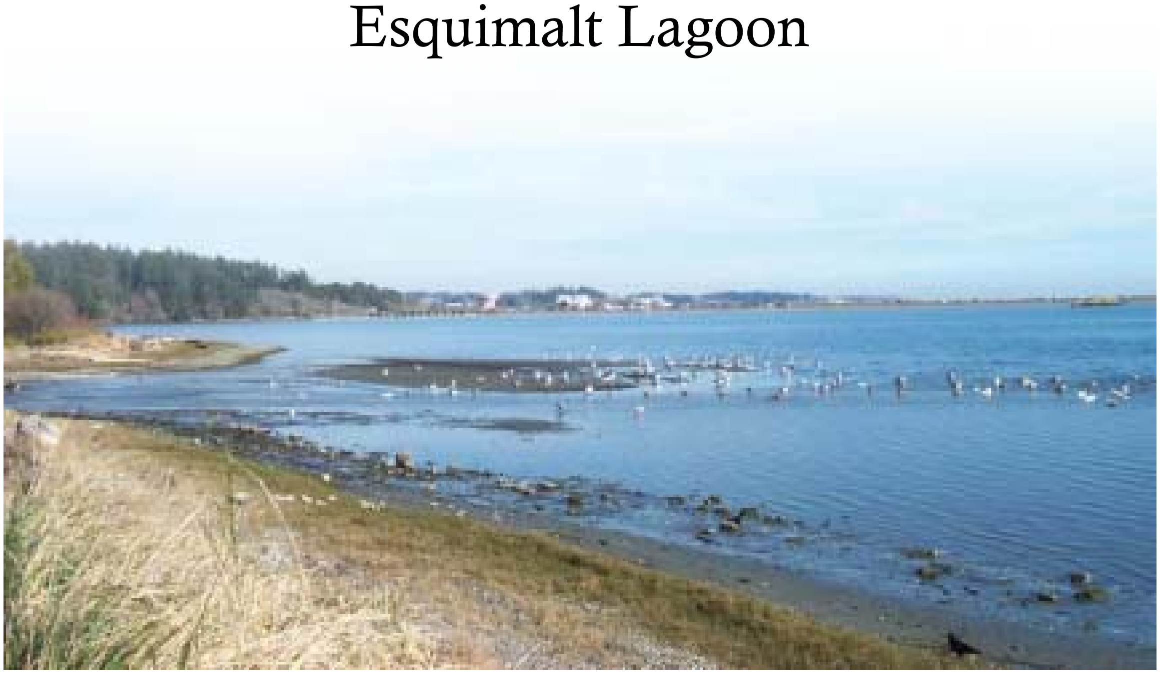
Development of a Water and Sediment Sampling & Monitoring Program for the Esquimalt Lagoon



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Executive Summary

Nep2ne Consulting was contracted by the Esquimalt Lagoon Stewardship Initiative to determine contamination present and entering the Esquimalt Lagoon, to investigate the source of contamination, and to develop an environmental monitoring program for residents in the area.

A sampling program was designed. This was done after a review of previous studies and reports in order to determine areas of concern and gaps in the information available on the lagoon. Sampling locations were chosen based on the information gathered, proximity to the shore and to probable sources of inputs.

Water and sediment samples were taken at 20 sites within the Esquimalt Lagoon on March 13, 2002. Samples were analyzed for metals and coliforms. Results of these analyses indicated elevated levels of arsenic, cadmium, copper, lead and zinc in the sediments, as well as copper and coliforms in the water. Samples were also analyzed for herbicides, pesticides, PCBs, PAHs, nitrates, nitrites, phosphate, and BOD. The concentrations of these parameters were either below detection or well below the guidelines. Conductivity, pH, dissolved oxygen, and temperature were within specified guidelines for water quality.

Based on the results of the first round, the sampling and analytical program was revised for the second round. This consisted of 13 locations in the lagoon and the addition of 12 locations in four freshwater inputs.

The second round of sampling in the lagoon occurred on June 18, 2002. This further confirmed the absence of herbicide, pesticide, nitrate, nitrite, and phosphate contamination. Ammonia was found in the lagoon, but well below specified guidelines. Although copper levels in water had exceeded the guidelines at all locations in the March sampling, it was not detected in the second round.

The freshwater inputs of Bee Creek, Colwood Creek, Selleck Creek, and Lagoon Road Outfall were sampled on June 19, 2002. Elevated levels of arsenic, lead, iron, nickel, and cadmium were discovered within Colwood Creek sediment. Nitrites, phosphates and ammonia were extremely low from all creeks, but elevated levels of nitrates were found to be entering the Esquimalt Lagoon through each of the four creeks tested. Fecal coliform contamination was discovered within all creeks, however Selleck Creek was an order of magnitude above all others. A bacteriological analysis of Selleck Creek on July 11, 2002 showed the presence of bacteria of human origin, but was negative for that of birds and cows.

Further monitoring of the Esquimalt Lagoon is recommended through residential visual observation of changing conditions, such as algal growth, and through further testing of freshwater inputs for fecal coliforms, nitrates, pH and temperature. Groundwater monitoring of present monitoring wells should be undertaken to analyze both fecal and nitrate levels within groundwater. Education of area residents about pollution prevention and septic field maintenance should occur through social gatherings.

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BOD – Biochemical Oxygen Demand
CCME – Canadian Council of Ministers of the Environment
CRD – Capital Regional District
DO – Dissolved Oxygen
DOE – Department of Ecology (Washington State)
ELSI – Esquimalt Lagoon Stewardship Initiative
EMS – Environmental Monitoring System
GPS – Geographic Positioning System
ISQG – Interim Sediment Quality guidelines
MDL – Method Detection Limit
PAH – Polycyclic Aromatic Hydrocarbons
PCB – Polychlorinated Biphenyls
PEL – Probable Effect Level
RPD – Relative Percent Difference
TOC – Total Organic Carbon
UTM – Universal Transverse Mercator
VEHEAP – Victoria and Esquimalt Harbours Environmental Action Program
WLAP – Ministry of Water, Land and Air Protection

1.0 Introduction

The Esquimalt Lagoon is a shallow, almost entirely landlocked body of water that receives freshwater inputs on its landward side from several creeks as well as marine water from the Juan de Fuca Strait. The lagoon and adjacent waterways constitute an ecologically sensitive area, supporting populations of cutthroat trout, providing rearing habitat for salmonids, and sustaining littleneck clams, mussels and Japanese oysters within intertidal gravel bars. Historically, the area also supported a productive crab fishery and served as spawning grounds for herring. Designated as a federal Migratory Bird Sanctuary, Esquimalt Lagoon has a highly diverse and abundant bird population and provides important feeding and over wintering habitat for waterfowl.

Periodically in the fall, dense algal blooms appear in the lagoon, creating oxygen-depleting conditions that have frequently resulted in fish and crab mortalities. Though nutrient inputs required for such algal growth may in part be attributed to the populations of birds that frequent the area, malfunctioning septic systems, yard and garden chemical use, and urban runoff have been identified as possible contributing factors. It is expected that contaminants from such anthropogenic sources enter the lagoon from the estimated 2000 ha watershed; however, only limited sampling has been conducted to date so more research is required to ascertain the presence and extent of such contamination.

To identify significant contaminant inputs as well as possible point and non-point sources for Esquimalt Lagoon, the Esquimalt Lagoon Stewardship Initiative (ELSI) proposed to develop a water and sediment sampling program. A project team from Royal Roads University was appointed to conduct baseline water and sediment quality sampling, to analyze the data for various parameters and to design and implement a long-term, volunteer-based monitoring program. The major research questions that were determined for the project are twofold:

- What are the significant contaminants (bacteriological, physical and chemical) present in the Esquimalt Lagoon, and what are the sources of these?
- How can a future volunteer-based program most effectively monitor such contamination in Esquimalt Lagoon?

2.0 Background

A review of past studies was conducted to determine the sampling required at Esquimalt Lagoon. The information available regarding past sampling efforts on Esquimalt Lagoon spanned from reports prepared by the Department of National Defense in the late seventies to recent data collected by the Capital Region District. After assessing these reports, the team assembled the data relating to past chemical and biological analysis of the soil, creeks and sediment in and around the lagoon. This data was then used to develop a sampling plan to fill information gaps and provide further background data on the contaminants in the lagoon.

2.1 Literature review

Many reports provided data on parameters tested in and around the lagoon and were used in the development of the sampling plan for the first round of sampling on March 13. These reports include:

- *Subtidal Survey of the Physical and Biological Features of Esquimalt Lagoon* - prepared for VEHEAP by Archipelago Marine Research, this report provides information on the physical and biological features of the lagoon. (Archipelago Marine Research 2000).

- *Stormwater Quality Annual Report Core Area – 2000*. This report contains a summary of the sampling program undertaken by the CRD. Sampling for fecal coliforms and metals is done at 20 locations along the shore of the lagoon. Additional sampling for fecal coliforms occurred at five sites in the middle of Esquimalt Lagoon and two more near the mouth of Colwood Creek.

  All of the samples collected in 2000 had fecal coliform levels below the Canadian recreational water quality guideline of 200 FC/100 mL, although the shellfish guideline of 14 FC/100 mL was exceeded in two samples gathered near Colwood Creek. The mean of the samples was 1 FC/100 mL during the winter and 5 FC/100 mL during the summer. These levels were lower than those observed in 1999.

  Levels of metals, and PAHs in sediment are also determined near some of the inputs (locations are rotated over a period of years). Based on most recent values, none of these locations exceeds the Marine Sediment Quality Guideline. (Capital Regional District 2001).

- *Stormwater Quality Survey Core Area – 2000: Fecal Coliform Data and Quality Assurance Results*. This report provides the sampling methods and quality assurance/quality control used in the stormwater quality survey, as well as historical fecal coliform data from discharges (1982 to 2000). Fecal coliform levels are generally gathered once in the wet (winter) and dry (summer) seasons. Levels are highly variable, but the highest values are typically found in inputs at the tip of the lagoon at Lagoon Road[1] and Ocean Boulevard[2] and at Selleck Creek[3]. (Capital Regional District 2001).

- *Assessment of Metals and PAHs in Sediments From Stormwater Discharges and Streams 1998 Sampling Program* by EnviroEd Consultants for CRD. Three locations in Esquimalt Lagoon were tested for metals, and PAHs in sediments (CRD outlet nos. 914, 916 and 920). All of the locations received a low contaminant rating. (EnviroEd Consultants 1998).

- *Esquimalt Lagoon State of the Ecosystem Report*, a major project completed in 1998 for Royal Roads University by a team of Bachelor of Science students. This study evaluated inputs of nitrates and fecal coliforms to the lagoon from freshwater sources on Royal Roads University property including Colwood Creek, the outflow from the Japanese Gardens, Hatley Creek, and an unnamed creek near Pacific Centre, as well as two piezometers. Eight samples from each location were analyzed for fecal coliform levels between February and May 1998. The mean fecal coliform levels in Colwood Creek were 33 cfu/100 mL on the lower portion of the creek, and 21 cfu/100 mL near Sooke Rd. The mean levels discovered in Hatley Creek were 34.5 cfu/100mL. The highest levels obtained during this study were from the unnamed creek (mean 64 cfu/100mL) while the outfall from the Japanese gardens contained the fewest (mean 6.5 cfu/100 mL). Six samples were analyzed for nitrates during the study period. Results indicate that the mean nitrate levels were highest in Colwood Creek (approximately 10 ppm), the Japanese Gardens (9.3 ppm), and Hatley Creek (21 ppm). (Anderton et al 1998).

- *Hydrogeology of Esquimalt Lagoon,* a report produced by the City of Colwood (1995-1996). This study examined discharge and recharge of water in the vicinity of Esquimalt Lagoon. The recharge areas include the northeast slope of Triangle Mountain, Glen Lake, Royal Colwood Golf and Country Club and possibly Langford Lake. The discharge areas include Esquimalt Lagoon and 30 different emerging springs surrounding the lagoon.

  Following sampling of the surrounding storm drains, the City of Colwood concluded that there are "high levels of failing septic systems and bird droppings in storm run-off to lagoon"; yet, there is inconclusive evidence that ground water upwelling is a source of fecal contamination to the lagoon. (1995-1996). Recommendations include, the monitoring of BOD, fecal coliforms, nitrogen as nitrate, phosphorous, heavy metals and mineral oil and grease in outfalls surrounding the lagoon. It was determined that the main source of fresh water into the lagoon was Colwood Creek, and that this

[1] CRD Outlet No. 932
[2] CRD Outlet No. 933
[3] CRD Outlet No. 928

accounts for 75%-95% of surface water flows into Esquimalt Lagoon. (Payne Engineering Geology 1996).

