2008 Water Quality

Investigations

Environmental Services | **Scientific Programs**

Esquimalt Lagoon

Photo courtesy of Arnold Rossander

Prepared For
Esquimalt Lagoon Stewardship Initiative

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ESQUIMALT LAGOON 2008 WATER QUALITY INVESTIGATIONS

Executive Summary

Esquimalt Lagoon is a tidally influenced water body located south of Victoria, BC, and is designated as a federal migratory bird sanctuary. This shallow lagoon has a maximum depth of approximately 3.5 m and is almost landlocked except for the northeast end, where tidal exchange occurs through a narrow channel. In 2007 and 2008, extensive phytoplankton blooms were observed in the lagoon. In September of 2008, a fish kill occurred. Phytoplankton blooms are thought to be increasing in size and occurring more frequently over the last few years.

The CRD Stormwater Harbours and Watersheds program collects water samples from the lagoon for fecal coliform analysis twice per year. In 2008, the lagoon sampling was expanded to include field analysis for pH, temperature, dissolved oxygen, turbidity, nitrate and phosphorous. Samples were also collected for phytoplankton analysis to determine the species present before, during and after the bloom.

High concentrations of phytoplankton were found in the samples from the lagoon, with some blooms characterized as extremely thick. None of the species identified in the amounts present are considered toxic to aquatic life. The high numbers of phytoplankton in the lagoon most likely caused the fish kill, due to high algal respiration at night, combined with overnight low tides and warm water conditions, causing dissolved oxygen levels to drop, suffocating fish and invertebrates.

The cause of the extensive phytoplankton blooms is not known; however, nutrient input such as nitrates from stormwater discharges and groundwater are suspected. Nitrate levels were low in the lagoon in 2008 when compared with guidelines for marine aquatic life. Comparisons of water quality studies done in the past indicate the nitrate levels in 2008 are higher than in recent years. Most of the stormwater discharges entering the lagoon at the southwest end had high nutrient levels. Upstream sampling of stormwater discharges flowing into the lagoon found nitrate levels above guidelines for freshwater throughout the catchment areas.

Phosphorus levels were high in stormwater discharges at and near the toe of the lagoon. Phosphorus levels were also high in the lagoon; however, there are no guidelines to compare phosphorus in marine waters to determine if the lagoon results are considered an issue for phytoplankton growth. Nitrates are considered more a limiting factor for algal growth than phosphorus in marine waters.

Most of the lagoon fecal coliform counts exceeded the shellfish harvesting guideline; however, none exceeded the primary contact guideline for human health protection. Two of the stormwater discharges sampled (Selleck Creek and discharge 933) had high fecal coliform counts above the primary contact guideline.

Based on the 2008 sampling results, the main sources of nutrients have been traced to stormwater discharges entering the southwest toe of the lagoon and Selleck Creek at the emergence of a natural spring. A high fecal coliform count was also traced to the spring; however, waterfowl were present and could be the source. The 2000 hectare catchment area for the lagoon consists of institutional, residential and commercial properties. Most of the residential area has recently been sewered; however, some properties still use septic tanks and fields. Any one of these land uses could contribute nutrients to the lagoon. Stormwater runoff and groundwater flows entering the lagoon are main transporters of nutrients into the lagoon. Further sampling investigations are required to determine specific sources.

Recommendations

It is recommended that the following be undertaken as budgets allow:

1. Carry out frequent water quality sampling of stormwater discharges 926, 928–933.
2. Sample discharges flowing into Esquimalt Lagoon between Colwood Creek (916) and Selleck Creek (928).
3. Initiate or continue upstream sampling of stormwater discharges with high nutrient or fecal coliform counts to determine the sources.
4. Collect Bacterial Source Tracking (BST) samples from discharges 928 and 933 to determine if sewage or wildlife is the source of fecal coliform bacteria.
5. Sample discharges with high nitrates levels for nitrite to assist with determining if the source is sewage or fertilizers.
6. Continue water quality sampling of Esquimalt Lagoon in 2009, before, during and after a bloom. One sampling session should be done at night during a bloom to confirm low dissolved oxygen levels.
7. Investigate the feasibility of sampling groundwater in the catchment area for nutrients and fecal coliform bacteria.
8. Dye test homes still operating on private septic systems in the Esquimalt Lagoon area to ensure they are not contributing nutrients to the lagoon.
9. Explore potential upstream sources of chemical fertilizers, including Royal Roads University, the Royal Colwood Golf Course, Hatley Memorial Gardens cemetery, playing fields, and new developments where hydroseeding and new sod may be factors.

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1.0 INTRODUCTION

Esquimalt Lagoon is a tidally influenced lagoon located south of Victoria, BC. This shallow lagoon has a maximum depth of approximately 3.5 m and is almost landlocked except for the northeast end, where tidal exchange occurs through a narrow channel. It is significant partly due to its unique ecology, its designation as a federal Migratory Bird Sanctuary and its importance to First Nations. The 2000 hectare catchment area for the lagoon consists of the Department of National Defence, Royal Roads University, a golf course, and residential and commercial properties. Phytoplankton blooms were documented and studied in the 1970s and 1980s. However, in recent years, Esquimalt Lagoon has experienced further developmental pressures and environmental changes including increased algal blooms. In 2007 and 2008 in addition to ongoing red-tinged algae blooms, a chalky blue-green bloom was reported in the southwest end of the lagoon. In 2008 observations of fish and invertebrate mortalities were reported.

Working with the Esquimalt Lagoon Stewardship Initiative (ELSI) coordinator, staff from the CRD Stormwater Harbours and Watershed Program (SHWP) conducted site-specific water quality monitoring and sampling investigations in 2008 in addition to SHWP standard yearly monitoring. Water and sediment were sampled from selected storm drains and creeks for measurement of fecal coliform, general water quality parameters and nutrients. Marine water was sampled in the lagoon for measurement of fecal coliform, general water quality parameters, nutrients and phytoplankton community structure. Finally, upstream source investigations were conducted in discharges where high nutrients were observed.

2.0 METHODS

2.1 CRD Annual Stormwater Quality Monitoring

Each year during the wet and dry season in and around the lagoon, SHWP undertakes the following monitoring program:

Stormwater discharges—All stormwater discharges and creeks entering the lagoon have been sampled and analyzed for fecal coliform bacteria at least twice in the last five years. Discharges previously rated high or moderate for public health concern are sampled every year. Sediment samples collected from stormwater discharges that have the potential to contain chemical contaminants are analyzed for metals and polycyclic aromatic hydrocarbons (PAH). Each discharge sampled is rated high, moderate or low for environmental concern. Discharges of a low concern for public and environmental health are re-sampled approximately every five years, depending on time, budgets and environmental conditions. CRD discharges flowing into Esquimalt Lagoon are 913–933 (see Figure 1).

