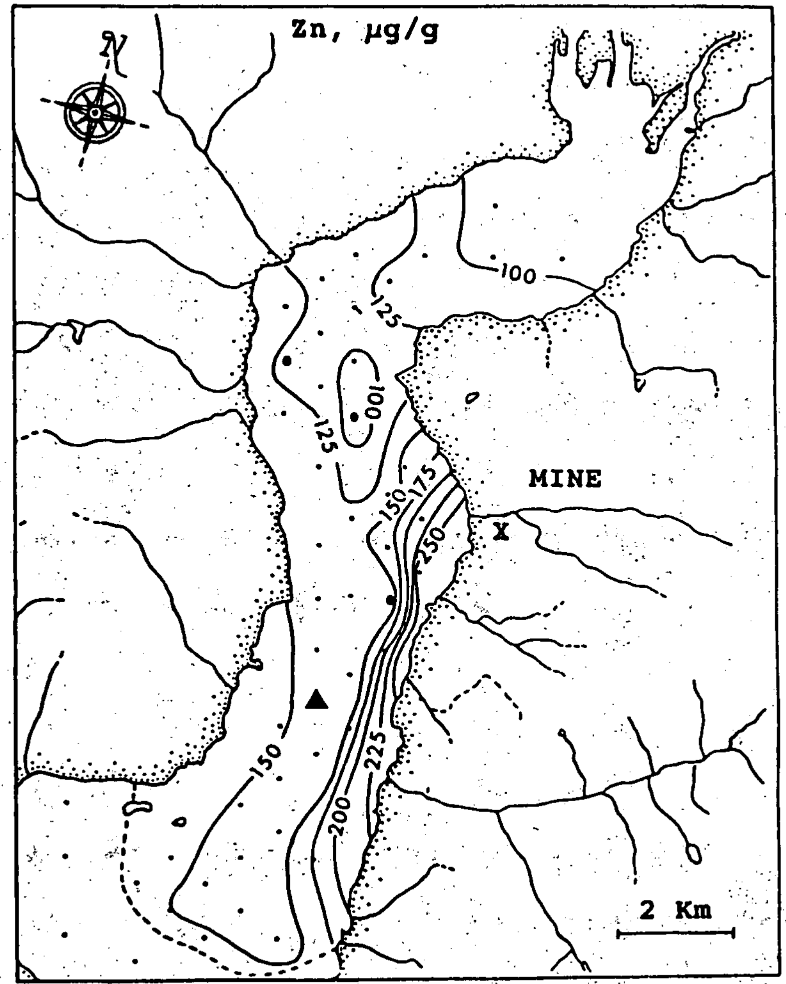
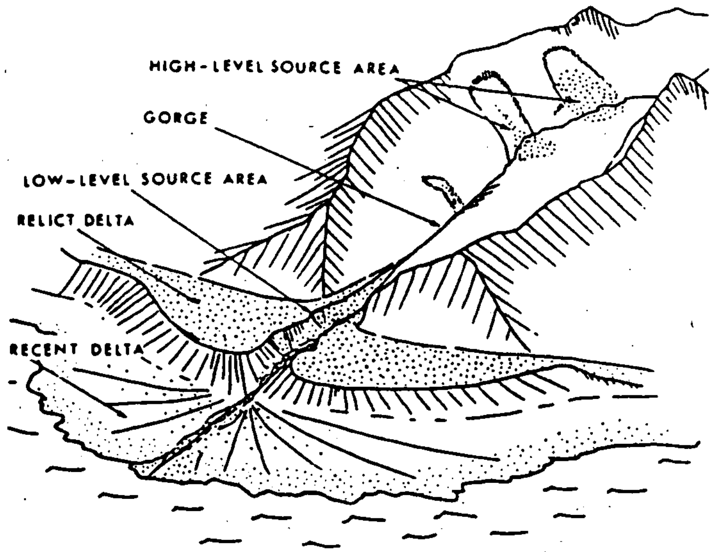


Figure 50: Zinc distribution (ppm) in surface sediments of inner basin, Howe Sound, May, 1987 (from Drysdale, 1990).



