An Investigation of High Arsenic Levels in Wells in the Sunshine Coast and Powell River Regions of B.C.

FINAL REPORT

Prepared for the
Coast Garibaldi Community Health Services Society

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Executive Summary

This study was initiated to provide a greater understanding of sources and occurrence of high arsenic concentrations in groundwater in the Sunshine Coast and Powell River regions of British Columbia. In 1994, it was discovered that many drinking water wells contained arsenic at levels much higher than Canadian drinking water guidelines. Results from a study conducted in 1994 revealed elevated arsenic concentrations throughout the region, however, the sources of the arsenic were not confirmed. The spatial and temporal variability of the results raised concerns as to the reliability of these results. This study was launched to address some of these concerns.

Arsenic is a carcinogen, meaning it can cause cancer. Consumption of water containing arsenic concentrations above drinking water guidelines over long periods of time can cause a variety of health effects. The Guidelines for Canadian Drinking Water Quality (GCDWQ) are currently referred to during the assessment of water potability and the approval of new water supplies in the region. The current guideline for arsenic is 0.025 ppm. This guideline may be lowered in the next few years due to developments in treatment technology as well as new research into effects of arsenic on human health. This must be taken into consideration when approving drinking water supplies. Various options are available for a management framework with which to manage water supplies in areas with high arsenic concentrations.

There are many treatment options for removing arsenic from water. None of these technologies are 100 percent effective, and on-going monitoring and maintenance is essential to ensure that the devices are working properly. Many ions that are naturally present in groundwater can dramatically lower the efficiency of the removal of arsenic from water.

All chemical measurements have some uncertainty associated with them. Arsenic is one element that seems to have a great deal of analytical variability. Results from QA/QC samples showed that variability of up to 25% can be expected in routine arsenic analysis.

Twenty-one sites were monitored in this study over the course of a year. Results did not show any systematic seasonal variability in arsenic concentrations, however, significant variability was observed in the samples over time. Half of the wells sampled had arsenic concentrations above drinking water guidelines. An analysis of arsenic speciation revealed that it is not possible to assume that the arsenic is in one form or the other. The arsenic was distributed between the two forms, with most samples containing approximately 80% of arsenic in the As (V) form. However, a few of the samples had arsenic predominantly in the arsenic (III) form.

Significant positive correlations (α=0.05) were found between the high arsenic concentrations and elevated concentrations of fluoride and boron in the water. pH and conductivity also correlated well with the arsenic concentrations. No significant correlation was found between arsenic and well depth.

The source of the arsenic is thought to be mineralization deposits in fissures that are present in the bedrock. The movement of groundwater through these fissures is thought to dissolve and transport the arsenic into the wells.

Introduction

In 1994, high levels of arsenic were found in drinking water obtained from wells in the Sunshine Coast and Powell River areas of British Columbia. This discovery led to the testing of a large number of wells for arsenic. The results, documented in a report for the Coast Garibaldi Health Unit (Carmichael et al, 1995), indicated elevated levels of arsenic in a number of wells. Similar levels of arsenic were found in wells on Bowen Island.

This study was launched to conduct a scientifically rigorous analysis of the high arsenic concentrations found in groundwater. The goals were to; determine the levels of arsenic in groundwater, to elucidate any seasonal variation in the arsenic concentrations, and investigate any relationships between arsenic and other water quality parameters. The sources of the arsenic were to be studied, along with arsenic speciation, analytical variability, and regulatory and treatment issues related to the issue.

The average arsenic (As) concentration in the earth's crust is 2 ppm (parts per million) but it can be much more concentrated in arsenic containing ores such as arsenopyrite (FeAsS). It can also be a constituent of other minerals such as pyrite (FeS_2). Arsenic is the 20th most common element in the earth and the 12th most common element in the human body. Arsenic is on the Drinking Water Substances Priority List 1, as it is one of the few metals that is known to be a carcinogen.

Arsenic can occur in different forms in the environment, in groundwater it is usually found as As (III) or As (V). In reality, arsenic binds to water to form H_3AsO_3 or $H_3AsO_3^{2-}$, arsenite and arsenate respectively. Arsenic in groundwater is usually assumed to be in the As (III) form due to the anoxic conditions present in the aquifer. The aqueous chemistry of arsenic is discussed in depth in the excellent review by Cullen and Reimer (1989).

High concentrations of arsenic have been found in many parts of the world including major parts of Bangladesh, in Taiwan, Chile, and in many parts of North America, especially along the western coast (Abernathy et al, 1999). In Canada, high levels of arsenic have also been found in Saskatchewan, Manitoba, Ontario, and Nova Scotia. In one area of Nova Scotia, 10% of samples of well water from areas with natural arsenic sources contained more than 0.5 ppm of arsenic. High levels of arsenic have been found locally in this study area, as well as on Vancouver Island, other regions of BC, and in Washington state.

Hydrogeology & Geological Setting

The study area is located along margins of the Coast Plutonic Complex on the west coast of BC. Figure one shows the location of the study area along the southwestern coast of British Columbia. A good review of the geologic setting is given in the 1995 report by Carmichael et al. This area is overlain by glacial sediments such as unconsolidated till, sand, and gravel from the Quaternary Period, mostly from the last Ice Age. A simplified overview of the bedrock indicates that the area is composed two major types of bedrock; granitic such as diorite, quartz diorite and granodiorite; and basaltic. The boundaries between these two bedrock types are not well mapped because there is little bedrock exposure at the surface. These two rock types are not well separated in all areas, in some places they are interbedded, with many basaltic extrusions present in fissures in the granitic rock. Distinct areas of different rock such as Upper Triassic basalt flows and pillow lavas of the Karmutsen Formation are also present in the study area, such as near McNaughton Point, north of Secret Cove (see Figure 1) and other locations along the coast.

Large masses of rocks are invariably faulted and fractured, especially in tectonically active areas such as the southern coast of BC. In this region, the fracture pattern generally trends in a northwest direction, which is also seen in the orientations of the many fjords along the coast. The fractures and fissures act as conduits for water. The exposed surface rocks were formed deep below the surface of the earth and raised up by tectonic activity and erosion. The environmental conditions which influence the rock today are very different from the conditions that the rock was subjected to in the past. While magma was cooling and forming the rock, superheated water circulated through the fissures. This water carried many different chemical species, which may have been precipitated in the fissures as the rock cooled. Many different minerals may have crystallized from the magma into the rock that now forms the bedrock through complex physical and chemical processes. These materials can include arsenopyrite (FeAsS), and other minerals which may also contain traces of arsenic. Today, when water circulates through the fissures, it has a much different chemical composition and weathers the material in and around the fissures. The weathered material dissolves into the water which is then intercepted by the wells.

