ENVIRONMENT CANADA
CONSERVATION AND PROTECTION
ENVIRONMENTAL PROTECTION SERVICE
PACIFIC AND YUKON REGION

MARINE ENVIRONMENTAL QUALITY REVIEW NEAR THE MACMILLAN BLOEDEL PULP MILL POWELL RIVER, B.C.

EP REGIONAL PROGRAM REPORT

87-23

By

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ABSTRACT

This report reviews the quality of the receiving environment in the vicinity of the MacMillan Bloedel pulp and paper mill at Powell River. EP (Environmental Protection) data, published reports and mill data are used to evaluate changes in sediment and water quality.

EP collected sediment and water quality information on 18 Nov 83 and inspected the intertidal zone in Sept 87. The main impact of the mill is on the benthic environment. Sediment volatile residues (SVR) were highest at stations nearest the outfalls. Data indicate that benthic species composition would be altered at stations with high SVR. Observations from the PISCES IV submersible indicate the existence of wood fibres covering the sediments over 1 sq. km. BC Ministry of Environment and Parks (BCMOEP) data indicate sediment toxicity to Macoma sp., when bioassays were conducted using sediments collected in the vicinity of the outfall.

PCBs and resin acids were undetectable at all sites sampled. Chromium, copper, lead, nickel and zinc were elevated at station B-6, compared to the reference site. Trend analysis of sediment metal concentrations (1979-83) indicate that zinc increased slightly at two sites, but remained below reference area levels. Most metal levels declined and all levels observed are below those which are known to alter benthic community structure.

Mill effluent had little or no influence on water quality parameters sampled. Dissolved oxygen saturation (DOSAT) was largely unchanged throughout the area sampled: above 50 m DOSAT > 90 %. Nutrients, colour, sulphides or PCBs were not elevated in the water column.

Intertidal observations indicate improved communities at all mill monitoring stations. Organisms not previously recorded (eg. amphipods and littorinids) were abundant. Healthy growths of mussels (M. edulis) and rock weed (Fucus sp.) were also found.

Future monitoring should include sediment coring, sediment bioassays, periodic intertidal surveys and sampling for organic chlorine compounds.

Keywords: pulpmill, benthic impact, fibre bacterial mat, trends, sediment trace metals, water quality

RESUME

Ce rapport revise la qualité de l'environnement récepteur dans les voisinage de l'usine de pâtes et papier de MacMillan Bloedel à Powell River. Les données du Service de Protection de l'environnement, (SPE), les rapports publiérs et les données d'usine sont utilisées pour évaluer les changements dans les sédiments et la qualité de l'eau.

Le SPE a collecté des sédiments et des informations sur la qualité de l'eau le 18 novembre 1983 et inspecté la zone intertidale en septembre 1987. L'impact principal de l'usine porte sur l'environnement benthique. Les résidus volatile des sédiments (SVR) furent les plus élevées aux stations près des effluents. Les données indiquent que la composition des espèces benthiques a deviait être modifié aux stations compostant un hut taux de SVR. Les observations prises du sousmarin pisces IV indiquent l'existence de fibres de bois couvrant les sédiments sur plus de $1km^2$. Les données du BC Ministry of Environnment and Parks (BCMOEP), indiquent que les sédiments sont toxiques au mollusque Macoma sp. quand les bioessais furent menés sur des sédiments récoltés dans le voisinage de l'effluent.

Les BPC et les aindes résineux furent non déteteés à tout les sites échantillonnés. Le chrome, cuivie, plomb, nickel, et zinc furent élevés à la station B-6 comparé au site de référence. Une analyse des tendances de la concentration des métaux dans le sédiments (1979-1983) indique que le zinc augmente légèrement aux deux sites, mais reste en dessous des niveaux des aires de référence. La plus part des niveaux de métaux ont diminués et tout les niveaux observés furent en dessaus de ceux dont on connait la capacité de changer la structure de la communauté benthique.

L'effluent de l'usine a peu ou pas d'influence sur la qualité de l'eau pour les paramètres échantillonnés. La saturation de l'oxygêne dissous (DOSAT) fut largement constant partout dans la région échantillonné: au dessus de 50 m, DOSAT 90%. Les éléments nutritifs, la coleur, les sulphures ou BPC ne furent pas élevés dans la colonne d'eau.

Les observations intertidales indiquent une amélioration des communautés à toutes les stations de surveillance de l'usine. Des organismes au paravant jamais rapportés (amphipocles et littorinedes) furent abondants. On a trouvé aussi une saine croissance des moules (M. edulis) et des algues marines (Fucus sp.).

Mots clef: usine de pâtes et papier, impact benthique, tapes de fibre-bactérier, tendances, métaux traces dans les sédiments, qualité de l'eau

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1.0 INTRODUCTION

This report evaluates the condition of the receiving environment in the vicinity of the MacMillan Bloedel pulp and paper mill at Powell River, located approximately 100 km northwest of Vancouver (Figure 1). This information along with present production levels will be used to estimate potential impacts associated with mill expansion and production increases. Recommendations will be made for improvements to the mill's monitoring program.

This review is based on Environmental Protection (EP) reports, consultant reports and previously unpublished EP oceanographic data collected in November 1983, PISCES IV submersible observations from April 1987 and intertidal data gathered in September 1987.

1.1 Historical Review

The pulpmill was established in 1912 and until 1980 discharged all effluent via a tailrace into the surface waters of Malaspina Strait (Figure 2). In 1980, 32 % of total mill discharge (the kraft mill effluent) was diverted to a new submarine diffuser. This was installed in 1980 to provide more dilution and dispersion of the effluent and reduce effects on surface waters. Two years previously, a primary clarifier was installed to reduce total suspended solids (TSS) loadings from the mill.

The quality of the receiving environment in the vicinity of the mill has been described in previous Environment Canada reports (Nelson 1979, Sullivan 1980, Sullivan 1981, Petrie and Holman 1983). MacMillan Bloedel has also conducted various water quality and benthic studies in the vicinity of the mill between 1970-1981 (in Nelson 1979). More recently, mill receiving environment monitoring efforts have been temporally sporadic and restricted to a few water quality parameters. The last mill water sampling survey was in April 1985. It should be noted that the dumpsite indicated on Figures 4, 5, and 6 received 100,000 cu. m. of dredge material from the vicinity of the mill log ponds, wharves and diffuser area (1977-1979: EP, Ocean Dumping Files). Much of this dredged material was wood debris and consequently sediments had high organic carbon values.

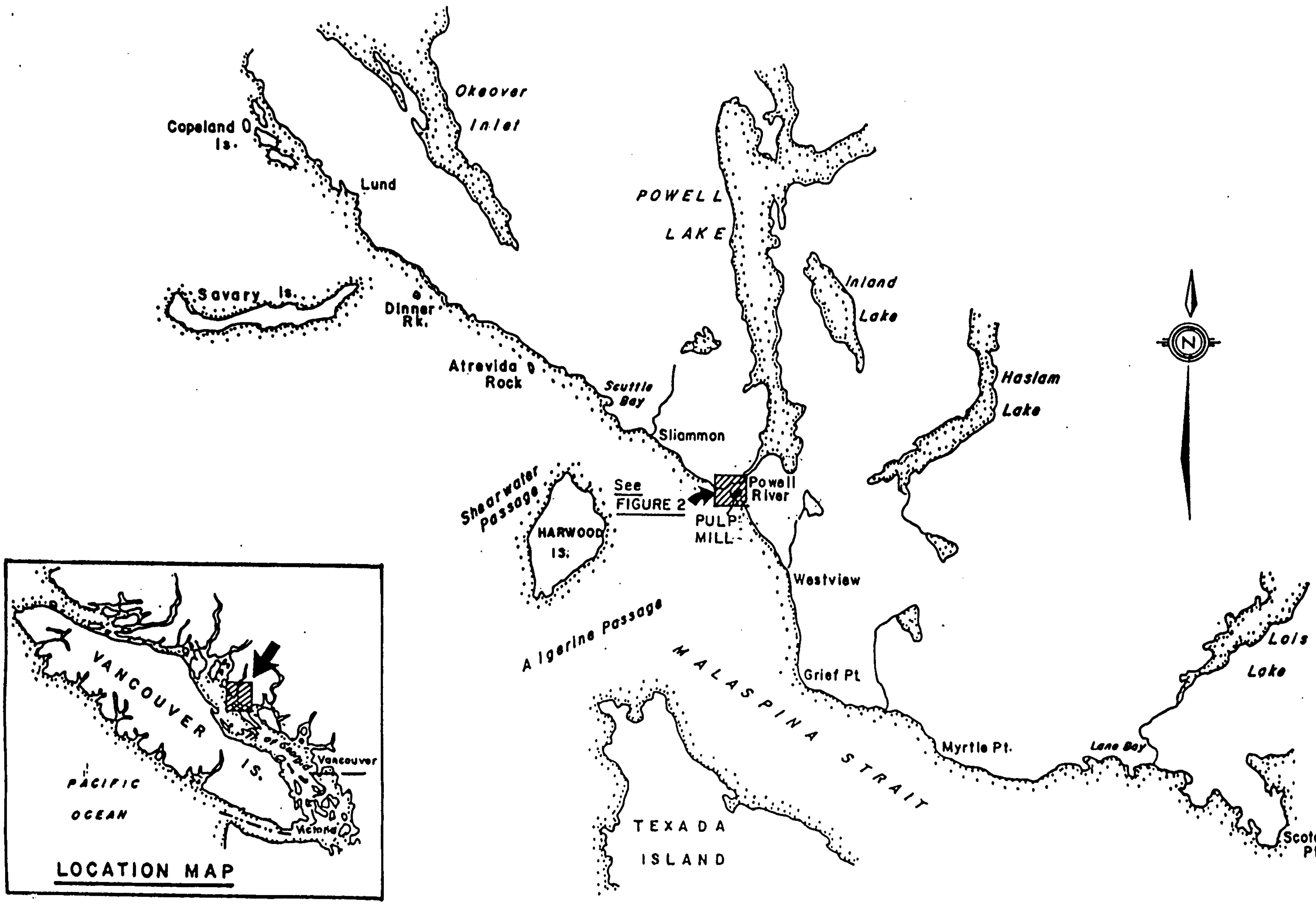


FIGURE 1 POWELL RIVER

1.2 Fisheries Resources

Fisheries resource information was reviewed by Knapp and Lashmar (1978). Herring spawning grounds, clams and oyster beds were identified within 2 km of the mill site but are closed to harvesting. The Sliammon Indian Band utilizes the Sliammon River as a salmon food fishery resource, operating a hatchery (1.1 million eggs) and harvest about 5000 chum,< 200 coho, and a few chinook each year. Prawns are harvested near the mill by two commercial boats. Prawns, crabs, and salmon are also recreationally fished in the vicinity (Neil Armstrong, DFO Fisheries Officer, pers. comm.).