Creeks—Water quality parameters are measured in Colwood Creek (discharge 916) at the point of discharge into Esquimalt Lagoon and two upstream locations. Parameters include fecal coliform, conventional water quality parameters [pH, temperature, dissolved oxygen (DO), specific conductivity, turbidity] and nutrients (nitrate as nitrogen and phosphorus). These parameters are compared to provincial or federal water quality guidelines to assess public and environmental health and to assess trends over time.

Esquimalt Lagoon—Marine surface water is sampled during ebb and flood tides at seven stations throughout the lagoon and analyzed for fecal coliform (stations EL-1 to EL-7) twice per year.

2.2 2008 Additional Monitoring

In 2008, due to ongoing occurrences of seasonal algal blooms and previous reports of stress or death of aquatic life in the lagoon, further investigations of water quality and stormwater influences were undertaken. These investigations involved increased parameter sampling and additional locations, including the following (see Figure 1 for sampling locations):

Stormwater discharges—Stormwater was sampled from discharges at the southwest end of the lagoon (929, 930, 931, 932, and 933) as colour changes due to algal blooms appear to have started at this end in previous years. Fecal coliform, with the addition of the conventional water quality parameters (pH, temperature, DO, specific conductivity, turbidity) and nutrients (nitrate as nitrogen and phosphorus), were measured to assess the quality of stormwater entering this end of the lagoon.

Creeks—In addition to the regularly sampled Colwood Creek (discharge 916), water quality parameters were measured in two creeks that enter the lagoon near the southwest end: Bee Creek (discharge 926) and Selleck Creek (discharge 928). Measurements included fecal coliform, pH, temperature, DO, specific conductivity, turbidity, nitrate as nitrogen, and phosphorus. Sediment was also collected in the three creeks and analyzed for metals and PAH.

Esquimalt Lagoon—Phytoplankton community analyses were conducted in marine surface water samples at four sampling stations (Phyto-1 to Phyto-4). Stations represented areas of previous strong discolouration due to high algal presence (Phyto-1, 3 and 4) and a background reference site (Phyto-2). Samples were collected on four occasions that spanned pre-bloom and bloom conditions. Water quality parameters (fecal coliform, pH, temperature, DO, salinity, turbidity, nitrate as nitrogen and phosphorus) were also measured at these sites.

Source Investigations—Investigations to find the source of high nitrates measured in stormwater discharges and creeks were undertaken upstream of 933, 932 and 928 (Selleck Creek). Measurements included fecal coliform, pH, temperature, DO, specific conductivity, turbidity, nitrate as nitrogen, and phosphorus. Additional tests for nitrite as nitrogen and ammonia as nitrogen were conducted on selected samples. Sediment was also analyzed for metals and PAH's at upstream locations in 926 and 928.

3.0 RESULTS

Selected stormwater discharges, creeks and the lagoon were sampled between August 5 and November 10, 2008 (Table 1). On September 18, 2008 fish and invertebrate mortalities were observed.

Table 1. Water Quality Sampling Dates in 2008 by Location and Tide

	Aug 5	Aug 6	Sept 2	Sept 3	Sept 19	Oct 08	Oct 22	Oct 28	Oct 30	Nov 10
Lagoon EL 1-7			flood	ebb						
Lagoon Phyto 1-4		Ebb		ebb	slack	flood				
Stormwater discharges	932 933			932 933	932 933	932 933				929 930 931 932 933
Creeks	926 928	916		916 926 928	916 926 928	916 926 928	928		928	
Upstream investigations							928	932 933	928	932 933

3.1 Phytoplankton Community

High concentrations of phytoplankton were seen in all samples throughout the sampling period, with some blooms characterized as “extremely thick” (Haigh 2008). The highest dominant species counts generally occurred at Phyto-4 (near the mouth of Colwood Creek—916) and Phyto-1 (southwest end of the lagoon) during all three months (Table 2). The dominant species were the dinoflagellates *Gyrodinium estuariale* (tentative identification), *Prorocentrum micans* and *Prorocentrum minimum*, with *Gymnodinium sanguineum* noted as present.

Phytoplankton samples collected August 5 were dominated by *G. estuariale* with very high biomass at sample locations Phyto-1 (68,000 cells/mL) and Phyto-4 (80,000 cells/mL).

Phytoplankton samples collected September 3 were dominated by *G. estuariale* (except for Phyto-1, *P. minimum*) with very high biomass at sample location Phyto-2 (11,000 cells/mL) and in “remarkable” numbers at Phyto-4 (300,000 cells/mL).

Phytoplankton samples collected September 19 (the day after fish kill reports were received) indicated that the dominant species in Esquimalt Lagoon was *P. micans*, with *P. minimum* significantly subdominant. Cell counts of *P. micans* varied from 3300 cells/mL at Phyto-3 to 6300 cells/mL at Phyto-1. The highest concentration of *P. minimum* was 3000 cells/mL at Phyto-3.

Phytoplankton samples collected October 8 were dominated by *P. micans* with very high biomass at Phyto-4 (9300 cells/mL) and much lower (320-580 cells/mL) at all other locations.

3.2 Fecal Coliform

Fecal coliform concentrations in the lagoon were measured at the four phytoplankton sampling stations on August 5, September 3 and 19 and October 08, 2008. On September 2 and 3, seven stations were sampled (EL-1 to EL-7) as part of SHWP regular monitoring program on flood (September 2) and ebb (September 3) tides. Two of these stations overlapped with the phytoplankton sampling sites (EL-2=Phyto-2 and EL-6=Phyto-4).

The highest fecal coliform concentrations occurred on September 19 at the southwest end of the lagoon during a slack tide, the day after the first reports of the chalky blue-green bloom and fish and crab mortalities (Table 3). Counts were highest at Phyto-3 (210 FC/100mL) and Phyto-1 and Phyto-2 (both 180 FC/100 mL). Fecal coliform at Phyto-4 was 70 FC/100 mL. The BC shellfish harvesting guideline for fecal coliform is 14 FC/100 mL and the Guideline for Canadian Recreational Water Quality for human health protection for primary contact (e.g. swimming, kayaking) is 200 FC/100 mL.

Stormwater flows at the point of discharge into the lagoon were also highest in fecal coliform on September 19 and correspond directly with the lagoon marine samples. Colwood Creek (discharge 916) had 300 FC/100 mL directly adjacent to Phyto-4; Selleck Creek (discharge 928) had 2500 FC/100 mL and is located at the southwest end of the lagoon closest to Phyto-2 and Phyto-3.

Lagoon samples for all other sample dates and locations ranged from <1 to 33 FC/100 mL with the exception of EL-6 on September 3 with 100 FC/100 mL. On this day, the adjacent stormwater discharge, Colwood Creek, also had elevated counts of 120 FC/100 mL.