The islands in Howe Sound such as Keats, Bowen, Gambier and along the coast such as S. Thormanby have different origins than the mainland. There are more rocks of volcanic origin on the islands, as well as metamorphic and sedimentary rocks.

Possible Changes to Arsenic Guidelines

The sixth edition of the Guidelines for Canadian Drinking Water Quality (Federal-Provincial Subcommittee on Drinking Water, 1996) lists the interim maximum acceptable concentration (IMAC) for arsenic as 0.025 ppm (mg/L). The lack of affordable and adequate treatment methods to effectively reduce arsenic below the IMAC is the reason for the value being interim. This is also an interim value because the lifetime cancer risk associated with arsenic at 0.025 ppm is greater than what is considered to be negligible. There are a number of studies currently in progress to provide more information and a more complete picture of the effects of arsenic on human health. Health Canada and various scientists, including those working with the EPA, AWWA, and other organizations are currently conducting research on this topic and their findings may lead to a revision of the guideline to a permanent MAC at some point in the future. The current IMAC implies a skin cancer risk of up to 1 in 1000, assuming lifetime consumption of water containing arsenic above 0.025 ppm.

The environmental protection agency (EPA) of the USA was ordered by the US Congress to produce a new regulatory guideline for arsenic in drinking water by January of 2000. The current American guideline is 0.050 ppm, based on data from 1943. A major study by the U.S. National Research Council (Christen, 1999, NAS, 1999), which was ordered by the US government, recommended lowering this guideline because it does not adequately protect human health. The EPA is expected to present the revised arsenic guideline by mid May 2000 and is expected to set a final guideline by January 1, 2001. This value will be based on extensive research and consultation with stakeholders. Discussions with individuals involved in the process indicate that level is expected to be somewhere between 0.002 and 0.025 ppm. The World Health Organization has a recommended guideline of 0.010 ppm for arsenic, which is the same as in some European countries such as Germany.

Policy and Management Issues

There are two cases to be considered: existing wells which have high levels of arsenic and new development sites in areas not serviced by a waterworks system. Information should be provided by the health unit to existing owners of existing wells containing high levels of arsenic on treatment options or use of bottled water. In new developments, it does not seem logical to have bottled water regulations, it would be desirable to focus development in areas with access to a municipal water utility, in areas with low arsenic levels, or in areas where the arsenic could be safely treated. Another option may be to direct development into areas with a deep sediment cover. This could allow deep wells into unconfined gravel aquifers, which may contain water with low levels of arsenic. However, with these types of wells, the problem of contamination from the surface must be addressed.

The CGHU provides technical advice to the Ministry of Transportation and Highways (MOTH) in regards to well water quality for new subdivision approvals. The Provincial Approving Officer of the MOTH has the final decision in all subdivision approvals. In discussions with staff and others involved in the field, the question of whether the CGHU should be involved in this issue had been raised. Since one of the mandates of the CGHU is to protect public health, involvement in this issue is inevitable, however, the method and amount of involvement should be clearly defined, as this has important implications for legal and financial impacts. British Columbia currently does not have groundwater legislation and does not regulate private water supply wells that supply single family homes except under the Health Act. Approval is not required for an individual to drill or use a well on their property for drinking water purposes. New developments in the study area require approval from the MOTH Approving Officer.

One of the objectives of this study was to learn what levels of arsenic in water are considered to be safe in order to provide information on approving new water supplies. The effect of future changes in these levels due to new research was also of concern. Currently the 0.025 ppm IMAC for arsenic from the GCDWQ is used, with rejection of any water supply above this level. This study has shown that the error associated with measurement of arsenic in water may affect results that are between approximately 0.020 and 0.030 ppm. This may lead to approval of supplies that are actually above 0.025 ppm or rejection of supplies that are below 0.025 ppm due to measurement errors. Future lowering of the IMAC may occur as treatment technologies improve and as a result of information provided by new research. Water supplies that are approved under current guidelines may no longer meet the possible lower guideline levels in the future.

People who wish to develop in areas where the water contains more than 0.025 ppm have expressed an interest in using treatment devices to reduce the arsenic levels from the tap to below 0.025 ppm. The CGHU was interested in the use of treatment devices as well as the maximum level at which to approve, if treatment devices were in fact accepted as a method to lower arsenic levels in order to meet the arsenic IMAC. Assuming a conservative lowering of the guideline to 0.010 ppm in the next few years, and an efficiency of 80% for the best treatment devices working at peak efficiency, a maximum approval level of 0.050 ppm seems prudent. This would be in keeping with the precautionary principle, and would lead to treated water at 0.010 ppm. If the device failed and water with 0.050 ppm of arsenic was consumed for a short period of time, health effects would not occur. If higher levels were allowed, the effect of the arsenic could be more harmful. However, the presence of a treatment device does not guarantee safe water, since these devices can malfunction.

Treatment devices require ongoing monitoring and maintenance (including water analysis). These devices can actually expose people to higher health risks than drinking water that has not been treated if the device is not properly maintained. This is because some devices can become sources of arsenic since they remove arsenic from water by sequestering it within the device. One site that was monitored during this study had a state-of–the-art treatment device installed. Analysis of the raw and treated water indicated that the device was malfunctioning. Since arsenic is tasteless and odorless, the homeowner was unaware that the device was not removing any arsenic from the water. If treatment devices are permitted to be used in order to receive approval for a drinking water supply, a procedure must be put in place to ensure that the devices are functioning properly. This is important in cases where a device is installed by a developer or an original owner and then the property is sold to new owners. This could be accomplished by establishing a maintenance bylaw that requires annual or semi-annual maintenance and monitoring. The recent Order-in-Council (#1309, September 23 1999) that allows local councils to pass bylaws to protect the public health by any means it deems necessary, subject to approval by the BC Minister of Health may be a law under which the regional district could regulate issues related to arsenic in drinking water.

On the other hand, all water supplies could be approved, except, perhaps in areas of extreme arsenic levels, such as the Middlepoint, Secret Cove, and Kelly Creek areas. This could be accompanied by a flag or restrictive covenant on the property title indicating that the water may not be safe for consumption, or a stronger statement to the effect that “the water contains a cancer causing chemical”. Depending on how the real estate transfers take place in the regions, this notification of new owners could be done by having an area on the real estate transfer form where a new owner has to sign to acknowledge that the water is not potable. A similar notification is required for the sale of homes containing certain types of insulation. This information could also be explained to real estate agents for them to inform prospective purchasers.