- *Red Tide in Esquimalt Lagoon due to Gymnodinium sanguineum hirasaka,* a study completed by L.N. Watanabe and H.G. Robinson (1979). This study determined that growth of dinoflagellate populations within the Esquimalt Lagoon was limited by nitrate. Nitrate levels on July 24, 1979 ranged from (2.12-20.3 ug/L). This study documented that red water was observed every fall between 1974-1977 and 1979, and confirmed that the salinity in the lagoon does not fluctuate with the seasons (Watanabe & Robinson 1979).

- *The Ecology of Esquimalt Lagoon 1. Nutrient inputs – The Role of Sewage,* a study completed by L.N Watanabe and H.G. Robinson (1980). In this report, Selleck creek, the Japanese Garden outfall, Colwood creek, Lagoon Rd outfall and Bee creek and three locations in the Esquimalt Lagoon were sampled to determine fecal coliform, nitrate, orthophosphate and ammonia levels. During the 1980's, 0 - 65 head of cattle grazed in the pasture above Bee creek, consequently fecal coliforms levels were drastically higher than present levels in the creeks (especially Bee creek ranging between (51 - 14,100 Fecal Coliforms/100ml) and Selleck creek had levels ranging between (61 - 36,360 Fecal Coliforms/100ml) and in the lagoon itself. Yet, it was determined that there was a large dilution/coliform mortality effect in the lagoon resulting in low levels of fecal coliforms in the lagoon (0 –246 Fecal Coliforms/ 100ml) compared to the creeks (0 - 36,360 Fecal Coliforms/100ml).

  In this study, it was established that the major nutrient entering the lagoon from streams was nitrates; sources include, vegetation (e.g. skunk cabbage), humus in water, bogs and fertilizers. Following statistical analysis, a correlation between levels of ammonia, phosphate and fecal coliforms was found; therefore, fecal coliforms are a source of these nutrients. There is no correlation between levels of fecal coliforms and nitrates. This study concluded that sewage has only a partial influence on the trophic levels of Esquimalt Lagoon. (Watanabe & Robinson 1980).

- *Core Area Liquid Waste Management Program 1999,* between (1976 – 1995) on the assessment of the on-site sewage disposal issue, initiated by the City of Colwood. In the 1980 Esquimalt Lagoon report, nutrient related conclusions were as follows; on-site septic systems only have a partial influence on the trophic status of the lagoon and the majority of fecal contamination detected was from animal sources. In 1981 the Esquimalt Lagoon Subdivision Dye Testing Survey concluded that, out of the 67 homes dye tested only 17 (26%) were positive. In addition, due to severe surface drainage problems, repairs of the systems would be difficult. The same test was conducted in 1983. Sixty-eight homes were dye tested of which 12 were suspected of having malfunctioning sewage disposal systems. Subsequently, these homes were retested to confirm the results; only 5 out of the 12 were positive. In a 1987 Triangle Mountain Outfall Water Survey, sewage seepage was determined to be affecting the quality of the surface run-off. In 1990 Esquimalt Lagoon Dye test survey was conducted in response to an algae bloom and aquatic life issues. Sixteen homes in the area were dye tested with no positive results. In 1996 the same test was done on 16 homes, 2 were found to be positive and were quickly repaired.

These studies concluded that both Triangle Mountain and Esquimalt Lagoon "have severe site and soil constraints for the continued use of on-site systems". In addition, septic fields in the vicinity of Esquimalt lagoon will continue to be a challenge to repair due to seasonal flooding and poor soil. It is recommended that Municipal sewers be extended to these areas as soon as possible. (Capital Regional District 1999).

3.0 Sampling Methodology

For the determination of contamination present and entering the Esquimalt Lagoon, samples were taken from the lagoon and surrounding creeks in March and June 2002.

Samples were collected from the lagoon on March 13, 2002 as a "baseline survey". Based on the results of the baseline analysis, site locations and parameters were revised. Sampling was conducted using the revised sampling and analytical plan within the lagoon on June 18, and from surrounding creeks on June 19. Selleck Creek was further sampled on July 11, 2002.

3.1 Sample Sites

3.1.1 Lagoon Sampling – March 13, 2002

Sample sites for the baseline survey of the lagoon were chosen based on judgmental sampling. The specific locations were selected after a review of past studies, aerial photographs and a hydrogeological map of the area, and in consultation with the project sponsor. Sample locations included areas along the shoreline, as well as along the peninsula, and two areas in the centre of the lagoon (Appendix A-1).

The majority of samples on the shoreline were focused along the residential and institutional areas (locations 1-12), which was hypothesized to be the likely source of contamination from anthropogenic sources, such as failing septic systems and urban run-off. Locations 13 and 14 were nearshore control locations that the team identified as most likely to be low in contaminants because of the large buffering capacity of the forest.

Location 15 was chosen to determine if there were any contaminants coming in through the mouth of the lagoon. To analyze any contamination from the road along the peninsula, locations 16, 17, and 18 were chosen.

Location 19 was chosen because it had been identified as a "dead zone" in the lagoon, an area with very little life present (Archipelago 2000), with location 20 as a deep-water control area.

3.1.2 Lagoon Sampling – June 18, 2002

Further sampling in June focused on 13 specific locations (Appendix A-2). These locations were chosen to monitor any seasonal variations. The locations were again based on judgmental sampling, and focused on the mouths of creeks and results received from March sampling.

3.1.3 Creek Sampling - June 19, 2002

Further sample sites were chosen in four specific creeks (Appendix A-2). The outfall along Lagoon Road entering the lagoon (C1), Selleck Creek (C2-C3), Bee Creek (C4-C10), and Colwood Creek (C11-C14). These creeks all carry a large amount of urban run-off from the area and were selected to determine probable sources of inputs into the lagoon.

Samples from Bee Creek were taken between each successive wetland to determine the "buffering" effect of vegetation within the creek. This was done in order to compare the results from more urbanized creeks, such as Selleck Creek, which do not flow through wetlands. CRD reports have indicated that Selleck Creek has a highest level of fecal coliform contamination of the inputs into Esquimalt Lagoon.

3.1.4 Selleck Creek – July 11, 2002

As a result of high coliform results within Selleck Creek, further microbial sampling was conducted at both locations C2 and C3. These sites are indicated in Appendix A-2.

3.1.5 GPS

Each lagoon site was sampled once during the ebb and flood tides. GPS readings of sample sites were taken the first tide, and these original GPS coordinates were used to relocate the sites during the successive tide.

Before use, the GPS receiver (Trimble, model GEO Explorer III) was configured to use Universal Transverse Mercator (UTM) coordinates, NAD 83 Datum, and metric units. After data was collected and downloaded into Pathfinder Office 2.51, a differential correction was used to correct anomalies between the unit used (rover) and the base station (Kettle Creek, WA). The differential correction files were downloaded from the Kettle Creek WA base station. (http://www.fs.fed.us/database/gps/kettle.htm)

3.1.5.1 Environmental Management System (EMS)

The Ministry of Water, Land and Air Protection (WLAP) collects environmental data into the Environmental Management System (EMS), in order to provide access to environmental data electronically. The results from this project were entered into the EMS system by setting up an individual EMS site number for each location.

Site numbers were generated by initially estimating a latitude and longitude for each site. The actual co-ordinates were later adjusted with the GPS points taken at each site.

3.2 Water Sampling

All water samples collected from the lagoon in March and June were taken from a boat, away from the motor (in this case, from the bow of the boat). Field parameters were obtained simultaneously on the opposite sides of the boat. All water samples were taken prior to sediment sampling. During Creek sampling, students stood in the creek and took the sample upstream of where they were standing. All water samples were taken 10 cm below the water surface.

Samples were taken in a specific order: first organic parameters, and then inorganic. In March, Lagoon samples were taken in order of:

1. Coliforms,
2. BOD,
3. Nutrients, and
4. Metals.

Lagoon Samples taken in June were taken in order of:

1. Nutrients, and
2. Metals.

The order in which samples were taken from the creeks was:

1. Coliforms,
2. Nutrients, and
3. Metals.

For 10 percent of all samples taken (i.e. every 10^{th} location), a replicate of each sample type was taken. As well, a "blank" sample was taken using deionized water for 10% of all water samples.

Samples were taken with no headspace, with the exception of coliform samples. Bottles used to collect samples for nutrients and metals analysis were rinsed three times prior to sampling; bottles used to collect samples analyzed for coliforms and BOD were not rinsed. Nitric acid (2 mL) was added as a preservative to samples that were to be analyzed for total metals. Coliform bottles contained sodium thiosulphate, to neutralize any residual chlorine that would kill the bacteria and lower the results.

3.3 Sediment Sampling

Sediment samples were taken after the completion of water sampling and field analysis of conductivity, pH, dissolved oxygen (DO), salinity, and light penetration.

All sediment samples from the lagoon were taken with an Eckman grab, which was emptied into a large stainless steel bowl. Sediment samples from the creek were obtained with a stainless steel scoop and placed into the stainless steel bowl. Once in the bowl, the sediment sample was mixed, large rocks and shells were removed, and the sample was evenly divided into two jars. A description of the sediment was recorded, including odour and texture.

All equipment used was cleaned with Sparkleen detergent and rinsed with seawater (or creek water) after use, prior to leaving the sample site.

3.4 Field Analysis

All field parameters taken from the lagoon were taken from a boat, on the opposite side of the boat as the samples were being collected. During creek sampling, measurements were made near sample location (50-100 cm across the creek). Field parameters included specific conductivity, pH, temperature, dissolved oxygen, and light penetration, and salinity.

At each sample location, visual observations were made and recorded, which included a description of the general location, surrounding vegetation, weather observations, and time of sampling. All of these observations were recorded on waterproof paper kept in the field binder, using 4H lead.

3.4.1 Conductivity

Conductivity was measured in the lagoon using a Cole Parmer 1481-60 conductivity meter, using a platinum probe. This meter was calibrated using a 3000 σS/cm calibration solution. Calibration of the meter was done prior to use, and at least once after every ten sampling sites. Each calibration was recorded in the field book. The probe was placed into the water 10-20 cm below the water surface and the value was recorded in σs/cm once the reading stabilized.

3.4.2 Dissolved Oxygen

Dissolved Oxygen (DO) was measured using a HANNA HI 9142 DO meter. After cleaning the probe and replacing the membrane, the probe was calibrated with a 0 ppm oxygen calibration solution prior to sampling. In the field, further calibrations were done by adjusting the meter slope in air to 100%. This air calibration was done at the discretion of the student, at a minimum of every tenth sample site. Each calibration was recorded in the field book. To measure the DO, the probe was set 10-20 cm below the surface of the water and the value was recorded in mg/L (ppm) once the reading stabilized.

3.4.3 Light Penetration

Light penetration into the lagoon was measured using a Secchi disc. Two readings were taken at each location, by lowering the Secchi disc to a depth at which it could no longer be seen, and raising it until it could be seen. An average of two values was recorded in metres.

3.4.4 Salinity

Salinity was measured using a refractometer. Distilled water showed that no calibration was necessary (this was checked at every sample location). Calibration is done by adjusting the reference scale to $0\ ^{0}/_{00}$ using distilled water. A drop of water sample was placed into the sample chamber, and the value was recorded in parts per thousand ($^{0}/_{00}$).

3.4.5 Temperature and pH

Temperature and pH at each sample site were determined using a Barnant 30 digital pH and temperature meter. The meter was calibrated using pH 4 and 7 buffer solution prior to use, and once every 10 samples. The meter was also calibrated any time the values seemed to drift. All calibrations and observations were recorded in the field binder. Both probes were placed in the water 10-20 cm below the water surface and the values were recorded in \C and pH units once the readings stabilized.

3.5 Laboratory Analysis

PSC Analytical Services in Vancouver, BC performed laboratory analysis of the majority of parameters. Coliforms and the bacteriological differential test were analyzed at JB Laboratories Ltd and MB Laboratories Ltd respectively, in Victoria, BC, due to the short holding time for these samples.

3.5.1 Water Analysis

Water parameters analyzed by PSC Analytical Services included: nitrates, nitrites, ammonia, orthophosphate, biochemical oxygen demand (BOD), total metals, and total dissolved metals. JB laboratories enumerated both fecal and total coliforms. MB laboratories performed a bacteriological scan, which included: fecal coliforms; *Enteroccus* (total, *E. avium* and *E. gallinarum*); *Escherichia coli* (total and *E.coli* O157); and *Staphylococcus* (total, *S. aureus, S. capitus, S. cohnii, S. haemolyticus, S. hominis, and S. saccharolyticus*).