Additional elevated fecal coliform results occurred on August 5 at discharge 933 (1000 FC/100 mL) during an ebb tide and on October 8 at Selleck Creek (1000 FC/100 mL) during a flood tide. Adjacent lagoon stations sampled at the same time did not appear to be correspondingly influenced in fecal coliform results. Adjacent phytoplankton results showed an interesting relation to these stormwater flows with high phytoplankton counts at Phyto-1 on August 5 (directly adjacent to 933) during an ebb tide, but low phytoplankton counts at Phyto-2 and Phyto-3 (directly adjacent to Selleck Creek) during a flood tide on October 8.

Bacterial Source Tracking (BST) is a laboratory test that can distinguish between various bacterial contributors (human, avian, ruminants, etc.) using DNA samples to determine the source of fecal coliform bacteria. BST samples from Bee and Selleck Creek were collected in 2006 and human was not identified as a definite source; however, additional samples are required to confirm the results.

Some of the lagoon fecal coliform counts exceed the shellfish harvesting criteria but only one sample on September 19 slightly exceeded the guideline for recreational use. However, the lagoon is a migratory bird sanctuary and it is not surprising to have elevated fecal coliform counts.

Table 2. Phytoplankton in August–October 2008, Esquimalt Lagoon Samples (Haigh 2008)

Date	Site	Dominant Species		Biomass	% Constituent					GYM SANG.
		Name	Cells/Ml		DT	DF	R	OF	MZ	
5 Aug	1	*Gyrodinium estuariale*	68,000	5.0	14	85	0	0	1	
	2	*Gyrodinium estuariale*	2200	4.0	1	90	0	1	8	+
	3	*Gyrodinium estuariale*	11,000	4.5	4	92	0	1	3	+
	4	*Gyrodinium estuariale*	80,000	5.0	1	98	0	0	1	+
3 Sep	1	*Prorocentrum minimum*	~800	4.5	5	90	0	1	4	
	2	*Gyrodinium estuariale*	11,000	5.0	0	99	0	0	1	+
	3	*Gyrodinium estuariale*	3600	4.5	4	88	0	1	7	
	4	*Gyrodinium estuariale*	300,000	5.0	0	100	0	0	0	+
19 Sep	1	*Prorocentrum micans*	6300	4.5	2	98	0	0	0	+
	2	*Prorocentrum micans*	3700	4.5	0	98	0	1	1	+
	3	*Prorocentrum micans*	3300	4.5	2	97	0	0	1	
	4	*Prorocentrum micans*	5300	4.5	1	95	0	2	2	
8 Oct	1	*Prorocentrum micans*	580	4.0	4	85	0	1	10	
	2	*Prorocentrum micans*	~320	3.5	3	95	0	1	1	
	3	*Prorocentrum micans*	~420	4.0	4	85	0	1	10	
	4	*Prorocentrum micans*	9300	5.0	1	97	0	1	1	

"Biomass" is total phytoplankton biomass approximated in a scale of 1.0 (very low) to 5.0 (very high). "% Constituent" is approximate percent of total phytoplankton biomass in five constituent groups: diatoms (DT), dinoflagellates (DF), raphidophytes (R), other flagellates (OF), and microzooplankton (MZ). "GYM SANG." notes the presence (+) of the dinoflagellate *Gymnodinium sanguineum* in the sample.

3.3 Nutrients

All four lagoon sites on the four sampling days had nitrate levels well below the recommended guidelines for aquatic life (Table 3). Nitrate levels were either elevated or above the guideline in stormwater discharges flowing into the lagoon at south west end throughout the sampling sessions.

The four lagoon sampling dates were in August, September and October before during and after an extensive algal bloom. Nitrate levels ranged from 0.098 to 0.506 mg/L N in August and 0.134 to 0.426 mg/L N in October, but were less than detection (0.002 mg/L N) to 0.100 mg/L N in September.

Nitrate was elevated above the Canadian Council of Ministers of the Environment (CCME) guideline of 2.95 mg/L nitrate as nitrogen at discharges 926, 928, 932 and 933. With the exception of discharge 932 on October 8 at 11.8 mg/L N, the highest nitrate concentrations (3.4–9.54 mg/L N) occurred on August 5 in all four of the above discharges. Discharges 932 and 933 also exceeded guidelines on September 3 at 5.9 mg/L N and 3.3 mg/L N, respectively. As with the marine lagoon samples, on average the lowest nitrate concentrations were measured on the day of the fish kill, September 19.

Nitrate in both lagoon and discharge samples were often high when fecal coliform measurements were low, with a few exceptions. Additionally there was no consistent, direct correlation between nitrate and phytoplankton blooms.

Phosphorus was higher in lagoon samples for almost every site than in discharge samples, ranging from 0.044 to 0.42 mg/L P in the marine waters. The CCME guideline for phosphorus in freshwater is a eutrophication trigger range of 0.035 to 0.1 mg/L P. There are no recommended guidelines for phosphorous in marine waters. Only one of the discharge samples (Selleck Creek) exceeded the phosphorus guideline for freshwater and was 0.31 mg/L P during the time of the fish kill. This sample also had the highest fecal coliform count during this portion of sampling, at 2500 FC/100 mL. All other discharge samples ranged from 0.00 to 0.09 mg/L P. No other phosphorus versus fecal coliform relation was noted.

3.4 Other Water Quality Parameters: Dissolved oxygen, pH, Temperature, Specific Conductivity, and Turbidity

Dissolved oxygen was generally high in both lagoon and discharge samples, ranging from 8.20–19.38[1] mg/L in lagoon samples and 8.80–11.6 mg/L in discharge samples (Table 3). All samples were collected during daylight hours.

Temperatures of lagoon and discharge samples ranged from 10.5–17.9 ºC, with the exception of very high temperatures in lagoon samples during the ebb tide on August 5, where temperatures reached 18.3–25.2 ºC.

Turbidity was highest in the lagoon versus discharge samples with the highest value of 133 NTU occurring on September 3 at Phyto-4, when the highest phytoplankton concentration was collected (300,000 cells/mL). Many of the high turbidity levels occurred with high phytoplankton numbers, although this was not consistently so. High turbidity was also noted on September 19, ranging from 4.49–22.9 NTU in lagoon samples. Selleck Creek had high turbidity of 7.71 NTU on September 3, but was below BC Approved Water Quality Guidelines (BC AWQG) of 8 NTU.

Specific conductivity and pH were unremarkable.

3.5 Stormwater Discharge Sediment Chemical Contaminants

Sediment samples were collected from six stormwater discharges (916, 920, 926, 928, 931, and 932) along the coastline of Esquimalt Lagoon in 2008. The samples were collected just before the point of discharge into Esquimalt Lagoon and at upstream sites for Bee (926) and Selleck (928) Creek. The sediment data collected by the CRD since 2000 are provided in Table 4 (CRD, 2008). All the data was compared to the CRD Marine Sediment Quality Guidelines (MSQG) also shown on Table 4. Any exceedences are shaded. None of the samples collected in 2008 exceeded the guidelines.