Attempts were made to determine the approach of other jurisdictions, such as other provinces, however, repeated requests for information did not generate many responses. Ontario also uses the GCDWQ as a guideline, but also has established an objective for arsenic at 0.010 ppm. Wisconsin has been the only state in the USA to have legislation for private wells. In the USA, the guideline for arsenic is 0.050 ppm, however, there are a number of smaller water utilities that do not meet this level. It is also expected that some utilities will not be able to meet the new level that the EPA will set. There is also the possibility that smaller systems may have a less stringent guideline to adhere to due to cost issues. This is because the public’s health may be better protected by spending money on other health care issues.

The EPA has also changed its policy on not allowing water utilities to use point of use (POU) or point of entry (POE) treatment devices in homes in order to meet guidelines. This was done to comply with the Safe Drinking Water Act. The reasoning behind allowing in-home treatment for homes served by small water utilities is that the costs for the utility to set up a central treatment facility would be prohibitive. The EPA determined the cost threshold between using POU/POE treatment or developing a central treatment occurred when the number of people served by the utility exceeded 150 (EPA, 1999b). This would correlate to 40 to 50 households, assuming an average of 3-4 people per household.

The 1994 study raised concerns as to the long term reliability of results of the chemical analysis that is done on well water when the well is first constructed. The question that this presented was whether the chemical composition of the initial water is representative of the future chemical composition of the water. While new wells were not monitored in this study, results from other wells indicate that chemical composition is not constant and can vary significantly over time. The water from a pump test does not necessarily have the same chemical composition as water that may be provided by the well in the future. This is because groundwater that has not been disturbed for periods has come to an equilibrium with the prevailing conditions in the subsurface. When a well is drilled and water is initially pumped out, the conditions in the subsurface change. As a well is used and a depression cone develops around it, the water that enters the well must flow greater distances to get into the well. This water can experience a different chemical, physical, and geological environment than the initial water. This may lead to changes in arsenic concentrations over time. It may be advisable to have new wells tested annually for a number of years in order to ensure that arsenic does not migrate to the area in which the well is located.

Water Treatment Devices

There are two categories of personal treatment devices; point of use devices which are usually attached to taps where water is obtained for drinking and cooking, and point of entry devices which are placed on the pipe bringing water into a home and treat all the incoming water.

These devices can use many different methods to remove contaminants such as arsenic. Most of these devices have different removal efficiencies for As (III) and As (V) due to As (III) being a neutral ion. This must be considered when choosing a treatment technology. Activated carbon is popular for removing many organic and inorganic contaminants, while reverse osmosis, absorption, ion exchange (Culligan, 1999), filtration with media such as activated alumina, and distillation are often used to treat inorganic ionic contaminants such as arsenic. A good overview of treatment technologies from the EPA is provided in Appendix 3.

A reverse osmosis (RO) treatment system which uses electricity to force water through a membrane, usually consists of a semi-permeable membrane, water storage tank and dispensing faucet. This system can remove inorganic chemicals and is often combined with an activated carbon filter to remove chlorine and organic chemicals. These devices remove 80 to 90% of As (V) and somewhat lower percentages of As (III) from water when operating at peak efficiency. Greensand (manganese coated sand) filters are often used in rural areas as point of entry devices. They can remove iron, manganese, and arsenic from water (Health Canada, 1999b), with lower efficiencies than RO. However, they are inexpensive and simple to use. Water supplies with high levels of suspended solids may need prefiltration in order for treatment devices to function properly.

Ion exchange is a method which removes up to 50% of As (III) and up to 90% of As (V). However, after the filter medium has adsorbed its capacity, it must be replaced or regenerated with strong chemicals. The point at which it needs to be replaced is not easy to determine. It depends on the flow through the device as well as the arsenic concentration. Filters containing activated aluminum oxide have recently appeared on the market. These devices are used to remove heavy metals, particularly lead from drinking water. Various pitcher-type products are also available. In addition to having activated carbon filters, these devices may include an ion-exchange resin for the removal of inorganic chemicals responsible for “hard” water (Health Canada, 1999b).

Distillation systems are commonly used to reduce the levels of all chemicals in drinking water. These systems boil water in one compartment and condense the vapour and collect it in another compartment. Distillation systems are effective for the removal of both organic and inorganic chemicals but are often combined with activated carbon for the removal of certain “volatile” chemicals (e.g. Trihalomethanes, tetrachloroethylene). There are no known beneficial, nor harmful health effects associated with the ingestion of demineralized or distilled water (Health Canada, 1999b). Distillation is most likely not a good method of removing arsenic because the arsenic may accumulate to dangerous levels in the boiling compartment and pose a potential health risk should the equipment malfunction and release this accumulation into the consumer’s tap water. This accumulation may be prevented in certain types of distillation equipment by draining the boiling chamber on a regular basis.

If treatment devices are not maintained properly, they can become sources of contaminants. This is because many devices remove contaminants from water by accumulating them in the device. When the assimilative capacity of the device is reached, the contaminants may be released into the water, often in higher concentrations than naturally present. The use of treatment devices on groundwater also may lead to the formation of microbiological growth which can be hazardous to human health. This can usually be avoided by keeping the treated water in a refrigerator. Bacteria can also grow in the device itself if it is not kept properly maintained.

Health Canada recommends that any water passing through a treatment device should satisfy the conditions set out in the GCDWQ. Some treatment devices are designed to be used only with chlorinated or non-chlorinated water. Improper use of these may lead to poor results. Many treatment devices also may require the water to be pretreated before it enters the device because the devices operate at peak efficiency only under a narrow range of chemical conditions. Some treatment methods require As (III) to be preoxidized to As (V) before treatment. Some of these factors that may require pretreatment are high pH, high levels of iron (Fe), manganese (Mn), total dissolved solids (TDS), or sulfate (S). Many of these factors are present in the sites that were monitored for this study, so these factors must be considered when installing a treatment device. The presence of certain other ions will dramatically reduce the performance of the devices. Health Canada has proposed a Drinking Water Safety Act (Bill C-14) which regulates the materials used in and criteria for point of use water treatment devices.