BOD was determined over 5 days using the method described in Standard Methods for the Examination of Water and Wastewater, 2000. The total nitrate and nitrite levels were determined using Auto Cadmium Reduction. The nitrite levels were evaluated using Auto Diazotization. From these two results, the nitrate levels were calculated. Ammonia was determined using automated Berthelot method. The ortho-phosphorous levels were analyzed using Auto Ascorbic Acid protocol. Metals were analyzed using Ultra Low Level Induction Coupled Plasma (ICP) Mass Spectroscopy, with the exception of the second round of lagoon sampling, in which metal were analyzed using ICP.

Fecal and total coliforms were enumerated using a standard plate count (Standard Methods for Examination of Water and Wastewater, 2000). *Escherichia coli* and *E. coli* 0157 were determined using methods from the Federal Drug Administration, Bacterial Analytical Method (FDA/BAM) 8th ed, 1995 + Revision A, 1998.

Staphylococcus aureus was determined using FDA/BAM 8th ed, 1995 + Revision A, 1998. Other microbial identifications (*E. avium, E. gallinarum, S. capitus, S. cohnii, S. haemolyticus, S. hominis, and S. saccharolyticus)* were determined with the use of Bergey's Manual of Systematic Bacteriology vols 1-4, International Journal of Systematic Bacteriology & Recommendations of the Taxonomic Subcommittees.

3.5.2 Sediment Analysis

All sediment analysis was conducted by PSC Analytical Services. Analysis included Total Organic Carbon (TOC), Polycyclic Aromatic Hydrocarbons (PAHs), total metals, herbicides, organo-chlorine pesticides, nitrogen-containing pesticides, and phosphorous-containing pesticides.

The metals were analyzed using HNO_3/HCl Induction Coupled Plasma (ICP) Spectroscopy. Chlorinated phenols and PAHs were analyzed using Gas Chromatograph/ Mass Spectrometry. Analysis of organonitrogen pesticides was done gas chromatography- nitrogen phosphorous detector. Organochlorine pesticides and PCBs were analyzed by Soil-Florisil-electron capture detector. Phosphorous-containing pesticides were analyzed by the Extraction-charcoal-nitrogen phosphorus detection method.

3.6 Criteria

The results were compared to three standards, the Washington State Department of Ecology (DOE) Guidelines, the Canadian Council of Ministers for the Environment (CCME) Environmental Quality Guidelines, and the British Columbia Ministry of Water, Land and Air Protection (WLAP) guidelines.

Due to the quantity of experimental data that has been used to develop them and the fact that they have been established for some time, the Capital Regional District prefers the Department of Ecology standards (J. Watson, personal communication, March 2002). For its' purposes, the CRD ranks the standards as DOE, followed by CCME and WLAP.

3.6.1 Criteria for Water Analysis

The criteria consist of the levels from the DOE, CCME, and WLAP guidelines that were used to analyze the marine and fresh water samples respectively (Table 3.1 and Table 3.2).

Table 3.1: Marine Water Criteria used to Analyze Esquimalt Lagoon results from March and June 2002.

Parameter	Units	DOE		CCME	WLAP	
		Acute Toxicity	Chronic Toxicity	Aquatic Life	Approved	Working
Dissolved Oxygen	mg/L	-	-	> 8	-	-
pH		-	-	7.0 - 8.7	-	-
Secchi Depth	m	-	-	1.2[1]	-	-
Ammonia	mg/L	0.23	0.035	-	1 [2]	-
Fecal Coliforms	cfu/100mL	-	-	-	14[3]	-
Arsenic	σg/L	69	36	12.5	-	12
Barium	σg/L	-	-	-	-	500 (minimal risk) 1000 (hazard)
Beryllium	σg/L	-	-	-	-	100 (minimal risk) 1500 (hazard)
Cadmium	σg/L	42	9.3	0.12	-	0.1
Chromium III	σg/L	-	-	56	-	56
Chromium IV	σg/L	1100	50	1.5	-	1.5
Cobalt	σg/L			1000		
Copper	σg/L	4.8	3.1	-	3	-
Lead	σg/L	210	8.1	-	140	-
Manganese	σg/L	-	-	-	-	100
Nickel	σg/L	-	-	-	-	75
Selenium	σg/L	290	71	-	-	54
Silver	σg/L	1.9	-	-	3	-
Uranium	σg/L	-	-	-	-	100 (minimal risk) 500 (hazard)
Zinc	σg/L	90	81	-	300	95

Notes:
[1]Recreation and aesthetics
[2]Ammonia based on average lagoon salinity (>30), temperature (15 deg C), and pH (8.2).
[3]Shellfish criteria [4]

[4] Recreational criteria: Canadian Recreational Quality Guideline is 200 fecal coliforms/100 mL

Table 3.2: Freshwater Criteria used to Analyze Bee Creek, Colwood Creek, Selleck Creek, and Lagoon Road outfall in June 2002.

Parameter	**Units**	**CCME**	**WLAP**	
		Aquatic Life	Approved	Working
Dissolved Oxygen	mg/L	5.5-9.5	-	-
pH		6.5-9.0		-
Fecal coliforms	cfu/100mL	-	14	-
Ammonia	σg/L	19	-	-
Nitrates	mg/L	45[1]	-	-
Aluminum	σg/L	5-100	-	-
Antimony	σg/L	6 [1]	-	20
Arsenic	σg/L	5	-	5
Barium	mg/L	-	-	5
Beryllium	σg/L	-	-	5.3 (chronic)
Cadmium	σg/L	0.017	-	-
Chromium III	σg/L	8.9	-	9
Chromium IV	σg/L	1	-	1
Cobalt	σg/L	50	-	0.9
Copper	σg/L	2-4	2	-
Lead	σg/L	1-7	3	-
Molybdenum	σg/L	73	1000	-
Nickel	σg/L	25-150	-	25
Selenium	σg/L	1	-	-
Silver	σg/L	0.1	0.1	-
Thallium	σg/L	0.8	-	0.3
Uranium	σg/L	100 [1]	-	300
Zinc	σg/L	30	-	-

Notes:
[1]Water community
Applicable standards were not available for all parameters.

3.6.2 Criteria for Sediment Analysis

The criteria used to compare the levels of metals in the sediment data are summarized in table 4.2. This consists of guidelines from the DOE and CCME.[5] At this point, the working sediment guidelines by WLAP are the same as the CCME guidelines.

Table 3.3: Marine Sediment Criteria used to Analyze Metals present in Esquimalt Lagoon Sediment in March 2002.

[5] This is the complete range of metals covered in the DOE and CCME guidelines.

Parameter	Units	DOE		CCME	
		Sediment quality guidelines[1]	Sediment Impact Zone[2]	ISQG[3]	PEL[4]
Arsenic	σg/g	57	93	7.24	41.6
Cadmium	σg/g	5.1	6.7	0.7	4.2
Chromium	σg/g	260	270	52.3	160
Copper	σg/g	390	390	18.7	108
Lead	σg/g	450	530	30.2	112
Silver	σg/g	6.1	6.1	-	-
Zinc	σg/g	410	960	124	271

Notes:
[1]DOE Sediment Quality Standards – "no effects level".
[2]DOE Sediment Impact Zone – "minor adverse effects level".
[3]CCME Interim Sediment Quality Guidelines
[4]CCME Probable Effect Level

Table 3.4: Freshwater Sediment Criteria used to Analyze Metals present in Bee Creek, Colwood Creek, Selleck Creek, and Lagoon Road Outfall in June 2002.

Parameter	Units	CCME		WLAP working	
		ISQG	PEL	ISQG	PEL
Arsenic	σg/g	5.9	17	5.9	17
Cadmium	σg/g	0.6	3.5	0.6	3.5
Chromium	σg/g	37.3	90	37	90
Copper	σg/g	35.7	197	36	197
Iron	σg/g	-	-	21,200	43,766
Lead	σg/g	35	91.3	35	91
Nickel	σg/g	-	-	16	75
Selenium	σg/g	-	-	5	-
Zinc	σg/g	123	315	123	315

Levels of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides and herbicides in sediment were compared to DOE and CCME standards.

3.7 Statistical Analysis

3.7.1 Relative Percent Difference

The results from the replicate samples were evaluated using the Relative Percent Difference (RPD) method. The formula is expressed as:

$$RPD = 100\left(\frac{\left|x_1 - x_2\right|}{\left(\frac{x_1 + x_2}{2}\right)}\right)$$

where x_1 and x_2 are the concentrations of the analytes above the detection limits. If the result was within 5 times the detection limit, the RPD was not calculated, as the difference was not statistically significant.

A relative percent difference less than or equal to 20% is considered good reproducibility, 20-30% is fair, 50% or greater is poor.

4.0 Results

A summary of the results obtained from the three sampling dates is presented due to the large amount of data collected. PSC Analytical Services Laboratory of Vancouver BC, analyzed the majority of samples; and JB Laboratories and MB Laboratories of Victoria, BC handled bacteriological samples. Complete results for all sampling are included (Appendix C).

4.1 Water Analysis

Analysis of the water samples was completed for field measurements, metals, nutrients, and fecal coliforms.

4.1.1 Field Analysis

Summary statistics were calculated per date and location for field measurements recorded on the sampling days (Table 4.1). All parameters were within guidelines, with the exception of Secchi depth, which has a CCME guideline of ∅1.2 m (Table 3.1).

Table 4.1. Summary Statistics of Field Parameters from the March and June Lagoon Sampling and the Creek Sampling

Location & Date	Parameter	Units	# Of Values	Min.	Max.	Mean	Std Dev.
Lagoon -- March	Field Dissolved Oxygen	mg/L	44	10.2	18.5	13.9	2.2
	Field pH	pH units	22	7.6	8.4	8.1	0.2
	Field Conductivity	σS/cm	44	7500	95400	44951	16950
	Field Temperature	Celsius	44	6.2	9.6	7.9	0.8
	Secchi Depth	m	12[1]	0.25	3	-	-
Lagoon – June	Salinity	$^0/_{00}$	28	25	37	33	4
	Field Dissolved Oxygen	mg/L	28	10.8	19	14.1	2
	Field pH	pH units	28	7.7	8.8	8.3	0.2
	Field Conductivity	σS/cm	28	42000	74000	49164	6140
	Hardness Total –T *	mg/L	28	3780	4830	4537	239
	Hardness Total –D *	mg/L	10	3680	4580	4366	253
	Field Temperature	Celsius	28	13.2	16.9	14.9	1
	Secchi Depth	m	12[1]	0.2	1.4	-	-
Creeks – June	Salinity	$^0/_{00}$	13	0	5	2	1
	Field Dissolved Oxygen	mg/L	13	5.3	10.6	9.1	1.7
	Field pH	pH units	13	6.6	7.6	7.3	0.3
	Temperature	Celsius	13	8.2	17.5	12.4	2.2

Notes:

[1]Minimum and maximum values for Secchi depth do not include values at sites where depth to bottom could be seen.
*This value was determined at the laboratory, PSC Analytical Services.

4.2.2 Metals

Levels of metals were analyzed for samples taken from the lagoon in March and June, as well as for samples collected from the June creek sampling. Samples from the March lagoon sampling and the June creek sampling were analyzed for total metals. Samples from the June lagoon sampling were analyzed for both total and dissolved metals.

Summary statistics were calculated for the concentrations of total metals found in the 44 samples collected from the March lagoon sampling (Table 4.2).

Table 4.2 Summary Statistics of Metals (Total) in Water from Esquimalt Lagoon for March 13, 2002

Metals Total	Units	# Of Values	Min.	Max.	Mean	Std Dev.
Aluminum	ug/L	44	<15.0	115	29.6	26.2
Antimony	ug/L	44	< 0.250	< 0.250	< 0.250	0.000
Arsenic	ug/L	44	< 5.0	< 5.0	< 5.0	0.0
Barium	ug/L	44	6.34	7.71	6.86	0.32
Beryllium	ug/L	44	< 1.00	1.47	1.01	0.07
Bismuth	ug/L	44	< 1.00	< 1.00	< 1.00	0
Cadmium	ug/L	44	< 0.50	< 0.50	< 0.50	0
Chromium	ug/L	44	< 10.0	47	18.4	10.0
Cobalt	ug/L	44	< 0.250	3.29	0.517	0.665
Copper	ug/L	44	64.3	158	111.1	28.7
Lead	ug/L	44	< 0.50	1.71	0.64	0.31
Lithium	ug/L	44	78.4	182	162.0	21.0
Manganese	ug/L	44	6.3	46	12.7	8.6
Molybdenum	ug/L	44	< 2.50	6.43	5.405	0.779
Nickel	ug/L	44	< 2.50	2.5	2.5	0
Selenium	ug/L	44	< 10.0	10	10	0
Silver	ug/L	44	< 1.00	1	1	0
Strontium	ug/L	44	2610	5950	5230	643
Thallium	ug/L	44	< 0.100	1.05	0.318	0.210
Tin	ug/L	44	< 0.50	5.25	0.85	0.94
Uranium	ug/L	44	0.532	1.48	1.241	0.176
Vanadium	ug/L	44	< 3.00	8.56	3.351	1.050
Zinc	ug/L	44	< 5.0	43	8.3	8.3

Summary statistics for total metals were calculated for the 28 samples from the June lagoon sampling (Table 4.3).

