A Comparative Review of the CRD's Environmental Monitoring Programs for the Clover Point and Macaulay Point Wastewater Outfalls

For: Environment Canada, Pacific and Yukon Region

January 2002 (revised)

Prepared by

2WE Associates Consulting Ltd.

4660 Vantreight Drive

Victoria BC, V8N 3X1

www.2weassociates.com

Contact: **Bob Wilson**

Tel: (250) 472-2254 Fax: (250) 472-9475

DISCLAIMER:

This report has been prepared on the basis of available information, sometimes without full access to the data and reports cited. Opinions expressed are those of the author and are not represented as the views of Environment Canada or any other agency.

LIST OF FIGURES

LIST OF TABLES

Background

2WE Associates was retained to conduct a short review of the marine environmental monitoring program conducted by the Capital Regional District (CRD) for its Clover Point and Macaulay Point outfalls since 1992. The work was carried out, on the basis of available documentation and discussion, to:

- Review the CRD's monitoring program since 1992/3
- Estimate current loadings for priority pollutants
- Evaluate fate & effects
- Evaluate the power of conclusions
- Look for weaknesses in program design
- Look for effluent-related environmental problems

This report is intended to complement a workshop presentation. Its organisation generally follows the terms of reference outlined above. The text draws on publicly available source material provided by Environment Canada and the CRD, on discussions with scientists, and on information drawn from other marine monitoring programs for municipal wastewater outfalls on the west coast of Canada and the USA.

A series of alterations has improved the CRD's monitoring program since 1992. The 1992 program was a benchmark for the current program design, and so was more intensive and spatially broader than in subsequent years. It led to a second stage (1993-99 inclusive) in which samples were taken at stations broadly defined by eight compass lines radiating outwards from each outfall centre to a distance of 800 metres (Fig. 1), with the various environmental media being sampled at frequencies ranging from monthly to every three years. Not every station was sampled, due to differing bottom conditions and other reasons. Reference areas were established at Parry Bay (for the Macaualay Point outfall) and Constance Bank (for the Clover Point outfall). This is the phase of the program reviewed for this report, although some information about the present program is also presented. In 2000, the program was redesigned to match the CRD's plan to move to a system of environmental indicators ("triggers") for investigation and decision making, using numeric criteria obtained from the monitoring program. Monitoring data for this phase of the program are still being evaluated by the CRD, and were not available for review.

The design of the monitoring program for the two outfalls is different. The seabed around the Clover Point outfall is predominantly rocky, so a mussel (*Modiolus modiolus*) biology and chemistry program substitutes for the benthic infaunal monitoring that takes place at Macaulay Point. There is, nevertheless, enough soft sediment near Clover Point to allow sediment chemistry monitoring to take place in association with both outfalls.

Characteristics of the wastewater outfalls are shown in Table 1. The two effluents are significant sources of BOD and TSS to the Georgia Basin, together comprising 20.5% of the BOD and 24.4% of the TSS in municipal wastewaters discharged to the Canadian portion of the Georgia Basin (Table 1).

Environmental monitoring has generally followed the pattern indicated in Table 2. The marine program before 2000 was cyclical. Effluent chemistry was determined quarterly, while sediment chemistry, sediment toxicity and benthic community analysis were done every three years. Analytes have varied slightly and the station list for the second two of the three benthic cycles was different than in 1992[1].

---

[1] Lyons, S. 2001. Summaries of Macaulay and Clover Points marine monitoring programs from 1992 to 1999. Environmental Services Branch, CRD.

Table 1. Characteristics of the wastewater outfalls.

	Clover Point	Macaulay Point
Screen size	6 mm	6 mm
Subtidal length	1,100 m	1,700 m
Depth at diffuser	60-65 m	60-65 m
Flow[2]	67.1 million L/d	42.3 million L/d
BOD[3] (1996-98)	7,186 t/y (13.6%)	3,627 t/y (6.9%)
TSS (1996-98)	5,309 t/y (14.0%)	3.934 t/y (10.4%)
FC[3]	5.2×10^{15} cfu/d	2.9×10^{15} cfu/d
NH_3[4,5]	558 t/y (8.4%)	493 t/y (7.5%)

Table 2: Program components and sampling frequencies (M = Macaulay Point; C = Clover Point)

	92	93	94	95	96	97	98	99	00	01	
Effluent chemistry	M, C	M, C	M, C	M, C	M, C	M, C	M, C	M,C	M,C	M,C	Quarterly; mostly monthly >00
Effluent toxicity	M, C										
Surface FC	?	?	?	?	M,C		?	?	?	M, C	Monthly; stations added in 01
Benthos	M		M			M		M	M	M	0.5 mm screen in 92, then 1 mm
Sediment chemistry	M, C	M, C	M, C	M, C	M, C	M, C	M, C	M,C	M,C	M,C	Parameters expanding
Sediment toxicity	M		M			M					*Neanthes*
Mussel tissue chem.	C			C			C	?	C	C	
Mussel biology	C			C			C	?	C	C	
Effluent dispersion model	M, C					M,C					Calibrated with FC data
Oil & grease chem. & toxicity			M, C								
Toxicity of 1,4-DCB					Lab						

---

2 Average daily dry weather flow for 2000, from CRD's LWMP. Based on 1996 data, daily average dry weather flow was 86% of the measured annual daily mean flow for Macaulay Point, and was 94% of annual daily mean flow for Clover Point.

3 Parenthesized percentages compare the outfall loadings to loadings from other municipal effluents in the Georgia Basin. Data from: Komex International Ltd. 1999. Georgia Basin Ecosystem Initiative sewage treatment facility inventory and optimization. PPR9-071, BC Ministry of Environment, Lands & Parks, and Environment Canada.

4 Data from: Pym, RV. 1997. 1996 Waste management permit monitoring for outfalls operated by the Capital Regional District. CRD.

5 Parenthesized figures compare the outfall loadings to ammonia loadings from a comprehensive inventory of wastewater sources to the Georgia Basin. Basin loading from: ENKON Environmental Ltd. 2000. Loadings of selected toxic substances in wastewaters discharged to the Georgia Basin. Environment Canada Report EC/GB-00-021.

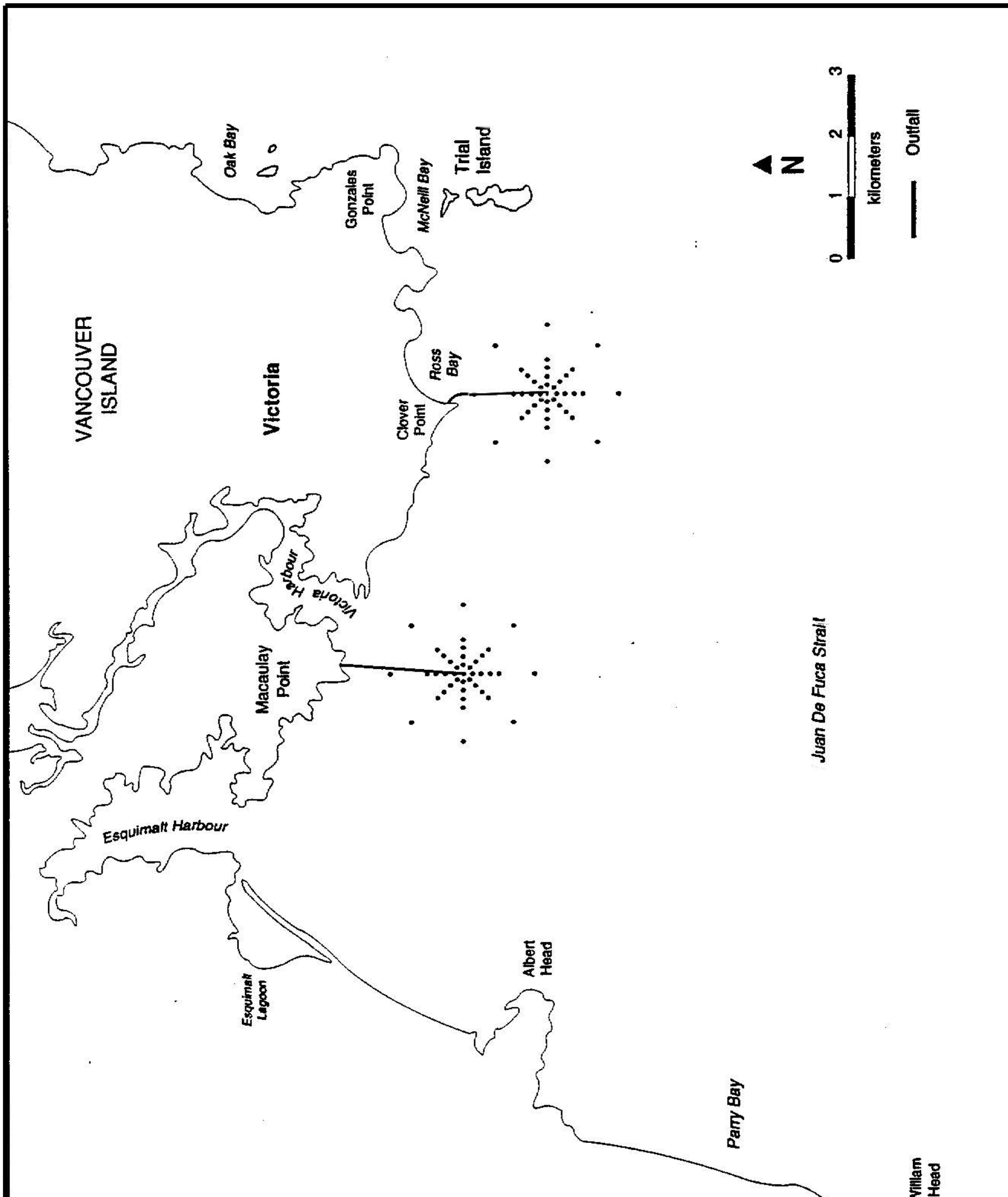

Figure 1. Idealised sampling pattern for the Clover and Macaulay Point outfall marine monitoring program. Not all stations have been occupied. *After EVS Environment Consultants*

Client: Environment Canada	17-May-02	2WE Associates Consulting Ltd.

The CRD's Monitoring Program

Approximately 41 reports have been produced for the program between 1992 and 2001. Material relevant to the terms of reference for this report is summarized in the following sections.

Monitoring Program Documentation

Effluent Chemistry

This section summarizes reports on effluent chemistry monitoring, which was undertaken on a quarterly or annual basis. There have been no effluent toxicity tests since 1992[6].

Hodgins, D.O., and S.W. Tinnis. 1997. A three-dimensional wastewater dispersion model for the south coast of the Capital Regional District, Phase II. Report prepared for the CRD Engineering Department by Seaconsult Marine Research Ltd. The report describes implementation and verification of a three-dimensional plume dispersion model for both outfalls, and provides a useful introduction to local oceanographic conditions. Both summer and winter simulations were presented. The model was calibrated with fecal coliform (FC) data collected in winter between Albert Head and Discovery Island (see Fig. 1 for place names; Discovery Island is just off the eastern edge of the figure, to the northeast of Trial Island).

The model ran on a 1 km grid. An EPA buoyant plume model (the UM model) was embedded in a 13-layer circulation model. The model domain extended almost to the US shoreline south of Macaulay Point, west to Beechey Head (East Sooke) and northeast to the Cordova Bay area in Haro Strait. Effluent is trapped at a depth of 40-50 m when currents and stratification are strong (best case), but trapping depth varies highly with tidal state in winter. In a November run (winter conditions), the mean trapping depth at Macaulay was 20.8 m, and at Clover was 25.5 m, but both plumes frequently contacted the surface during periods of slack water. Tidal advection and wind then moved the surface contamination away from the outfall locations. Solids surfacing with the plume provide a food source for seabirds (illustrated by a photograph in Seaconsult's report).

The data for Macaulay Point show more variability than for Clover Point. Observations and the model indicate a minimum dilution of 25,000:1 above the outfall for Macaulay Point. At Clover Point minimum dilution indicated was <10,000:1.

Modelled surface concentrations of fecal coliform above 20 cfu/ 100 mL were found along the Victoria foreshore from the Inner Harbour to Trial Island. The model layer between 25-35 m depth was the most highly impacted. At this depth, the plume follows topography. Below this depth, the current rotates with increasing depth towards the southeast at Macaulay, but not at Clover, where it remains in an east-west orientation. FC levels >10cfu/ 100 mL extended from Albert Head to Discovery Island at the mean trapping depth. Higher predicted coliform counts at depth generally followed topography, with the highest concentrations being found in the vicinity of the diffusers and along the 60 m contour connecting them. Wintertime conditions (Table 3) appeared to represent the worst case both in terms of trapping depth and extent of the effluent plume below the mean trapping depth. The summer currents are lower, and coliform die-off occurs more quickly.

Table 3. Wintertime current conditions

	Clover	Macaulay
Peak current	120 cm/s	80 cm/s
Mean current	25 cm/s	<10 cm/s
Orientation at 25-35 m	E – W	E - W

[6] S. Lyons, CRD, pers. comm.