1.3 Existing Information on Marine Environmental Quality

Nelson (1979) reviewed the environmental impact of the mill up to 1979. In 1978 the mill operations included a kraft semi-bleach pulp mill, two stone groundwood mills, one sawdust refiner groundwood mill, one thermo-mechanical pulpmill (TMP), six paper machines and a sawmill:

		1986	1978
PULP PRODUCTION	AIR DRIED TONNES/DAY	1657	1502
BOD5 (Biochemical Oxygen Demand)	TONNES/DAY	32	28
TSS (Total Suspended Solids)	TONNES/DAY	21	57

More recent EP data from Powell River was reported in Sullivan (1980, 1981, 1982). A general review of B.C. marine environmental quality was reported by Kay (1986) which included a review the environmental impact of all coastal pulpmills. He noted that the elevated sediment mercury and cadmium levels described in Nelson (1979) and Sullivan (1980) were higher than at other mill sites.

1.3.1 Contaminated Shellfish

As part of a larger shellfish monitoring survey, sites in Malaspina Strait were sampled in 1973 (Nelson and Goyette 1976). A zone of zinc-contaminated oysters (Crassostrea gigas) extended as far north as Lund (18 km away; Figure 1) and was linked to zinc hydrosulfite bleaching at the Powell River mill. Oysters were more contaminated near this mill site (max. 17,280 ug/gm) than at six other mill and harbour sites on Vancouver Island and in Howe Sound. Subsequently the use of zinc compounds as brightening agents was suspended at coastal mills by the mid-1970's (D. Goyette, pers. comm.).

1.3.2 Benthic Degradation The main environmental impacts previously identified at Powell River were to the near-shore benthic environment. High fibre (TSS) loadings, before the installation of the clarifier and diffuser, had degraded near-shore benthic sediment quality to the extent that sediment had become reducing, with a concurrent depression of benthic invertebrates, commonly seen in organically-polluted marine sediments (Nelson 1979). The fibre and bark deposits were confirmed by observations from the PISCES IV submersible in 1978 (Petrie and Holman 1983).

In addition, high concentrations of mercury (Hg) were found next to the mill site (max 21.0 mg/kg; Nelson 1979). In 1980 elevated trace metals (Hg, Cd, Cu, Pb and Zn) were also reported (Sullivan 1980). However, contamination of biota by mercury and other metals was not thought to be a problem (Nelson 1979, Sullivan 1980). Further surveys in the area (Sullivan 1981, 1982) indicated elevated sediment cadmium levels, but did not confirm elevated levels of Hg, Zn, Cu, or lead.

Although changes were noted in benthic infaunal invertebrates between pre-diffuser (1979) and post-diffuser sampling (1980), no firm conclusions could be drawn due to the natural variability of natural populations (Young 1980), and the limited time interval between the installation of the diffuser and the one-time post-diffuser sampling program. Further invertebrate population and sediment-toxicity studies are required to delineate the zone of impact on benthic invertebrate populations.

1.3.3 Changes in Water Quality Some influence of the effluent on water quality parameters was noted before the installation of the diffuser:

PARAMETER	EFFECT OF EFFLUENT	REFERENCE
colour	increased	Nelson 1979
light penetration	decreased	"
salinity	decreased	"
dissolved oxygen	decreased	Costantino 1973
photosynthesis	decreased	"

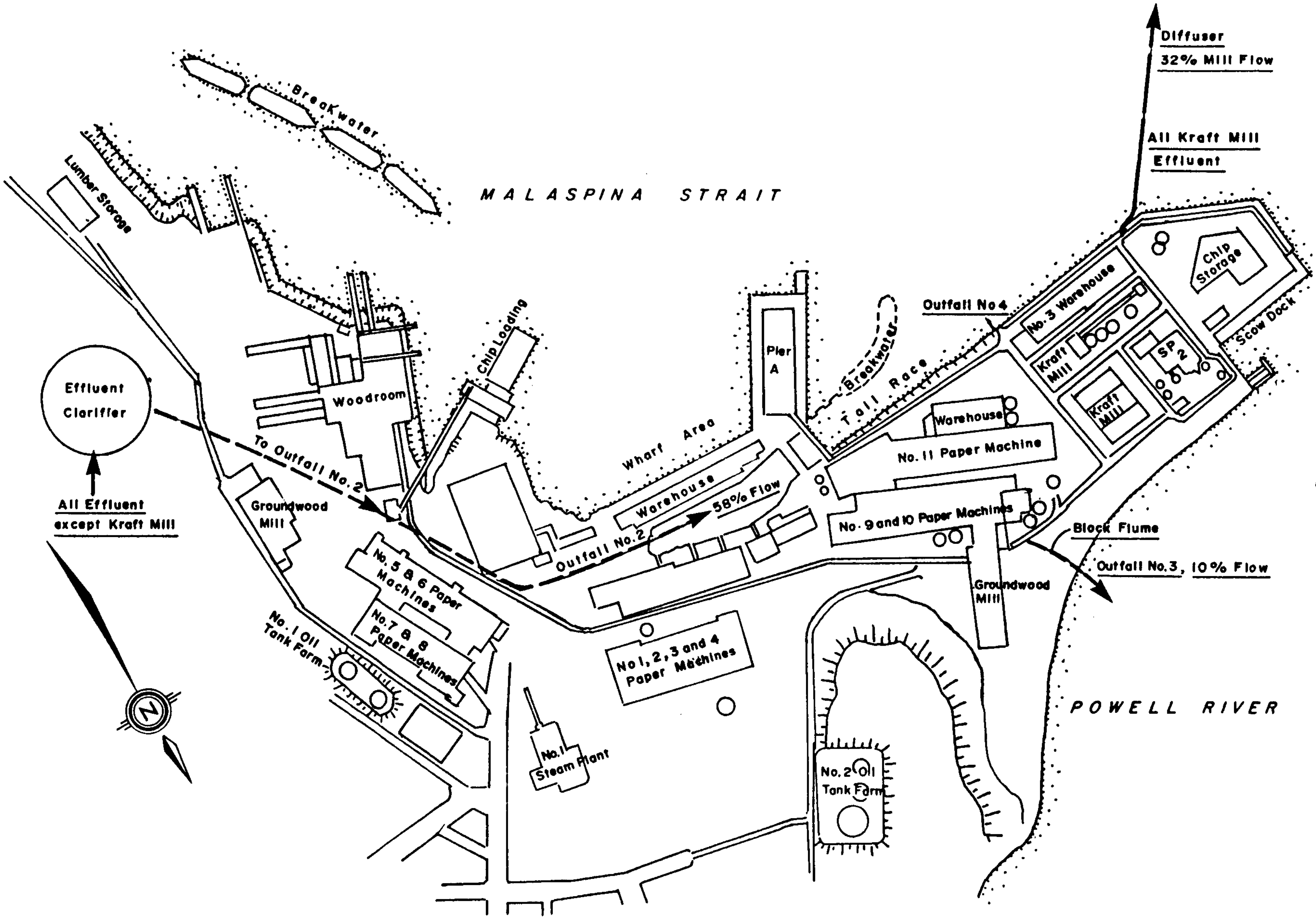


FIGURE 2 POWELL RIVER PULP MILL

Surface currents tended to disperse mill effluent towards the NW on a rising tide, and in a southerly direction on a falling tide (Figure 3), hence greater changes in water quality were noted in regions with higher effluent concentration.

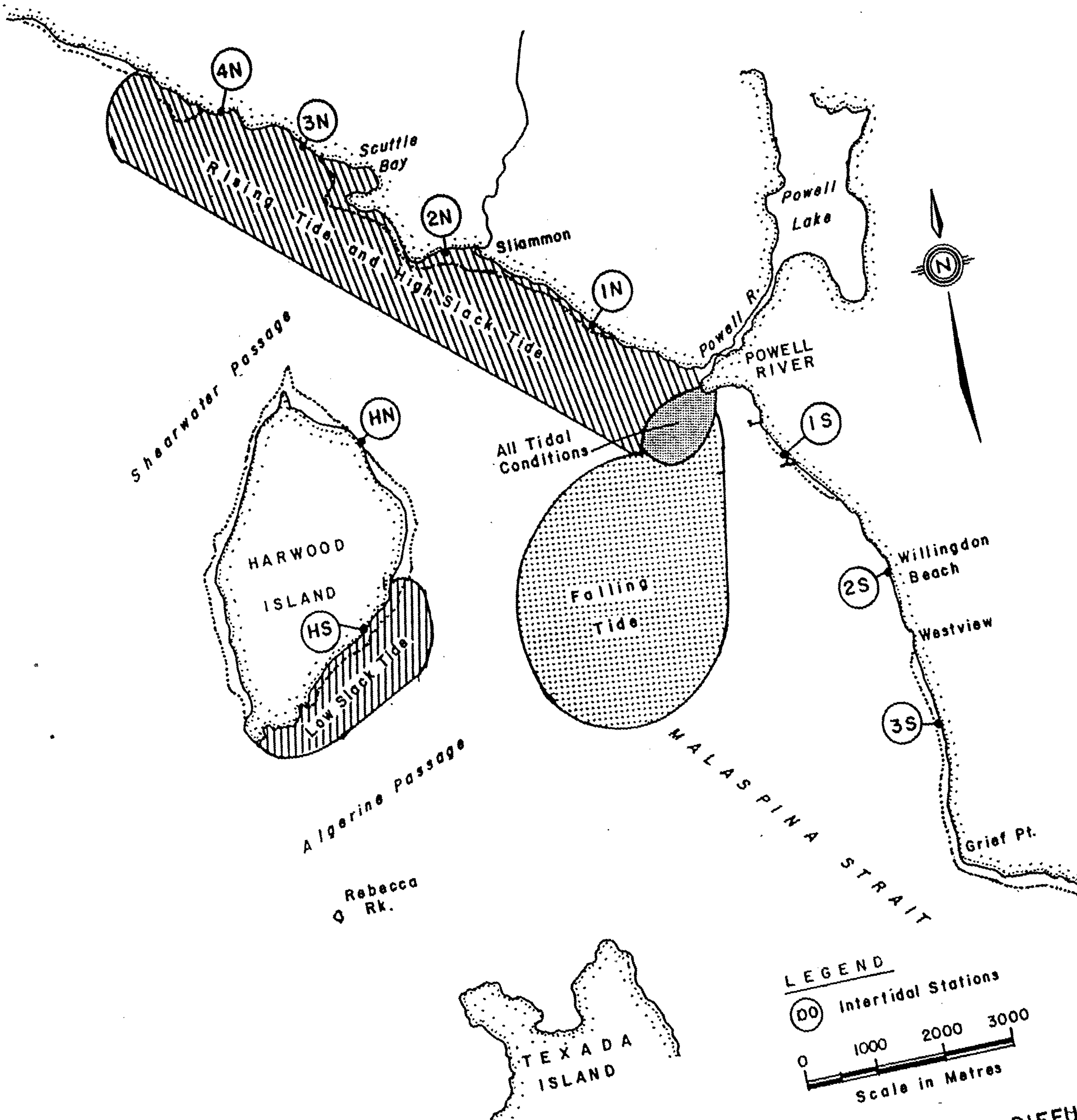
In general the diffuser has improved the quality of the surface water layers (Sullivan 1982) and has reduced complaints about foam on the beaches and discoloured waters, received by local Fisheries Officers (N. Armstrong, pers. comm.).