The issue of residuals must also be considered. Some of these devices, for example reverse osmosis, use large amounts of the water supply (up to 50%) to backwash the arsenic into the drain. This becomes important if there is a low well yield or a low capacity for the septic field. Since most of the arsenic would go into a septic tank, there is a concern as to accumulation of arsenic in the tank. While a review of the interactions between arsenic and bacteria is beyond the scope of this study, a preliminary search of this topic revealed that different bacteria respond differently to arsenic. This may have implications for bacterial balance in septic tanks. If the sludge from a septic tank has accumulated large amounts of arsenic, it may be considered special waste under environmental regulations. Arsenic leaching through the tank could possibly reenter the water supply, leading to a long term increase in the arsenic concentration of the water in the aquifer. This could be of concern in areas of low water supplies with high arsenic concentrations. Residuals are also important in devices that accumulate arsenic such as ion exchange filters. Disposal of the residuals is important because they may contain very high concentrations of arsenic and could be extremely toxic. Disposal of these residuals may require compliance with BC Ministry of Environment regulations, as they may meet criteria for "special waste".

A number of water treatment companies were contacted in regards to arsenic treatment. It was found that there is no universal solution. Each treatment option has its advantage and disadvantage and removal efficiency. It is important for a total chemical analysis to be performed before treatment options can be chosen, because the properties of the water will determine which options are suitable for each particular water supply.

Discussions with individuals involved in the drinking water remediation industry indicate that the best available technology to deal with the arsenic problem is reverse osmosis (RO). However, this process is relatively expensive and not 100 percent effective. Real life testing in one case showed that an average of 86% removal of arsenic was achieved with regular maintenance (EPA, 1999a). With the high pH conditions present in this study area, the deterioration of the membranes becomes important. The membranes may rupture and allow all of the arsenic to pass through the device. Water treated by reverse osmosis is corrosive and this must be taken into account when considering RO as a treatment option.

There are some promising treatment technologies in the development phase, however, they are not ready for individual homeowner use at this time. Some of the new methods may only be useful for large water utilities, as they require chemical or physical treatment. A number of new treatment methods using zero valent iron are in the research and development stage (McRae, 1999) and may be coming to market in the next few years such, e.g. the AsRT technology developed by Nikolaidis (Breslin, 1998). These devices promise to be very inexpensive and reliable. It may be worth waiting for these devices before embarking on a new management strategy. These processes will not be perfect and may require other treatment, as shown by the zero valent iron raising the pH of the treated water. This may be of concern in areas with naturally elevated pH levels.

The report by Carmichael et al (1995) gave a good review of treatment options along with a list of pros and cons of each technology. The information in the treatment chapter was reviewed and it was discovered that no major advances in treatment technology have occurred since the publication of the report. An appendix in the same report also gave a list of questions to consider when purchasing a treatment device. This list is a good starting point for individuals looking to purchase a treatment device.

Costs of treatment

The old adage that "you get what you pay for" applies in this case. An important consideration would be to buy or lease a treatment device from a reputable company that will guarantee the system will remove arsenic to below guideline levels permanently with proper maintenance. POU RO units start at approximately $500 and can be leased as well. POE systems cost considerably more, as they have to treat a larger volume of water. Some companies have relatively inexpensive ion exchange columns which they claim will remove arsenic to below guideline levels. If this was guaranteed, it would be acceptable as a POE or POU device. Changes to the plumbing code could also be enacted to allow two separate water lines in a home, an untreated system for toilets and outside taps and a treated line for kitchen and drinking water taps. This could lower the volume of water requiring treatment and help reduce costs.

In new developments, the ideal situation would be to connect to a municipal water system. If the cumulative costs of well drilling, possible lower property values due to well water containing high levels of arsenic, and associated costs of treatment are considered, it may be cost effective for a developer to connect new developments to a municipal water supply. These costs may be offset by possible higher property values due to a municipal water connection rather than a well.

Health Issues

Arsenic that enters the body from ingestion of contaminated water can be partially absorbed by the body and partitioned to various organs. It excreted from the body via the urine, which means urine may be used to monitor arsenic exposure. High levels of arsenic are also found in nails and hair, which can also be used to monitor exposure to arsenic. The most common test for arsenic exposure is a blood test. Arsenic is a tasteless and odorless toxin which has been a known poison for centuries. A fact sheet dealing with arsenic in drinking water from Health Canada is given in Appendix 2. It gives an excellent overview of the possible effects of arsenic on human health.

Initial symptoms of arsenic poisoning are non specific, for example, headaches and irritability. Lifetime consumption of water containing arsenic above drinking water guidelines is believed to increase the risk for certain types of cancer including; skin, kidney, bladder, liver, lung and other internal cancers. Skin problems can also occur after several years of exposure to arsenic above guideline values. For example, skin lesions can appear, hyperpigmentation (dark spots) or hypopigmentation (white spots) and keratoses of the hands and feet can also occur. After a dozen or so years of exposure skin cancers can be expected. Blackfoot disease, which was seen in studies in areas of high arsenic in Taiwan, can also afflict people who drink water containing high concentrations of arsenic (Tseng et al, 1968). Other problems that can occur include; thickening and discoloration of the skin, nausea, diarrhea, decreased production of blood cells, abnormal heart rhythm, blood vessel damage and numbness in the hands and feet. (Health Canada, 1999a). Arsenic may also be a tumor promoter, however, the dose response curve is not known at low concentrations. The acute toxic dose is thought to be approximately 60 ppm. In one study twenty or thirty years after exposure to 0.500 ppm of arsenic, internal cancers (lung, kidney, liver and bladder) occurred among 10% of all exposed (Wilson, 1999).

The exact mechanism of arsenic toxicity is not fully understood. However, arsenic can also be used as a cure for some conditions such as leukemia. The use of arsenic as a medicine has decreased dramatically over the last 100 years, but it still is known to have some positive effects. It has been found to increase growth in some plants, again the mechanism is not fully understood.

The different forms of arsenic have different degrees of toxicity, with the trivalent form (As III) being the most toxic, followed by the pentavalent form (As V), and then by the organic forms. While it has been reported that the trivalent form may be up to 60 times more toxic than the pentavalent form, discussions with a member of the NAS committee undertaking a major study on arsenic for the American government, indicate that there may not be much of a difference in the toxicity of the two arsenic species (W. Cullen, personal communication).