Table 4.3 Summary Statistics of Metals(Total) in Water from Esquimalt Lagoon for June 18, 2002

Metals Total	Units	# of Values	Min.	Max.	Mean	Std. Dev
Aluminum	mg/L	28	< 0.02	0.11	0.03	0.02
Antimony	mg/L	28	< 0.05	< 0.05	< 0.05	0.00
Arsenic	mg/L	28	< 0.05	< 0.05	< 0.05	0.00
Barium	mg/L	28	0.006	0.009	0.007	0.000
Beryllium	mg/L	28	< 0.0002	< 0.0002	< 0.0002	0.0000
Bismuth	mg/L	28	< 0.05	< 0.05	< 0.05	0.00
Boron	mg/L	28	2.75	3.55	3.33	0.19
Cadmium	mg/L	28	< 0.002	< 0.002	< 0.002	0.000
Calcium	mg/L	28	239	300	282.64	13.86
Chromium	mg/L	28	< 0.005	< 0.005	< 0.005	0.000
Cobalt	mg/L	28	< 0.005	< 0.005	< 0.005	0.000
Copper	mg/L	28	< 0.005	< 0.005	< 0.005	0.000
Iron	mg/L	28	0.031	0.189	0.069	0.037
Lead	mg/L	28	< 0.03	0.03	0.03	0.00
Magnesium	mg/L	28	772	990	930.18	49.72
Manganese	mg/L	28	< 0.001	< 0.001	< 0.001	0.000
Molybdenum	mg/L	28	< 0.005	0.01	0.005	0.001
Nickel	mg/L	28	< 0.008	< 0.008	< 0.008	0.000
Phosphorus	mg/L	28	< 0.1	< 0.1	< 0.1	0.0
Potassium	mg/L	28	276	365	341	21
Selenium	mg/L	28	< 0.03	< 0.03	< 0.03	0.00
Silver	mg/L	28	< 0.01	< 0.01	< 0.01	0.00
Sodium	mg/L	28	8150	10500	9666.07	529.89
Strontium	mg/L	28	4.47	5.8	5.44	0.32
Sulfur	mg/L	28	649	849	776.5	43.3
Tellurium	mg/L	28	< 0.05	< 0.05	< 0.05	0.00
Thallium	mg/L	28	< 0.03	< 0.03	< 0.03	0.00
Tin	mg/L	28	< 0.02	< 0.02	< 0.02	0.00
Titanium	mg/L	28	< 0.003	< 0.003	< 0.003	0.000
Vanadium	mg/L	28	< 0.005	< 0.005	< 0.005	0.000
Zinc	mg/L	28	< 0.005	< 0.005	< 0.005	0.000
Zirconium	mg/L	28	< 0.005	0.006	0.005	0.000

Levels of dissolved metals were also determined for five of these samples (Table 4.4).

Table 4.4 Summary Statistics of Dissolved Metals in Water from Esquimalt Lagoon, June 18, 2002

Metals Dissolved	Units	# of Values	Min.	Max.	Mean	Std Dev.
Aluminum Dissolved	mg/L	10	< 0.02	< 0.02	< 0.02	0.00
Antimony Dissolved	mg/L	10	< 0.05	< 0.05	< 0.05	0.00
Arsenic Dissolved	mg/L	10	< 0.05	< 0.05	< 0.05	0.00
Barium Dissolved	mg/L	10	0.006	0.007	0.006	0.000
Beryllium Dissolved	mg/L	10	< 0.0002	< 0.0002	< 0.0002	0.0000
Bismuth Dissolved	mg/L	10	< 0.05	< 0.05	< 0.05	0.00
Boron Dissolved	mg/L	10	2.72	3.43	3.248	0.20
Cadmium Dissolved	mg/L	10	< 0.002	< 0.002	< 0.002	0.0000
Calcium Dissolved	mg/L	10	234	286	273.1	14.49
Chromium Dissolved	mg/L	10	< 0.005	< 0.005	< 0.005	0.0000
Cobalt Dissolved	mg/L	10	< 0.005	< 0.005	< 0.005	0.0000
Copper Dissolved	mg/L	10	< 0.005	< 0.005	< 0.005	0.0000
Iron Dissolved	mg/L	10	< 0.005	0.014	0.0059	0.00
Lead Dissolved	mg/L	10	< 0.03	< 0.03	< 0.03	0.00
Magnesium Dissolved	mg/L	10	752	939	894.6	52.38
Manganese Dissolved	mg/L	10	< 0.001	< 0.001	< 0.001	0.000
Molybdenum Dissolved	mg/L	10	0.005	0.01	0.0085	0.001
Nickel Dissolved	mg/L	10	< 0.008	< 0.008	< 0.008	0.000
Phosphorus Dissolved	mg/L	10	< 0.1	< 0.1	< 0.1	0.00
Potassium Dissolved	mg/L	10	272	353	330.5	21.91
Selenium Dissolved	mg/L	10	< 0.03	< 0.03	< 0.03	0.00
Silver Dissolved	mg/L	10	< 0.01	< 0.01	< 0.01	0.00
Sodium Dissolved	mg/L	10	7840	10100	9484	659.04
Strontium Dissolved	mg/L	10	4.33	5.55	5.2	0.33
Sulfur Dissolved	mg/L	10	692	904	842.3	59.84
Tellurium Dissolved	mg/L	10	< 0.05	< 0.05	< 0.05	0.00
Thallium Dissolved	mg/L	10	< 0.03	< 0.03	< 0.03	0.00
Tin Dissolved	mg/L	10	< 0.02	< 0.02	< 0.02	0.00
Titanium Dissolved	mg/L	10	< 0.003	< 0.003	< 0.003	0.000
Vanadium Dissolved	mg/L	10	< 0.005	< 0.005	< 0.005	0.000
Zinc Dissolved	mg/L	10	< 0.005	< 0.005	< 0.005	0.000
Zirconium Dissolved	mg/L	10	< 0.005	0.005	0.005	0.000

Levels of total metals were analyzed for samples collected at 12 sites along creeks entering Esquimalt Lagoon. Summary statistics were calculated (Table 4.5).

Table 4.5 Summary Statistics for Metals (Total) from Colwood Creek, Bee Creek, Selleck Creek and Lagoon Road Outfall for June 19, 2002

Metals Total	Units	# of Values	Min.	Max.	Mean	Std. Dev
Aluminum	ug/L	14	8	149	74.0	37.1
Antimony	ug/L	14	< 0.005	0.162	0.043	0.054
Arsenic	ug/L	14	0.1	0.5	0.3	0.1
Barium	ug/L	14	5.06	9.33	6.59	1.22
Beryllium	ug/L	14	< 0.02	< 0.02	< 0.02	0.00
Bismuth	ug/L	14	< 0.02	0.07	0.03	0.02
Cadmium	ug/L	14	< 0.01	0.02	0.01	0.00
Chromium	ug/L	14	0.2	0.3	0.2	0.0
Cobalt	ug/L	14	< 0.005	0.241	0.035	0.064
Copper	ug/L	14	0.47	2.05	0.95	0.49
Lead	ug/L	14	0.3	1.71	0.61	0.36
Lithium	ug/L	14	0.06	1.01	0.59	0.34
Manganese	ug/L	14	0.934	202	56.202	50.778
Molybdenum	ug/L	14	< 0.05	0.67	0.19	0.23
Nickel	ug/L	14	< 0.05	< 0.05	< 0.05	0.00
Selenium	ug/L	14	< 0.2	0.3	0.2	0.1
Silver	ug/L	14	< 0.02	< 0.02	<0.02	0.00
Strontium	ug/L	14	82.6	98.9	90.471	5.754
Thallium	ug/L	14	0.003	0.026	0.018	0.006
Tin	ug/L	14	< 0.01	0.06	0.02	0.02
Uranium	ug/L	14	0.021	0.062	0.040	0.016
Vanadium	ug/L	14	0.81	2.85	1.65	0.50
Zinc	ug/L	14	0.5	5.5	2.2	1.6

The results from the lagoon sampling (marine) were compared to three standards: the Department of Ecology (DOE), the Canadian Council for Ministers of the Environment (CCME) and the Ministry of Water, Land and Air Protection (WLAP). The creek samples (freshwater) were compared to the CCME and WLAP guidelines. The findings were summarized by location and date (Table 4.6).

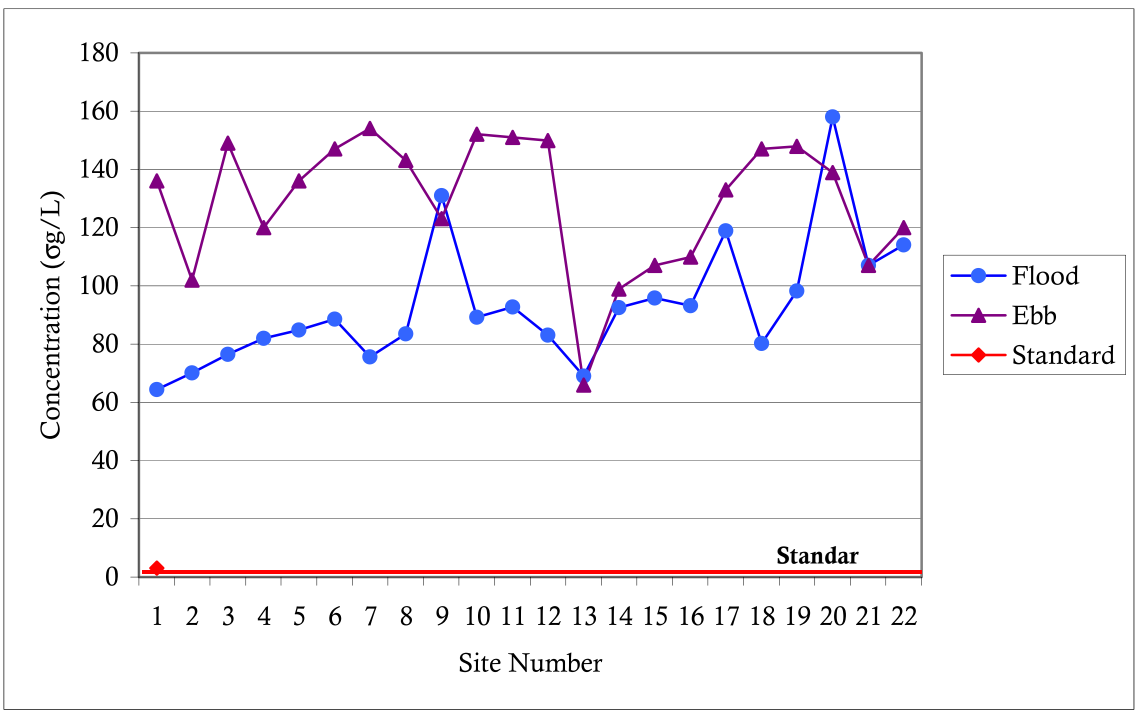
Table 4.6. Summary of Metals Analysis of Water Results

Date	Parameter	Observations
Lagoon - March	Metals (total)	Majority are below guidelines (if available) Metals over the DOE guidelines: copper (3.0 σg/L) at all locations Metals over the WLAP guidelines: copper (3.1 σg/L) at all locations
Lagoon - June	Metals (total) Metals (dissolved)	Majority of metals were below the detectable limit*
Creeks -- June	Metals (total)	Majority below guidelines Metals over the WLAP guidelines: copper (2.0 σg/L) at C14

* Levels measured in mg/L

In March, levels of copper exceeded both the DOE and the WLAP guidelines (3.1 and 3.0 σg/L, respectively) at all sampling locations. Levels were generally higher on the ebb tide than on the flood tide (figure 4.1).