Lyons, S. 2001. Quality assurance and quality control for priority pollutant monitoring of Clover and Macaulay Point outfalls in consideration of the enhanced monitoring program. CRD Environmental Programs, Environmental Services Department. The report contains a description of the 2001 effluent monitoring program revisions, including QA/QC considerations.

The CRD's current priority pollutant list (Table 4) is based on EPA's. It includes metals (both total and dissolved), halogenated compounds, volatile organics, chlorophenols, methyl phenols, nitrophenols, total phenols, ketones, phthalates, halogenated pesticides, organophosphates, herbicides, PAHs, PCBs as individual Aroclors, total PCBs, other miscellaneous organics, conventionals including oil and grease, and the N-nutrients. The list does not include co-planar PCBs, or nonylphenol and its derivatives. In general, parameters measured in the effluent are also measured in sediment, and the parameter set for mussel chemistry is reduced compared to these two.

Table 4. Present parameter lists for effluent, sediment, and mussels.

	EFFLUENT	SEDIMENT	MUSSELS
METALS (TOTAL + DISSOLVED (latter just in effluent)			
aluminum	✓	✓	✓
antimony	✓	✓	✓
arsenic	✓	✓	✓
beryllium	✓	✓	✓
boron (dissolved only)	✓		
cadmium	✓	✓	✓
chromium	✓	✓	✓
chromium III	✓	✓	✓
chromium VI	✓	✓	✓
copper	✓	✓	✓
iron	✓	✓	✓
lead	✓	✓	✓
magnesium	✓	✓	✓
manganese	✓	✓	✓
mercury	✓	✓	✓
molybdenum	✓		
nickel	✓	✓	✓
phosphorus	✓	✓	✓
potassium	✓	✓	✓
selenium	✓	✓	✓
silver	✓	✓	✓
thallium	✓	✓	✓
tin	✓		
zinc	✓	✓	✓
SIMULTANOUSLY EXTRACTED METALS			
cadmium		✓	

	EFFLUENT	SEDIMENT	MUSSELS
copper		✓	
lead		✓	
mercury		✓	
nickel		✓	
zinc		✓	
HALOGNATED COMPOUNDS			
1,1,1-trichloroethane	✓	✓	
1,1,2,2-tetrachloroethane	✓	✓	
1,1,2-trichloroethane	✓	✓	
1,1-dichloroethane	✓	✓	
1,1-dichloroethene	✓	✓	
1,2,4-trichlorobenzene	✓	✓	
1,2-dichlorobenzene	✓	✓	
1,2-dichloroethane	✓	✓	
1,2-dichloropropane	✓	✓	
1,2-diphenylhydrazine	✓		
1,3-dichlorobenzene	✓	✓	
1,4-dichlorobenzene	✓	✓	✓
2-chloroethylvinyl ether	✓	✓	
4-bromophenyl phenyl ether	✓	✓	
4-chloro-3-methylphenol	✓		
4-chlorophenyl phenyl ether	✓	✓	
bis (2-chloroisopropyl) ether	✓	✓	
bis(2-chloroethoxy)methane	✓	✓	
bis-2-chloroethyl ether	✓	✓	
bromodichloromethane	✓	✓	
Bromomethane	✓	✓	
chlorodibromomethane	✓	✓	
Chloroethane	✓	✓	
Chloroethene	✓	✓	
Chloromethane	✓	✓	
cis 1,3-dichloropropene	✓	✓	
Dibromomethane	✓	✓	
Dichloromethane	✓	✓	
hexachlorobenzene	✓	✓	
hexachlorobutadiene	✓	✓	
hexachlorocyclopentadiene	✓	✓	
Hexachloroethane	✓	✓	
Pentachlorophenol	✓	✓	
tetrabromomethane	✓	✓	

	EFFLUENT	SEDIMENT	MUSSELS
Tetrachloroethene	✓	✓	
Tetrachloromethane (carbon tet)	✓	✓	
trans 1,3-dichloropropene	✓	✓	
trans-1,2-dichloroethene	✓	✓	
tribromomethane (bromoform)	✓	✓	
Trichloroethene	✓	✓	
Trichloroethylene	✓		
trichloromethane (chloroform)	✓	✓	
PHTHALATES			
bis(2-ethylhexyl) phthalate	✓	✓	✓
butyl benzyl phthalate	✓	✓	✓
diethyl phthalate	✓	✓	✓
dimethyl phthalate	✓	✓	✓
di-n-butyl phthalate	✓	✓	✓
di-n-octyl phthalate	✓	✓	✓
PESTICIDES			
2,4-DDD	✓	✓	
2,4-DDE	✓	✓	
2,4-DDT	✓	✓	
4,4-DDD	✓	✓	
4,4-DDE	✓	✓	
4,4-DDT	✓	✓	
aldrin	✓	✓	
alpha-BHC	✓	✓	
alpha-endosulfan	✓	✓	
alpha-HCH		✓	
benomyl	✓		
beta-BHC	✓	✓	
beta-endosulfan	✓	✓	
beta-HCH	✓	✓	
captan	✓		
cis-chlordane	✓	✓	
cis-nonachlor	✓	✓	
cis-permethrin	✓		
delta-BHC	✓	✓	
delta-HCH	✓	✓	
dicofol	✓		
dieldrin	✓	✓	
endosulfan	✓	✓	
endrin	✓	✓	
gamma-lindane-BHC	✓	✓	

	EFFLUENT	SEDIMENT	MUSSELS
heptachlor	✓	✓	
heptachlor epoxide	✓	✓	
lindane	✓	✓	
methoxychlor	✓	✓	
mirex	✓	✓	
oxychlordane	✓	✓	
toxaphene	✓	✓	
trans-chlordane	✓	✓	
trans-nonachlor	✓	✓	
trans-permethrin	✓		
PCBs			
PCB Aroclor 1016	✓	✓	
PCB Aroclor 1221	✓	✓	
PCB Aroclor 1232	✓	✓	
PCB Aroclor 1242	✓	✓	
PCB Aroclor 1248	✓	✓	
PCB Aroclor 1254	✓	✓	
PCB Aroclor 1260	✓	✓	
Total PCB's	✓		
AROMATICS			
2,4-dinitrotoluene	✓	✓	
2,6-dinitrotoluene	✓	✓	
benzene	✓	✓	
ethyl benzene	✓	✓	
nitrobenzene	✓		
toluene	✓	✓	
xylenes	✓	✓	
PHENOLICS			
2,4,6-trichlorophenol	✓	✓	✓
2,4-dichlorophenol	✓	✓	✓
2,4-dimethylphenol	✓	✓	✓
2,4-dimethylphenol	✓	✓	
2,4-dinitrophenol	✓	✓	✓
2-chlorophenol	✓	✓	
2-methyl-4,6-dinitrophenol	✓	✓	✓
2-nitrophenol	✓	✓	✓
4-nitrophenol	✓	✓	✓
pentachlorophenol	✓	✓	✓
phenol	✓	✓	✓
total phenols	✓	✓	✓
KETONES			

	EFFLUENT	SEDIMENT	MUSSELS
dimethyl ketone	✓		
isophorone	✓	✓	
methyl ethyl ketone	✓		
methyl isobutyl ketone	✓		
ORGANOPHOSPHATES			
chlorpyrifos	✓		
diazomet	✓		
diazinon	✓		
fonofos	✓		
malathion	✓		
parathion	✓		
sulfotep	✓		
HERBICIDES			
2,4,D-amine	✓		
atrazine	✓		
dinoseb	✓		
diphenylamine	✓		
ethylfluralin	✓		
glyphosate	✓		
mecoprop	✓		
metalochlor	✓		
symazine	✓		
triallate	✓		
PAHs			
2-chloronaphthalene	✓	✓	✓
acenaphthene	✓	✓	✓
acenaphthylene	✓	✓	✓
anthracene	✓	✓	✓
benzo(a)anthracene	✓	✓	✓
benzo(a)pyrene	✓	✓	✓
benzo(b)fluoranthene	✓	✓	✓
benzo(g,h,i)perylene	✓	✓	✓
benzo(k)fluoranthene	✓	✓	✓
chrysene	✓	✓	✓
dibenz(a,h)anthracene	✓	✓	✓
fluoranthene	✓	✓	✓
fluorene	✓	✓	✓
indeno(1,2,3-c,d)pyrene	✓	✓	✓
naphthalene	✓	✓	✓
phenanthrene	✓	✓	✓
pyrene	✓	✓	✓

	EFFLUENT	SEDIMENT	MUSSELS
OTHERS			
1,2-diphenylhydrazine	✓		
3,3-dichlorobenzidine	✓		
acrolein	✓	✓	
acrylonitrile	✓		
alpha-terpineol	✓		
benzidine	✓		
N-nitrosodimethylamine	✓		
N-nitrosodi-n-propylamine	✓	✓	
N-nitrosodiphenylamine	✓		
NUTRIENTS			
nitrogen, ammonia total	✓		
nitrogen, nitrate, total	✓		
nitrogen, nitrite, total	✓		
total Kjeldahl nitrogen	✓		
CONVENTIONALS			
BOD5	✓		
acid volatile sulfur		✓	
alkalinity	✓		
chemical oxygen demand	✓		
chloride	✓		
conductivity	✓		
fecal coliforms	✓		
fluoride, dissolved	✓		
hardness (as $CaCO_3$)	✓		
pH	✓		
sad cyanide	✓		
sulphate, dissolved	✓		
sulphate, total	✓		
sulphide, total	✓		
total cyanide		✓	
total organic carbon	✓	✓	
total suspended solids	✓		
wad cyanide	✓		
moisture		✓	✓
age			✓
gonad index			✓
shell length			✓
shell width			✓
gravel		✓	
sand		✓	

	EFFLUENT	SEDIMENT	MUSSELS
silt		✓	
clay		✓	
mineral oil & grease	✓		
total oil & grease	✓		

Commencing in May 2001, the sampling frequency for effluent was changed to monthly for most parameters, but quarterly for halogenated compounds (except 1,4-DCB), all the pesticides and herbicides, and PCBs.

ASL Analytical Service Laboratories Ltd. and EVS Environment Consultants. 1994. Characterisation and possible environmental effects of oil and grease in wastewater discharged through the Clover and Macaulay Point outfalls. Report to the CRD. (not seen in the original. Information about this and other reports not seen in the original is drawn from a very useful summary recently prepared by the CRD[7]). A study undertaken to characterise the oil and grease portion of the effluent. Oil and grease contains phthalates, PAHs, chlorinated benzenes, metals, and cyanide, but lipophilic compounds were expected not to adversely affect birds or other organisms ingesting them because of their tight binding to the fats.

Paine, M.D. 1996. Chemical composition of wastewater discharged through Capital Region District (CRD) outfalls: 1988 – 1995. Prepared for CRD Environmental Services Group, Victoria, BC by Paine, Ledge and Associates (PLA) North Vancouver, BC. The report has data on the list of priority pollutants sampled up to 1995. No temporal trends were identified.

Pym, R.V. 1997. 1996 waste management permit monitoring for outfalls operated by the Capital Regional District of British Columbia, Canada. CRD Engineering Department. This report has data for effluent flow, TSS, BOD, FC, and NH_3. It also has ambient coliform data that will be discussed later.

Eade, A. 1998. 1997 Sewage, sludge and leachate contaminants report. Capital Regional District Marine Monitoring Program. CRD. The extensive list of contaminants analysed does not contain either nonyl phenol (NP) or its derivatives.

Paine Ledge and Associates and EVS Environment Consultants Ltd. 1999. Effluent quality for the Clover and Macaulay Point outfalls: effects of source control and treatment options, and comparison to other marine discharges. Report to the CRD. (not seen in the original) This report discusses loadings and trends and makes comparisons with other outfalls. Concentrations of metals, oil and grease and BOD were generally higher at Macaulay Point than at Clover Point, but the loads were more similar due to higher flows at Clover Point. Concentrations of organics rarely differed by more than 2-fold in the two effluents. In general, the concentration of organics was higher at Macaulay Point but loadings were higher at Clover Point.

Sediment Chemistry and Toxicity Monitoring

CRD 1993-1999 Clover Point and Macaulay marine sediment chemistry field sampling reports. (not seen in the original) These reports were produced in-house at CRD. They detail methods, QA/QC and provide analytical results.

EVS Consultants. 1994. Data analysis of 1993 sediment chemistry off the Macaulay Point outfall and recommended sediment monitoring sampling design. Report to the CRD. This document contains an analysis of spatial extent of impact and the variability between 1992 and 1993 for 17 metals and 5 CBs.

[7] Lyons, S. 2001. Summaries of Macaulay and Clover Points marine monitoring programs from 1992 to 1999. CRD

Benthic effects were found at 100 m but not 400 m in 1992. At these stations abundance was increased, and diversity reduced. The outfall stations were dominated by capitellids (sludge worms).

Chemical analysis was done on each of three sediment samples per site. This was a huge chemical effort: 125 samples from 41 stations, that typified the sediment chemistry monitoring from 1993 until at least 1997. The M0 (the CRD station naming convention is 'M' or 'C' for the outfall, followed by the distance from the outfall in metres, followed by the compass direction from the outfall) and M100E stations had Cd and Cu above the 2001 warning levels in 1993. TOC was not reported. Spatial analysis indicates the plume solids deposit predominately to the east and downslope. Triplicate chemical analyses were a continuing recommendation.