Methods

Analysis was conducted by the Pacific Environmental Science Center (PESC) of Environment Canada, Analytical Service Laboratories Ltd. (ASL), and in laboratories at UBC. Boron and other metals were analyzed with the EXT-XW test at PESC using ICP spectroscopy. Fluoride was measured by ion chromatography at PESC. The pH and conductivity analysis for the Bowen Island samples were performed at PESC, while all other pH and conductivity analysis were done at UBC (January) or in the field (June). Total arsenic was measured by a variety of methods. In January and June, the EXT-XW test at PESC was used with a detection limit of 0.050 ppm. The samples from January, April, September, and November were analyzed for low level arsenic by graphite furnace (gf) atomic absorption spectroscopy with a detection limit of 0.0005 ppm at PESC. The January and June samples were also analyzed for low level arsenic at ASL with ICP-MS.

Arsenic speciation was determined by ASL using procedures adapted from the American Public Health Association (APHA, 1995) and from the US EPA (1986). The procedure involved instrumental analysis by hydride vapour atomic absorption spectrophotometry (HVAAS) using a Trizma buffer to maintain the pH of the sample at 7.0 and inhibit the degradation of the trivalent arsenic species. Pentavalent arsenic (As V) was then determined by difference between the total and trivalent arsenic (As III). Other arsenic species are negligible in groundwater.

Sampling strategy

A sampling strategy was developed to help determine the spatial and temporal distribution of the arsenic contamination problem. Twenty one wells were chosen from Langdale, at the southern end of the Sunshine Coast to Lund, north of Powe1l River, in order to determine the spatial extent of the problem. Sites chosen in a manner that would allow a wide range of arsenic concentrations to be studied. To determine seasonal variability, it was decided that the sites would be sampled five times over the course of the year. The sampling dates and parameters tested are give in Table 1. QA/QC sampling was done with duplicates and blanks composing 10% of the total samples in the January and June sets. Spiked samples were also submitted with these two sets. This sampling strategy was limited by a number of factors including; cooperation and availability of well owners, availability of CGHU staff for sampling, and the limited budget of the project. The frequency of sampling and the number of sites that could be monitored was limited by laboratory budget.

Table 1. Sampling dates & parameters analyzed.

Sunshine Coast & Powell River Area		Bowen Island	
Date	**Parameters tested**	**Date**	**Parameters tested**
End of January 1999	Arsenic, Fluoride, Boron, other metals, pH, conductivity, TSS, As speciation		
Mid April 1999	Arsenic	Early May	Arsenic, Boron, other metals
End of June	Arsenic, Fluoride, Boron, other metals, pH, conductivity, As speciation	End of June	Arsenic, Fluoride, Boron, other metals, pH, conductivity, As speciation
End of September	Arsenic	End of September	Arsenic
Mid November	Arsenic	Mid November	Arsenic, Boron, other metals

Quality Control & Quality Assurance (QA/QC) and Uncertainty Analysis

This study was in part undertaken because the large scale well water survey conducted in 1994 did not have a rigorous QA/QC procedure, especially for sampling, which was conducted by individual homeowners. This lack of control over sampling, along with variability in analytical results, led to questions about the accuracy and precision of data generated from the analysis of these samples. The reliability of results was also of concern due to CGHU providing technical advice to the Ministry of Transportation and Highways in regards to well water quality for new subdivision approvals. The concern involved the error range of the results, especially when they were near drinking water guidelines.

Sampling in this study was conducted in accordance with generally accepted methods that are standard in analytical environmental chemistry, such as those developed by the APHA (1995). All samples were collected in a similar fashion after a flushing of pipes to prevent stagnant water from being sampled. Collection was performed by clean techniques with certified clean containers and standard methods of sample preservation and storage. Samples were taken from as close to the well head as possible

A series of QA/QC samples were submitted to the laboratory to determine the precision and accuracy of the analysis. These QA/QC samples included field blanks, duplicate, and spiked samples. A QA/QC check on the analyte of greatest importance, arsenic, was also done by having the same samples analyzed at two different laboratories, and with two different methods in the same laboratory. QA/QC data was also obtained from PESC in order to monitor laboratory method performance.

QA/QC Results

The results from the QA/QC reference samples that were submitted with two sets of samples are shown in Table 2. Reference samples are used to check the accuracy and precision of the analysis by analyzing samples of “known” concentration. However, there is no way to know the true concentration, since the standard solutions also have an error range associated with them. The true concentration is often determined by performing many analysis and averaging the results.

Table 2. QA/QC sample results, Jan & June 1999.

Sample	expected result	actual result	% difference
Jan-99			
SC-11	0.0025 ppm As standard	0.0030 ppm	20
SC-12	As blank-Vancouver tap water	0.0006 ppm	
SC-13	As blank-deionized water	<0.0005 ppm	
SC-14	5 ppm B standard	4.75 ppm	5
SC-15	1 ppm F standard	1 ppm	0
SC-16	B, F blank-Vancouver tap water	0.05 ppm F, <0.05 ppm B	
SC-17	B, F blank-deionized water	0.05 ppm F, <0.05 ppm B	
Jun-99			
SC-11	As blank deionized water	0.0002 ppm	
SC-12	0.0025 ppm As standard	0.0028 ppm	8

The arsenic reference material was diluted at UBC to a final concentration of 0.0025 ppm. The results from the lab indicate that is was measured as 0.003 and 0.0028 ppm respectively. This leads to a 20 and 8% difference for the two analysis. The percent difference is calculated by dividing the absolute value of the difference by the smaller of the two values and converting it to a percentage. Since the concentration of the standard is about 10 times the detection limit (DL), the result can be viewed with confidence. Results within 2 to 3 times the DL value may or may not be statistically significant. While a 20% error may seem high, this is near the top of the range of variability which would be expected due to the propagation of errors which add up throughout the sampling and analysis steps of the procedure. There is also an error of approximately +/- 5% in the concentration of the standard that was used as the reference standard. This is introduced from the error range of the original 1000 ppm stock solution from which the standard was prepared, as well as the errors associated with the dilution steps. The arsenic blanks indicate that any result above 0.001 ppm should be significant. Any results below this level may or may not be statistically significant.

The results from the boron and fluoride standards are within experimental error and are acceptable. The blanks are at or near detection limits and indicate false positives should not be of concern in this study.

Duplicate samples are used to monitor the reproducibility of results. Duplicate analysis is done by performing multiple analysis on the same sample. The results from the duplicates done over the sampling period are given in Table 3. In January, duplicates were taken from 2 sites in different containers. The samples were given different sample numbers, in order for the duplicate test to be blind, i.e., the laboratory did not know that the samples were duplicates. The reference standards that were submitted were also blind.