Figure 4.1 Levels of Copper (Total) in Water Samples from Esquimalt Lagoon, March 13, 2002



In June, a test with a lower detection limit was run on the lagoon samples; however, levels equal to or above 5 σg/L were not detected in any samples.

In the June creek sampling, the level of copper at site C14 was 2.05 σg/L, which slightly exceeded the WLAP approved guideline for copper (2.0 σg/L) in freshwater.

4.2.3 Nutrients & Fecal Coliforms

Nutrients

Nutrients in the form of nitrogen (nitrates, nitrites, ammonia) and phosphorous (ortho-phosphate) were summarized by location and date (Table 4.7).

Table 4.7. Summary statistics of nitrate, nitrite, ammonia, and orthophosphate analysis including minimum, maximum, mean, and standard deviation values.

Parameter	Date	Location	Units	# Values	Min	Max	Mean	Std Dev
Ammonia	18-Jun	Esquimalt Lagoon	mg/L	28	0.015	0.147	0.054	0.026
	19-Jun	Bee Creek	mg/L	6	< 0.005	< 0.005	< 0.005	0
		Colwood Creek	mg/L	4	< 0.005	0.022	0.011	0.008
		Lagoon Road Outfall	mg/L	1	< 0.005	< 0.005	-	-
		Selleck Creek	mg/L	3	< 0.005	< 0.005	< 0.005	0
Nitrate	14-Mar	Esquimalt Lagoon	mg/L	44	<0.02	0.59	0.24	0.16
	18-Jun	Esquimalt Lagoon	mg/L	28	0.02	0.25	0.04	0.05
	19-Jun	Bee Creek	mg/L	6	2.37	3.09	2.72	0.23
		Colwood Creek	mg/L	4	0.72	2.08	1.11	0.65
		Lagoon Road Outfall	mg/L	1	8.8	8.8	-	-
		Selleck Creek	mg/L	3	5.22	5.55	5.37	0.17
Nitrite	14-Mar	Esquimalt Lagoon	mg/L	44	<0.002	0.018	0.007	0.003
	18-Jun	Esquimalt Lagoon	mg/L	28	< 0.002	< 0.002	< 0.002	0
	19-Jun	Bee Creek	mg/L	6	< 0.002	0.016	0.005	0.006
		Colwood Creek	mg/L	4	< 0.002	0.015	0.007	0.006
		Lagoon Road Outfall	mg/L	1	0.004	0.004	-	-
		Selleck Creek	mg/L	3	< 0.002	0.013	0.008	0.006
O-Phosphate	14-Mar	Esquimalt Lagoon	mg/L	44	< 0.001	0.019	0.009	0.005
	18-Jun	Esquimalt Lagoon	mg/L	28	0.004	0.024	0.012	0.006
	19-Jun	Bee Creek	mg/L	6	< 0.001	0.008	0.005	0.003
		Colwood Creek	mg/L	4	<0.001	0.004	0.002	0.002
		Lagoon Road Outfall	mg/L	1	0.002	0.002	-	-
		Selleck Creek	mg/L	3	0.004	0.016	0.011	0.006

In March and June, all nitrogen results from the lagoon were <1 mg/L.

June nitrogen analysis of the four creeks showed that each creek had a different amount of nitrate, but the amount of nitrate throughout each creek did not differ very much (Appendix A-3). Nitrites in all creeks were <0.02 mg/L, and ammonia was <0.25 mg/L at all creek sites.

All ortho-phosphate results from the lagoon in March and both the lagoon and creeks in June were <0.025 mg/L.

Fecal Coliforms

Fecal coliform results from each location in March and June were summarized by location and date (Table 4.8)

Table 4.8. A Summary of Fecal Coliform Results analyzed from Esquimalt Lagoon, Bee Creek, Colwood Creek, Selleck Creek, and Lagoon Road outfall in March, June and July 2002.

Location	Date (2002)	# of Values	Fecal Coliforms (cfu/100mL)			
			Min	Max	Mean	Std Dev
Esquimalt Lagoon	Mar-13	44	< 10	150	20	27
Bee Creek	Jun-19	6	210	770	372	211
Colwood Creek		4	73	160	98	42
Lagoon Road Outfall		1	2	2	2	-
Selleck Creek		3	> 7400	> 9300	>8400	960
Selleck Creek	Jul-11	2	104	189	146	60

Fecal coliform results from Lagoon sampling in March at locations 1, 5, 8, 12, 13, and 18, were all above the WLAP guideline for shellfish harvesting of 14 cfu/100mL.

From each of the four creeks analyzed in June, all contained fecal coliforms above the shellfish guideline, with the exception of Lagoon Road outfall (Appendix A-5).

Microbial Investigation

To further investigate the source the high coliform results in Selleck Creek, samples were collected from the two locations (C2 and C3) in July and a bacteriological scan was performed. This included fecal coliforms (Table 4.8), *Enterococcus, Escherichia coli*, and *Staphylococcus* (Table 4.9).

Table 4.9: Bacteriological Scan including: Enterococcus, Escherichia coli, and Staphylococcus; performed on Selleck Creek Sites, collected July 11, 2002.

Bacteria		Units	Selleck Creek Site	
Genus	Species		C2	C3
Enterococcus	Total	cfu/100mL	ND[1]	0.02
	E. avium	cfu/100mL	N/A[2]	ND
	E. gallinarum	cfu/100mL	N/A	0.02

Escherichia coli	Total	cfu/100mL	92	78
	E. coli O157	cfu/100mL	ND	ND
Staphylococcus	Total	cfu/100mL	304	864
	S. aureus	cfu/100mL	ND	ND
	S. capitus	cfu/100mL	ND	462
	S cohnii	cfu/100mL	ND	ND
	S. haemolyticus	cfu/100mL	98	304
	S hominis	cfu/100mL	ND	ND
	S. saccharolyticus	cfu/100mL	6	ND
Other	*Kluyvera cryocrescens*	cfu/100mL	62	22
	Escherichia hermannii	cfu/100mL	29	4
	Klebiella pneumoniae pneumoniae	cfu/100mL	6	N/A

Notes:
[1]ND: Non Detect, no colony forming units were detected in the test
[2]N/A: Not Applicable, the test was not run as no bacteria within the specific genus were detected.

4.3 Sediment Analysis

Sediment samples from the March lagoon sampling were analyzed for total organic carbon (TOC), metals, herbicides, pesticides, PCBs, and PAHs. Samples collected from the lagoon in June were analyzed for nitrogen-containing pesticides, phosphorous-containing pesticides and herbicides. Sediment from the June creek sampling was analyzed for metals. Samples from Colwood Creek were also tested for nitrogen-containing pesticides, phosphorous-containing pesticides and herbicides. Many of these parameters were not detected; however, elevated levels of some metals were found (Table 4.13). Complete data for all of the sediment sampling is included (Appendix C).

4.3.1 Carbon

Sediment from the March lagoon sampling was analyzed for carbon content (Table 4.10). The total organic carbon correlated with sediment size (i.e. larger percentage of fine particles (<0.075 mm) correlated with higher TOC).

Table 4.10. Summary Statistics for Carbon in Sediment from Esquimalt Lagoon, March 13, 2002

Parameter	# Of Values	Min.	Max.	Mean	Std Dev.
Inorganic Carbon – Total	22	500	3600	1652	901
Organic Carbon - Total	22	4000	80000	45109	28232
Carbon - Total	22	5000	82000	46682	28632

4.3.2 Metals

Summary statistics were calculated for levels of metals in sediment gathered during the March lagoon sampling (Table 4.11).

Table 4.11 Summary Statistics for Total Metals in Sediment Samples from Esquimalt Lagoon, March 13, 2002

Metals Total	Units	# Of Values	Min.	Max.	Mean	Std Dev.
Aluminum	σg/g	22	3375	16200	11155	3375
Antimony	σg/g	22	2	2	2	0
Arsenic	σg/g	22	8	18	11	4
Barium	σg/g	22	9.3	37.1	22.1	9.9
Beryllium	σg/g	22	0.096	0.4	0.2	0.1
Bismuth	σg/g	22	10	10	10	0
Cadmium	σg/g	22	0.4	11.9	5.8	4.4
Calcium	σg/g	22	4170	32400	8623	6062
Chromium	σg/g	22	8.3	44.9	27	12
Cobalt	σg/g	22	0.945	5.9	4.6	0.9
Copper	σg/g	22	5.4	57.1	32.7	18.9
Iron	σg/g	22	4627	23500	16705	4627
Lead	σg/g	22	2	41	18	12
Magnesium	σg/g	22	2910	12100	8348	3256
Manganese	σg/g	22	32.78	215	174	33
Molybdenum	σg/g	22	0.4	15.6	6.9	6.1
Nickel	σg/g	22	5.7	29.8	18.5	8.1
Phosphorus	σg/g	22	500	2590	1423	634
Potassium	σg/g	22	462	4060	2231	1375
Selenium	σg/g	22	3	3	3	0
Silver	σg/g	22	1	1	1	0
Sodium	σg/g	22	1920	43600	23496	17340
Strontium	σg/g	22	16.6	181	64.4	36.8
Sulfur	σg/g	22	750	16400	9121	5936
Tellurium	σg/g	22	5	5	5	0
Thallium	σg/g	22	5	5	5	0
Tin	σg/g	22	1.217	6	3	1
Titanium	σg/g	22	103.4	866	658	103
Vanadium	σg/g	22	10.82	55.1	40.0	10.8
Zinc	σg/g	22	22.6	127	77	40
Zirconium	σg/g	22	0.437	2.6	1.8	0.4

Sediment from the creek sampling was also analyzed for metals (Table 4.12).

Table 4.12 Summary Statistics for Metals in Sediment from Colwood Creek, Selleck Creek, Bee Creek, and the Lagoon Road Outfall, June 19, 2002

Total Metals	Units	# Of Values	Min.	Max.	Mean	Std Dev
Aluminum	σg/g	14	7210	13700	9213	1889
Antimony	σg/g	14	< 0.1	5.9	0.6	1.5
Arsenic	σg/g	14	0.6	6	2.2	1.4
Barium	σg/g	14	18.6	114	37	25
Beryllium	σg/g	14	< 0.1	0.3	0.2	0.1
Bismuth	σg/g	14	< 0.1	0.1	0.1	0
Cadmium	σg/g	14	< 0.05	0.28	0.09	0.07
Calcium	σg/g	14	2900	19000	5946	4247
Chromium	σg/g	14	11.1	26.2	17.6	4.8
Cobalt	σg/g	14	4.6	13.2	6.7	2.2
Copper	σg/g	14	7.5	33	17	8
Iron	σg/g	14	10700	24800	16043	4325
Lead	σg/g	14	1.7	35.6	9.3	9.3
Magnesium	σg/g	14	3640	6790	5287	1108
Manganese	σg/g	14	241	923	449	201
Molybdenum	σg/g	14	< 0.1	1.6	0.4	0.4
Nickel	σg/g	14	8.2	17.8	12.4	2.6
Potassium	σg/g	14	< 100	212	139	41
Selenium	σg/g	14	< 0.5	2	0.7	0.4
Silver	σg/g	14	< 0.05	0.07	0.05	0.01
Sodium	σg/g	14	< 100	980	217	228
Strontium	σg/g	14	9.1	52.7	22.3	13.4
Tellurium	σg/g	14	< 0.1	0.1	0.1	0
Thallium	σg/g	14	< 0.05	0.07	0.05	0.01
Tin	σg/g	14	0.1	0.5	0.3	0.1
Titanium	σg/g	14	296	881	619	172
Vanadium	σg/g	14	28	63	39	9
Zinc	σg/g	14	24.2	202	56	46
Zirconium	σg/g	14	0.9	2.6	1.6	0.5

Results for the marine sediment were compared to the DOE and CCME guidelines. Results for the creek sediment were compared to the CCME and WLAP guidelines for freshwater sediment. Findings were summarized by location and date (Table 4.13).

Table 4.13 Summary of Findings for Metals from Analysis of Sediment Samples from Esquimalt Lagoon, March 13, 2002.