[1] The dissolved oxygen values of 16.98 and 19.38 mg/L exceed theoretical values for dissolved oxygen in water. These values could be attributed to phytoplankton respiration

Table 3. Esquimalt Lagoon and Stormwater Discharges Sampling Results—Summer 2008

Sampling Event	Sample time	Parameter	Dissolved oxygen[2] (mg/L)	pH	Temperature[3]	Salinity (ppt)	Conductivity[4] (us/cm)	Turbidity[5] (NTU)	Phosphorus[6] (mg/L P)	Nitrate[7] as N (mg/L), lab	Nitrate as N (mg/L), field	Flow (L/min)	Fecal coliform count[8] (FC/100mL)	Phytoplankton	Comments
		Freshwater Guidelines[1] (BC and CCME)	**6**	**6.5 to 9**	**19**	**-**	**-**	**8**	**0.035 to 0.1**	**2.95**	**2.95**	**-**	**200/14**	**na**	
		Marine Guideline[1] (BC,CCME and CRWQ)	**6**	**7.0 to 8.7**	**SS**	**-**	**na**	**SS**	**SS**	**3.6**	**3.6**	**na**	**200/14**	**na**	
		Sites													
5-Aug	**1315**	Phyto-1	12.24	7.76	19.9	30	-	19.1	0.071	0.356	-	-	3	ebb	
	1350	Phyto-2	14.6	8.07	18.3	-	-	9.1	0.053	0.416	-	-	< 1	ebb	
	1410	Phyto-3	9.8	8.1	20.3	30.6	-	4.5	0.117	0.098	-	-	15	ebb	
	1540	Phyto-4	8.82	8.3	25.2	26.5	-	-	0.044	0.506	-	-	3	ebb	
	1130	932 (discharge at toe)	10.98	6.72	12	-	372	0.42	0.075	-	6.1	-	29	na	
	1145	933 (discharge at toe)	10.77	7.1	14.4	-	422	0.67	0.014	9.54	8.3	-	1000	na	
	1430	928 (Selleck Ck.)	9.39	7.52	17.9	-	350	-	0.026	5.49	3.4	-	140	na	
	1500	926 (Bee Ck.)	10.94	7.78	14.24	-	342	-	0.023	3.5	-	-	70	na	
6-Aug	**1100**	916 (Colwood Ck.)	10.02	7.04	14.04	-	257	1.38	0.024	1.37	1.5	-	80	na	
3-Sep	**1140**	Phyto-1	9.13	8.2	16.7	29.9	-	2.58	0.079	0.1	-	-	4	ebb	green-brown, jellyfish present
	1107	Phyto-2	16.98*	8.2	16.9	27.6	-	4.21	0.17	0.006	-	-	<	ebb	brown-orange, murky
	1159	Phyto-3	10.86	8.4	17.9	29.7	-	3.56	0.11	0.005	-	-	20	ebb	dark brown, clear
	1227	Phyto-4	19.38*	8.7	16.8	28.3	-	133	0.077	0.002	-	-	33	ebb	brown-orange, murky, odour
	1500	932 (discharge at toe)	11	7.6	12.1	-	372	0.24	0.01	-	5.9	25	<	na	
	1456	933 (discharge at toe)	10.24	8.03	13.7	-	404	1.88	0.06	-	3.3	35	10	na	
	1437	928 (Selleck Ck.)	9.8	8.16	16.3	-	348	7.71	0.09	-	2.3	25	140	na	
	1418	926 (Bee Ck.)	10.8	8	12.8	-	342	2.17	0.08	-	0.8	75	40	na	
	1320	916 (Colwood Ck.)	9.82	7.7	12.6	-	242	1.96	0.06	-	0.9	25	120	na	
	1126	EL-1	-	-	-	-	-	-	-	-	-	-	1	ebb	brown, clear
	1107	EL-2	-	-	-	-	-	-	-	-	-	-	<	ebb	brown, murky
	1206	EL-3	-	-	-	-	-	-	-	-	-	-	1	ebb	brown, slightly murky
	1211	EL-4	-	-	-	-	-	-	-	-	-	-	3	ebb	brown-orange, murky
	1216	EL-5	-	-	-	-	-	-	-	-	-	-	1	ebb	clear, sulfur odour
	1226	EL-6	-	-	-	-	-	-	-	-	-	-	33	ebb	brown-orange, murky
	1227	EL-7	-	-	-	-	-	-	-	-	-	-	100	ebb	brown-orange, murky
19-Sep	**1157**	Phyto-1	8.2	7.81	13.9	28.5	-	4.49	0.42	0.016	-	-	180	slack	brown-red, murky
	1237	Phyto-2	11.75	8.3	14.6	28.9	-	9.44	0.16	0.004	-	-	180	slack	brown, murky
	1218	Phyto-3	8.35	7.94	14.9	29.1	-	14.8	0.19	< 0.002	-	-	210	slack	brown, murky
	1350	Phyto-4	8.84	8.05	15.2	29	-	22.9	0.34	< 0.002	-	-	70	slack	murky
	1323	932 (discharge at toe)	11.3	7.07	12.2	-	371	1.48	0.01	-	1.3	35	< 1	na	
	1137	933 (discharge at toe)	10.1	7.7	12.8	-	460	1.4	0.09	-	1.7	10	20	na	
	1438	928 (Selleck Ck.)	9.39	7.84	15.4	-	373	3.84	0.31	-	1.4	-	2500	na	
	1414	916 (Colwood Ck.)	9.73	7.56	12.8	-	243	1.25	0.05	-	0.9	-	300	na	