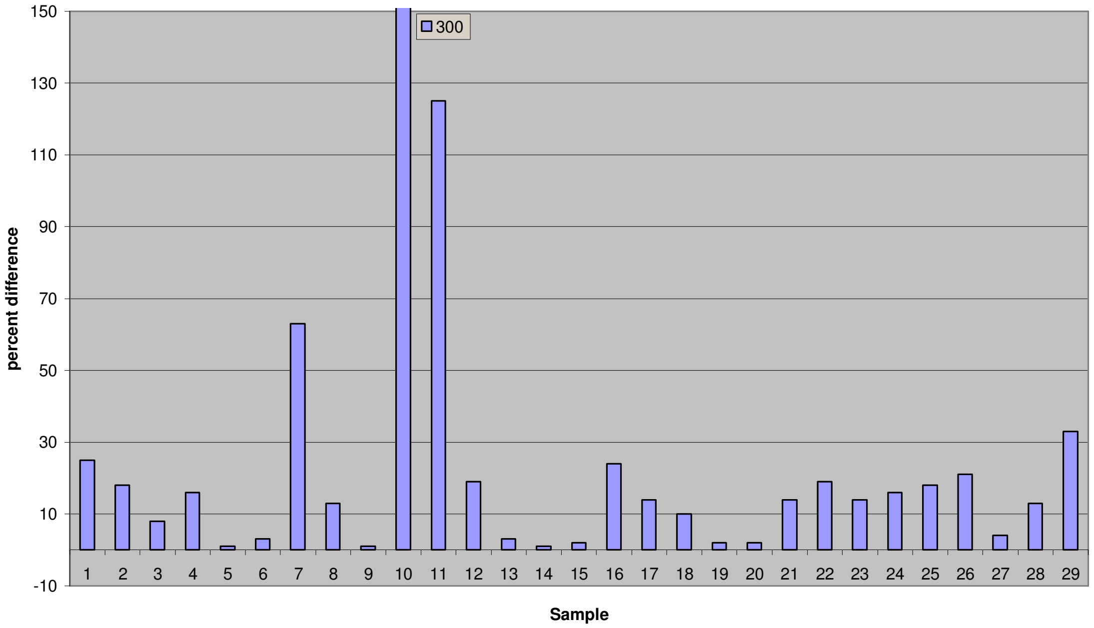
The duplicate results show very small deviations in the boron and fluoride analysis, which indicates that the tests for boron and fluoride are reliable and reproducible. Arsenic was analyzed by 3 methods, the comparison between the methods will be done later in this section, and only the duplicate results will be discussed here. The duplicates show a 0-12% deviation which does not seem unreasonable. One point that was noted after the completion of the study was that the arsenic duplicates were done on samples of relatively high concentration. While there is no evidence to indicate that the results would have been different if duplicates had been done on samples with lower concentrations, this may be an issue that could be addressed in any future sampling.

Table 3. Duplicate sample results.

Jan-99			
	SC-4	**SC-5**	**% difference**
	990396-004	**990396-005**	
F (ppm)	0.14	0.14	0
B (ppm)	0.57	0.58	2
As-gf (ppm)	0.153	0.157	3
As-icp (ppm)	0.13	0.14	8
As-icpms (ppm)	0.177	0.156	10
	PR-6	**PR-7**	
	990396-016	**990396-017**	
F (ppm)	3.4	3.4	0
B (ppm)	7	6.97	0.4
As-icp (ppm)	0.68	0.69	1
As-icpms (ppm)	0.84	0.79	6
Jun-99			
	SC-4	**SC-5**	
	993207-004	993207-005	
F (ppm)	0.15	0.15	0
B (ppm)	0.69	0.68	1
As-gf (ppm)	0.15	0.15	0
As-icp (ppm)	0.16	0.17	6
As-icpms (ppm)	0.19	0.17	12

Concerns were raised during the 1994 study as to the precision and accuracy of results due to large variations in arsenic concentrations in samples taken from the same well. There are many laboratories in the area which measure arsenic by a number of different techniques. It was decided to have the analyte of interest, arsenic, analyzed at two labs with different methods and instrumental procedures. The results of this comparison are shown in Table 4, with a graphical presentation given in Figure 2. The analysis at PESC was done with graphite furnace or ICP spectroscopy, while ASL used a ICP-MS.

Figure 2. Differences in duplicate sample results from two different laboratories



The January results mostly show a 1-25% difference range on the samples from the same site that were sent to two different labs. There were a few very high differences. These differences were on samples of very low concentration and are not of great concern because they were at levels near the detection limits. These levels are not in the range that are harmful to human health. The one sample which does not fit this category is SC-7 which has a 63 % difference between the two methods. This is of concern because this is in a range that is harmful to human health. This difference is most likely due to a random error which can occur in analysis and can not be controlled. This is a statistical event and can be seen to be similar to the results of surveys where reliability is often defined as 19 times out of 20. This means that 95% of the time the results are accurate, however, 5% of the time an error may occur. The June results show a 4 to 33% difference which is similar to what was seen in the January samples. In general, it was noted that the results from ASL were higher, especially in the June samples. Results from a recent EPA conference which focussed on interlab comparisons of probable quantification limits (PQL, the lowest level at which the results could be trusted), indicate that a 30-40% variability can be expected in results. They deemed this to be acceptable at low arsenic levels near the DLs. Different laboratories produce work of varying quality and this must be considered when submitting water samples for analysis.

Table 4. Duplicate samples – Different methods of analysis at two different labs.

Jan /99	As-PESC GF/ICP (ppm	As-ASL ICP-MS (ppm)	% difference
SC1	0.0015	0.0012	25
SC2	0.0195	0.023	18
SC3	0.025	0.027	8
SC4	0.153	0.177	16
SC5	0.157	0.156	1
SC6	0.227	0.22	3
SC7	0.24	0.39	63
SC8	1.2	1.36	13
SC9	0.11	0.111	1
SC10	0.0008	0.0002	300
PR1	0.0009	0.0004	125
PR2	0.0037	0.0031	19
PR3	0.0107	0.011	3
PR4	0.0138	0.014	1
PR5	0.0048	0.0047	2
PR6	0.68	0.84	24
PR7	0.69	0.79	14
PR8	0.82	0.9	10
PR9	0.49	0.48	2
PR10	0.09	0.088	2
PR11	0.0772	0.068	14
Jun-99			
SC4	0.16	0.19	19
SC7	0.29	0.33	14
SC8	1.17	1.36	16
SC9	0.1	0.118	18
PR6	0.52	0.43	21
PR9	0.51	0.53	4
PR10	0.07	0.079	13
PR11	0.08	0.106	33

Table 5. Arsenic analysis results from two different methods in the same lab.

