FINAL REPORT

Water and Sediment Quality Assessment

for Departure Bay Creek, Nanaimo, BC,

(22 November 2006)

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and

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Background

This report documents a study of the water and sediment quality conducted on Departure Bay Creek, Nanaimo, BC, on 22 November 2006.

The field portion of this study was undertaken by 3rd year undergraduate students attending the Environmental Monitoring (RMOT 306) course at Malapsina University-College, offered as part of the Bachelor of Natural Resources Protection. Students worked under the supervision of the course instructor, Dr. Eric Demers (Malaspina). Logistical support was provided by Fisheries and Oceans Canada (DFO), and the City of Nanaimo. DFO provided funding for the analytical processing of field samples. This report was written by Dr. Eric Demers and Margaret Wright (DFO).

Specific objectives for this study of Departure Bay Creek included:

- establish 10 water quality sampling stations with proper Global Positioning System (GPS) referencing;
- obtain field measurements of water quality at the 10 sampling stations;
- obtain hydrological measurements at 4 selected sampling stations;
- obtain 10 water samples and 4 sediment samples for submission to an analytical laboratory; and,
- collect water samples for coliform analysis at Malaspina University-College.

Methods

Sampling Stations

A total of 10 stations were established for sampling water and sediment quality on Departure Bay Creek, during 22 November 2006 (Figure 1, Tables 1 and 2). Stations were generally numbered from the downstream end to the upstream end of the watershed. The location of each station was based on a previous water quality survey completed on 31 March 2006 by the Nanaimo & Area Land Trust (NALT) (Rob Lawrance, City of Nanaimo, personal communication). All stations were easily accessed near public road crossings and/or City of Nanaimo parks, except for Station DC10 which was located at the northernmost end of the Nanaimo Golf Club and was accessed through private property (with permission from the landowner at 2990 Cosgrove Crescent).

Most stations were located on the main stem of Departure Bay Creek, except for Stations DC4, DC7 and DC10. Station DC4 was located on a small side channel connected to the main stem of Departure Bay Creek in Woodstream Park. Station DC7 was located on a small tributary that joined Departure Bay Creek on its right bank in Woodstream Park. Station DC10 was a ditch draining small ponds at the northernmost end of the Nanaimo Golf Club. This ditch entered the storm sewerage system just downstream of Station DC10 to eventually daylight in the main stem of Departure Bay Creek (between Stations DC8 and DC9) at the north end of Keighley Road (based on City of Nanaimo's CityMap).

Table 1. Description of the sampling stations used for water and sediment quality on Departure Bay Creek, during 22 November 2006. All northing and easting coordinates are based on zone 10U.

Station	UTM Coordinates		General Location
	Northing	Easting	
DC1	0429394	5450857	Departure Bay waterfront
DC2	0429271	5450777	Departure Bay Centennial Park
DC3	0429070	5450836	Bay St. crossing, Woodstream Park
DC4	0428992	5450919	Woodstream Park, Side channel
DC5	0428993	5450871	Woodstream Park, Main stem
DC6	0428842	5450929	Woodstream Park, Main stem
DC7	0428810	5450928	Woodstream Park, Small tributary
DC8	0428412	5451159	3068 Newton St.
DC9	0428081	5451086	3048 Neyland Rd
DC10	0428381	5450719	Nanaimo Golf Club, private access via 2990 Cosgrove Cr.

Table 2. Sampling activities conducted at each station on Departure Bay Creek, during 22 November 2006. An "X" indicates that samples or measurements were taken.

Station	Field Measurements		Sample Collection		
	Water Quality	Basic Hydrology	Water	Coliform	Sediment
DC1	X	X	X	X	X
DC2	X		X	X	
DC3	X		X	X	
DC4	X		X	X	
DC5	X		X	X	
DC6	X	X	X	X	X
DC7	X	X	X	X	X
DC8	X	X	X	X	X
DC9	X		X	X	
DC10	X		X	X	
TOTAL	10	4	10	10	4