EVS Environment Consultants Ltd. 1997 Review of 1992-1995 sediment chemistry data for the Clover Point and Macaulay Point outfalls. (not seen in the original) This is the interpretative report for the four annual data sets. 1,4-DCB, Cu, Pb, Hg, Ag, and Zn were identified as the substances with the greatest potential to impact sediment around the outfalls. The authors used toxicity emission units to evaluate spatial and temporal changes; there was some interannual variability and no temporal or spatial trend.

IRC Integrated Resource Environmental Consultants. 1998 Review of CRD sediment bacteria monitoring programs at Clover and Macaulay Point outfalls. Report to the CRD (not seen in the original). The report is an analysis and interpretation of sediment FC data from 1985 to 1997. Statistically elevated levels of FC occur within 280 m of the outfalls but there was interannual variability in the spatial pattern. The consultants recommended discontinuance of the sediment FC program, instead using Fe, TOC and particle size to quantify accumulated influence of the discharge on sediment quality. CRD appears to have accepted this recommendation.

Paine Ledge and Associates. 1999 Sediment contamination near the Clover and Macaulay Point wastewater outfalls, 1995 - 1997. Report to the CRD. A review was undertaken to identify which chemicals should be used in the trigger process: Cu, Hg, Pb, and TOC were recommended. The report does not contain the raw data, or information about variances, but these factors would have been considered in arriving at the conclusions.

The criteria for identifying sediment contaminants as suitable for the trigger process were:

- Frequently detected above quantitation limits
- High concentrations near the outfall relative to background or reference sites
- Exceedance of criteria

The report used three years of data. Since analyses were available for three field replicates per site per year, each site could contribute up to nine points to an overall site mean.

Most metals were detected in both outfall stations and reference sediments. Cr(III) and Cr(VI) were never detected, and Tl was detected only at the Clover Point outfall site and at the Constance Bay reference site. All 16 PAH tested were found at the Macaulay outfall, and most were found at the Clover Point outfall. 1,4-dichlorobenzene (DCB), several phthalates and bis(2-chloroethoxy)methane were the only other base neutrals frequently detected at the outfall stations. Volatile organics, PCBs (except Aroclor 1254) and pesticides were rarely or never detected in sediment. Detection limits for some pesticides were higher than the CCME TELs but adequate to determine exceedance of PELs.

Ratio to reference (RTR) values were used to identify parameters whose concentrations were high. RTR values >10 were found for many substances: Cd (Macaulay but not Clover), Cu, Pb, Hg, As, most PAHs, 1,4-DCB, and phthalate esters. RTR values for acid volatile sulfur were >100 at both outfalls, indicating that many metals would have low bioavailability. TOC levels at both outfalls rarely exceeded 10x reference levels, and were lower at Clover Point than Macaulay Point.

After comparison with criteria, two groups of trigger chemicals were identified for the outfall stations. The first group were those that exceeded CRD sediment quality standards, which are based on Washington Department of Ecology (WaDOE) standards for Puget Sound:

- Hg, most PAH (and especially HPAH), 1,4-DCB, and one or more phthalate esters.

A second group was identified for compounds exceeding the CCME PELs, which are generally lower than the WaDOE standards, but which did not exceed the latter:

- Cu, Pb, Ag.

Cd, Cr, Ni, and Zn exceeded CCME's TELs in one or more years.

PAH, 1,4-DCB and phthalates were not recommended as indicators due to uncertainties about the sources of PAH and doubt about the toxicological significance of elevated concentrations of dichlorobenzene and phthalates.

In the near-field stations, concentrations of metals with criteria decreased rapidly from the Clover Point outfall, all reaching 25% of background within the first 100 m. Concentrations off Macaulay Point also decreased with distance, but not so quickly. Spatial examination determined that:

- Metal and TOC contamination is spatially more extensive off Macaulay Point than off Clover Point, although levels at the outfall are generally similar.
- Above background concentrations of Hg and Pb persisted to 800 m off Clover Point.
- Many metals were >1.5 times background 800 m away from the Macaulay outfall.
- All metals were within their PELs beyond 200 m from the outfalls.
- TOC levels did not decrease strongly with distance at either outfall. TOC levels were 0.5-1.8% at the Clover outfall, and 3.1-5.8% at the Macaulay outfall.

BC has assigned a 100 m radius around each outfall as an initial dilution zone (IDZ).

Paine Ledge and Associates. 1999. Trend analyses of sediment chemistry data from off the Clover and Macaulay Point outfalls. Report to the CRD (not seen in the original). Having identified the sediment chemistry triggers, this report went on to analyse temporal trends and make comparisons between sediment and effluent chemistry and SQOs. The analysis included other priority pollutants. The report confirmed the trigger set previously identified and suggested that sediment Ag and Zn might also be suitable candidates.

Paine Ledge and Associates. 1999. Priority pollutants in sediments off the Clover and Macaulay Point outfalls, 1988 – 1997. Report to the CRD. (not seen in the original) Another review was undertaken to identify compounds of concern and trends. The author looked at data quality and found data for 1994 – 1997 to be OK, while earlier data were suspect. Chemicals elevated over reference or exceeding SQOs were Cu, Hg, Pb, PAHs and TOC. Concentrations in sediment were generally higher off Macaulay Pt than off Clover Pt., reflecting the situation in the effluent. PAH and 1,4 DCB have been increasing (n=4) over time at both outfalls but not at the reference stations, while phenol has been decreasing at all sites. The author recommended discontinuance of VOC monitoring in sediment, and recommended compositing subsamples to reduce analytical cost. This marked the end of separate analysis of the three field replicates in the sediment chemistry program. He also recommended changes to the station layouts, with more stations at <200 m but fewer overall at Clover Point.

Axys Environmental Consulting Ltd. 2000 Macaulay Point spatial data analysis. Report to the CRD. (not seen in the original) The report contains a spatial analysis of eight metals, including the metallic triggers, using a GIS.

- The dominant direction of metals deposition was confirmed to be generally southeast to east.
- Pb has been increasing over time.
- Ag has been decreasing over time and retrenching towards the 100 m contour.
- Cu has also been decreasing over time.
- As, Cd, Hg, Zn stable appear to have been stable over time.

These authors recommended adding stations: M100S, M200S, M100N and M200N. These stations were part of the design in 1992 but had become disused. They also recommended a spatial analysis at Clover Pt, as well as analysis between regular stations where there are significant differences, to investigate why the differences might occur, and they recommended seafloor photography.

EVS Environment Consultants Ltd. 1994 Macaulay Point sediment toxicity testing, 1994. (not seen in the original) This and the next report deal with sediment toxicity. 105 sediment samples, including reference sites in Parry Bay were tested with Neanthes. Only five test sites were different than controls.

EVS Environment Consultants Ltd. 1997 Macaulay Point monitoring project. Laboratory report. (not seen in the original) The report has results of the 1997 Neanthes toxicity tests.

Sediment toxicity testing was carried out in 1992, 94, and 97. In 1992, an amphipod (*Rhepoxinius abronius)*, an echinoderm (*Stonglyocentrotus purpuratus*), and a polychaete (*Nereis arenaceodentata*) were tested. The only toxic station in the amphipod test was one of the reference sites, and *Rhepoxinius* tests were not performed thereafter because "acute lethality has not been an issue"[8]. The echinoderm tests did not demonstrate toxicity and were not repeated.

Looking at the toxicity data set as a whole, over the three years 1992, 1994 and 1997, a pattern of interannual variability in the *Nereis* test results emerges (Table 5). Stations tabulated are those in which toxicity was evident in at least one year. The results of sediment toxicity tests have not been well correlated with either sediment chemistry or the results of benthic community analysis[9]. Sediment toxicity tests have not been performed since 1997, and their status in the program is presently under review[10].

Table 5. Interannual variability in results of sediment toxicity tests with Nereis arenaceodentata. .

	1992	1994	1997[11]
M0	✓		✓
M100NE			✓
M100E	✓		✓
M100SE		✓	✓
M100SW	✓		
M100W	✓		✓
M200SE			✓
M200SW			✓
M200W		✓	✓
M200NW			✓
M400SW	✓		✓
M800E		✓	✓
M400N		✓	

Benthic Community Monitoring

The benthic infaunal monitoring program is carried out at Macaulay Point but not at Clover Point, where there is a hard-bottom community around the outfall.

8 EVS Environment Consultants Ltd. 1994 Macaulay Point sediment toxicity testing, 1994.
9 CRD. 2000. Liquid waste management plan. Appendix 8B – Trigger process for the Clover and Macaulay Point wastewater outfalls. CRD.
10 S. Lyons, CRD, pers. comm..
11 Growth rates in 1997 were low at all stations, including controls

Aquametrix Research Ltd. 1995. 1994 Macaulay Point environmental monitoring program: field sampling and marine benthos component. Report to the CRD. (not seen in the original). The report interprets data from the 1994 benthic monitoring program Differences were apparent between the reference stations and outfall terminus, with the outfall being 6x richer but less diverse. The sludge worm *Capitella capitata* occurred at the outfall station in very great abundance, sometimes >10,000/m^2 on an individual sample basis. Abundance was reduced within about 200 m of the outfall, increasing to reference levels at 400 and 800 m. The reduced abundance close to the outfall is indicative that enrichment has tipped the benthic community beyond the edge of available assimilative capacity of the habitat.

EVS Environment Consultants. 2000. Macaulay Point outfall marine assessment data analysis. Report prepared for the CRD Engineering Department. The report identifies trends in the benthic invertebrate data for 1992, 94, and 97 and assesses effects using a weight of evidence approach with the sediment chemistry and toxicity data.

Stations were assigned to one of three groups: within 100 m, 200–800 m, and reference. Two types of analysis were performed on the benthic data. The ten most abundant taxa were identified and assigned to functional groups (e.g., deposit feeders, filter feeders), and the groups were qualitatively compared for the three station intervals. Non-Metric Multidimensional Scaling (NMDS) was performed to look at relationships among the abundances of six major taxa, accounting for >97% of the total abundance. Data were log-transformed and Bray-Curtis distances between pairs of stations were calculated for the NMDS. As a non-parametric analog of PCA, NMDS is somewhat equivalent to the cluster analysis often performed on benthic data sets, but is less amenable to power estimation.

The principal findings were:

- Reduced taxa richness at 100 m stations, more so in 1992 and 1994 than in 1997.
- Reduced taxa richness at a few 200 m stations in 1994 but not in 1997.
- Increased abundance at 100 m stations. Abundance at M100SE was higher than at the outfall in 1997.
- Increased abundance at some or most 200 m stations
- Increased abundance at some or most stations ≥400 m.
- Positive correlations between abundance and TOC, indicating an enrichment effect.
- The primary axis of effect is east-west, with an emphasis on the east and southeast quadrants. Contour plots for Cu and Hg indicate enhanced deposition to the east and southeast but not to the west. TOC is enhanced in all directions.
- A generally decreasing spatial pattern of benthic community effects over the three years, although the interannual changes were small and sediment quality standards were exceeded more frequently in 1997 than in 1994.

It should be noted that data from the 1992 infauanal program are not comparable with the two later years, because a 0.5 mm screen was used to separate invertebrates and debris from the sediment. The screen size was increased to 1 mm in 1994, where it remained until at least 1999. The smaller screen size would have led to more juveniles being included in the 1992 counts than in later years. Current practice prefers the 1 mm size but, even so, the issue of counting juveniles may remain to be dealt with.

Mussel Monitoring

CRD's mussel monitoring program is carried out around the Clover Point outfall.

Paine Ledge and Associates. 1997. Bioaccumulation of metals and organics in horse mussels (Modiolus modiolus) collected off the Clover Point Wastewater outfall, 1995.

Three replicates of at least 5 animals per station were collected and pooled for chemical analysis (i.e., 3 analyses per station). Pb and Cu (at least) were positively correlated with shell length within stations. Concentrations of Cu. Pb, and several PAH were higher near the outfall than further away and at the reference sites. Distance from the outfall was the primary determinant of contaminant concentrations, but within distance analysis suggests higher concentrations in the southeast. Pb at the outfall and at C100E was over the BC criterion for protection of human consumers of shellfish, but this criterion is no longer in the current list of approved and working guidelines for the Province, and the Canadian Food Inspection Agency's guideline is for Pb in fish protein concentrate. Cu, Pb, and Mn were the only metals detected that did not show depletion at the outfall compared to the reference site. However, in 1992, it was Cd, Se, and Zn that were the exceptions to the reverse gradient. Metals were uncorrelated with growth, though individual tissue weights were not determined.

The reference site for this study was moved to Constance Bank from 10 Mile Point (the latter was used in 1992).

Mussel ages ranged from 2 - >20 years, with a modal age of 5. There were no differences in the average age, length, or growth of the mussels by station. The data analysis used to determine whether there were growth differences is unconvincing, and an insufficient number of mussels from each station were aged.