Location	Results
Lagoon -- March	Majority are below guidelines Metals over the DOE guidelines: Cadmium: guideline 5.1 σg/g (sites 1-7, 17, 19-20) Metals over the CCME guidelines: Arsenic: guideline 7.24 σg/g[1] (sites 1-2, 4-7, 13, 17, 19-20)[1] Cadmium: guideline 4.2 σg/g[2] (sites 1-7, 13, 17-20); guideline 0.7 σg/g[1] (sites 8-11) Copper: guideline 18.7σg/g[1] (sites 1-9, 17-20) Lead: guideline 30.2 σg/g[1] (sites 2, 17) Zinc: guideline 30.2 σg/g[1] (sites 5-7)
Creeks – June	Majority below guidelines All results that exceeded guidelines were found in Colwood Creek Levels above the CCME and WLAP guidelines: Arsenic (site C14) guideline 5.9 σg/g, result 6 σg/g Lead (site C12) guideline 35 σg/g, result 35.6 σg/g Zinc (site C14) guideline 123 σg/g, result 202 σg/g Levels above the WLAP guidelines: Iron (site C14) guideline 21,200 σg/g, result 24,800 σg/g Nickel (site C14) guideline 16 σg/g, result 17.8 σg/g

Notes:
[1] CCME Interim sediment quality guideline
[2] CCME Probable effect level

For the March lagoon sampling, the range of cadmium levels that exceeded the DOE guideline was 7.6 to 11.9 σg/g. Of the metals that exceeded the CCME guidelines, the ranges were as follows: Arsenic (10 to 18 σg/g), Cadmium (0.9 to 11.9 σg/g), Copper (24.1 to 57.1 σg/g), Lead (32 to 41 σg/g), and Zinc (125 to 127 σg/g).

4.3.3 Pesticides & Herbicides

Analysis for pesticides and herbicides was done for sediment samples from each sampling date. Sediment from the March lagoon sampling was analyzed for herbicides, nitrogen containing pesticides, organochlorine pesticides and phosphorous-containing pesticides. The sediment samples collected during the June lagoon sampling were analyzed for herbicides, nitrogen containing pesticides and phosphorous-containing pesticides. The sediment samples from Colwood Creek sampling were also analyzed for nitrogen containing pesticides, phosphorous-containing pesticides, and herbicides. None of these samples contained detectable levels.

4.3.4 PAHs

Sediment from the March lagoon sampling was analyzed for polycyclic aromatic hydrocarbons (PAHs). In the majority of the samples these substances were not detected. Small quantities of a few PAHs were detected at some locations; however, all of these detected levels were well below the guidelines.

4.3.5 PCBs

The March lagoon sediment samples were examined for polychlorinated biphenyls (PCBs) and resulted in undetectable levels in all samples.
The list of specific PCBs included in the analysis is included in the results (Appendix C).

4.4 QA/QC Replicates

The Relative Percent Difference (RPD) between the field replicates was calculated to assess the accuracy of the results, as outlined in the methodology. Calculations for each individual parameter are also included (Appendix E).

4.4.1 RPD for Water Analysis

Two pairs of field replicates per round of sampling (ebb tide and flood tide) were analyzed to evaluate the precision of the sampling method during the March lagoon sampling. One pair of replicates was collected during the June lagoon sampling and two pairs during the creek sampling. Results of the RPD calculations were summarized by location and date (Table 4.14).

Table 4.14. Summary Table of Average RPD Calculations for Water Samples from Esquimalt Lagoon, 2002

Time	Location	Replicate No.	Tide	Parameter	RPD (%)	Rating
March	Lagoon	1	flood	metals	27.4	fair
				nutrients	--	*
			ebb	metals	26.4	fair
				nutrients	84.9	poor
		2	flood	metals	11.5	good
				nutrients	--	*
			ebb	metals	5.8	good
				nutrients	12.7	good
June	Lagoon	1	flood	metals	5.3	good
				nutrients	46.1	poor
			ebb	metals	9.8	good
				nutrients	23.6	fair
June	Creeks	1	--	metals	5.4	good
				nutrients	13.5	good
		2	--	metals	18.9	good
				nutrients	7.9	good

*RPD not calculated as values less than 5 times the MDL.

The RPD for nutrients for replicate flood samples in March was not calculated, as the concentrations in the samples were below the assay detection limit.

4.4.2 RPD for Sediment Analysis

Two pairs of field replicates were collected during the March lagoon sampling. One pair was gathered during the June creek sampling. RPD calculations for metals and phosphorous levels were summarized by location and date (Table 4.15).

Table 4.15 Summary Table of Average RPD Calculations for Sediment Samples from Esquimalt Lagoon, 2002

Time	Location	Replicate No.	Parameter	RPD (%)	rating
March	Lagoon	1	metals	74.8	poor
		2		13.6	good
June	Creeks	1	metals	25	fair
			phosphorous	12.2	good

Two pairs of field replicates were analyzed for the March lagoon sampling. The average RPD for metals in the samples was 35.7% or fair. This is misleading, as the RPD of one pair of samples was 13.6% or good, while the other was 74.8% or poor. Particle size analysis indicates that the latter pair of samples was quite different in composition, which may account for the high RPD. RPD values were not calculated for organochlorine pesticides, phosphorous-containing pesticides, chlorinated phenols, phenoxy acid herbicides, and polychlorinated biphenyls (PCBs), as all of these compounds were not detected. The RPD was not calculated for PCBs as all levels were either not detected or less than five times the detectable limit.

One pair of field replicates was analyzed for the June lagoon sampling. The RPD for these samples was not calculated, as pesticides and herbicides were not detected.

One pair of field replicates was analyzed for the creek sampling. The RPD for the metals was 25.0% or fair. The RPD for phosphorous levels was 12.2% or good. The RPD value for the pesticides and herbicides was not calculated, as levels were not detected.

5.0 Discussion

The results were graphed and compared to DOE, CCME, and WLAP guidelines, mapped to view visually, and evaluated against applicable past studies done on the Esquimalt Lagoon. Contaminants present and entering the lagoon were identified. Possible sources of these contaminants were determined (Table 5.1 and 5.2) and discussed.

Table 5.1 Common Sources of the Contaminants found in Esquimalt Lagoon

Metals	Possible sources
Arsenic	Wood preservative
	Combustion of fossil fuels
	Agricultural chemicals
Cadmium	Metal plating
	Coating operations
	Transportation equipment
	Machinery
	Photography
	Pigment as nickel-cadmium
	Metal recyclers
	Oil spills
	Tire wear
Copper	Break pads
	Domestic plumbing
	Anti-fouling paint
Lead	Batteries
	Paints
	Fossil fuels combustion
	Sewage waste
	Lead pipes
	Remnants of leaded gasoline
Zinc	Road marking paints
	Tire and pavement wear
	Galvanized roof gutters
	Stormdrain conduits

Table 5.2 Common Sources of the Nutrients and Fecal Coliforms Entering Esquimalt Lagoon

Nutrients	Possible Sources
Nitrates	Vegetation
	Acid rain
	Pesticides/herbicides
Phosphates	Failing septic fields
	Detergents
	Fertilizer, pesticides, herbicides
Ammonia	Failing septic fields
	Fertilizer, pesticides, herbicides
	Bird excrement
	Decaying organic material
Fecal Contamination	**Possible Sources**
Fecal coliforms	Failing septic fields
	Domestic animals
	Wildlife in the area (avian)

5.1 Water Analysis

5.1.1 Metals

The results of the March lagoon sampling indicate that the only metal of concern in the water of Esquimalt Lagoon is copper. Values range from a minimum of 64.3 σg/L to a maximum of 158.0 σg/L. These levels far exceed the chronic and acute DOE guidelines (4.8 and 3.1 σg/L respectively) and the approved WLAP guideline (3.0 σg/L).

Potential sources for this contamination are varied, including inputs from sea as well as from land. Possible sources of copper from land include break pad debris and domestic plumbing. Ablation from copper based anti-fouling paint could also be a contributing factor.

To further investigate the source of copper contamination, levels of dissolved metals were also analyzed in June. This was done in order to determine if the metals detected in the March lagoon sampling were actually dissolved in the water column, or the result of disturbed sediments. The results for both total and dissolved metals in June were less than 5 σg/L at all locations, which did not correspond with the levels found in March, indicating that copper is not a problem in the water. Further sampling should be done to confirm or refute these findings.

The comparison of total and dissolved metals determined that 85-95% of metals in the water column are dissolved. This indicates that particulates from sediment in the water column are having minimal effect on the results.

Results from the June creek sampling indicate that metals contamination of the creek water is minimal. At one location, site C14 in Colwood Creek, the amount of copper in the water was 2.05 σg/L, slightly above the WLAP guideline of 2 σg/L. Water samples from further downstream did not exceed this level, ranging from 1.34 to 1.58 σg/L. A comparison of the levels from C14 and C12 (below the Royal Colwood Golf Course) shows that concentrations of the majority of metals are decreased as they travel through the golf course, indicating that the golf course acts as a pollution-buffering zone.

5.1.2 Nutrients and Coliforms

Nutrients

Analysis of samples collected during this study indicates that nutrient input into Esquimalt Lagoon can mainly be found in the form of nitrate. Nitrite, ammonia, and phosphorous inputs are minimal (Table 4.7 - section 4.2.3). These nutrient inputs are similar to those found in 1980 by Watanabe and Robinson. As indicated further by Watanabe and Robinson (1980), nitrates enter the lagoon through freshwater inputs. Analysis of water within the lagoon shows that through both dilution and aquatic life uptake, nitrate levels are reduced to minimal levels (virtually non-detectable).

Once in the lagoon, nitrogen is converted from nitrate into ammonia. Nitrate is utilized by phytoplankton. Zooplankton and fish consume a high proportion of the phytoplankton and return nitrogen into the water in their excreta either as the rapidly assimilable form present in the urine (ammonia and urea), or death of aquatic life, and ammonia levels would be expected to increase in the fall, as algae die within the lagoon. Levels may also increase following turnover events, which bring up dead and decaying organisms from the bottom. Another source of the ammonia within the lagoon may be from bird excrement that contains uric acid, which decomposes into ammonia.

Orthophosphate levels entering and within the lagoon are insignificant.

Nitrate has been shown to be the limiting nutrient in the Esquimalt Lagoon (Watanabe and Robin 1979). As this nutrient will increase algal blooms, it should continue to be monitored within freshwater inputs. Creek levels of nitrates from June 2002 have been mapped (Appendix A-4). Nitrate levels found in June to 2002 had significantly increased from those found in 1979 (Watanabe 1980), however the levels within Colwood Creek have decreased to less than half of the concentration found in 1998 (Anderton *et al*).

Algal blooms are natural phenomena within the lagoon, however increased nitrates entering from freshwater inputs will increase the amount of growth. In the fall, decreased sunlight cause the algae to die, and sink to the bottom of the lagoon where it is decomposed by bacteria. This decomposition will use up the available oxygen within the lagoon, rendering the area anoxic. If persistent, these anoxic conditions may result in fish kills, or foul-smelling byproducts produced by anaerobic bacteria.

The foul smell experienced by residents in the area is a result of byproducts (including hydrogen sulfide, thioalcohols, and ammonia) produced by anaerobic bacteria. These odourous compounds are brought to the surface through seasonal turnover of the lagoon. This turnover (or "roll-over") is a result of temperature differences between layers of water within the lagoon. As the surface temperature is cooled, it sinks to the bottom because of its density and the bottom substrate is brought up to the surface, releasing the smelly gases.

Fecal Coliforms

Fecal coliforms are indicator organisms. Their presence is an indication of fecal contamination from both humans and animals. This fecal contamination will contain other pathogenic bacteria, as well as aquatic nutrients. Past studies of Esquimalt Lagoon (Watanabe and Robinson 1980), have shown correlation of ammonia and ortho-phosphate to the amount of fecal coliforms, however we were unable to discover such a correlation, as we did not have a large amount of data to compare.

The fecal coliforms entering Esquimalt Lagoon have a short lifetime and are quickly diluted. For this reason, it has been shown that fecal contamination entering the lagoon should be analyzed from surrounding creeks.

During the course of this project, levels of fecal coliforms were determined for four inputs into the lagoon (Appendix A-5).

The amount of fecal coliforms from each creek differed, with Selleck creek containing fecal coliforms over 10 times greater than every other creek analyzed. This was expected as past studies (CRD 2000) have shown Selleck Creek to periodically have a high contaminant rating.

Samples from Bee Creek were analyzed for fecal coliforms after each anticipated "buffering zone" (e.g. Figure 5.1), to determine whether wetland vegetation within the creek buffered such contamination. It was determined that the wetland vegetation did not buffer nitrate (Appendix A-3) or fecal coliform (Appendix A-5) inputs into Esquimalt Lagoon in June of 2002.

Figure 5.1: First hypothesized "buffering zone" in Bee Creek, located between sites C4 and C5.