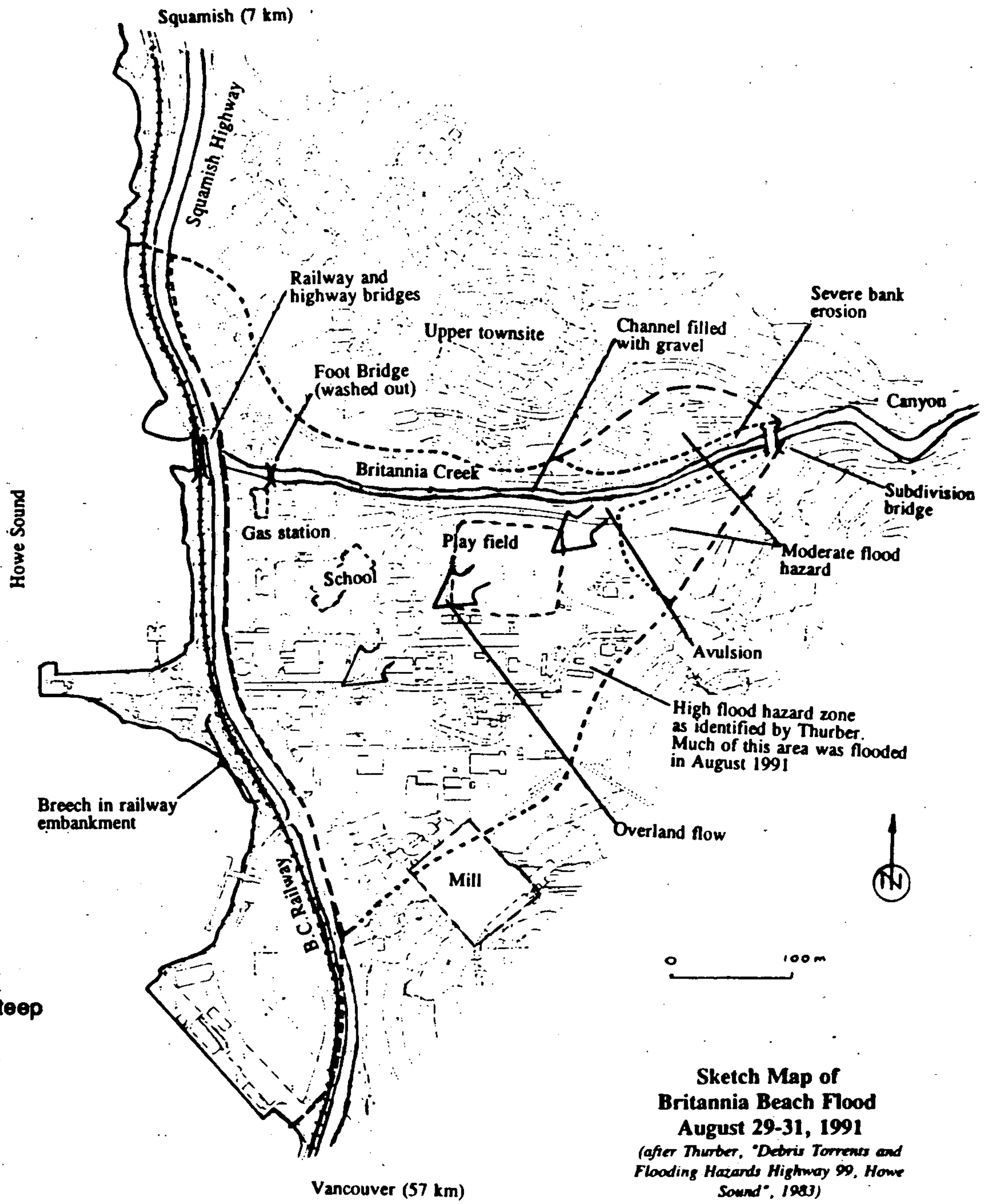


Figure 51 (left) Schematic illustration of debris sources along steep mountain streams such as Britannia Creek that discharge across raised fan deltas into a fiord (from Eisbacher, 1983).

Figure 52 (right) Sketch map of effects of Britannia Beach flood of August 29-31, 1991. By B. Claus using base map from Thurber Consultants (1983).

the reduced gradient on the alluvial fan caused debris deposition in the creek channel severely reducing capacity. The creek then flowed over its banks and through the townsite to pond behind the railway embankment which eventually failed (Figure 52). Bank erosion, channel erosion and slide debris partly associated with past mining road construction appear to be the main sources of sediment supply. There is some speculation that the 1989 dam breach may have either loosened up the channel bed, and/or transported additional debris down channel. Temporary debris dams may have also contributed to surges.

The sediment and debris sources remaining upstream are considerable and severe flooding with debris will undoubtedly re-occur (Figure 51). A potential rock avalanche on the Jane creek tributary also provides concern. The lesson to learn is that re-construction and further development must wait until suitable zoning, and/or engineering works such as setback dykes and a dredging program are in place. One possible solution is to restrict flood prone areas to day use activities with no overnight residences.

Acknowledgements: Eric Wiess, B.C. Environment; Frank Baumann, Geological Engineer, Squamish; Robin Gardner, Provincial Emergency Program.

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