A modification to the sample station layout for this component was recommended, but the author was concerned about autocorrelation, (i.e., stations so close together they would not be independent). Elimination of site replication in favour of more stations was recommended as a way to improve the spatial discrimination of future work. Recommendations included addition of gonad weight measurement to improve biological characterisation, and discontinuation of 1,4-dichlorobenzene analysis in tissue. Chlorobenzenes had rarely been detected in tissue.

Kingzett, B.C, and Bourne, N.F. 1996. Age determination of horse mussels, Modiolus modiolus collected at Clover Point, and Constance Bank (1995). Project Data Report, Kingzett Professional Services. (not seen in the original) The report contains the 1995 data and recommendations for the acetate peel ageing technique for mussels.

Paine, M. 1997. Bioaccumulation of metals and organics in horse mussels (Modiolus modiolus) collected off the Clover Point wastewater outfall, 1995. Paine, Ledge and Associates, report to the CRD. (not seen in the original) Chemical analyses included metals, PAHs and CBs. Biological measurements included age, length, and growth. Similar spatial patterns were observed in 1992. Cu, Pb and several PAHs were highest at the outfall site. Concentrations of all other metals were lowest at the outfall site and for some metals increased to a maximum at the Constance Bank reference site. Recommendations were made to improve aspects of the methodology.

Blackbourn, J. 1999. Gonadal index of horse mussel (Modiolus modiolus) collected off Clover Point in 1998. Report to the CRD. (not seen in the original) Gonads of mussels at most stations were in the developing stage, but mussels at the outfall station were at the spawning stage.

Kingzett, B.C. and N.F. Bourne. 1999 Age determination of horse mussels, Modiolus modiolus collected at Clover Point, and Constance Bank (1998). Project Data Report, Kingzett Professional Services. (not seen in the original) A data report.

Paine, Ledge and Associates. 2000 Analysis of 1998 Clover Point outfall mussel monitoring data. (not seen in the original) Unlike in 1992 and 1995, PAHs were not detected in any tissue samples in 1998. Cu and Pb continued to be highest near the outfall. Concentrations of Al, As, Cd, Co, Fe, Hg, Ni, and Ag increased with increasing distance from the outfall (continued depletion). There was no spatial trend for Cr, Mg, Mn, Se, and Zn. There were no differences over the last two sampling times in age, length or growth, and these measurements did not show an effect, but tissue growth (individual weight?), not measured before, was highest near the outfall in 1998. Recommendations were made to increase the sampling frequency to annual, the number of stations to >20, and to add reproductive status (measured in 1998 for the first time) to the list of measurements.

General

Marine Monitoring Advisory Group. 1993. Scientific consensus on the state of the receiving environment around the Clover and Macaulay Point sewage outfalls: knowledge and concerns. Report to the CRD. This document contains a partial summary of earlier work and a description of scientific issues.

The Macaulay Pt outfall includes the leachate from the Hartland Road landfill, estimated at 2-3% of total flow. The effluent screens are 6 mm, i.e., quarter-inch

Acute toxicity in the effluent in 1992 was probably due to high NH_3 and low DO.

Maximum contaminant concentrations in sediment near the Macaulay outfall are lower than concentrations in either Esquimalt or Victoria harbours.

Early studies also suggested decreased benthic richness near the Macaulay outfall.

The size of the shellfish closure area in 1992 was 40 km^2. All of the shoreline is closed, together with an area offshore between Esquimalt Lagoon and McNeil Bay (Fig. 2). Resources affected are clams, mussels and free-swimming pink and spiny scallops. The closure area looks generally similar to the average area affected by FC counts >20 CFU in Seaconsult's model, although instantaneous higher values may extend over a larger area (Fig.3).

EVS Environment Consultants Ltd. 1996 Investigations of effects of 1,4-dichlorobenzene exposure on juvenile polychaete worms. Report to the CRD. (not seen in the original). The toxicity of 1.4-DCB to *Nereis* was investigated in the lab. There were no adverse effects on survival at any of the test concentrations, which were selected to bracket those found at the Macaulay Point outfall station. Statistically significant differences in weight occurred only at the highest concentration tested, which was >10x the level found in sediment at the outfall.

Pym, R.V. 1997. 1996 waste management permit monitoring for outfalls operated by the Capital Regional District of British Columbia, Canada. CRD Engineering Department. This report has data for just flow, TSS, BOD, FC, and NH_3. Surface FC counts at Macaulay and Clover Points were generally 3 – 12 cfu/100mL. The maximum at Macaulay was 110 cfu/100 mL, and at Clover was 530. The FC data substantiated predictions of the plume model that diluted wastewater would reach the surface at both locations in several winter months. The surface over almost the whole sampling area for Clover Point (Fig. 1) appears contaminated between September and May.

Taylor, L.A., P.M. Chapman, R.A. Miller and R.V. Pym. 1998 The effects of untreated municipal sewage discharge to the marine environment off Victoria, British Columbia, Canada. Water Sci Technol 38(10): 285-292. The authors prepared a summary paper for the open literature. They stated that there have been no effects on conventional water quality, other than the elevation of FC. Coliform levels did not appear to be increased at local beaches during the summer months. Sediment contamination was confined to within 100 to 400 meters of the outfall, while sediment toxicity has been detected up to 400 meters away. In the benthic community, abundance increased and richness decreased within 100 meters of the outfall. Some tissue chemicals increased with distance while others decreased.

CRD. 2000. Liquid waste management plan. Appendix 8B – Trigger process for the Clover and Macaulay Point wastewater outfalls. CRD. This document contains the rationale for selecting and quantifying the trigger process parameters (Table 6), and data analysis for a few selected parameters.

Biological warning levels were proposed as the primary trigger. Chemical warning levels will be used to assist in identifying the contaminants that are responsible for the biological levels being exceeded. The critical effects sizes were selected by consensus.

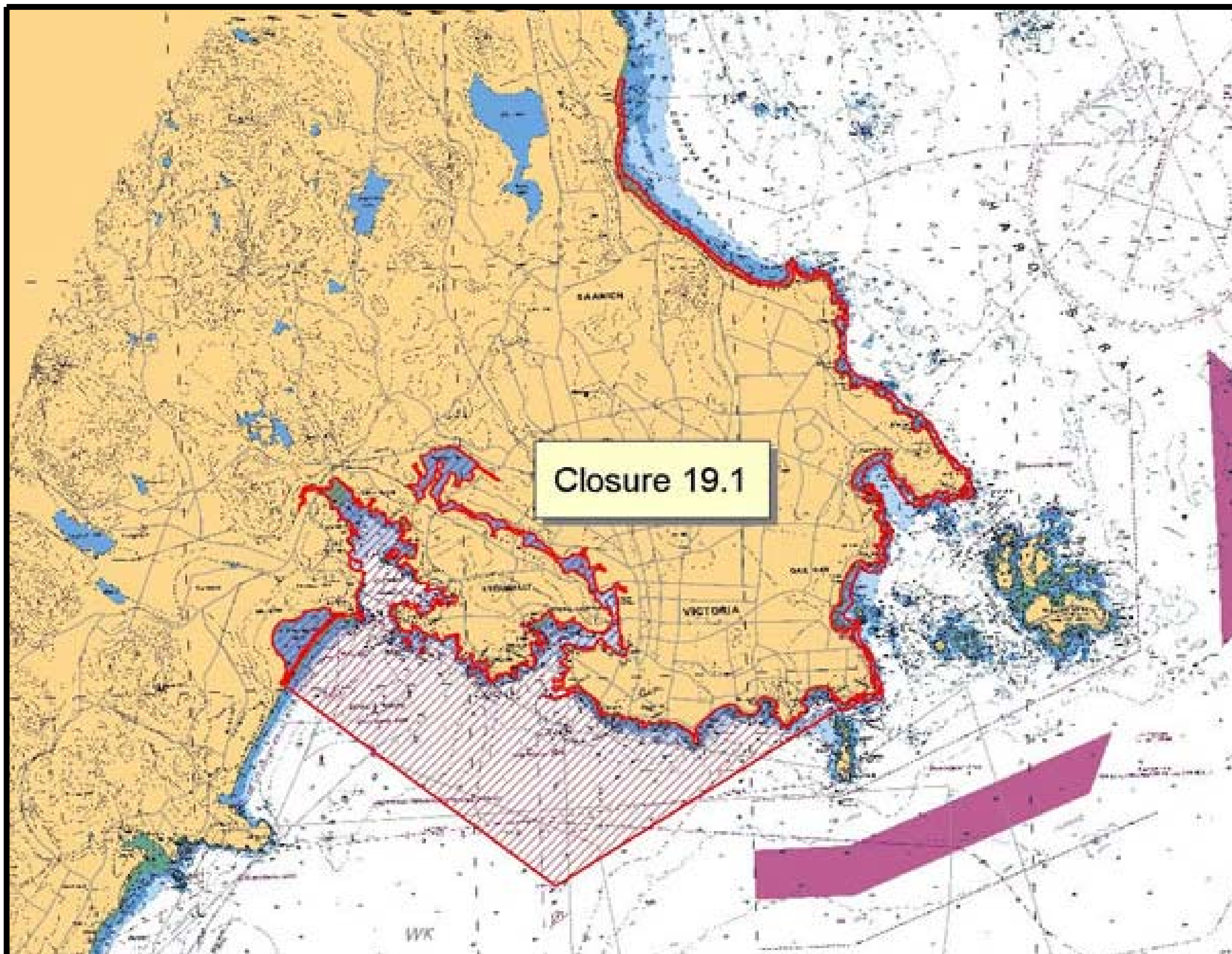

Fig. 2. The present shellfish closure area off Victoria. *source: DFO*

Client: Environment Canada	30 Apr 02	2WE Associates Consulting Ltd.

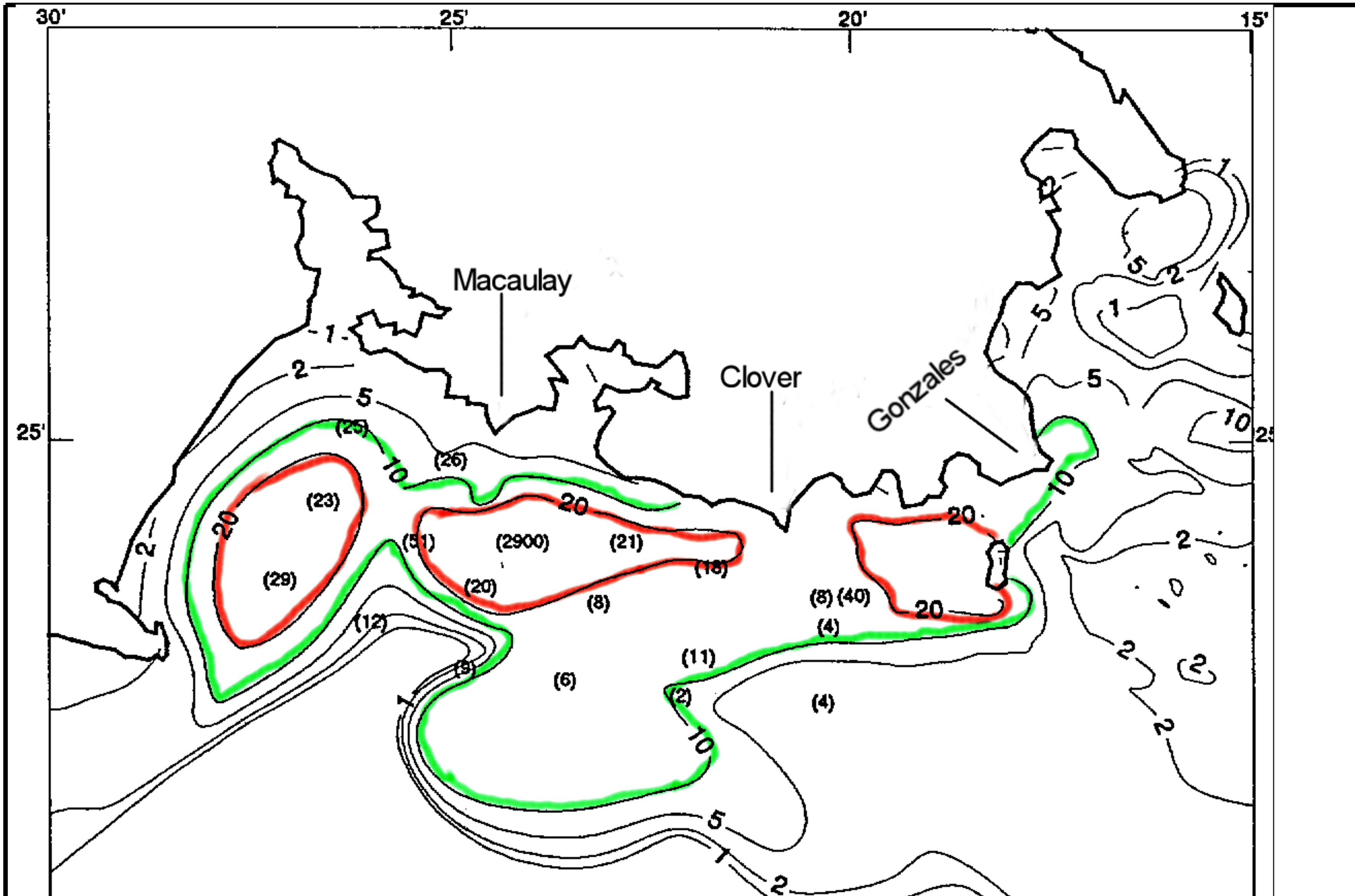

Fig. 3. Comparison of modelled FC concentrations (contours) with observational data (figures in parentheses), for 20:00 GMT on 11 December 1996. The modelled 20 CFU contour is in red, the 10 CFU contour in green. *Source: Hodgins and Tinis, 2000*

Client: Environment Canada	17-May-02	2WE Associates Consulting Ltd.