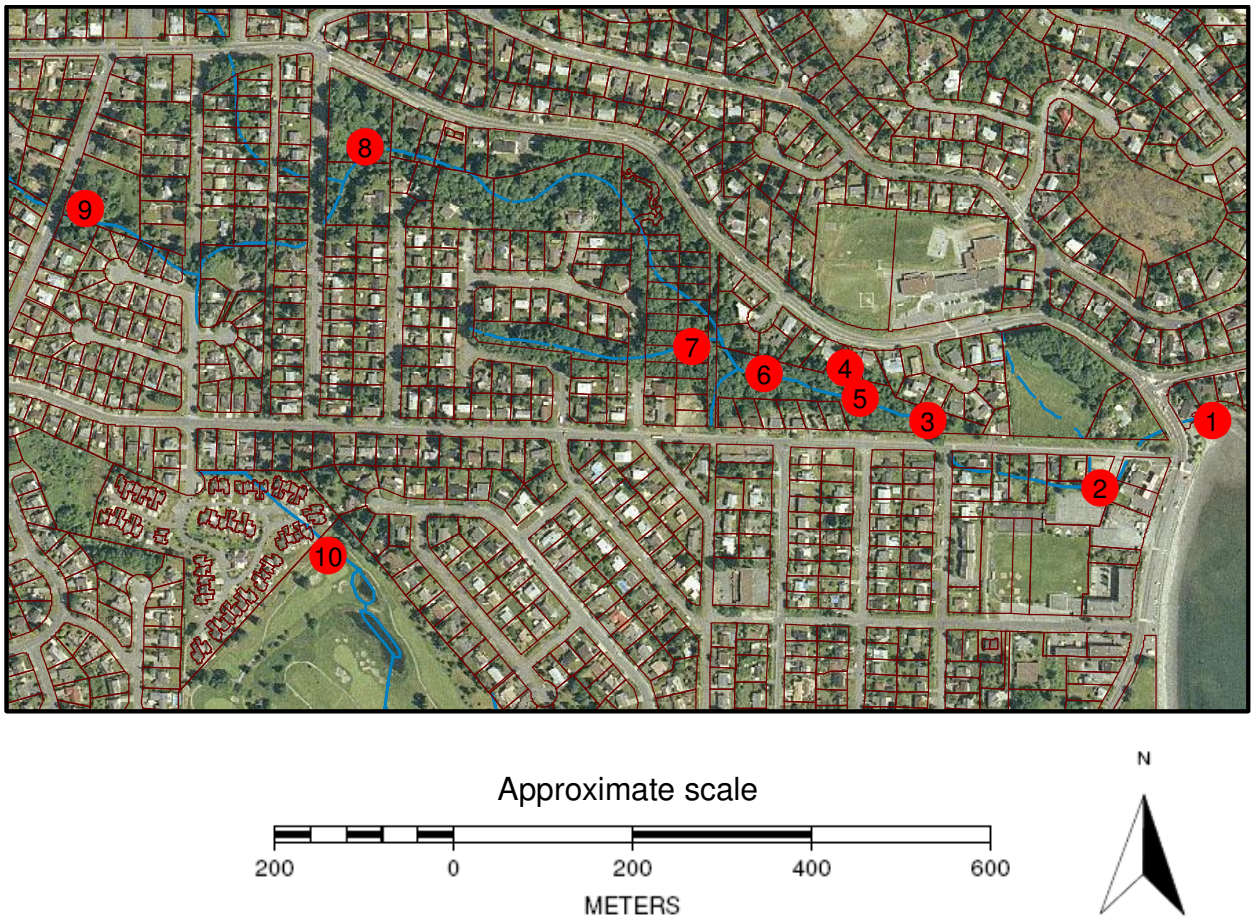

Figure 1. Approximate location of the sampling stations (red numbered circles; prefix "DC" not included for clarity) used for water and sediment quality on Departure Bay Creek, during 22 November 2006. Departure Bay Creek and some of its tributaries are shown as blue lines. Table 2 details the sampling activities conducted at each station. This map and aerial photo (taken in 2003) were obtained from the City of Nanaimo's CityMap. Map scale is approximated.

Field Measurements

At each sampling station, Universal Transverse Mercator (UTM) coordinates were obtained with a Garmin 12XL Global Positioning System (GPS) receiver. Then, field measurements of water temperature (to the nearest 0.01 ^{o}C), dissolved oxygen (to the nearest 0.01 mg/L), conductivity (to the nearest 0.1 µSiemens/cm) and pH (to the nearest 0.01 pH unit) were obtained with a Hydrolab DataSonde probe attached to a Hydrolab Surveyor 4 datalogger. The electronic probe was placed directly in the creek water. At least one photograph was taken at each sampling station (see Appendix 1).

Basic hydrological measurements were taken at 4 stations: DC1, DC6, DC7 and DC8. Local flow conditions and/or stream characteristics prevented reliable similar measurements at the remaining stations. Water velocity (in m/s) was measured along a 2-m stream length. A water-filled plastic vial (20 ml) was dropped slightly upstream of the stream length and allowed to float

downstream through the stream length. A stopwatch was used to measure the travel time of the vial between the upstream and downstream ends of the stream length. The average travel time from 3-5 passes was used to calculate average surface velocity. A correction factor (k = 0.85) was then applied to obtain an estimate of the mean water column velocity (Hauer and Lamberti 1996).

Stream wetted widths were measured with a metered tape to the nearest 0.1 m, and wetted depths were measured (along the same wetted widths) with a meter stick to the nearest 0.01 m. Total cross-sectional areas (in m^2) were calculated as the sum of the areas of cross-section polygons. Stream discharge (in m^3/s) was obtained as the product of mean water column velocity and cross sectional area.

Water Quality

Water samples were collected from each of the 10 sampling stations on 22 November 2006 (Tables 2 and 3). At each station, three clean laboratory-supplied and pre-labelled sample containers were used to collect the water samples. Samples for general parameters and total metals were obtained by directly immersing the containers by hand just below the water surface while facing upstream. Care was taken not to disturb the bottom sediments. Samples for dissolved metals were obtained using a 60-ml syringe and filtered through non-reusable 0.45 µm inline filters. All sample containers and syringes were rinsed 3 times prior to sample collection. Total and dissolved metal samples were preserved with laboratory-supplied nitric acid, and bottles were inversed five times for adequate mixing. All water samples were stored in a cooler with ice packs and shipped within 24 hours for laboratory analyses at the Pacific Environmental Science Centre (Environment Canada), in North Vancouver, BC.

Table 3. Sampling containers and preservatives used for water quality samples taken from Departure Bay Creek, on 22 November 2006. All containers, preservatives and filters were provided by the Pacific Environmental Science Centre (Environment Canada), North Vancouver, BC.