Ebb and flood currents measured in the vicinity of the diffuser at 35 m depth (plume trapping depth) were 35 cm/s and 20 cm/s respectively (Gillie and Daniel 1981). The same study determined that the net flow at 35 m is 2.2 cm/s toward the southeast (135 degrees true) while the net surface flow (at 3 m) is 2.5 cm/s north (2 degrees true). Therefore, the net movement of effluent should be through Malaspina Strait.

1.3.4 Intertidal Impact Intertidal impact (invertebrate and algal species reductions) was also more evident NW of the mill compared to south-eastern sites (Young 1977 *inter alia*, in Nelson 1979). The intertidal impact of the mill extended NW along the coast for a distance of about 6.5 km (Melville 1973). More recent observations by Young (1980) did not reveal any spatial trends with intertidal biomass or diversity due to mill influence. Natural environmental factors such as temperature, dessication and rock abrasion were cited as natural limiting factors masking any mill influence. Hence little recovery was noted after the commissioning of the diffuser in August 1980 (Young 1981).

1.4 Bioassay Data

Bioassays using herring eggs and larvae (*Clupea harengus pallasi*) were conducted by E.V.S. Consultants Ltd., in order to assess the effectiveness of the diffuser in providing sufficient dilution of effluent to protect marine fish species (Reid and McGreer 1982). Concentrations typical of *in situ* effluent dilutions (200:1; = 0.025 Toxic Units) did not significantly affect herring egg hatchability, survival or larval growth. However, at higher concentrations (0.01-0.05 T.U.), larval growth was less, and at 0.1-1.0 T.U. all larvae died within 96 h.



EFFLUENT DISPERSAL PATTERNS BEFORE DIFFUS
1977 as modified from Constantino 1973)

Table 1 lists bioassay data from the Powell River mill for the period 1980-1986 (from Kay 1986). The mill has routinely been able to meet the British Columbia Ministry of Environment and Parks (BCMOEP) objective of 96h LC50 of 34%, although in recent years only 75% compliance with the objective was achieved.

TABLE 1. Bioassay Data from MacMillan Bloedel Powell River Mill. (modified from Kay 1986).

YEAR	96 h LC 50 (% vol effluent)	Pass/Fail (P/F)
1975	30	1P
1976	65	6F
1977	65	1P/6F
1978	no record	no record
1979	30	no record
1980	30	2P
1981	34	3P
1982	34	4P
1983	34	4P
1984	34	3P
1985	34	3P/1F
1986	34	3P/1F

2.0 MATERIALS AND METHODS

Sampling in Malapsina Strait was done from the DFO oceanographic vessel, C.S.S. Vector, on 18 Nov 83 at stations shown in Figures 4 and 5. Stations were located using ship's LORAN-C and radar. Station positions are described in Appendix I. Table 2 summarizes water quality and sediment parameters sampled. Techniques are summarized in Table 3. Lab analyses were done at the EP/DFO West Vancouver laboratory.

2.1 Water Samples

Water samples were taken at discrete depths using polypropylene NIO bottles and standard oceanographic techniques. Conductivity, temperature, depth (CTD) profiles were taken using a Plessy Intruments Model 9400 CTD sensor as described by Goyette and Macleod (1984).

2.1.2 Analytical Procedures - Water Oxygen concentrations were determined in the ship's lab using the azide modification of the Winkler method. The equations of Gameson and Robertson (1955) were used in the calculation of dissolved oxygen saturation. Nutrient samples were immediately frozen after collection (Strickland and Parsons 1971), then analyzed using an automated colorimeter (Technicon Auto-analyzer II). Tri-stimulus colour values of previously frozen samples were determined spectrophotometrically in the lab. Sulfides in water were determined with a sulfide-ion electrode, after preservation on-board with zinc acetate and sodium bicarbonate. For non-filterable residue (NFR) analysis, water was filtered on-board using pre-weighed standard glass fibre filters. The filters were then stored frozen prior to analysis in the lab. PCB samples were placed in hexane-washed heat-treated glass jars and stored in a cooler before analysis.

2.2 Sediment Samples

Sediment grabs were taken at the stations depicted in Figure 6 using a stainless steel 0.1 sq. m Smith-MacIntyre grab. The surficial (2 cm) sediment layer was collected using a plastic scoop, avoiding the sediment near the sides of the grab. Samples for trace metal analysis, volatile residue and particle size were placed in paper sediment bags inside plastic bags and immediately frozen. Sediments for PCB and resin acid analysis were collected with a metal spoon, placed in heat-treated glass jars, and stored in a cooler prior to analysis.

Frozen sediment samples were analysed by the EPS/DFO West Vancouver Laboratory for trace metals according to the procedures described by Swingle and Davidson (1979). PCB's were analyzed using electron capture gas liquid chromatography. Resin acids were also determined using gas liquid chromatography.

TABLE 2. WATER QUALITY AND BENTHIC SAMPLING STATIONS: TYPES OF SAMPLES TAKEN (refer to Figures 4 & 5).

SEDIMENT SAMPLES

STATION	DEPTH	PS/SVR/TM	RESIN ACIDS
B-1	215	X	X
B-4	236	X	X
B-5	163	X	X
B-6	190	X	X
B-7	78	X	X
B-8	90	X	X
B-9	133	X	X
B-10	80	X	X
B-11	114	X	X

PS Particle Size
SVR Sediment Volatile Residue
TM Trace Metals

WATER QUALITY SAMPLING

STATION	CTD	D.O.	NFR	SULPHIDE	COLOUR	NUTS	PCB
W-7	X	X	X	X	X	X	
W-1	X	X	X	X	X		
W-8	X	X	X	X			
W-6	X	X	X	X	X	X	X
W-5	X	X					
W-4	X						
W-2	X	X	X				
W-12	X	X	X				
W-3	X	X	X				

CTD Conductivity, Temperature, Depth Profiles
D.O. Dissolved Oxygen
NFR Non-filterable Residue
NUTS Nutrients: phosphates, nitrates, ammonia
PCB Polychlorinated Biphenyls

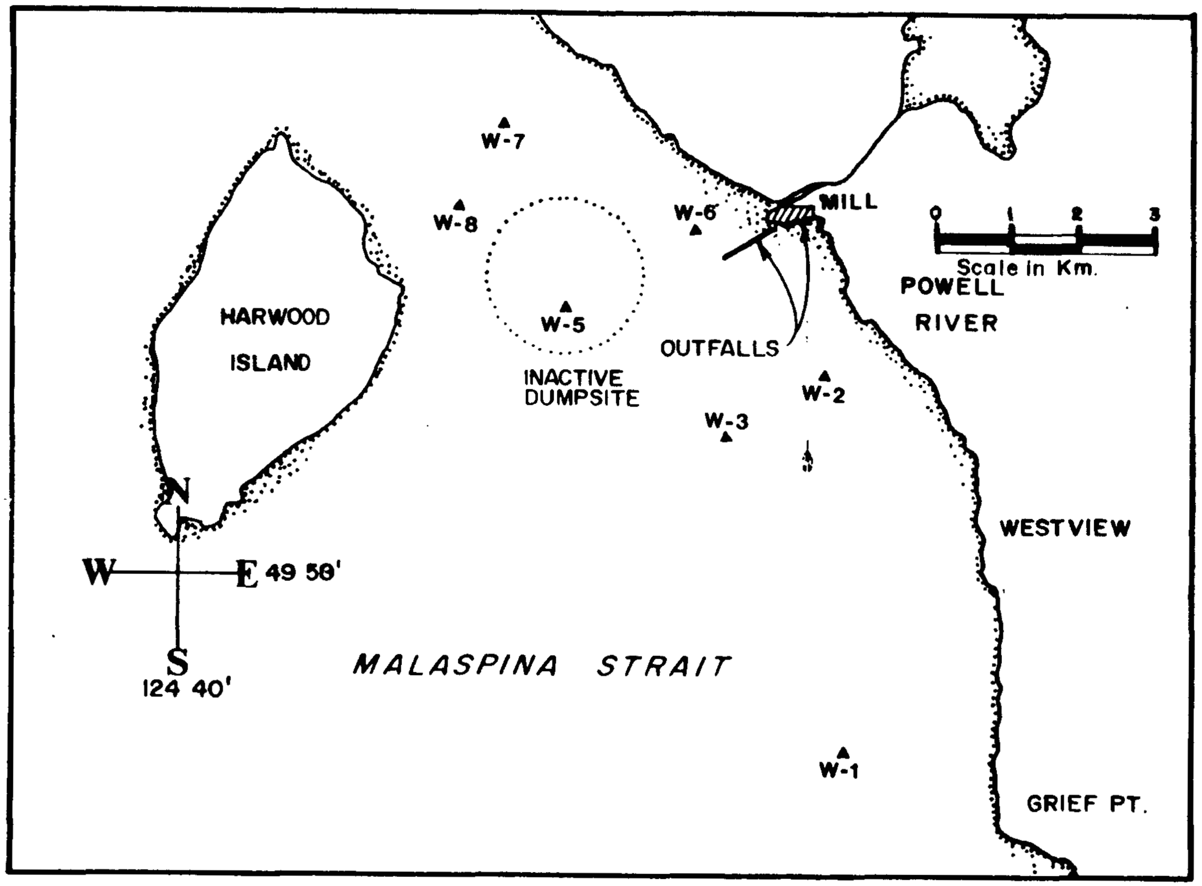


FIGURE 4 WATER SAMPLING STATION LOCATIONS 18 NOV 83

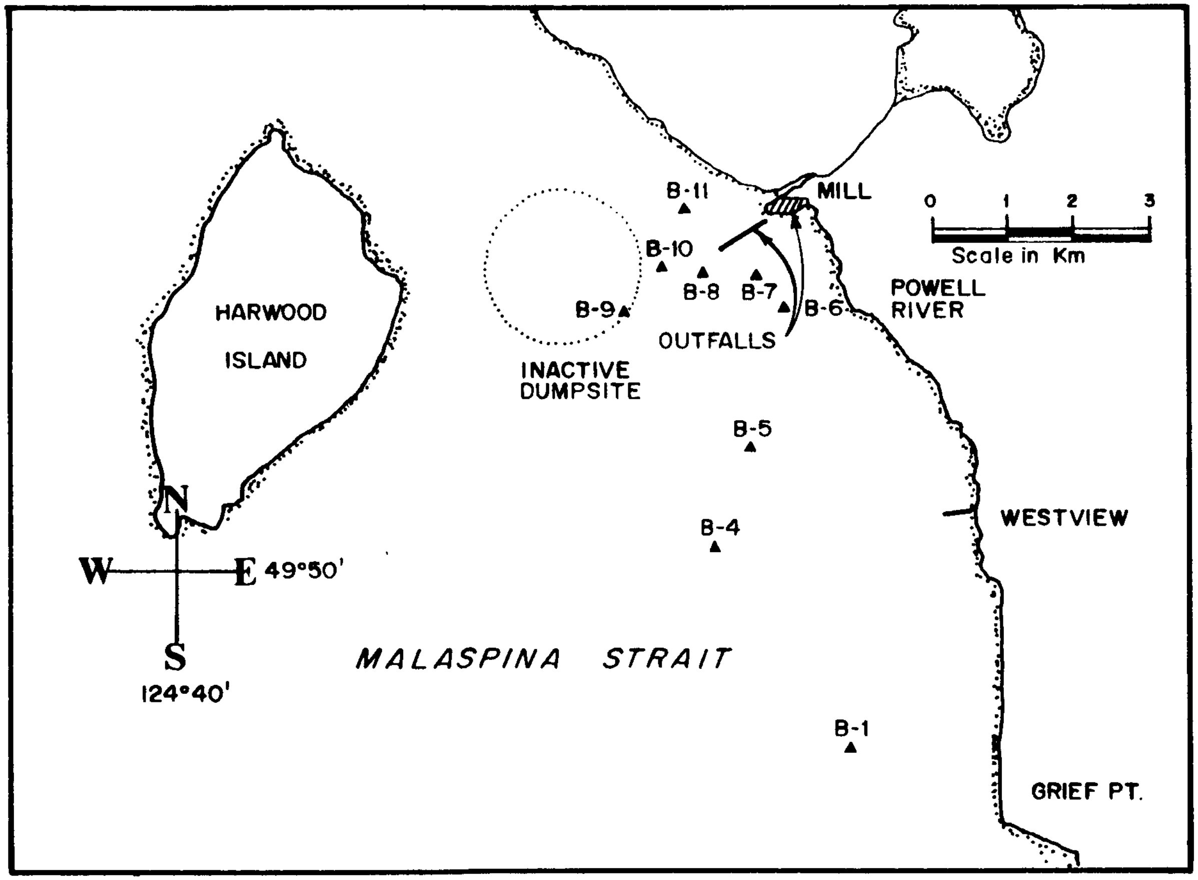


FIGURE 5 SEDIMENT SAMPLING STATION LOCATIONS 18 NOV 83

TABLE 3. SUMMARY OF EP METHODS FOR WATER AND SEDIMENT ANALYSES

PARAMETERS	METHODS	REFERENCES*
WATER		
SALINITY, TEMP., DEPTH	C.T.D.	GOYETTE AND MACLEOD 1984
DISSOLVED OXYGEN	AZIDE MODIFICATION OF WINKLER	SWINGLE AND DAVIDSON 1979
COLOUR	SPECTROPHOTOMETER	SWINGLE AND DAVIDSON 1979
NON-FILTERABLE RESIDUE	WEIGHING ELECTRONIC BALANCE	SWINGLE AND DAVIDSON 1979
NUTRIENTS	AUTOMATED COLORIMETER	SWINGLE AND DAVIDSON 1979 STRICKLAND AND PARSONS 1971
SULPHIDES	SULFIDE-ION ELECTRODE	SWINGLE AND DAVIDSON 1979
P.C.B.	GAS LIQUID CHROMATOGRAPHY	SWINGLE AND DAVIDSON 1979
SEDIMENT		
PARTICLE SIZE	FREEZE-DRYING, SCREENING	SWINGLE AND DAVIDSON 1979
TRACE METALS	OPTICAL EMMISION SPECTROMETER	SWINGLE AND DAVIDSON 1979
VOLATILE RESIDUE	WT. LOSS ON IGNITION 550 C FOR 1 HR.	SWINGLE AND DAVIDSON 1979
P.C.B.	GAS LIQUID CHROMATOGRAPHY	SWINGLE AND DAVIDSON 1979
RESIN ACIDS	GAS LIQUID CHROMATOGRAPHY	SWINGLE AND DAVIDSON 1979

* SEE ALSO COLODEY 1987

3.0 RESULTS AND DISCUSSION

3.1 Water Quality

Six stations were sampled in Malaspina Strait in the vicinity of the mill outfall, and one at a reference location off Grief Point (Figure 5).

EP data collected 18 Nov 83 indicate only a minor influence of the mill effluent upon the dissolved oxygen saturation (DOSAT) of the water column (Table 4). Above 50 m, water quality at all stations was consistantly above 90 % saturation (8.5 - 9.0 mg/L). Below 50 m D.O. decreased to a median concentration of 51% saturation (4.7 mg/L) when all stations are considered. Similar patterns of DO concentrations were found in November 1979 (Sullivan 1980).

Colour was not elevated at any station, indicating that the effluent was well-dispersed. Non-filterable residue did not exhibit any consistent pattern throughout the area sampled, although maxima at 20 m and 10 m were noted at stations W-3 and W-8. Nutrients (phosphates, nitrates, ammonia) were all at low concentrations throughout the area sampled (Table 5). PCB's were not detected in samples near the outfall (W-6).

3.1.1 Water Quality Monitoring Recommendations

Mill effluent is generally trapped, as a 5-15 m layer, centered at a mean depth of 35 m. It is also well diluted (>500:1 outside Initial Dilution Zone of 100 m) according to dye studies conducted in Feb.-March 1981 (Gillie and Daniel 1981). Stations in the present study were not located sufficiently close to the outfall to detect the zone of influence, hence new station locations should be selected prior to further water sampling. Appendix 2 shows six locations which should be considered as future sampling sites. They were selected based on current patterns in the vicinity of the diffuser as determined by Gillie and Daniel (1981). The reference location for the mill outfall can continue to be off Grief Point.

Any future effluent dilution studies should delineate the 1:6000 dilution boundary in Malaspina Strait. Sublethal effects were predicted to occur up to this dilution in Sweden (see Section 3.5.1: Potential Zone of Predicted Impact of Chlorinated Organic Compounds). Chloroform has been

TABLE 4. DISSOLVED OXYGEN, COLOUR AND NFR DATA FROM MALASPINA STRAIT 18 NOV 83.

STATION	DEPTH m	SALINITY ppt	TEMP C	D.O. mg/L	SATURATION %	COLOUR ADMI #	NFR mg/L
W-2	0	15.862	8.50	9.2	89	--	12
	5	25.588	9.52	9.2	97	--	11
	10	25.931	9.61	8.2	87	--	12
	20	26.434	9.59	8.7	93	--	12
	50	29.933	9.61	4.7	51	--	12
	75	30.422	9.86	4.7	52	--	12
W-6	0	16.504	9.38	9.3	92	5	9
	5	25.608	9.52	9.3	98	--	12
	10	25.628	9.55	9.0	95	5	15
	20	26.129	9.58	9.0	96	5	13
	50	29.695	9.63	4.1	45	5	16
	77	30.327	9.83	5.2	57		13
W-5	0	18.689	9.22	9.1	91	--	--
	5	25.682	9.55	9.0	95	--	--
	10	25.820	9.54	8.9	94	--	--
	20	26.569	9.59	4.9	52	--	--
	50	29.683	9.61	5.6	61	--	--
	100	30.517	9.93	4.1	45	--	--
	150	30.565	9.42	5.2	57	--	--
W-3	0	23.560	9.25	9.4	97	--	10
	5	25.538	9.54	9.2	97	--	11
	10	25.633	9.55	9.0	95	--	16
	20	26.659	9.60	9.1	97	--	19
	50	29.616	9.63	8.0	87	--	17
	100	30.550	9.98	4.5	50	--	17
	150	30.610	9.41	4.1	45	--	15
W-7	0	24.876	9.58	9.4	99	9	9
	5	25.678	9.54	9.3	98	10	10
	10	25.766	9.56	9.5	101	5	11
	20	26.145	9.54	9.0	95	6	11
	50	29.466	9.65	5.4	59	9	13
	62	30.161	9.68	4.5	49	--	--
W-8	0	25.340	9.47	9.2	97	--	12
	5	25.755	9.58	9.3	98	--	15
	10	25.807	9.56	8.9	94	--	37
	20	26.358	9.56	8.8	94	--	11
	50	29.611	9.65	6.8	74	--	12
	100	30.534	9.79	4.2	46	--	11
	120	30.559	9.63	---	9	--	--

STATION	DEPTH m	SALINITY ppt	TEMP C	D.O. mg/L	SATURATION %	COLOUR ADMI #	NFR mg/L
REFERENCE SITE							
W-1	0	25.450	9.49	9.0	95	--	13
	5	25.520	9.53	9.2	97	5	12
	10	25.868	9.56	8.9	94	8	11
	20	26.669	9.61	9.0	96	6	12
	50	29.104	9.68	6.5	71	5	12
	100	30.506	9.70	4.5	49	5	14

Table 6. NUTRIENTS, SULPHIDE AND PCB SAMPLES COLLECTED 18 NOV 83

STATIONS

NUTRIENTS
mg/L

DEPTH (m)	W-6 O-PO4	W-7 OPO4	W-6 T-PO4	W-7 T-PO4	W-6 NO3	W-7 NO3	W-6 NO4	W-7 NO4	W-6 NH3	W-7 NH3
0	.037	.040	.059	.063	.008	.009	.28	.28	.017	.017
5	.046	.050	.068	.065	.009	.009	.30	.31	.016	.018
10	.0.42	.063	.069	.066	.009	.009	.32	.31	.016	.018
20	.044	.061	.0090	.065	.009	.009	.32	.31	.015	.018
50	.072	.072	.090	.081	<.005	.005	.41	.40	.013	.013
77/62	.085	.076	.090	.094	<.005	<.005	.43	.44	.013	.012

SULPHIDE
mg/L

DEPTH (m)	W-1*	W-6	W-7
0	<0.05	<0.05	<0.05
5	<0.05	<0.05	<0.05
10	<0.05	<0.05	<0.05
20	<0.05	<0.05	<0.05
50	<0.05	<0.05	<0.05
100	<0.05		
150	<0.05		
180	<0.05		

PCB
mg/L

DEPTH (m)	W-6
0	<0.05
10	<0.05
50	<0.05

* Reference Site

proven to be a valuable stable effluent tracer compound (Xie et al. 1986, A. Kringstad, pers. comm.) which could be used to evaluate the dispersion of local effluents, particularly at mills with a hypochlorite bleaching stage.