There are three benthic community indicators (total richness, Swartz Dominance Index (SDI), polychaetes (enhancement over reference), two primary mussel community indicators (tissue weight and shell length), and two secondary mussel indicators (age structure and reproductive status). For bioaccumulation, the levels of chemicals in mussel tissue will be compared to CCME and health guidelines. There appears to be less confidence in values of the polychaete abundance indicator levels because of variability in the data.

Of the many contaminants measured in sediment, the ones correlated with benthic effects are TOC, Cd, Cu, and 1,4-DCB. These have been selected as the indicators. The correlation with TOC confirms that enrichment effects are a possibility.

Table 6. Parameters used in the trigger process and their action levels

	Warning Level	**Effects Level**
SDI	≤ 16.5 taxa/ 0.1 m^2	≤ 5 taxa/ 0.1 m^2
Total Richness	≤ 58.8 taxa/ 0.1 m^2	≤ 29.4 taxa/ 0.1 m^2
Polychaete abundance	.228 ind/0.1m^2	≤ 186.8 ind./ 0.1 m^2
Mussel tissue weight	<90% reference	<80% reference
Mussel shell length	<90% reference	<80% reference
Reproduction/ age structure	Stat diff from ref	-
Cu bioaccumulation	40 mg/kg wet wt	400 mg/kg wet wt
Pb bioaccumulation	0.8 mg/kg wet wt	6.3 mg/kg wet wt
TOC	3.5%	-
Cd	0.5 mg/kg dry wt	-
Cu	150 mg/kg dry wt	-

The lab tests on 1,4-DCB showed reduced weights only at the highest concentration, which was >10x that previously measured at the M0 site in 1992.

Lyons, S. 2001. Wastewater and marine assessment program 2000. Environmental Services Dept., Environmental Programs, CRD. This report contains an outline of the current monitoring program

The effluent monitoring program was revised, as described earlier.

Mussel biomonitoring off Clover Point was done at 23 sites plus the reference station in September. The sampling station layout followed an 8-armed compass rose, with stations radiating out to 800 m directly east and west, 200 m N and S (across the slope) and 400 m in the other quadrants. A tissue composite of 3x5 animals was made at each station for chemical analysis. Analyses were done for an extensive list of pollutants (Table 4). Shell length, width, and age were measured, and the state of gonadal development was determined for an additional 10 animals at each site.

Sediment chemistry was determined at 23 sites off Macaulay Point, one site (the outfall) at Clover Point, 3 reference stations in Parry Bay, and one reference station on Constance Bank (the reference site for the mussel biomonitoring). The sediment chemistry sampling protocol received a major revision. All the stations at Clover Point except the outfall and reference station were dropped from the program due to the difficulty of obtaining satisfactory samples.

The radiating station layout for Macaulay Point stations was quite similar to the mussel station layout at Clover Point. Sampling followed PSEP protocols, with no significant exceptions. The parameter set was intermediate between the effluent set and the mussel set (Table 4).

The sampling grid for benthic invertebrates at Macaulay Point was the same as the sediment sampling grid. There were also the same three reference stations in Parry Bay. The sampling protocol followed PSEP, with a one mm screen. It should be noted that specimen identification work was performed by a different laboratory in 2001.

Other Literature

ENKON *Environment Ltd. 1999. Sources and releases of toxic substances in wastewaters within the Georgia Basin. EC/GB-99-003*. Recommendations included

- Monitor pharmaceuticals (estradiols and sterols) in WWTP effluents.
- As a lower priority, monitor bisphenol A, chloramines in WWTP effluents, the latter to be done in conjunction with environmental monitoring because of persistence issues.
- Discontinue monitoring of PCBs because sources are under control.
- Discontinue monitoring of phthalates until sample contamination can be controlled.
- Discontinue monitoring for benzene, dichloromethane, trichloroethylene and tetrachloroethylene because the major sources are atmospheric.

The report suggests data quality problems for the CRD's phthalate, chlorinated phenol, nitrophenol, and dicholoromethane analyses in sediment before 1999. ENKON suggests that the phthalate data from the CRD and the GVRD should be used with caution, because of the difficulty of eliminating sample contamination with phthalate esters leaching from plastics used in sampling or laboratory procedures.

The only analyses for nonyl phenol and its ethoxylates are being done by GVRD. ENKON reported that these compounds occur in WWTP effluent and at CSOs at concentrations 20-30x higher than the lowest concentrations known to cause effects. They noted that GVRD was unsuccessful in its attempt to measure estradiol in effluent.

ENKON Environmental Ltd. 2000. Loadings of selected toxic substances in wastewaters discharged to the Georgia Basin. Environment Canada Report EC/GB-00-021. This report tabulates toxic pollutant loadings to the Georgia Basin. Loadings calculated by ENKON for pollutants important in the receiving environment around the two outfalls are shown in Table 7

Table 7. Loadings (kg/y)of pollutants important around the two outfalls (1993-97)

	Clover Pt	**Macaulay Pt**	**Importance**
Ag	106±47	77±69	Has exceeded SQO; sediment concentration decreasing over time
Cd	7.7±2.1	20±0.2	Exceeded warning level in 1993; correlated with benthic effects; sediment concentration stable over time
Cu	2,803±211	2,268±366	Part of trigger process; exceeded warning level in 1993; sediment concentration correlated with benthic effects
Hg	19.8±23.9	8.8±7.1	Part of trigger process; has exceeded SQO
Pb	308±126	304±87	Part of trigger process; sediment concentration increasing over time
HPAH	Several not calculated	Several not calculated	Has exceeded SQO, sediment concentration increasing over time
1,4-DCB	27±5	55±42	Has exceeded SQO; correlated with benthic effects; sediment concentration increasing over time

Rick Thompson, at IOS, maintained two moorings off the outfalls for a period of three years. The current from Haro Strait sweeps around the corner of Victoria, creating an eddy off its southern foreshore. Net transport within this eddy is towards the south, consistent with the deposition patterns seen for some contaminants, but the currents are strongly tidally driven and mixing is intense. There should be no reason, however, for the pattern of contaminant deposition in sediment to be dominated by the effect of net transport. Further to the west in Juan de Fuca Strait, net transport along the Canadian shore is seawards in the spring for at least the top 125 m of the water column[12].

Concerns have been expressed that whales are vulnerable to the effects of contaminants discharged with sewage. Investigations have been undertaken to look at contaminant levels in grey whales and orcas, the two species regularly found in the Georgia Basin.

Grey whales are vulnerable to sediment contamination. They may spend months at a time occupying a limited range in the Georgia Basin, where they feed by straining invertebrates from mouthfuls of sediment. Their stomachs contain large quantities of sediment and debris along with the food material. Varanesi *et al*[13] described the results of tissue analysis for PCBs, DDTs, PAHs and trace elements in samples taken from animals stranded on southern California, the outer Washington coast, Puget Sound/ Juan de Fuca Strait, and Alaskan shores. Lipid content in the blubber of these animals was low (<1 – 16%), indicating that lipophilic compounds should have been at near maximum concentrations. There was no significant relationship between contaminant concentration and location of stranding. Although high variability in the data might have masked such a finding, the authors suggested that the feeding habits and migration patterns of gray whales contributed to a blurring of contaminant differences across the animals' range in western North America, especially for substances accumulated over periods of years. The levels of Hg and PCBs found in blubber were reported to be below those associated with toxicological effects in seals.

BC's southern resident and transient killer whale populations are considered among the most contaminated cetaceans in the world. While dose-response information for orcas does not exist, the total dioxin TEQ factor for PCBs in most killer whales is well beyond the toxicity thresholds established for harbour seals.[14] The large proportion of salmon (92%) in the diet of southern residents, suggests that salmon are likely the major food source of this contaminant. However, southern residents have about 3x the contamination level of northern residents, suggesting a regional difference. What is the cause? Within the range of the southern residents, Puget Sound salmon have about 4x as much PCBs (2 ppm on a lipid weight basis) as Fraser River salmon, a situation reflected in 8x the contamination levels in Puget Sound seals as compared to southern Strait of Georgia seals. Rockfish, which comprise perhaps 1% of the diet, have been found to have PCB levels up to 60 ppm on a lipid weight basis in Puget Sound, and thus may contribute significantly to the whales' total PCB load. Higher concentrations of contaminants in southern killer whales are thought to result from industrial and domestic activities. The food web in southern Puget Sound is significantly more contaminated than the food web in northern BC, which, combined with the relatively poor flushing of Puget Sound, suggests that this is a more important source of contaminants than the southern Strait of Georgia.[15]

The Sierra Legal Defense Fund recently (2001) launched a campaign based on the presence of PCBs in WWTP effluent from the GVRD. A comparison of loadings to the Georgia Basin from rainfall and other continuing sources by R.W. Macdonald indicated that the loading from GVRD effluents was a small fraction of the total. The implication is that PCBs from municipal effluents are probably not a major source of the PCBs found in killer whales.

The traditional POPs (the "legacy" POPs) are the ones that pose the biggest threat to orcas. However, there is a growing category of lightly regulated chemicals that may have similar effects. These include the polychlorinated paraffins, brominated flame retardants, fluorinated organic surfactants (PFOS), polychlorinated naphthalenes, polychlorinated terphenyls, and alkyl phenol ethoxylates. The physicochemical resemblance of these poorly

---

[12] Thomson, R.E. 1994. Physical oceanography of the Strait of Georgia – Juan de Fuca Strait system. pp 36-100 *In* Wilson, R.C.H., R.J. Beamish, F. Aikens, and J. Bell. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait. Can Tech Rep Fish Aquat Sci No. 1948.

[13] Varanesi, U., J.E. Stein, K.I. Tilbury, J.P Meadon, C,A. Sloan, R.C. Clark, and S-L. Chan. 1994. Chemical contaminants in gray whales (*Eschrichtius robustus*) stranded along the west coast of North America. Sci. Tot Environ. 145: 29-53.

[14] Ross, P.S., G.M. Ellis, M.G. Ikonomou, L.G. Barrett-Lennard, and R.F. Addison. 2000. High PCB concentrations in free-ranging Pacific killer whales, *Orcinus orca*: effects of age, sex, and dietary preference. Mar. Poll. Bull. 40: 504-515

[15] P.S. Ross, IOS, pers. comm.

investigated compounds to several banned organochlorines suggests that these chemicals may be a concern in local environments.[16]

Other Marine Wastewater Monitoring Programs

GVRD

Like the CRD, the Greater Vancouver Regional District has planned a trigger assessment process for its Iona WWTP outfall, which provides primary treatment of about 600 million $L.d^{-1}$. The discharge from this outfall is about 5 times the volume from Clover and Macaulay Points combined. The Iona Deep Sea Outfall Environmental Monitoring Program began before1988, when an outfall reconstruction program extended the discharge 1.8 km offshore in the Strait of Georgia. The average discharge depth, about 85 m, is deeper than the CRD's.

From its inception, the GVRD's monitoring program included:

- effluent chemistry
- plume dispersion modeling
- *particulate deposition modelling*
- benthic community assessment
- *fish histopathology*
- contaminant bioaccumulation in fish
- sediment chemistry
- sediment toxicity
- sediment microbiology
- water column chemistry
- water column microbiology

Receptors in this list in italics have not been included in the CRD's program. Sediment toxicity assessment is no longer part of the GVRD's program, a change the CRD is evaluating. The GVRD's coliform monitoring program is more extensive then the CRD's, including sediment samples.

Like the CRD, the GVRD has continually refined its monitoring program to improve the quality of the data and information. The present program is based on explicit hypotheses about effects, which has focused attention on the power of the sampling design to discriminate effects thought important. While hypotheses are implicit in the CRD's trigger process, it would be fair to say that hypothesis testing has been less emphasised in their program.

GVRD has proposed an indicator set somewhat different from the CRD's (Table 8):

The list of toxic chemicals assessed includes nonyl phenol, its ethoxylates and several other EDCs. Testing for 17β-estradiol was unsuccessful. Sediment chemistry and benthic community assessments are now being done annually, with the other environmental components usually being carried out on a cyclical basis at least once every five years. One important difference in the benthic infaunal monitoring component is that the GVRD does not include juveniles in the count or biomass estimates; the GVRD also estimates biomass.

The species richness and dominance indicators are the same for both programs, although absolute values for GVRD are still under discussion. The GVRD's crustacean abundance indicator is relative abundance of the amphipod *Heterophoxus sp.,* which is common in the Strait of Georgia and Burrard Inlet but reduced in the area nearest the Iona outfall. *Heterophoxus* is also found in San Francisco Bay, where it is thought to be only somewhat tolerant of pollution. The brittlestar indicator used is relative abundance of the soft-bottom species *Amphiodia urtica*, whose abundance is reduced near the outfalls both in Orange County and at Iona. Investigation in California indicated that

[16] P.S. Ross, IOS, pers. comm..

at least some of the reduction might be due to predation by fish that lived and fed near the outfall structure[17]. There are few *Amphiodia* in the CRD's monitoring area, but they do not occur at the outfall and are absent or rare in the easterly direction. *Amphiodia* does occur at the reference area. *Heterophoxus*, however, is more common except at the outfall. Abundances are higher in the westerly and northerly direction than in the easterly direction.[18] These observations support previous interpretation of the Macaulay Point benthic data sets.

Table 8. A comparison of the indicator sets chosen by the CRD and the GVRD.

	CRD	GVRD
Benthic species richness	✓	✓
Benthic species dominance	✓	✓
Benthic species composition		✓
Polychaete abundance	✓	
Crustacean abundance		✓
Brittlestar abundance		✓
Mussel morphometry	✓	
Mussel bioaccumulation	✓	
Water chemistry		✓
Sediment chemistry	✓	

Orange County

Orange County, in southern California, operates two municipal wastewater treatment plants for domestic and commercial sewage and industrial wastes from approximately 2.2 million people and almost 1,000 industrial/commercial sources. Wastewater receives a combination of advanced primary and secondary treatment that removes a minimum of 75% of the suspended solids. The County has an EPA permit that allows it to operate with less than full secondary treatment[19].

The outfall is about twenty times as large as either of the CRD's. The average volume discharged to the ocean in 1995 was about 1,000 million L/d, with peak flows being about double. The effluent is discharged at Huntington Beach, through an ocean outfall extending 8.2 km from the shoreline. The 1.8 kilometer long outfall diffuser has 500 ports and is situated at a nominal depth of 60 m.

Under its permit, the County is required to conduct an extensive monitoring program that includes testing of influent samples (to evaluate source control), final effluent, biosolids, and receiving water. The receiving water program is designed to assess the fate and environmental effects of the discharged wastewater on the marine environment and human health. In 2000-01, the County budgeted US$2.1 million for research and monitoring, about US$0.97 per capita serviced and 4.2% of its non-capital wastewater treatment and disposal budget.

Evaluation of the ocean monitoring program data is based on comparisons with 15 receiving water criteria specified in the permit

- Floating particulates, oil and grease
- Discolouration of the ocean surface
- Natural light transmittance
- Dissolved oxygen

[17] CSDOC. 2000. Annual report 1995 including a ten-year synthesis: 1985 – 1995. Marine monitoring compliance report, County Sanitation Districts of Orange County, Fountain Valley, CA.
[18] Abundance information from Brenda Burd, Ecostat Research, pers. comm..
[19] CSDOC 2000. *op.cit.*.

- pH
- Coliform bacteria
- Visually observed floatables
- Dissolved sulfides
- Nutrients
- Inert solids
- Toxics
- Organic material
- Marine communities
- Human health
- Achievement of water quality standards

The sampling frequency varies from five times weekly to annual. Sampling stations include 17 stations 3 days per quarter (9 monthly) offshore water quality, 53 annual (13 quarterly) benthic community, 10 quarterly sediment chemistry and toxicity, 11 semiannual trawl, and 17 (5 days per week) for surf zone/shoreline sampling of total coliform bacteria and grease particles. A summary of parameters measured for the monitoring program is presented below. Attributes in this list shown in italics have not been part of the CRD's program since 1992.

Offshore water quality - *physical* (temperature, light transmittance, light transparency, water colour [Forel/Ule scale], and total suspended solids [TSS]); *chemical* (salinity, dissolved oxygen, acidity/alkalinity [pH], ammonium, oil and grease), and bacteriological (fecal coliform bacteria)
Whole effluent toxicity testing – *48-hour larval development tests* using purple sea urchins or red abalone at concentrations ranging from 0.32% to 3.2% (calculated to bracket the initial dilution ratio)
Bottom physical and chemical environment - sediment grain size, priority metals, PCBs, DDTs, other OC pesticides, total organic carbon, dissolved sulfides, cyanide, total volatile solids, and *chemical oxygen demand*. As of 2000, EDCs other than the organochlorines were not included in the monitoring program.
Bottom biology/ecology – *cluster analysis* of distribution and abundance of infaunal invertebrates, *bottom (demersal) fish, and macroinvertebrate communities*
Organism chemical effects – priority metals, PCBs and organochlorine pesticides in tissues (*fish* and macroinvertebrates); and *histopathological analyses of fish livers*
Surf zone and nearshore water quality indicators - public health/bacteriological (total coliform bacteria and grease particles)

Southern California Wastewater Treatment Plant Marine Monitoring

The Southern California Bight (SCB), a 500 km section of coastline from Point Conception, California, to the United States-Mexico international border, has one of highest coastal population densities in North America. A recent inventory[20] identified 114 marine monitoring programs, each having a lifespan of over ten years, underway to assess the effects of this large population. The four largest municipal WWTPs (including Orange County, see above) were spending US$10.2 million per year between 1994 and 1997 (about US$0.60 per capita) on monitoring, split 15.6% on effluent monitoring and 84.4% on receiving water monitoring. In contrast, federal monitoring programs cost only US$3.1 million annually, while state agencies spent US$0.5 million.

Effluent and shoreline microbiological monitoring comprised just over half of the WWTP permit holders' monitoring effort. The components monitored were: *intertidal organisms*, *kelp beds* and rocky subtidal components, sediment chemistry, benthic infauna, *fish*, shellfish, and water quality. Italicised components are not included in the CRD's program.

[20] Schiff, K.C., S.B. Weisberg, and V.E. Raco-Rands. 2001. Inventory of ocean monitoring programs in the Southern California Bight. SCCWRP 1999-00 Annual Reports. http://www.sccwrp.org/pubs/annrpt/99-00/abst18_ar22.htm

More than 80,000 shoreline bacteriological samples were being collected annually in southern California to protect beachgoer health, but sampling frequency varied from daily to monthly among sampling sites. Sampling five times per week resulted in observing about 80% of the events in which State standards were exceeded. This frequency dropped to 55, 25, and 5% for three times per week, weekly, and monthly sampling, respectively. Follow-up re-sampling the next day after an exceedance was not completely effective, because nearly 70% of the water quality exceedances were single-day events, even at the most frequently contaminated sites[21].

The southern California program has developed a technique for monitoring enteroviruses. Assays for the detection of enteroviruses by reverse transcriptase-polymerase chain reaction (RT- PCR) were performed on 63 coastal seawater samples either influenced by freshwater outlets or near high-use sandy beaches. The RT-PCR is a primer-based molecular biology technique that can be used to detect the genomes of specific groups or types of RNA viruses. Of the 63 samples, 21 (33%) were positive for enteroviruses, 35 (56%) were negative, and 7 (11%) were inconclusive. Results of 60 and 54 samples did not demonstrate any significant logistical correlation to total and fecal coliforms, respectively ($p>0.05$). Correlation analysis of 14 samples showed a significant, but weak, association with levels of enterococci ($r = 0.50$, $p < 0.05$) in samples only from Santa Monica Bay. Inconclusive results occurred for over 10% of the samples, where inhibition of PCR occurred due to substances in the seawater. There was no strong relationship between the presence of enteroviruses and levels of indicator bacteria.[22] Virus monitoring is not carried out in BC's environmental monitoring programs.

Sediment toxicity tests have been carried out, sometimes with puzzling results. During the summer of 1997, sediment core samples were taken at 25 stations in Santa Monica Bay. Toxicity testing was performed on 4 cm sections of the entire length of each core, against purple sea urchin fertilization and amphipod survival. The sea urchin test identified sections as being toxic at 6 stations, all located near current or former wastewater outfall locations. The amphipod test identified sections from 17 of the stations, scattered throughout the bay and at numerous core depths, as having toxic sediments. Spatial and temporal patterns indicated that toxicity was most strongly associated with the historical disposal of sludge. Many of the sections toxic to the amphipods did not have chemical levels expected to cause toxicity and were in locations where a source of toxicity was not apparent[23].

The Southern California Coastal Water Research Project Authority (SCCWRP)

In addition to individual agency and operator-funded marine monitoring programs, management decisions based on water quality in southern California are supported by regional-scale, non-repetitive research projects. The SCCWRP is a regional umbrella group for federal, state, and local agencies, who collectively provide the budget. SCCWRP conducts research in support of marine water quality issues, many of which are related to municipal wastewater discharge and urbanization. In 2000-2001, this organization supported 31 separate research projects from their annual budget of $2.8 million. None of these projects concerned:

- Pharmaceuticals
- Hormones
- EDCs other than organochlorines

[21] Leecaster, M.K., and S.R. Weisberg. 2001. Effect of temporal sampling frequency on shoreline microbiology assessments. SCCWRP 1999-00 Annual Reports. http://www.sccwrp.org/pubs/annrpt/99-00/abst26_ar37.htm
[22] Noble, R.T., and J.A. Fuhrman. 2001. Enterovirus detection by reverse transcriptase polymerase chain reaction from the coastal waters of southern California. SCCWRP Annual Reports 1999-00. http://www.sccwrp.org/pubs/annrpt/99-00/abst20_ar31.htm
[23] Greenstein, D.J., S.M. Bay, A.W. Jirik, J.S. Brown, and C. Alexander. 2001. Toxicity assessment of sediment cores from Santa Monica Bay. SCCWRP Annual Reports, 1999-00. http://www.sccwrp.org/pubs/annrpt/99-00/abst13_ar13.htm

Despite reports of the poor ability of bivalves to metabolise PAH, e.g. Anderson (1985)[24], they can do this slowly. BaP can be metabolized by CyP450 in the gills and digestive gland, with the digestive gland playing the major role. But induction cannot always be seen in bivalves exposed to known inducers. The lack of conclusive evidence for induction of P450 metabolism, the low levels of xenobiotic metabolism often difficult to measure, and the uncertain mechanism of reportedly elevated concentrations of CyP 450 indicate that these systems are not well enough understood for the tool to have any monitoring value.[25] The significance of PAH metabolism to the appearance of neoplastic disease (tumours) in bivalves is not clear. In *Mytilus edulis*, neoplasms are not generally correlated with BaP residues[26].

Gunther et al (1997)[27] compared survival of amphipods (*E. estuarius*) exposed to sediments from San Francisco Bay containing PAHs to EROD induction in sanddabs (*Citharichthys stiagmeus*). Sanddabs may occur off Victoria. The sediments contained from 1-30 ppm PAH, 3-20 ppb of PCB and variable concentrations of several trace elements. A highly significant correlation (r^2=0.9) was found between survival of the amphipods and EROD activity in the sanddabs, although there was some EROD activity in fish where the amphipod survival was >80%. Amphipod survival could be accurately predicted by the contaminant exposure biomarker in fish.

The literature indicates that PAH contamination causes a measurable increase in DNA damage in mussels. In a caged mussel experiment, Steinert *et al*. (1998)[28] suspended bags at four depths at a reference and PAH-contaminated site. The Comet assay was used to find damaged DNA, as indicated by strand breakage. Hemocyte nuclei were fixed in agarose gel. The extent of strand breakage was determined by epifluorescence in fragments that migrated away from the nuclei. The ecological significance of DNA damage is unclear.

A comparison was made in Southern California between the use of total coliform, fecal coliform and enterococcus indicators. On the basis of nearly 1000 samples, it appeared that all three bacterial indicators were correlated. However, the enterococcus standard appeared to be the most conservative and was exceeded most frequently[29]. GVRD has obtained similar correlations, but maintains FC measurements for methodological reasons.[30]

San Francisco Bay

Contaminant monitoring for the WWTP outfalls discharging to San Francisco Bay is included in a multi-agency funded regional monitoring program. The Regional Monitoring Program for Trace Substances monitors contaminant concentrations in water, sediments, and fish and shellfish tissue. The San Francisco estuary is surrounded by a highly urbanized landscape, with agricultural land lying upstream. Urban runoff, agricultural runoff, treated wastewater, and dredging activities all introduce contaminants to estuarine waters[31].

Monitoring is designed to obtain data describing the concentration of toxic trace elements and organic contaminants. The objectives are:

---

[24] Anderson, R.S. 1985. Metabolism of a model environmental carcinogen by bivalve molluscs. Mar Env Res 17: 137-146

[25] Stegeman, J.J. 1985. Benzo[a]pyrene oxidation and microsomal enzyme activity in the mussel (*Mytilus edulis*) and other bivalve mollusc species from the western North Atlantic. Mar. Biol. 89: 21-30.

[26] Mix, M.C. 1983. Hemic neoplasms of bay mussels, *Mytilus edulis*, from Oregon: occurrence, seasonal prevalence, seasonality and histopathological progression. J. Fish. Dis. 6: 239-248.

[27] Gunther, A.J., R.B. Spies, J. Stegeman, B. Woodin, D. Carney, J. Oakden, and L. Hain. 1997. EROD activity in fish as an independent measure of contaminant induced mortality of invertebrates is sediment bioassays. Mar Env Res 44: 41-49.