	As-gf (ppm)	As-icp (ppm)	% difference
SC4	0.153	0.13	18
SC5	0.157	0.14	12
SC6	0.227	0.2	14
SC9	0.11	0.13	18
PR10	0.09	0.08	13
PR11	0.0772	0.07	10

Table 5 shows the results of the arsenic analysis by two different methods at PESC. One method is the graphite furnace (gf) method and the other is the ICP method. The samples that were analyzed using both of these methods show a 10 to 18% difference in results. These results also agree with the other results of error analysis indicating that a 10 to 25% error is to be expected in these types of analysis. PESC recommends that the results from the gf method be used in preference to results from the ICP analysis due to better precision and accuracy.

QA/QC Results for Laboratory Performance

Laboratory documentation for standard operating procedures (SOPs) from PESC indicate that the in-lab standards that are used for internal QA/QC also show some variation. The graphite furnace method for determining arsenic has a standard deviation of 12.2%. Arsenic seems to be one of the metals that displays a larger variation than most other metals. This may be due to some physical characteristic of the ion that does not lend itself to easy analysis. Figure 3 shows a typical control chart for arsenic, indicating the variability over a 3 month period. An analysis of arsenic reference material recoveries over a different time period indicated that the recoveries ranged from 93 to 115%. Blank data indicated that any results above 0.001 ppm, or 2 times the DL should be reliable. Duplicate data indicated that a maximum 25 % difference is seen in the results. Data for other metals also has the same type of trend. The data that is presented shows worst case scenarios. It should be expected that most results would be of higher reliability. The QA/QC data from ASL for the June set indicates that the internal reference material that was analyzed by the lab had a recovery of 78% recovery (measured value = 0.091 ppm, expected value = 0.116 ppm). This leads to a 27% difference. This is acceptable by the lab for its QA/QC check. The duplicates gave values of 0.79 and 0.67 ppm, an 11% difference. The standard recovery for the January set was better, with only a 2% difference.

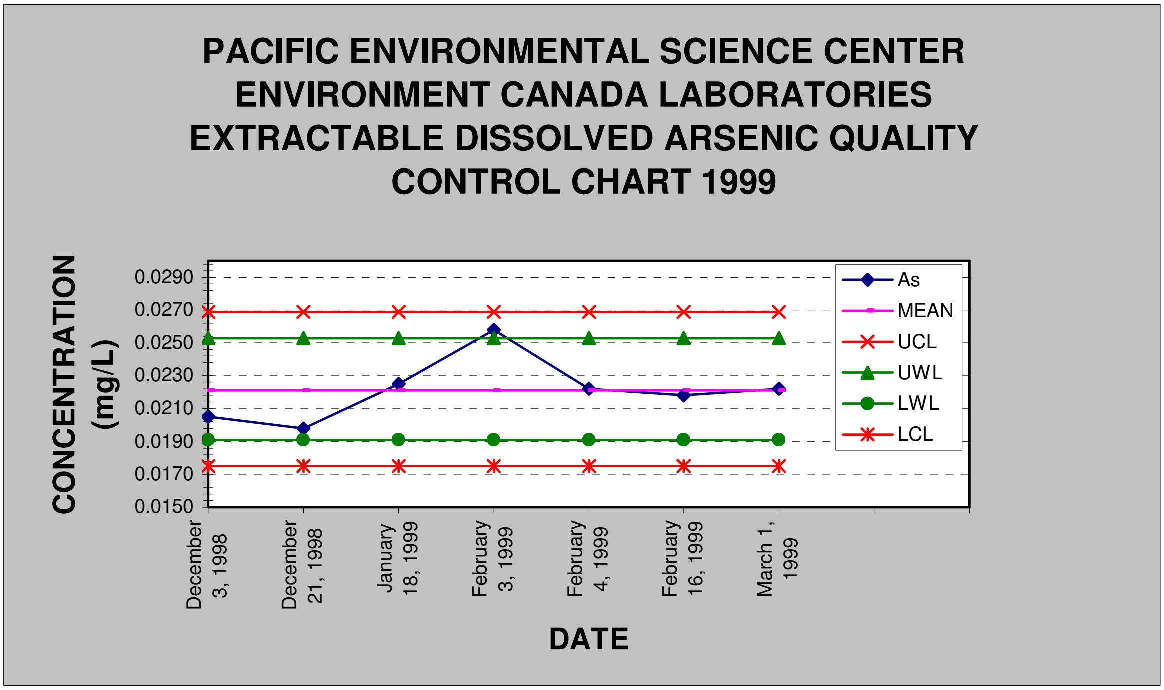


Figure 3. PESC control chart for Arsenic.

The QA/QC data for fluoride indicated that a 4% relative standard deviation (RSD) is obtained over the long term in the ion chromatography method. This is a precise method and variability should not be of any concern in this study. Warning limits are set by the lab above and below the expected value. For example, the expected value for the fluoride standard was 98, and the warning limits were set at 90 and 116. The confidence limits were set at 84 and 123. If the result of the standard is within the warning limits, no action is taken. If the result is between the warning limits and the confidence limits, the results are examined to see if a problem exists. If the result for the standard is above or below the confidence limits, the analysis is stopped until the problem is found. In most cases the results for fluoride were at about the 92 or 93 level, so an error of 5-6% was found in most of the QA/QC samples. However, about 10% of the time, larger errors of 20-30% can occur.

What also must be remembered is that the uncertainty in the results comes from many sources including sampling error and error in analysis. Sampling error consists of the sample not representing the actual conditions that are present at the site. This can occur if the water has been standing in a pipe or tank for a long time, for example, when the tap is not run for enough time before a sample is obtained.

The QA/QC that is performed by the lab involves using standard solutions made up in purified water. Real samples often have a different matrix than the standards, for example, the samples may have a higher or lower pH or conductivity than the standards. This can dramatically affect instrument performance and accuracy, especially in samples from this area which have a very high pH.