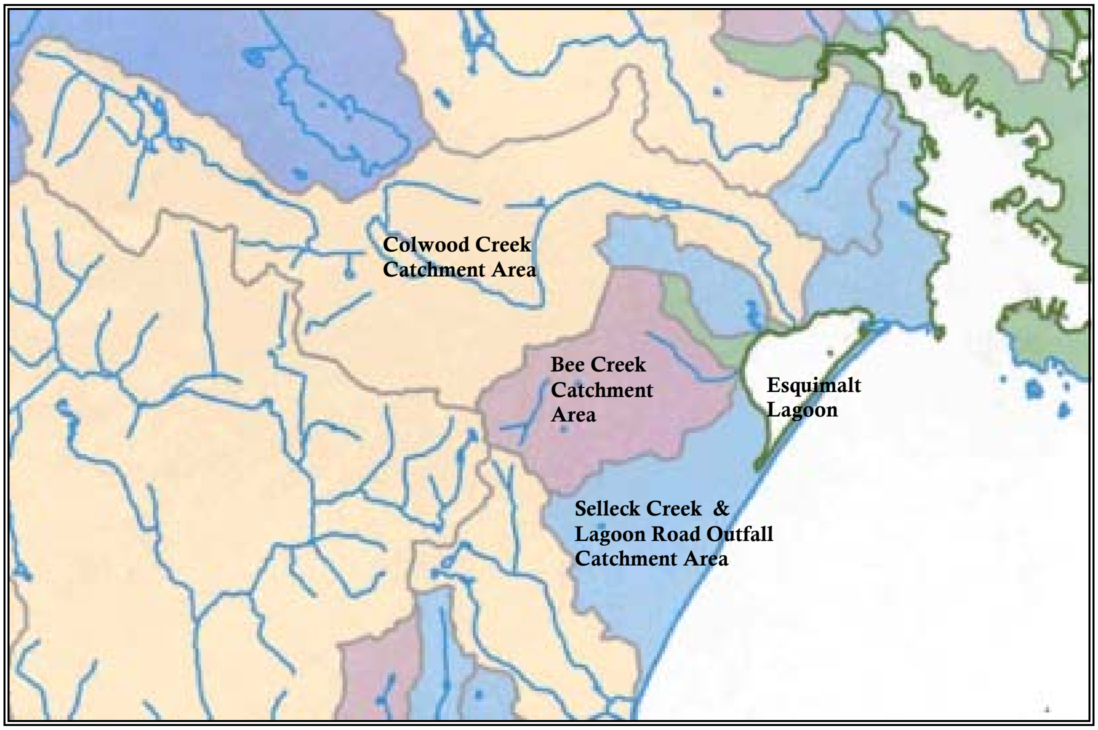
Microbial Investigation

Differential testing of fecal organisms from Selleck creek has shown the presence of human bacterial contamination. Neither *E. avium*, a bacterium associated with bird feces, or *E. coli* O157, a bacterium contained in cow feces, were found to be present in Selleck Creek on July 11, 2002. Bacteria present included *S. capitus*, and *S. haemolyticus*, two common bacteria associated with human skin (Holt 1986).

This evidence of human bacterial contamination within Selleck Creek indicates septic fields in the area are leaking. Past studies have attempted to address this issue (CRD 1999), although their findings have been inconclusive. The Selleck Creek catchment area (Figure 5.2) should be further studied to address this issue. CRD data gathered from 1993-2000 demonstrate fluctuations of fecal coliform values ranging from 70-140,000 cfu/100mL (CRD 2000). The levels of indicator organisms (coliforms) are often, but not constantly, high within this creek. For example, fecal coliform data collected in this study showed fecal coliform values of >74,000 cfu/100mL on June 19, 2002, to <200 cfu/100mL on July 11, 2002. It is recommended that this creek be monitored for fecal coliforms on a more frequent basis, and further upstream.

It is important to note that over 75% of the surface freshwater inputs to Esquimalt Lagoon come from Colwood Creek (Payne Engineering Geology 1996). Selleck Creek contributes approximately 2.5%. For this reason, it is important to continue monitoring levels in Colwood Creek as well as other freshwater inputs. Catchment areas for the major creeks surrounding the lagoon are shown in Figure 5.2.

Figure 5.2 Watershed Boundaries Surrounding The Esquimalt Lagoon.



5.2 Sediment Analysis

5.2.1 Metals

Levels of metals in sediment were analyzed for the March Lagoon sampling and the June creek sampling[6].

Marine sediments

The results of the March lagoon sampling were compared to two standards, the DOE and CCME guidelines. The CCME provides two guidelines, the Interim Sediment Quality Guideline (ISQG) and the probable effect level (PEL). The results of this analysis indicate that there are levels of arsenic, cadmium, copper, lead and zinc that exceed the CCME guidelines in the lagoon. Overall, these are more stringent than the DOE guidelines. As a result, there is only one metal, cadmium, which exceeded the DOE guidelines. Common sources of these contaminants include various point and non-point sources (Table 5.1).

All locations where metals were over applicable guidelines have been highlighted in maps (Appendix A).

[6] Metals analysis was not done on sediment from the June lagoon sampling.

Arsenic

The values for arsenic ranged from below the detectable limit (8 σg/g) to 18 σg/g. None of these values is over the PEL of 41.6 σg/g, but 11 are over the detection limit and the CCME guideline. These locations (sites 1-2, 4-7, 13, 17, 19-20) have been identified on a map (Appendix A-6). In this instance, the CCME ISQG is below the MDL of the test, therefore, it is possible that all of the locations in the lagoon exceed the ISQG of 7.24 σg/g.

Potential anthropogenic sources of arsenic include wood preservatives and arsenical pesticides (MELP 1998) and the combustion of fossil fuels (CRD 2001).

Cadmium

Levels of cadmium in lagoon sediment ranged from 0.4 σg/g to 11.9 σg/g. The DOE standard is 5.1 σg/g, which was exceeded at 10 sampling locations (Appendix A-7).

The CCME standard is more stringent. Cadmium levels were over the CCME ISQG of 0.7 σg/g at 16 locations (sites 1-7, 13, and 17-20). In addition, they were over the PEL of 4.2 σg/g at sites 8-11 (Appendix A-8).

Sources of cadmium in the environment are varied. They include metal plating and coating operations, painting, printing and photography. It is also found in solar batteries and in pigment as nickel-cadmium. Other common sources of cadmium are metal recyclers, oil spills, and tire wear (CRD 2001).

Cadmium contamination has implications for the health of marine organisms in the lagoon. The presence of cadmium is strongly associated with lead and zinc. In the presence of zinc, the toxicity of cadmium is enhanced. Organisms at risk for acute toxicity include mammals and some species of trout (MELP 1998). In addition, plant growth can be suppressed (MELP 1998).

Interestingly, levels of cadmium in the lagoon are considerably higher than those reported by the CRD, although other parameters are not. Data collected from 1993 to 2000 at outfalls entering the lagoon[7] range from 0.0 to 0.2 σg/g (EnviroEd Consultants 1998, CRD 2001). The CRD samples sediment directly below the outfalls. It is possible that the flushing of fine sediment away from the outfall reduces the concentration of cadmium in the samples.

Copper

[7] CRD outfall numbers 913-933

Levels of copper in the sediment of Esquimalt Lagoon ranged from 5.4 σg/g to 57.1 σg/g. These levels exceeded the CCME ISQG guideline for copper of 18.7 σg/g at sites 1-9, and 17-20 (Appendix A-9).

There are several ways that copper can enter the natural environment. One of the greatest contributing factors to copper pollution is break pad debris. This debris is deposited on the road surface and flushed by rainwater into water bodies. Not all break pads contain copper but usage of copper in break pads is said to be increasing (Sustainable Conservation 2002). Another source is domestic plumbing and equipment (MELP 1998). Both of these sources are likely contributors to Esquimalt Lagoon due to the proximity of residential development and the road network.

The effect of this pollutant is dependent upon the amount. Copper is an important nutrient for plants and animals in small doses. Long exposure to excess levels, however, can result in chronic effects to mollusks, fish and crustacea (MELP 1998).

Lead

The results for lead ranged from 2 to 41 σg/g. At two locations (sites 2 and 17), the levels exceed the CCME ISQG of 30.2 σg/g (Appendix A-10).

Anthropogenic sources of lead that could enter the Esquimalt Lagoon are the result of urban development, including batteries, paints and sewage waste. Remnants of lead from past fossil fuel combustion is another source as particles may still remain in the soil. Other sources include exterior and road marking paints and tire wear (CRD 2001).

Because it is toxic to all animals, lead pollution is a serious concern. Toxicity effects decrease with increasing dissolved oxygen. This is of most concern to lagoon life during fall months when dissolved oxygen is depleted from the water column due to decomposition of aquatic plants.

Zinc

Levels of zinc ranged from 22.6 σg/g to 127 σg/g. The ISQG of 124 σg/g was exceeded at sites 5,6 and 7 (Appendix A-11).

The primary sources of zinc are non-point. These include road-marking paints, exterior paints, tire and pavement wear, galvanized roof gutters, and stormdrain conduits (CRD 2001).

Zinc is an essential nutrient for plants, but can be toxic to aquatic organisms, especially fish. Toxicity increases with increasing temperature, dissolved oxygen, copper and cadmium concentrations (MELP 1998).

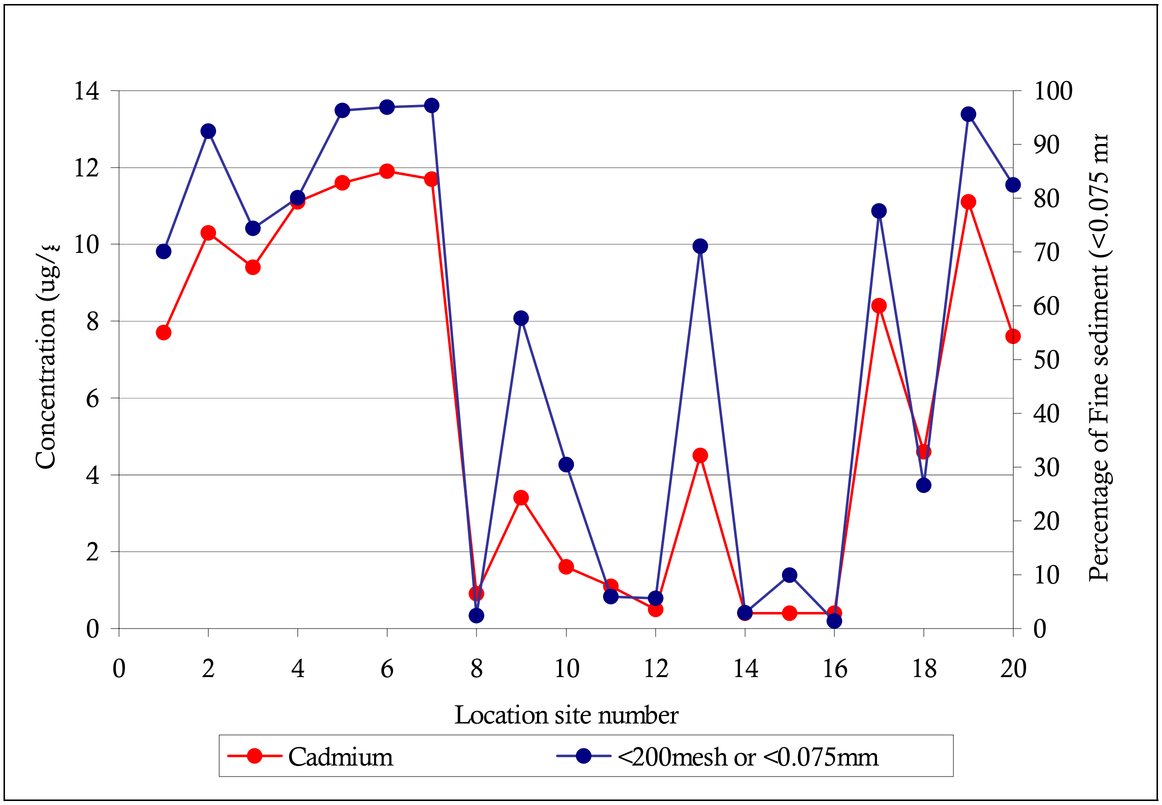
The location of these points indicates that there is potentially a source or sources of zinc in the Selleck Creek catchment area. The catchment area for Selleck Creek is southwest of the lagoon (Figure 5.3). The primary land use in this area is single family residential. All of the potential non-point sources identified above are present or likely to be found in this area.