[28] Steinert, S.A., R.S. Montee, & M.P. Sastre. 1999. Influence of sunlight on DNA damage in mussels exposed to polycyclic aromatic hydrocarbons. Mar Env Res 46: 355-358

[29] Noble, R.T., M.K. Leecaster, D.F. Moore, K.C. Schiff and S.B. Weisberg. 2001. Relationships among bacterial indicators during a regional survey of microbiological water quality along the shoreline of the Southern California Bight. SCCWRP 1999-00 Annual Reports. http://www.sccwrp.org/pubs/annrpt/99-00/abst22_ar32.htm

[30] Stan Bertold, GVRD, pers. Comm..

[31] San Francisco Estuary Regional Monitoring Program Fact Sheet. http://www.sfei.org/rmp/Fact_Sheets/98factsheet.html

- To describe patterns and trends in contaminant concentration and distribution;
- To describe general sources and loadings of contamination to the estuary;
- To measure contaminant effect on selected parts of the estuary ecosystem;
- To compare monitoring information to relevant water quality objectives and other guidelines;
- To synthesize and distribute information from a range of sources to present a more complete picture of the sources, distribution, fates, and effects of contaminants in the estuary ecosystem.

Contaminants included in the program are priority metals, PCBs, PAHs, OC pesticides, and organotins. The parameter set does not include:

- Pharmaceuticals
- Hormones
- EDCs other than organochlorines and organotins

Before regional monitoring was put into place, scientists had been conducting research and monitoring activities on the estuary for decades. These activities were typically geared to a specific need, limited in coverage, and failed to provide an overall picture of the estuary's condition. In addition, sampling methods used by different studies were rarely comparable. The regional monitoring program was set up by the state agency responsible for water quality to address the need for comprehensive, long-term monitoring. The program is managed by a separate institute (SFEI).

Monitoring information feeds into an estuary preservation plan known as the Comprehensive Conservation and Management Plan (CCMP) for the San Francisco Estuary, and into actions by CALFED, the consortium of agencies charged with restoring the marine environmental resources of the Bay area.

Seventy-seven public and private organizations that discharge treated wastewater, cooling water, or urban runoff, or are involved in dredging activities, pay for the monitoring program. Many of these participants also contribute expertise or logistical support. The annual budget for monitoring is currently US$2.5 million (about US$0.12 per capita). In addition, a number of federal and state agencies contribute funds or in-kind services to the program.

The monitoring program is coordinated by a Steering Committee and a Technical Review Committee, which meet quarterly. The Steering Committee advises the Regional Board on issues such as distribution of program costs, reviews progress, and evaluates effectiveness. The Technical Review Committee works with SFEI staff on program design and methods for sampling and analysis. Committee members include representatives from wastewater treatment plants, stormwater dischargers, industry, cooling water dischargers, dredgers, SFEI staff, and the Regional Board. Outside scientific expertise and review is frequently provided.

Regional monitoring began in 1993. In an effort to capture seasonal variability, samples are taken three times a year: during the rainy season (March-April), during a period of declining freshwater outflow (May-June), and during the dry season (August-September). In addition, the USGS collects phytoplankton, water quality, and suspended sediment data monthly. Stations are located both close to outfalls and as close to background as possible. The basic data set includes:

- Conventional water quality data (such as salinity, dissolved oxygen, and temperature) and chemistry (such as metals, pesticides, and PAHs; EDCs were not included in the parameter set as of 1999);
- Aquatic toxicity (effect on laboratory organisms);
- Sediment characteristics (such as particle size) and chemistry;
- Sediment toxicity (effect on laboratory organisms); and
- Contaminant bioaccumulation in transplanted shellfish.

In addition, pilot studies were underway to evaluate the incorporation of benthic community studies and contaminant bioaccumulation in fish tissue. The program was scheduled for a major review in 2000.

Discussion

Effluent Chemistry and Toxicity

The ENKON report on contaminants sources and levels recommended discontinuance of PCB monitoring in the effluent. PCBs were never detected at either outfall in sampling from 1995 to 1997.

Analytical quality control problems have been identified for the phthalates group measured in both effluent and sediment.

ENKON also recommended discontinuance of effluent monitoring for BHC isomers, benzene, dichloromethane, tri- and tetrachloroethylene, as the major sources are atmospheric and effluent levels are too low to worry about. However, all these compounds have been detected in the CRD's effluents.

Several compounds discharged in the effluent are important because they are included in the trigger process, because their levels are correlated with benthic effects, or because the corresponding SQOs have been exceeded in the data set. These chemicals are Ag, Cd, Cu, Pb, Hg, PAH but especially HPAH, and 1,4-dichlorobenzene. Loadings calculated by ENKON[32] for these chemicals (except PAH) in the two effluents are shown in Table 7. Relative standard deviations higher than 20% indicate that several were either highly variable or are inadequately characterised:

- Ag at both outfalls
- Cd at Clover Point
- Hg at both outfalls
- DCB at Macaulay Point

ENKON calculated loadings for several years up to and including 1997. When data from the 2001 and 2002 effluent monitoring becomes available, the CRD's ability to estimate annual loadings should be improved.

Effluent toxicity tests have not been undertaken by the CRD since 1992. At that time, failures were attributed to low DO and high ammonia during the test. These conditions are unlikely to have improved, but the reasons for failure might be less conducive to regulatory action than would be a demonstration of other causes of toxicity.

Effluent chemistry monitoring covers metals and the "legacy" persistent organic pollutants well. It does not, however, include such recently recognised contaminants as the polychlorinated paraffins, brominated flame retardants, fluorinated organic surfactants, polychlorinated naphthalenes, polychlorinated terphenyls, and alkyl phenol ethoxylates. Of these, only the last group has been monitored by the GVRD.

Fecal Coliforms

The information underlying the offshore boundary of the present shellfish closure is over a decade old[33]. The monitoring program does not include a component for coliforms in sediment, which the GVRD uses to confirm the spatial extent of the Iona plume, or in shellfish. The present shellfish harvesting closure affects a variety of subtidal marine resources, as well as shoreline resources that would be also impacted by storm sewer outfalls and landwash.

---

[32] ENKON, 2000. *op.cit.*

[33] Hal Nelson, Environment Canada, pers. comm.; Seakem and Low. 1990. Capital Region marine monitoring program data compilation and analysis. Report by Seakem Oceanography Ltd. and C. Low and Associates for the CRD.

Sediment Chemistry and Toxicity

Maximum observed OC and metal concentrations near the Macaulay outfall are lower than maximum concentrations in either Esquimalt or Victoria harbours. There is little evidence to indicate the extent to which sediment chemistry at the outfall stations has been influenced by problems in the harbours.

We do not have information to evaluate the fate of chemicals discharged in the effluent that do not settle to the bottom. For those that do, complex geochemical processes may govern the partitioning of contaminants, even those that are normally particle reactive. For example, the residence time of Cr^{+3} in the San Francisco Bay water column may be >3 days if it is complexed by colloidal/ organic matter.[34]

The inclusion of further sediment toxicity testing is under review by the CRD.

Mussel Monitoring

It is not clear from the documentation reviewed how values for mussel shell length and tissue weight will be adjusted for age. In 1995, the technique derived a length or weight to age curve by pooling all the samples, and then examining differences between individual station means and the overall mean. If population differences occur, this technique would be improved by deriving individual growth rates for each station. The current monitoring program appears to age more mussels from each location, enabling comparison of station rates.

The trigger process does not categorise an increase in growth rates (i.e. enrichment) as an adverse effect.

Benthic Community Monitoring

The reference station data have been pooled over several annual collections to increase the power of comparisons to reference. Outlier analysis is proposed for the circumstance where a new reference sample is outside the reference range, but the need to re-evaluate changes over time in the reference condition is recognised. If a trend in reference values becomes evident, at what point would some of the earlier reference samples be left out of the pool? How would a sudden discontinuity (e.g., due to a change in methodology) be dealt with?

Two out of three benthic endpoints must exceed their warning levels for an effect to be judged at the station level. For adverse effects to be recognised, species richness and polychaete abundance must exceed their individual effects levels. But could these effects be transient? One supposes so but would have to presume not. Trend analysis of chemicals in sediment will take place once a warning level is exceeded, in order to determine whether effects levels will ever likely be exceeded[35], but what happens it there is no significant trend? The trigger process seems vague on this point, but may include a confirmatory sampling step before an effect is judged and further action taken.

The Non-Metric Multidimensional Scaling technique, used in the 2000 waste assessment, comes from the Plymouth (UK) lab and is a recognised method of dealing with non-linear data. The Bray-Curtis distance index used is also widely used, but is susceptible to being swamped in pair-wise comparisons by one relatively tolerant species that occurs everywhere. More information could be drawn from the data set by using cluster analysis and the same bootstrap technique adopted by the GVRD. This technique would provide estimates of the power of the sampling design to discriminate differences between the reference and near-field sites.

Polychaetes have been a focus of the benthic data analysis, and indeed capitellids sometimes occur in very high abundance (>10,000/ m^2 on a single replicate basis). This tremendous enrichment indicates that there is enough

---

[34] Khalil, E.A-S., and Flegal, A.R. 1995. Chromium in San Francisco Bay: superposition of geochemical processes causes complex spatial redistributions of redox species. Mar. Chem 49: 189-199.

[35] CRD, 2000. *op.cit.*

oxygen in the bottom environment to support all these worms and the microbial degradation process associated with the particulates in the sediment, i.e., that there is lots of assimilative capacity. Close to the outfall, however, the CRD's monitoring indicates that abundance is reduced and assimilative capacity may be overwhelmed. It should be noted that bottom water entering Juan de Fuca Strait is reduced in dissolved oxygen at certain times of the year; values as low as 1 mg/L have been recorded in September, entirely due to natural causes[36]. DO concentrations off the bottom at both outfalls in April, 1989, was, however, near saturation[37]. The concentration of dissolved oxygen in bottom water has not been measured in recent CRD monitoring, and it remains an open question as to what might be happening. There is, however, an alternative explanation for the apparent reductions in abundance.

As might be expected from the high density of polychaetes, sampling precision for the 1999 and 2000 benthic data near the Macaulay Point outfall is poor.[38] There may be no practical way to take enough replicates near the outfall to be sure of the numbers. In addition, the benthic samples were often themselves subsampled in the taxonomic lab, a procedure which contributes to sampling variability. The 2001 benthic data set is being sorted and identified differently, bringing this part of the monitoring procedure into line with the GVRD's recent practice. By implication, both the conclusions about adverse effects and the levels proposed for the trigger process may change, although it is unlikely that our understanding of the general pattern of enrichment close to the outfall will be altered.

The focus on polychaetes led to species richness in some classes being underrepresented, for example in the echinoderms[39]. The species richness may go up in 2001, with the change in taxonomic procedures, which should cause reconsideration of the effects levels for polychaete enhancement.

Endocrine Disruption and Biomarkers

Public attention has recently focused on reports of increased incidence of hormone-dependent cancers and on reductions in sperm counts in men. A number of studies have documented physiological and morphological changes in wildlife exposed to EDCs. However, the broad structural diversity of EDCs suggests that they may produce effects through a number of different pathways, including direct binding to and activation of the estrogen receptor, binding to other receptors that may then interact with the estrogen receptor, or through pathways such as the aryl hydrocarbon receptor responsible for organochlorine degradation. Several assays have been developed to identify and assess the endocrine disruption potential of contaminants but, because of the diversity of structure and pathways, it is reasonable to think that a variety of assays should be involved in any thorough investigation.[40]

The endocrine system regulates hormone-dependent physiological functions necessary for survival and reproduction. While *in-vivo* tests have been developed to assess, e.g., exposure to chemicals that bind the corticosteroid receptor in fish (corticosteroids stimulate glucogen production), these tests do not appear simple to execute and are sensitive to outside factors such as the stress experienced by fish during capture and holding.[41] It is important to recognise in discussion of EDCs that the range of potential effects goes well beyond the reproductive area, into other physiological processes that are hormone-mediated. Identification of a target structural group or physiological process is an initial challenge for investigators planning a monitoring activity.

---

[36] W.R. Crawford, IOS, pers. comm.
[37] Colodey, A.G., R.A. Salmon, and P.G. Lim. 1992. Environmental monitoring near the Macaulay Point and Clover Point marine sewage outfalls at Victoria, British Columbia in 1989 and 1990. EP Regional Data Report DR 92-14.
[38] Brenda Burd, Ecostat Research, pers, comm.
[39] Brenda Burd, Ecostat Research, pers. comm.
[40] Gillesby, B.E., and T.R. Zacherewski. 1998. Exoestrogens: mechanisms of action and strategies for identification and assessment. Environ Toxicol Chem 17: 3-14.
[41] Hontela, A. 1998. interregnal dysfunction in fish from contaminated sites: in vivo and in vitro assessment. Environ Toxicol Chem 17: 44-48

EDCs do have the potential to interfere with the hormone pathways that affect fish reproduction. Manifestations may be decreased fertility and egg production in females, and reduced gonad size or feminization of genetically male fish. Male fish exposed to estrogenic compounds also show induced production of vitellogenin (measurable in blood), but the ecological significance of this process is in question. In general, the ecological implications of exposure to EDCs remain to be established.[42] The US EPA has developed guidelines for assessing whole life-cycle effects[43]. These include reproductive endpoints such as time of spawning, egg number, fertility and fecundity. These gross measurements are more easily obtained and are more relevant ecologically than are the results of *in vitro* challenges using captured fish. In the CRD's program, it is easily possible to imagine measuring some of these parameters in mussels. The reproductive index measurements presently underway may be susceptible to the influence of EDCs, but in the absence of accompanying chemical investigations it is not possible to know why an effect might occur.