Results

Arsenic, depth, conductivity, and pH

A plot of the total arsenic concentrations from the 1994 study are presented in Appendix 5. The results of the analysis conducted for this study are given in Appendix 1. Maps showing the maximum arsenic concentrations and each of the 21 sites sampled in 1999 are given in Appendix 4. Table 6 gives the arsenic concentrations for each of the wells during the five sampling dates, along with the district lot in which the site is located and the depths of the well. A blank value in the table indicates that a sample was not taken for that particular site at that date. The blank values are either for duplicate samples, for wells that were not in use, or not accessible at the date. Thirteen of 21 samples from the first set were found to have arsenic values above the guideline and arsenic concentrations ranged from 1.4 to <0.0005 ppm. Statistical analysis did not indicate any systematic seasonal variation in the arsenic concentrations. However, four of the sites including; SC-7, PR-4, 6, and 9 had significantly higher arsenic concentrations in the September and November samples. No explanation could be found for this increase. The lack of seasonal variation could be due to the wells being relatively deep which means it takes long periods of time for surface water to get down to the aquifer, masking any seasonal differences. Any differences may also be masked by analytical variability. A comparison with the 1994 data set also indicates that there is not a lot of seasonal variation in the arsenic concentrations, and that lab error clouds this interpretation. The June samples had lower conductivity and higher pH values than the January samples. This seems to contradict the theory that arsenic levels may be lower in the winter due to dilution of arsenic with increased precipitation.

Table 6. Sampling site locations, total arsenic concentrations, and well depths.

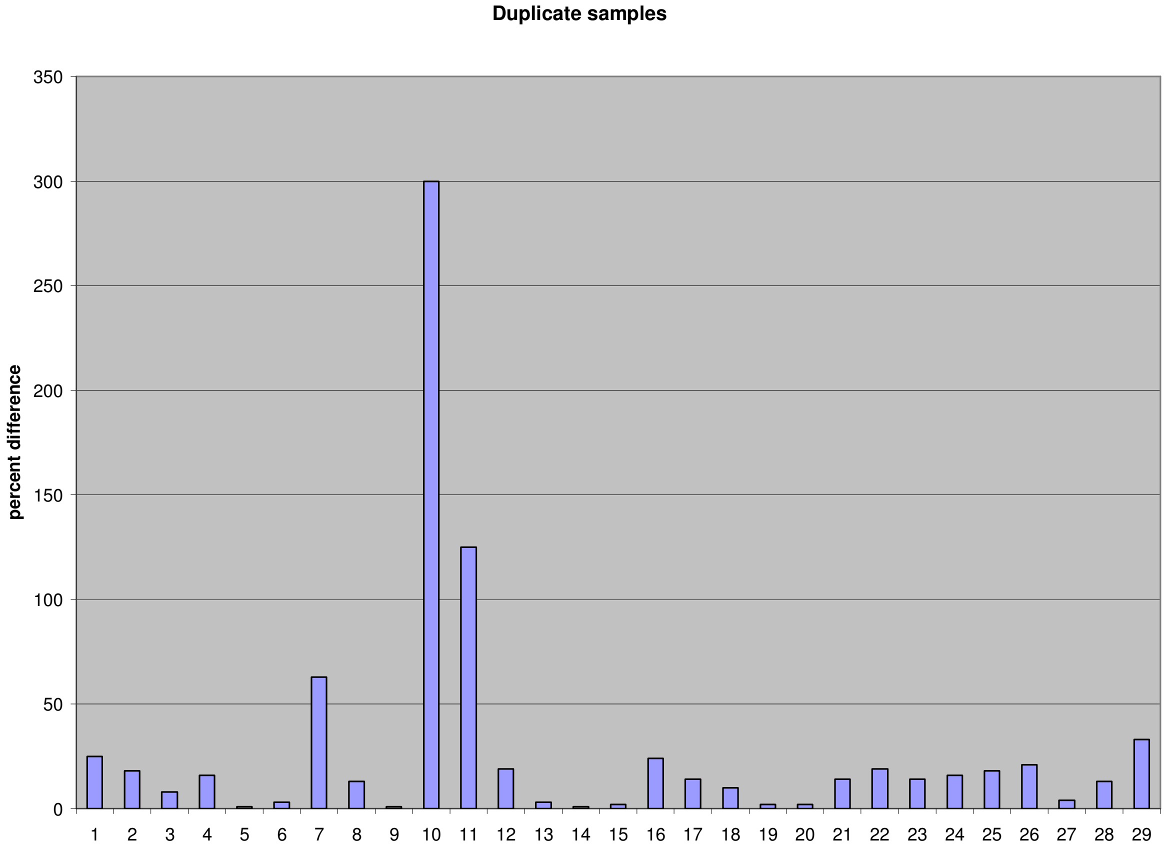
SITE	District Lot	Jan 28/99 As (ppm)	Apr 14/99	Jun 25/99	Sept 30/99	Nov 18/99	Depth (m)
SC-1	4454	0.0015	0.0009	0.0009	0.001	0.0011	96
SC-2	906	0.0195	0.019	0.022	0.0224	0.02	125
SC-3	1319	0.025	0.022	0.0253	0.024	0.026	64
SC-4	4537	0.153	0.135	0.19	0.24	0.168	70
SC-5	4537	0.157		0.17			70
SC-6	6289	0.227	0.035				61
SC-7	6289	0.24	0.255	0.33	0.86	0.97	61
SC-8	3971	1.2		1.36	1.12	1.43	198
SC-9	3976	0.11	0.102	0.118	0.1	0.123	183
SC-10	5939	0.0008	<0.0005	0.0007	0.0017	<0.0005	38
PR-1	4730	0.0009	<0.0005	0.0003	0.0008	0.0009	137
PR-2	4733	0.0037	0.0031	0.0037	0.0041	0.0031	30
PR-3	1958	0.0107	0.013	0.0169	0.016	0.02	34
PR-4	1959	0.0138	0.013	0.0137	0.018	0.019	94
PR-5	1651	0.0048	0.0037	0.005	0.0054	0.0043	?
PR-6	5145	0.68		0.43	0.5	1.01	119
PR-7	5145	0.69					119
PR-8	5142	0.82					24
PR-9	1479	0.49	0.436	0.53	0.45	0.84	73
PR-10	5252	0.09	0.072	0.079	0.107	0.097	6
PR-11	5259	0.0772	0.085	0.106	0.119		52
PR-13	1958			0.0046		0.0022	25
			7-May	**25-Jun**	**30-Sep**	**18-Nov**	
Bowen Bay			0.0019	0.0018	0.0037	<0.0005	
Bluewater				0.014	0.019	<0.0005	
Tunstall 1			0.0023	<0.0005	0.0008	<0.0005	30
Tunstall 3			0.0009	<0.0005	0.0068	0.0051	137
Tunstall 6a			0.001	<0.0005	0.0072	0.0018	76

One of the first items noted about the water in this area was the extremely high pH. This may be due to basic basaltic bedrock. