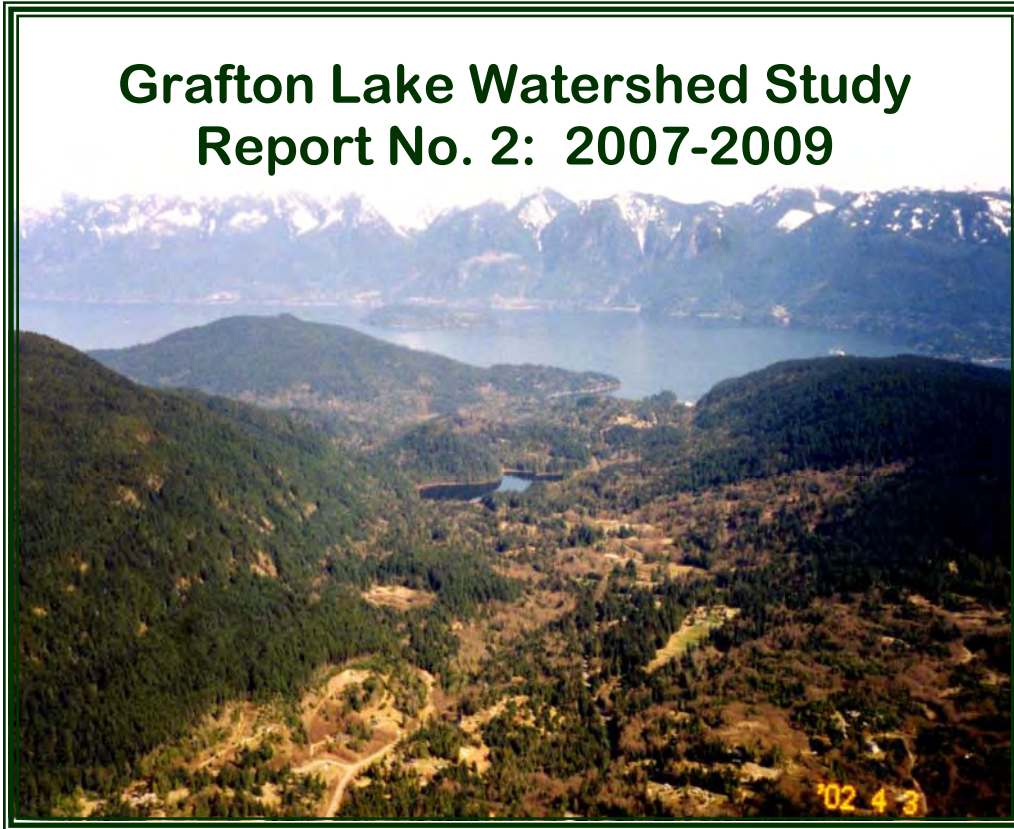


Grafton Lake Watershed Study Report No. 2: 2007-2009



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Executive Summary

This report presents the results of a watershed environmental monitoring and public education project, known as the **Grafton Lake Watershed Study 2007 – 2009**, that was implemented for the Cove Bay Water System of the Bowen Island Municipality. The work plan included a public education & communication (E&C) program, monitoring of water quality and water quantity (hydrology), and assessment of the Grafton Lake reservoir ecosystem. The Project's overall goals were twofold:

- to increase community knowledge of the Grafton Lake watershed as the source of Bowen Island's largest water utility, and of individual actions that can be taken to protect and sustain water supplies; and
- to generate information to be used in support of science-based decision making and management by local government concerning land uses and the sustainability of the supporting ecosystem on Bowen Island.

Recommendations

Based on the results of the study, the municipality is encouraged to implement the following general and specific actions:

Public Involvement

1. Adopt an on-going program of public communications and education (C&E) as recommended in this report and previously, as a means of continuing to involve the public at large in reducing the risks to water sources in the watershed. Specifically:
 - Use the current Watershed Quest school program with remaining schools on the island (Island Pacific School, Montessori School, Bowen Island Home-Supported Learners) in 2010 to get further use from the student quest that was developed; and
 - Continue with a public informational campaign especially around the issue of swimming in Grafton Lake.
2. To maximize the benefits and cost efficiency of the C&E program, it is recommended that the scope should extend to all the community water systems on the island, including those that are not managed by the municipality.

Water Quality

3. Continue water quality monitoring in the watershed using Bacterial Source Tracking (BST) to assist in the location of failing septic systems and other sources of human fecal contamination. Work with the Pacific Environmental

Science Centre of Environment Canada, or other agencies, to refine the BST methods for use on Bowen Island.

4. Examine whether the fecal contamination documented in Grafton Lake reservoir is sufficient to justify legally prohibiting contact recreation in Grafton Lake, taking into consideration that the CBWS is served by a disinfection facility.
5. Work with the Coastal Health Authority to develop and implement a plan to address the remediation of failing septic systems and other sources of contamination, should any be found.
6. Undertake a preliminary sampling program to assess whether or not detectable concentrations of pharmaceuticals and personal care products are present in the source waters of the Grafton lake watershed.
7. Implement a continuous water quality monitoring program, using, automated sampling apparatus, on streams that receive runoff from commercial operations such as quarries, incineration facilities, mechanics shops, and waste storage/transfer facilities. Parameters to be monitored should include turbidity, pH, nutrients, total metals, oil and grease and hydrocarbons. The Municipality is encouraged to employ a collaborative rather than adversarial approach when working with the owners and/or operators of these facilities. However, it is desirable that water samples should be collected by an independent party, not the owner/ operator.

Hydrology

8. Regarding the automated hydrometric station on Bowen Brook at Harding Road:
 - continue the necessary field calibration to complete the stage-discharge curve for that location;
 - incorporate the stage-discharge relationship into the Emerald system; and
 - install the recording weather station (thermometer and rain gauge) at Harding Road, as already planned for incorporation into the Emerald system.
9. Ensure that the allocation of potable water through the CBWS (e.g., to supply the planned increases in population density in Snug Cove) does not exceed reservoir's storage capacity to supply nor compromise the lake's ecological functions.

Grafton Lake Ecosystem

10. Continue to manage the Grafton Lake reservoir in a manner that mimics the natural seasonal lake level fluctuation in order to sustain the lake ecosystem, its flora and fauna. Specifically:
 - avoiding unnecessary draw-down in winter;
 - delay the summer draw-down as much as possible; and
 - delay any increase in water level (e.g., installation of stop-logs at the outlet) until after the vegetation enters winter dormancy in mid to late November.

11. Continue to monitor the health of the lake ecosystem by conducting an ecological assessment at least every three to five years, beginning in 2011, in order to ensure continued compliance with the Drinking Water Protection Act. As part of the next assessment, the following are also recommended:
 - complete a lake water temperature monitoring study for a period of one year at one-meter depth intervals.
 - complete an accurate bathymetric survey of the lake; and
 - undertake an inventory of fish and other aquatic species.

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The report was written by Alan Whitehead, M.Sc., R.P.Bio. of Whitehead Environmental Consultants Ltd. and D.G. Blair-Whitehead, M.Sc. of Blair Whitehead and Associates.

1. INTRODUCTION

1.1 *Background*

The Grafton Lake Watershed Project is an initiative of the Cove Bay Water System (CBWS), one of the water utilities of the Bowen Island Municipality (BIM). The Project was first started in 2002 as a follow-up to the Long Range Plan 1997 (LRP 1997), prepared by Dayton & Knight Ltd. and AJ Whitehead & Associates (1998). The LRP1997 recommended that the CBWS should develop an overall management plan which, among other actions, would include:

1. Development and implementation of a watershed-level educational program to address land use issues related to the protection of water quality and quantity;
2. Design and implementation a water quality monitoring program on the major watercourses draining into Grafton Lake;
3. Design and implementation a water quantity (hydrological) monitoring program to encompass the major watercourses draining into Grafton Lake and the lake outlet; and
4. Undertaking of an ecological assessment of Grafton Lake every three years, beginning in 2001.

Whitehead Environmental Consultants Ltd. (WEC), was subsequently retained by BIM to begin implementation of those recommendations. WEC undertook a work program during 2002 and 2003 that culminated in the issuance of a first report titled “Grafton Lake Watershed Study 2002 – 2003,” endorsed by the Municipal Council. That report included a number of recommendations for watershed management, continued water quality monitoring, water quantity (hydrology) monitoring, and public outreach (education & communication).

BIM subsequently retained WEC in 2007 to implement the recommended actions. The report that follows below presents the results of an environmental monitoring and education work plan that was implemented between 2007 and 2009.

1.2 *Scope of Project*

The scope of the **Grafton Lake Watershed Project 2007-2009** closely followed the actions recommended in 2003. The 2007-2009 work plan consisted of the following components:

1. Community outreach, in the form of an education and communication (E&C) program, aimed at adults and children of the Bowen Island community at large.

2. Water quality monitoring, which entailed the measurement of selected water quality parameters in Grafton lake and a number of the streams that feed the lake.
3. Hydrological monitoring, which entailed measurement of stream flows in the main streams feeding into Grafton Lake at different times of year; and
4. Ecological monitoring of the Grafton Lake ecosystem, with a special focus on water level fluctuations and waterfowl populations.

1.3 Goals and Objectives

The overarching aim is to protect and sustain water quality and quantity in the Grafton Lake watershed for present and future generations, in accordance with the provincial Drinking Water Protection Act and its Regulation. The Project's goals were twofold:

- to increase community knowledge and individual actions toward protecting and sustaining water supplies; and
- to support science-based decision making by local government concerning land uses on Bowen Island.

Specific objectives were as follows:

Education and Communication

- a. to reduce the risks to water quality in public water supplies in the Grafton Lake watershed;
- b. to increase public understanding of where Bowen Island drinking water comes from; and
- c. to promote personal action to ensure the continued good quality of the island's drinking waters sources.

Watershed Management

To generate scientific data that:

- d. links the quality of raw drinking water (source water) in the Grafton lake watershed with the adjacent land uses;
- e. quantifies the seasonal variation in the quantity of water flowing into Grafton Lake;
- f. can be used to determine how water levels in the lake can be managed for human use while sustaining the lake's other ecological functions and values.

1.4 Organization of the Report

This report is organized into seven main sections and three appendices. Section 2 summarizes the education and communication (E&C) campaign. Section 3 and Section 4 present the results of the water quality and water quantity monitoring programs, respectively, and Section 5 presents the results of the Grafton Lake ecological monitoring campaign. The Project's conclusions and recommendations are presented in Sections 6 and 7, respectively. The appendices include supplemental information on E&C, water quality and stream flow data, as well as a series of photographs. The entire report is also

available in electronic format, with the scientific data provided as Excel® spreadsheets to facilitate further use by the Municipality.

2. EDUCATION & COMMUNICATION

2.1 Overview

A multi-faceted approach was undertaken for a watershed-level public education and communication (E&C) program to address land use issues related to the protection of water quality in the Grafton Lake watershed. The focus of this section of the report will be to explore key features of the education and communication campaign to protect source water quality in the watershed while ensuring safe and reliable water supply to both the public and the environment, especially during times of summer drought.

As in many other jurisdictions in Canada, management of municipal water supply on Bowen Island has taken pro-active steps to meeting the demand for high quality and adequate water supplies for Island residents and our island environment. The education campaign is one such measure. As the largest of the six municipal water systems, Cove Bay Water System (CBWS) has shown leadership to manage their water system with a sustainable water management approach by using multiple barrier approach to the protection of drinking water “from source to tap” that includes public education and communication.

The goal of the education and communication campaign was to protect water quality in the watershed. The campaign objectives were to:

- reduce the risks to water quality in public water supplies in the Grafton Lake watershed;
- increase understanding of where Island drinking water comes from;
- promote steps to ensure its source water quality.

2.2 E&C Program Development

In 2007, the consultant team hired by CBWS began planning for an environmental education and communication process that uses public participation and stakeholder engagement as an integral part of the plan. The plan included a threefold approach:

- use of multiple educational activities aimed at multiple audiences;
- use of common themes throughout all education and communication initiatives;
- use watershed monitoring and other data to ensure scientific accuracy.

The first stage of the process included formative research: e.g. What was it that we wanted people to do or not do? Who was the target audience? What base-line statistics needed to be gathered in order to measure success? What did we know about the knowledge, attitudes, and current practices about source water protection of our target

audience? A number of formative research methods were used to answer these questions including a survey, two focus group meetings, community open houses, meetings with stakeholders, and water quality monitoring in the watershed.

This research indicated that the top perceived threats to drinking water quality included: erosion/runoff; septic system failure; and poor farm and garden practices around livestock and pesticide management. Water quality monitoring results in the watershed indicated that there were some concerns around septic system maintenance on properties within the water supply watershed and public swimming in the water supply lake/reservoir.

Based on these initial steps, an education and communication campaign was designed that included engaging public media, community events, and a “Watershed Quest” school program. The overall aim of the campaign was focused on raising the profile of source water protection within the community with the objective of reducing risks to water quality in both public and private water supplies. Specifically, we wanted residents of the Grafton Lake watershed and municipal water systems users to increase their understanding of where their drinking water comes from and to promote steps they can take to ensure its quality. These steps included:

- protecting riparian habitat,
- proper maintenance of septic systems,
- no swimming in the Grafton Lake reservoir, and
- encouraging best practices for water quality for homes, farms, and commercial areas in the watershed.

The campaign, coordinated by a Steering Committee of island residents, water system committee members, municipal staff, and the education consultant began in early 2009. A “water super hero” called Raindrop was selected to be the campaign’s mascot. Raindrop, an engaging cartoon character from the *Bowen Island Waterscape Poster*, led islanders on a treasure hunt or quest to find out about source water protection in the watershed. Questing is an international phenomenon that has place-based education as its core. It is about discovering the stories of home and using them for learning, community building, and stewardship.

2.3 E&C Program Implementation

2.3.1 School Program

During the week of May 25-29, 2009, over 250 grade 1-7 students and parents volunteers from Bowen Island Community School participated in the Grafton Lake Watershed Quest. The consultant coordinated the Watershed Quest school program that included teacher training, classroom activities, and a field day in the watershed (including a custom Grafton Lake Watershed Quest worksheet).

Students followed Raindrop’s mystery clues and participated in volunteer-led activities at two municipal parks and the Grafton Lake reservoir as they moved through the watershed

from its headwaters to the reservoir while discovering first hand where their drinking water comes from and how to protect it. Two classes went “questing” each morning accompanied by teachers and parent volunteers. A variety of community group volunteers, Simon Fraser University students and faculty, and municipal staff/CBWS members all contributed to the Quest. One young student put it like this: “... the Watershed Quest was a lot of fun and I learned a lot about our water system! Thanks!” Teachers indicated that highlights of the program were Raindrop’s school visit to each classroom prior to the field trip, hands-on activities and “questing” during the 2 hour field trip, and learning about local drinking water and watershed issues. Many parents who accompanied the students also learned up close and personal where their water comes from and how they can impact the water quality in the watershed.

2.3.2 Public Media

Concurrently to the development of the Watershed Quest, a series of monthly articles called “Raindrop Says...” on key topics about protecting water quality in the watershed was produced. These articles were accompanied by illustrations of Raindrop. Each article, published in our community newspaper, *The Undercurrent*, had an accompanying graphic with Raindrop’s key message and was 300-400 words and written in lay terms. The topics of the articles included:

- The Story of Water on Bowen Island
- Where does Bowen Island’s water come from?
- Let’s Celebrate Drinking Water Week!
- Drinking Water Protection Begins at Home
- The Grafton Lake Watershed Quest
- How is Your Drinking Water Protected?
- We are All Downstream.

2.3.3 Community Events

The consultant organized a table at our community fair, Bowfest, from 2007-2009. In 2007, the theme was to introduce the study, to collect survey data, and to answer any questions about the watershed. In 2008, focus was on providing information on water quality in the watershed, how homeowners can maintain septic system health, and general information about the study. In 2009, the focus was on the “story of water on Bowen Island” through the Grafton Lake Watershed Quest and to collect post-campaign survey information.

2.4 Campaign Formative Evaluation

There was no significant change in attitudes about swimming in Grafton Lake. Although there is now an increased level of discussion and awareness of the issue, much still needs

to be done to have a “culture” of compliance regarding this long-time local swimming location.

As well, there was no significant change in perception about easy access to source water protection information from the community newspaper. This is probably due to the change in editor and newspaper style that happened mid-campaign. Articles that were submitted were shortened; run without a graphic or the “Raindrop Says” headline was missing. It is hoped that in future campaigns the community editor keeps to a consistent style to increase ease of access to the information provided.

The good news is that based on the post-campaign surveys, there were three areas with meaningful results:

- 83% of respondents knew the largest source of drinking water is the Grafton Lake watershed (up from 42%)
- 60% had received information about how to protect drinking water from community events (up from 20%)
- 60% recognized that failing septic systems negatively impact water quality (up from 47%).

Results from the Grafton Lake Watershed Quest were also significant in that all participating teachers indicated that the program was informative, meaningful to both their students and parents, and they would like to participate should the program be offered again. Some comments from teachers include:

- *“the student learning was great/ could not be achieved in the classroom.”*
- *“to actually follow Raindrop from the headwaters to our classroom was so powerful. Great initiative.”*
- *“this experience was extremely positive for students, parent volunteers and teachers.”*

The text to the Grafton Lake Watershed Quest and photos from the field day may be found in Appendix 1.

3. WATER QUALITY 2007 – 2008

3.1 *Water Quality Sampling Locations*

The water sampling locations were selected following the delineation of the sub-watersheds and land use analysis completed in 2002 -2003 and a review of updated land use information. The sampling locations and their respective catchments are shown in Map 1.

The water quantity or hydrological aspects are described in Section 4. Stream flow conditions (i.e., water quantity), including the amount of runoff from recent rains, can influence the quality of surface waters through dilution.

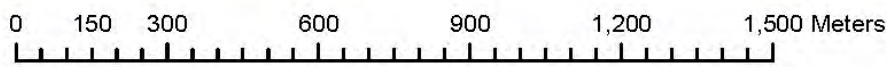
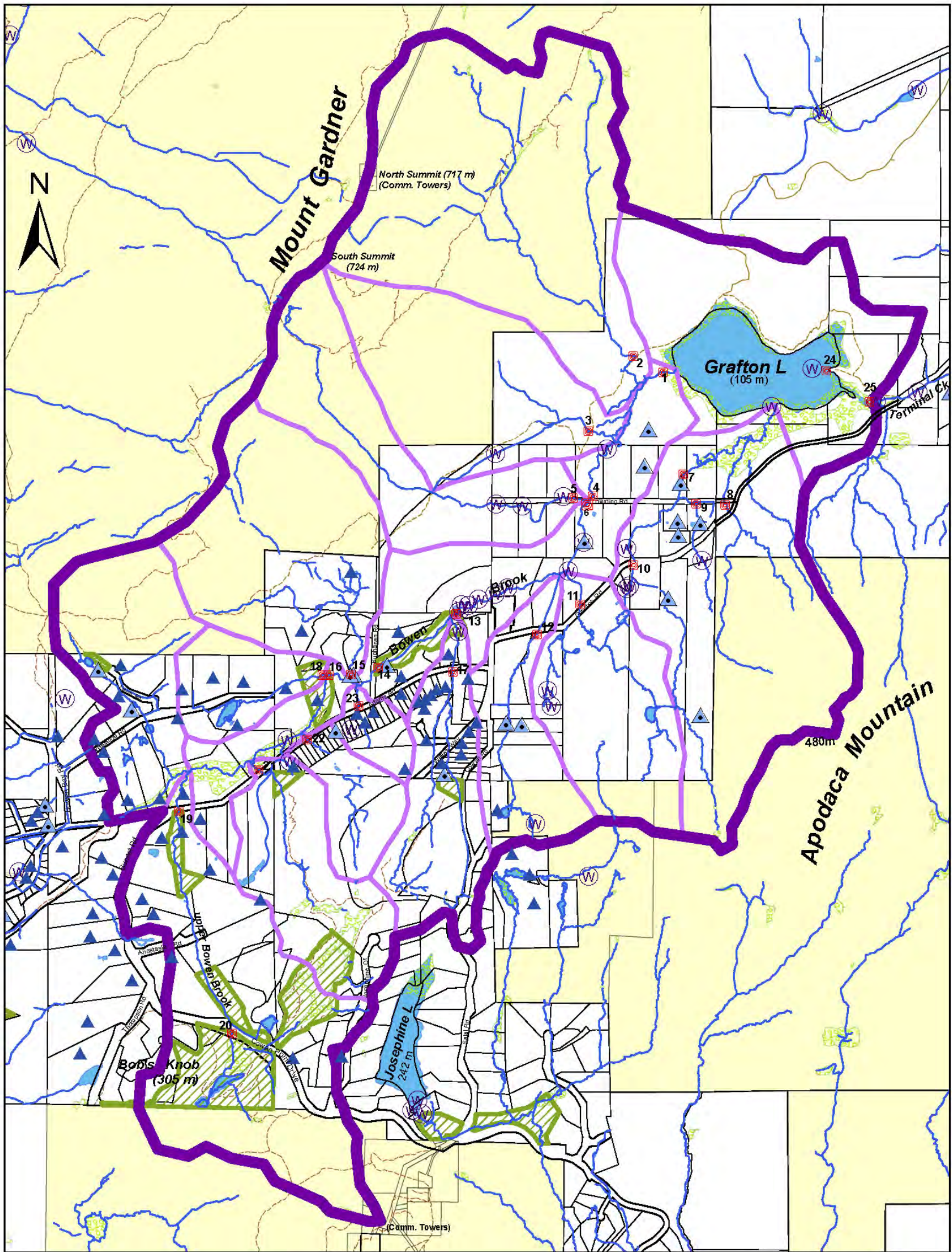
3.2 *Water Quality Methods*

Sampling for water quality during the present study was carried out on three occasions:

- 22 August 2007 - (summer low flow conditions; minimum dilution; 5.6 mm precipitation on four out of the previous 21 days; 7.5 mm precipitation during the previous week);
- 25 June 2008 - (early summer conditions, moderate dilution; 67 mm precipitation on six out of the previous 21 days; <2 mm precipitation during the previous week); and
- 10 October 2008 - (early fall conditions; “first flush”; 75 mm precipitation on 12 out of the previous 21 days; 42 mm precipitation during the previous week).

For reference purposes, we also note that the samples collected in June 2002 represented the “end of the wet season” during dry weather and conditions of decreasing flow, and the sample in November 2002 represented the “end of the dry season” during conditions of increasing precipitation and stream flow (WEC 2003).

The water samples were collected by hand (“grab samples”) directly from the streams and surface of the lake, using bottles provided by the laboratories. Upon return to the vehicle, preservatives provided by the laboratory were added to the samples as appropriate. The samples were then placed in a cooler with ice packs and delivered to the laboratories within 24 hours. Once at the labs, the samples were analyzed for a variety of standard parameters including physical characteristics such as colour and turbidity, nutrients, dissolved and particulate substances such as sulphate, metals and petroleum-based chemicals, and bacteria.



Map 1.
Surface Water Quality Sampling Sites,
Grafton Lake Watershed and Subwatersheds,
Bowen Island.

Prepared by Whitehead Environmental Consultants Ltd.
20 August 2008.

Base map courtesy of the Bowen Island Municipality and
Bowen Island Conservancy GIS.

All feature locations are approximate.

| LEGEND | | SAMPLING SITE NAMES | |
|--------|----------------------------------------|---------------------|--------------------------------|
| | Water Quality Sampling Site and Number | 1 | Bowen Brook at mouth |
| | Well, drilled | 2 | Still Creek u/s trail crossing |
| | Well, dug | 3 | Robb Creek u/s trail crossing |
| | Water intake, licensed | 4 | Bowen Brook d/s Harding Rd |
| | Stream | 5 | Spooher Brook at mouth |
| | Grafton Lake Watershed | 6 | Bowen Brook u/s Harding Rd |
| | Subwatershed | 7 | Harding Creek d/s Harding Rd |
| | Municipal Park | 8 | Klink Creek u/s Harding Rd |
| | Wetland | 9 | Cliffe Creek d/s Harding Rd |
| | Lake, Pond, Reservoir | 10 | Harding Creek u/s Grafton Rd |
| | Public Trail | 11 | Mac-Wha Creek d/s Grafton Rd |
| | | 12 | Proudlock Brook u/s Grafton Rd |
| | | 13 | Bowen Brook d/s Lister Creek |
| | | 14 | Bowen Brook d/s Buchanan Rd |
| | | 15 | Billington Creek at mouth |
| | | 16 | Bowen Brook d/s Peggie's Creek |
| | | 17 | Lister Creek u/s Adams Rd |
| | | 18 | Peggie's Creek at mouth |
| | | 19 | Bowen Brook u/s Adams Rd |
| | | 20 | Bowen Brook u/s Sunset Rd |
| | | 21 | Phantom Creek d/s Adams Rd |
| | | 22 | unnamed creek #1 d/s Adams Rd |
| | | 23 | unnamed creek #2 d/s Adams Rd |
| | | 24 | Grafton Lake at Rocky Point |
| | | 25 | Grafton Lake at outlet |

u/s = upstream, d/s = downstream

The full list of parameters measured at each sampling site is shown in Table 3-1. Land uses within the sub-watersheds were taken into account when selecting each sampling site and the parameters to be measured at each site. For example, Harding Brook was selected because of the presence of a lumber yard, and Billington Creek because there is an active rock quarry, heavy duty mechanics shop and waste incineration operation in its catchment. Similarly, Proudlock Creek was selected because there is active grazing of livestock (sheep and, to a lesser extent, llamas) and Phantom Brook and the unnamed watercourse on Adams Road were selected because of the presence of many septic fields in their catchment areas.

The chemical and physical analysis was conducted at BCAT Laboratories in Burnaby, and the bacteriological analysis was completed at Environment Canada's Pacific Environment Science Centre (PESC) in North Vancouver. Laboratory analyses were carried out using standard chemical and microbiological methods (see Laboratory Reports in Appendix 2).

The results obtained from the laboratory were compared with the existing federal and provincial standards, criteria or guidelines¹ for raw drinking water and protection of aquatic life. Also, the results of other parameters were considered in relation to their value as indicators of ecological conditions (environmental health). Measurements that did not meet the maximum allowable concentration or criterion (MAC) or the guideline level were flagged for further consideration, while those that fell well below the MAC or met the guideline level were considered acceptable and not examined further.

The standards, criteria and guidelines for each water quality parameter, for raw drinking water and aquatic life protection, are shown in Table 3-2.

3.3 Water Quality Results

This section starts with an overview of water quality parameters, to provide a context for the discussion of other results. The results for each sampling date are then presented together with the results from 2002 and discussed. Graphs showing the results for the three sampling dates are also provided, and the complete data set is included in Appendices 2-1 and 2-2.

3.3.1 Overview of the Water Quality Parameters

Water quality measurements or parameters are commonly grouped into categories to provide a logical order for their discussion and interpretation. These categories commonly have names such as Physical Tests, Dissolved Anions, Nutrients, Metals (total and dissolved), Microbiological Tests, Hydrocarbons, Pesticides, Organic Matter and

¹ The terms "Standards", "Criteria" and "Guidelines" are used to denote different levels of legal strength and enforceability. The actual meaning of the terms varies depending on the specific wording of the legislation or regulations to which they pertain. Standards and Criteria can include specific values such as maximum or minimum allowable concentrations or ranges of values and, generally, can be considered to carry greater weight legally than Guidelines. (See Canadian Drinking Water Guidelines [References])

others. Some of these categories are self-explanatory while others are not; also, category names can vary between laboratories. The individual parameters included under each category are shown in the Appendix 2. General comments on individual parameters or categories are provided below, and discussion of the results is presented in Section 3.4.2.

Colour - The naturally occurring range of water colour can be 0 to 300 colour units (CU). Higher values are usually associated with organic compounds originating in wetlands, lakes and springs associated with organic soils. Human-caused sources of colour are usually associated with agriculture and industrial effluents. Colour is regarded as a pollution problem in terms of aesthetics, but is not generally considered a detriment to public health or aquatic life. Increased colour may interfere with the passage of light, thereby impeding underwater photosynthesis in stream and lake ecosystems.

Turbidity - Highly variable in nature, this characteristic is strongly influenced by runoff and other conditions. High turbidity reduces light penetration; therefore, it impairs photosynthesis of submerged vegetation and algae. In turn, the reduced plant growth may suppress productivity of algae-consuming aquatic invertebrates which are food for fish. High levels of turbidity increase the total available surface area of solids in suspension upon which bacteria can grow. Turbidity can interfere with the disinfection of drinking water and is also aesthetically unpleasant. Materials that contribute to turbidity are silt, clay, organic material or micro-organisms. Human caused sources (on Bowen) can include erosion from land clearing, road building, agriculture, residential developments, sewage and other effluents.

Total Suspended Solids (TSS) are a measure of the particulate matter that is suspended in a water sample and most of which can be removed by filtration (except the extremely small particles); for this reason, TSS is also known as non-filterable residue or NFR. High concentrations of TSS increase turbidity, thereby restricting light penetration (hindering photosynthetic activity). Suspended material can result in damage to fish gills and can interfere with water treatment processes. Settling or sedimentation of suspended solids can cause impairment to spawning habitat by smothering fish eggs. Natural sources include materials washed from undeveloped areas by surface runoff. Human caused (anthropogenic) sources on Bowen Island include forest harvesting, road building, residential development, intensive cultivation, quarrying and incineration, among others.

Total Dissolved Solids (TDS) (also known as filterable residue, FR) is a measure of the amount of dissolved material in a water sample. Values in fresh water naturally range between 0 to 1000 mg/L. Generally, streams on the BC coast of have TDS concentrations <75 mg/L, while those in the interior of the province can have up to 750 mg/L. High concentrations of TDS limit the suitability for drinking water and irrigation supply. Dissolved salts such as sodium, chloride, magnesium and sulphate contribute to elevated TDS, whether from natural or man-made sources. The main anthropogenic sources on Bowen Island include road salts, quarrying and blasting, intensive agriculture and others.

Conductivity is a measure of the amount of electrically charged ions in the water, which reflects the concentration of dissolved substances. While interior streams in BC range up

to 500 $\mu\text{S}/\text{cm}$, coastal streams have specific conductivity values in the order of 100 micro Siemens per centimeter ($\mu\text{S}/\text{cm}$), reflecting the dilution by greater precipitation. Values naturally tend to increase in the summer when there is less dilution by rainwater. Natural sources of soluble substances include minerals in local soils, while human-caused sources (on Bowen) include domestic and hobby farm effluents, roads (de-icing salts), blasting residues and others.

pH is the concentration of hydrogen ions, and is commonly used as a measure of chemical reactivity. Natural fresh waters have a pH range from 4.0 to 10.0, although in B.C. most coastal streams commonly have pH values of 5.5 to 6.5 and lakes have a pH of 7.0 or greater. Waters with a pH above 7 are considered alkaline, while those with a pH below 7 are considered acidic. Values of pH between 6 and 9 are desirable.

Sulphate is an oxidized form of sulfur that is widely distributed in natural waters, where it may be present in at low to very high concentrations. Sources of sulphur include local minerals, decomposition and combustion of organic matter, and manufactured materials such as battery acid (sulphuric acid), drywall (which contains gypsum), Epsom salts and copper sulphate (used as an algicide in swimming pools). In addition, atmospheric dust originating from fossil fuel and biomass combustion is an important source of sulphate, which can increase the acidity of the atmosphere and form acid rain. The B.C. criterion for SO_4 in drinking water is 500 mg/L, as high concentrations of sulphate in drinking water can have purgative effects.

Nutrients include the various forms of nitrogen (ammonia, nitrite, nitrate and organic nitrogen), as well as phosphorus and potassium (N, P, K). The concentrations of nutrients, particularly nitrogen and phosphorus can influence the health and stability of aquatic ecosystems and, in some cases, drinking water aesthetics (including taste and odour) and human health. Potassium (K) is not a concern in freshwater ecosystems and is, therefore, not considered further in this report.

Total nitrogen (TN) includes all forms (species) of nitrogen (ammonia, nitrate, nitrite and organic nitrogen) in water. The importance of nitrogen in the aquatic environment varies according to the relative amounts of the nitrogen forms present. Ammonia, nitrate and nitrite are all analyzed for directly in the lab; in contrast, organic-N is measured by subtracting the results for ammonia-N from that for Total Kjeldahl Nitrogen (a laboratory technique which measures ammonia-N plus organic-N). Man-made sources of nitrogen on Bowen include septic field effluents and other sewage, gardening and agricultural fertilizers, compost piles, animal wastes and, possibly, blasting residues.

The breakdown of organic matter yields a variety of nitrogen-containing compounds collectively known as organic nitrogen, which can be further mineralized through microbial activity into the inorganic forms. Ammonia-N, the first N species resulting from the breakdown of organic-N, is oxidized to produce nitrite-N which is highly reactive (typically more toxic) and, therefore, short-lived; it, in turn, is further oxidized to produce nitrate-N which is stable and very soluble. The oxidized forms (nitrate and nitrite) are most readily absorbed by plants.

Ammonia (NH_3-N) in excessive amounts can be toxic to fish food organisms, while organic-N in excess can deplete dissolved oxygen and cause taste and odour problems. *Nitrate* (NO_3-N) is the main nitrogen compound found in natural waters; it is a key plant nutrient together with phosphorus and potassium. Most surface waters have less than 0.3 mg/L of nitrate, unless there are inputs from human sources. Nitrate is highly soluble and is the primary form of nitrogen used by plants for growth; excessive nitrate in fresh waters may result in phytoplankton blooms or aquatic weed proliferations. Nitrite (NO_2-N) can be toxic to certain organisms (e.g., fish) at very low doses; however, as indicated above, it tends to be short-lived under natural conditions and is often undetectable or present only at very low concentrations.

Phosphate phosphorus (PO_4-P). Since most P occurs as phosphate, the standard laboratory method for measuring total-P in fresh water is to chemically oxidize all P to PO_4 . This approach is generally acceptable in waters that contain very little suspended (particulate) matter that might contain undissolved P; however, in waters with a high content of particulate matter, such an approach can over-estimate the amount of biologically available P. Ortho-phosphate is a measure of the inorganic oxidized form of soluble phosphorus, which is an essential nutrient for plant growth. PO_4-P is readily available for uptake during photo-synthesis; it is also commonly in very short supply (i.e., a limiting nutrient), especially in freshwater systems. Hence, elevated concentrations of phosphate can contribute to blooms of suspended algae and/or proliferation of aquatic weeds. Natural sources are the local soils and minerals, while human-made sources (on Bowen) include domestic sewage, livestock and fertilizers. There is no maximum allowable concentration of PO_4-P . The total phosphorus concentrations in most lakes not affected by anthropogenic inputs is generally less than 0.01 mg/L (10 μ g/L). Lakes with <10 μ g/L phosphorus are considered oligotrophic, while 10-25 μ g/L P is considered mesotrophic, and >25 μ g/L is considered eutrophic.²

In order to effectively monitor this nutrient in streams, the provincial guideline for total-P for protection of aquatic life in freshwater is 0.005 to 0.015 mg/L (MELP 1998). Accordingly, a laboratory detection limit of 0.002 mg/L or 0.001 mg/L is commonly used for monitoring freshwater ecosystems. The detection limit used by the laboratory in 2007-2008 was 0.01 mg/L, which did not allow for detection or tracking of changes occurring below that level.

Metals include a broad array of minerals that originate either in the soils or underlying bedrock, or in discharges of man-made substances. They can be measured as total, dissolved and particulate forms.² Metals are important because many of them are either essential micronutrients (e.g., boron, fluoride, iron, manganese, zinc) or, at certain concentrations, can be toxic to humans, pets and livestock, as well as fish, plants and wildlife (e.g., arsenic, lead, mercury, zinc). Individual metals can exert their effect alone or in combination with other parameters. They can be absorbed internally through the gut and gills, for example, or externally through the skin. The MAC's for the most toxic

² The particulate fraction is calculated arithmetically, by subtracting the concentration of the dissolved fraction from the concentration of total metal.

metals are typically very low. The metals that are addressed in this report are described further below.

Aluminum. The potential toxicity of Al increases with decreasing water pH below 6.4, and the MACs are based on the dissolved fraction of Al.

Arsenic (As) is a particularly toxic metal that can affect a broad variety of animals, including humans, at relatively low concentrations. Its toxicity is due to its interference with very basic metabolic reactions at the intracellular level. It is also naturally widespread in the Howe Sound region as a result of local geological conditions (Kohn 200x). Chemicals containing arsenic have been used, until recently, as a wood preservative, which is probably the main source of man-made arsenic on Bowen Island. The MAC for As in drinking water in Canada is 0.025 mg/L and for protection of aquatic life is 0.05 mg/L; the USEPA has set a MAC of 0.010 mg/L in drinking water (USEPA undated).

Manganese. As one of the most abundant metals on the earth's surface, manganese makes up approximately 0.1% of the earth's crust where it is a component of over 100 minerals. Levels in freshwater typically range from 1 to 200 µg/L (USEPA 2004). Manganese intake from drinking water is normally substantially lower than intake from food (USEPA 2004). The colour related aesthetic objective for manganese in drinking water is 0.05 mg/L. Like iron, manganese is objectionable in water supplies because it stains laundry and fixtures black, and at excessive concentrations causes undesirable tastes in beverages. Manganese is present in some ground waters because of chemically reducing underground conditions coupled with presence of manganese mineral deposits. Manganese is also occasionally present, seasonally, in surface waters when anaerobic decay processes in sediments is occurring (Anon. 2006).

Sodium (Na), the sixth most common element in the earth's crust, is also a component of sodium chloride (NaCl), a very important compound found in the ocean and everywhere in the living environment. Common sources on Bowen are sea spray (which can travel inland over long distances), road salt use in winter and discharges from water softeners.

Zinc (Zn) is a naturally occurring element. Exposure to high levels of zinc occurs mostly from eating food, drinking water, or breathing workplace air that is contaminated. Low levels of zinc are essential for maintaining good health; however, exposure to large amounts of zinc can be harmful, causing stomach cramps, anemia, and changes in cholesterol levels. While some Zn is released into the environment by natural processes, most (on Bowen) comes from human activities like quarrying and burning of waste, as well as leaching from galvanized water pipes. Rain and snow remove zinc dust particles from the air; depending on the type of soil, some zinc compounds can move into the groundwater and into lakes, streams, and rivers. Most of the zinc in soil stays bound to soil particles and does not dissolve in water.

It does accumulate in fish and other organisms, but it does not build up in plants. The Canadian Drinking Water Guidelines and the USEPA recommend that drinking water

should contain no more than 5 mg/L, primarily because of taste (Health Canada 2010; Agency for Toxic Substances and Disease Registry [ATSDR] 2010).

Microbiological Tests. The microbiological organisms of concern in water quality include bacteria, viruses, fungi and parasites. These are important because of their potential to affect the health of humans, pets and livestock, as well as plants, fish and wildlife. Sources include fecal matter from wildlife, pets and livestock, as well as sewage and other organic residues. Fecal coliform bacteria are used as indicators of the possible presence of organisms that can cause disease in humans, as they are usually associated with feces and are relatively easy to test for in the laboratory.

The use of fecal coliform as an indicator of fecal contamination has its limitations because it cannot distinguish between human sewage and other sources of fecal bacteria. This limitation is acute in watersheds that contain significant populations of warm-blooded wildlife (mammals and birds) and livestock in addition to humans. For example, the presence, in surface waters, of fecal coliform from deer, beaver, birds, poultry, horses, sheep or other livestock does not necessarily mean that the water will cause disease in humans. The risk to public health is associated mainly with the human (and, to a lesser extent, pets and livestock) sources of microbial contamination, rather than natural wildlife. The Grafton Lake watershed, indeed many watersheds on Bowen Island, are a case in point, because they support large populations of deer and other mammals, as well as numerous birds including waterfowl.

The need for indicators other than coliform bacteria to distinguish among the natural and human-related sources of microbiological contamination has been identified for some time (Mara and Oragui 1985) and was addressed in our earlier report (WEC 2003). With advancing knowledge of microbiology and related laboratory methods, alternative indicators have been proposed and are beginning to be used for this purpose (Long et al. 2000). One of these alternatives is the Bacteroides test, which is available through the Pacific Environmental Science Centre (PESC) of Environment Canada, was used for the present study. Since this test can distinguish between fecal contamination from ruminants, dogs and humans, it was used to identify catchments where human fecal contamination was present.

Hydrocarbons and pesticides. These include a wide variety of man-made compounds that are of concern because exposure can (at excessive concentrations) be harmful to many forms of life, from plants to fish and wildlife to humans. Many are persistent chemicals that do not break down naturally in the environment. Typical sources on Bowen include fuels, lubricants and hydraulic fluids, as well as gardening, household and agricultural products. Pesticides were tested for in 2002 and found to be undetectable; they were not tested for in 2007-2008. Petroleum hydrocarbons were tested for in selected streams in 2007 – 2008.

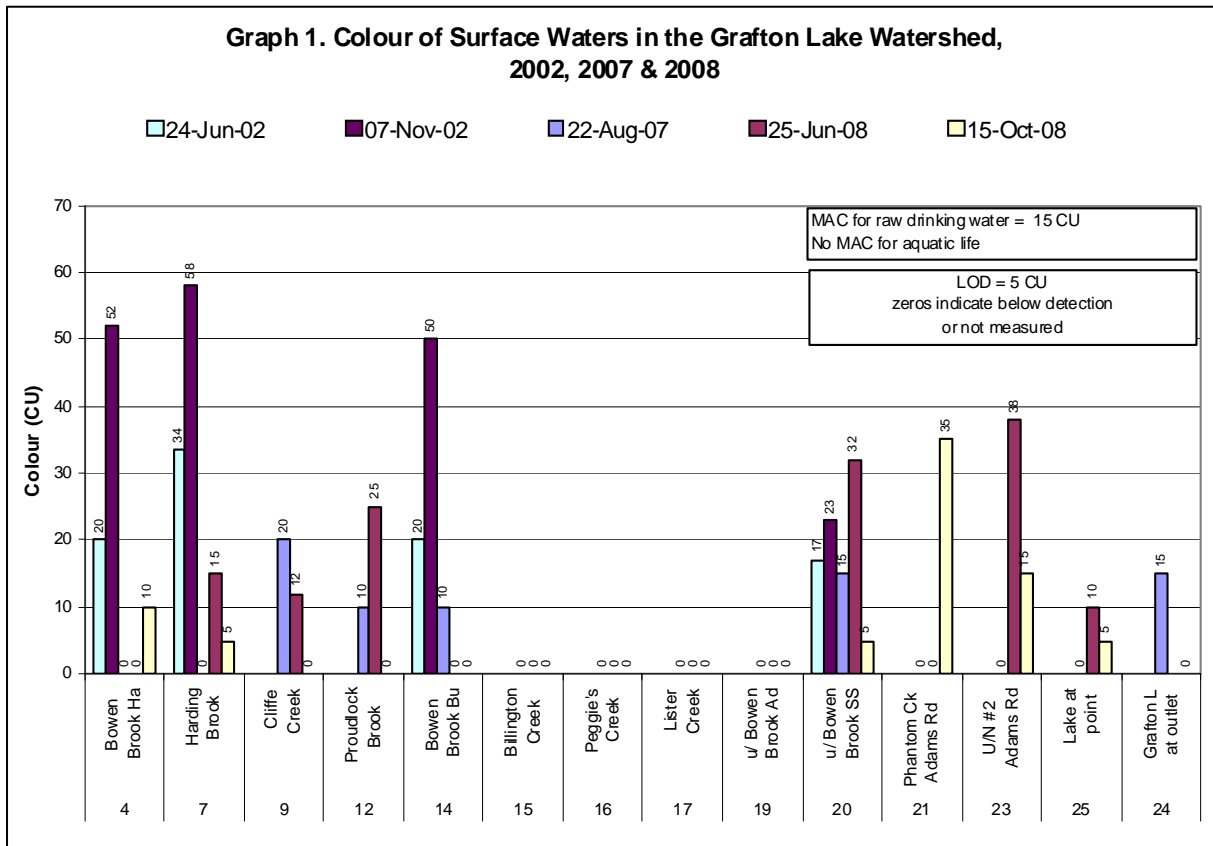
Pharmaceuticals and Personal Care Products (PPCPs) are another category that is gaining increasing attention because they may have undesirable environmental effects. These include products used by individuals for personal health and cosmetics or used in

agriculture to enhance growth or health of livestock. Many of these manufactured chemicals do not break down in treatment systems and are ultimately discharged into the environment. The risks are not yet well known, but may include disruption of hormonal systems in aquatic organisms, resistance to antibiotics, and neurobehavioural changes. The ability to test for these compounds is not yet widely available in commercial laboratories. PPCPs were not examined in this study.

3.3.2 Detailed Water Quality Results

Colour

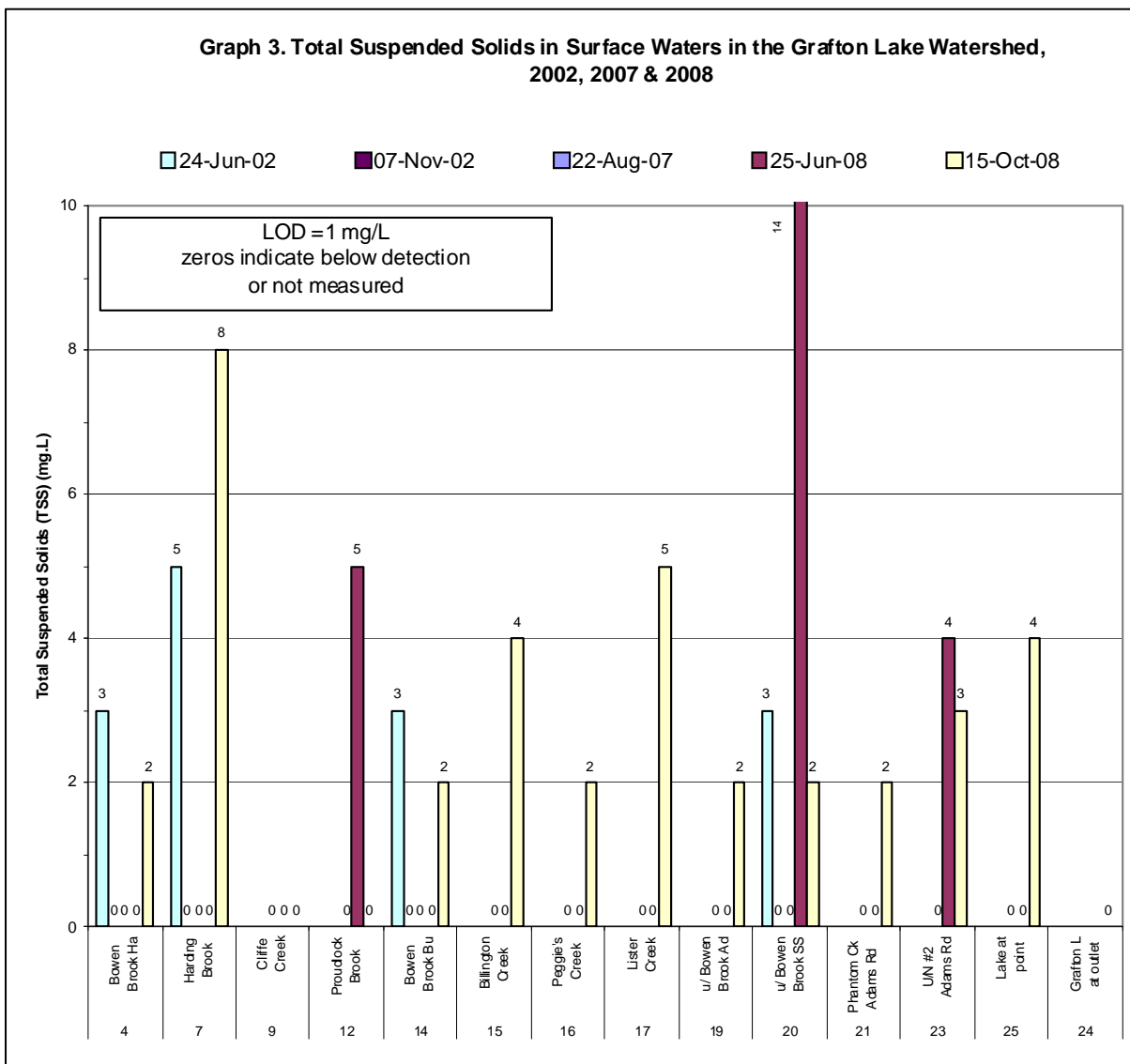
The colour of water at most stations varied considerably between dates and often exceeded the guideline of 15 CU for drinking water (Graph 1). Peak values were associated with the early rainy season, when organic matter was being flushed out of the forest litter by runoff, while



lowest values occurred during the summer dry season. The highest values were recorded in November 2002 and the lowest in October 2008. The results are indicative of natural conditions due to organic matter content in the mostly forested watersheds. The site with consistently the most highly coloured water was Bowen Brook at Sunset Road, while the site with the greatest variability was Harding Brook.

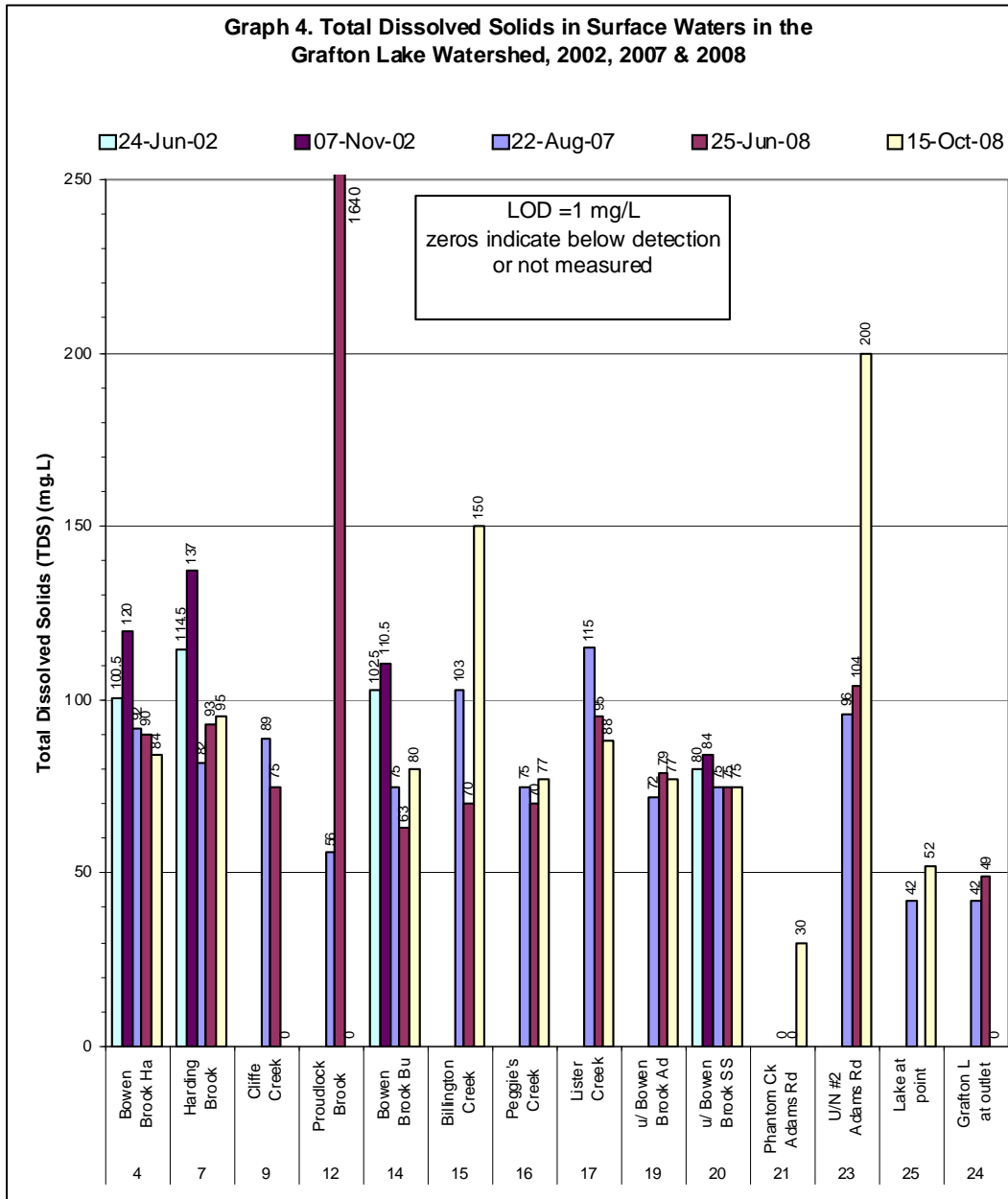
Total Suspended Solids (TSS)

Most TSS measurements ranged from below the detection limit of 1 mg/L to 5 mg/L (Graph 3), except at Harding Brook in June 2008 (8 mg/L) and upper Bowen Brook in October 2008 (14 mg/L). The latter site is at the outlet of a natural wetland that receives water from two constructed ponds (Quarry Park); the suspended matter may have originated as plankton from the ponds and open water within the wetland. Harding Brook is fed in part by a large paved area (the Bowen Building Centre) which provide no runoff detention; this condition exacerbates peak flows during periods of rainfall and likely contributes to the suspension of fine sediments from the low-gradient stream bed between Grafton Road and Harding Road. During periods of lower flow, this flatter reach of Harding Brook is a natural settling area for suspended matter. The overall pattern among sites and between dates is similar to turbidity, with higher values associated with periods of recent precipitation, as might be expected.



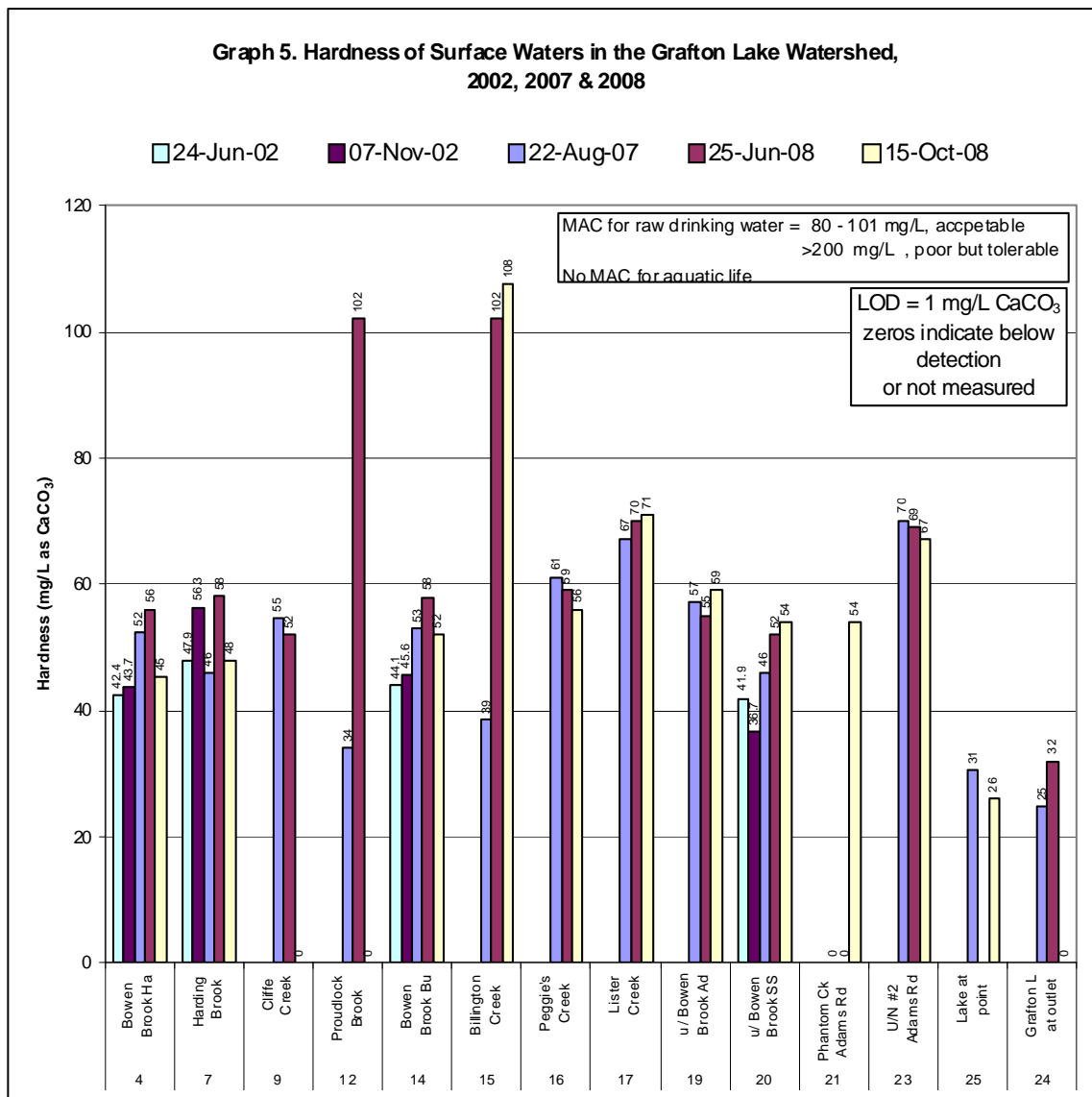
Total Dissolved Solids (TDS)

TDS ranged from less than 1 mg/L to 200 mg/L, with most values falling between 50 and 110 mg/L (Graph 4). This range is considered normal. The highest value (1640 mg/L) was recorded in Proudlock Brook in June 2008; this peak coincides with high levels of several other parameters, all of which are suggestive of a human cause.



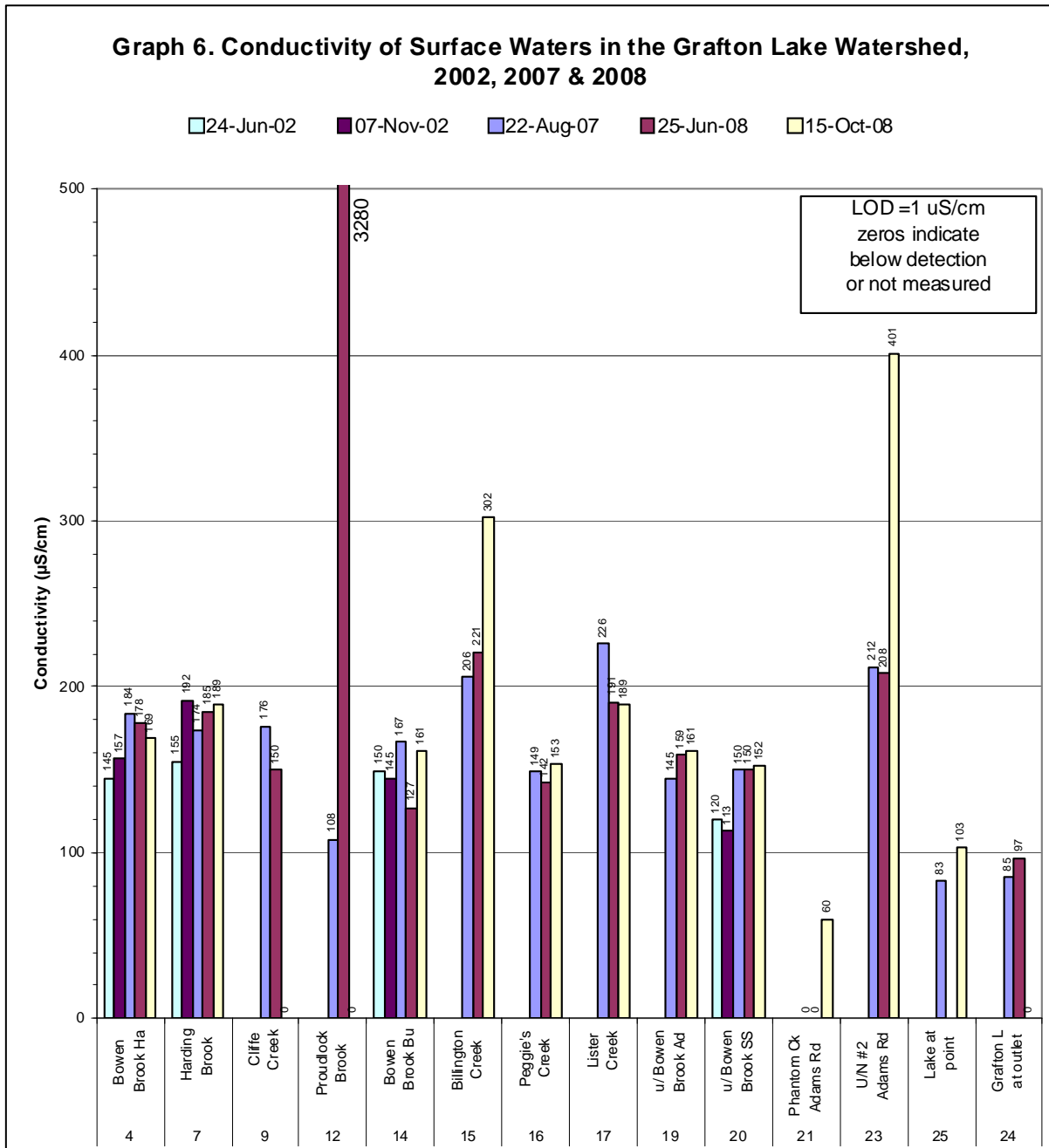
Hardness

Hardness values at most stations fell between approximately 40 and 70 mg/L (Graph 5). Within sites, values tended to be variable, although increasing trend was notable in all sites on Bowen Brook; the reasons for the trends are not known. Peak values were recorded in Billington Creek (102 and 108 mg/L in June and October 2008), and Proudlock Brook (102 mg/L) in June 2008. These high values appear to be related to land uses in the catchments. Hardness of Grafton Lake water was the lowest on any sampling occasion, with values below 32 mg/L. The hardness/softness of the water determined the MACs for aluminum (Al), cadmium (Cd), chromium (Cr) and lead (Pb).



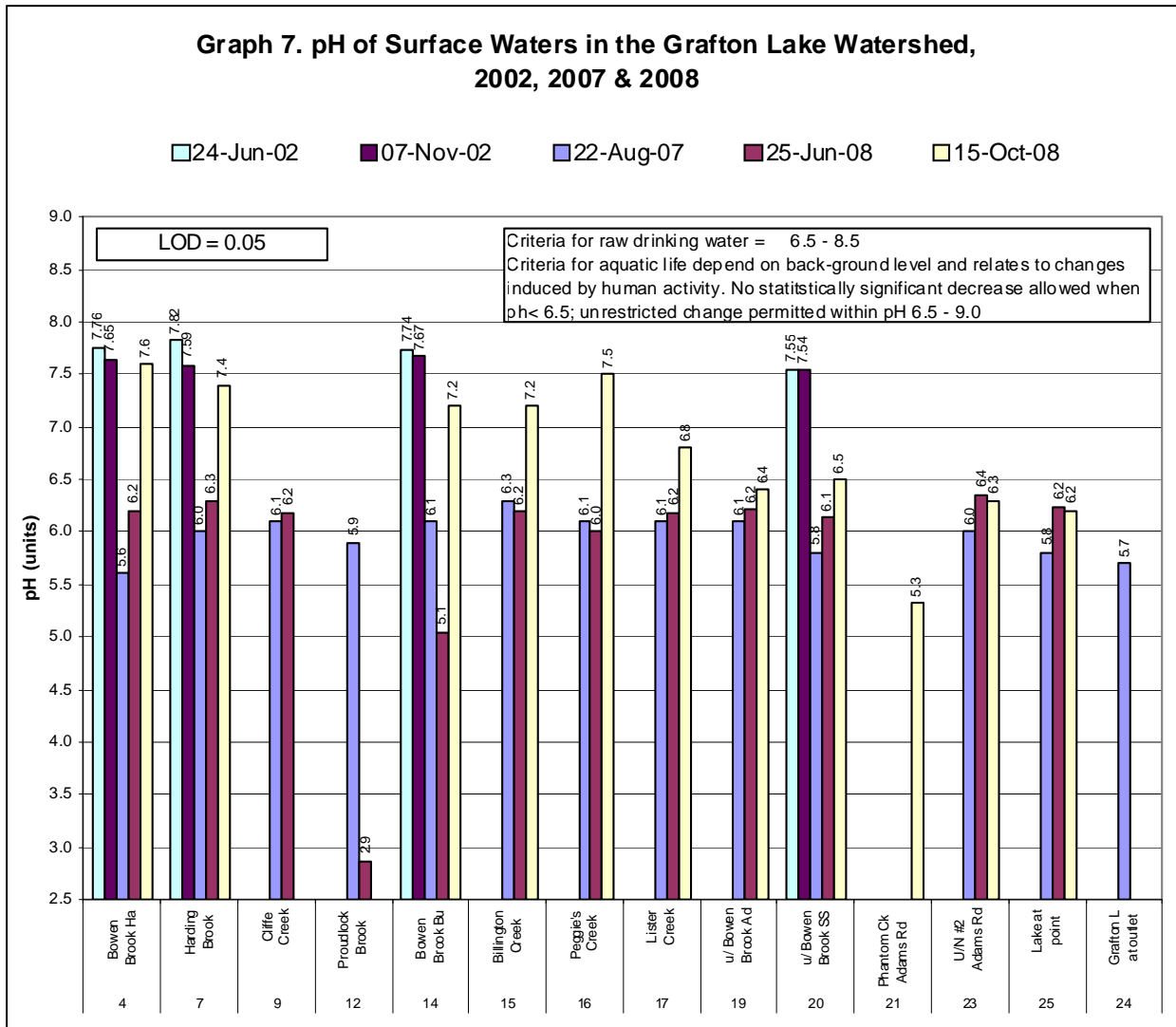
Conductivity

Conductivity of water sampled at most stations on most dates fell within the range of approximately 100 – 200 $\mu\text{S}/\text{cm}$ (Graph 6). The lowest values, 60 $\mu\text{S}/\text{cm}$ was measured in Phantom Brook in October 2008. Conductivity in Grafton Lake ranged between 83 and 103 $\mu\text{S}/\text{cm}$, well below the average for the streams. An extreme peak value of 3280 $\mu\text{S}/\text{cm}$ was recorded in Proudlock Brook in June 2008; this anomaly is thought to reflect inputs of man-made chemicals in the watershed (see pH, Ammonia and Phosphate). Other high values, possibly indicative of human impacts, occurred in unnamed #2 at Adams Road and in Billington Creek, both in October 2008.



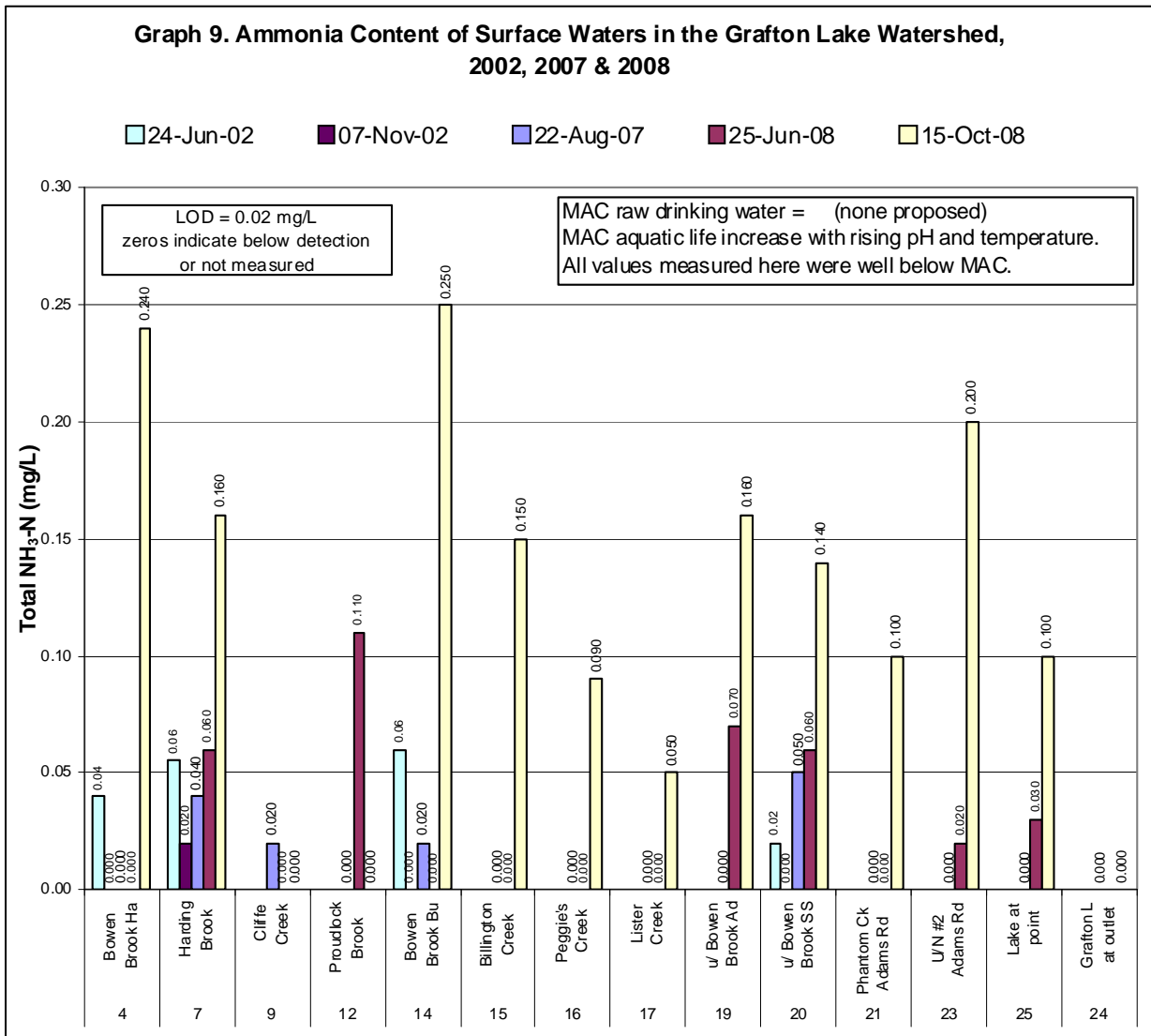
pH

Water pH measurements tended to cluster around the range of 6.0 to 7.0 (Graph 7). Many readings fell slightly below the desirable range of 6.5 – 9.0, as is common in south coastal B.C due to naturally high acidity caused by high rainfall. Values at the high end of the ranges were close to neutral (6.8 – 7.8), while the low values ranged from 5.5 to 6.3. An exceptionally low pH value was recorded in Proudlock Brook in August 2008; the extremely high acidity would have been toxic to aquatic life. This acidity, which coincided with high levels of ammonia, organic-N and phosphate in this stream, strongly suggests that the cause of this anomaly may have been agricultural fertilizer. Measurements below 6 were recorded in Bowen Brook (Sunset Road, Buchanan Road and Harding Road), as well as Grafton Lake; these values are all considered natural. The slightly acid conditions determined the MACs for aluminum, manganese, mercury and ammonia.

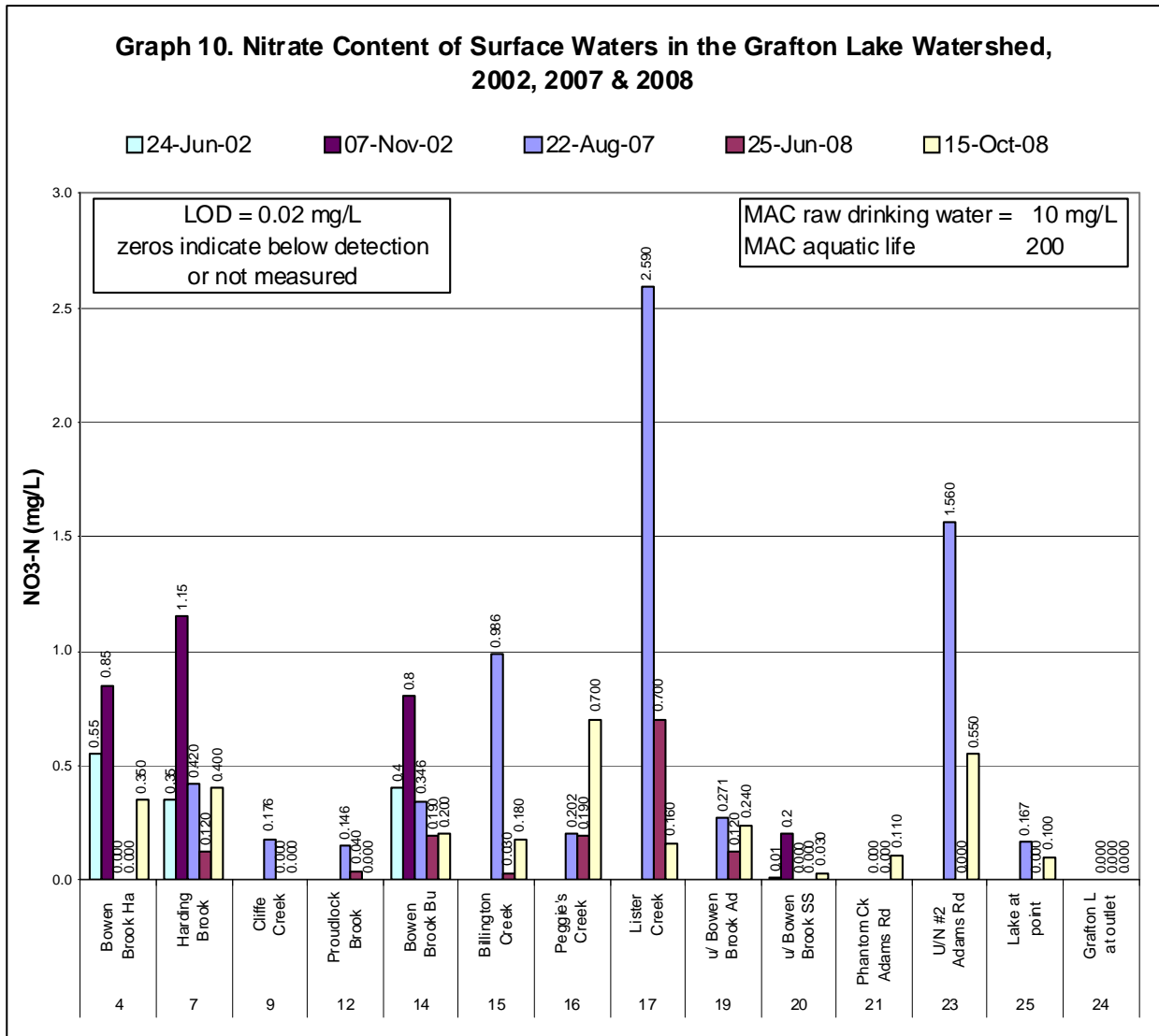


Nitrogen (Graphs 9 – 12)

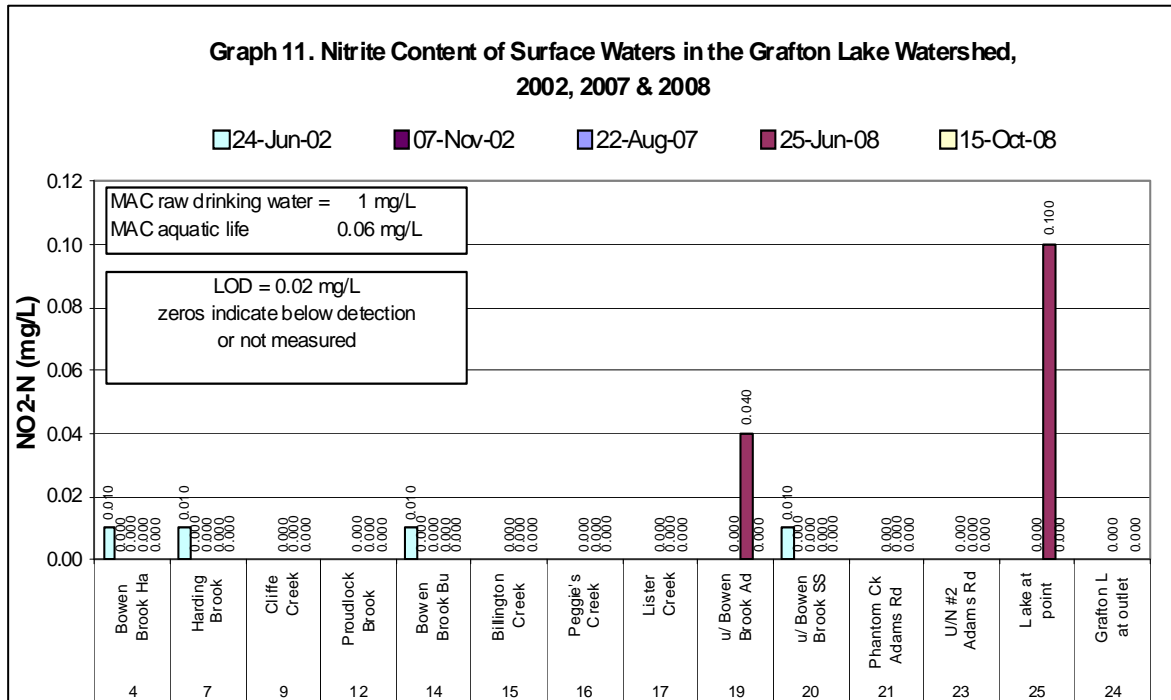
Ammonia-N (Graph 9) ranged from below detection (<0.02 mg/L) to 0.25 mg/L. The highest values within each creek tended to occur in October 2008. In August 2008, NH₃-N in Proudlock Creek was the highest (0.110 mg/L) among all measured streams. Ammonia-N content in Grafton Lake was generally very low, only being detectable in August and October 2008. A trend of increasing ammonia was evident between 2002 and 2008; the causes of this trend are not yet clear. All NH₃-N values measured were well below the MAC for aquatic life (there is no MAC or guideline for drinking water).



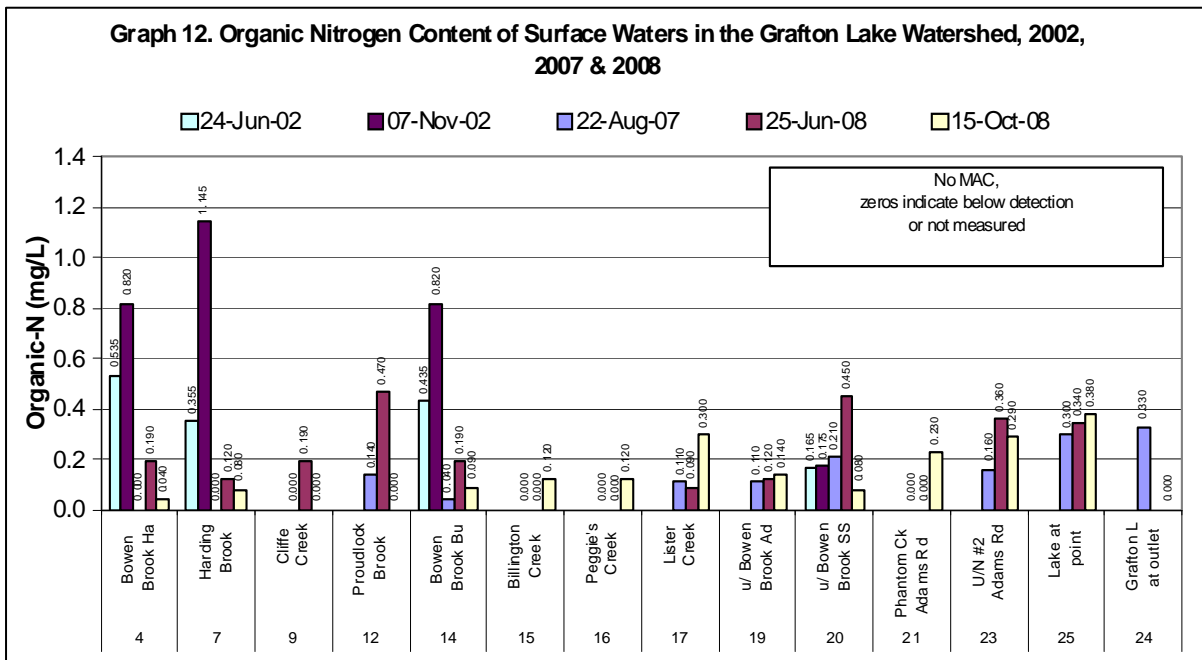
Nitrate-N concentrations (Graph 10) were consistently below 1.0 mg/L, with most sites showing less than 0.05 mg/L and only two sites reporting values above 1.5 mg/L. The maximum values, 2.50 and 1.56 mg/L, were recorded in Lister Creek and unnamed #2 in August 2007. Land uses in the catchments of both these streams are relatively dense residential, which suggests that the elevated NO₃-N concentrations may be due, at least in part, to human activities such as gardening, hobby farming and, possibly, septic fields. We note, however, that none of the readings exceed the MAC for drinking water.



Nitrite-N concentrations (Graph 11) have tended to be less than the laboratory detection limit of 0.01 mg/L. However, higher values were recorded in June 2008 at upper Bowen Brook at Sunset (0.04 mg/L) and in Grafton Lake (0.10 mg/L). While none of the results exceeded the MAC for drinking water, the latter value at Grafton Lake did exceed the MAC for aquatic life.

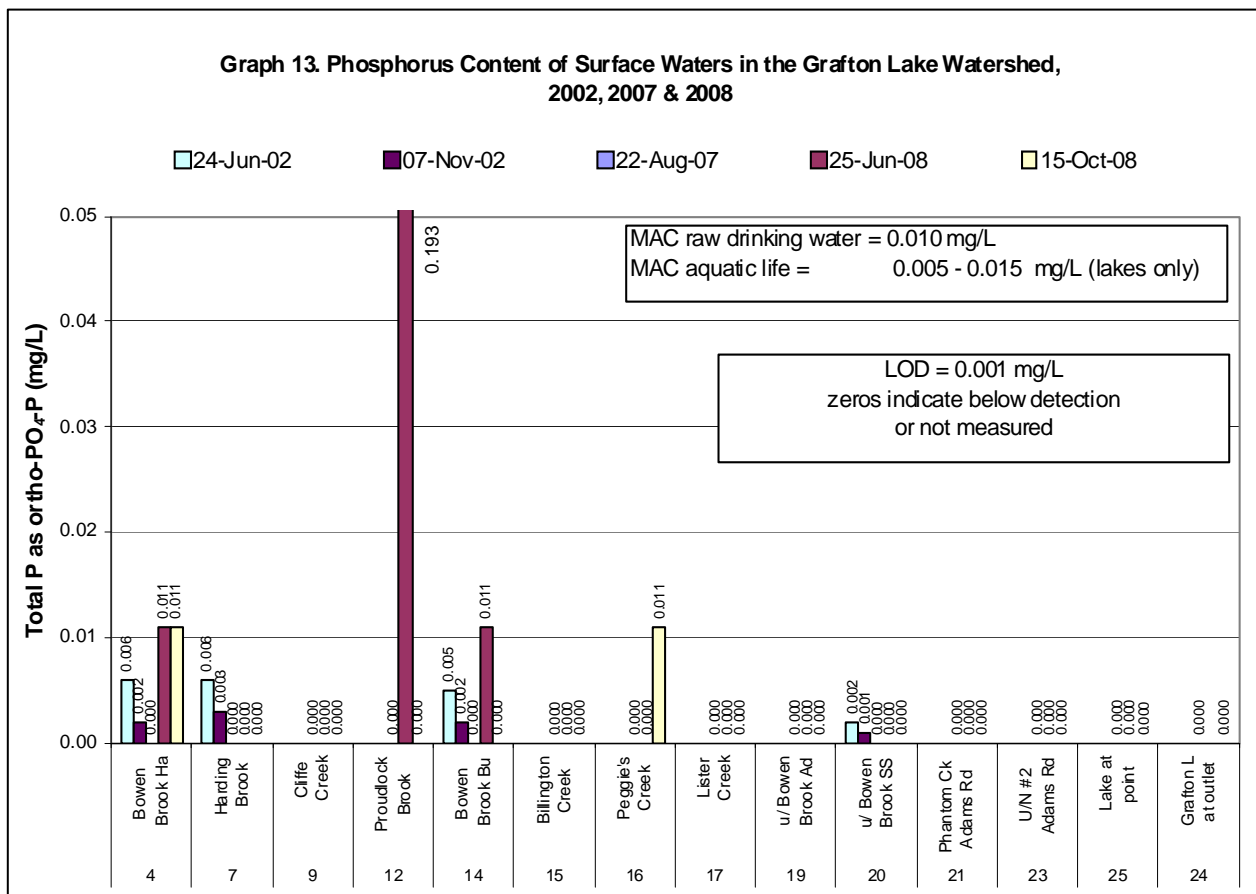


Organic nitrogen (Graph 12) was generally less than 0.4 mg/L at most stations. However, values above 0.8 mg/L were recorded in November 2002 in Bowen Brook at all elevations, and in Harding Brook. Values for Grafton Lake ranged between 0.30 and 0.38 mg/L, higher than in most streams on the same dates.



Phosphorus

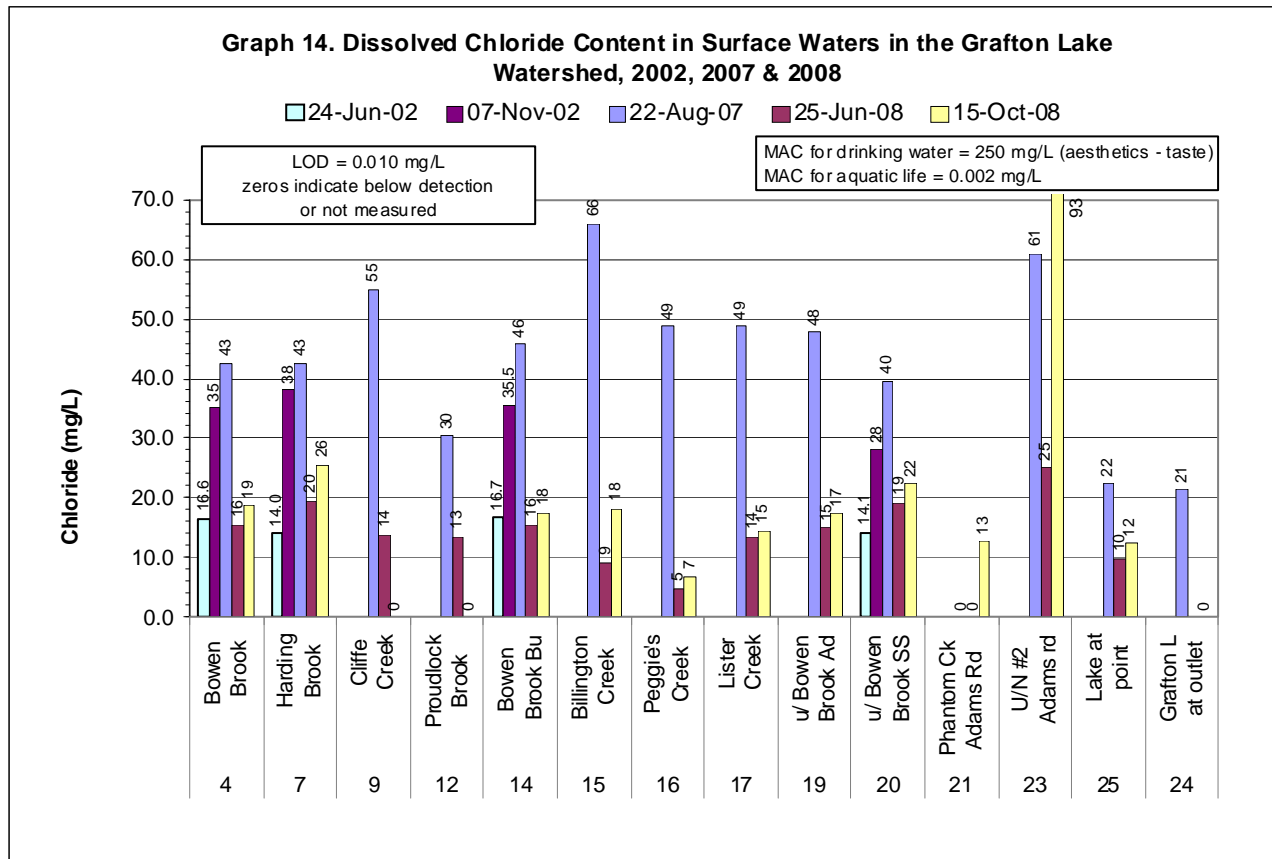
Phosphate-P concentrations (Graph 13) in 2007-2008 were almost entirely below the 0.01 mg/L detection limit used³. Values recorded in 2002, when a detection limit of 0.001 mg/L was employed, ranged between ≤ 0.001 mg/L and 0.006 mg/L. Bowen Brook (at Harding Road, Buchanan Road and Sunset Road) and Harding Brook at Harding Road were the only sites where PO₄ was measured in 2002. The maximum value, an exceptional 0.193 mg/L, was recorded in Proudlock Brook in June 2008. This peak value appears to be related to human activity in this subwatershed, possibly the use of fertilizer (see nitrogen and sulphate). PO₄-P concentrations in 2008 at this site, as well as in Bowen Brook at Harding Road and at Buchanan Road and Peggie’s Creek, slightly exceeded the MAC for drinking water; the MAC for aquatic life was only exceeded in Proudlock Brook in June 2008. The PO₄-P concentrations observed in Grafton Lake suggest that it is not affected by phosphorus enrichment from human sources (i.e., oligotrophic).



³ The higher limit of detection (LOD) used in 2007 – 2008 than in 2002 was due to a change in commercial laboratory, and was problematic because the 0.01 mg/L LOD used by BCAT is higher than the MAC for aquatic life. A detection limit of 0.001 mg/L, as provided in 2002 by ASL Labs, had been requested of BCAT in 2007 and again in 2008; however, the analysis was conducted at the higher LOD.

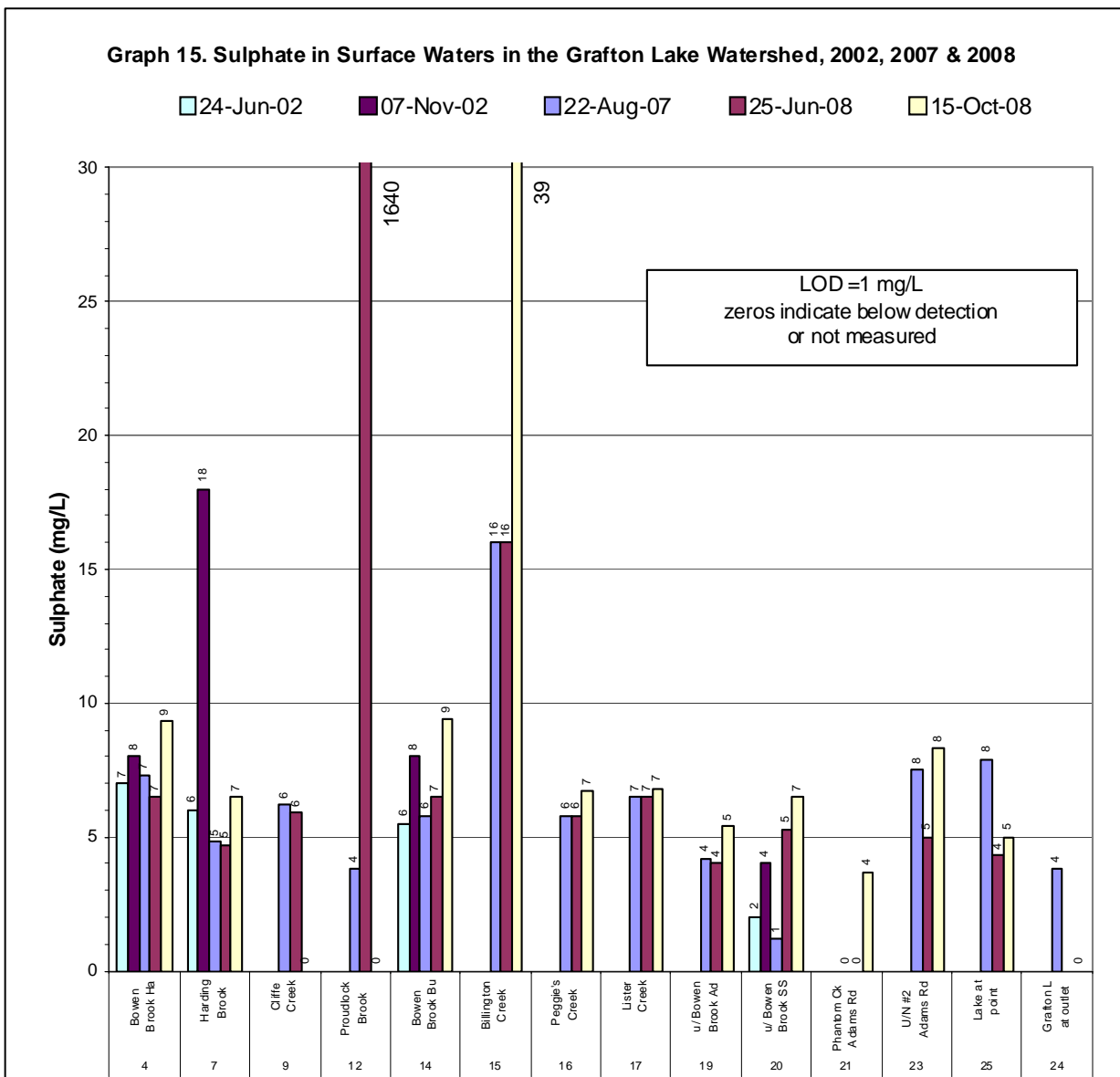
Chloride

Chloride (is examined here to ascertain whether the use of road salt during the winter has a measurable residual effect on water quality. Dissolved chloride concentrations ranged between 5 and 93 mg/L Cl⁻, with most values under 20 mg/L (Graph 14). This range is well below the MAC of 250 mg/L for drinking water, which is based on aesthetics (taste). The highest concentrations within streams were measured in August 2007, during conditions of summer low flow and minimum dilution by runoff. At that time, showed Cl⁻ content in all but one stream was ≥40 mg/L. The lowest concentrations were recorded in June 2008 under conditions of moderate dilution by recent rainfall. The peak value (93 mg/L Cl⁻) was measured in Unnamed #2 at Adams Road in October 2008 under “first flush” conditions, when other streams presented Cl⁻ concentrations of 7 – 26 mg/L. This result, while suggestive of a chloride release of within the catchment, possibly from scouring of road salt-containing sediment in the roadside ditches, does not coincide with a correspondingly high value for sodium (Graph 20). Instead, it is more suggestive of a release of chlorinated water, for example from a swimming pool or another man-made source.



Sulphate

Sulphate concentrations at most sites was consistently below 10 mg/L and well below the 500 mg/L MAC (Graph 15). Above average values were recorded in all of the catchments most affected by human activity: Harding Brook in 2002, Billington Creek in 2007 and 2008 and Proudlock Brook in 2008. The highest value, 1640 mg/L, occurred in Proudlock Creek in June 2008, the same occasion that this stream reported exceptionally high concentrations of phosphorus, and TDS together with very high conductivity and turbidity and very low pH. The second-highest reading, 39 mg/L, occurred in Billington Creek in October 2008; this stream, not sampled in 2002, also showed above average values (16 mg/L) in August 2007 and July 2008. As indicated previously, land uses in the catchment of Billington Creek include a quarry, heavy duty mechanics shop and incineration of woody debris. Harding Brook reported 18 mg/L in November 2002; its catchment includes hobby farms and a lumber yard. The sulphate results indicate that land uses in the catchments of these three streams are having a measurable adverse effect on surface water quality.



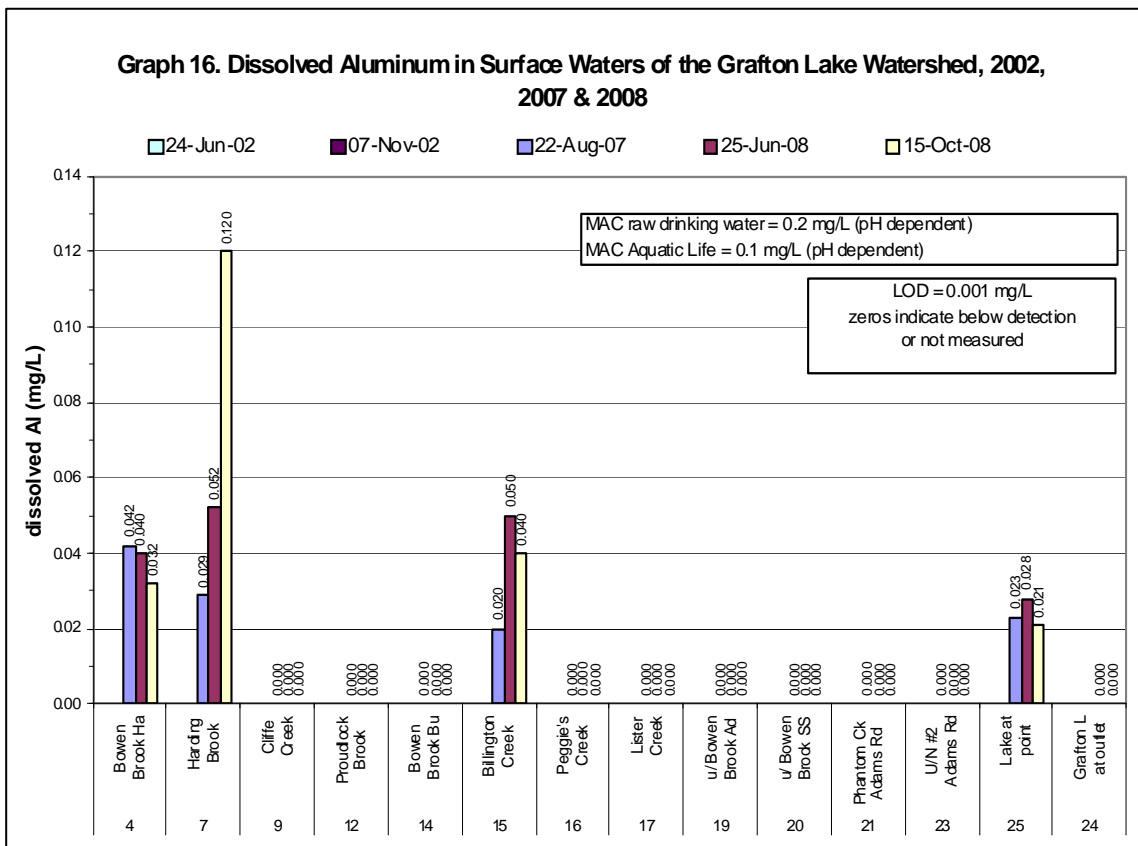
Metals

Total metals were measured in 2002 and in 2007-2008 at selected sites. Measurements in 2002 included total metals only, at four sites, while measurements in 2007-2008 included dissolved and particulate fractions at three sites. The dissolved and particulate fractions as a percentage of total metals at all measured sites for each date during the 2007-2008 monitoring campaign are shown in Graphs A through I, Appendix 3.

The following sections present the results for the more important metals. A number of metals that are automatically measured in the laboratory analysis, which were either undetectable or present at very low concentrations or for which there is no MAC or guideline, are excluded.

Aluminum (Graph 16)

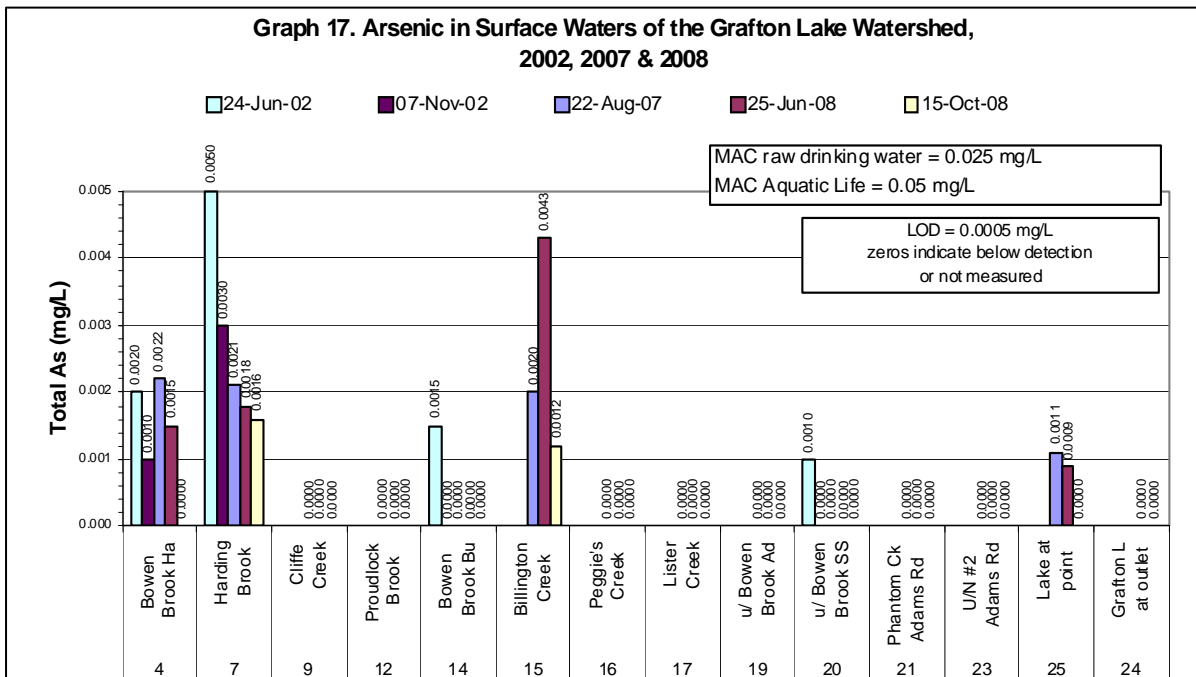
Dissolved aluminum was measured only in 2007-2008 (Graph 14). Most readings ranged between 0.02 and 0.05 mg/L, and all but one site showed values below the MACs for drinking water and aquatic life. Harding Brook, however, reported 0.120 mg/L in October 2008, which exceeds the MAC for aquatic life. On this date, which represented fall first-flush conditions, >79% of total-Al occurred as dissolved form, compared to <25% on the previous two sampling dates which represented low to moderate flow conditions.



Arsenic

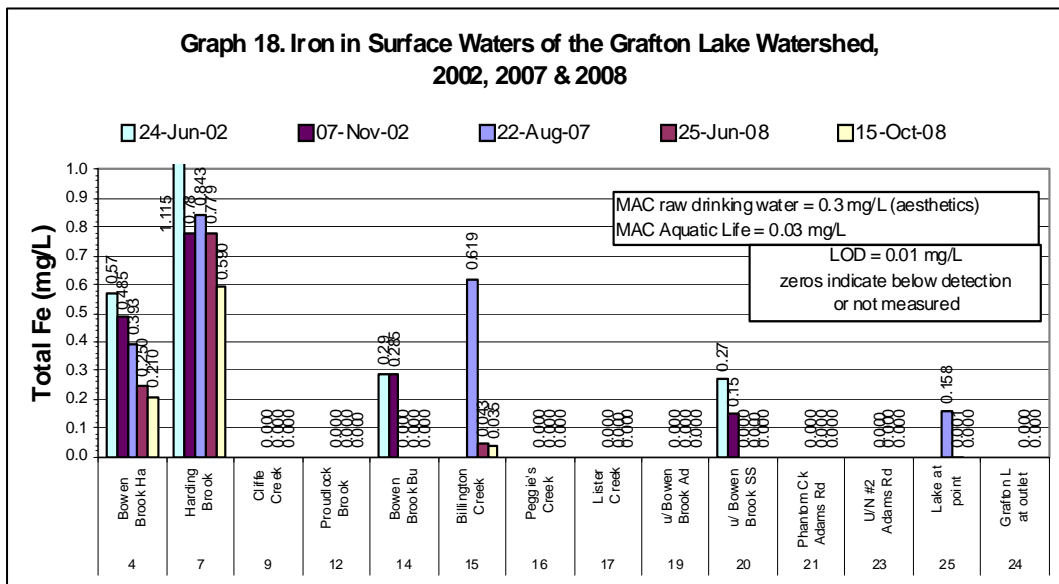
Concentrations of total arsenic (T-As) ranged from below detection to 0.005 mg/L, with most values at or below 0.002 mg/L (Graph 17). All readings were well below the MAC s for drinking water or aquatic life.

The highest concentrations occurred in Harding Brook on all dates except June 25th 2008, when the reading was higher in Billington Creek. This metal was not detectable in detectable in Bowen and Harding Brooks in June 2008 (early summer moderate flow) nor in Bowen Brook in October 2008 (fall first flush). When detectable, over 70% of the As was in dissolved form in all streams. The lumber yard in the Harding Brook catchment has been identified previously as a potential source of arsenic leaching from treated wood; similarly, the quarry and associated uses in the Billington Creek catchment has been identified as a potential source of metals and other contaminants. We note, as well, that the data for Harding Brook show a trend of decreasing arsenic content between June 2002 and October 2008. No trends were evident in the other streams.



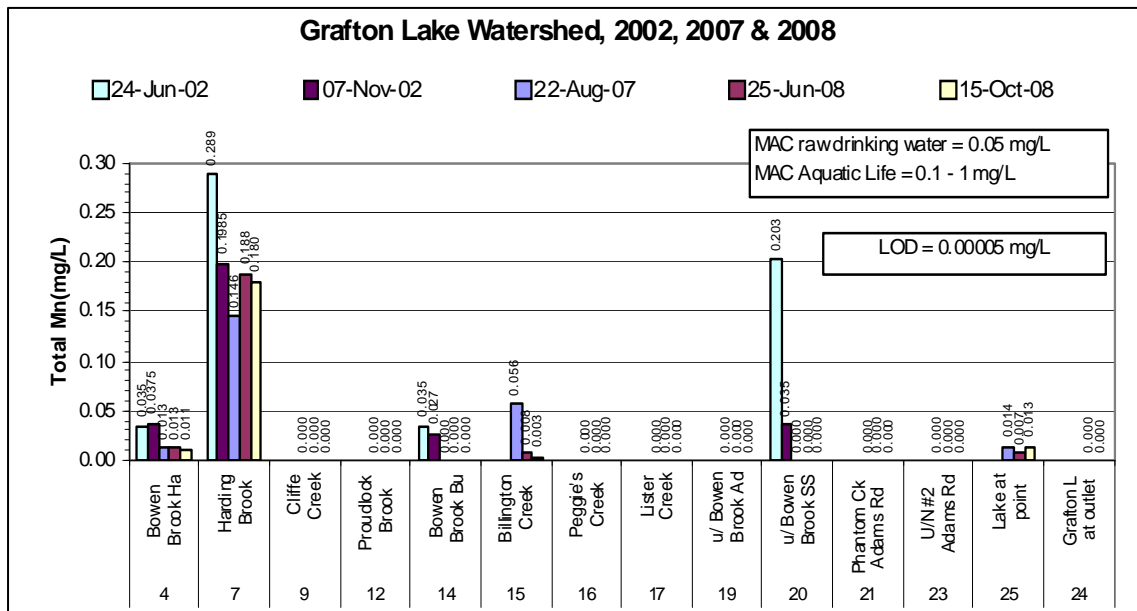
Iron

Iron concentrations ranged between 0.001 – 0.115 mg/L and often exceeded the MACs for drinking water, particularly in Bowen Brook at Harding Road, Harding Brook and (on one occasion) in Billington Creek (Graph 18). The highest values on any date were recorded in Harding Brook and the lowest in Grafton Lake. Overall, there appears to have been a trend of decreasing Total-Fe content over time at all sites measured, although the Fe content in Harding Brook remains high compared to other sites. Most of the Fe present in the waters was in the dissolved form. Since the water quality issue regarding Fe is aesthetics (taste and staining) rather than public health, the values recorded are not considered a concern.



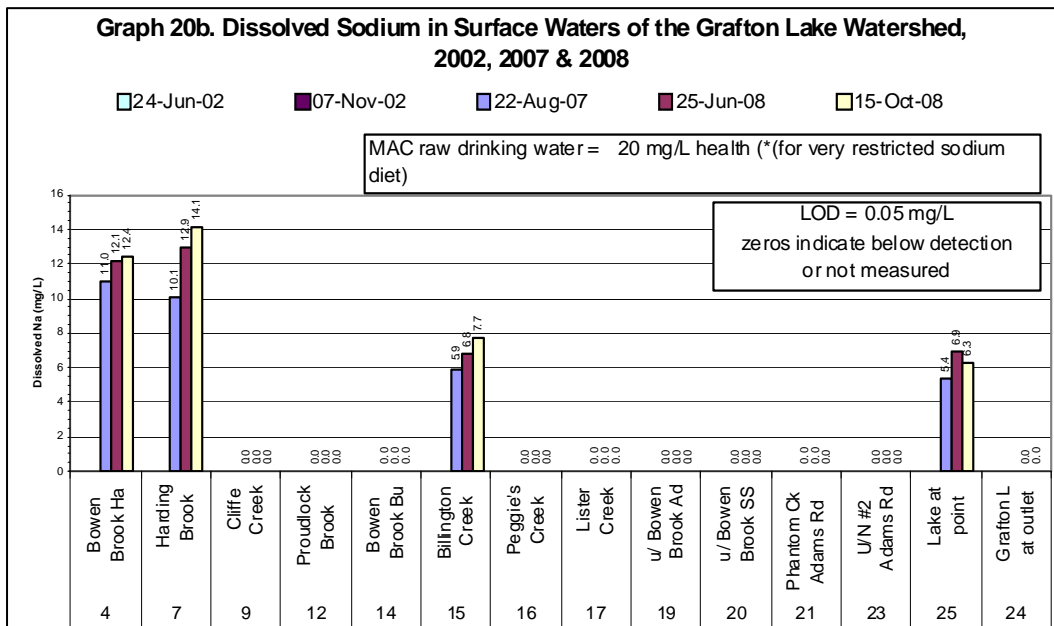
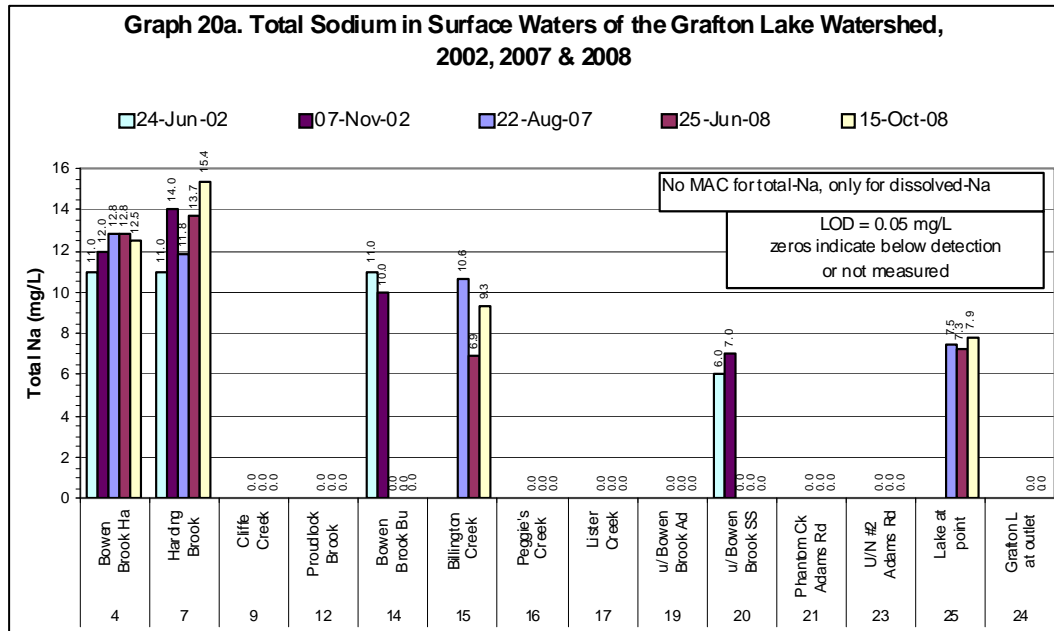
Manganese

Total manganese was usually present in low concentrations in most sites sampled, except in Harding Brook, where the readings were consistently several times higher than at other locations and exceeded the MAC for drinking water and aquatic life (Graph 19). The dissolved fraction always represented > 80% of total-Mn in all streams. The other exceedances of the drinking water MAC were recorded in Bowen Brook at Sunset Drive in June 2002 and, to a much lesser extent, Billington Creek in August 2007. Since the drinking water MAC for Mn is related to staining and taste, rather than public health, these results are not considered a cause for concern.



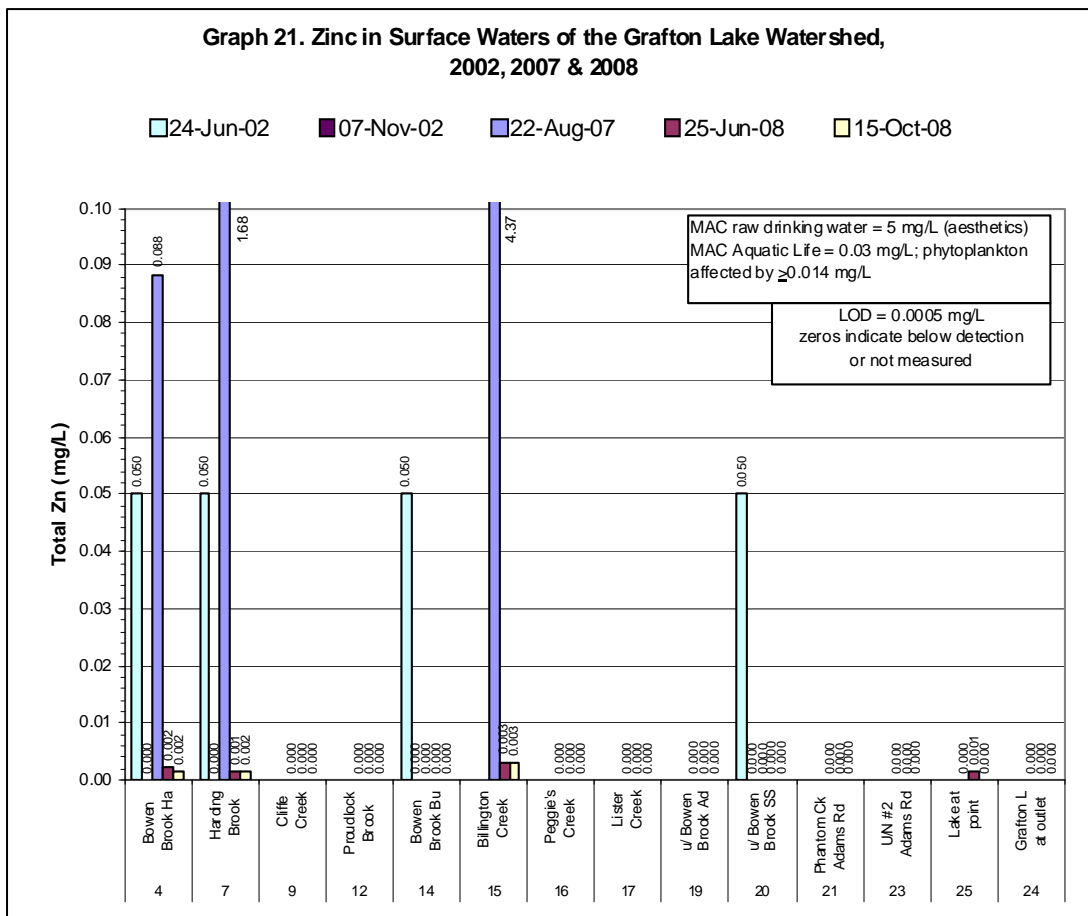
Sodium

Concentrations of total sodium ranged from 6.0 – 15.4 mg/L, with most (56-97%) occurring in dissolved form when present at detectable concentrations (Graphs 20a and 20b). The content of sodium in stream waters tended to increase from the upper to the lower watershed, while Grafton Lake exhibited low values (7.3- 7.9 mg/L). This element was observed because of the extensive use of road salt during winter; however, the low variation between sampling dates and generally low concentrations suggest that sodium content in the Grafton Lake source water does not present a concern.



Zinc

Concentrations of total zinc ranged from undetectable (<0.0005 mg/L) to over 4 mg/L, with most values being less than 0.005 mg/L (Graph 21). Total-Zn content in Grafton Lake was always <0.001 mg/L. Exceptionally high concentrations of Zn were recorded on this date in Billington Creek (4.37 mg/L), lower Bowen Brook (1.68 mg/L) and Harding Brook (0.88 mg/L) on 22 August 2007, all of which exceeded the MACs for aquatic life. Dissolved zinc predominated (>80%) on all dates except during summer low flow conditions in August 2007, when the particulate fraction was >98% in all samples. The reason for the peak Zn values in all streams (and not the lake) on this date coinciding with the predominance of particulate Zn is unknown; however, factors that may have contributed to such an occurrence include precipitation from groundwater discharges into the streams, deposition of Zn-rich dust, and/or other causes. The MAC for drinking water was not exceeded on any occasion.



Synthetic Hydrocarbons

The hydrocarbon compounds tested for at the laboratory included benzene, ethylbenzene, styrene, toluene, meta/para- and ortho- and total xylene, volatile hydrocarbons 6-10 and volatile petroleum hydrocarbons. No detectable concentrations of these substances were found in any of the samples. However, a strong odour of gasoline was detected in Billington Creek on one occasion after a heavy rain storm after the water sampling program had been completed. The source of this hydrocarbon was likely the flushing, by heavy rains, of fuel spilled during crushing of vehicles at the Buchanan Road quarry site in preparation for loading on a truck for transport off-island.

Microbiological Tests

The results of microbiological testing confirmed the presence of fecal coliform bacteria and human fecal matter in Bowen Brook at Harding Road and in Grafton Lake in June 2008, and again in the lake in October 2008 (Table 3-3). Potential presence of human fecal contamination was also detected at an additional eight sites, five in June 2008 and three further sites in October 2008. Harding Brook presented the highest content of fecal coliform on all sampling dates; however, potential presence of human fecal matter was only detected once.

Table 3-3. Presence of Human Fecal Contamination in Surface Waters of the Grafton Lake Watershed, 2007 and 2008.^a

| Site No. | Stream | 22-Aug-07 | | 25-Jun-08 | | 15-Oct-08 | |
|----------|---------------------------------|-----------------|-----------------|------------------|-----|------------------------|----------------|
| | | BST | FC ^b | BST | FC | BST | FC |
| 4 | Bowen Brook at Harding Road | no ^c | 24 | YES ^d | 30 | no | 9 |
| 7 | Harding Brook at Harding Road | no | 72 | no | 420 | potential ^e | 29 |
| 12 | Proudlock Brook at Grafton Road | no | 3 | no | 17 | no | - ^f |
| 14 | Bowen Brook at Buchanan Road | no | 16 | potential | 20 | potential | 17 |
| 15 | Billington Creek at the mouth | no | 7 | potential | 8 | no | <1 |
| 17 | Lister Creek at the mouth | no | 1 | potential | 1 | no | 3 |
| 19 | Bowen Brook at Adams Road | - | - | - | - | potential | 3 |
| 20 | Bowen Brook at Cowan Point Road | no | 1 | potential | - | no | 27 |
| 21 | Phantom Creek at Adams Road | - | - | - | - | potential | 9 |
| 23 | Unnamed #2 at Adams Road | no | 1 | potential | 6 | potential | 3 |
| 25 | Grafton Lake at rocky point | no | 2 | YES ^d | 1 | YES ^g | - |

^a Fecal contamination was determined from the presence of bacterial source tracking (BST) using Bacteroides method.

^b Fecal coliform, colony forming units, CFU/100 mL

^c no markers for human BST present

^d one of two markers for human BST present

^e one of two markers for human BST potentially present

^f a dash - indicates that the site was not sampled on that date

^g both markers for human BST present

The above findings strongly suggest that additional microbiological monitoring is necessary in the watershed in order to confirm and pinpoint the sources of human fecal contamination.

3.3.3 Catchments of Concern

Significant water quality concerns were identified in the following catchments of the Grafton lake watershed:

- Proudlock Brook
- Billington Creek
- Lower Bowen Brook
- Harding Brook
- Grafton Lake

The specific issues associated with each site are summarized by below sampling date.

22 August 2007:

Dissolved-Al in Bowen Brook at Harding Road, Harding Brook and Billington Creek was 0.193, 0.129 and 0.324 mg/L, respectively, compared to pH-dependent MACs of 0.033, 0.047 and 0.066 mg/L, respectively, for Aquatic Life and a MAC of 0.2 mg/L for raw drinking water. While Al is not considered a serious threat to public health, it can be important in areas of low pH due to possible adverse effects on embryonic development in fish and other aquatic life. The wide distribution of this exceedance suggests that high levels of dissolved Al are a natural condition in the watershed; however, the highest values in Billington Creek, which drains a quarry and incineration site, may be indicative of Al enrichment due to human activity.

Total-Cu in lower Bowen Brook, Harding Brook, Billington Creek and Grafton Lake was 0.441, 0.065, 0.354 and 0.041 mg/L, respectively. These values are much higher than the MAC for copper, which is dependent on hardness and, on this occasion, ranged between 0.004 and 0.007 mg/L for these sites. Since copper is acutely toxic to most forms of aquatic life at relatively low concentrations, it is evident that conditions at lower Bowen Brook and Billington Creek in particular, and in Harding Brook and Grafton Lake to a lesser extent, were impaired on this occasion. Exceedances were not noted on the other sampling dates. Copper concentrations other watersheds on the island have been lower or undetectable (WEC et al. 2004). Additional investigation is necessary to ascertain the source(s) of this excess copper and whether this contamination is persistent.

Total-Zn in Billington Creek was 4.37 mg/L and in Harding Creek was 0.168 mg/L, both of which are substantially higher than the MAC of 0.03 mg/L for Aquatic Life. Similarly, Total-Zn in Bowen Brook at Harding Road was 0.088 mg/L, which is slightly higher than this MAC. These exceedances were only observed on this sampling date, which suggests that the higher concentrations may have been due to human activity rather than a natural condition.

25 June 2008:

Proudlock Creek had very acidic water with a pH of 2.9 on this occasion. This is the lowest value recorded anywhere on Bowen Island, to our knowledge, and would have been harmful to human health if used for raw water supply without prior treatment; moreover, it would be very harmful if not lethal to aquatic life. The contamination appears to have been due to a human-made cause, as the low pH coincided with exceptionally high levels of other parameters such as conductivity, colour, TDS, turbidity, sulphate, phosphate and, to a lesser extent, organic nitrogen. It was not possible to determine the cause of the acidification due to the delay between sampling and receipt of the laboratory report. Known land uses in the Proudlock Creek watershed include hobby farms (sheep, crops, other?) and residential. It would be useful to investigate further in this catchment to ascertain whether any of the land uses or activities may pose a risk to water quality.

Bowen Brook at Harding Road and Grafton Lake contained BST markers for human fecal matter on this date. The contamination in the lake is likely to have originated from recreational swimming at the rocky point. The source of contamination in the stream is not known; however, the most likely cause is one or more failing septic fields. Given the presence of potential fecal contamination in a number of tributary streams on this same date, it would seem prudent to conduct additional testing in upper Bowen Brook at Cowan Point Road, Unnamed #2 at Adams Road, Lister Creek, Billington Creek and Bowen Brook at Buchanan Road, in addition to the first two sites.

15 October 2008:

Grafton Lake contained definitive BST markers for human fecal matter on this date. As indicated above, the contamination is likely to result from recreational swimming at the rocky point. Disinfection (chlorination) by the CBWS is intended to ensure the safety of drinking water at the tap with regard to bacterial contamination from human feces. However, chlorination alone may not eliminate other pathogens that may be present. Accordingly, it is considered prudent to conduct additional testing, as indicated above, and to explore means of managing recreational swimming in the lake.

Table 3-1. Water quality parameters measured at the sampling sites in the Grafton Lake Watershed, 2007 – 2008.

| PARAMETER | Sample Identification | | | | | | | | | | | |
|-------------------------------------|-----------------------------|-------------------------------|------------------------------|-----------------------------|---------------------------|-------------------------|---------------------------|----------------------------|-----------------------------|------------------------------|-----------------------------|------------------------|
| | 4 | 7 | 14 | 15 | 16 | 17 | 19 | 20 | 21 | 23 | 24 | 25 |
| | Bowen Brook at Harding Road | Harding Brook at Harding Road | Bowen Brook at Buchanan Road | Billington Creek near mouth | Peggie's Creek near mouth | Lister Creek near mouth | Bowen Brook at Adams Road | Bowen Brook at Sunset Road | Phantom Creek at Adams Road | Unnamed stream at Adams Road | Grafton Lake at rocky point | Grafton Lake at outlet |
| PHYSICAL TESTS | | | | | | | | | | | | |
| Colour (C.U.) | x ⁽¹⁾ | x | x | x | x | x | x | x | x | x | x | x |
| Conductivity (µS/cm) | x | x | x | x | x | x | x | x | x | x | x | x |
| Total Dissolved Solids (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| Hardness (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| pH (S.U.) | x | x | x | x | x | x | x | x | x | x | x | x |
| Total Suspended Solids (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| Turbidity (NTU) | x | x | x | x | x | x | x | x | x | x | x | x |
| DISSOLVED ANIONS | | | | | | | | | | | | |
| Alkalinity CaCO ₃ (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| Chloride (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| Fluoride (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| Sulphate (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| NUTRIENTS | | | | | | | | | | | | |
| Ammonia Nitrogen N (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| Total Kjeldahl Nitrogen (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| Nitrate Nitrogen N (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| Nitrite Nitrogen N (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| Total Nitrogen N (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| Organic Nitrogen ⁽²⁾ | x | x | x | x | x | x | x | x | x | x | x | x |
| Dis Ortho-Phosphate P (mg/L) | x | x | x | x | x | x | x | x | x | x | x | x |
| Total N – arithmetic ⁽²⁾ | x | x | x | x | x | x | x | x | x | x | x | x |
| METALS, TOTAL AND DISSOLVED | | | | | | | | | | | | |
| Aluminum (µg/L) | x | x | | x | | | | | | | | x |
| Antimony (µg/L) | x | x | | x | | | | | | | | x |
| Arsenic (µg/L) | x | x | | x | | | | | | | | x |
| Barium (µg/L) | x | x | | x | | | | | | | | x |
| Boron (µg/L) | x | x | | x | | | | | | | | x |
| Cadmium (µg/L) | x | x | | x | | | | | | | | x |
| Calcium (mg/L) | x | x | | x | | | | | | | | x |
| Chromium (µg/L) | x | x | | x | | | | | | | | x |
| Copper (µg/L) | x | x | | x | | | | | | | | x |
| Iron (µg/L) | x | x | | x | | | | | | | | x |
| Lead (µg/L) | x | x | | x | | | | | | | | x |
| Magnesium (µg/L) | x | x | | x | | | | | | | | x |
| Manganese (µg/L) | x | x | | x | | | | | | | | x |
| Mercury (µg/L) | x | x | | x | | | | | | | | x |
| Phosphorus (µg/L) | x | x | | x | | | | | | | | x |
| Potassium (mg/L) | x | x | | x | | | | | | | | x |
| Selenium (µg/L) | x | x | | x | | | | | | | | x |
| Sodium (µg/L) | x | x | | x | | | | | | | | x |
| Uranium (µg/L) | x | x | | x | | | | | | | | x |
| Zinc (µg/L) | x | x | | x | | | | | | | | x |
| HYDROCARBONS | | | | | | | | | | | | |
| Benzene (µg/L) | x | x | | x | | x | | | | | | |
| Ethylbenzene (µg/L) | x | x | | x | | x | | | | | | |
| Styrene (µg/L) | x | x | | x | | x | | | | | | |
| Toluene (µg/L) | x | x | | x | | x | | | | | | |
| Meta/Para- Xylene (µg/L) | x | x | | x | | x | | | | | | |
| Ortho-Xylene (µg/L) | x | x | | x | | x | | | | | | |
| Total Xylene (µg/L) | x | x | | x | | x | | | | | | |
| Volatile H.C. 6-10 (µg/L) | x | x | | x | | x | | | | | | |
| VPH (µg/L) | x | x | | x | | x | | | | | | |
| BACTERIAL TESTS | | | | | | | | | | | | |
| Fecal Coliform (CFU/100) | x | x | x | x | x | x | x | x | x | x | x | x |
| Bacteroides (+/-) ³ | x | x | x | x | x | x | x | x | x | x | x | x |

1. x indicates parameter was measured; empty cell indicates parameter was not measured at this site.

2. Organic-N calculated as TKN minus ammonia-N; Total-N calculated as the sum of ammonia-n plus nitrate-N plus nitrite-N plus organic-N;

3. presence/absence, of markers for human, ruminant, pig, horse, dog and “general” bacteroides.

Table 3-2. Water quality standards, criteria and guidelines referenced in the Grafton Lake Watershed Project 2007-2008.

| Parameter | Units | Detection Limits | Canadian Guidelines (CCREM 1993) | | B.C. Criteria (WLAP 2001) | |
|---------------------------------------|-------|------------------|----------------------------------|-----------------------|---------------------------|------------------------|
| | | | Drinking W. MAC* | Aquat. Life MAC | Drinking W. MAC | Aquat. Life MAC/Avg. |
| Physical Tests | | | | | | |
| Colour | CU | 5 | 15 | - | 15 | - |
| Conductivity | uS/cm | 2 | - | - | - | - |
| Hardness as CaCO ₃ | mg/L | 0.7 | - | - | 500 | - |
| Total Suspended Solids (TSS) | mg/L | 3 | - | +10 ⁽²⁾ | - | +10 |
| Turbidity | NTU | 0.1 | 5 | - | 1 ⁽⁶⁾ | 5 ⁽⁶⁾ |
| pH ⁽²⁾ | | | 6.5 - 8.5 | 6.5-9.0 | 6.5 - 8.5 | 6.5 - 9.0 |
| Dissolved Anions | | | | | | |
| Alkalinity-Total as CaCO ₃ | mg/L | 1 | - | - | - | - |
| Chloride Cl | mg/L | 0.5 | 250 | 0.002 ⁽³⁾ | 250 | 0.6/0.2 |
| Fluoride F | mg/L | 0.02 | 1.5 | - | 1.5 | 0.2 |
| Sulphate SO ₄ | mg/L | 1 | 500 | - | 500 | 100 |
| Nutrients | | | | | | |
| Total Kjeldahl Nitrogen N | mg/L | 0.05 | - | - | - | - |
| Nitrate Nitrogen N | mg/L | 0.005 | 10 | - | 10 | 200/≤40 * |
| Nitrite Nitrogen N | mg/L | 0.001 | 1 | 0.06 | 1 | /0.2 |
| Dissolved ortho-Phosphate P | mg/L | 0.001 | - | - | - | 0.01 ⁽⁷⁾ |
| Bacteriological Tests | | | | | | |
| Coliform Bacteria - Fecal | CFU | 1 | <1 | - | 0 | - |
| Coliform Bacteria - Total | CFU | 1 | <1 | - | - | - |
| Total Metals | | | | | | |
| Aluminum T-Al | mg/L | 0.005 | - | 0.005 ⁽⁴⁾ | 0.2 ⁽⁸⁾ | 0.036/0.013 |
| Antimony T-Sb | mg/L | 0.0005 | - | - | 0.006 | 0.05 |
| Arsenic T-As | mg/L | 0.0005 | 0.025 | 0.05 | 0.025 | 0.05 |
| Barium T-Ba | mg/L | 0.02 | 1 | - | 5 | 5/1 |
| Beryllium T-Be | mg/L | 0.001 | - | - | - | 0.053 |
| Boron T-B | mg/L | 0.1 | 5 | - | 5 | - |
| Cadmium T-Cd | mg/L | 0.00005 | 0.005 | 0.0002 ⁽⁴⁾ | 0.005 | 0.002 |
| Calcium T-Ca | mg/L | 0.1 | - | - | - | - |
| Chromium T-Cr | mg/L | 0.001 | 0.05 | 0.02 ⁽⁵⁾ | 0.05 | 0.02 ⁽⁷⁾ |
| Cobalt T-Co | mg/L | 0.0003 | - | - | - | 0.05 |
| Copper T-Cu | mg/L | 0.001 | 1 | 0.002 ⁽⁴⁾ | 0.5 | ⁽⁹⁾ /≤0.002 |
| Iron T-Fe | mg/L | 0.03 | 0.3 | 0.3 | 0.3 | 0.3 |
| Lead T-Pb | mg/L | 0.0005 | 0.01 | 0.001 ⁽⁴⁾ | 0.01 | 10/4 |
| Lithium T-Li | mg/L | 0.005 | - | - | - | - |
| Magnesium T-Mg | mg/L | 0.1 | - | - | 100 | - |
| Manganese T-Mn | mg/L | 0.0003 | 0.05 | - | 0.05 | 0.1 - 1.0 |
| Mercury T-Hg | mg/L | 0.00005 | 0.001 | 0.0001 | 0.001 | 0.001/0.002 |
| Molybdenum T-Mo | mg/L | 0.001 | - | - | 0.25 | 2/<1 * |
| Nickel T-Ni | mg/L | 0.001 | - | 0.025 | 0.2 | 0.025 |
| Phosphorus T-P | mg/L | 0.3 | - | - | - | - |
| Potassium T-K | mg/L | 2 | - | - | - | - |
| Selenium T-Se | mg/L | 0.001 | 0.01 | 0.01 | 0.01 | 0.001 |
| Silver T-Ag | mg/L | 0.00002 | 0.05 | 0 | - | 0.001 |
| Sodium T-Na | mg/L | 2 | - | - | 200 | - |
| Thallium T-Tl | mg/L | 0.0002 | - | - | 0.013 | <0.02 |
| Tin T-Sn | mg/L | 0.0005 | - | - | - | - |
| Titanium T-Ti | mg/L | 0.01 | - | - | 0.1 | 0.1 |
| Uranium T-U | mg/L | 0.0002 | 0.02 | - | 0.1 | 0.3 |
| Vanadium T-V | mg/L | 0.03 | - | - | 0.1 | - |
| Zinc T-Zn | mg/L | 0.005 | 5 | 0.03 | 5 | 0.03 |

* MAC =maximum allowable concentration; < indicates "less than", ≤ indicates "less than or equal to", a dash "-" indicates "none established"

- (1) BOD = biochemical oxygen demand
- (2) maximum allowable increase when background TSS < 100 mg/L
- (3) CCEM guideline is based on Total Residual Chlorine
- (4) Value is dependent on pH, hardness or alkalinity (see references)
- (5) to protect fish; 0.002 mg/L to protect other aquatic life incl. phyto- and zooplankton
- (6) induced turbidity where background <5 NTU (Nephelometric turbidity units)
- (7) value applies to lakes only (no criteria have been developed for streams)
- (8) provincial criteria for Al for drinking water and aquatic life are based on dissolved fraction rather than total
- (9) MAC depends on hardness according to the formula: (0.094*hardness)+2. Corresponding MAC for creeks are: 26.4, 21.7 and 17.8 mgCu/L, respectively.

4. HYDROLOGY

4.1 Overview

This section provides the results to date of the stream flow monitoring (hydrometric) work that was initiated as part of the present study. The 2002-2003 Grafton Lake Watershed Study (WEC 2003) had offered the following recommendations regarding water quantity monitoring:

1. Develop a hydrological monitoring program for the Grafton Lake watershed. At the very least, this program should include measurement of stream flows at or near each of the water quality stations, and on each sampling occasion.
2. The Bowen Island Municipality should consider the installation of a series of permanent, automated hydrometric stations at key locations within the watershed. As a minimum, one station should be installed near the mouth of Bowen Brook and another at the outlet of Grafton Lake.
3. The Bowen Island Municipality should consider the installation of a municipal weather station (recording rain gauge and air temperature thermometer) at a secure location within the Grafton Valley.

It was not possible to implement all of these recommendations, due to budgetary and other constraints. However, the following activities were completed jointly by WEC and staff from the Municipality's Public Works Department:

- Installation of an automated water level recording system (hydrometric station) on Bowen Brook at Harding Road; and
- Planning for the installation of a municipal weather station (recording rain gauge and air temperature thermometer) near the hydrometric station.

Details are provided below.

4.2 Hydrology Methods

4.2.1 Stream flow

An automated stream flow monitoring (hydrometric) station was established on Bowen Brook immediately upstream of Harding Road. The apparatus consists of a pressure sensor (transducer) which is connected to a data logger and radio communications device (Photo 4-1). The system was designed and installed for the Municipality by the engineering firm Kerr Wood Leidal Ltd., who own and operate the Emerald Flow Works system (<http://www.flowworks.com/>), a “suite of online data collection, monitoring, analysis, and reporting tools”.

The system takes a pressure reading once every five minutes. This pressure reading is converted into a water level (stage) reading and stored in the data logger. The data stored

in the logger is the transmitted by cellular telephone to the centralized Emerald database several times per day. The Emerald website can be accessed online and the data can then be downloaded and/or manipulated using built-in tabulation and graphing software.

The intent is for the stage readings (recorded in centimeters [cm]) to be converted to actual stream discharge measurements (recorded in liters per second [L/s] or cubic meters per day [m³/d]). Measurement of stream flows and water levels under a variety of flow conditions is required in order to develop a “stage-discharge curve” that can be used to convert the stage measurements into discharge measurements. Municipal staff are currently in the process of developing the necessary stage-discharge curve, as time and resources allow.



Photo 4-1. Automated hydrometric station on Bowen Brook viewed from Harding Road. A limited number of stage and stream flow measurements have been completed to date for the Municipal hydrometric station; however, these are insufficient to allow accurate estimation of stream flows from the water level readings. Accordingly, the analysis provided in this report is based on stage values rather than discharge.

Stage and discharge data collected through the Volunteer Streamflow Monitoring Project (VSMP) in 2004-2006 (Whitehead, unpublished data) has been used, as much as possible, to complement the Emerald data.

4.2.2 Precipitation and temperature

The automated weather station (rain gauge and thermometer) has not been installed to date due to lack of municipal resources. The system will also be designed and deployed by KWL and integrated to the Emerald system, and will be connected to the same data logger and communications system as the Bowen Brook hydrometric station.

The Municipality has selected a site for this weather station on Harding Road approximately 50 m east of the Bowen Brook crossing. The site is located between the road and an open pasture, where accurate rainfall measurements can be made without interference by tree cover. The intent is that the combination of precipitation, temperature and stream flow data can be used to monitor water supplies and manage the watershed with respect to fire hazard, flood hazard and other issues.

4.3 Hydrology Results

4.3.1 Stream Stage (water level)

The stage data for Bowen Brook collected in the Emerald system during 2008 and 2009 is presented in Graphs 4-1 and 4-2. The statistics for each quarter year are presented in Table 4-1.

Table 4-1. Quarterly and Yearly Stage Statistics for Bowen Brook, 2008 and 2009.

| Period | Min | Max | Avg | Median | Mode | Range |
|------------------|-------|-------|-------|--------|-------|-------|
| | (m) | (m) | (m) | (m) | (m) | (m) |
| 2008 Jan-Mar | 0.354 | 0.627 | 0.404 | 0.392 | 0.364 | 0.273 |
| 2008 Apr-Jun | 0.303 | 0.435 | 0.342 | 0.339 | 0.323 | 0.132 |
| 2008 Jul-Sep | 0.297 | 0.405 | 0.312 | 0.309 | 0.310 | 0.108 |
| 2008 Oct-Dec | 0.308 | 0.588 | 0.384 | 0.375 | 0.336 | 0.279 |
| 2008 YEAR | 0.297 | 0.627 | 0.361 | 0.354 | 0.333 | 0.330 |
| 2009 Jan-Mar | 0.369 | 0.865 | 0.423 | 0.408 | 0.385 | 0.496 |
| 2009 Apr-Jun | 0.300 | 0.488 | 0.349 | 0.347 | 0.306 | 0.188 |
| 2009 Jul-Sep | 0.241 | 0.467 | 0.309 | 0.305 | 0.303 | 0.137 |
| 2009 Oct-Dec | 0.303 | 0.842 | 0.410 | 0.408 | 0.405 | 0.539 |
| 2009 YEAR | 0.241 | 0.865 | 0.373 | 0.367 | 0.350 | 0.624 |

Notes: Stage = water depth at the automated hydrometric station; Min = minimum value; Max = maximum value; Avg = average value; Median = the middle value in the range; Mode = the most common reading; Range = maximum minus minimum.

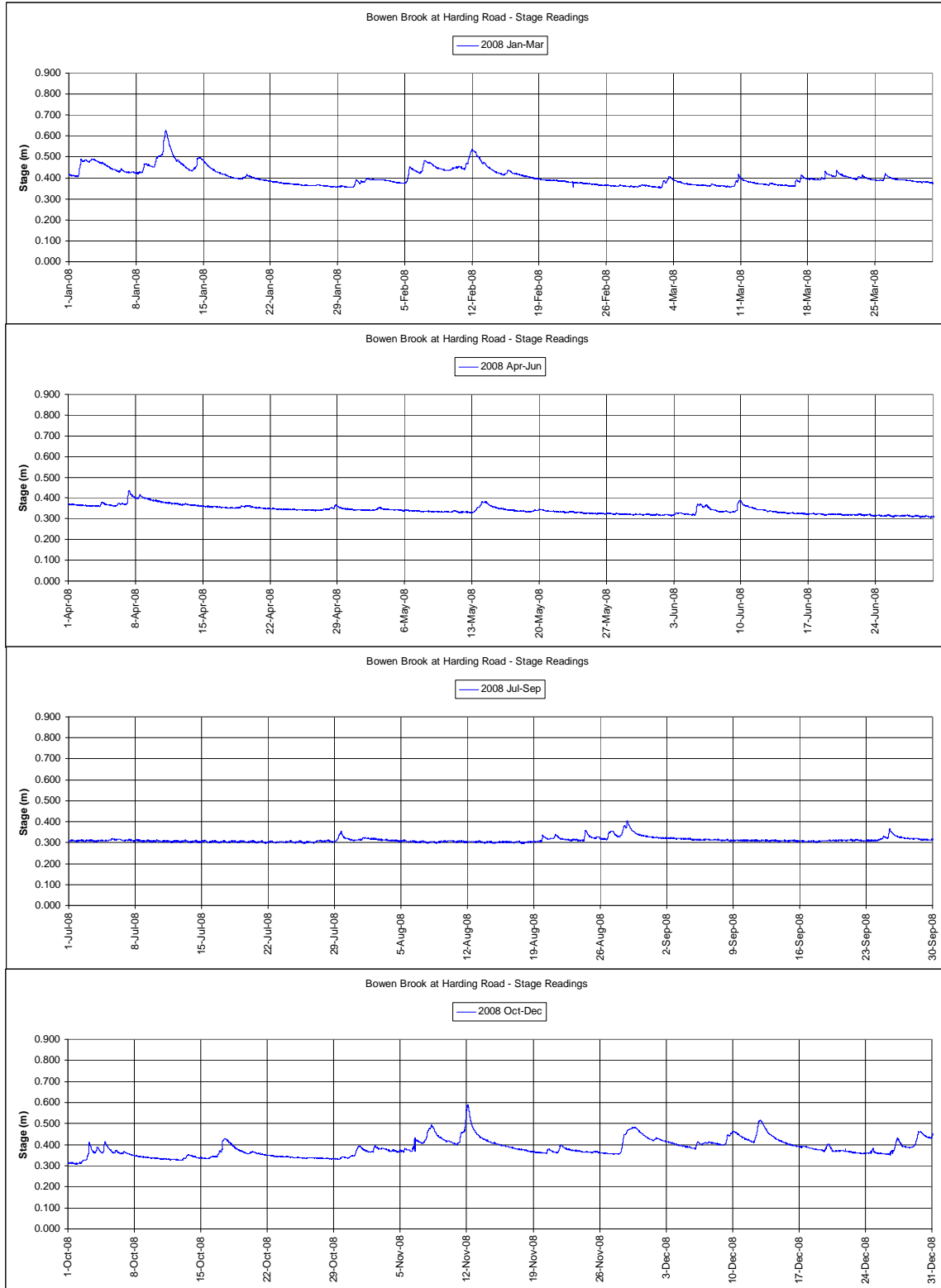
The stream’s stage ranged between 0.241 m and 0.865 m over 2008 and 2009, with the difference between highest and lowest water levels in 2009 being almost twice that in 2008. Seasonal patterns were as expected, with peaks water levels associated with rainfall events. The lowest levels (and, therefore, lowest flows) occurred during the warmest period of the dry season, typically in July and August. At this time of year, there is no runoff from rainfall and the stream is fed entirely by groundwater discharges into the stream bed. The highest water levels tended to occur in late fall and winter (November – February), during periods of heavy rainfall.

The stream’s response to rainfall was also very noticeable, particularly during intense precipitation events. For example, a thunderstorm on 13 August 2009 which delivered 19.8 mm of rain within 2 hours⁴ resulted in a rapid increase in stage (~0.15 m) within the same period (Graph 4-3). The stream did not return to the pre-storm stage until more than

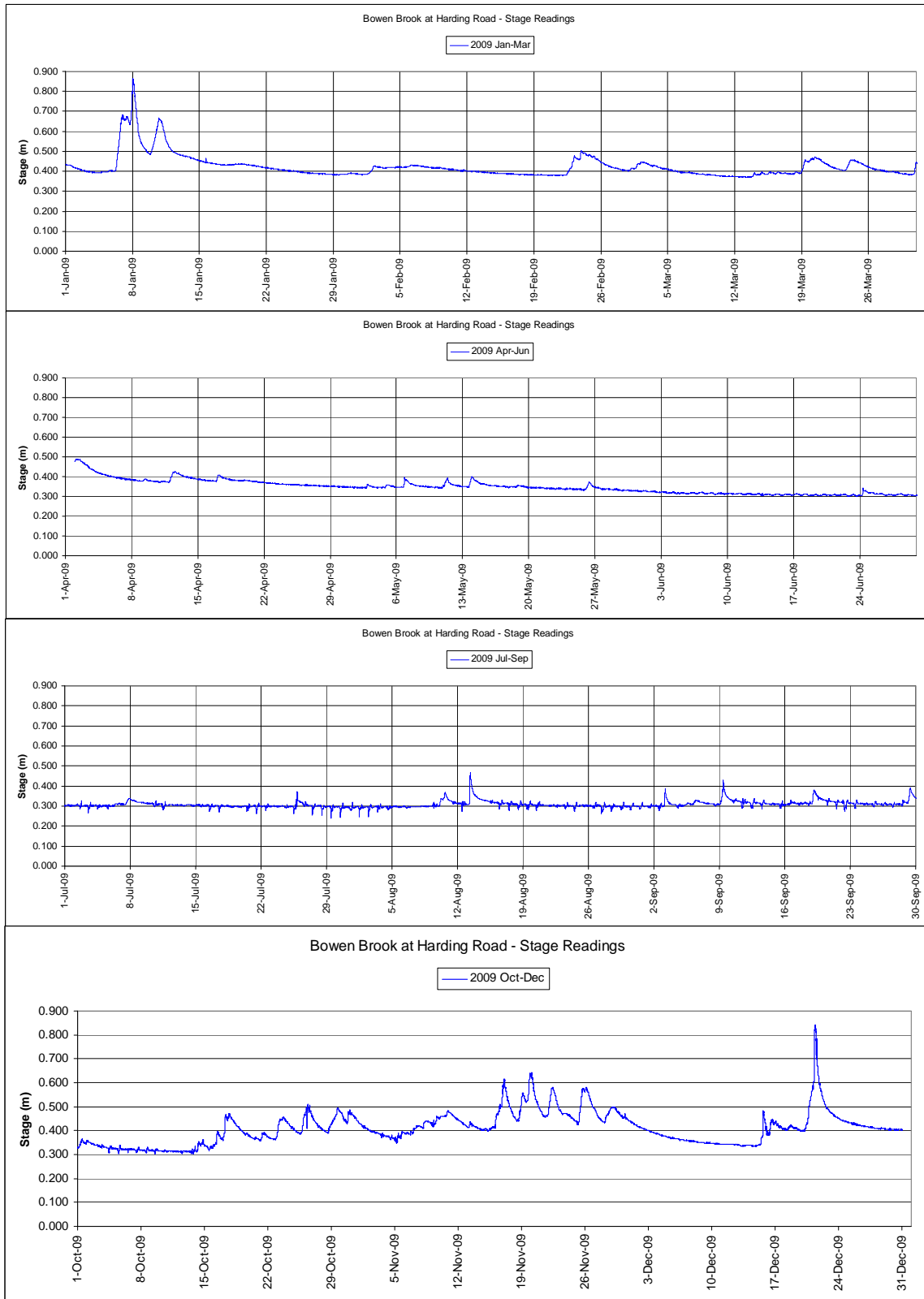
⁴ This rainfall intensity is significantly above average.

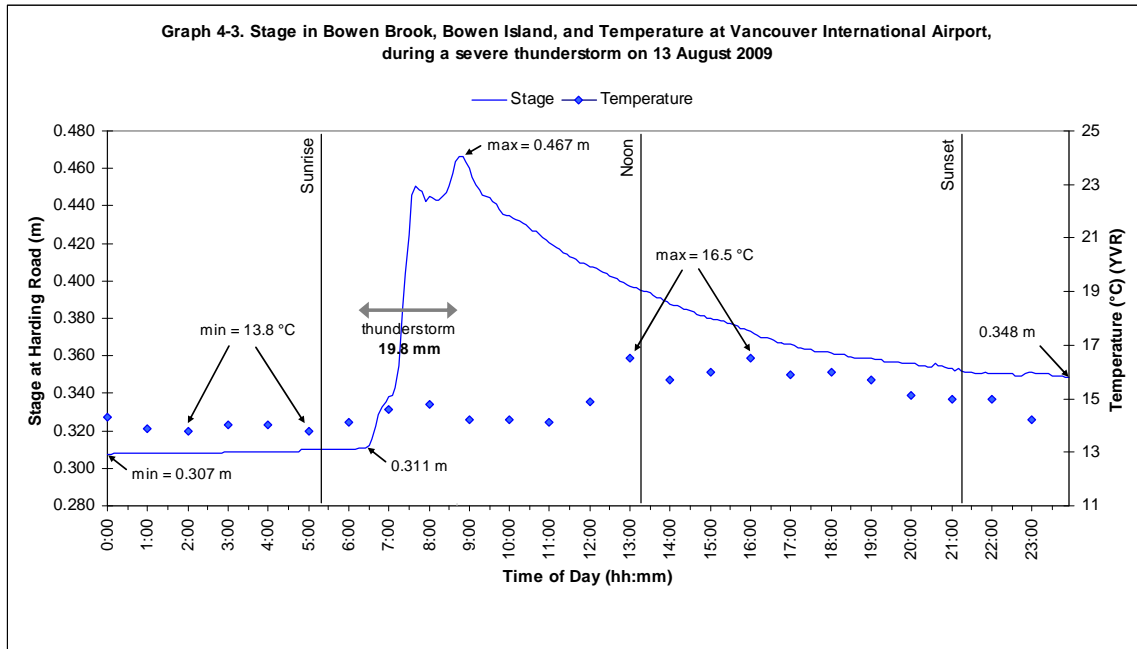
48 hours had passed. These results demonstrate the important role that vegetation plays in slowing down the rate of runoff within the watershed.

Graph 4-1. Water level (stage) in Bowen Brook at Harding Road during 2008.



Graph 4-2. Water level (stage) in Bowen Brook at Harding Road during 2009.

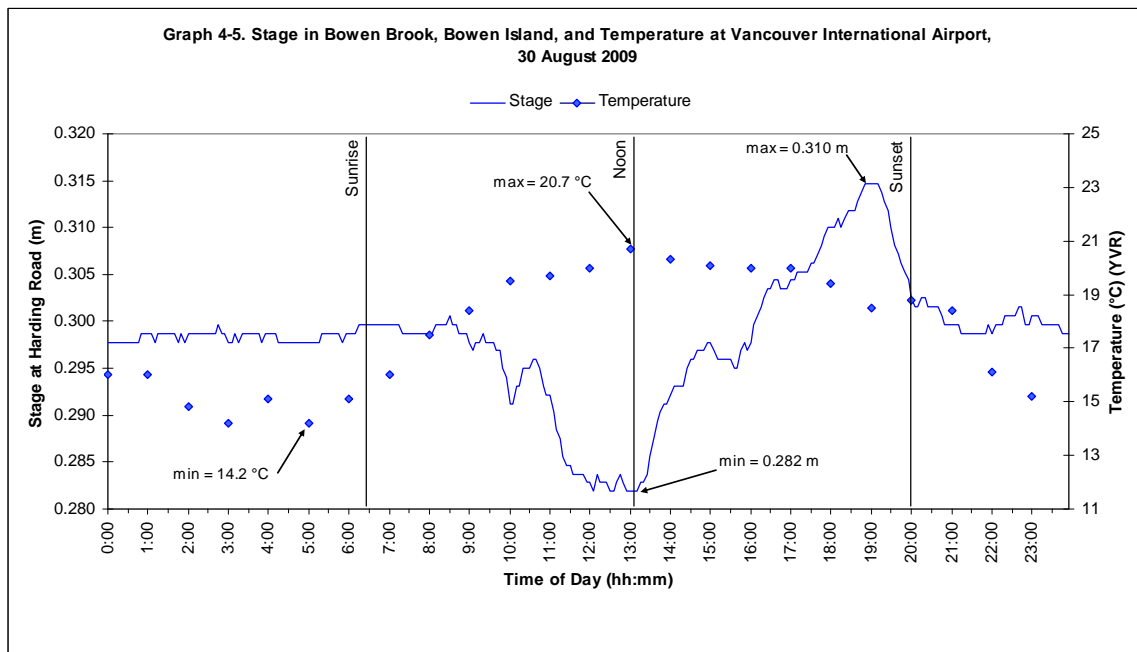
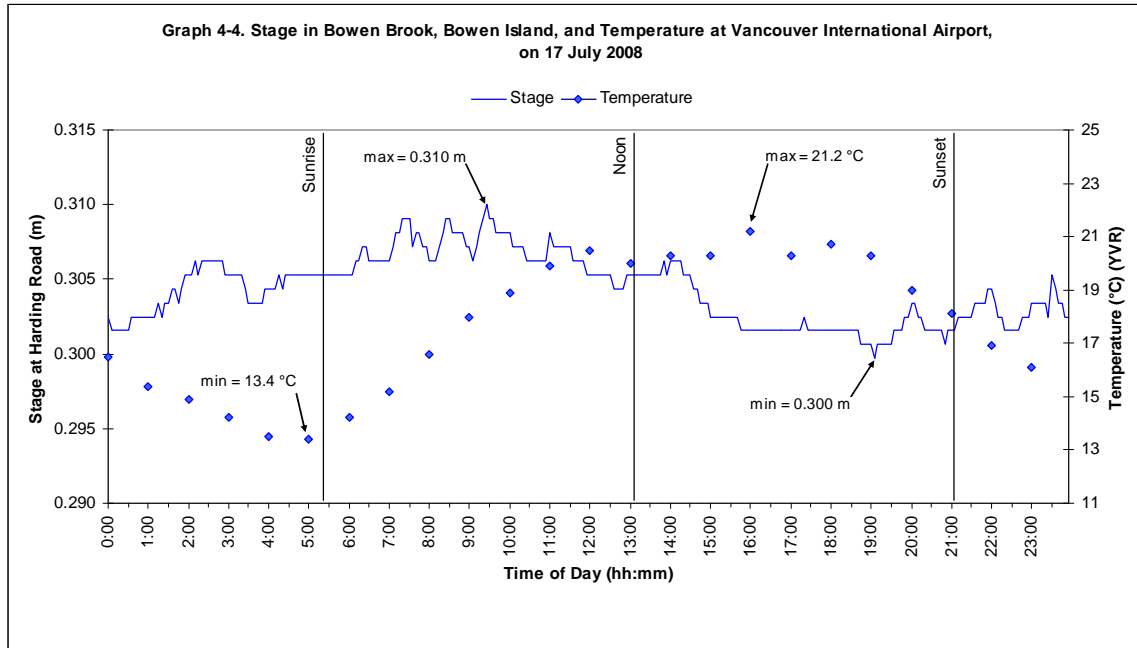




Water losses through evaporation and evapotranspiration (ET) from vegetation in the summer were high enough to be detectable on a daily basis (for example, see Graph 4-1 July – September and Graph 4-2 June – August).⁵ The normal change in water level between the coolest and warmest time of day (i.e., before sunrise vs. mid- afternoon) reached ~10 cm in July and August as water inputs to the stream decreased due to daytime ET (Graphs 4-4 and 4-5). The change in water level was most pronounced during the warmest period of the day, when the rate of ET would have been highest.

These ET results demonstrate the measurable “pulse” of the ecosystem during the water-stressed time of year.

⁵ Hourly temperatures for Vancouver International Airport, available online through Environment Canada, were used.



4.3.2 Stream Discharge (flow)

Stream discharge data for Bowen Brook at Harding Road was collected by the VSMN between February 2003 and August 2005 (WEC 2005). During that period, flows ranged between less than 10 L/s in summer and over 300 L/s in winter. The minimum and maximum recorded values were 1 L/s in August 2004 and 1200 L/s in December 2004. The yearly average based on that preliminary data is approximately 132 L/s.

A preliminary stage-discharge curve was developed from the above VSMP data and additional and additional measurements collected in 2006. The relationship between the water depths in the culverts under Harding Road is shown in Graphs 4-5, 4-6 and 4-7, which also show the correlation coefficient (R^2 value). As can be seen in the graphs, the highest correlation between stage and discharge ($R^2 = 0.9583$) was obtained by using the sum of the water depths in all three culverts. Accordingly, even though the water level in the north culvert has been found to be too low for manual flow measurement on occasion during periods of low flow, it was concluded that the stage-discharge relationship based on the sum of water depths in all three culverts would be preferable. The corresponding stage-discharge formula is:

$$y = 1.3555x^{0.6316} \quad (R^2 = 0.9583)$$

where y = the sum of water depths in all three culverts (in cm); and
 x = the discharge or flow in Bowen Brook at Harding Road (in L/s)

It is suggested that the above relationship can be used in the development of the new stage-discharge curve for the automated hydrometric station.

Municipal personnel, assisted by a VSMP volunteer, have already begun to collect flow data concurrently with stage (water depth) measurements at the culverts and at the hydrometric station's staff gauge. Once stage data from the automated station's staff gauge are available for a sufficient range of flows, it will be possible to combine the two data sets (VSMP and Emerald) and develop a reasonably accurate stage-discharge curve for the automated station which will, in turn, allow for the conversion of water level readings to discharge values. This conversion can likely be incorporated into the Emerald system and automated in order to allow online readings of stream flow in real time.

4.3.3 Watershed Yield

The boundary of the Grafton Lake watershed was delineated using the updated 1-m contour LiDar topographic mapping available from the BIM GIS. This mapping significantly increased the accuracy of the watershed boundary, facilitating a more accurate measurement of the watershed's surface area.

Based on an updated watershed surface area of 644 hectares (1591 acres, measured from the BIM GIS), the average annual water yield of the Grafton Lake watershed is estimated to be 17.7 cubic meters per day per hectare ($m^3/day/ha$) or 1574 Imperial gallons per acre per day (Igp/ac).

5. GRAFTON LAKE ECOSYSTEM

5.1 Overview

The 1997 Long Range Plan (LRP) for the CBWS recommended that water levels in Grafton Lake should be managed in a manner that would mimic natural seasonal water level cycles and thus preserve the lake's natural ecological functions and aesthetic values (Dayton & Knight Ltd. and A.J.Whitehead & Associates, 1998). The LRP also recommended that an ecological assessment of the lake's wetlands should be conducted every three years. These recommendations were reiterated in the 2002-2003 study (WEC 2003), which was subsequently endorsed by the Bowen Island Municipal Council.

Accordingly, the work plan for 2007 – 2009 included an investigation of the lake ecosystem to assess the effects of its use as a reservoir on its role as habitat for waterfowl and other wildlife. The reader is also directed to Section 5 of the 1997 LRP report for additional discussion of the lake ecosystem, including fish, which is not repeated here.

5.2 Methods

Three aspects of the lake were investigated: waterfowl and other wildlife, water level variation, and water temperature variation. The methods for each are described below.

5.2.1 Waterfowl and wildlife

Wetland habitat around the lake was mapped in detail using aerial photography and GIS. Then, wildlife use of the lake ecosystem was documented through a series of field investigations, focusing on the waterfowl nesting. Observations were made on the following dates:

- 5 May 2007
- 8 May 2007
- 11 May 2007
- 25 June 2008
- 18 July 2008
- 14 Aug 2008
- 11 Feb 2009
- 23 May 2009

During each occasion, a sector of the lake perimeter was visited, either on foot or from a canoe, to record the presence of any wildlife (direct sightings and other sign such as calls, nests, browse, scat, etc.). The locations of important sightings were recorded with a GPS and mapped. Christmas Bird Count records held by the Bowen Nature Club were also consulted for species sightings.

5.2.2 Lake Water Level

The water level of the lake was recorded on every visit and incidentally on a number of occasions, using the staff gauge at the outlet dam. This gauge is calibrated in meters above sea level. A graph of the variation in water level over time was created from the data collected during this project and by municipal staff, and this information was correlated with wildlife observations. A map showing the changes in the lake perimeter (high and low water levels) was also prepared.

5.2.3 Lake Water Temperature

Lake water temperature data available from the B.C. Ministry of Environment (MoE), Water Stewardship Division's monitoring program was compiled and graphed. In addition, an attempt was made to measure and record the changes in water temperature with depth over time. An array of recording thermometers was installed at 1 m depth intervals in the centre of the lake, configured to record water temperature once every hour (Figure 5-1). The system was deployed on July 18th 2008 with the intent of accessing the array once every three months to download the data over a 12 month period.

5.3 Results

5.3.1 Wildlife

Waterfowl nesting sites and other wildlife recorded during the study are shown in Map 5-1. Wildlife species observed at the lake, either on the water or in the lake's perimeter wetlands, are listed in Table 5-1.

The most commonly observed waterfowl species were Canada Goose, followed by Ring-necked Duck and Mallard. Two waterfowl species, Ring-necked Duck and Pied-billed Grebe, are considered particularly sensitive to abnormal changes in water level because they build floating nests out of wetland vegetation. However, the nests of Mallard and Canada Goose are also susceptible when they are located within the lake's wetland fringe.

The Red-legged Frog, which reproduces in the marshes surrounding the lake, is considered a species at risk according to the B.C. Government's Conservation Data Centre (CDC 2010). It has been placed on the Blue List, which classified species that are vulnerable due to degradation and loss of habitat.

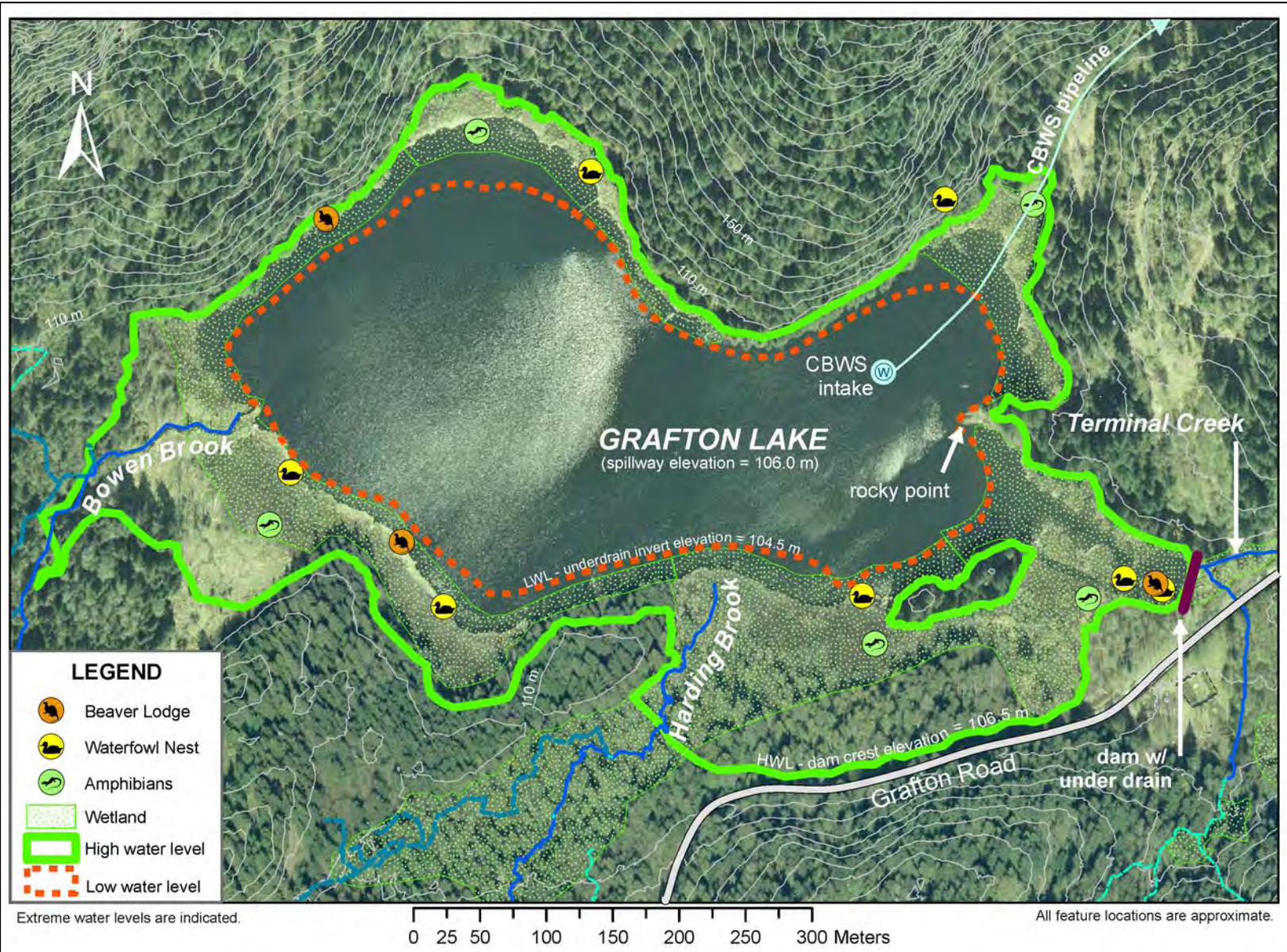
The beaver population is causing significant, although natural, changes to the riparian vegetation of Grafton Lake and Terminal Creek, particularly trees and woody shrubs. Two individuals have been observed by Municipal staff using a remote-control video camera installed at the outlet dam (Bob Robinson, pers. comm.). The beaver are considered a nuisance due to their interference with the outlet and water releases into Terminal Creek, which requires on-going maintenance by municipal staff. Beaver are

also commonly associated with *Giardia*, a disease organism that can occur in drinking water reservoirs; however, giardiasis has not been reported in drinking water supplies obtained from the Grafton Lake reservoir.

Table 5-1. Wildlife species observed at Grafton Lake, 2003 - 2009

| Common name | Scientific Name | Nest | On Lake | In Wetland | Notes |
|----------------------------|----------------------------------------|------|---------|------------|---------------------------------------------------------------------------------------------------|
| Canada Goose | <i>Branta canadensis</i> | y | y | y | Nests in wetland and on cliff ledges; often preyed upon by eagles; feeds in wetlands and on land. |
| Mallard | <i>Anas platyrhynchos</i> | | y | y | Ducklings also seen; feeds in shallows. |
| Ring-necked Duck | <i>Aythya collaris</i> | y | y | y | Floating nest in reeds; ducklings observed; feeds in shallows. |
| Bufflehead | <i>Bucepala albeola</i> | | y | | Feeds in deeper water; more common in winter. |
| Hooded Merganser | <i>Lophodytes cucullatus</i> | | y | | Feeds in deeper water; cavity nest in dead tree; more common in winter. |
| Pied-billed Grebe | <i>Podilymbus podiceps</i> | y | y | y | Floating nest in reeds; feeds throughout. |
| Red-winged Blackbird | <i>Agelaius phoeniceus</i> | y | | y | Nests in cattail marsh; feeds in wetlands |
| Yellowthroat | <i>Geothlypis trichas</i> | | | y | Nests in wetland shrubs; feeds in wetlands. |
| Song Sparrow | <i>Melospiza melodia</i> | | | y | Nests in wetland shrubs; feeds in wetlands. |
| Willow Flycatcher | <i>Empidonax traillii</i> | | | y | Nests in wetland shrubs. |
| Alder Flycatcher | <i>Empidonax alnorum</i> | | | y | Nests in wetland shrubs. |
| Wilson's Warbler | <i>Wilsonia pusilla</i> | | | y | Nests in wetland shrubs. |
| Bald-headed Eagle | <i>Haliaeetus leucocephalus</i> | | | y | Adults and juveniles perched on dead trees beside lake; prey on waterfowl. |
| Beaver | <i>Castor canadensis</i> | y | y | y | Two lodges observed; two individuals observed; nuisance from damming outlet. |
| Columbia Black-tailed Deer | <i>Odocoileus hemionus columbianus</i> | | y | | Observed swimming in mid-lake; browsing in wetland edges. |
| Turtle (unidentified) | -- | | y | y | Sunning on log; approx. 20 cm long. |
| Pacific Tree Frog | <i>Hyla regilla</i> | | | y | Commonly heard in wetlands. |
| Red-legged Frog | <i>Rana aurora</i> | | | y | Reproduce in wetlands; blue-listed in B.C. |

Additional discussion of the lake's wildlife populations in relation to natural or human-caused water level variation is provided in Section 5.3.2, below.

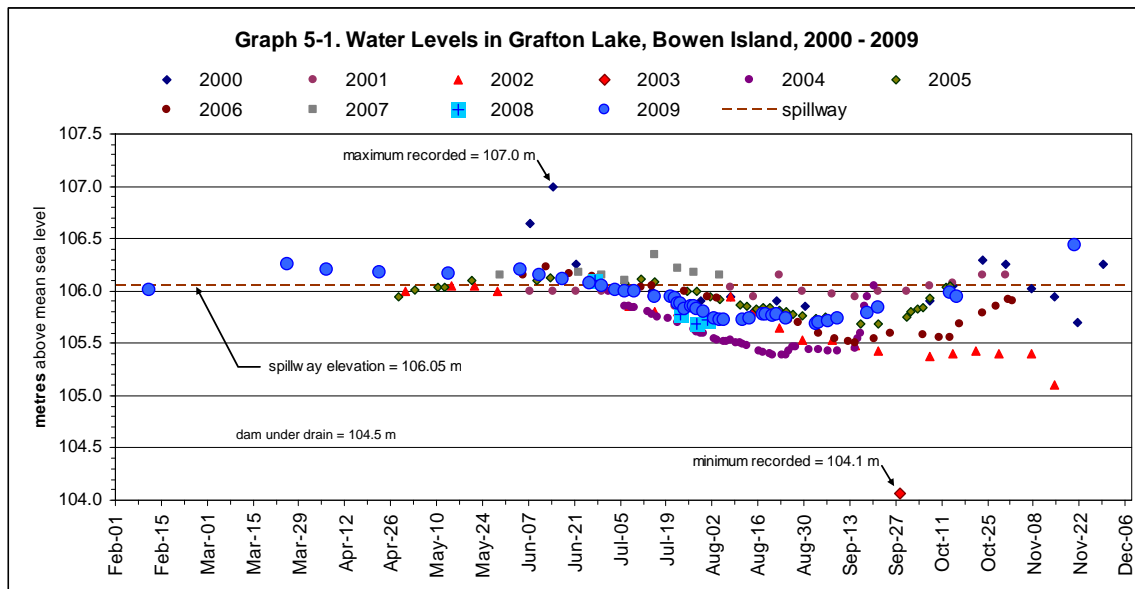


Map 5-1.
Locations of waterfowl nests, beaver lodges and frog observations in Grafton Lake, Bowen Island, 2003 - 2009.

Prepared by Whitehead Environmental Consultants Ltd., February 15, 2010.
 Base map courtesy of the Bowen Island Municipality and Bowen Island Conservancy GIS.

5.3.2 Lake Water Levels

The available measurements of water levels in Grafton Lake since 2000 are shown in Graph 5-1. The elevation of the outlet dam spillway is reported to be 106.05 m above mean sea level (geodetic), and the invert of the dam’s under drain is 104.5 m (LRP 2007). The lake’s water level normally fluctuates approximately 1 m over the course of a year, between approximately 105.3 and 106.3 m. The lake elevation tends to remain above the spillway elevation between mid-autumn and early summer, and to drop below the spillway during the summer – fall dry season, typically reaching its lowest level between late August and mid October. Factors that influence the timing of these variations include rainfall patterns, management of releases to Terminal Creek, and dam-building by beavers at the lake outlet (and corresponding controls by the Municipality).



The maximum recorded lake level is 107.0 m (0.95 m above the spillway), measured on June 14th 2000 shortly after a period of very high rainfall (flood conditions), during which the crest of outlet dam was overtopped. The lowest recorded value is 104.1 m, measured on September 28th 2003 during summer drought conditions. This extreme low water level (approximately 0.4 m below the dam’s under drain) resulted from releases necessary to sustain fish in Terminal Creek downstream, as required under the terms of the Water Licence. A siphon and a pump was used during this period to achieve the necessary 8.5 L/s (0.3 ft³/s) flow out of the lake into Terminal Creek. Minimum water levels reported in the 1997 LRP 2007 report range between 104.9 and 105.8 m between 1993 and 1996. The low and high water level range is shown in Map 5-1.

The vegetation of the lake’s shoreline, including emergent and submerged species can be considered to be adapted to the normal fluctuation of approximately 1 m. This range includes a progressive draw-down of approximately 0.75 m during the mid to late

growing season, and inundation of approximately 0.25 m during the dormant season to early growing season. The distribution of wetland vegetation appears to have remained relatively stable relative to the conditions observed in 1997 and 2002.

Waterfowl that depend on the lakeshore vegetation, such as species that nest and feed in wetlands, are also adapted to the existing cycle of water level fluctuation. Temporary inundation during the winter season has a negligible effect as long as it does not persist into the growing season. Excessive drawdown (or inundation) during the nesting season could adversely affect the reproductive success. Waterfowl species observed in Grafton Lake that would be susceptible to harm due to abnormal water level changes include: Pied-billed Grebe, Canada Goose, Mallard and Ring-necked Duck.

5.3.3 Lake Water Temperatures

The changes in lake water temperature are presented in this section, as measured by the MoE monitoring program at the CBWS intake in 2006 and 2007, and by the temperature sensors deployed in the lake in the fall of 2008.

Due to extreme weather conditions in 2008 (prolonged cover of ice and snow on the lake), the temperature sensors were not accessed after initial installation and, in addition, the sensors placed between the surface and 6 m depth did not collect data for unknown reasons; as a result, data were collected only for the interval of July 19 – October 13, 2008 and at 1-m depth intervals from 7 m to 13 depths.

The MoE data is plotted in Graphs 5-2 and 5-3 (entire data set for each year), 5-4 (selected days), and 5-5 (selected weeks) and represents water collected from a depth of approximately 8 m below the surface and 2 m above the lake bottom (24 feet; Bob Robinson, personal communication). The depth series measured by WEC in the centre of the lake is shown in Graph 5-6.

Surface temperatures recorded during water sampling ranged between 13°C in October and 24.3°C in August (Table 5-2). Subsurface water temperature measurements at the CBWS intake during 2006 and 2007 ranged from approximately 6°C in the spring, to a maximum of 11°C in the early fall and a minimum of 4.5°C in winter (Graphs 5-2 and 5-3). The relatively rapid increase observed in late October (Graph 5-2) reflects the displacement of subsurface water by relatively warmer surface water as the latter sank with the onset of cooler air temperatures in the fall.

The “fall turnover”, which is the rapid reduction temperature that occurred with the sinking of cooled of surface waters, took place at the end of October 2006 (Graph 5-3). The fall turnover is a period during which the water mass in the lake is no longer stratified by the layer of warm surface water that forms during the summer. Water chemistry in the lake changes during turnover, as the oxygen-rich surface waters reach the lake bottom and contact the sediment surface; the change from anoxic to aerobic conditions changes the solubility of phosphorus in the sediment, releasing this key

nutrient into the water column, where it becomes available for plankton growth during the following growing season.

Subsurface water temperature during the spring of 2007 ranged between approximately 6.7°C and 7.7°C, with a steadily increasing trend reflecting the increasing day length. Depending on daily weather, temperatures ranged from a minimum of 6.6°C in the pre-dawn hours to a maximum of 8.°C on sunny days.

Table 5-2. Air and water temperatures recorded during water sampling in Grafton Lake, 2007 and 2008.

| Date | Time | Temperature | | Notes |
|-----------|-------|-------------|------------|----------------|
| | | Air (°C) | Water (°C) | |
| 22-Aug-07 | 16:57 | 22.5 | 24.3 | At lake outlet |
| 22-Aug-07 | 17:17 | 22.0 | 22.7 | At rocky point |
| 25-Jun-08 | 09:45 | 16.5 | 18.8 | At rocky point |
| 8-Oct-08 | 15:45 | 11.5 | 13.0 | At rocky point |

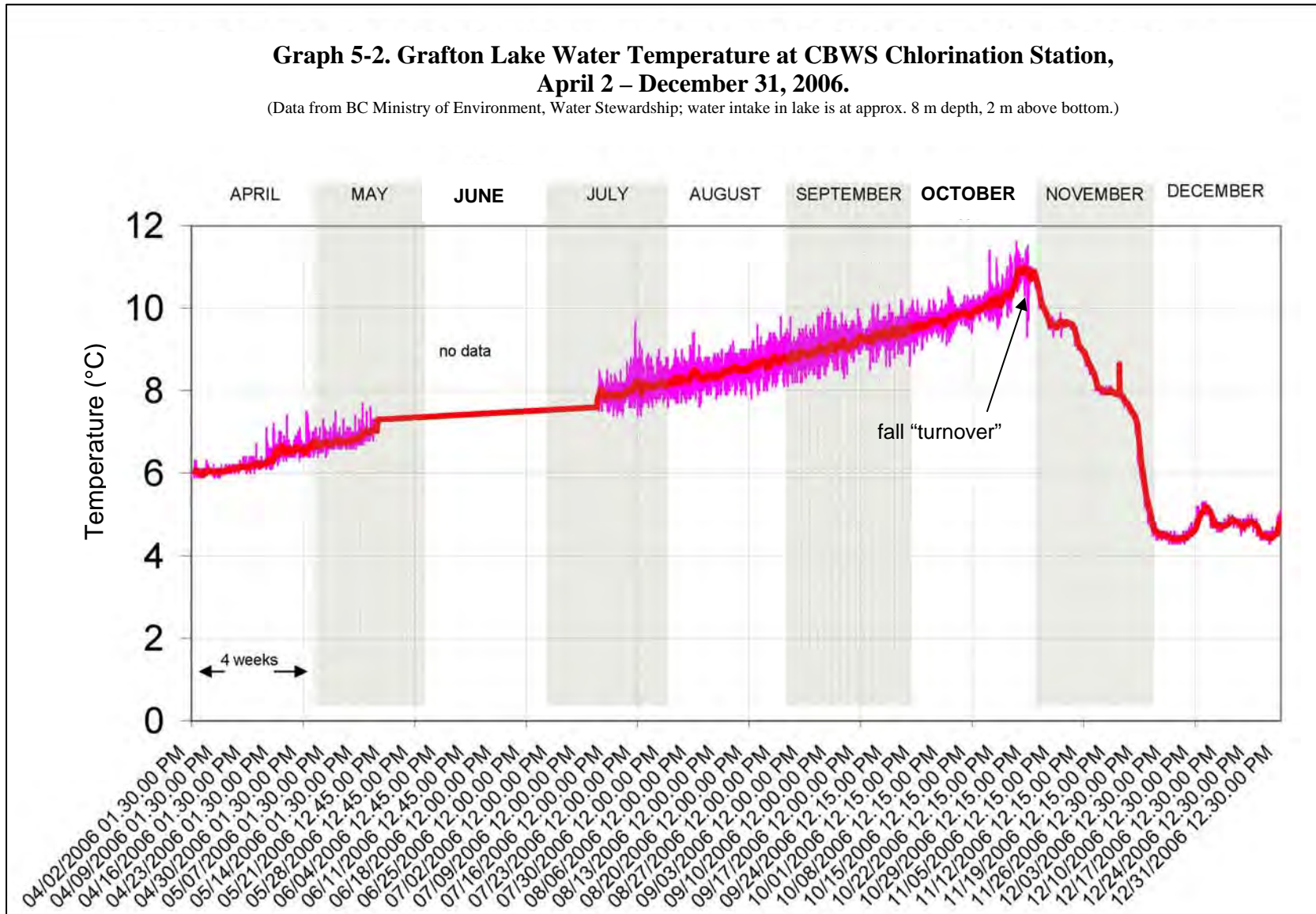
The increase in water temperature as day length increased between three different weekly periods separated by one month can be readily observed in Graph 5-4. The daily temperature range in April tended to be smaller than the range in May and June. Similarly, the difference in average temperatures between weeks became more pronounced with each advancing month. The apparent lack of synchrony between the exposure to sunlight and the timing of the high and low temperatures likely results from a combination of factors: e.g., the dampening (lag period) effect of the overlying water layers, given that the CBWS intake is located at depth and not at the surface; the rate of water draw through the CBW intake pipe and, possibly, currents induced by wind and temperature changes.

The same patterns that were observed on a weekly basis were readily apparent within individual days (Graph 5-5). However, the influence of daily weather plays a greater part in determining the range of temperatures, as well as the timing of the high and low temperatures within any given day (see May 5th and May 6th). The increase in temperature noted during the night followed by the decrease after sunrise indicate the lag period of thermal transfer between surface and deeper strata. The lag period between air and subsurface temperatures is also evident in the temperature profiles for water depths of -7 m and -8 m shown in Graph 5-6.

Graph 5-6 presents the water temperatures measured at 7 m depth and below, and in the corresponding air temperatures, between July 19th and October 10th 2008. (As indicated previously, it was not possible to obtain data for the shallower portion of the water column due to equipment malfunctions.) The beginning of the 2008 fall turnover is evident in early October, as water temperature at -7 m began to decrease immediately following the onset of markedly colder air, during which night time air temperatures dropped to < 5°C.

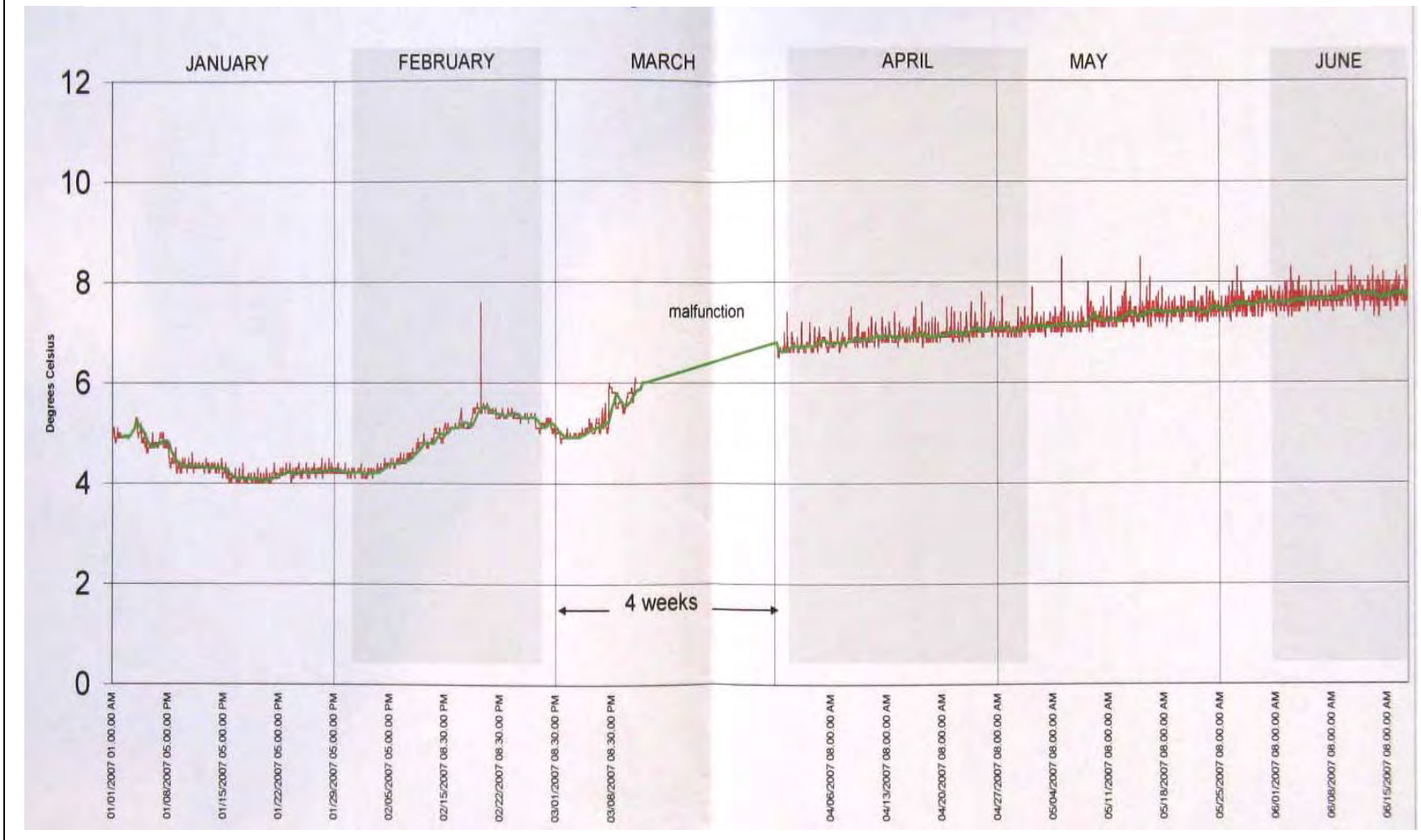
**Graph 5-2. Grafton Lake Water Temperature at CBWS Chlorination Station,
April 2 – December 31, 2006.**

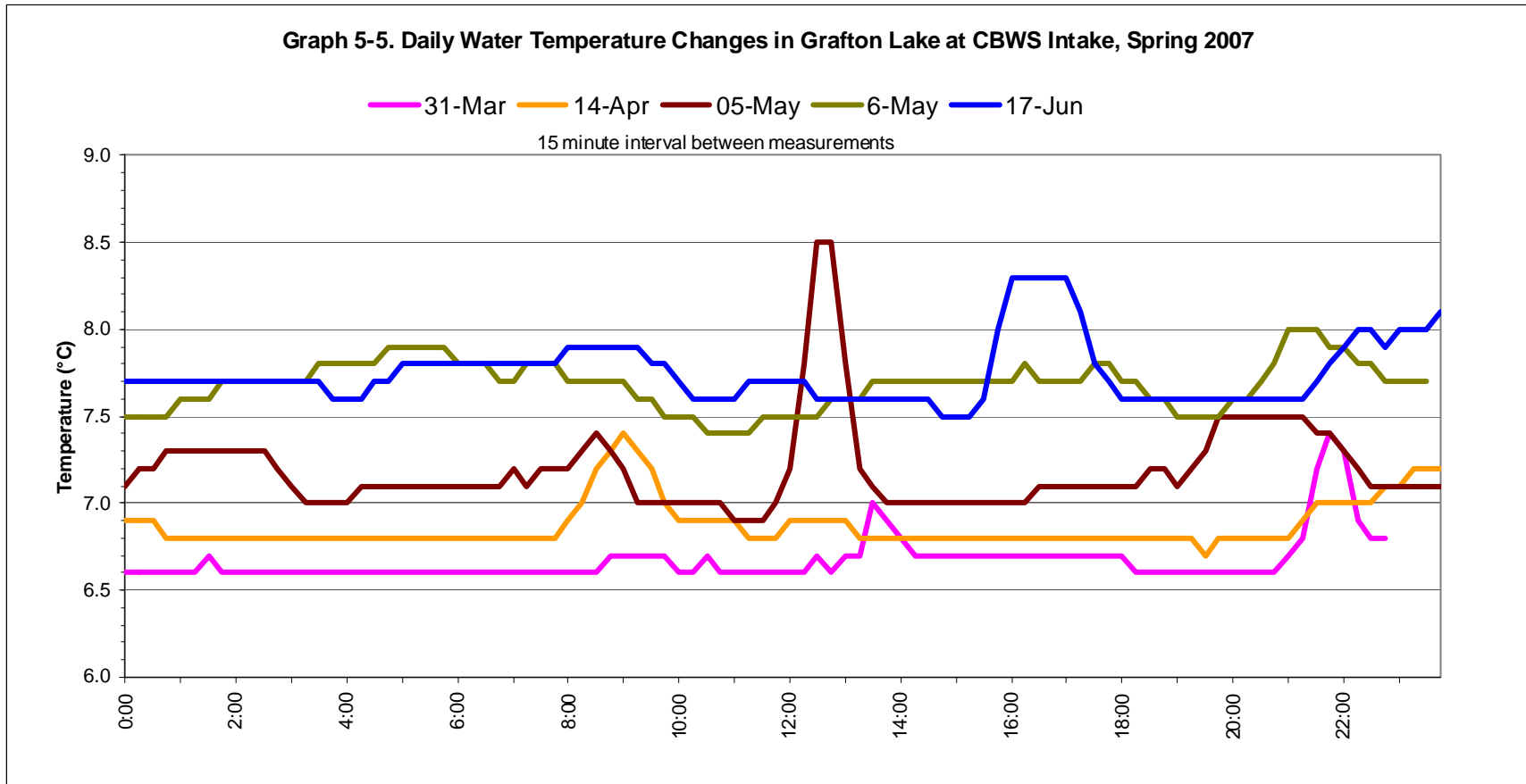
(Data from BC Ministry of Environment, Water Stewardship; water intake in lake is at approx. 8 m depth, 2 m above bottom.)



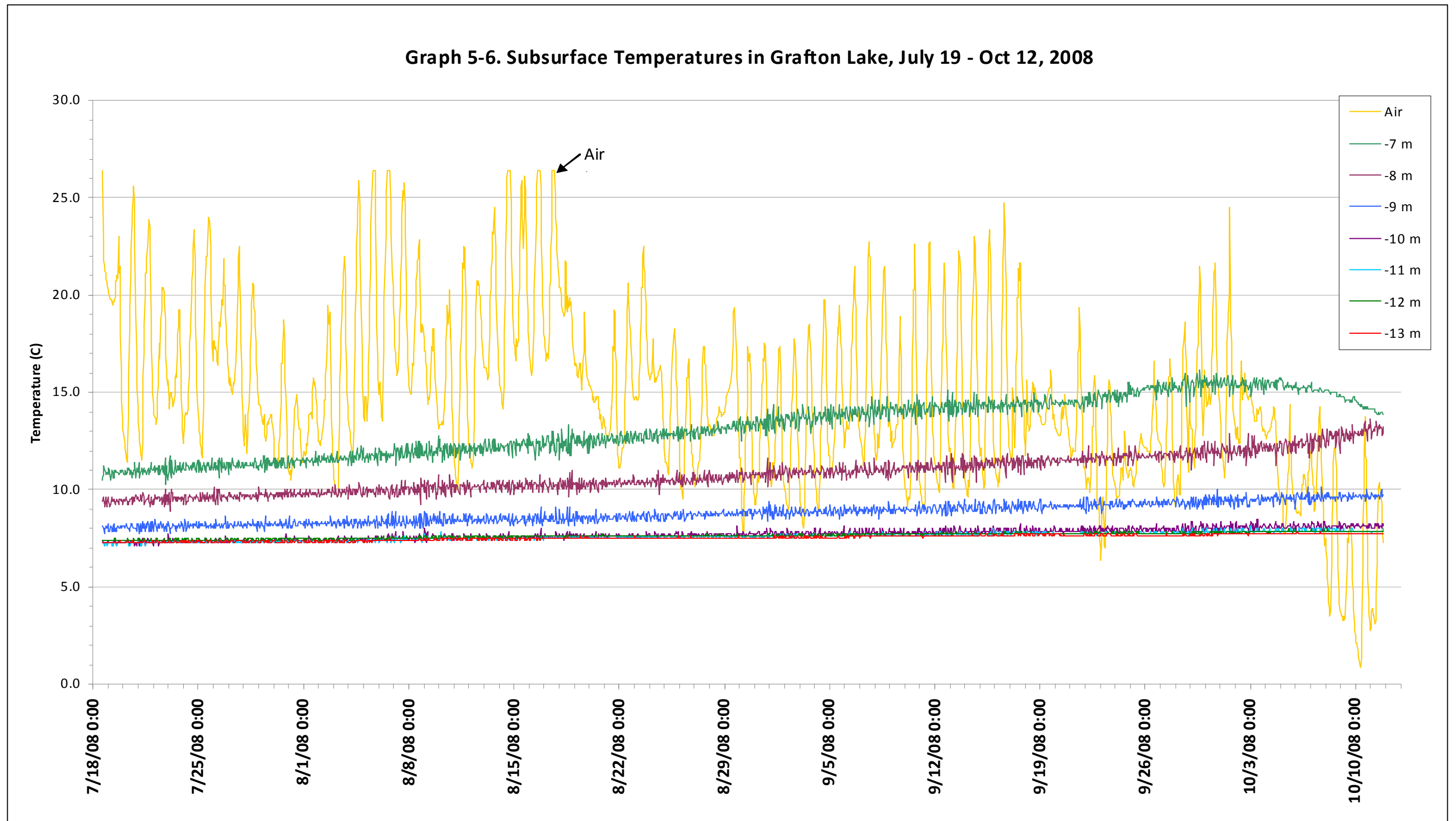
**Graph 5-3. Grafton Lake Water Temperature at CBWS Chlorination Station,
January 1 – June 17, 2007**

(Photographed from plot of data from BC Ministry of Environment, Water Stewardship; water intake is at approx. 8 m below surface, 2 m above bottom)





Graph 5-6. Subsurface Temperatures in Grafton Lake, July 19 - Oct 12, 2008



6. CONCLUSIONS

6.1 *Public Involvement*

An education and communication program was implemented between 2007 and 2009, which included a community survey, two focus group meetings, community open houses, and meetings with stakeholders. The participants' top perceived threats to drinking water quality included: erosion/runoff, septic system failure, and poor farm and garden practices around livestock and pesticide management. The campaign was successful in increasing islanders' understanding of where their drinking water comes from and in promoting steps that can be taken to ensure the quality of water supplies, such as proper maintenance of septic systems, protecting riparian habitat, conscientious land use practices, and no swimming in the Grafton Lake reservoir.

The two year education and communication campaign successfully used multiple educational activities to multiple audiences to increase understanding of where Island drinking water comes from and to promote steps to ensure its source water quality. By using both formal (school-based) and community media to leverage the key messages, public understanding and actions to protect source water quality in the Grafton Lake watershed improved over the two year project timeframe.

In spite of these successes, there is still a need to address the issue of recreational swimming in the Grafton Lake reservoir. Swimming in the lake is still perceived as a public right, and there are no legal means of preventing this use of the reservoir at present.

6.2 *Water Quality*

6.2.1 *Key Findings*

The quality of source waters for the CBWS continues to be relatively good. The major exceptions included:

- the presence of human fecal contamination in a number of streams and the Grafton Lake reservoir; and
- releases of other contaminants such as fertilizers, metals and hydrocarbons into streams due to inadequate land use practices.

6.2.2 *Inventory of Contamination Sources*

The known sources of contamination in the Grafton Lake watershed include:

- confirmed presence of human fecal matter in the following catchments:
 - lower Bowen Brook at Harding Road (failing septic systems or other sources of human waste); and

- Grafton Lake reservoir at rocky point (contact recreation: swimming)
- probable presence of human fecal matter (due to failing septic systems or other sources of human waste) in the following catchments:
 - upper Bowen Brook (Adams Road),
 - middle Bowen Brook (Buchanan Road),
 - Phantom Creek (Adams Road),
 - unnamed #2 (Adams Road),
 - Billington Creek, and
 - Lister Creek.
- confirmed presence of elevated concentrations of metals, nutrients, hydrocarbons or other chemicals in the following catchments:
 - Proudlock Brook (fertilizer, acid or other?),
 - Billington Creek (hydrocarbon fuel, Al, Cu, Zn),
 - Lower Bowen Brook (Al, Cu), and
 - Harding Brook (Al, Zn).

Potential additional sources of contamination include:

- Road construction and repairs,
- Runoff from incineration site, and
- Fire suppression (buildings and forest).

6.3 Hydrology

An automated hydrometric station was installed on Bowen Brook at Harding Road. This station is now providing real-time measurements of stream water level (stage) at 15-minute intervals, which are available online.

Calibration of the hydrometric station data to develop a stage-discharge relationship for Bowen Brook is still pending. Installation of a recording rain gauge to complement this hydrometric station is also pending.

The hydrometric system was sensitive enough to detect daily changes in stream water level due to evapotranspiration in the watershed during the summer. These results demonstrate the measurable “pulse” of the ecosystem during the water-stressed time of year. Analysis of the available data on stream stage and precipitation records also revealed that the stream’s response to rainfall was very noticeable, particularly during intense precipitation events, in spite of forest cover over most of the watershed.

A preliminary stage-discharge curve was developed for the water level in the three culverts under Harding Road, using the data available through the Volunteer Stream Flow Monitoring Project. The corresponding stage-discharge formula is:

$$y = 1.3555x^{0.6316} \quad (R^2 = 0.9583)$$

where y = the sum of water depths in all three culverts (in cm); and
 x = the discharge or flow in Bowen Brook at Harding Road (in L/s)

The average annual water yield from the Grafton Lake watershed was estimated to be 17.7 m³/d/ha (1574 Igpd/ac).

6.4 Grafton Lake Ecosystem

A total of 18 wildlife species that are in some manner dependent on the wetlands of the Grafton Lake reservoir were indentified. These included six species of waterfowl, six perching birds, one raptor, two mammals, one reptile and two amphibians. Of these, the red-legged frog is considered at risk (Blue-listed) by the provincial government, and the beaver is considered a nuisance wildlife by the CBWS operators.

The lake water level normally fluctuates approximately 1 m over the course of a year, between approximately 105.3 and 106.3 m. The lake's shoreline vegetation and wildlife be considered to be adapted to this variation. Temporary inundation during the winter season has a negligible effect as long as it does not persist into the growing season. Excessive drawdown (or inundation) during the nesting season could adversely affect the reproductive success of some wildlife. Waterfowl species observed in Grafton Lake that would be susceptible to harm due to abnormal water level changes include: Pied-billed Grebe, Canada Goose, Mallard and Ring-necked Duck.

Tracking of lake water temperatures revealed that the fall turnover in 2006 (and likely in 2008) took place over approximately one month, beginning in mid to late October and ending in late November. The onset of the turnover appears to take place once night-time temperatures begin to drop below 5°C. Additional temperature data at different water depths is needed to complete our understanding of the lake's water movements and nutrient cycling from the sediments.

7. RECOMMENDATIONS

Based on the results of the 2007 – 2009 Grafton Lake Watershed Study, the municipality is encouraged to implement the following general and specific actions:

Public Involvement

12. Adopt an on-going program of public communications and education (C&E) as recommended in this report and previously, as a means of continuing to involve the public at large in reducing the risks to water sources in the watershed. Specifically:
 - Use the current Watershed Quest school program with remaining schools on the island (Island Pacific School, Montessori School, Bowen Island Home-Supported Learners) in 2010 to get further use from the student quest that was developed; and
 - Continue with a public informational campaign especially around the issue of swimming in Grafton Lake.
13. To maximize the benefits and cost efficiency of the C&E program, it is recommended that the scope should extend to all the community water systems on the island, including those that are not managed by the municipality.

Water Quality

14. Continue water quality monitoring in the watershed using Bacterial Source Tracking (BST) to assist in the location of failing septic systems and other sources of human fecal contamination. Work with the Pacific Environmental Science Centre of Environment Canada, or other agencies, to refine the BST methods for use on Bowen Island.
15. Examine whether the fecal contamination documented in Grafton Lake reservoir is sufficient to justify legally prohibiting contact recreation in Grafton Lake, taking into consideration that the CBWS is served by a disinfection facility.
16. Work with the Coastal Health Authority to develop and implement a plan to address the remediation of failing septic systems and other sources of contamination, should any be found.
17. Undertake a preliminary sampling program to assess whether or not detectable concentrations of pharmaceuticals and personal care products are present in the source waters of the Grafton lake watershed.

18. Implement a continuous water quality monitoring program, using, automated sampling apparatus⁶, on streams that receive runoff from commercial operations such as quarries, incineration facilities, mechanics shops, waste storage/transfer facilities and active, commercial agriculture. Parameters to be monitored should include turbidity, pH, conductivity, anions, nutrients, total metals, oil and grease, hydrocarbons, and pesticides, as appropriate to each catchment. It is desirable that the water samples should be collected by an independent party, not the owner/ operator.

Hydrology

19. Regarding the automated hydrometric station on Bowen Brook at Harding Road:
 - continue the necessary field calibration to complete the stage-discharge curve for that location;
 - incorporate the stage-discharge relationship into the Emerald system; and
 - install the recording weather station (thermometer and rain gauge) at Harding Road, as already planned for incorporation into the Emerald system.
20. Ensure that the allocation of potable water through the CBWS (e.g., to supply the planned increases in population density in Snug Cove) does not exceed reservoir's storage capacity to supply nor compromise the lake's ecological functions.

Grafton Lake Ecosystem

21. Continue to manage the Grafton Lake reservoir in a manner that mimics the natural seasonal lake level fluctuation in order to sustain the lake ecosystem, its flora and fauna. Specifically:
 - avoiding unnecessary draw-down in winter;
 - delay the summer draw-down as much as possible; and
 - delay any increase in water level (e.g., installation of stop-logs at the outlet) until after the vegetation enters winter dormancy in mid to late November.
22. Continue to monitor the health of the lake ecosystem by conducting an ecological assessment at least every three to five years, beginning in 2011, in order to ensure continued compliance with the Drinking Water Protection Act.

As part of the next assessment, the following actions are also recommended:

⁶ For examples of automated portable samplers, see: <http://www.isco.com/products/products2.asp?PL=20110&image=Samplers3.jpg> and <http://www.sircosamplers.com/portable-water-samplers.cfm>.

- complete a lake water temperature monitoring study for a period of one year at one-meter depth intervals.
- complete an accurate bathymetric survey of the lake; and
- undertake an inventory of fish and other aquatic species.

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APPENDIX 1

Education and Communication:

- Grafton Lake Watershed Quest
- Photographs of the field day

The Grafton Lake Watershed Quest

From towering cedar trees to slithering slugs, all living things – including you - rely on a continued supply of fresh, clean water. Bowen Island is surrounded by water, so there shouldn't be any problem, right? Wrong! As you probably know, we can't drink ocean water. It's filled with salt that draws moisture out of our bodies. So, where does our drinking water come from? And what can we do to protect our water supplies? Join our water superhero, Raindrop, as he explores the Grafton Lake watershed and helps you answer these questions and more.

This quest will take you to three sites:

1. Quarry Park on Sunset Road;
2. Bowen Brook at Buchanan Park; and
3. Grafton Lake.

At each site, carefully follow Raindrop's rhyming clues and use your map to find your way. Collect mystery words and use their letters to locate the treasure box where you can sign the guestbook and stamp your quest sheet.

Hey!



Raindrop's my name,
Drinking water's my game!

Clues in bold give you information.
Clues in italics tell you which way to go.

Headwaters at Quarry Park

1. Where does our water come from? Follow me and learn.
We'll check out all the sources at each and every turn.
And as we walk together on this watershed quest,
Always remember that you are the guest.
The plants and animals who live herein,
Are the ones whose home that you are in.
So please walk softly, don't run and shout,
But look and listen for who is about.

Here's something to get inside your head
What's this thing called a watershed?



*Stand facing the map, then turn to your right,
Be ready to explore a beautiful site,
You'll see many plants of all different kinds
Now walk down the trail as it wiggles and winds
When you come to a bench on the left of the trail,
Stop and listen to more of my tale.*

**2. Look for the tree with branches three,
Gazing past it, what do you see?
About 10 years back, the land right here,
For roads and houses was made clear
But the buildings were not built
And to keep the water from a lot of silt,
The workers dug a great, big hole,
And placed wetland plants round the empty bowl.
The lake filled with water, that we can see,
And in 2005 Quarry Park came to be.**

Looking past the trident tree you can see a

 A
1 4 7

As you stand at the bench, turn left if you please,
Now head up the trail that runs through the trees.
Pass four rocks on the right as you walk up the hill
Find a bridge made of stone, then stand very still.

3. Now listen closely as you look all around,
 You might hear a waterfall or just a dripping sound.
 The different noises are due to a reason
 The amount that's flowing depends on the season.
 In summer, when it's hot and dry,
 Not much water will go by.
 But in the winter, cold and wet,
 Water's rushing fast, you bet!

*Rainfall on Bowen Island averages 99 mm in July and 262 mm in February. That's a difference of ____ mm.

Rain, sleet, hail and snow are different forms of

_____.

14 19 5 9 2

From the stone bridge take about 60 steps,
 Past the stone circle on your left
 And head over to the wooden gate
 Where you'll stop and contemplate.

4. Now, one and all, please pause at the gate,
 To find something that nature did not make.
 This bright turquoise culvert gives us a clue,
 That when it rains, water flows through.
 It travels downhill on its way to the lake,
 All part of the cycle my friends and I take!

Next, go through the gate and look to your right,
 At a five word sign as it comes into sight.
 The message is one that you'll need to read,
 If you're riding the trail on a galloping steed!

The sign says:

_____ 3 12

_____ 20

_____ 8



Onto the bridge now you go
 And think about the water cycle – don't be slow!
 Stop right here and look about
 This stuff's important- without a doubt.

5. Move your eyes to the left and what do you see?
 Across the water - a wildlife tree!
 This tall, dead tree in a wetland stands,
 A home for many in these fragile lands.
 The tree's near a place, that's known in these parts
 as the headwaters - where our watershed starts.

Turn right around and look down, down, down
 under the bridge at what you have found.

What is flowing under the bridge?

_____.

10 23

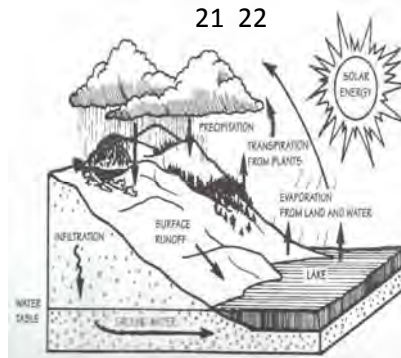
6. Station 1: **Watershed Model:**

From where, do you think, this water comes a-calling?
 As part of the cycle, it comes from rain that's falling.
 My water buddies and I take an enormous round trip,
 From the sky down to the ground and up again we flip.
 Each stage in our journey has a special name
 They all end in "-tion" but they're really not the same.
Evaporation means we rise up into the air,
 From ponds, streams and puddles left behind down there.
Transpiration happens when plants breathe us out,
 Sending water vapour into the air all about.
Condensation can happen to us in a cloud
 When we all get together in a really big crowd
 We cluster around bits of dust
 To turn from a gas to water where we adjust
 And fall down as hail or rain or snow,
 That's called precipitation as you well know.
 We flow downhill all the way to the sea,
 From the headwaters near the old, dead tree.

What is the phrase that describes the movement of water?

11

21 22



Walk across the bridge and to your right take a look
 Skip between the skinny alders but not in the brook!
 Stop right by the where the waters flow
 Nearby an egg shaped peninsula you must go!

7. Station 2: Wetlands

Touch the wet moss and gently squeeze
Hmmm, that's a notion sure to please.
Wetlands act just like a sponge
Before our water takes the plunge.
Because wetlands do store water
For plants, birds, fish, bugs – even an otter!
And then wetlands release water in the summer drought
That's what this verse is all about.

Wetlands are important because they act like a sponge to store water so that there is water in the streams during the _____ drought.
_____ 25 18

Go back and continue on the path uphill
Turn right at wood gate and for a moment be still.
Check out the sign with symbols brown/yellow/red.
Then go through the gate to where it is said
You'll find alder trees that like to "keep their feet wet"
Keep walking along, don't pause yet!

8. Stop at the bridge and the water you see
Starting right here it all comes to be
Known as the stream that is called Bowen Brook
So pause here a moment and do take a look!

Take some steps along the path - now this is the key
To go back to the bench by the trident tree
Head back to the parking lot, but before you go,
from where does the water at Quarry Park flow?

_____ E _____
6 16

Now that you have learned and been around
Where the headwaters of Bowen Brook are found
And that stream leads us to Grafton Lake
So, the next step in our Quest we'll take!



Bowen Brook at Buchanan Park.

Stop, Look, and Listen and then you must go
Along the trail to the white post – but do take it slow
And find the marker that says PARK on two sides
Then stop nearby, in a spot where a forest creature just might hide.

9. The forest here has maple, Douglas-Fir and hemlock
A mix of trees, shrubs, plants and some rock
This forest helps to keep our water clean
By filtering out the dirt before it gets to the stream.

They call this forest a riparian zone
It also provides habitat - don't you know
For animal travel, water, food and nests
This is an area that they like best.

Forests are important because they help keep our water _____ .
_____ 24

Go downhill to a bridge and find on your right
It crosses over a stream that has come into sight
So stop and listen as you take a look,
At this flowing stream or babbling _____!

10. This brook's first name is the same as the island you are standing on.

The name of this stream is:
_____ 17
_____ 13

This stream also provides water for many people who live in the watershed.

(Go to Stations 3 & 4 – Stream Sense & Fish)

Walk quietly up the bridge and then look with care
And you may see some fish beneath you there
Trout, water bugs, insects and some fish called Kokanee
Are some of the things that you might see.

Cutthroat Trout, Kokanee are a type of freshwater fish called:
_____ that need clean, cool water.
_____ 15 26



Go uphill along the trail with the red-roofed house on your right
Count the horseshoes that come into your sight.
Continue on 'til the end of the trail
Then to Grafton Lake for the end of my tale!
There are _____ horseshoes.

Grafton Lake

Clean water is what people and nature all need
 We can protect our watershed – yes, indeed!

**11. We must keep Grafton Lake clean and clear
 To protect all the water drops you hold so dear
 But how do we get to the homes and the school?
 Through pipes after treatment – it’s totally cool!
 To protect all the water that you love to sip
 Ask someone who works here to give you a tip.
 Follow that person and as a look you do take,
 With special permission to see Grafton Lake.**

Grafton Lake supplies water to the

 Bay

 System.

Now, ask a question to the guy or gal
 Don't be shy – I know they're a pal
 To find answer that you'll need
 Some words about me, Raindrop, you must read

*To finish up your watershed quest
 Is to find the sign that says it best:*



*It shows forests, water, soils, and water, hey- isn't that great?
 (Here's a hint, you can find it on a gate).*

The sign says:

Protect

At the sign, your quest's nearly done and it's time we revealed

The place where the treasure box has been concealed.
 So, use all the letters that you have found,

That box is somewhere close around.

To find the treasure box, stand in front of the gate and

_____ beyond _____
 1 2 3 4 5 6 7

_____ the
 8 9 10 11 12 13

_____ Look
 14 15 16 17 18 19 20 21 22

Inside the G _____ B _____!
 23 24 25 26 27 28



Put your quest stamp here:

Congratulations! You have completed the Grafton Lake Watershed Quest!



"Raindrop" visits Bowen Island Community School – May 2009



Students explore the headwaters of the Grafton Lake while searching for clues. May 2009



Students learn about the water cycle and how water moves from the headwaters to the lake



Students learn about the importance of wetlands and riparian habitat for clean water. May 2009



Students at Buchanan Park – midway through the watershed quest. May 2009



Students get a chance to see local fish that need clean water too, with community volunteers



Last stop: at Grafton Lake and time to solve the all the Quest Clues with the help of CBWS chairman, Bill Hamilton



The treasure and Raindrop is found!

May 2009

APPENDIX 2.

Water Quality Laboratory Reports

- BCAT
- PESC

ANALYTICAL REPORT
Certificate #: A0806S565

Project: 053-4

For: Whitehead Environmental Consultants **Date Received:** 26-Jun-08

 RR1 CH-11,621 Cates Hill Road **Date Completed:** 14-Jul-08

Bowen Island, B.C. V0N 1G0

Account: IAO

Attention: Alan Whitehead

Fax: 604-947-0141

P.O. # 053-4

Tele: 604-947-0144

Analytical Results

| Parameter (Unit) | Analytical Method | Detection Limit | Analytical Result | | | |
|-------------------------------------|-------------------|-----------------|-------------------|--------------|--------------|--------------|
| | | | Sample ID 19 | Sample ID 20 | Sample ID 23 | Sample ID 25 |
| PHYSICAL TEST | | | | | | |
| Colour (C.U.) | APHA 2120B | 5 | <5 | 32 | 38 | 10 |
| Conductivity (uS/cm) | APHA 2510B | 1.0 | 159 | 150 | 208 | 97 |
| Total Dissolved Solids (mg/L) | APHA 2540C | 1 | 79 | 75 | 104 | 49 |
| Hardness (mg/L) | APHA 2340B/C | 1 | 55 | 52 | 69 | 32 |
| pH (S.U.) | APHA 2540D | 0.1 | 6.2 | 6.1 | 6.4 | 6.2 |
| Total Suspended Solids (mg/L) | APHA 2530B | 1 | <1 | 14.0 | 4.0 | <1 |
| Turbidity (NTU) | APHA 4500B | 0.05 | 0.85 | 5.28 | 2.95 | 0.71 |
| DISSOLVED ANION | | | | | | |
| Alkalinity CaCO ₃ (mg/L) | APHA 2320B | 0.5 | 35.6 | 30.4 | 37.7 | 18.9 |
| Chloride (mg/L) | APHA 4110B | 0.10 | 15.0 | 19.1 | 25.0 | 9.75 |
| Fluoride (mg/L) | APHA 4110B | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Sulphate (mg/L) | APHA 4110B | 0.5 | 4.0 | 5.28 | 5.0 | 4.3 |
| NUTRIENT | | | | | | |
| Ammonia Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | 0.07 | 0.06 | 0.02 | 0.03 |
| Total Kjeldahl Nitrogen (mg/L) | APHA 4500NB | 0.02 | 0.19 | 0.51 | 0.38 | 0.37 |
| Nitrate Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | 0.12 | <0.01 | <0.02 | <0.02 |
| Nitrite Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | 0.04 | <0.02 | <0.02 | 0.10 |
| Total Nitrogen N (mg/L) | EPA/APHA Cal | 0.02 | 0.42 | 0.57 | 0.40 | 0.50 |
| Diss Ortho-Phosphate P (mg/L) | APHA 4110B | 0.01 | <0.010 | <0.010 | <0.010 | <0.010 |
| NON-HALOGENATED VOLATILES | | | | | | |
| Benzene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Ethyl benzene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Styrene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Toluene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Meta/Para- Xylene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Ortho-Xylene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Total Xylene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Volatile H.C. C6-C10 (ug/L) | EPA 503B/8260B | 100 | - | - | - | - |
| VPH (ug/L) | EPA 503B/8260B | 100 | - | - | - | - |
| BACTERIAL TEST | | | | | | |
| Fecal Coliform (CFU/100 mL) | APHA 9222 | 1 | - | - | 6 | 1 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |



ANALYTICAL REPORT

Certificate #: A0806S565

Project: 053-4

For: Whitehead Environmental Consultants **Date Received:** 26-Jun-08

RR1 CH-11,621 Cates Hill Road **Date Completed:** 14-Jul-08

Bowen Island, B.C. V0N 1G0

Account: IAO

Attention: Alan Whitehead

Fax: 604-947-0141

P.O. # 053-4

Tele: 604-947-0144

Analytical Results

| Parameter (Unit) | Analytical Method | Detection Limit | Analytical Result | | | |
|-----------------------------|-------------------|-----------------|-------------------|-------------|-------------|--------------|
| | | | Sample ID 4 | Sample ID 7 | Sample ID 9 | Sample ID 12 |
| TOTAL METAL ANALYSIS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | 46 | 63 | - | - |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | 0.09 | 0.09 | - | - |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | 1.5 | 1.8 | - | - |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | 16.8 | 18.2 | - | - |
| Boron (ug/L) | EPA 200 ICPMS | 5 | 14 | 17 | - | - |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | <0.05 | <0.05 | - | - |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | 0.6 | 0.7 | - | - |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | 0.8 | 1.2 | - | - |
| Iron (ug/L) | EPA 200 ICPMS | 10 | 250 | 779 | - | - |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | <0.1 | - | - |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | 4046 | 3950 | - | - |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | 12.7 | 188 | - | - |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | <0.1 | - | - |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | 38 | 35 | - | - |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | <0.5 | - | - |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | 12800 | 13700 | - | - |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | 0.03 | <0.02 | - | - |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | 2.3 | 1.4 | - | - |
| DISSOLVED METALS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | 40 | 52 | - | - |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | <0.5 | <0.05 | - | - |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | <0.5 | - | - |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | 16.0 | 17.0 | - | - |
| Boron (ug/L) | EPA 200 ICPMS | 5 | 2 | 14 | - | - |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | <0.05 | <0.05 | - | - |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | <0.50 | - | - |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | 1.0 | - | - |
| Iron (ug/L) | EPA 200 ICPMS | 10 | 220 | 650 | - | - |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | <0.1 | - | - |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | 3690 | 3600 | - | - |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | 12.00 | 180 | - | - |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | <0.1 | - | - |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | <20 | <20 | - | - |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | <0.5 | - | - |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | 12100 | 12900 | - | - |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | <0.02 | <0.02 | - | - |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | 1.0 | - | - |



ANALYTICAL REPORT

Certificate #: A0806S565 **Project:** 053-4
For: Whitehead Environmental Consultants **Date Received:** 26-Jun-08
RR1 CH-11,621 Cates Hill Road **Date Completed:** 14-Jul-08
Bowen Island, B.C. V0N 1G0 **Account:** IAO
Attention: Alan Whitehead **Fax:** 604-947-0141
P.O. # 053-4 **Tele:** 604-947-0144

Analytical Results

| Parameter (Unit) | Analytical Method | Detection Limit | Analytical Result | | | |
|-----------------------------|-------------------|-----------------|-------------------|--------------|--------------|--------------|
| | | | Sample ID 14 | Sample ID 15 | Sample ID 16 | Sample ID 17 |
| TOTAL METAL ANALYSIS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | - | 63 | - | - |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | - | 0.87 | - | - |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | - | 4.3 | - | - |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | - | 11.63 | - | - |
| Boron (ug/L) | EPA 200 ICPMS | 5 | - | 9 | - | - |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | - | <0.05 | - | - |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | - | 0.5 | - | - |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | - | 0.6 | - | - |
| Iron (ug/L) | EPA 200 ICPMS | 10 | - | 43 | - | - |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | - | <0.1 | - | - |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | - | 2708 | - | - |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | - | 7.78 | - | - |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | - | <0.1 | - | - |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | - | 32 | - | - |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | - | <0.5 | - | - |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | - | 6935 | - | - |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | - | 0.03 | - | - |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | - | 3.2 | - | - |
| DISSOLVED METALS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | - | 50 | - | - |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | - | 0.65 | - | - |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | - | 3.0 | - | - |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | - | 11.00 | - | - |
| Boron (ug/L) | EPA 200 ICPMS | 5 | - | 9 | - | - |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | - | <0.05 | - | - |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | - | <0.5 | - | - |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | - | 0.6 | - | - |
| Iron (ug/L) | EPA 200 ICPMS | 10 | - | 35 | - | - |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | - | <0.1 | - | - |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | - | 2530 | - | - |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | - | 7.50 | - | - |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | - | <0.1 | - | - |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | - | <20 | - | - |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | - | <0.5 | - | - |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | - | 6750 | - | - |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | - | <0.02 | - | - |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | - | 3.0 | - | - |



ANALYTICAL REPORT

Certificate #: A0806S565 **Project:** 053-4
For: Whitehead Environmental Consultants **Date Received:** 26-Jun-08
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Bowen Island, B.C. V0N 1G0 **Account:** IAO
Attention: Alan Whitehead **Fax:** 604-947-0141
P.O. # 053-4 **Tele:** 604-947-0144

Analytical Results

| Parameter (Unit) | Analytical Method | Detection Limit | Analytical Result | | | |
|-----------------------------|-------------------|-----------------|-------------------|--------------|--------------|--------------|
| | | | Sample ID 19 | Sample ID 20 | Sample ID 23 | Sample ID 24 |
| TOTAL METAL ANALYSIS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | - | - | - | - |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Boron (ug/L) | EPA 200 ICPMS | 5 | - | - | - | - |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Iron (ug/L) | EPA 200 ICPMS | 10 | - | - | - | - |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | - | - | - | - |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | - | - | - | - |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | - | - | - | - |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | - | - | - | - |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| DISSOLVED METALS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | - | - | - | - |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Boron (ug/L) | EPA 200 ICPMS | 5 | - | - | - | - |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Iron (ug/L) | EPA 200 ICPMS | 10 | - | - | - | - |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | - | - | - | - |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | - | - | - | - |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | - | - | - | - |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | - | - | - | - |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |



Analytical Results (A0708S511R)

| Parameter (Unit) | Analytical Method | Detection Limit | Analytical Result | | | |
|-----------------------------|-------------------|-----------------|-------------------|-----------|-----------|-----------|
| | | | Sample ID | Sample ID | Sample ID | Sample ID |
| | | | 25 | - | - | - |
| TOTAL METAL ANALYSIS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | 32 | - | - | - |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | 0.10 | - | - | - |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | 0.9 | - | - | - |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | 9.37 | - | - | - |
| Boron (ug/L) | EPA 200 ICPMS | 5 | 7.0 | - | - | - |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | <0.05 | - | - | - |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | 0.7 | - | - | - |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | 0.7 | - | - | - |
| Iron (ug/L) | EPA 200 ICPMS | 10 | 71 | - | - | - |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | - | - | - |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | 2010 | - | - | - |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | 7.1 | - | - | - |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | - | - | - |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | 22 | - | - | - |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | - | - | - |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | 7290 | - | - | - |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | <0.02 | - | - | - |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | 1.4 | - | - | - |
| DISSOLVED METALS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | 28 | - | - | - |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | 0.10 | - | - | - |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | 0.9 | - | - | - |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | 9.35 | - | - | - |
| Boron (ug/L) | EPA 200 ICPMS | 5 | 7.0 | - | - | - |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | <0.05 | - | - | - |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | 0.7 | - | - | - |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | 0.7 | - | - | - |
| Iron (ug/L) | EPA 200 ICPMS | 10 | 70 | - | - | - |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | - | - | - |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | 1600 | - | - | - |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | 7.0 | - | - | - |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | - | - | - |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | 20 | - | - | - |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | - | - | - |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | 6900 | - | - | - |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | <0.02 | - | - | - |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | 1.3 | - | - | - |

Certified by:


 Parker Shieh, Ph.D. Environmental Services

Date: 7/15/2008

ANALYTICAL REPORT

Certificate #: A0810S585 **Project:** Grafton L W/S
For: Whitehead Environmental Consultants **Date Received:** 18-Oct-08
RR1 CH-11, (621 Cates Hill Road) **Date Completed:** 5-Nov-08
Bowen Island, B.C. V0N 1G0 **Account:** IAO
Attention: Alan Whitehead **Fax:** 604-947-0141
P.O. # 053-4 **Tele:** 604-947-0144

General Analytical Comments:

The methods of analyses are based on the "Standard Methods for the Examination of Water and Wastewater", 21st Edition published by the American Public Association (APHA); "Test Methods for Evaluating Solid Waste, Physical and Chemical Methods, SW846, 3rd Edition, published by US EPA; and the protocols of chemical analysis published by British Columbia Ministry of Environment (BCMOE).

Methods not described above may be conducted with recognized professional standards and QA/QC protocols to achieve the accuracy for the results. The results in this report apply to the samples analyzed in accordance with the samples indicated in the chain of custody or sample submittal form. The samples will be archived for 30 days after the report issued unless otherwise arrangement.

Reporting units: mg/L = milligrams per Litre, equivalent to parts per million (ppm)
ug/L = micrograms per Litre, equivalent to parts per billion (ppb)
mg/Kg = milligrams per Kilograms, equivalent to parts per million (ppm). It is normally used for the solid samples and the results are based on a dry weight basis unless otherwise noted.

Symbol: "<" = less than the analytical detection limit
"-" = the parameter or sample is not requested for analysis

Certified by:


Parker Shieh, Ph.D. Environmental Services

Date: 11/5/2008



ANALYTICAL REPORT

Certificate #: A0810S585

Project: Grafton L W/S

For: Whitehead Environmental Consultants **Date Received:** 18-Oct-08

RR1 CH-11, (621 Cates Hill Road) **Date Completed:** 5-Nov-08

Bowen Island, B.C. V0N 1G0

Account: IAO

Attention: Alan Whitehead

Fax: 604-947-0141

P.O. # 053-4

Tele: 604-947-0144

Analytical Results

| Parameter (Unit) | Analytical Method | Detection Limit | Analytical Result | | | |
|-------------------------------------|-------------------|-----------------|-------------------|-------------|--------------|--------------|
| | | | Sample ID 4 | Sample ID 7 | Sample ID 14 | Sample ID 15 |
| PHYSICAL TEST | | | | | | |
| Colour (C.U.) | APHA 2120B | 5 | 10 | 5 | <5 | <5 |
| Conductivity (uS/cm) | APHA 2510B | 1.0 | 169 | 189 | 161 | 302 |
| Total Dissolved Solids (mg/L) | APHA 2540C | 1 | 84 | 95 | 80 | 150 |
| Hardness (mg/L) | APHA 2340B/C | 1 | 45 | 48 | 52 | 108 |
| pH (S.U.) | APHA 2540D | 0.1 | 7.6 | 7.4 | 7.2 | 7.2 |
| Total Suspended Solids (mg/L) | APHA 2530B | 1 | 2 | 8 | 2 | 4 |
| Turbidity (NTU) | APHA 4500B | 0.05 | 0.82 | 3.50 | 0.66 | 0.18 |
| DISSOLVED ANION | | | | | | |
| Alkalinity CaCO ₃ (mg/L) | APHA 2320B | 0.5 | 34.2 | 33.1 | 35.2 | 63 |
| Chloride (mg/L) | APHA 4110B | 0.10 | 18.7 | 25.6 | 17.6 | 18.1 |
| Fluoride (mg/L) | APHA 4110B | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Sulphate (mg/L) | APHA 4110B | 0.5 | 9.3 | 6.5 | 9.4 | 39.3 |
| NUTRIENT | | | | | | |
| Ammonia Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | 0.24 | 0.16 | 0.25 | 0.15 |
| Total Kjeldahl Nitrogen (mg/L) | APHA 4500NB | 0.02 | 0.28 | 0.24 | 0.34 | 0.27 |
| Nitrate Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | 0.35 | 0.40 | 0.20 | 0.18 |
| Nitrite Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | <0.01 | <0.01 | <0.01 | <0.01 |
| Total Nitrogen N (mg/L) | EPA/APHA Cal | 0.02 | 0.87 | 0.80 | 0.79 | 0.60 |
| Diss Ortho-Phosphate P (mg/L) | APHA 4110B | 0.01 | 0.011 | <0.010 | <0.010 | <0.010 |
| NON-HALOGENATED VOLATILES | | | | | | |
| Benzene (ug/L) | EPA 503B/8260B | 0.1 | <0.1 | <0.1 | - | <0.1 |
| Ethyl benzene (ug/L) | EPA 503B/8260B | 0.1 | <0.1 | <0.1 | - | <0.1 |
| Styrene (ug/L) | EPA 503B/8260B | 0.1 | <0.1 | <0.1 | - | <0.1 |
| Toluene (ug/L) | EPA 503B/8260B | 0.1 | <0.1 | <0.1 | - | <0.1 |
| Meta/Para- Xylene (ug/L) | EPA 503B/8260B | 0.1 | <0.1 | <0.1 | - | <0.1 |
| Ortho-Xylene (ug/L) | EPA 503B/8260B | 0.1 | <0.1 | <0.1 | - | <0.1 |
| Total Xylene (ug/L) | EPA 503B/8260B | 0.1 | <0.1 | <0.1 | - | <0.1 |
| Volatile H.C. C6-C10 (ug/L) | EPA 503B/8260B | 100 | <100 | <100 | - | <100 |
| VPH (ug/L) | EPA 503B/8260B | 100 | <100 | <100 | - | <100 |
| BACTERIAL TEST | | | | | | |
| Fecal Coliform (CFU/100 mL) | APHA 9222 | 1 | 9 | 29 | 17 | <1 |
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ANALYTICAL REPORT

| | |
|-------------------------------------------------|---------------------------------|
| Certificate #: A0810S585 | Project: Grafton L W/S |
| For: Whitehead Environmental Consultants | Date Received: 18-Oct-08 |
| RR1 CH-11, (621 Cates Hill Road) | Date Completed: 5-Nov-08 |
| Bowen Island, B.C. V0N 1G0 | Account: IAO |
| Attention: Alan Whitehead | Fax: 604-947-0141 |
| P.O. # 053-4 | Tele: 604-947-0144 |

Analytical Results

| Parameter (Unit) | Analytical Method | Detection Limit | Analytical Result | | | |
|----------------------------------|-------------------|-----------------|-------------------|--------------|--------------|--------------|
| | | | Sample ID 16 | Sample ID 17 | Sample ID 19 | Sample ID 20 |
| PHYSICAL TEST | | | | | | |
| Colour (C.U.) | APHA 2120B | 5 | <5 | <5 | <5 | 5 |
| Conductivity (uS/cm) | APHA 2510B | 1.0 | 153 | 189 | 161 | 152 |
| Total Dissolved Solids (mg/L) | APHA 2540C | 1 | 77 | 88 | 77 | 75 |
| Hardness (mg/L) | APHA 2340B/C | 1 | 56 | 71 | 59 | 54 |
| pH (S.U.) | APHA 2540D | 0.1 | 7.5 | 6.8 | 6.4 | 6.5 |
| Total Suspended Solids (mg/L) | APHA 2530B | 1 | 2 | 5 | 2 | 2 |
| Turbidity (NTU) | APHA 4500B | 0.05 | 0.16 | 0.90 | 0.80 | 0.40 |
| DISSOLVED ANION | | | | | | |
| Alkalinity CaCO3 (mg/L) | APHA 2320B | 0.5 | 51.3 | 47.0 | 36.3 | 29.9 |
| Chloride (mg/L) | APHA 4110B | 0.10 | 6.78 | 14.6 | 17.3 | 22.3 |
| Fluoride (mg/L) | APHA 4110B | 0.05 | <0.05 | <0.05 | <0.05 | 4.9 |
| Sulphate (mg/L) | APHA 4110B | 0.5 | 6.7 | 6.8 | 5.4 | 6.5 |
| NUTRIENT | | | | | | |
| Ammonia Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | 0.09 | 0.05 | 0.16 | 0.14 |
| Total Kjeldahl Nitrogen (mg/L) | APHA 4500NB | 0.02 | 0.21 | 0.35 | 0.30 | 0.22 |
| Nitrate Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | 0.70 | 0.16 | 0.24 | 0.03 |
| Nitrite Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Total Nitrogen N (mg/L) | EPA/APHA Cal | 0.02 | 1.00 | 0.56 | 0.70 | 0.39 |
| Diss Ortho-Phosphate P (mg/L) | APHA 4110B | 0.01 | 0.011 | <0.010 | <0.010 | <0.010 |
| NON-HALOGENATED VOLATILES | | | | | | |
| Benzene (ug/L) | EPA 503B/8260B | 0.1 | - | <0.1 | - | - |
| Ethyl benzene (ug/L) | EPA 503B/8260B | 0.1 | - | <0.1 | - | - |
| Styrene (ug/L) | EPA 503B/8260B | 0.1 | - | <0.1 | - | - |
| Toluene (ug/L) | EPA 503B/8260B | 0.1 | - | <0.1 | - | - |
| Meta/Para- Xylene (ug/L) | EPA 503B/8260B | 0.1 | - | <0.1 | - | - |
| Ortho-Xylene (ug/L) | EPA 503B/8260B | 0.1 | - | <0.1 | - | - |
| Total Xylene (ug/L) | EPA 503B/8260B | 0.1 | - | <0.1 | - | - |
| Volatile H.C. C6-C10 (ug/L) | EPA 503B/8260B | 100 | - | <100 | - | - |
| VPH (ug/L) | EPA 503B/8260B | 100 | - | <100 | - | - |
| BACTERIAL TEST | | | | | | |
| Fecal Coliform (CFU/100 mL) | APHA 9222 | 1 | <1 | 3 | 3 | 27 |
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ANALYTICAL REPORT

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|-------------------------------------------------|---------------------------------|
| Certificate #: A0810S585 | Project: Grafton L W/S |
| For: Whitehead Environmental Consultants | Date Received: 18-Oct-08 |
| RR1 CH-11, (621 Cates Hill Road) | Date Completed: 5-Nov-08 |
| Bowen Island, B.C. V0N 1G0 | Account: IAO |
| Attention: Alan Whitehead | Fax: 604-947-0141 |
| P.O. # 053-4 | Tele: 604-947-0144 |

Analytical Results

| Parameter (Unit) | Analytical Method | Detection Limit | Analytical Result | | | |
|-------------------------------------|-------------------|-----------------|-------------------|--------------|--------------|--------------|
| | | | Sample ID 21 | Sample ID 23 | Sample ID 24 | Sample ID 25 |
| PHYSICAL TEST | | | | | | |
| Colour (C.U.) | APHA 2120B | 5 | 35 | 15 | 5 | - |
| Conductivity (uS/cm) | APHA 2510B | 1.0 | 60 | 401 | 103 | - |
| Total Dissolved Solids (mg/L) | APHA 2540C | 1 | 30 | 200 | 52 | - |
| Hardness (mg/L) | APHA 2340B/C | 1 | 54 | 67 | 26 | - |
| pH (S.U.) | APHA 2540D | 0.1 | 5.3 | 6.3 | 6.2 | - |
| Total Suspended Solids (mg/L) | APHA 2530B | 1 | 2 | 3 | 4 | - |
| Turbidity (NTU) | APHA 4500B | 0.05 | 0.29 | 0.92 | 1.02 | - |
| DISSOLVED ANION | | | | | | |
| Alkalinity CaCO ₃ (mg/L) | APHA 2320B | 0.5 | 8.5 | 34.2 | 3.0 | - |
| Chloride (mg/L) | APHA 4110B | 0.10 | 12.7 | 93.2 | 12.3 | - |
| Fluoride (mg/L) | APHA 4110B | 0.05 | 0.13 | <0.05 | <0.05 | - |
| Sulphate (mg/L) | APHA 4110B | 0.5 | 3.7 | 8.3 | 5.0 | - |
| NUTRIENT | | | | | | |
| Ammonia Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | 0.10 | 0.20 | 0.10 | - |
| Total Kjeldahl Nitrogen (mg/L) | APHA 4500NB | 0.02 | 0.33 | 0.49 | 0.48 | - |
| Nitrate Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | 0.11 | 0.55 | 0.10 | - |
| Nitrite Nitrogen N (mg/L) | EPA Colorimetric | 0.02 | <0.02 | <0.02 | <0.02 | - |
| Total Nitrogen N (mg/L) | EPA/APHA Cal | 0.02 | 0.54 | 1.24 | 0.68 | - |
| Diss Ortho-Phosphate P (mg/L) | APHA 4110B | 0.01 | <0.010 | <0.010 | <0.010 | - |
| NON-HALOGENATED VOLATILES | | | | | | |
| Benzene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Ethyl benzene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Styrene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Toluene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Meta/Para- Xylene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Ortho-Xylene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Total Xylene (ug/L) | EPA 503B/8260B | 0.1 | - | - | - | - |
| Volatile H.C. C6-C10 (ug/L) | EPA 503B/8260B | 100 | - | - | - | - |
| VPH (ug/L) | EPA 503B/8260B | 100 | - | - | - | - |
| BACTERIAL TEST | | | | | | |
| Fecal Coliform (CFU/100 mL) | APHA 9222 | 1 | 9 | 3 | - | - |
| | | | | | | |
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ANALYTICAL REPORT

Certificate #: A0810S585 **Project:** Grafton L W/S
For: Whitehead Environmental Consultants **Date Received:** 18-Oct-08
RR1 CH-11, (621 Cates Hill Road) **Date Completed:** 5-Nov-08
Bowen Island, B.C. V0N 1G0 **Account:** IAO
Attention: Alan Whitehead **Fax:** 604-947-0141
P.O. # 053-4 **Tele:** 604-947-0144

Analytical Results

| Parameter (Unit) | Analytical Method | Detection Limit | Analytical Result | | | |
|-----------------------------|-------------------|-----------------|-------------------|-------------|--------------|--------------|
| | | | Sample ID 4 | Sample ID 7 | Sample ID 14 | Sample ID 15 |
| TOTAL METAL ANALYSIS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | 40 | 147 | - | 42 |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | <0.05 | 0.23 | - | 0.62 |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | 1.6 | - | 1.2 |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | 16.0 | 22.0 | - | 16.0 |
| Boron (ug/L) | EPA 200 ICPMS | 5 | 23 | 27 | - | 5 |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | <0.05 | <0.05 | - | <0.05 |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | 0.6 | 1.0 | - | <0.5 |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | 0.7 | 1.6 | - | 0.4 |
| Iron (ug/L) | EPA 200 ICPMS | 10 | 210 | 590 | - | 35 |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | <0.1 | - | <0.1 |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | 3170 | 3190 | - | 3470 |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | 11.3 | 180 | - | 3.47 |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | <0.1 | - | <0.1 |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | 36 | 32 | - | 28 |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | <0.5 | - | <0.5 |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | 12500 | 15400 | - | 9280 |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | <0.02 | <0.02 | - | 0.03 |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | 1.5 | 1.6 | - | 3.1 |
| DISSOLVED METALS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | 32 | 120 | - | 40 |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | <0.5 | 0.21 | - | 0.60 |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | 1.6 | - | 1.2 |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | 15.0 | 20.0 | - | 15.0 |
| Boron (ug/L) | EPA 200 ICPMS | 5 | 9 | 26 | - | 5 |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | <0.05 | <0.05 | - | <0.05 |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | <0.5 | - | <0.5 |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | 1.0 | - | 0.4 |
| Iron (ug/L) | EPA 200 ICPMS | 10 | 200 | 570 | - | 32 |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | <0.1 | - | <0.1 |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | 2910 | 3100 | - | 2900 |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | 11.00 | 180 | - | 3.00 |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | <0.1 | <0.1 | - | <0.1 |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | <20 | <20 | - | <20 |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | <0.5 | - | <0.5 |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | 12400 | 14100 | - | 7660 |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | <0.02 | <0.02 | - | <0.02 |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | <0.5 | 1.0 | - | 3.0 |

ANALYTICAL REPORT

| | |
|-------------------------------------------------|---------------------------------|
| Certificate #: A0810S585 | Project: Grafton L W/S |
| For: Whitehead Environmental Consultants | Date Received: 18-Oct-08 |
| RR1 CH-11, (621 Cates Hill Road) | Date Completed: 5-Nov-08 |
| Bowen Island, B.C. V0N 1G0 | Account: IAO |
| Attention: Alan Whitehead | Fax: 604-947-0141 |
| P.O. # 053-4 | Tele: 604-947-0144 |

Analytical Results

| Parameter (Unit) | Analytical Method | Detection Limit | Analytical Result | | | |
|-----------------------------|-------------------|-----------------|-------------------|--------------|--------------|--------------|
| | | | Sample ID 16 | Sample ID 17 | Sample ID 19 | Sample ID 20 |
| TOTAL METAL ANALYSIS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | - | - | - | - |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Boron (ug/L) | EPA 200 ICPMS | 5 | - | - | - | - |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Iron (ug/L) | EPA 200 ICPMS | 10 | - | - | - | - |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | - | - | - | - |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | - | - | - | - |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | - | - | - | - |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | - | - | - | - |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| DISSOLVED METALS | | | | | | |
| Aluminum (ug/L) | EPA 200 ICPMS | 1 | - | - | - | - |
| Antimony (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Arsenic (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Barium (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Boron (ug/L) | EPA 200 ICPMS | 5 | - | - | - | - |
| Cadmium (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Chromium (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Copper (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Iron (ug/L) | EPA 200 ICPMS | 10 | - | - | - | - |
| Lead (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Magnesium (ug/L) | EPA 200 ICPMS | 50 | - | - | - | - |
| Manganese (ug/L) | EPA 200 ICPMS | 0.05 | - | - | - | - |
| Mercury (ug/L) | EPA 200 ICPMS | 0.1 | - | - | - | - |
| Phosphorus (ug/L) | EPA 200 ICPMS | 20 | - | - | - | - |
| Selenium (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |
| Sodium (ug/L) | EPA 200 ICPMS | 50 | - | - | - | - |
| Uranium (ug/L) | EPA 200 ICPMS | 0.02 | - | - | - | - |
| Zinc (ug/L) | EPA 200 ICPMS | 0.5 | - | - | - | - |

Bacterial Source Tracking (BST) - *Bacteroides* Method, Analysis Sheet

Environment Canada, Environmental Toxicology Section, Pacific Environmental Science Centre

| | | | |
|-----------------------------------------------|--|---------------------|------------------------|
| Client and Sample Information: | | Arrival at PESC: | 23Aug07 |
| Alan Whitehead | | Folder number: | 200701004 |
| Whitehead Environmental Consultants Ltd. | | Analyst(s): | MLS, LL |
| Project: Grafton Lake Watershed, Bowen Island | | Results checked by: | Michelle Linssen Sauv  |
| Sampling Date: 22Aug07 | | | |

Legend:

- = absent
- + = all possible markers present (1 of 1 for pig, horse, dog, elk; 2 of 2 for human, ruminant animal; result is **bolded**)
- *+ = 1 of 2 possible markers present
- +f or *+f = faint
- ? = unsure (potentially present)

| PESC sample # | Client's Sample Description | Fecal Count (per 100mL) | Human | Ruminant Animal | Pig | Horse | Dog | Elk | General <i>Bacteroides</i> | Summary of fecal pollution source identification evidence by BST: |
|---------------|-----------------------------|-------------------------|-------|-----------------|-----|-------|-----|-----|----------------------------|-------------------------------------------------------------------|
| 162010 | 4 | 24 | - | *+ | - | - | - | - | + | ruminant animal |
| 162011 | 7 | 72 | - | + | - | - | - | - | + | ruminant animal |
| 162012 | 12 | 3 | - | + | - | - | - | - | + | ruminant animal |
| 162013 | 14 | 16 | - | *+f | - | - | - | - | +f | ruminant animal |
| 162014 | 15 | 7 | - | - | - | - | - | - | + | general <i>Bacteroides</i> only; other species |
| 162015 | 17 | 1 | - | - | - | - | - | - | + | general <i>Bacteroides</i> only; other species |
| 162016 | 20 | 1 | - | - | - | - | - | - | + | general <i>Bacteroides</i> only; other species |
| 162017 | 23 | 1 | - | - | - | - | - | - | + | general <i>Bacteroides</i> only; other species |
| 162021 | 25 | 2 | - | *+f | - | - | - | - | + | ruminant animal |

Note: The system of scoring is as follows: '+' denotes a definitively positive result (all markers possible for a particular species are present, clear and sufficiently bright). '*+' denotes a sample for which 1 out of 2 markers was detected (for those species with more than one marker), which is not as definitive as if both markers were present, but is still a positive result. The occurrence of 1 out of 2 markers, or a faint or unsure result, may be due to a few reasons: 1. the method is at the edge of detection for this sample with respect to the amount of fecal matter present for a particular species. 2. not every single organism may carry both markers but in a herd (or larger number) of animals, you would expect to find both markers represented. In cases like this then, it is probable that an individual organism, possibly two organisms, caused this fecal pollution and that this particular individual did not have both markers. 3. the fecal material inoculation is old, or other sample conditions (eg protozoa, temperature) are allowing the bacteria and DNA to degrade (bands can become smeared).

Note: A positive result for general *Bacteroides* only indicates fecal contamination without implicating a specific source. If a sample also tests positive for markers from one or more specific animal group tested, then this is likely the, or definitely one of the contributors of the general *Bacteroides*. We do not have specific primers for other potential contributors (eg birds, seals, bears) at this time. If a sample tests positive for only general *Bacteroides*, it could be interpreted as "other species of animal" and the fecal contamination in the sample could not be attributed to human, ruminant animal, pig, horse, dog or elk sources.

QA/QC passed: All three negative controls (equipment blank, extraction blank and PCR blank) tested clear, and the PCR positive control reference test worked well.

Ruminant = deer, elk, goat, sheep, llama = pseudoruminant (<http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=92346>) (above note added by AW 20-Sep-07)

Bacterial Source Tracking (BST) - *Bacteroides* Method, Analysis Sheet

Environment Canada, Environmental Toxicology Section, Pacific Environmental Science Centre

| | | | |
|-----------------------------------------------|--|---------------------|------------------------|
| <u>Client and Sample Information:</u> | | Arrival at PESC: | 26Jun08 |
| Alan Whitehead | | Folder number: | 200800601 |
| Whitehead Environmental Consultants Ltd. | | Analyst(s): | MLS, LL |
| Project: Grafton Lake Watershed, Bowen Island | | Results checked by: | Michelle Linssen Sauvé |
| Sampling Date: 25Jun08 | | | |

Legend:

- = absent
 + = all possible markers present (1 of 1 for pig, horse, dog, elk; 2 of 2 for human, ruminant animal; result is **bolded**)
 *+ = 1 of 2 possible markers present
 +f or *+f = faint
 ? = unsure (potentially present)

| PESC sample # | Client's Sample Description | Fecal Count (per 100mL) | Human | Ruminant Animal | Pig | Horse | Dog | Elk | General <i>Bacteroides</i> | Summary of fecal pollution source identification evidence by BST: |
|---------------|---------------------------------|-------------------------|-------|-----------------|-----|-------|-----|-----|----------------------------|-------------------------------------------------------------------|
| 176015 | 4, Bowen Br u/s Harding Rd | 30 | *+ | + | - | - | - | - | + | <i>human, ruminant animal</i> |
| 176016 | 7, Harding Ck u/s Harding Rd | 420 | - | *+? | - | - | - | - | + | potential ruminant animal |
| 176017 | 12, Proudlock Br u/s Grafton Rd | 17 | - | *+ | - | - | - | - | + | ruminant animal |
| 176018 | 14a, Bowen Br u/s Buchanan Rd | 20 | *+? | + | - | - | - | - | + | <i>potential human, ruminant animal</i> |
| 176019 | 15, Billington Ck u/s mouth | 8 | *+? | - | - | - | - | - | + | <i>potential human</i> |
| 176020 | 17, Lister Ck u/s mouth | 1 | *+? | *+? | - | - | - | - | + | <i>potential human, potential ruminant</i> |
| 176021 | 20, Bowen Br u/s Sunset Dr | n/p | *+? | + | - | - | - | - | + | <i>potential human, ruminant animal</i> |
| 176022 | 23, unnamed ck d/s Adams Rd | 6 | *+? | *+ | - | - | - | - | + | <i>potential human, ruminant animal</i> |
| 176014 | 25, Grafton Lk @ rocky point | 1 | *+ | *+ | - | - | - | - | + | <i>human, ruminant animal</i> |

Note: The system of scoring is as follows: '+' denotes a definitively positive result (all markers possible for a particular species are present, clear and sufficiently bright). '*+' denotes a sample for which 1 out of 2 markers was detected (for those species with more than one marker), which is not as definitive as if both markers were present, but is still a positive result. The occurrence of 1 out of 2 markers, or a faint or unsure result, may be due to a few reasons: 1. the method is at the edge of detection for this sample with respect to the amount of fecal matter present for a particular species. 2. not every single organism may carry both markers but in a herd (or larger number) of animals, you would expect to find both markers represented. In cases like this then, it is probable that an individual organism, possibly two organisms, caused this fecal pollution and that this particular individual did not have both markers. 3. the fecal material inoculation is old, or other sample conditions (eg protozoa, temperature) are allowing the bacteria and DNA to degrade (bands can become smeared).

Note: A positive result for general *Bacteroides* only indicates fecal contamination without implicating a specific source. If a sample also tests positive for markers from one or more specific animal group tested, then this is likely the, or definitely one of the contributors of the general *Bacteroides*. We do not have specific primers for other potential contributors (eg birds, seals, bears) at this time. If a sample tests positive for only general *Bacteroides*, it could be interpreted as "other species of animal" and the fecal contamination in the sample could not be attributed to human, ruminant animal, pig, horse, dog or elk sources.

QA/QC passed: All three negative controls (equipment blank, extraction blank and PCR blank) tested clear, and the PCR positive control reference test worked well.

Bacterial Source Tracking (BST) - *Bacteroides* Method, Analysis Sheet

Environment Canada, Environmental Toxicology Section, Pacific Environmental Science Centre

| | | | |
|-----------------------------------------------|--|---------------------|------------------------|
| <u>Client and Sample Information:</u> | | Arrival at PESC: | 16Oct08 |
| Alan Whitehead | | Folder number: | 200801098 |
| Whitehead Environmental Consultants Ltd. | | Analyst(s): | MLS, GL |
| Project: Grafton Lake Watershed, Bowen Island | | Results checked by: | Michelle Linssen Sauv  |
| Sampling Date: 15Oct08 | | | |

Legend:

- = absent
 + = all possible markers present (1 of 1 for pig, horse, dog, elk; 2 of 2 for human, ruminant animal; result is **bolded**)
 *+ = 1 of 2 possible markers present
 +f or *+f = faint
 ? = unsure (potentially present)

| PESC sample # | Client's Sample Description | Fecal Count (per 100mL) | Human | Ruminant Animal | Pig | Horse | Dog | Elk | General <i>Bacteroides</i> | Summary of fecal pollution source identification evidence by BST: |
|---------------|-----------------------------|-------------------------|-------|-----------------|-----|-------|-----|-----|----------------------------|-------------------------------------------------------------------|
| 182571 | 4 | n/p | - | *+? | - | - | - | - | + | potential ruminant animal |
| 182581 | 7 | n/p | *+? | *+ | - | - | - | - | + | potential human, ruminant animal |
| 182582 | 11 | n/p | - | *+? | - | - | - | - | + | potential ruminant animal |
| 182583 | 12 | n/p | - | *+? | - | - | - | - | + | potential ruminant animal |
| 182584 | 14 | n/p | *+? | *+? | - | - | - | - | + | potential human, potential ruminant |
| 182585 | 15 | n/p | - | - | - | - | - | - | + | general <i>Bacteroides</i> only |
| 182586 | 16 | n/p | - | *+? | - | - | - | - | + | potential ruminant animal |
| 182587 | 17 | n/p | - | *+? | - | - | - | - | + | potential ruminant animal |
| 182588 | 19 | n/p | *+? | *+? | - | - | - | - | + | potential human, potential ruminant |
| 182589 | 20 | n/p | - | *+? | - | - | - | - | + | potential ruminant animal |
| 182590 | 21 | n/p | *+? | *+? | - | - | - | - | + | potential human, potential ruminant |
| 182591 | 23 | n/p | *+? | *+? | - | - | - | - | + | potential human, potential ruminant |
| 182592 | 24 | n/p | + | *+ | - | - | - | - | + | human, ruminant animal |

Note: The system of scoring is as follows: '+' denotes a definitively positive result (all markers possible for a particular species are present, clear and sufficiently bright). '*+' denotes a sample for which 1 out of 2 markers was detected (for those species with more than one marker), which is not as definitive as if both markers were present, but is still a positive result. The occurrence of 1 out of 2 markers, or a faint or unsure result, may be due to a few reasons: 1. the method is at the edge of detection for this sample with respect to the amount of fecal matter present for a particular species. 2. not every single organism may carry both markers but in a herd (or larger number) of animals, you would expect to find both markers represented. In cases like this then, it is probable that an individual organism, possibly two organisms, caused this fecal pollution and that this particular individual did not have both markers. 3. the fecal material inoculation is old, or other sample conditions (eg protozoa, temperature) are allowing the bacteria and DNA to degrade (bands can become smeared).

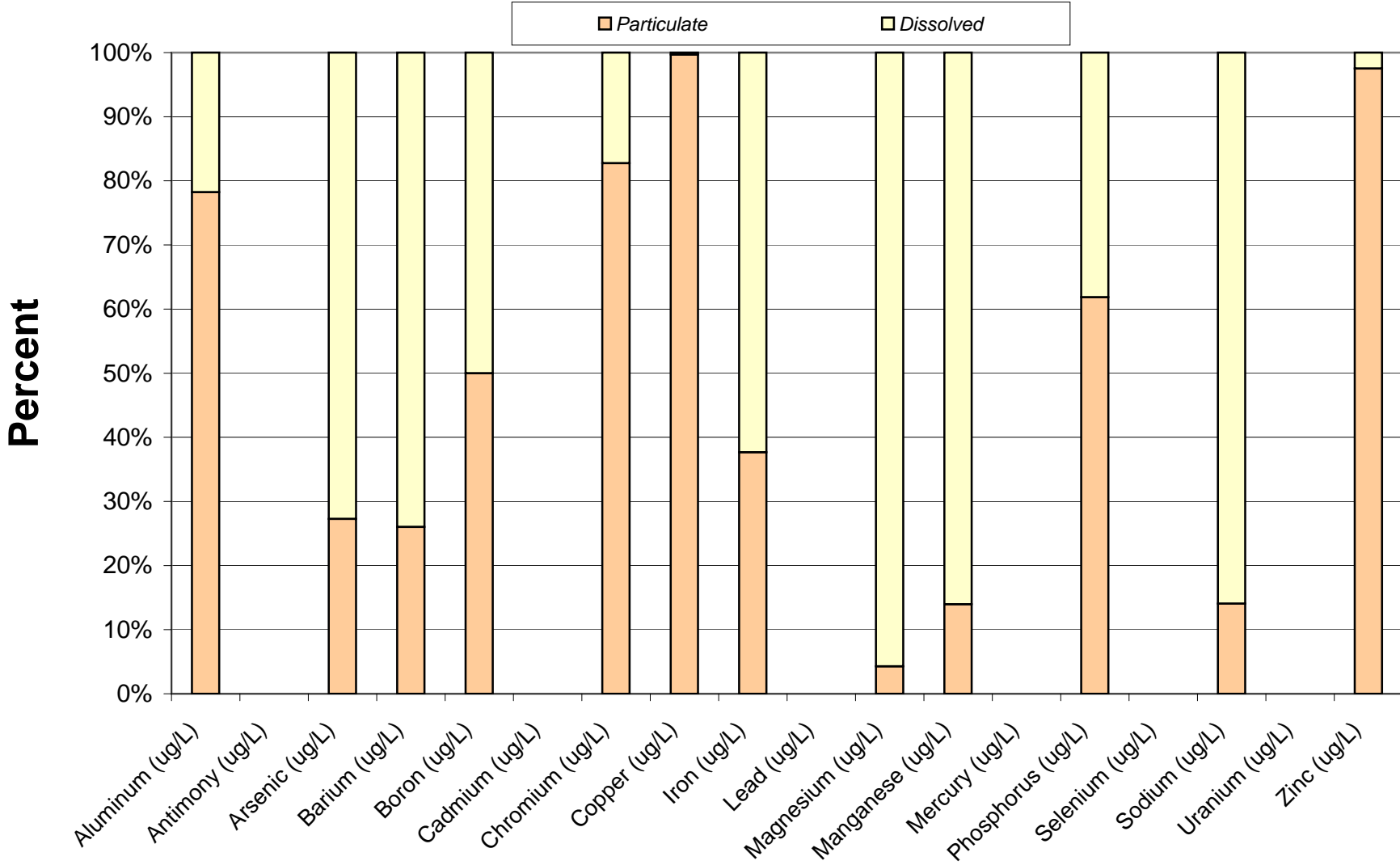
Note: A positive result for general *Bacteroides* only indicates fecal contamination without implicating a specific source. If a sample also tests positive for markers from one or more specific animal group tested, then this is likely the, or definitely one of the contributors of the general *Bacteroides*. We do not have specific primers for other potential contributors (eg birds, seals, bears) at this time. If a sample tests positive for only general *Bacteroides*, it could be interpreted as "other species of animal" and the fecal contamination in the sample could not be attributed to human, ruminant animal, pig, horse, dog or elk sources.

QA/QC passed: All three negative controls (equipment blank, extraction blank and PCR blank) tested clear, and the PCR positive control reference test worked well.

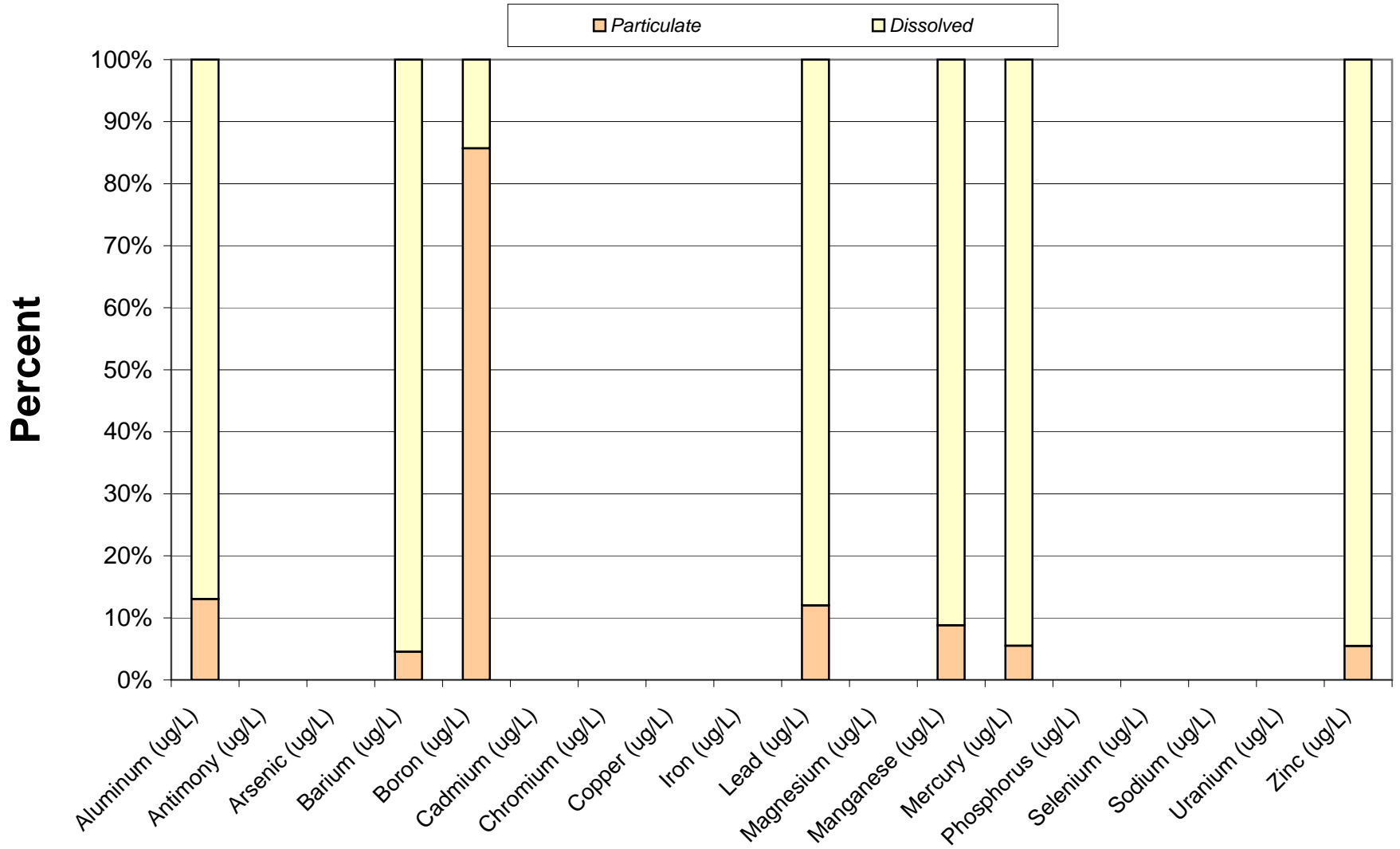
APPENDIX 3.

Dissolved and Particulate Metals Fractions in Bowen Brook,
Harding Brook and Billington Creek, Bowen Island

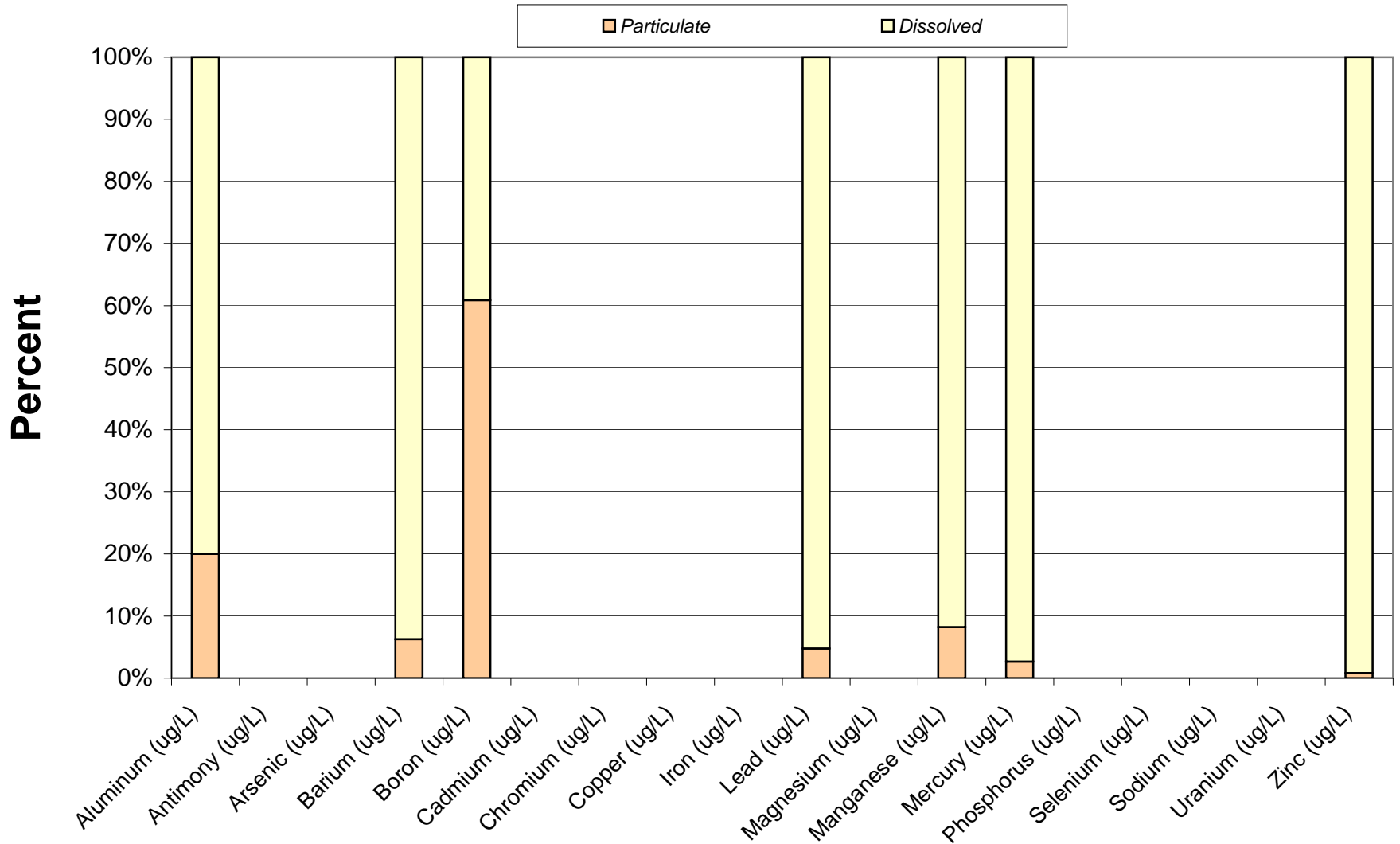
Graph A. Dissolved and Particulate Portions of Total Metals Content in Surface Water in Bowen Brook, 22 August 2007



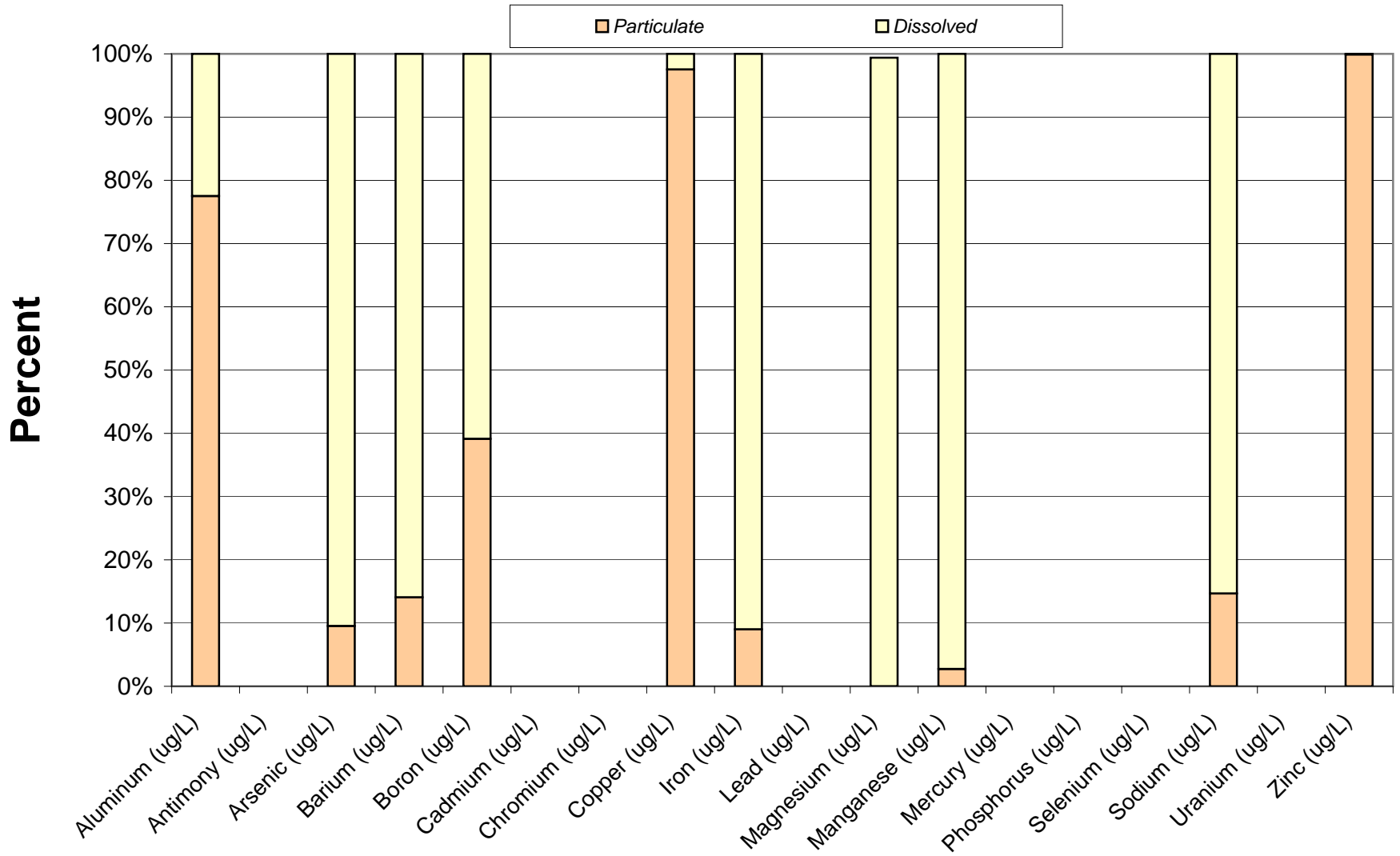
Graph B. Dissolved and Particulate Portions of Total Metals Content in Surface Water in Bowen Brook, 25 June 2008



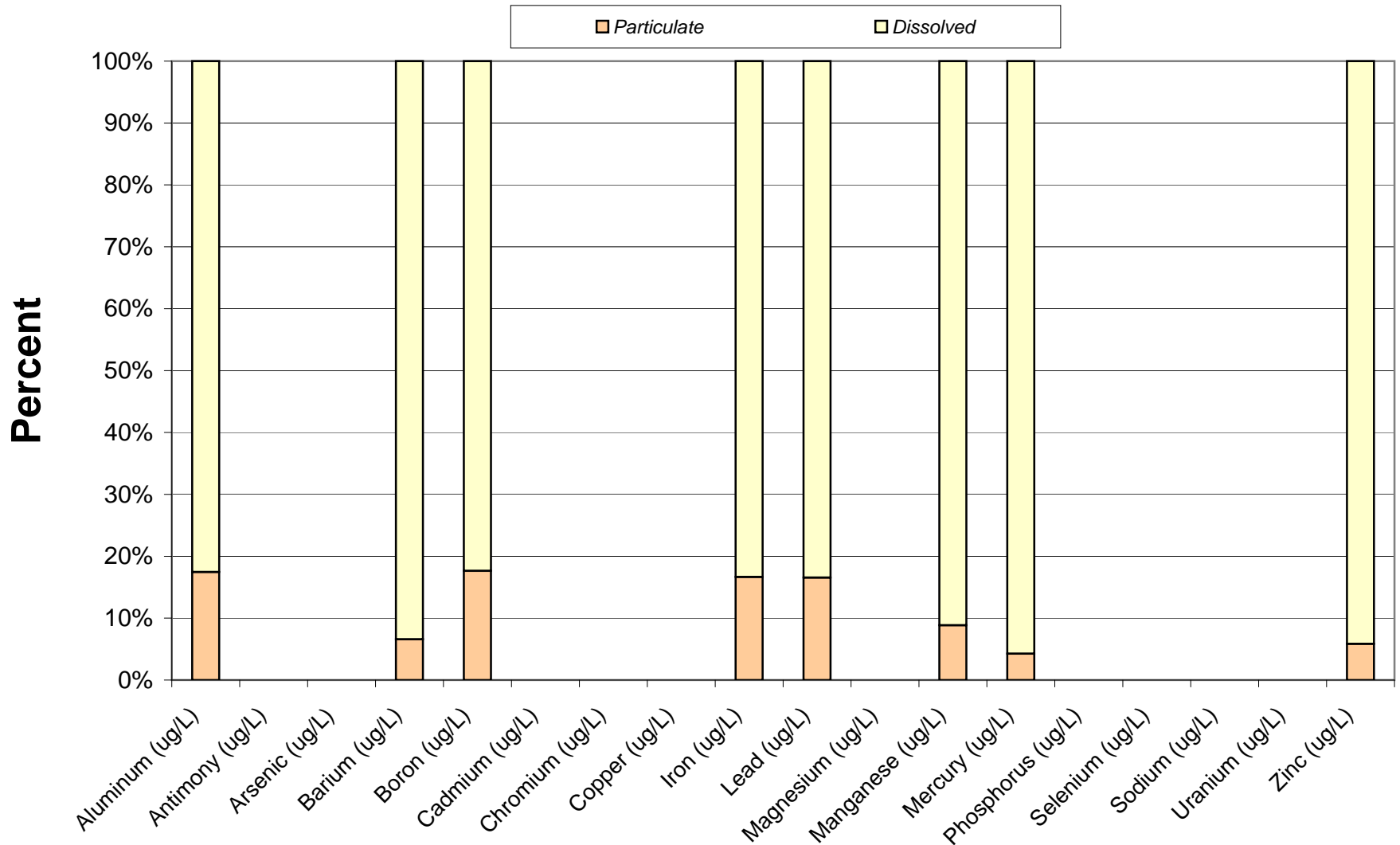
Graph C. Dissolved and Particulate Portions of Total Metals Content in Surface Water in Bowen Brook, 15 October 2008



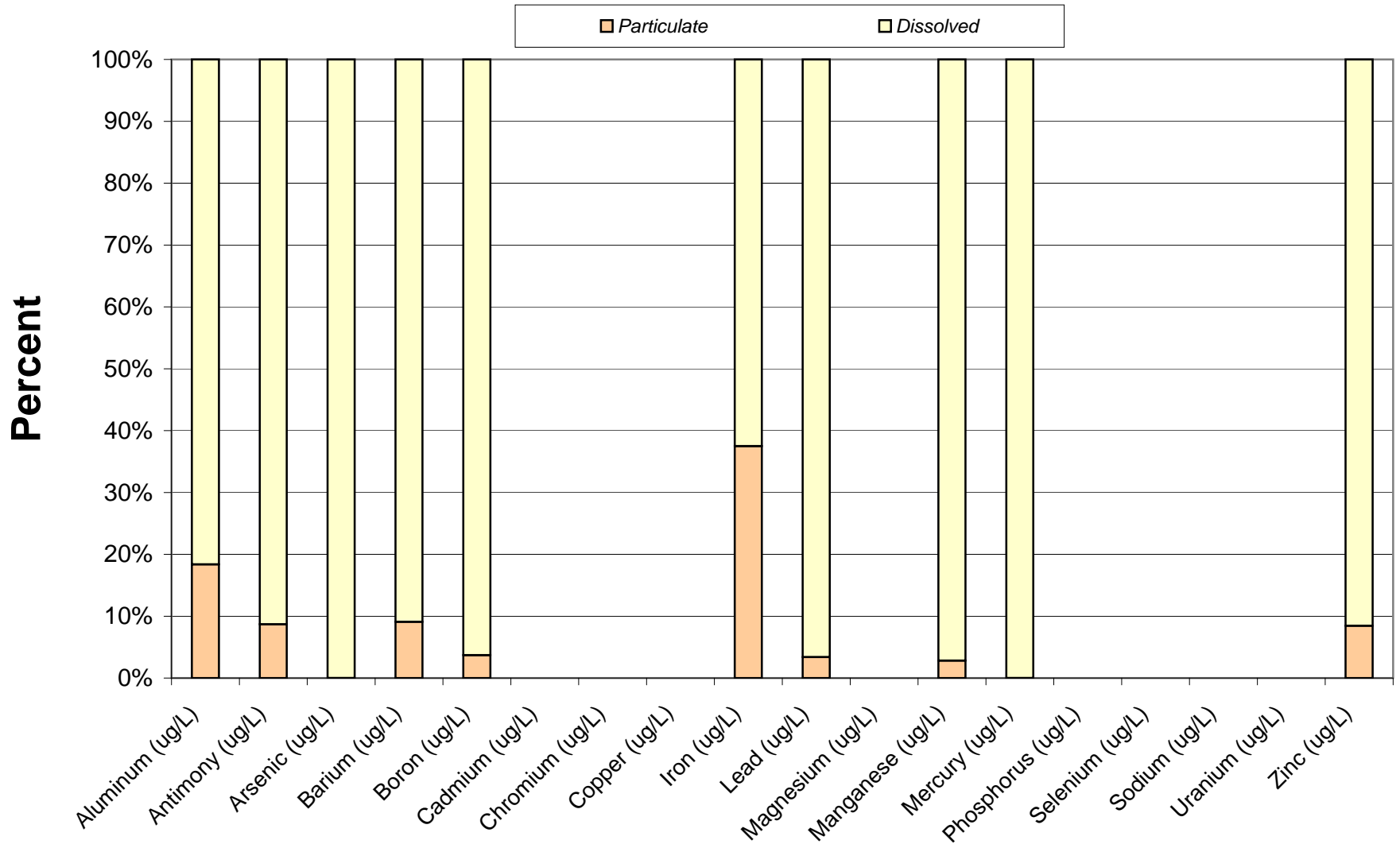
Graph D. Dissolved and Particulate Portions of Total Metals Content in Surface Water in Harding Brook, 22 August 2007



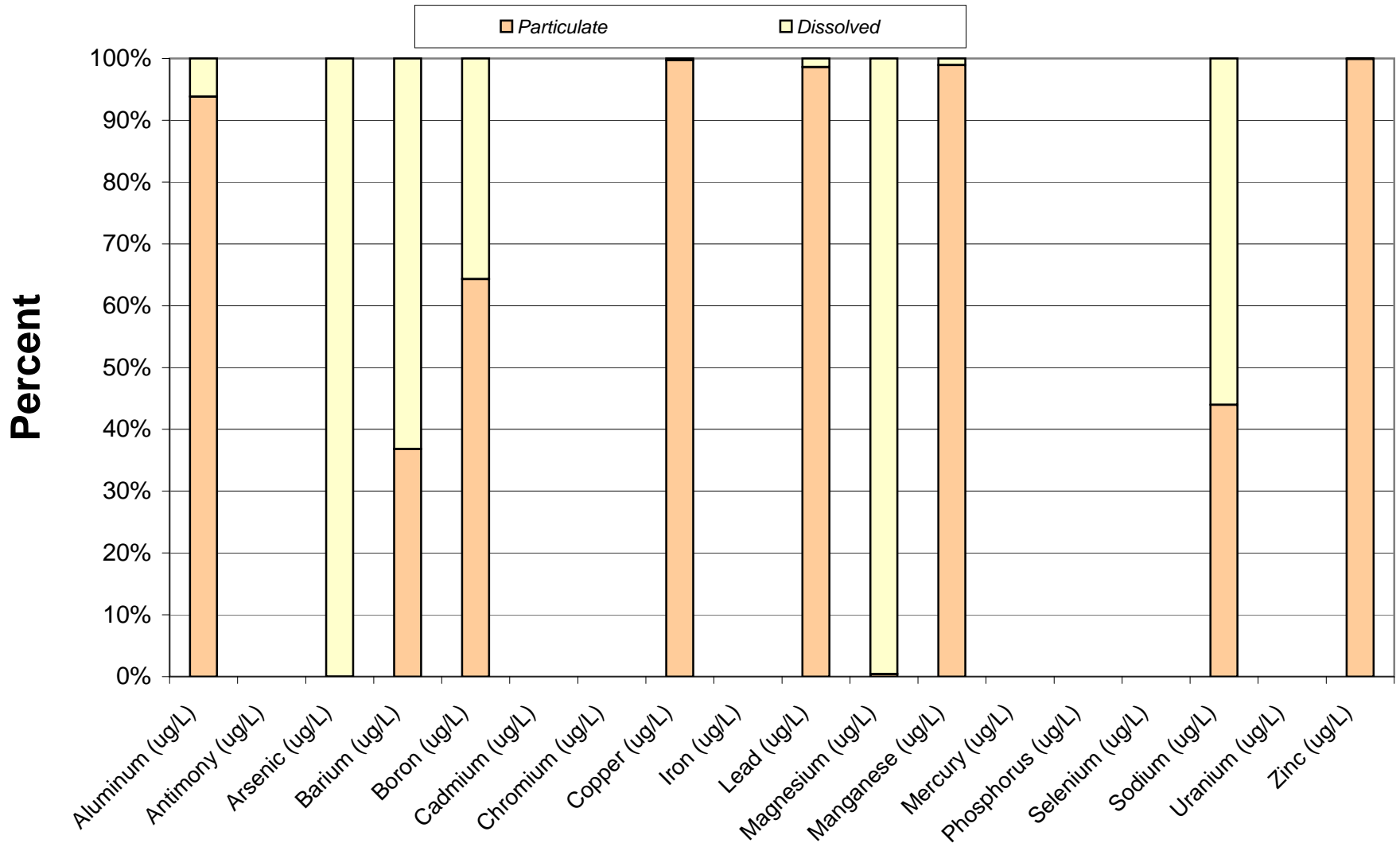
Graph E. Dissolved and Particulate Portions of Total Metals Content in Surface Water in Harding Brook, 25 June 2008



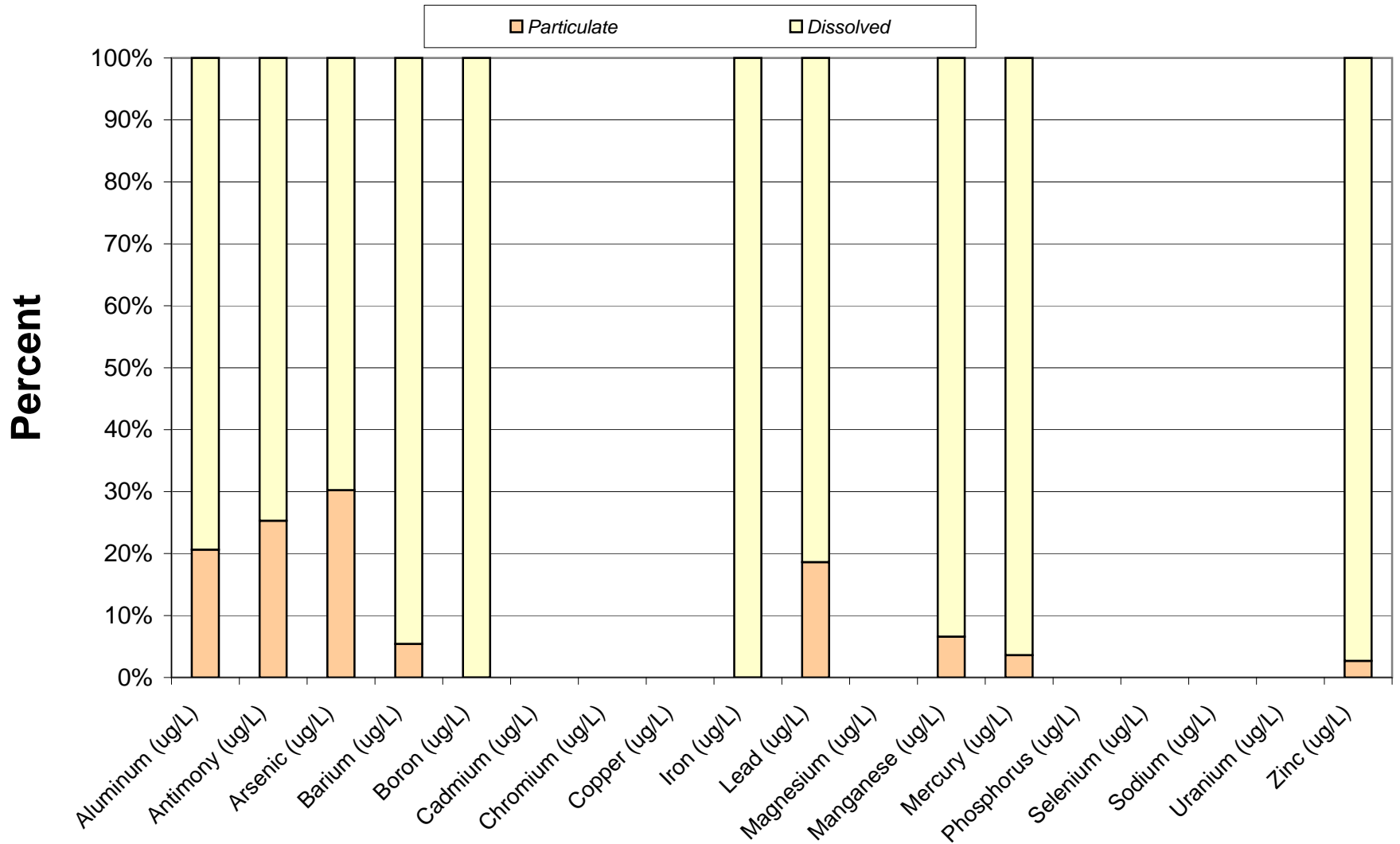
Graph F. Dissolved and Particulate Portions of Total Metals Content in Surface Water in Harding Brook, 15 October 2008



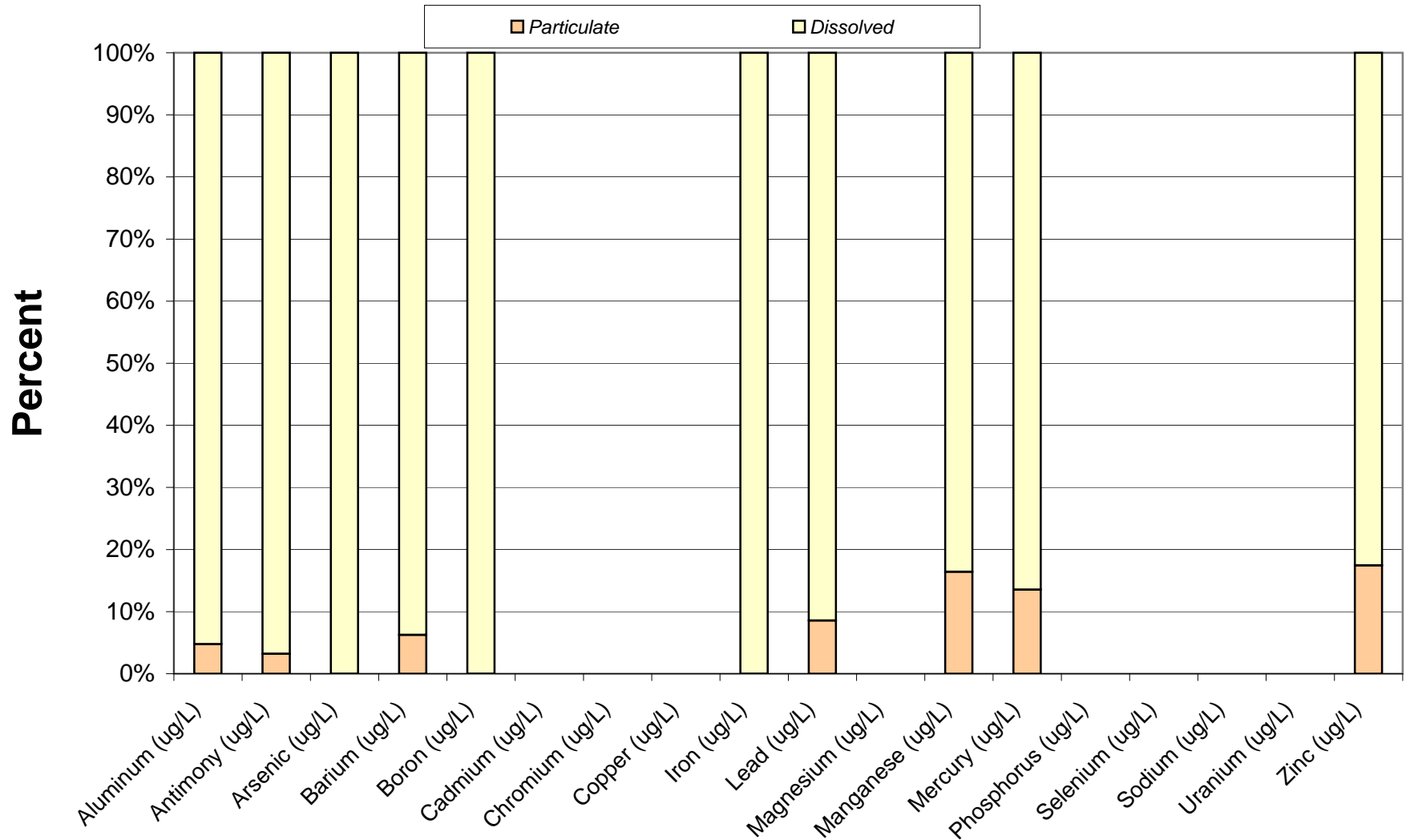
Graph G. Dissolved and Particulate Portions of Total Metals Content in Surface Water, Billington Creek, 22 August 2007



Graph H. Dissolved and Particulate Portions of Total Metals Content in Surface Water, Billington Creek, 25 June 2008



Graph I. Dissolved and Particulate Portions of Total Metals Content in Surface Water, Billington Creek, 15 October 2008



APPENDIX 4. PHOTOGRAPHS



Photo 1. Marsh wetland at east end of Grafton Lake, viewed from vicinity of outlet dam. 8-May-07



Photo 2. Swamp wetland in forest on west side of side Grafton Lake. 8-May-07



Photo 3. Marsh on northeast side of Grafton lake viewed from cliff on north side.
11-May-07



Photo 4. Outer edge of marsh on southwest side of Grafton lake, viewed to north.
18-Jul-08



Photo 5. Automated water quality monitoring apparatus in CBWS chlorination shed, operated by Ministry of Environment Water Stewardship. 17-Jul-07



Photo 6. Snow and ice cover on Grafton lake, viewed from south side toward rocky point. 11-Feb-09



Photo 7. Outlet dam on Grafton lake and beaver dam debris removed by BIM staff. Inset shows water level of 105.20 m on that date. 25-Mar-09



Photo 8. Grafton lake outlet dam during summer draw-down. Inset shows staff gauge indicating a water level of 104.87 m on that date. Note remote-control video camera in log on far side of dam, used to monitor beaver activity. 23-Jul-09



Photo 9. Grafton lake outlet dam during summer draw-down. Ropes attach to outlet pipes installed through under drain to overcome damming by beavers and ensure compliance with water release requirements to Terminal Creek. 19-Aug-09



Photo 10. Lake bed in marsh at east end of Grafton Lake exposed by water draw down in summer. 19-Aug-09



Photo 11. Marsh sediments at east end of Grafton Lake exposed by water draw down in summer. Oxidation of nitrogen in these sediments during exposure to air causes release of nitrate into water once sediments become re-submerged. 19-Aug-09



Photo 12. Yellow pond lily plant exposed to overheating during lake draw of Grafton Lake reservoir down in summer. 19-Aug-09



Photo 13. Deployment of recording temperature sensors in Grafton Lake. Arrows indicate individual sensors spaced at 1-m depth intervals. 18-Jul-08



Photo 14. Buoys marking location of temperature monitoring system in Grafton Lake, viewed toward outlet dam. 18-Jul-08



Photo 15. Close-up of temperature monitoring device (battery-powered thermister and data logger) installed to measure air temperature beside Grafton lake. 25-Mar-09



Photo 16. Water temperature monitoring system after retrieval from Grafton Lake. Photo shows anchor, floats and rope on which temperature sensors were attached. 23-Jul-09



Photo 17. Mated pair of Canada geese swimming toward nest (arrow) on islet in wetland at east end of Grafton Lake. These geese were later preyed upon by a Bald Eagle and killed. 6-Apr-09



Photo 18. Nest of Canada Goose on cliff ledge beside north shore of Grafton Lake. Eggs in this nest, first observed in 2007, were depredated by ravens (see next photo). 13-May-09



Photo 19. Remains of Canada Goose egg preyed upon by Common Raven on north side of Grafton Lake. 11-May-07



Photo 20. Mallard ducks swimming and bathing in marsh at east end of Grafton Lake during summer draw down conditions. 24-Aug-09



Photo 21. Beaver lodge at edge of wetland on southwest shore of Grafton Lake. This is understood to be the second of three lodges recorded to date. 13-May-09



Photo 22. Red alder tree felled by a beaver on the southeast side of Grafton Lake. Tree diameter at cut is approximately 20 cm. 19-May-09



Photo 23. Newest beaver lodge at east end of Grafton Lake, viewed from outlet dam. This lodge was built during late 2009. 3-Feb-10



Photo 24. Stumps of red alder trees and smaller shrubs cut by beaver beside terminal Creek immediately downstream of the Grafton lake outlet dam. 3-Feb-10



Photo 25. Columbia black-tailed deer swimming across Grafton Lake in a NE direction. 23-May-09

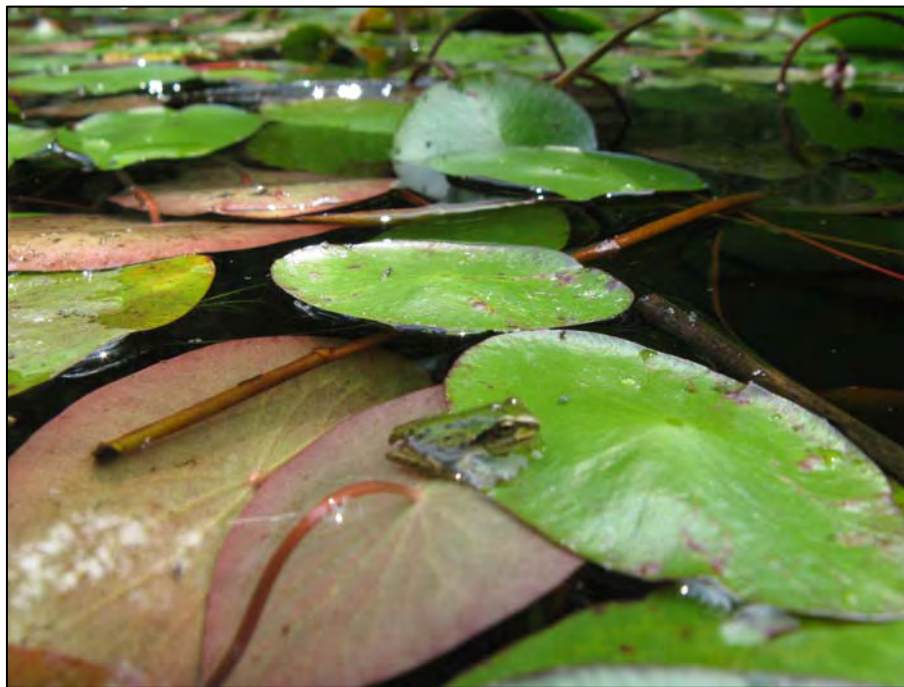


Photo 26. Pacific tree frog resting on water shield leaves in marsh at east end of Grafton Lake. Many individuals, adults and juveniles, were observed at this location. 23-Jul-09



Photo 27. Contact recreation in Grafton Lake reservoir at rocky point. Bacteriological analysis of water sampled at this location confirmed the presence of human fecal contamination. 18-Jul-08



Photo 28. Crushed vehicles loaded on truck at Buchanan Road quarry, ready for transport off-island for ultimate disposal/recycling. 22-Apr-09