Analytical Parameters	Container	Filtration	Preservative
General parameters			
Non-filterable residues, pH, hardness, alkalinity, dissolved anions, nutrients	1 L plastic	None	None
Total metals	250 ml plastic	None	Nitric acid
Dissolved metals	250 ml plastic	0.45 µm	Nitric acid

Total and Fecal Coliform

Water samples for total and fecal coliform enumeration were collected from each of the 10 sampling stations on 22 November 2006 (Table 2). At each station, a sterile pre-labelled 120-ml Whirl-Pak® bag was used to collect a 100 ml water sample by directly immersing the bag by hand just below the water surface while facing upstream. All samples were stored in a cooler with ice packs and transported to Malaspina University-College for laboratory analysis.

In the laboratory, water samples were tested for total coliform and fecal coliform (*Escherichia coli* or *E. coli*) using the m-coliBlue24 membrane filtration method (Millipore Corporation). A 50-ml volume of sample was filtered through a 47-µm membrane filter (marked with 3-mm gridlines) using a vacuum pump. The filtration apparatus was then rinsed with approximately 5 ml of sterile water. Two filtration blanks (one before and one after the ten samples) were completed with 50-ml samples of sterile water using the same filtration procedures. Each membrane filter (including blanks) was then transferred to a 100-mm petri plate containing an absorbent pad saturated with m-ColiBlue24 broth. All membrane filters were incubated at 37°C for 18 hours (until bacterial colonies were clearly visible).

Upon completion of the incubation period, membrane filters were then examined for bacterial colonies under a dissection microscope (16X magnification). A red or blue colony represents a total coliform "positive" result (Table 4). A blue colony specifically represents an *E. coli* "positive" result. A clear or white colony represents a total coliform negative result.

Table 4. Possible outcomes of the m-coliBlue24 membrane filtration method.

Bacteria Type	Positive Result	Negative Result
Total coliform	Red or blue colony	Clear or white colony No colony
E. coli	Blue colony only	Non-blue colony

Whenever possible, all colonies present on a membrane filter were counted. If too many colonies were present to allow for direct counts (i.e., >200 colonies), sub-sample counts were taken from ten randomly selected squares (each 9 mm^2). Average counts for the ten squares were then extrapolated for the entire filter area (908 mm^2).

Sediment Quality

Sediment samples were collected from 4 sampling stations on 22 November 2006 (Table 2). These stations were selected based on the local flow conditions and stream substrate characteristics. These stations had relatively similar substrate types that could be used for reliable analytical comparisons. At each station, three clean laboratory-supplied and pre-labelled sample containers were used to collect the sediment samples (Table 4). Sediments were taken using a clean stainless steel spoon and transferred directly into the sample containers, with no headspace. The sampler moved slightly upstream while sampling to avoid possible contamination of samples. All samples were stored in a cooler with ice packs. Sediment samples to be analysed for organic substances (oil and grease, hydrocarbons) and metals were shipped on the same day for laboratory analyses at the Pacific Environmental Science Centre (Environment Canada), in North Vancouver, BC. Sediment samples to be analysed for particle size distribution were shipped to Cantest Ltd, in Burnaby, BC, on 02 February 2007.

Table 4. Sampling containers used for sediment quality samples taken from Departure Bay, on 22 November 2006. All containers were provided by the Pacific Environmental Science Centre (PESC), North Vancouver, BC.

Analytical Parameters	Container	Analysed By
Total oil and grease, hydrocarbons	180 ml amber glass	PESC
Total metals	125 ml plastic cup	PESC
Particle size determination	125 ml plastic cup	Cantest

Quality Assurance / Quality Control

Throughout this study, measures were taken to ensure that potential contamination of water and sediment samples was minimized. This included wearing gloves to collect all samples, using only new clean containers, preserving samples as prescribed by the analytical laboratory, and storing collected samples in well-labelled containers. All field measurements and information were recorded on waterproof datasheets.

Data Analyses – Comparison with Applicable Guidelines

Water quality results were compared with the provincial and federal water quality guidelines for the protection of freshwater life. The BC Water Quality Guidelines are the maximum allowable concentration (for potential acute effects) and the 30-day average concentration (for potential chronic effects) (BCMWLAP 1998a, 1998b). The guidelines from the Canadian Council of Ministers of the Environment were also used for water quality comparisons (CCME 1999). Both sets of guidelines were applicable to all 10 sampling stations.

It is important to note that for some metal parameters, analytical detection limits were above applicable guidelines. These include antimony, arsenic, cadmium, chromium, cobalt, copper, lead, selenium and silver. For these metals, measured values reported to be below method detection limits cannot be assumed to be below the applicable guidelines.

The percentage of total metal concentration that was made up of dissolved metal was calculated for every pair of dissolved and total metal concentrations. The purpose of this comparison was to assess the proportion of total metals that was bio-available and to confirm the accuracy and reliability of dissolved metal concentrations. Dissolved metal concentrations were plotted against total metal concentrations (log-log scale) to show the relative abundance of cases in which dissolved metal concentration exceeded total metal concentration, thereby indicating the possibility of contamination of dissolved metal samples.

Sediment quality parameters were compared to provincial and federal standards. Total metal concentrations at each station were compared with the BC Sediment Quality Guidelines (BCMWLAP 2002). These included guidelines for Sensitive Contaminated Sites (SCS) and

Typical Contaminated Sites (TCS). The SCS are concentrations below which harmful effects on benthic organisms are not likely to be observed, and the TCS are concentrations at which some effects may be observed.