continued

Table 3, continued

Sampling Event	Sample time	Parameter	Dissolved oxygen[2] (mg/L)	pH	Temperature[3]	Salinity (ppt)	Conductivity[4] (us/cm)	Turbidity[5] (NTU)	Phosphorus[6] (mg/L P)	Nitrate[7] as N (mg/L), lab	Nitrate as N (mg/L), field	Flow (L/min)	Fecal coliform count[8] (FC/100mL)	Phytoplankton	Comments
		Freshwater Guidelines[1] (BC and CCME)	**6**	**6.5 to 9**	**19**	**-**	**-**	**8**	**0.035 to 0.1**	**2.95**	**2.95**	**-**	**200/14**	**na**	
		Marine Guideline[1] (BC,CCME and CRWQ)	**6**	**7.0 to 8.7**	**SS**	**-**	**na**	**SS**	**SS**	**3.6**	**3.6**	**na**	**200/14**	**na**	
		Sites													
8-Oct	**1012**	Phyto-1	10.1	7.7	10.4	27.9	-	3.98	0.13	0.247	-	-	16	flood	slightly brown, clear
	1110	Phyto-2	14.7	8.4	11.6	29.4	-	2.48	0.09	0.134	-	-	1	flood	dark green
	1035	Phyto-3	10.1	8.2	10.3	25.8	-	4.49	0.1	0.426	-	-	12	flood	clear
	1058	Phyto-4	11.35	8.3	11.2	30.1	-	10.1	0.3	0.141	-	-	7	flood	brown-red, murky
	1223	932 (discharge at toe)	10.8	7.2	12.2	-	375	0.36	0.01	11.8*	2.9*	45	25	na	
	1200	933 (discharge at toe)	10.8	7.9	12.7	-	434	2.04	0.00	-	0.2	35	22	na	
	1305	928 (Selleck Ck.)	10.3	7.7	12.7	-	343	4.48	0.01	-	2.7	35	1000	na	
	1334	926 (Bee Ck.)	11.6	7.8	10.5	-	345	2.39	0.00	-	0.1	45	16	na	
	1420	916 (Colwood Ck.)	8.8	7.6	10.5	-	227	1.72	0.02	-	1	30	<1	na	
22-Oct	**11:00**	928 (Selleck Ck.)	11.57	7.92	10.32	-	359	8.29	0.04	-	2.6	40	110	na	
28-Oct	**15:30**	931 (discharge at toe)	10.57	7.34	11.35	-	396	0.18	0.04	-	3.6	10	-	na	
	11:50	932 (discharge at toe)	10.88	7.57	12.06	-	374	0.09	0.04	-	5.4	30	-	na	
30-Oct	**15:00**	928 (Selleck Creek)	11.07	7.95	10.5	-	355	5.17	0.06	-	1.2	90	200	na	
10-Nov	**12:00**	929 (discharge at toe)	9.46	7.54	11.7	-	326	0.63	0.09	-	1.4	30	-	na	
	12:42	930 (discharge at toe)	9.39	7.09	12.1	-	339	0.21	0.06	-	3.1	25	-	na	
	12:20	931 (discharge at toe)	10.15	7.16	11.7	-	379	0.29	0.05	-	4.6	25	-	na	
	11:30	932 (discharge at toe)	10.03	7.01	12.11	-	322	0.11	0.11	-	4.5	50	-	na	
	10:40	933 (discharge at toe)	10.67	7.12	11.99	-	381	7.16	0.06	-	1.7	20	-	na	

Notes:

1 BC = BC Approved Water Quality Guidelines and BC shellfish harvesting guideline; CCME = Canadian Council of Ministers of the Environment; CRWQ = Guideline for Canadian Recreational Water Quality; CCME guidelines were adopted when provincial guidelines were unavailable. ss = site specific for parameters that require development of guidelines based on ambient levels.

2 minimum dissolved oxygen levels for the protection of aquatic life. The marine dissolved oxygen levels were often supersaturated.

3 maximum daily water temperature for streams with unknown fish distribution

4 Due to high variability in specific conductance, MOE has not developed a guideline for aquatic life protection. However, natural levels range from 50 to 1500 µS/cm.

5 for watercourses with ambient levels below 80 nephelometric turbidity units (NTU); site specific for marine waters

6 phosphorous freshwater eutrophication trigger range; site specific for marine waters

7 All nitrate and phosphorus results in marine (lagoon) samples were obtained by lab analyses, while freshwater (creek and discharge) samples were tested using field equipment, with some duplicates submitted to the lab for verification. Field meter readings for phosphorus were consistent with lab analyses; however, nitrate readings using field meters were consistently lower than lab analyses.

8 200 FC/100 mL is the Guideline for Canadian Recreational Water Quality for human health protection from primary contact (e.g. swimming, kayaking). The 30-d log mean must not exceed 200 FC/100 mL. SHWP compares single samples to the guideline. 14 FC/100 mL is the BC MOE shellfish harvesting guideline and is based on a minimum of five samples collected over 30-days: the median fecal coliform concentration should not exceed 14 FC/100 mL.

* the dissolved oxygen values of 16.98 and 19.38 mg/L exceed theoretical values for dissolved oxygen in water. These values could be attributed to phytoplankton respiration. The high nitrate lab measurement appears to be an outlier and was different than field measurement, a second field measurement with a different metre gave a similar result; therefore lab measurement is considered an erroneous value.

Discharge 920, located on Royal Roads property, had high concentrations of copper in 2006 and 1996. Two subsequent samples collected in 2007 and 2008 had low concentrations of copper. In 2002 a study of water quality of the lagoon found elevated levels of copper throughout (McElroy, Meeres and Pickett, 2002). This study also identified elevated levels of arsenic, cadmium, copper, lead and zinc in the lagoon sediments.

Bee Creek, discharge 926 located at the foot of Heatherbell Road, had high concentrations of high molecular weight polycyclic aromatic hydrocarbons (HPAH) in 2006 and 2007 but not 2008. An upstream sample was also collected in 2008 and there were no exceedences. The source of the high concentrations of HPAH is unknown; however, a possible source may be contaminated soil located on the property the creek flows through (3221 Heatherbell Road). The property owner retained a consulting company to investigate the source. Based on their investigations to date, it is suspected that a heating oil underground storage tank once existed and may have caused the contamination (Adams, April 14, 2007). The property owner is investigating remediation options.

Selleck Creek, discharge 928 located at the foot or Portsmouth Drive, was sampled at the point of discharge and at four upstream locations downstream of and on the Aquattro development property in 2008. None of the samples collected in 2008 or in prior years exceeded any of the CRD MSQG guidelines.

3.6 Upstream Investigations of Creeks and Stormwater Discharges

SELLECK CREEK (928)

In the summer of 2008, high levels of nitrate, phosphorus and fecal coliform concentrations were found in Selleck Creek. Upstream investigations were done on October 22 and 30, 2008, to narrow down the sources. Of the six nitrate results taken at the mouth of the creek, only one (5.39 mg/L N) exceeded the CCME guideline of 2.95 mg/L N for aquatic life. This result was found on August 5, 2008. One of the six nitrate results was elevated at 2.7 mg/L N on October 8.

Two fecal coliform results (1000 FC/100 mL, and 2500 FC/100 mL) found at the mouth of the creek exceeded the guideline of 200 FC/100 mL for primary recreational activities. The highest fecal coliform count of 2500 FC/100 mL was found on September 19, 2008. Additionally, significant fish and crab mortality was observed at this point of discharge September 18-20, 2008. Birds in the area were seen to be consuming the dead fish and their presence could explain the high fecal coliform count.

Of the six phosphorus results collected at the mount of the creek, one (0.31 mg/L P) exceeded the upper level of the CCME trigger range (0.1 mg/L P) on September 19, 2008. One other result was high at 0.09 mg/L P on September 3, 2008.

The upstream sampling sites are shown on Figure 2. Upstream discharge site 928-2 is in the mainstem of Selleck Creek, immediately downstream of the outlet from a settling pond across from 208 Seafield Road (Figure 2). Site 928-3 is in the mainstem downstream of the driveway to 205 Seafield Road at the southwest corner of the property. Site 928-4 is in the mainstem on the upstream (Aquattro) side of the driveway. Site 928-5 the upper most sampling site and is in the mainstem near the centre of the Aquattro development and is immediately downstream of the confluence of two tributaries from a pond fed by underground springs.

Table 4. Esquimalt Lagoon Stormwater Discharge Sediment Chemical Contaminant Data, 2000 to 2008

Contaminant		Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Silver	Zinc	LPAH	HPAH
MSQG[1]		57	5.1	260	390	450	0.41	6.1	410	5.2	12
CRD Discharge #	Sample Date	Concentration in Sediment (μg/g)									
914	05-06-17	3	0.2	29	23	12	0.03	0.1	73	0.1	<1
915	00-07-05	4	0.1	37	30	11	0.03	0.1	135	0.1	1
915	01-07-03	4	0.1	42	35	7	0.02	0.1	72	0.1	<1
915	06-08-03	5	0.3	48	48	18	0.02	0.1	115	0.1	<1
916	04-08-25	1	0.2	16	14	6	0.01	0.1	66	0.1	<1
916	08-09-03	3	0.1	32	27	10	0.03	0.1	101	0.2	1
920	00-07-17	1	0.1	31	32	4	0.01	0.1	59	0.1	<1
920	06-06-21	2	0.4	20	316	15	0.05	0.1	236	0.1	<1
920	07-08-20	4	0.5	45	56	39	0.16	0.2	188	0.3	1
920	08-07-23	5	0.5	34	47	33	0.09	0.2	168	0.1	1
922	00-07-17	4	0.1	21	11	3	0.01	0.1	28	0.1	<1
922	06-07-20	2	0.2	18	25	4	0.02	0.1	30	0.1	<1
926	01-07-09	2	0.1	26	54	14	0.02	0.1	42	0.6	4
926	06-08-15	2	0.3	15	13	9	0.03	0.1	44	2.2	19
926	07-07-10	5	0.2	34	32	14	0.13	0.2	63	1.1	12
926	08-07-23	3	0.1	15	13	6	0.02	0.1	40	1.1	4
926-2	08-07-23	1	0.1	18	21	6	0.01	0.1	38	0.1	<1
927	00-06-19	23	0.1	25	20	7	0.03	0.1	104	0.1	<1
927	02-06-27	57	0.1	30	55	15	0.11	0.1	241	0.2	1
927	03-06-24	21	0.0	23	15	7	0.03	0.0	80	0.1	<1
927	06-08-02	39	0.2	16	25	8	0.06	0.1	90	0.1	<1
927	07-07-10	35	0.3	24	46	13	0.11	0.1	117	0.1	<1
928	00-06-19	2	0.1	30	38	11	0.01	0.1	55	0.1	<1
928	06-08-02	2	0.2	29	26	12	0.03	0.1	80	0.9	7
928	07-07-10	3	0.3	47	43	15	0.11	0.1	82	0.5	2
928	08-10-30	5	0.4	64	77	28	0.12	0.2	166	0.1	<1
928-2	08-10-22	2	0.1	29	29	6	0.02	0.1	51	0.1	<1
928-3	08-10-22	3	0.2	43	37	14	0.06	0.1	76	0.1	1

[1]MSQG are the CRD marine sediment quality guidelines.

continued

Table 4, continued

Contaminant		Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Silver	Zinc	LPAH	HPAH
MSQG		57	5.1	260	390	450	0.41	6.1	410	5.2	12
CRD Discharge #	Sample Date	Concentration in Sediment (µg/g)									
928-4	08-10-30	4	0.2	41	33	12	0.05	0.1	48	0.1	<1
928-5	08-10-30	7	0.2	48	56	4	0.04	0.1	58	0.1	<1
931	01-07-13	1	0.1	22	11	8	0.01	0.1	45	0.1	<1
931	02-06-27	2	0.1	30	18	10	0.01	0.1	65	0.1	<1
931	08-07-23	2	0.1	6	9	4	0.01	0.1	23	0.1	<1
932	02-06-27	2	0.1	35	18	5	0.01	0.1	35	0.1	<1
932	07-07-12	3	0.1	39	49	18	0.01	0.1	55	0.1	<1
932	08-10-28	2	0.1	40	51	6	0.01	0.1	50	0.1	<1
933	01-07-09	3	0.1	28	29	11	0.02	0.1	66	0.1	<1
933	04-08-05	4	0.2	28	48	27	0.03	0.1	81	0.1	<1

The October 22 upstream investigation included sampling the mouth of the creek and sites 928-2 and 928-3. The fecal coliform counts were low at the mouth (point of discharge) (110 FC/100 mL) and at upstream sites 928-2 (100 FC/100 mL) and 928-3 (40 FC/100 mL). An elevated nitrate level of 2.5 mg/L N was found at the mouth of the creek. Only one of the upstream nitrate levels was high at site 928-3 with a result of 3.5 mg/L N. All three sites had turbidity levels (8.29–9.37 NTU) above the BC AWQ guideline of 8 NTU. Phosphorus was above the lower end of the CCME guidelines of 0.035 to 0.1 mg/L in all samples, ranging from 0.036–0.055 mg/L. Field notes indicate the water at 928-3 was “sudsy”, there were geese in the area, and that the riparian zone on the Aquattro property was newly hydro-seeded.

The October 30 upstream investigation included sampling the mouth of the creek and sites 928-4 and 928-5. The fecal coliform count exceeded primary contact criteria at the mouth (200 FC/100 mL) and at upstream sites 928-4 (210 FC/100 mL) and 928-5 (5400 FC/100 mL). Nitrate exceeded CCME guidelines at all sites sampled, ranging from 4.77–4.85 mg/L N. On this date, nitrite was also sampled and was very low, ranging from 0.007–0.017 mg/L N. Turbidity exceeded the CCME guideline of 8 NTU at 928-5 (10.0 NTU). Phosphorus was above the lower end of the CCME guideline of 0.035 to 0.1 mg/L P in all samples, ranging from 0.046–0.071 mg/L P. Field notes indicate that at least ten ducks were present in the pool immediately above 928-5.

DISCHARGE 932

Upstream sites contributing to discharge 932 at the toe of the lagoon were investigated on October 28 and November 10, 2008, due to previous high levels of nitrate measured from August to early October. Nitrate results at the mouth of the discharge during August–October ranged from 1.3–6.10 mg/L N, exceeding CCME guidelines of 2.95 mg/L N for aquatic life (Table 3). Fecal coliform results were generally low, ranging from less than detection to 29 FC/100 mL. Phosphorus was low, with the exception of 0.075 mg/L P on August 5.

Upstream discharge site 932-3 is the flow from the northwest pipe entering a manhole at the north side of the intersection of Lagoon Road and Anchorage Avenue (Figure 3). Site 932-4 is the flow from the northwest entering a manhole at the intersection of Lagoon Road and Lanai Lane and 932-5 is in the flow from the south entering the same manhole. Upstream of all the sampling sites were either dry, wet only or the flow was too low to sample.

On October 28, discharge 932 and the three upstream sites showed nitrate exceeding guidelines in all four sites (2.9-5.7 mg/L N). Phosphorus ranged from 0.033–0.88 mg/L P, with the highest concentration in the south flow at Lanai Lane (932-5). Fecal coliform samples were not collected due to time constraints.

On November 10, all four sites were again sampled, with nitrate exceeding guidelines only at the point of discharge (4.5 mg/L N). Nitrate was still elevated at 932-3 (2.1/2.6 mg/L N), but quite low at 932-4 and 932-5. Phosphorus was also high at the point of discharge, exceeding the upper guideline at 0.111 mg/L P. All other parameters were unremarkable. Fecal coliform samples were not collected due to time constraints.

Discharge 933

Upstream sites contributing to discharge 933 at the toe of the lagoon were investigated on October 28 and November 10, 2008, in tandem with discharge 932, due to previous high levels of nitrate measured from August to early October. Nitrate results at the point of discharge into the lagoon during August-October ranged from 0.2–9.54 mg/L N, exceeding CCME guidelines of 2.95 mg/L N for aquatic life. Fecal coliform results were high in August at 1000 FC/100 mL, but low for all other samples collected. Phosphorus was generally low, but was elevated at 0.09 mg/L P on September 3.

The upstream locations were sites 933-1 and 933-2 located in a manhole at the intersection of Lagoon Road and Anchorage Avenue, with 933-1 representing the flow from the south and 933-2 representing flow from the northwest (Figure 3).

On October 28, the manhole at Lagoon and Anchorage (site 933-1 and 933-2) was sampled for all parameters except fecal coliform (Table 3). The point of discharge was not sampled. Nitrate was higher in the northwest flow (933-2) at 4.3 mg/L N than in the south flow (2.1 mg/L N). The phosphorus was above the lower end of the CCME guideline (0.035 mg/L and 0.1 mg/L P) for site 933-2 at 0.06 mg/L P. The other flow entering the manhole (933-1) had low phosphorus.

On November 10, only phosphorus was elevated (0.06 mg/L P) and above the lower end of the CCME guideline. Turbidity was elevated at 7.16 NTU at the point of discharge into the lagoon and significantly lower than the upstream sites at 0.77 NTU. All other parameters were within guidelines. Fecal coliform samples were not collected due to time constraints.

Discharges 929–931

To compare the results found in discharges 932 and 933, discharges 929, 930 and 931 were sampled on November 10 for all parameters except fecal coliform. All three discharge into the toe of the lagoon (Figure 3). Discharges 930 and 931 had nitrate levels (3.1 and 4.6 mg/L N respectively) exceed the guideline of 2.95 mg/L N. All three discharges had phosphorus levels above the lower end of the CCME guideline. All other parameters were unremarkable. These discharges need to be sampled again to confirm the results.

4.0 DISCUSSION AND CONCLUSIONS

In 2007 reports of unusual and extensive algal blooms were observed in Esquimalt Lagoon during late summer. As a result, CRD staff increased and expanded the annual stormwater quality monitoring in 2008 for the lagoon and surrounding stormwater discharges to include sampling for nutrients and other parameters to determine the cause. In addition, water samples were collected for phytoplankton analysis to determine what species were present, and to what extent, before, during and after a bloom occurs. On September 18, 2008, dead fish and crab were observed in Esquimalt Lagoon. An unusual chalky blue-green algae bloom at the southwest toe of the lagoon, especially at the mouth of Selleck Creek, was also observed. Fish kills have been observed intermittently in Esquimalt Lagoon over the last 30 years.

Phytoplankton analysis of four areas of the lagoon on September 19 during the fish kill indicated there were no phytoplankton inherently toxic to aquatic life present. While up to 6300 cells/mL of *Prorocentrum micans* were found in some samples, this alga is a frequent bloom-former in BC coastal waters and has never been identified as toxic to fish. The highest concentration of *Prorocentrum minimum* on this date was 3000 cells/mL. *P. minimum* is less frequently observed in BC coastal waters, but is not likely a toxic alga species, either. The only phytoplankton species directly toxic to aquatic life were collected on August 5 at Phyto-1 and in numbers too small to cause widespread harm (*Alexandrium* sp. ~20 cells/mL and *Dictyocha speculum* ~1 cell/mL). In BC, *Alexandrium* species can cause paralytic shellfish poisoning and, at concentrations of ~500 cells/mL, have been implicated in fish kills. *Dictyocha speculum* can cause fish kills at ~300 cells/mL (Haigh 2008).

Dissolved oxygen levels measured at the surface the day after the fish kill were normal (near saturation) and did not show direct evidence of causing the fish kill. However, it is very likely that the observed fish kill was due to low overnight oxygen levels caused by high algal respiration at night, low overnight tides, and warm water conditions (Haigh 2008). Phytoplankton produce oxygen by photosynthesis during daylight hours, but deplete dissolved oxygen in the water column during nightly respiration. In addition, as the algae naturally die off, the bacterial decomposition of this added organic matter will further deplete oxygen supplies and can create anoxic conditions lethal to aquatic life (Rabalais et al. 1996, Haigh 2008). This effect is magnified in shallow and low flush water bodies such as Esquimalt Lagoon.

Previous phytoplankton sampling on August 5 and September 3 showed extremely thick blooms with counts as high as 300,000 cells/mL. Overall, the biomass (total phytoplankton) rating during the sampling period from August to October averaged 4.5 on a scale of 1.0 (very low) to 5.0 (very high). As the lagoon contains significant eel grass beds, these blooms may have caused excessive shade, compounding the problem (Haigh 2008).

POSSIBLE CAUSES OF THE BLOOMS

Temperate marine systems are thought to be nitrogen limited. Therefore, increases of nitrogen can lead to over-enrichment and increased plant growth (Haigh 2008). Nitrogen in very high quantities (>16 mg/L N) can cause direct toxicity in aquatic marine invertebrates and fish (CCME 2005a); however, the nitrate levels at the four phytoplankton sampling sites were lowest on the day after the fish kill (September 19) and well below the CCME interim marine guideline. Phosphorus enrichment is generally more of a concern in freshwater systems where it is usually the limiting factor (CCME 2005b). In freshwater systems, high levels of phosphorus can cause eutrophication. There are no marine guidelines available to compare the lagoon phosphorus results to determine if they are a contributing factor.