Near-bottom water quality should also be sampled for increases in ammonia (Pearson 1980) and organic contaminants such as chlorophenols which were recently found in the sediments and the effluent (B. Moore, BCMOEP pers. comm.).

3.2 Sediment and Benthic Quality

Sediment samples were collected from nine sites in Malaspina Strait for particle size, trace metal levels, sediment volatile residue, resin acids, and PCB analyses (Table 6). Sediments ranged from very fine sand at some of the deeper stations to granules at station B-7. Percent Silt and Clay was highest at the control site B-1, one of the deeper stations.

As expected, sediment volatile residue was highest at stations nearest the outfalls (Figures 6 & 7). PCBs and resin acids were undetectable at all sites sampled. Station B-6 had maximum levels of all metals except cadmium which was maximal at the adjacent station B-7 (Table 6).

Of all sediment parameters, only sediment volatile residue (Figure 7) was above the AET level (Apparent Effect Threshold; Tetra Tech 1986). The AET level is the contaminant concentration which always produces a depression in benthic species composition. It should be noted that the AET level is the least sensitive sediment criteria level for the benthos, because it indicates the level at which damage always occured in Puget Sound communities. The PET (Potential Effects Threshold) level is more sensitive. It is the level above which some biological damage can occur, and below which no toxicity was ever noted in the Tetra Tech study. In the present study for example, the PET level for lead (11 mg/kg) is exceeded in 2 instances (Figure 8), hence damage to benthic invertebrates could be resulting from high lead levels at B-6 and B-7. Station B-6 also had elevated levels of zinc, chromium, copper and nickel (Figure 8).

According to AET criteria, benthic infaunal species would be significantly altered at stations B-7, B-8, and B-9 due to the increase in sediment volatile residues associated with the mill outfall (Figure 7).

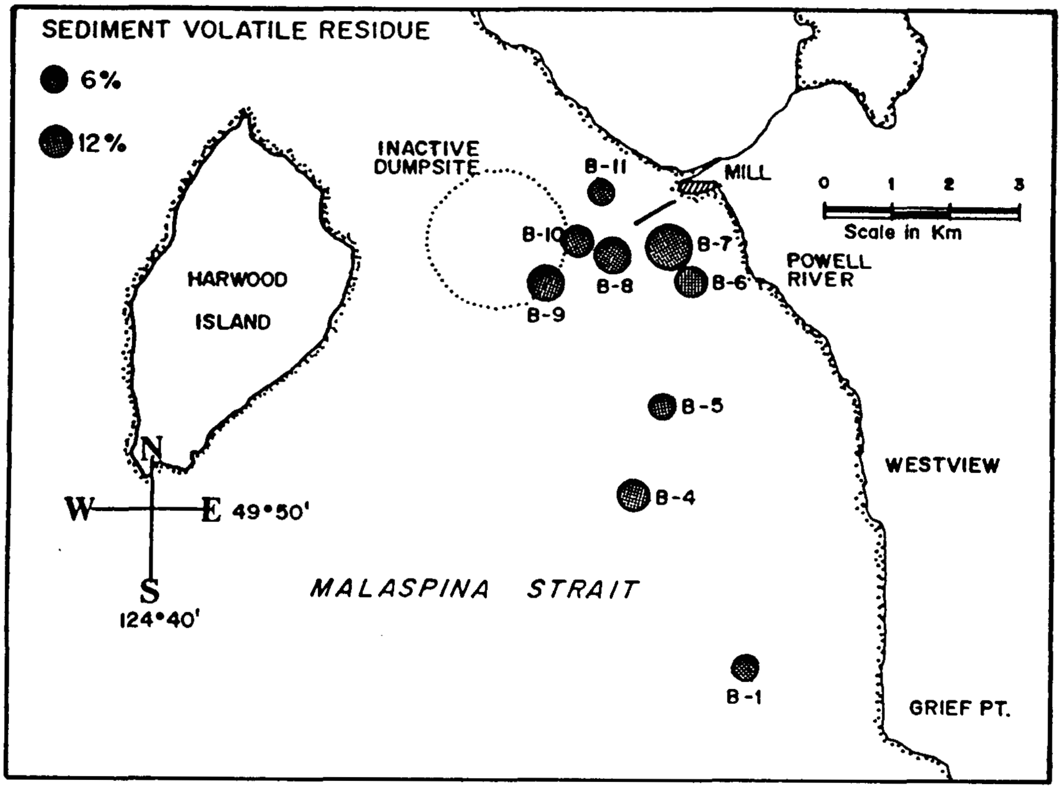


FIGURE 6 SEDIMENT VOLATILE RESIDUE AT VARIOUS LOCATIONS - POWELL RIVER. NOVEMBER 1983

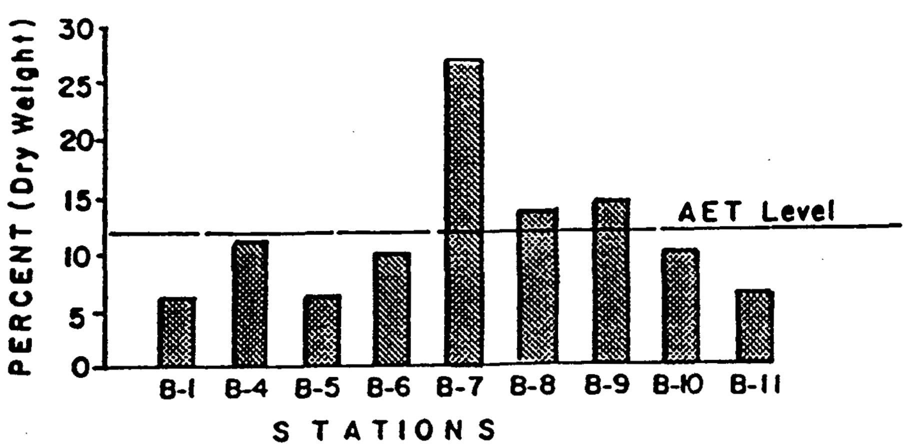


FIGURE 7 SEDIMENT VOLATILE RESIDUE AT POWELL RIVER - NOVEMBER 1983

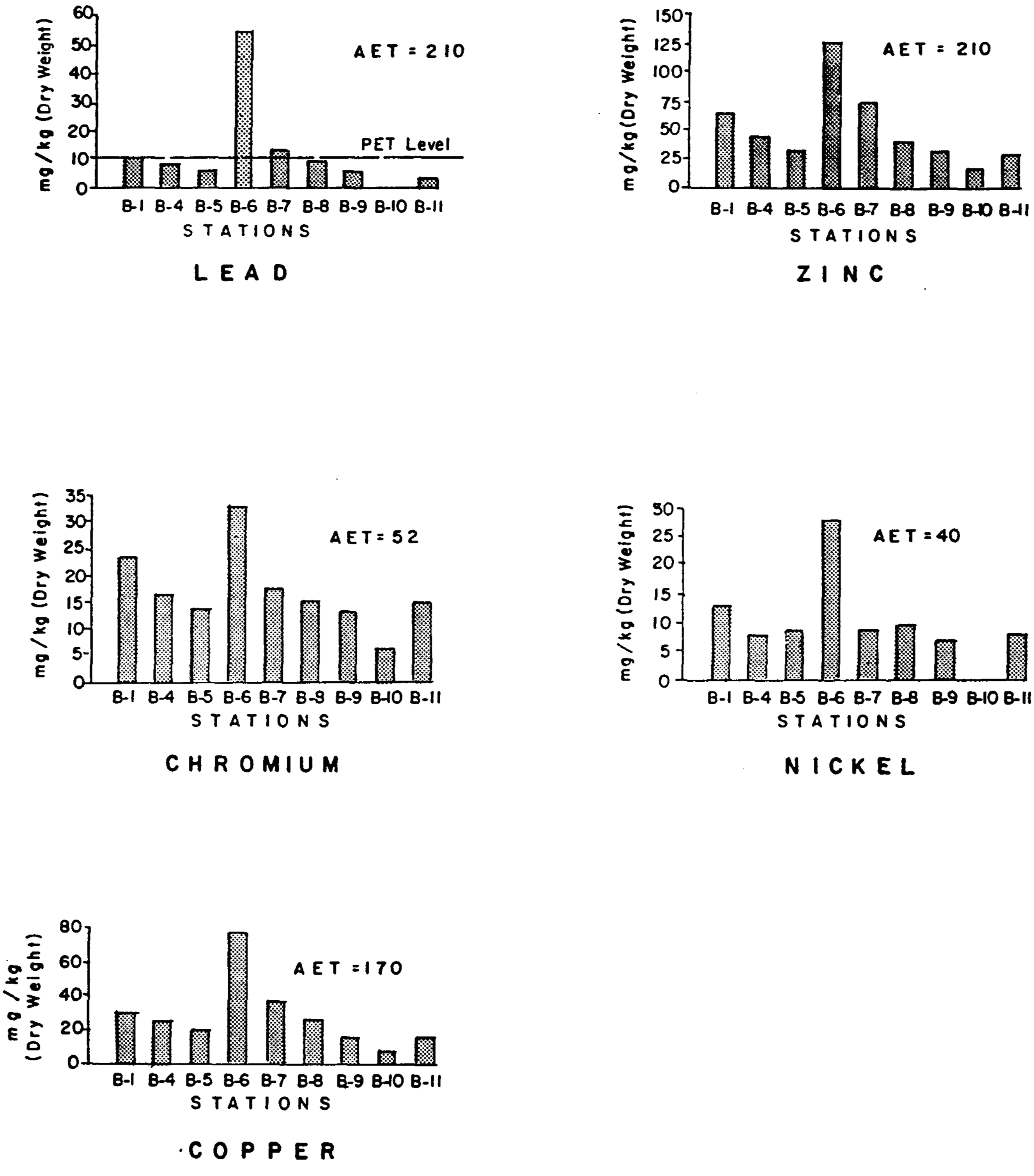


FIGURE 8 SEDIMENT TRACE METAL LEVELS AT POWELL RIVER - NOVEMBER 1983

Such biological changes associated with organic loading from a pulp mill have been well-documented by Pearson and Rosenberg (1976). Species diversity, abundance and biomass, as well as trophic structure of benthic communities changed in response to high organic carbon (cellulose) inputs. Other ecosystem changes due to organic deposits from a pulp mill were further reviewed by Pearson (1980). In some instances changes in near-bottom water quality have been identified, mainly decreases in D.O. and increases in ammonia and phosphate which diffused from the sediments into the water column. Similar changes in interstitial water, including increases in sulphides, were noted by Duff (1981).

High sediment volatile residues at Station B-9 may be due to historical ocean dumping activities as previously noted in Section 1.1.

3.2.1 Observations from Pisces IV Submersible Figure 9 delineates the approximate area of benthic impact determined by direct observations from the PISCES IV submersible near the outfall in April 1987 (Appendix II). Wood fibres and bacterial growth were seen to cover an area extending 1 km west and at least 300 m east of the outfall. Although distribution of the fibre-bacterial mat is patchy in some areas, general trends were evident: rockfish (Sebastes spp.) and sole (Pleuronectidae) were less abundant in areas with more wood fibre and bacterial mat, whereas ratfish were more abundant in these more impacted areas. Prawns (Pandalus platyceros) and shrimp (Pandalus sp.) were seen in areas with boulders, logs or other suitable "cover" habitat.

Similar organic deposits (and bacterial growth) have been described near many other B.C. marine mills like Crofton (Colodey 1987), Harmac (Ellis and Ostrovsky 1983), Woodfibre, Prince Rupert, Ocean Falls (Pomeroy 1983), Gold River (Petrie and Holman 1983), Port Alberni (Sullivan 1982) and Port Alice (Goyette, pers. comm.).

3.2.2 Trends in Sediment Trace Metal Data: 1979-1983 Data from five stations were examined for trends in selected trace metal results. Only those metals and stations sampled more than once could be analysed (Table 7).

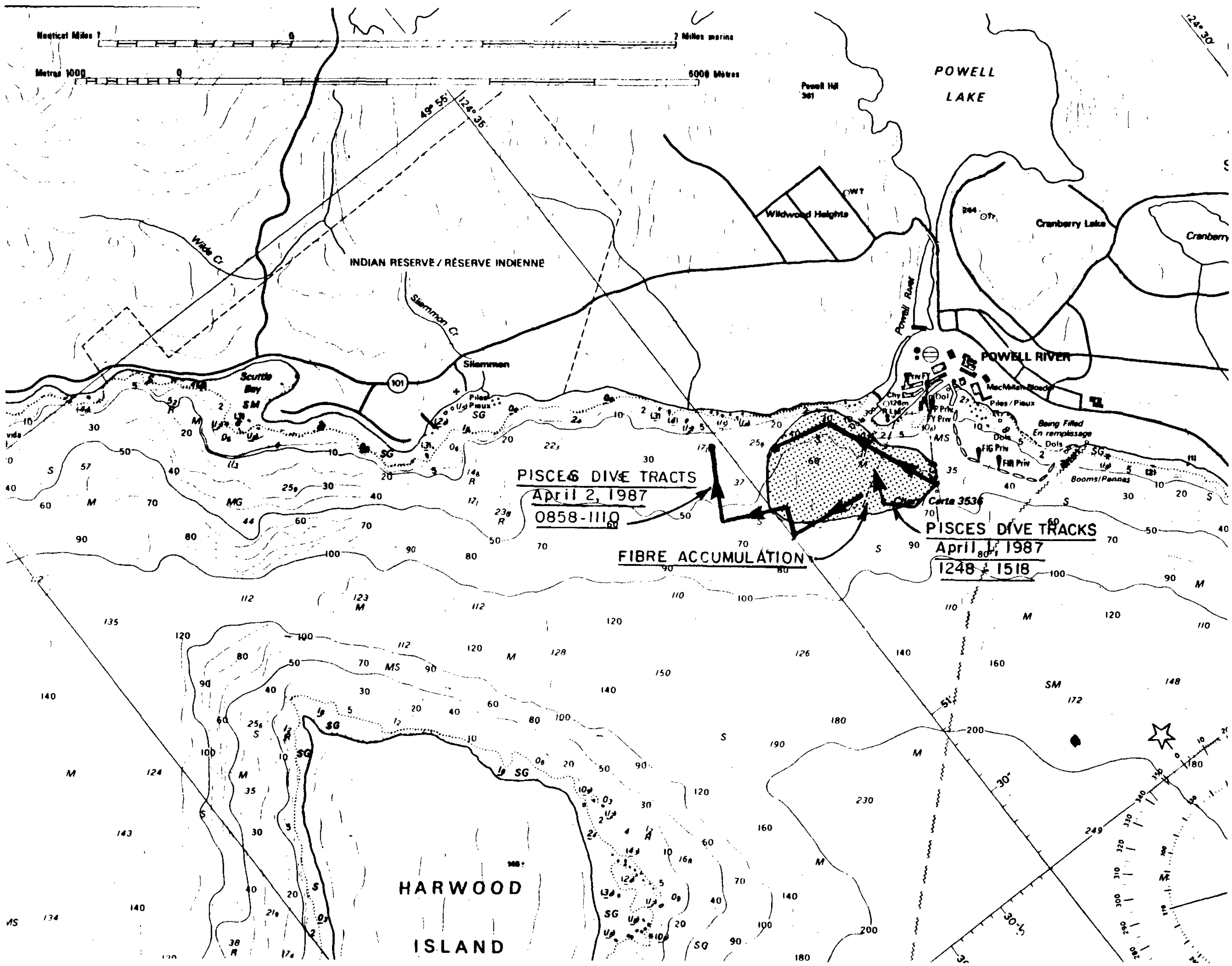


FIGURE 9 PISCES DIVE TRACKS, POWELL RIVER - APRIL 1-2,1987 SHOWING AREA OF FIBRE ACCUMULATION

TABLE 6. SEDIMENT DESCRIPTION, PARTICLE SIZE, VOLATILE RESIDUE, PCB, RESIN ACID AND TRACE METAL DATA COLLECTED 18 NOV 83.

STATION	DEPTH (m)	MEDIAN PARTICLE SIZE	SILT & CLAY (%)	SVR (%)	PCB mg/kg dry wt.	RA mg/kg dry wt.	Al (%)	Fe (%)	Cd mg/kg dry wt.	Cr	Cu	Ni	Pb	Zn
B-1	203	very fine sand	20.3	6.38	<0.02	<0.02	1.16	1.80	.30	23.3	31.2	13	11	64.4
B-4	236	fine sand	9.3	11.30	--	<0.02	.89	1.26	<0.3	16.3	26.2	8	8	44.2
B-5	190	very fine sand	13.7	6.39	<0.02	<0.02	.76	1.00	<0.3	13.6	19.9	9	6	32.6
B-6	163	medium sand	3.1	10.10	<0.02	<0.02	1.75	2.31	.70	32.5	77.4	28	54	126.0
B-7	78	very coarse sand	8.8	27.30	<0.02	<0.02	.73	.96	1.40	17.2	37.2	9	13	72.3
B-8	90	fine sand	4.1	13.80	--	<0.02	.81	1.20	.30	14.9	26.5	10	10	40.0
B-9	133	granules	4.0	14.70	<0.02	<0.02	.73	1.06	<0.3	13.1	16.5	7	6	30.4
B-10	80	very fine sand	6.1	10.20	<0.02	<0.02	.56	.52	<0.3	6.3	7.6	<3	<3	16.3
B-11	114	fine sand	6.6	6.50	--	<0.02	.87	1.35	<0.3	14.3	16.8	8	4	29.2
BENTHIC AET LEVELS* (TETRA TECH 1986)			>96	12.00	480	----	----	3.40	3.40	52.0	170	40	210	210

* statistically significant depressions in benthic infauna would always be expected at these concentrations

SVR Sediment Volatie Residue
PCB Polychlorinated Biphenyls
RA Resin Acids
___ Underscored values indicate maxima

DESCRIPTIONS OF SEDIMENTS COLLECTED

B-1 -grey/green mud with worm tubes
B-4 -grey/green mud with maldanid polychaetes
B-5 -grey/green mud with many very small stick-like worm tubes on surface
B-6 -grey/green mud with many small and large polychaetes
B-7 -grey/green mud worm tubes and amphipods, wood fibres chip size
B-8 -grey/green mud worm tubes and amphipods
B-9 -grey/green mud worm tubes and amphipods
B-10 -coarse grey mud, crinoids, amphipods, polychaetes, wood debris
B-11 -grey mud, wood debris/bark, polychaetes amphipods and ophiuroids

Table 7. Trends in Sediment Trace Metal Levels: 1979-1983.

	79	81	83	TREND
	MS-20	---	B-1	
CD	1.23	---	0	NT
CR	40	---	23	D
CU	85	---	31	D
NI	41	---	13	D
PB	21	---	11	D
ZN	186	---	64	D

	79	81	83	TREND
	MS-4	MS-4	B-4	
CD	1.23	0.66	0.3	NT
CR	16	---	16	NT
CU	26	21	26	NT
NI	11	---	8	D
PB	9.88	7	8	NT
ZN	38	37	44	I

	79	81	83	
	MS-10	MS-10	B-9	
CD	1.2	.8	0.3	D
CR	8	---	13	I
CU	8	20	17	I
NI	10	---	7	D
PB	9.78	13	6	NT
ZN	17	39	30	I

	79	81	83	
	MS-7	MS-7	B-6	
CD	2.5	7.2	.7	D
CR	25	---	33	I
CU	189	97	77	D
NI	19	---	28	I
PB	73	29	54	D
ZN	338	292	126	D

	79	81	83	
	MS-9	MS-9	B-11	
CD	1.22	4.86	0.3	NT
CR	15	---	14	NT
CU	24	72	17	D
NI	9.78	---	8	NT
PB	9.78	23	4	NT
ZN	30	266	29	NT

NT	NO TREND
D	DECREASE
I	INCREASE

ELEMENT SUMMARY

ELEMENT	INCREASE	DECREASE	NO TREND
CD	0	2	3
CR	2	1	2
CU	1	3	1
NI	1	3	1
PB	0	2	3
ZN	2	2	1
TOTAL	6	13	11

STATION SUMMARY

STATION	INCREASE	DECREASE	NO TREND
B-1	0	5	1
B-4	1	1	4
B-6	2	4	0
B-9	3	2	1
B-11	0	1	5
TOTAL	6	13	11

The element summary (Table 7) indicates that most elements were decreasing, or that no trend was apparent. It can be seen from the totals that more elements decreased than increased and that no trends were determined in eleven instances.

Zinc increased slightly at B-9 and B-4 (to 30 and 44 mg/kg) but remained below levels found at the control site (B-1: 64 mg/kg). There was a dramatic linear decrease in Zinc noted at station B-6 (338 to 292 to 126 mg/kg). Chromium increased at B-9 and B-6 (to 13 and 33 mg/kg). This is somewhat above the B-1 reference location levels (23 mg/kg). Chromium increases near the Crofton pulp mill outfall have also been documented (Colodey 1987).

The station summary of trends (Table 7) indicates that station B-9 (former ocean dump site) accounted for most increases noted. Most of the decreased trends were from station B-1 and B-6. (It was previously noted in Section 3.2 that maximum values for most metals occurred at B-6).

In summary, most sediment metal concentrations declined and levels observed are well below those found to change benthic community structure (Tetra Tech 1986). Sediment toxicity is discussed in the following section.

3.2.3 Benthic Monitoring Recomendations and Research Needs The present sediment data collected by EP indicate the need for more intensive benthic sampling, in order to better define the zone of benthic impact, caused by the documented accumulation of organic (wood fibres, chips, bacterial growth) matter in the vicinity of the present diffuser and the historic discharge area for the mill. The BCMOEP (British Columbia Ministry of Environment and Parks) conducted sediment bioassays in Sept. 1987 and found that sediment in the vicinity of the outfall was toxic to clams *Macoma* sp. (B. Moore pers. comm.). Further sediment bioassays should be conducted by the mill in addition to benthic invertebrate sampling to delineate the zone of impact from the outfall on the benthic invertebrate community.

It is also recommended that a series of core stations be established by the mill in order to determine the depth of fibre, and spatial extent of the accumulations in the same manner as presently done by British Columbia Forest Products at Crofton.

EP monitoring should include sampling traditional sediment constituents like particle size, volatile residues, and trace metals, but concentrate on contaminants like resin acids, chlorophenols, and other chlorinated compounds. Monitoring should be at sites sampled for this report as well as sites allocated for mill core sampling.

The interaction between near bottom water quality (over fibre/bacteria areas) and macro-epibenthos (like shrimp/prawns and sole) should be studied, as results would be applicable at other coastal mill sites.

3.3 Intertidal Quality

As noted in the introduction, the intertidal zone was affected by the mill discharge before the diffuser was installed in 1980. On 23 Sept 87 an intertidal inspection was conducted by EP to evaluate the present intertidal conditions at established mill monitoring sites 1N, 2N, and 3N (Figure 3). The beach-walk survey indicated generally improved communities at all mill stations. Organisms not previously reported in mill monitoring reports, such as amphipods and littorinid snails were abundant. Mussels (*Mytilus edulis*) and rock weed (*Fucus* sp.) were relatively more abundant than in previous descriptions and photographs presented in mill monitoring reports.

3.3.1 Intertidal Monitoring Recommendations As previously noted (Sect.1.3.4) gross intertidal community alterations were noted in the vicinity of the mill prior to the installation of the diffuser. Widespread effects were previously found by Nelson and Goyette (1976) with regard to zinc contamination of oysters. Recent information from Sweden and the U.S.A. indicate that the chlorine bleach plant effluent can produce chlorinated organic compounds. (see Sect. 3.5). The zone of influence with regard to chlorinated organic compounds may be extensive. Since clams and oysters are harvested from the intertidal zone of the Malaspina Strait, samples of these organisms should be submitted for analysis of specific chlorine compounds, such as 3,4,5-trichloroguaiacol. Oysters should also be resampled to document present metal levels.

Beach-walk photographic surveys to generally assess the intertidal communities should also be periodically repeated.

3.4 Expanded Production

Table 8 lists production, BOD and TSS data for 1985-1986. Figure 10 shows the relative proportion of each process line as it relates to total mill production in 1986. Due to mill expansion, TSS and BOD loadings are both expected to increase. This increased loading will continue to degrade the benthic habitat in the vicinity of the mill diffuser as indicated in Figure 9.

The present mill expansion will increase the mill's newsprint production by about 90 ADT/D using a CTMP process. The main concerns with this process are toxicity due to resin acids or other unknown effluent constituents (L. Adamache, pers. comm.). Federal Pulp and Paper Liquid Effluent Regulations require that the discharge from such new facilities be non-toxic (ie. 96h LC 50 = 100%).

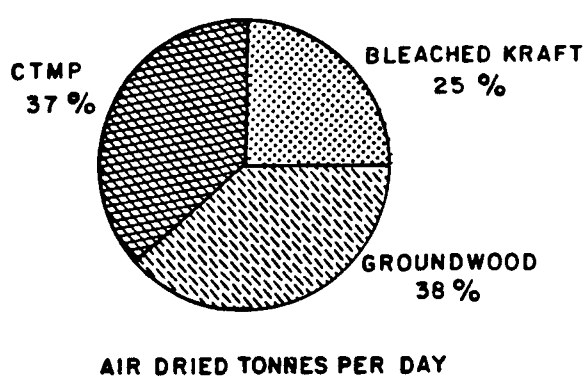


FIGURE 10 RELATIVE PROPORTION OF EACH MILL PROCESS LINE - POWELL RIVER 1986

Table 8. Powell River Production and Waste Loadings 1985-86.

PRODUCTION YEAR	ADT/D	DAYS	FLOW m3/d
1985	1683	340	259367
1986	1657	358	308566

TSS YEAR	KG/ADT	FED. LIMIT	% COMPLIANT n		LOADING T/D	PROV. LIMIT
1985	11.80	12.30	0	75	19.9	30.5
1986	12.61	12.30	12	58	20.9	30.5

BOD5 YEAR	KG/ADT	FED. LIMIT	% COMPLIANT n		LOADING T/D	PROV. LIMIT
1985	18.10	23	0	100	30.5	44.5
1986	19.04	23	11	82	31.5	44.5

TOXICITY YEAR	n	PROV LIMIT 96H LC50	% COMPLIANT
1985	4	34%	75
1986	4	34%	75

3.5 Chlorinated Organic Compounds

3.5.1 Chlorinated Compounds Recent research in Sweden has studied the link between organic chlorine compounds contained in chlorinated bleach plant effluents and their biological effects (Sodergren et al. 1987). The studies used both model ecosystem experiments and field sampling (Annergren et al. 1985).

In these studies, there was a clear linkage between the benthic sediment dynamics (erosional or depositional) and the concentrations of extractable organic chlorine (EOCL). Within 2 km of the discharge, the bottom sediments were covered with fibres and had high levels (1100 ug/g) of EOCL compounds. The identified fraction (chlorinated phenols, guaiacols, catechols and PCB) constituted only a minor portion (<1%) of the EOCL content of the sediment. Sundelin (1987) describes the impact of sediments from a bleached kraft mill as more toxic than sediments collected near an unbleached kraft mill.

The EOCL concentrations in fish tissue in Swedish studies, determined by neutron activation analysis (NAA), served as an indicator for exposure to mill effluents. Although more than 90% of the EOCL compounds remain unidentified, 3,4,5-triochloroguaiacol, chlorocatechols, chlorinated phenols, were identified. Toxaphene, PCB and DDTs, although not linked to mill effluents, were also identified.

EOCL concentrations in fish and gastropod tissues decreased along a gradient from the chlorine-bleached kraft mill outfall, and decreased in magnitude in conjunction with lowered chlorine consumption at the mill. Biological effects in fish, associated with the increased EOCL concentrations included:

- impaired liver function
- impaired immune defence
- impaired ion balance
- impaired reproduction
- skeletal deformities

Skeletal abnormalities were observed and associated with low (50 - 200 ug/L) concentrations of chloroveratrols, which are bacterially methylated guaiacols (Annergren et al. 1985). Increased parasitism and fin erosion in fish within 10 km of the outfall was also noted. Fish with pelagic larval stages (herring) had decreased recruitment within 8 km of the outfall. Contaminated sediments hampered the reproduction and survival of the benthic amphipod Pontoporeia affinis, and the survival of the clam Macoma balthica, and micro-crustaceans like harpacticoid copepods and ostrascods (Sodergren et al. 1987).

Swedish model ecosystem studies were conducted using the brown alga Fucus vesiculosus with adherent fauna, three-spined sticklebacks, and small flounders (Platichtys flesus). They were supplied with 5 types of bleached-kraft mill effluent concentrations equivalent to a flow-through dilution of 400 and 2000:1. The table on next page summarizes the results:

Dilution	Effects
1:166	lowest fry survival, increased parasitism of fish, decreased invertebrate abundance
1:330	low fry survival, parasitism high
1:1140	altered fry survival and parasitism rates
1:5910	effects predicted to exist at low levels

The addition of oxygen bleaching or aeration lagoons reduced the predicted area affected from >5000:1 to about 2000:1 dilution by reducing the amount of organically bound chlorine discharged.

3.5.2 MONITORING RECOMMENDATIONS: Although there is no direct data to indicate that biological effects of chlorinated compounds noted in Sweden, exist at Powell River, there is a need to clarify the present level of contamination by chlorinated compounds. Samples of resource species (prawns, shrimp, cod, crab, oysters, and clams) should be analysed for specific mill-generated chlorinated compounds like 3,4,5-trichloroguaiacol (345-TCG) to determine the potential zone of contamination. Other chlorinated compounds of mill origin have been correlated to 345-TCG including: tetrachloroguaiacol, 2,3,7,8-TCDD (dioxin) and 2,3,7,8-TCDF (furan) (Kirkegaard and Renberg 1987).

In addition to field studies to determine the zone of chlorinated organic contamination, long-term bioassays should be conducted to evaluate the lethal and sub-lethal effects of these effluent compounds on a variety of marine species. Data from Mehrle et al. (1988) indicates that a 28-day exposure phase followed by a 28-day depuration phase is necessary to fully describe the impact of 2,3,7,8-TCDD and 2,3,7,8-TCDF on rainbow trout fry. Delayed mortality of the fry were noted even at 38 pg/L (parts per quadrillion) 2,3,7,8-TCDD.

4.0 SUMMARY OF RESULTS AND RECOMMENDATIONS

1. FIBRE ACCUMULATION. The main identified impact of the mill at Powell River is to the benthic ecosystem. Observations in April 1987 indicate an extensive accumulation of woodfibres and bacterial growth. A regular coring program and a sediment toxicity program should be established in order to monitor changes in the size of the impacted area. Research on changes to near-bottom water-quality and it's influence on the health/abundance of epi-benthic organisms (shrimp, prawns, groundfish) should also be conducted.

2. WATER QUALITY. No change in water quality (due to effluent) was detected at the present water sampling locations. Therefore, water sampling stations should be re-located closer to the diffuser to better detect the presence of the effluent. Demarkation of 1:6000 dilution would be useful in interpreting future chronic sublethal bioassays using local B.C. species.

3. INTERTIDAL SAMPLING. Beach walk photographic surveys should continue on a periodic basis to monitor the continued improvement of the intertidal zone. Samples of clams, oysters and herring roe, should be submitted for metal and 3,4,5-TCG analysis and for histological examination.

4. ORGANIC CHLORINATED COMPOUNDS. Recent research in the USA (Amendola et al. 1987, USEPA 1987) and Sweden have identified a series of persistent, toxic compounds which are formed during the chlorine bleaching stage of pulpmills. These compounds cause a wide variety of sublethal effects in fish, even at low concentrations. The zone of influence from these compounds can extend for tens of kilometers from the outfall of the mill (Rappe et al. 1987). A study should be undertaken to determine if similar concentrations and effects occur in the Powell River area.