In the absence of SCS and TCS, Level 1 and Level 2 Sediment Quality Guidelines (SQG: BCMWLAP 1999), or lowest effect level (LEL) and severe effect level (SEL) (BCMWLAP, 1998a, 1998b) were used. Level 1 SQGs reflect the concentrations of contaminants that are not likely to impact sediment-dwelling organisms, whereas Level 2 SQGs reflect the concentrations of contaminants that are likely to cause minor impacts on sediment-dwelling organisms.

The federal sediment quality guidelines are outlined by CCME (1999). Two assessment values are used to establish an association between the concentration of each chemical measured in the sediment and any adverse biological effect observed. The lower value, referred to as the threshold effect level (TEL), represents the concentration below which adverse biological effects are expected to rarely occur. To date, spiked-sediment toxicity data are limited; therefore, interim sediment quality guidelines (ISQGs), are reported instead of TELs. The upper value, referred to as the probable effect level (PEL), defines the level above which adverse effects are expected to occur frequently.

Results

On 22 November 2006, the water levels in Departure Bay Creek were near bankfull. A total of approximately 278 mm of precipitation had fallen over 20 consecutive days between 2 and 21 November 2006 (data for Victoria Airport retrieved from http://www.theweathernetwork.com). During this sampling program, weather conditions were overcast with rain, wind calm and air temperature of 5^{o}C.

Field Measurements

Water temperature ranged from 7.59 to 9.46^{o}C at the time of sampling (Table 5), and there was a general warming trend from upstream to downstream (i.e., from Station DC10 to DC1). Dissolved oxygen ranged from 5.34 to 9.04 mg/L. The lowest dissolved oxygen level was obtained at Station DC4, which was located in a stagnant side channel with no measurable flow. Conductivity ranged from 50.7 to 339.9 µS/cm, and there was a general increasing trend from upstream to downstream. The highest conductivity value was measured at Station DC10, located in a small ditch that drains ponds at the Nanaimo Golf Club. This high conductivity water appears to be strongly diluted when it enters Departure Bay Creek upstream of Station DC8. The pH measurements were relatively constant and ranged from 7.09 to 8.16, with the lowest measurement obtained from the stagnant side channel at Station DC4.

Table 5. Field measurements of water temperature, dissolved oxygen, conductivity and pH taken from 10 stations on Departure Bay Creek during 22 November 2006.

Station	Time	Temperature (^{o}C)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	pH
DC1	14:52	9.08	8.10	172.5	7.95
DC2	14:43	9.20	7.76	186.8	7.96
DC3	14:37	9.21	6.85	170.9	7.98
DC4	14:20	9.20	5.34	214.1	7.09
DC5	14:25	9.13	6.67	161.6	8.08
DC6	14:00	9.46	6.87	200.1	8.16
DC7	15:45	8.47	8.69	97.9	7.82
DC8	16:00	8.04	8.94	92.3	7.76
DC9	15:15	7.59	8.08	50.7	7.42
DC10	15:30	7.67	9.04	339.9	7.97

The hydrological measurements are representative of near bankfull conditions (Table 6). As expected, there was an increased in water discharge from upstream to downstream. The small tributary at Station DC7 contributes <10% of the discharge of Departure Bay Creek, as measured just downstream of their confluence at Station DC6.

Table 6. Basic hydrological measurements taken from 4 stations on Departure Bay Creek during 22 November 2006.

Station	Wetted Width (m)	Mean Water Depth (m)	Water velocity (m/s)	Water Discharge (m^3/s)
DC1	3.8	0.28	0.49	0.53
DC6	3.9	0.13	0.55	0.28
DC7	1.0	0.06	0.32	0.02
DC8	3.0	0.15	0.39	0.17

Water Quality

Water quality results were compared to BC Provincial water quality guidelines and the federal CCME guidelines for the protection of aquatic life (Table 7).

Most sample values were within normal range for the physical variables and dissolved ions. One notable exception was that all pH values indicated acidic conditions, with a range of 2.49 to 5.63. These pH measurements are significantly lower than those obtained as part of the field measurements. The electronic probe used for field measurements was calibrated before and after its use for this project, and readings were found to be consistent among calibrations. Therefore, the low pH measurements were most likely due to laboratory error.

Nutrient values were also within normal range for nitrogen and phosphorus. One exception was the ammonia and total phosphorus at Station DC10, which were at least 10 times higher than the average for the other nine stations.

All dissolved metal concentrations were below the applicable guidelines, with the exception of zinc which exceeded the BC 30-day mean guideline in 9 out of 10 water samples (all sampling stations, except Station DC7).

For total metals, there were exceedances for aluminium, copper, iron, nickel and zinc. All samples had total aluminium concentrations that exceeded the BC 30-day mean guideline, and 8 of 10 samples exceeded the BC maximum and CCME guidelines (all sampling stations, except Stations DC4 and DC6). Seven samples had copper concentrations that exceeded all three applicable guidelines (all sampling stations, except Station DC3, DC6 and DC8). Nine samples had iron concentrations that exceeded the BC maximum and CCME guidelines (all sampling stations, except Station DC6). One sample (Station DC10) exceeded the BC maximum and CCME guidelines for nickel. All samples had total zinc concentrations that exceeded the BC 30-day mean guideline, and one sample (Stations DC2) exceeded the BC maximum guideline.