Phytoplankton blooms in Esquimalt Lagoon are thought to be increasing and changing in nature and the nutrient levels in Esquimalt Lagoon marine waters and in freshwater flows entering the lagoon appear to be significantly higher during 2008 sampling than in previous studies during the 1970s and 1980s (Haigh 2008, Rabalais et al. 1996, Robinson & Watanabe 1980). Water quality monitoring by ELSI volunteers show increasing levels of nitrates since 2003. Frequent exceedences of 2.95 mg/L N were measured at all monitoring sites with the exception of Phyto-4. Large spikes were measured at Phyto-1 (December 2003, November 2004 and June 2006). One large spike occurred in November, 2004, near Phyto-3 (Luke and Sabourin 2007). Fecal coliform concentrations for Colwood Creek remain low, but have increased in recent years compared to measurements taken before 2004. All measurements before June, 2004, were below 30 FC/100 mL. Since then, there have been counts of 90, 180, 190 and 210 FC/100 mL (CRD 2007).

During the current sampling investigation for Esquimalt Lagoon, nitrates, phosphorus and fecal coliform were high in both the lagoon and in freshwater inputs and their catchment areas around the southwest end of the lagoon. Selleck Creek (928) and discharges 929 through 933 were all high in nitrate and phosphorus at least once in 2008. Bee Creek also had a high nitrate level. Upstream investigations for Selleck Creek, 932 and 933 revealed high nitrate, phosphorus and fecal coliform (in Selleck Creek), but attempts to identify specific sources were inconclusive. The furthest upstream sources of nitrate and fecal coliform in Selleck Creek emerged from a pond fed by an underground spring. The catchment area for the southwest toe of the lagoon contains numerous springs of various sizes (Boyle, pers. comm. 2009).

NUTRIENT SOURCES

The main source of nutrients entering the lagoon is through non-point sources such as stormwater runoff, groundwater and atmospheric deposition. Sources of nitrate include fertilizers, sewer ex-filtration, failing septic systems, animal manure, industrial sources and acid rain (CCME 2005a, Nolan 1988). Animal manure generally contributes fewer nitrates but more bacteria to aquatic systems than inorganic fertilizers and fertilizers generally contribute more nitrate than sewage (Nolan, Hitt and Ruddy 2002). In urban areas, nitrate contamination of groundwater increases with population density, well-drained soils such as sand and gravel aquifers, and decreasing woodlands (Nolan, Hitt and Ruddy 2002, Nolan 1988). Nitrate is highly soluble and does not bind readily to soil particles in water, allowing it to be transported easily through groundwater and surface waters over distances (CCME 2005a). Nitrate can also be persistent in groundwater for decades and can accumulate as increasing amounts of nitrogen are leached into the system (Nolan 1988).

Sourcing of nitrate contributions, as to whether they are mainly from sewage or fertilizers, may be aided by further analyses of water samples for the ratio of nitrite to nitrate, as well as by levels of potassium. Nitrite (NO_2^-) is the form of nitrogen produced in sewage and nitrate (NO_3^-) is the form found in fertilizers. Finding high levels of nitrite could indicate nearby sewage sources. However, as nitrite naturally converts to the more stable nitrate form, high nitrate levels would not rule out sewage sources. Upstream Selleck Creek samples indicate high nitrite vs. nitrate ratios. This comparison has not been completed for surrounding discharges.

Fecal coliform in groundwater does not travel as far or survive as long as nitrate. Areas where the soils are gravelly or highly fractured are the most susceptible groundwater contamination by bacteria (Alberta Agriculture and Rural Development 2008). There is a large population of birds in the lagoon and surrounding area that could be the main cause of high fecal coliform counts found in stormwater discharges. BST samples have been collected from Bee and Selleck Creek to determine if the source of fecal coliform bacteria are human; however, the results of the analysis were inconclusive.

High levels of phosphorus were found in the lagoon and in stormwater discharges. Relevant sources of phosphorus include fertilizers, pesticides and detergents. However, phosphorus is not as important a nutrient for causing an increase in phytoplankton in marine waters. Studies indicate that nitrogen is the limiting nutrient for algal blooms in marine waters.

The majority of fertilizers contain a mix of nitrate, phosphorus, and potassium in varying ratios. Analysis of potassium ratios to nitrates in upstream samples may also provide an indication of fertilizer inputs to groundwater, if positive. While low levels or absence of potassium would not completely rule out fertilizers as a nutrient source, this information could provide valuable direction in determining other sources.

The difficulty in determining a specific source of nutrients (nitrate, phosphorus and sewage) contributing to Esquimalt Lagoon partially lies in the morphology of the lagoon watershed. The Esquimalt Lagoon watershed extends through the City of Colwood and District of Langford and the majority of the watershed and underlying aquifer is composed of the Colwood Delta and Outwash Plain gravels and sands (Monahan and Levson 2000). The groundwater aquifer extends beyond the margins of the lagoon watershed and is rated by the Ministry of Water, Land and Air Protection as Moderately to Highly vulnerable (Kenny 2004). The main sources of nitrate, phosphorus and high fecal coliform counts have been traced to Selleck Creek (928) at the emergence of a natural spring on the Aquattro site, and CRD discharges 929 to 933 near the toe of the lagoon. The contributing areas uphill of these sites are mainly residential with portions of woods in the Royal Roads University property. There are a number of springs feeding these flows, according to City of Colwood staff (Boyle and Munn 2009), which could have the same source flows as Selleck Creek.

Due to the porosity of the aquifer, groundwater emerging from springs in this lower catchment area could originate from much further distances, though nearer sources are more likely. Nitrate and bacteria are the most common groundwater contaminants worldwide and groundwater can be very difficult to remediate (Alberta Agriculture and Rural Development 2008).

5.0 RECOMMENDATIONS

It is recommended that the following be undertaken as budgets allow:

1. Carry out frequent water quality sampling of stormwater discharges 926, 928–933.
2. Sample discharges flowing into Esquimalt Lagoon between Colwood Creek (916) and Selleck Creek (928).
3. Initiate or continue upstream sampling of stormwater discharges with high nutrient or fecal coliform counts to determine the sources.
4. Collect Bacterial Source Tracking (BST) samples from discharges 928 and 933 to determine if sewage or wildlife is the source of fecal coliform bacteria.
5. Sample discharges with high nitrates levels for nitrite to assist with determining if the source is sewage or fertilizers.
6. Continue water quality sampling of Esquimalt Lagoon in 2009, before, during and after a bloom. One sampling session should be done at night during a bloom to confirm low dissolved oxygen levels.
7. Investigate the feasibility of sampling groundwater in the catchment area for nutrients and fecal coliform bacteria.
8. Dye test homes still operating on private septic systems in the Esquimalt Lagoon area to ensure they are not contributing nutrients to the lagoon.
9. Explore potential upstream sources of chemical fertilizers, including Royal Roads University, the Royal Colwood Golf Course, Hatley Memorial Gardens cemetery, playing fields, and new developments where hydroseeding and new sod may be factors.

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