DFO experiments with chinook salmon alevins exposed to secondary treated sewage effluent showed that the lowest concentration that led to the development of ovaries in genetically male fish, exposed for 29 days post-hatching, was 30% effluent, or a 17β-estradiol concentration of 1 µg/L. In 30% secondary treated effluent, 2 out of 20 genetic males developed as physiological females, and 1 out of the 20 showed intersex gonads. Primary treated sewage effluent showed a stronger effect, with 30% effluent affecting gonadal development in 100% of the genetic males. Treatments with 10% primary or secondary treated effluent did not affect testicular development, and even 100% effluent did not affect gonadal development in genetic females.[44]

One problem with implementing this approach more broadly is that there is not one genetic probe that can be used for all species, so considerable development may be needed to switch from chinook salmon to, e.g., mussels or sanddab. Also, considerable investigation is required to isolate and assess the substances in a sewage effluent that may be responsible for estrogenic effects. One such approach underway at IOS is based on the Toxicity Index Evaluation. An effluent is chemically fractionated and a yeast bioassay is used on each fraction. The yeast has been genetically modified to screen for estrogenic compounds. The initial separation into polar and non-polar fractions results in pharmaceuticals and other water soluble compounds coming out with the polar fraction, while organochlorines come out with the non-polar fraction. Fractions showing estrogenic activity are then examined using MS to identify the substances present. This technique is not yet at the commercial stage (at least locally), but the procedure is straightforward and would take a biochemist about a month to set up.[45]

Many traditional pollutants can interfere with hormone-mediated metabolism. NOAA is using a simple CYP1A1 induction assay, called the Reporter Gene System (RGS), in its National Status and Trends Program[46,47]. Mussel tissues and sediments are extracted with a solvent system. The extract is used in an assay with a transgenic cell line (TV101L cells) which has been stably infected with a plasmid containing firefly luciferase linked to human CYP1A1 promoter sequences. Induction is determined by luminometry, in a manner similar to the response in the Microtox test. The ratio of luminosity after 6 h to luminosity after 16 h can be used to provide additional information about the type of contaminants involved, because the response to PAHs is faster than the response to dioxins, furans and co-planar PCBs). Results are expressed in BaP equivalents. This testing method has been recognised by the APHA[48].

---

[42] Arcand-Hoy, L.D., and W.H. Benson. 1998. Fish reproduction: and ecologically rele3vant indicator of endocrine disruption. Environ. Toxicol. Chem. 17: 49-57

[43] 61 Fed. Reg. 56273-56322 (Oct 31, 1996)

[44] Alfonso, L.O.B., J.L. Smith, M. Ikonomou, and R.H. Devlin. 2001?. Y-chromosomal DNA markers for discrimination of chemical substances and effluent effects on sexual differentiation in salmon. SEATAC poster provided through Colin Gray.

[45] Michael Ikonomou, IOS, pers. comm..

[46] Anderson, J.W., J.M. Jones, S. Steinert, B. Sanders, J. Means, D. McMillin, T. Vu, and R, Tukey. 1999. Correlation of CYP1A1 induction, as measured by the P450 RGS biomarker assay, with high molecular weight PAHs in mussels deployed at various sites in San Diego Bay in 1993 and 1995. Mar Env Res 48: 389-405.

[47] Anderson, J.W., J.M. Jones, J. Hameedi, E. Long, and R.H. Tukey. 1999. Comparative analysis of sediment extracts from NOAA's bioeffects studies by the biomarker, P450 reporter gene system. Mar. Env Res 48: 407-425.

[48] American Public Health Association. 1996. P450 reporter gene response to dioxin-like organics (Method 8070). In: *Standard Methods for the Examination of Water and Wastewater* (19th ed., Suppl., pp. 24-25), APHA, Washington, DC.

The results of testing sediment extracts with the RGS correlate well with benthic community effects, and NOAA has derived two thresholds (= warning levels) for which the test is predictive of (1) effects on the benthic community and (2) chronic toxicity. Results from tests using mussel extracts correlate well with PAH TEFs in the mussel tissue, and indicate that the RGS can be used as a screening tool for detection of CYP1A1-inducing compounds in tissue and as an estimate of potential human health or ecological risk from ingestion of contaminated organisms.

Similar tests incorporating the luciferase gene have been developed commercially by the Dutch company Biodetection Systems[49]. Separate tests have been developed for AH induction effects and for estrogenic effects, the latter sensitive to 0.5 pM of pseudo-estrogens, such as nonyl phenol. Because some chemicals that induce an EROD response also show estrogenic activity (e.g. PCBs, dioxins) it is not clear that the tests are able to discriminate between some types of organochlorine compounds and hormones or other hormone mimics.

The Current Trigger Process

The trigger process is specific to sediment-bound contaminants. Possible effects of water-soluble contaminants (e.g., hormones, pharmaceuticals, etc.) and other substances in the water column are not dealt with unless they impact benthic fauna. There is, for example, no trigger related to fecal coliform concentrations.

Attachment A of the triggers document indicates two approaches to developing indicators:

1. Benthic data plus chemistry data. Critical species or taxa are selected for each chemical with presence/ absence being plotted against concentration. The concentration above which a species or taxa is always absent is considered the toxic threshold for that species. For one chemical, all the toxic thresholds are plotted against concentration, and the concentration that protects a large number (90 or 95%) of the species is called the toxic threshold. This is the Ontario Ministry of Environment (OME) approach. The number developed could be sensitive to the influence of rare species, so the species selection would have to be done with care.
2. Just benthic data, no chemistry. Results of benthic monitoring are examined to determine whether they fall outside reference ranges. This approach was developed for the Great Lakes and Puget Sound. Selection of the desired effect size would be an issue, as would similarity of habitat type.

The approach selected by the CRD combines features of both. The reference range approach developed for the Great Lakes and Puget Sound was used to establish biological warning levels. Once the biological criteria were defined, the OME approach was used to identify the associated chemical warning levels.

Biological effect levels were set 2 SD away from the reference mean, for total richness and the Swartz Dominance Index. “At this level, the benthic community has begun to change, but is not yet experiencing community-level adverse effects”[50]. The 2 SD figure comes from PSEP, but there still may be questions about how a biologically meaningful reduction in richness and diversity is defined. The performance of the two biological indicators will be sensitive to changes in the very high abundances of *Capitella* found adjacent to the Macaulay outfall. If other effects are evident in the data, for example among less common species and species that do not occur at all near the outfall, the dominance of *Capitella* in the metrics will tend to mask them.

Concerns with the CRD’s Monitoring Program

What might be the science gaps in the present monitoring program?

[49] www.biodetectionsystems.com/index

[50] CRD. 2000. The trigger process: an early warning of adverse environmental effects for the Clover and Macaulay Point outfalls. LWMP.

1. The list of priority pollutants tested in the effluent does not include EDCs, other than those measured for their toxic or bioaccumulation potential. Specifically, nonylphenol and its ethoxylates are missing from the list. Estradiols and sterols have not been measured in effluent or sediment, other than coprostanol (and coprostanol has been dropped from the parameter set), but it should be noted that the GVRD experienced difficulty measuring estradiol in effluent.

2. Several recently recognised and poorly regulated persistent organic pollutants are also missing from the monitoring program.

3. The 1997 plume dispersion model has defined the area influenced by the plume. A suspended solids dispersion and deposition study, similar to the one done for the GVRD, has not been done. Absence of this information makes it difficult to deal with questions about the fate of particulates discharged with the effluent, and hinders further development in sampling program layout.

4. Similarly, other than early bottom photography, there has been no attempt to look for sediment "traps" between larger features on the bottom near Clover Point (e.g., with towed video or Roxann) that might harbour a soft bottom community[51]. The bottom around the Clover Point outfall is relatively flat, however.

5. The trigger process is specific to sediment-bound contaminants. Possible effects of water-soluble contaminants (e.g., hormones, pharmaceuticals, etc.) and other substances in the water column are not captured unless they impact benthic fauna. There is, for example, no trigger related to fecal coliform concentrations in water or shellfish.

6. FC are monitored monthly, but now only at a depth of 1m. Profiling would give a better indication of the spatial extent of the plume under differing seasonal and current conditions, since the plume traps at depth during the summer, and modeling suggests that the 25-30 m layer is the one maximally impacted.

7. Since studies in southern California did not show a correlation between coliform bacteria and enteroviruses, it may be worth considering a pilot monitoring effort for enteroviruses. Use of the discharge area for contact recreation is limited, however.

8. The information underlying the offshore boundary of the shellfish closure is now over a decade old. While there was a report in the early 1980's that sediment FC contamination extended 2.5 km from the Macaulay Point outfall, and that scallops were contaminated beyond market standards, the offshore extent of coliform contamination does not appear to be well known. Sediment FC monitoring was dropped by the CRD after 1999 for a number of valid reasons, and there is no monitoring for FCs in shellfish. This parameter is spatially under-monitored with reference to the modelled plume, and the issues of resource contamination and the size of the shellfish closure could be re-examined.

9. There is no fish health survey component, other than for mussel growth. Fish health surveys are a common component of other wastewater monitoring programs.

10. In the 1995 mussel monitoring program, insufficient mussels from each station were aged to determine the growth rates at individual stations. This problem affects subsequent correlations between metals and growth rates.

---

[51] Sidescan sonar work on the Victoria Harbour approaches, conducted by the GSC for the CRD, was not reviewed for this report.: Mosher, D.C., and B.D. Bornhold. 1994. Geophysical survey of Victoria Harbour and approaches. Report prepared for the CRD.

11. The CRD does not measure biomass as one of the parameters in the benthic infaunal monitoring program. This would seem to be an omission, considering that enrichment effects have been identified. In the same vein, bottom water DO and sediment redox potential might also help interpret benthic infaunal data sets.

12. Up until 2001, taxonomic identification of infauna from the Macaulay Point samples focused on polychaetes. While other taxonomic groups were keyed out and reported, at least some species were lumped in with others. In 2001, the taxonomic lab used by CRD was changed to the same lab used by GVRD. As a result: the present warning and effects levels may need to be re-estimated.

13. Taxonomic identification before 2001 did not differentiate between adult and juvenile forms. If sampling takes place in the fall, this should be less of an issue than it has been for the GVRD, where sampling takes place in the spring. Experience with the GVRD's data indicates that adding juveniles into the data analysis produces a different picture than it does if the analysis is done with adults only. Juveniles settle indiscriminately over a broad area, and their presence in the data set can mask chronic effects due, for example, to sediment toxicity.

14. The benthic invertebrate data suggest an enrichment effect (>125% reference) at the 800 m stations both east and west of the Macaulay outfall. These are the outermost stations, so the monitoring area for Macaulay Point may not large enough to delimit the area of enrichment. However the power of the enrichment observation should be tested, a procedure that will be difficult with non-metric multi-dimensional scaling analysis.

Concerns for Environment Quality

Has discharge of the effluents created an environmental problem?

1. Diluted sewage reaches the surface during winter at both locations, as evidenced by the model and FC levels. Solids surfacing with the plume also provide a food source for seabirds, and presumably for other marine life. Since many contaminants are found in association with solids, the surfacing plume is a source of contaminants to local seabirds.

2. The plume dispersion model shows that maximum FC concentrations follow topography above the 60 m level. At the surface, modelled concentrations of fecal coliform above 20 cfu/ 100 mL were found along the Victoria foreshore from the Inner Harbour to Trial Island. The monitoring program area is not large enough to delineate the affected area modelled for the plume, if the criterion of concern is 14 MPN/100 mL, and there is presently no subsurface monitoring for FC. It should be noted, however, that the CRD has a separate shoreline bacteriological monitoring program that was not reviewed for this report.

3. The 1998 mussel gonadal index study indicates that the timing of gonadal maturation was more advanced at the outfall terminus than further away. This finding is not inconsistent with the range of effects caused by EDCs, although similar effects might be caused by nutrient enrichment.

4. The mean richness and total abundance data for benthic infauna suggested an adverse impact on the benthic community close (<100-200 m) to the Macaulay Point outfall in both 1994 and 1997. The data suggest that assimilative capacity was being overwhelmed within this zone.

5. The gradient of chemicals in mussels indicates a sublethal effect near the outfall (metal depletion), but effects on growth appear limited.

6. There are grounds for concern about the potential for endocrine disruption in benthic ecosystems, based on sediment quality guidelines. Specifically two chemicals can be mentioned:
   - Butyl benzyl phthalate has exceeded Washington sediment quality standards (SQS) in sediment at both outfalls (1995 and 96)
   - Dibutyl phthalate has exceeded SQS at the Clover Point outfall (1996)

   The extent to which sample contamination has contributed to this problem might be an issue.