Dissolved metals are more bio-available than metals that are bound to particles. Hence, the ratio of dissolved metal concentration to total metal concentration is an index of the potential biological impact of a metal. Expressed as a percentage, the ratios from all 10 stations ranged from 2.5 to 136%. All of the percentages above 100% are in error because, by definition, dissolved metal concentration cannot be higher than total metal concentration. In practice, however, dissolved / total percentages above 100% are common because of unavoidable sample contamination and/or analytical measurement error. For these samples, 14 of 120 ratios calculated were greater than 100%, and these represented all samples analysed for sulphur and 4 samples analysed for sodium.

A graph of dissolved and total metals plotted against each other (log-log axes) indicates that, for most metals, the ratio of dissolved to total concentration was near 100% since most points were scattered near the 1:1 line (Figure 2). The graph also shows lower bioavailability for manganese and iron, which have points scattered below the 1:1 line.

Table 7. Water quality screening for Departure Bay Creek, Nanaimo, during 22 November 2006.

	BC Water Quality Guidelines [a]			Sampling Stations									
	BC Max	BC 30-day Mean	CCME [b]										
Variable	mg/L	mg/L	mg/L	DC 1	DC 2	DC 3	DC 4	DC 5	DC 6	DC 7	DC 8	DC 9	DC 10
General/Physical													
Residue, Nonfilterable (NFR)	+ 25 of background [c]			27	15	16	<5	10	<5	11	7	18	12
Hardness,Ca+Mg - calc.				53.9	59.3	54.0	32.4	59.7	65.5	28.6	31.4	19.9	70.9
Hardness, Total - calc.				54.2	59.5	54.1	33.0	59.8	65.7	28.7	31.6	19.9	71.1
pH	6.5 - 9.0		6.5 - 9.0	3.16	3.30	2.49	2.83	3.10	2.81	3.89	3.52	5.63	2.90
Dissolved Ions													
Alkalinity (to pH 4.5)				51.7	<0.5	49.3						<0.5	
Chloride (Cl)	600	150		17.5	17.2	17.2	26.0	18.8	21.5	9.9	9.3	5.2	38.0
Fluoride (F)	0.2 - 0.3 [d]			0.04	0.04	0.04	0.05	0.04	0.04	0.02	0.04	0.01	0.07
Sulphate (SO4)	100			9.0	9.0	9.5	16.3	10.2	10.9	5.7	5.3	3.5	12.4
Bromide (Br)				<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Nutrients													
Nitrogen, Ammonia as N	3.74 - 19.1 [e]	0.718 - 1.84 [e]	0.715 [e]	0.002	<0.002	< 0.002	0.046	<0.002	0.004	<0.002	0.021	0.005	0.288
Nitrogen, Nitrate as N	200	40	13	1.45	1.58	1.67	0.59	1.78	1.89	1.21	0.94	0.77	0.94
Nitrogen, Nitrite as N	0.18 - 0.60 [f]	0.06 - 0.20 [f]	0.06	0.007	0.008	0.007	0.017	0.007	0.007	0.014	0.018	0.006	0.013
Phosphorus, Ortho as P				<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.23
Phosphorus, Total as P				0.056	0.037	0.040	0.031	0.023	0.015	0.045	0.056	0.040	0.410
Dissolved Metals													
Aluminum (Al)	0.10 [g]	0.05 [g]	0.10 [g]	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Antimony (Sb)	0.02			< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Arsenic (As)	0.005			< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Barium (Ba)	5	1		0.008	0.009	0.008	0.007	0.009	0.010	0.004	0.005	0.003	0.024
Berylium (Be)	0.0053			< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Boron (B)	1.2			0.06	0.07	0.06	0.16	0.06	0.07	0.05	0.04	0.02	0.18
Cadmium (Cd)	0.0000083 - 0.000025 [h]		0.0000083 - 0.000025 [h]	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Calcium (Ca)				14.5	16.0	14.7	9.1	16.3	17.8	7.9	8.7	5.7	18.7
Chromium (Cr)	0.001 [i]		0.001 [i]	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cobalt (Co)	0.11	0.004		< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Copper (Cu)	0.0039 - 0.0087 [j]	0.002 - 0.0028 [j]	0.002 [j]	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Iron (Fe)	0.3		0.3	0.102	0.048	0.036	0.219	0.033	0.032	0.025	0.048	0.018	0.049
Lead (Pb)	0.010 - 0.053 [k]	0.0037 - 0.0054 [k]	0.001 - 0.002 [k]	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Magnesium (Mg)				4.3	4.7	4.2	2.4	4.6	5.1	2.2	2.3	1.3	5.9
Manganese (Mn)	0.76 - 1.32 [l]	0.69 - 0.92 [l]		0.008	0.008	0.006	0.022	0.006	0.006	< 0.001	0.010	0.006	0.009
Molybdenum (Mo)	2	1	0.073	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Nickel (Ni)	0.025 - 0.065 [m]		0.025 - 0.065 [m]	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Phosphorus (P)				< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.4
Potassium (K)				1.4	1.4	1.4	0.3	1.5	1.6	1.1	1.1	0.8	4.0
Selenium (Se)		0.002	0.001	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Silicon (Si)				4.57	5.00	4.59	6.14	5.04	5.53	2.51	2.83	1.76	3.28
Silver (Ag)	0.0001 [n]	0.00005 [n]	0.0001	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sodium (Na)				14.6	15.6	14.3	28.2	15.5	16.8	10.5	7.5	3.5	42.0
Strontium (Sr)				0.065	0.072	0.066	0.055	0.073	0.080	0.037	0.039	0.024	0.108
Sulfur (S)				3.16	3.34	3.10	5.47	3.38	3.67	1.95	1.84	1.20	4.25
Tin (Sn)				< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Titanium (Ti)				< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Vanadium (V)				< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Zinc (Zn)	0.033 [o]	0.0075 [o]		0.010	0.012	0.010	0.008	0.016	0.014	0.007	0.014	0.016	0.012