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APPENDIX I

SAMPLING STATION LOCATIONS
18 NOVEMBER 1983

APPENDIX I. SAMPLING STATION LOCATIONS 18 NOV 83.

BENTHIC STATIONS

	LATITUDE		LONGITUDE		
B-1	49	48.76	124	33.18	REFERENCE SITE
B-4	49	50.10	124	34.42	
B-5	49	50.78	124	34.10	
B-6	49	51.68	124	33.70	
B-7	49	51.98	124	34.05	
B-8	49	51.94	124	34.62	
B-9	49	51.70	124	35.50	
B-10	49	51.98	124	35.05	
B-11	49	52.38	124	34.85	

WATER SAMPLING STATIONS

	LATITUDE		LONGITUDE	
W-1	49	48.70	124	33.20
W-2	49	51.40	124	33.28
W-3	49	50.91	124	34.30
W-5	49	51.32	124	35.72
W-6	49	52.20	124	34.64

A P P E N D I X   I I

PROPOSED WATER SAMPLING STATION LOCATIONS
FOR FUTURE MONITORING

APPENDIX II. PROPOSED WATER SAMPLING STATION LOCATIONS FOR FUTURE MONITORING.

WATER SAMPLING STATIONS

	LATITUDE NORTH		LONGITUDE WEST		
D-1	49	52.59	124	34.68	
D-2	49	52.21	124	34.39	
D-3	49	52.29	124	34.10	
D-4	49	52.04	124	34.18	
D-5	49	52.21	124	33.86	
D-6	49	51.82	124	33.57	
W-1	49	48.76	124	33.18	REFERENCE SITE
W-7	49	52.90	124	37.40	

A P P E N D I X I I I

PISCES DIVE RECORDS

DIVE LOGS

April 1, 1987 A.M.

Dive 1390: Neil Holman and Drew Kilbach (observers)

Neil Holman is preparing the log comments for this dive.

April 1, 1987 P.M.

Dive 1391: Neil Holman and Al Colodey (observers)

TIME	
1248	Pisces leaves surface
	-66 m: on bottom, course 330: wood fibres, ratfish, rockfish, anemones on logs, lingcod
	-at diffuser port # 9, Dungeness crab and rockfish
	-course 150: abundant shrimp, ratfish, cumaceans, abundant wood fibres, no white bacterial mat, small juvenile sole, anemones
	-abundant prawns, wood fibres, wood chips
1313	-68 m: transition area from coarse wood fibres/chips becoming finer sediment, fewer shrimp more rock fish
1316	-71.5 m: more coarse wood fibres/chips/bark, ratfish, prawns
	-eelpout, ratfish, no shrimp, odd prawn
	-many squat lobsters barely visible on bark/fibre surface when sub. is < 1 m above substrate
	-72 m: finer sediments and more shrimp, eelpouts

1352 -37.6 m, course 313: patch of white matting (Beggiatoa), wood fibres, no rockfish, few shrimp or prawns, no rockfish

1401 -51.2 m: visibility < 1 m, fine sediment, abundant sole and rockfish, no fibres/chips (estimated position 400 m due east of the pipe); course now 320

-patch of Beggiatoa 30 m long: numerous perch, sole, ratfish

1430 -43 m: on top of pipe (Pender estimates our position 75 m from pipe)

-at diffuser port # 27, course 330, crossed over pipe, ling cod more abundant on west side of pipe, large boulders with anemones, fine sediment with coarse wood fibres, and bacterial mat in mounds, sole very abundant

1500 -27 m: course change to 310 to get deeper water and determine where mat ends or becomes discontinuous

1505 -continuous mat visibility >3 m, few fish in area

1510 -lights off visibility >10 m, blanket of white fibre/mat, odd sole

1517 -45 m fine sediment, discontinuous white patches, sediment more firm than in previous areas, few fish

1518 end of dive

April 2, 1987 A.M.

Dive 1392: Neil Holman and Al Colodey (observers)

0858 -Pisces on surface

0901 -2 m plankton quite thick

-16 m wood fibres and chunks visible in water column

-28 m: in brown effluent plume

-35 m: copepods, 55 m: large numbers of amphipods

0907 -73 m: on bottom just west of outfall, visibility 10 m, coarse wood fibres, ratfish, shrimp, clouds of mysids, occasional cumaceans

0915 -73.5 m: course 310, coarse wood fibres on sediments

0916 -coarse wood fibres present rockfish, ratfish, large pink shrimp, dogfish

-74 m: patch of *Beggiatoa*, coarse wood fibres

0918 -75 m: rockfish, midshipmen, large red rockfish sitting on bottom with drooping dorsal fin, numerous very small ratfish, pile perch

-3 small ratfish, eelpout, prawn, rockfish

-patch of *Beggiatoa*, coarse sediment, wood chips/fibres

-4 ratfish, Dungeness crab, 3 - 4 m visibility

0920 -76 m: sole, cod, midshipmen, anemones, pink shrimp

-eelpouts common, pink shrimp common, brittle stars and squat lobsters common, mysids common at 1 m above bottom

-large prawns under logs, anemones and snails (Polinices sp.)

0921 -75 m: bottom sediments relatively fine wood fibres, large ratfish, many large shrimp, squid present, mysids 1-2 m above bottom

0923 -76 m: cleaner sediment with less wood fibre, shrimp abundant, occasional medium to very small ratfish, small sole, large burrows in sediment, sidestripe shrimp

0926 -75 m: fine sediment, shrimp, ratfish, midshipmen, beer bottle

0935 -75 m: heading 350, > 5 m visibility, many shrimp (> 5/ m2), large prawn, Dungeness crab, rockfish, numerous squat lobsters, large holes in sediment

0937 -fine, clean sediment, orange-striped rock fish, shrimp less abundant, 30 cm potholes in sediment (likely from sole), fewer fish present

-very silty sediments, large reddish sea cucumber with large orange spikes, small ratfish

-course 000 heading north

0941 -73 m: south edge of Beggiatoa mat begins, slow current from 350

-undulating waves of bacterial mat

0945 -73 m: continue heading north,

- fibre covered with brown silt layer

- 2 sole, large ratfish,

- large striped rockfish

0948 -71 m: clean sediment, 3-4 shrimp/ m2, rockfish abundant

-box crabs and medium ratfish

0949 -fine sediment, with little wood fibre/ chips
-large barn door skate (*Raja binoculata*)
-*Beggiatoa* patchy,
-small ratfish nuzzling top of sediment with nose (feeding?)

0950 -69 m: large midshipmen, shrimp, rockfish, sole, ratfish

0953 -67 m: *Beggiatoa*, sole buried in sediment, small ratfish abundant

-large sole, occasional shrimp (<1/ m2), mysids 1-2m above bottom, midshipmen

-66 m: ratfish, eelpouts, shrimp, *Beggiatoa*, sea cucumbers, ratfish

0956 -65 m: *Beggiatoa*, very small ratfish, pile perch, 2 very small ratfish, 2 sole,

-few mysids at 1 m from sediment

-pile perch common,

1000 -62 m: stop, change course to 270 (parallel to shore) to determine westerly extent of fibre area

-test consistency of bottom with manipulator arm: jelly-like *Beggiatoa* with silt over-layer, reducing sediments below *Beggiatoa* (undulating mat)

-very few fish in area: large sole, few shrimp, prawns or ratfish

1009 -same kind of undulating bottom with *Beggiatoa*, small sole, occasional shrimp, small midshipmen

1011 -siltier area, sole common

1012 -bottom very flat, totally covered with brown silt, no *Beggiatoa*, few fish, hermit crabs

1013 -*Beggiatoa* present again

1014 - 55 m: silty, with clean gravel beneath, sole, medium ratfish, burrows, poacher

1015 -54 m: sole, large ratfish

1017 -1-2 cm silt on clean gravel

1018 -53 m: silt on clean gravel, poachers, no ratfish, no shrimp, few mysids

1019 -1 ratfish

1020 -55 m: heavy silt and brown sediment, small sole, no prawns, ratfish, poachers, sole abundant, large anemone on rock

1021 -55 m: sole, ratfish

1022 -silt overlying clay, no *Beggiatoa*

1032 -position fix from surface: 1 mi west. of previous day finish

1035 -54 m: 1/2 nm NW of pipe

1036 -55 m: northerly course to re-discover edge of *Beggiatoa* mat

1035 -54 m: 1/2 nm NW of pipe

1036 -55 m: northerly course to re-discover edge of *Beggiatoa* mat

1037 -53 m: numerous sole, grey clay, no shrimp, or ratfish & rockfish, pink shrimp present

1040 -51 m: brown silt over clay, sole & pile perch common, no ratfish, shrimp, prawns or crabs

1041 -very clean uniform silt, pile perch, large and small sole common

1042 -49 m: clean sediments. No ratfish. Shrimp, or prawns, pile perch, 2 hermit crabs

1043 -sole

1046 -45 m: sediment is coarser but clean, grey clay beneath, box crab, sole common, burrow

1048 -42 m: some wood debris, chips/fibres, squat lobster,dungeness crab, burrows

1049 -dungeness crab, beer bottle

1051 -small wood bits on silt

1052 -37 m: silt with woody chips and bits and bark, hermit crab

1053 -35 m: bark and chips on grey clay, large hermit crab

1054 -32 m: seafeathers, sole, no: shrimp, prawn, crab, or rockfish

1058 -30 m: grey clay, starfish, brittle stars, hermit and box crabs, sea feathers abundant

1059 -no Beggiatoa, nudibranchs, snails (Polinices) present

1100 -good visibility (10 m)

1102 -orange anemones, large octopus

1105 -24 m: school of quillback rockfish near large boulder

1107 -20 m: seapens, tubeworms

1110 18.7 m: end of dive

Species List

anemone	*Metridium senile*
sea cucumber	*Parastichopus* sp.
sea pen	*Ptilosarcus gurneyi*
box crab	*Lopholithodes foraminatus*
brittle stars	Ophiuroidea
cumaceans	Cumacea
Dungeness crab	*Cancer magister*
hermit crabs	Paguridae
pink shrimp	*Panadalus* sp.
sidestripe shrimp	*Pandalopsis dispar*
snail	*Polinices* sp.
octopus	Octopoda
barn door skate	*Raja binoculata*
dogfish	*Squalus acanthias*
eelpout	Zoarcidae
lingcod	*Ophiodon elongatus*
midshipmen	*Porichthys notatus*
pile perch	*Rhacochilus vacca*
poacher	Agonidae
ratfish	*Hydrolagus colliei*
rockfish	*Sebastes* sp.
sole	Pleuronectidae