Sediment Deposition Patterns and Metal Contamination

All of these metals (arsenic, cadmium, copper, lead and zinc) display the same general affinity for sediment. Arsenic and cadmium are readily adsorbed onto clay particles. Lead is highly insoluble and strongly absorbed by sediment. Zinc also strongly adsorbed onto particles. Several of the metals contribute to the toxicity of each other. Cadmium, zinc and lead, in particular, are correlated (MELP 1998).

These metals also show the same general pattern of distribution. The contamination is concentrated at the southwest end of the lagoon, near the residential area. This correlates with observations made of the sediment during sampling. Fine sediments were present in the "toe" of the lagoon and along the north shore, as far as Bee Creek. There are few, if any, animals visible in this sediment. In contrast, sites near the mouth of the lagoon have abundant shellfish (particularly clams and sand dollars) and large sediment. These metals were graphed along with sediment size and show a strong correlation between the percentage of fine sediment within the sample, and the level of metal it contained. This correlation has been illustrated using cadmium (Figure 5.3).

Figure 5.3 Comparison of cadmium concentration to the percentage of fine sediment (<0.075 mm) in each sediment sample taken from Esquimalt Lagoon in March 2002.



There are two possible pathways for this deposition of fine sediment and metals. It may be due to either sediment or contaminant loading from the upland sources, or deposition through tidal action. Tidal currents in the lagoon are stronger at the mouth and along the north shore in front of Royal Roads University (Westland 1993). Tidal flushing is poor in the southwest portion of the lagoon and along Coburg Peninsula. The result of this is that fine sediment and associated contaminants are not flushed out of the lagoon by tidal action.

Metals in Freshwater Sediment from the Creeks

Results from the June creek sampling were compared to the CCME and the WLAP guidelines for freshwater. Overall, levels of metals in the creeks were generally low. There were, however, elevated levels at two locations in Colwood Creek, C14 and C12 (Appendix A-2).

At site C14, the concentrations in the sediment exceeded the CCME and WLAP guidelines for arsenic and zinc, and the WLAP guidelines for iron and nickel. The guideline for arsenic is 5.9 σg/g and the level was 6.0#σg/g. Zinc was found at 202 σg/g (guideline 123 σg/g). Iron was present at 24,800 σg/g (guideline 21,200 σg/g). Finally, nickel was present at 17.8 σg/g (guideline 16.0 σg/g).

At site C12, the lead level was 35.6 σg/g, slightly above the CCME and WLAP guideline of 35.0 σg/g.

Levels of contaminants at C14 were higher than those at C12 (below the Royal Colwood Golf Course), indicating that as the waters of the creek travel through the golf course, the golf course acts as a pollution-buffering zone. Upon leaving the golf course, the water travels through a culvert under Sooke Road. The sample was collected approximately 1 metre below this culvert, which may be the source of the elevated lead level. Further downstream, the level of lead was reduced to 4.7 and 3.8 σg/g, suggesting that this metal was filtered, diluted or taken up by plants and other organisms.

At the time of sampling (June 2002), construction of the Millstream connector was ongoing, perpendicular to Colwood Creek near site C14. This may be contributing to the metal pollution at this site in the creek, as the riparian area is minimal to buffer contamination from the large amount of imperious area. Also sediment transport may be occurring.

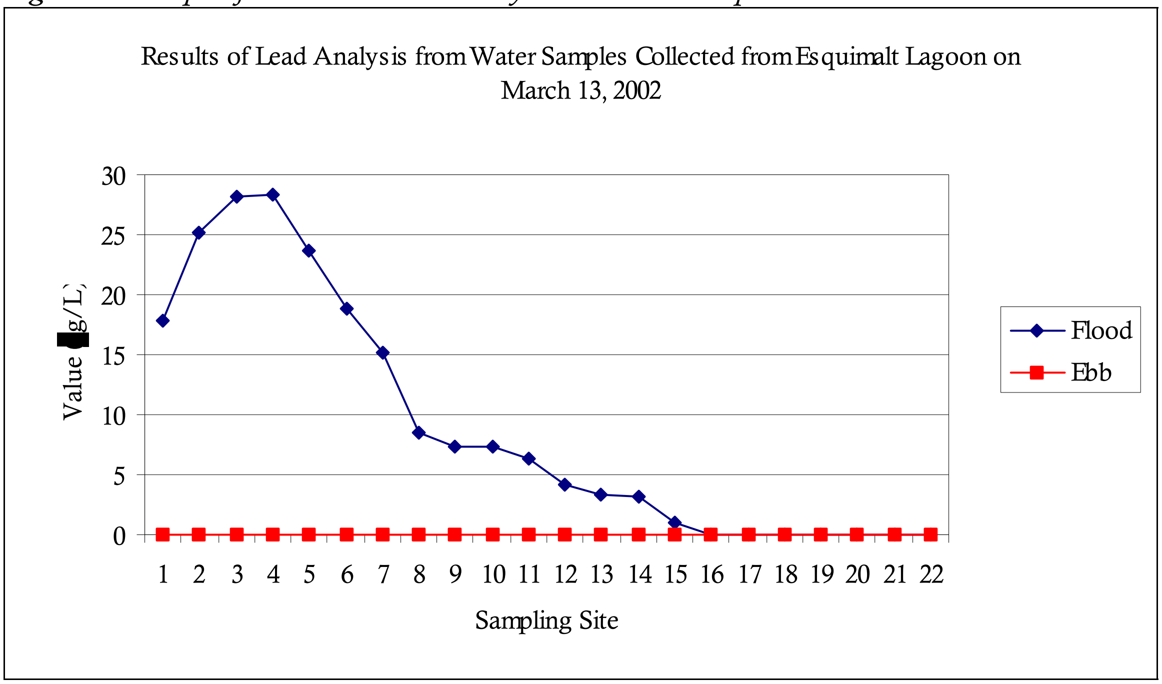
5.3.2 Non-Detectable Contaminants

Tests were run for a number of contaminants including pesticides, herbicides, PAHs, and PCBs. All of these substances were either not detected or were present at concentrations well below the guidelines. These substances were considered as possible contaminants of concern due to the urbanization in the catchment area for the lagoon. Their absence is a positive indicator for the health of the lagoon.

5.4 QA/QC

Metal levels from March sampling indicated patterns relevant to the sample number, rather than the actual location. For example, the levels of iron were high for the initial samples and then non-detectable in subsequent samples (Figure 5.4).

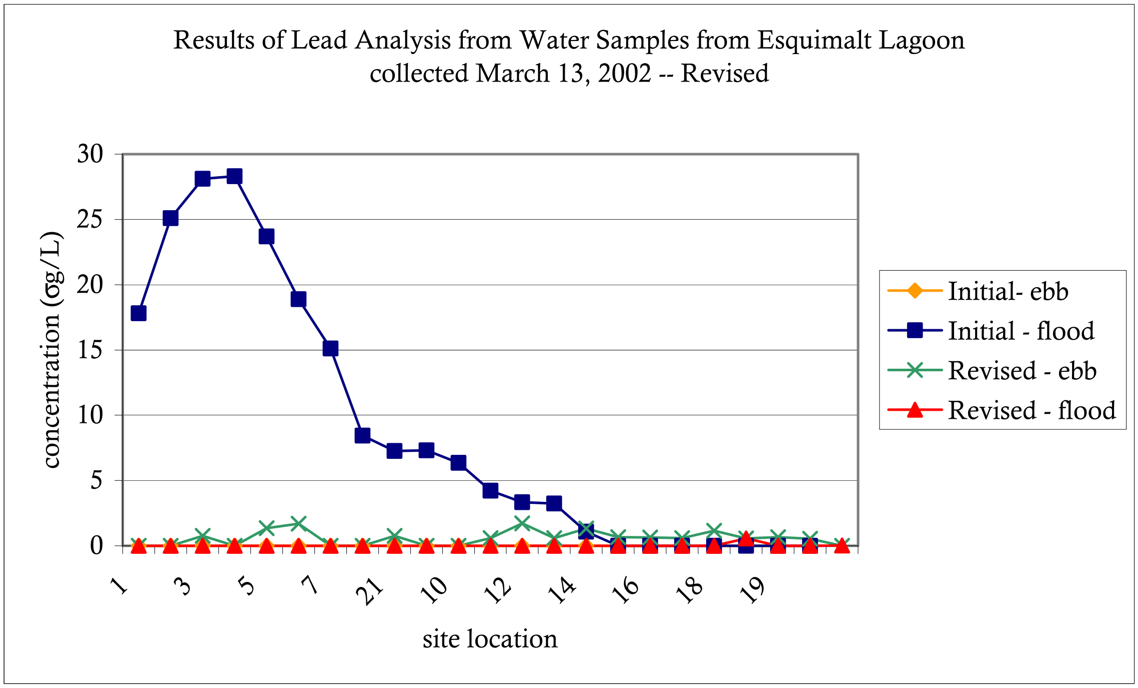
Figure 5.4 Graph of the Initial Lead Analysis in Water Samples



There were also unexpectedly high levels of chromium (mean 11.9 σg/L), copper (mean. 35.5 σg/L), and zinc (mean 37.4 σg/L) in the field blanks.

Metal result patterns and field blank results were reported to the laboratory (PSC Analytical), and they discovered the samples had been cross-contaminated. The samples were re-analyzed and results were received on June 3, 2002. Revised values were compared to the initial results (Figure 5.5).

Figure 5.5 Revised Graph of Lead Analysis in Water Samples



6.0 Monitoring Plan

The goal of the community-monitoring program (Appendix E) is twofold. Firstly, to empower local residents by putting them in closer contact with the natural environment in their community, to encourage community environmental stewardship and secondly, to allow continuous monitoring of the outfalls entering the Lagoon that have a pronounced effect on the water quality of the Lagoon. This will be achieved by having members of the community volunteer their time to take water samples at various locations around the lagoon thereby monitoring the quality of the Lagoon itself.

The key outfalls of interest for this project include: Lagoon Rd outfall, Selleck Creek, Bee Creek and Colwood Creek. A total of 10 samples will be taken from 8 sampling locations (including 1 replicate + 1 blank per sampling round) from these key outfalls by volunteers, one from Lagoon Rd outfall, two from Selleck Creek, two from Bee Creek and three from Colwood Creek. A surface water sampling kit is recommended to test the following parameters at each location: nitrates, fecal coliforms, turbidity, pH, temperature and dissolved oxygen (DO). In addition, field parameters and a general site description will be recorded at each location. A resident observation sheet will also be completed, noting qualitative information observed from events leading up to and following the roll over event occurring periodically in the Lagoon, in order to better determine the cause and effect relationship of this event.

Due to budget constraints, the program is designed for shore sampling and for the use of test kits for the analysis of the samples to allow for greater volunteer involvement in the community-monitoring project.

The environmental monitoring program manual (Appendix F) contains timelines, equipment lists, sampling budget, sampling protocol, data analysis techniques and sample field sheets.

7.0 Conclusion and Recommendations

Contamination present within Esquimalt Lagoon is lower than had been anticipated. Levels of herbicides, pesticides, and PCBs were below detection. PAHs were well below applicable standards (majority were below detection). Contaminants that are present include metals, aquatic nutrients, and fecal coliforms.

Metals within Esquimalt Lagoon include arsenic, cadmium, copper, lead and zinc in the sediment; and copper in the water. These metals are common contaminants arising from urban development and run-off. Because of minimal flushing, these contaminants remain within the southwest side of the lagoon adhered to sediments. Due to this poor flushing, these sediments may be representative of past run-off and urban development. Furthermore, water sampling does not indicate metal contamination (with the exception of copper). It is possible that contaminated sediment in the lagoon has been present for a long period of time, and may represent historic land uses as well current practices.

Nitrogen as a nutrient enters the lagoon in the form of nitrate, and was found within the lagoon as ammonia. Because nitrate is the limiting nutrient contributing to algal growth, it should be monitored from the freshwater inputs.

Fecal contamination has been shown to be of human origin, most likely from failing septic fields. From these failing septic fields, other domestic waste (household cleaners, paint thinners, etc) may also be within this contaminated runoff, and as such fecal coliforms should be monitored from the creeks on an ongoing basis.

As a result of this study, it is recommended that:

- A monitoring program be undertaken by the community, this will include:
  - Monitoring of the inputs into the lagoon for nitrates, fecal coliforms, pH, turbidity, and temperature;
  - Visual observations of conditions within the lagoon including algal growth, odour, colour, weather, and other physical observations;
- Retesting of copper levels in the lagoon should be performed in order to confirm the results of the March sampling;
- Pollution Prevention workshops in the area to address non-point sources of contamination;
- Septic socials be held to educate residents on the care and maintenance of their septic fields; and
- Groundwater monitoring for coliforms and nitrates.

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