Table 7. Water quality screening for Departure Bay Creek, Nanaimo, during 22 November 2006. (continued)

	BC Water Quality Guidelines [a]			Sampling Stations									
	BC Max	BC 30-day Mean	CCME [b]										
Variable	mg/L	mg/L	mg/L	DC 1	DC 2	DC 3	DC 4	DC 5	DC 6	DC 7	DC 8	DC 9	DC 10
Total Metals													
Aluminum (Al)	0.10 [g]	0.05 [g]	0.10 [g]	0.82	0.28	0.68	0.07	0.59	0.09	0.88	0.45	0.58	0.47
Antimony (Sb)	0.02			< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Arsenic (As)	0.005			< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Barium (Ba)	5	1		0.017	0.012	0.014	0.008	0.014	0.012	0.009	0.009	0.008	0.032
Berylium (Be)	0.0053			< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Boron (B)	1.2			0.06	0.07	0.07	0.17	0.07	0.07	0.06	0.04	0.03	0.20
Cadmium (Cd)	0.0000083 - 0.000025 [h]		0.0000083 - 0.000025 [h]	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006
Calcium (Ca)				15.2	17.3	16.5	15.2	17.5	18.2	8.6	8.9	6.1	19.7
Chromium (Cr)	0.001 [i]		0.001 [i]	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006
Cobalt (Co)	0.11	0.004		< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006
Copper (Cu)	0.0039 - 0.0087 [j]	0.002 - 0.0028 [j]	0.002 [j]	0.010	0.073	< 0.006	0.008	0.010	< 0.006	0.008	< 0.006	0.009	0.018
Iron (Fe)	0.3		0.3	1.160	0.443	0.906	0.601	1.200	0.177	0.976	0.620	0.720	0.538
Lead (Pb)	0.010 - 0.053 [k]	0.0037 - 0.0054 [k]	0.001 - 0.002 [k]	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Magnesium (Mg)				4.4	5.0	4.6	2.5	4.9	5.1	2.3	2.4	1.5	6.0
Manganese (Mn)	0.76 - 1.32 [l]	0.69 - 0.92 [l]		0.063	0.022	0.044	0.029	0.038	0.013	0.027	0.029	0.029	0.039
Molybdenum (Mo)	2	1	0.073	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Nickel (Ni)	0.025 - 0.065 [m]		0.025 - 0.065 [m]	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.04
Phosphorus (P)				< 0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.5
Potassium (K)				1.4	1.5	1.4	0.3	1.5	1.6	1.1	1.1	0.8	4.1
Selenium (Se)		0.002	0.001	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Silicon (Si)				5.84	5.75	5.97	6.44	6.26	5.80	3.97	3.62	2.83	4.38
Silver (Ag)	0.0001 [n]	0.00005 [n]	0.0001	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sodium (Na)				14.5	15.8	15.0	29.1	15.9	17.0	10.3	7.3	3.4	42.0
Strontium (Sr)				0.069	0.076	0.072	0.061	0.076	0.082	0.040	0.039	0.026	0.110
Sulfur (S)				2.65	3.18	2.85	5.10	3.06	3.22	1.64	1.41	0.88	3.93
Tin (Sn)				< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Titanium (Ti)				0.065	0.024	0.058	0.006	0.049	0.008	0.074	0.036	0.049	0.035
Vanadium (V)				< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Zinc (Zn)	0.033 [o]	0.0075 [o]		0.032	0.051	0.021	0.021	0.023	0.015	0.014	0.018	0.023	0.021

NOTES:

Results are expressed as mg/L except where noted.

"<" means less than the detection limit.

Values that exceed one or more of the lowest guideline values are in boxes.

[a] BC Water Quality Guidelines (WQG) compiled from http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html#approved.

[b] Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines (WQGs) compiled from CCME (2003).

[c] Relative change from background (reference) conditions.

[d] Fluoride guideline is dependent on hardness: 0.2 mg/L if hardness is < 50 mg/L, 0.3 mg/L if hardness >= 50 mg/L.

[e] Ammonia guideline is dependent on temperature and pH. Guideline range shown is based on temperatures of 7 to 10°C and pH of 7.1 to 8.2 based on field measurements.

[f] Nitrite guideline is dependent on chloride concentration. Guideline range shown is based on chloride concentrations of 5.2 to 38 mg/L based on this table.

[g] Aluminium guidelines for pH >= 6.5.

[h] Cadmium guideline = $0.001 * 10^{\{0.86[\log(\text{hardness})]-3.2\}}$ mg/L. Guideline range shown is based on hardness of 19.9 to 71.1 mg/L based on this table.

[i] Chromium guideline is for the more toxic Chromium VI. The guideline for Chromium III is 0.0089 mg/L.

[j] The BC maximum copper guideline is (0.000094(hardness)+2) mg/L.
The BC 30-day mean copper guideline is 0.002 ug/L for hardness < 50 mg/L, and 0.00004*(hardness) mg/L for hardness >= 50 mg/L.
The CCME guideline for copper is 0.002 mg/L at hardness of 1-120 mg/L.

[k] The BC maximum lead guideline is $0.001(e^{(1.273\ln(\text{hardness}) - 1.460)})$ mg/L for hardness > 8 mg/L.
The BC 30-day mean lead guideline is $0.001(3.31 + e^{(1.273\ln(\text{hardness}) - 1.4704)})$ mg/L for hardness > 8 mg/L.
The CCME guideline for lead = 0.001 mg/L for hardness = 0-60 mg/L, and 0.002 mg/L for hardness of 60-120 mg/L.

[l] The BC maximum manganese guideline is 0.01102*(hardness)+0.54 mg/L. The BC 30-day mean manganese guideline is 0.0044*(hardness)+0.605 mg/L.

[m] Nickel guideline is 0.025 mg/L for hardness = 0-60 mg/L, and 0.065 mg/L for hardness of 60-120 mg/L.

[n] The BC maximum silver guideline is 0.0001 mg/L for hardness =< 100 mg/L. The BC 30-day mean silver guidelines is 0.00005 mg/L for hardness =< 100 mg/L.

[o] The BC maximum zinc guideline is 0.033 mg/L for hardness =< 90 mg/L. The BC 30-day mean zinc guidelines is 0.0075 mg/L for hardness =< 90 mg/L.

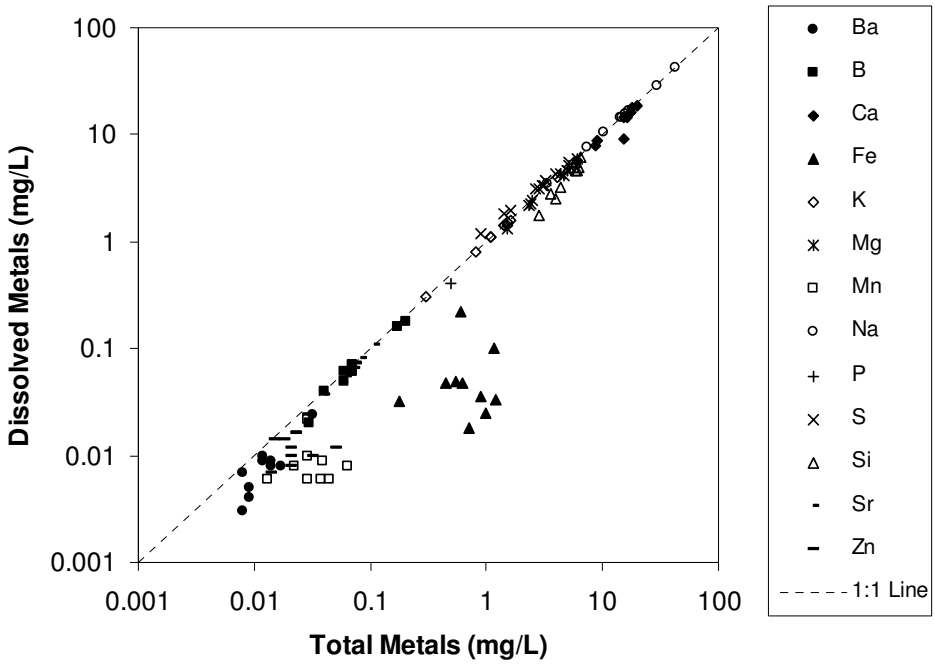

Figure 2. Dissolved metal concentrations plotted against total metal concentrations for water samples taken at 10 stations on Departure Bay Creek during 22 November 2006. Different symbols represent different metals. Values below the 1:1 line indicate that a metal is less bio-available than values closer to the 1:1 line. Values above the 1:1 line may indicate possible sample contamination and/or analytical error.

Total and Fecal Coliform

All samples collected from Departure Bay Creek contained some *E. coli* bacteria and other coliforms (Table 8). There was a general increase in bacterial content (both total coliform and *E. coli*) from upstream to downstream (i.e., from Station DC10 to DC1). Similarly, the percentage contribution of *E. coli* in total coliform also increased from upstream to downstream. One notable exception was the lower bacterial counts from the stagnant side channel at Station DC4.

The filtration blanks completed with sterile water before and after the ten field samples did not produce any bacterial colonies.

Table 8. Total coliform and *E. coli* counts from water samples taken at 10 stations on Departure Bay Creek during 22 November 2006. All values are expressed as number of bacteria per 100 ml.

Station	Total Coliform	*E. coli*	% *E. coli*
DC1	7,385	5,912	80.1
DC2	3,329	2,240	67.3
DC3	4,701	2,280	48.5
DC4	218	46	21.1
DC5	3,491	2,805	80.3
DC6	1,340	170	12.7
DC7	2,344	64	2.7
DC8	3,928	538	13.7
DC9	1,444	314	21.7
DC10	1,273	62	4.9
Filtration blank (before)	0	0	–
Filtration blank (after)	0	0	–

Sediment Quality

Sediment particle size was composed mainly of gravel and sand. The predominant sediment size at Stations DC 6 and DC 7 was found to be gravel (75.2% and 90.6%, respectively), with sand being the second most abundance substrate. The predominant particle size at Stations DC1 and DC 8 was found to be sand (74.4% and 66.3% respectively), with gravel being the second most abundance substrate.

Most total metal concentrations were below the applicable guidelines, although there was one exceedance at Station DC7 and four exceedances at Station DC8. The copper concentration at Station DC8 exceeded CCME interim sediment quality guideline. The iron concentration at Stations DC7 and DC8 exceeded the BC sensitive contaminated site guideline. The manganese concentration at Stations DC8 exceeded the BC sensitive contaminated site guideline. The zinc concentration at Station DC8 exceeded CCME interim sediment quality guideline.

Table 9. Sediment quality screening for Departure Bay Creek, Nanaimo, during 22 November 2006.

	BC Sed. Quality Guidelines [a]		CCME [d]					
	SCS [b]	TCS [c]	ISQG [e]	PEL [f]	Sampling Stations			
Variable	mg/kg	mg/kg	mg/kg	mg/kg	DC 1	DC 6	DC 7	DC 8
Particle Size (%)								
Gravel (>2.0 mm)					24.9	75.2	90.6	31.8
Sand (0.053 - 2.0 mm)					74.4	24.3	9.1	66.3
Silt (0.002 - 0.053 mm)					0.3	0.3	0.2	1.2
Clay (<0.002 mm)					0.4	0.2	0.1	0.7
Total Metals								
Aluminum (Al)					6430	11800	13300	13800
Antimony (Sb)					< 5	< 5	< 5	< 5
Arsenic (As)	12	20	5.9	17	< 5	< 5	< 5	< 5
Barium (Ba)					18.0	26.6	22.6	39.7
Berylium (Be)					0.1	< 0.1	< 0.1	< 0.1
Boron (B)					7	3	3	3
Cadmium (Cd)	2.1	4.2	0.6	3.5	< 0.5	< 0.5	< 0.5	< 0.5
Calcium (Ca)					5270	7280	7790	7040
Chromium (Cr)	64	110	37.3	90	9.7	21.9	26.2	23.2
Cobalt (Co)					4.9	10.1	11.1	11.7
Copper (Cu)	120	240	35.7	197	12.6	23.2	32.0	40.5
Iron (Fe)	21200 [h]	43766 [h]			10000	20900	24000	29200
Lead (Pb)	63	110	35	91.3	7	7	9	24
Magnesium (Mg)					3300	5770	6980	7110
Manganese (Mn)	460 [h]	1100 [h]			138	390	290	551
Molybdenum (Mo)					< 1	< 1	< 1	< 1
Nickel (Ni)	36 [g]	49 [g]			10	20	23	24
Phosphorus (P)					297	244	295	350
Potassium (K)					279	144	175	207
Selenium (Se)	5 [h]				< 5	< 5	< 5	< 5
Silicon (Si)					271	141	92	73
Silver (Ag)	1.6 [g]	2.2 [g]			< 1	< 1	< 1	< 1
Sodium (Na)					751	162	192	202
Strontium (Sr)					30.5	13.5	14.2	18.8
Sulfur (S)					166	98	98	179
Tin (Sn)					< 5	< 5	< 5	27
Titanium (Ti)					978	1750	1950	1920
Vanadium (V)					31	64	67	77
Zinc (Zn)	220	380	123	315	30.9	72.4	59.8	126.0
Oil & Grease tests								
Hydrocarbons					< 10	< 10	43	< 10
Total Oil & Grease					22	< 10	118	< 10

NOTES:

All values in mg/kg dry weight, except for particle sizes which are reported as percentages.

[a] BC Ministry of Water, Land and Air Protection (2002) Generic Sediment Quality Guidelines except where noted.

[b] Sensitive Contaminated Site, MWLAP (2002).

[c] Typical Contaminated Site, MWLAP (2002).

[d] Canadian Council of Ministers of the Environment (1999). Sediment Quality Guidelines for the Protection of Aquatic Life.

[e] Interim freshwater sediment quality guideline (dry weight), CCME (1999).

[f] Probable effects level, CCME (1999).

[g] Level 1 and Level 2 SQG from BCMWLAP (1999).

[h] SQG from BCWLAP (1998). The Level 1 is represented by the lowest level (LEL) and Level 2 by the severe effects level (SEL).

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APPENDIX 1. Photographs taken at the sampling stations on Departure Bay Creek during 22 November 2006.

Photo 1. Station DC1 at the Departure Bay beachfront, looking upstream towards the culvert under Departure Bay Road.

Photo 2. Station DC2 at Departure Bay Centennial Park, just west of the 7-Eleven Food Store and Gas Station. Water flows through very dense vegetation at this location (shown by yellow pointer).

Photo 3. Station DC3 at the Bay Street crossing (at the east end of Woodstream Park), looking upstream.

Photo 4. Station DC4, a stagnant side channel on the left bank of Departure Bay Creek, in Woodstream Park. This side channel is connected to Departure Bay Creek, which flows in the background as indicated by the yellow pointer.

Photo 5. Station DC5 located in Woodstream Park, looking upstream from the pedestrian bridge located nearest to the parking lot on Bay Street.

Photo 6. Station DC6 located in Woodstream Park, looking upstream.

Photo 7. Station DC7, a small tributary connected to the right bank of Departure Bay Creek (in Woodstream Park), looking upstream. A small footpath bridge is shown by the yellow pointer.

Photo 8. Station DC8 located at 3068 Newton Street, looking downstream.

Photo 9. Station DC9 at 3048 Neyland Road, looking upstream towards the culvert under Neyland Road.

Photo 10. Station DC10 located at the northernmost end of the Nanaimo Golf Club, looking upstream from the storm sewerage culvert with the golf course in background.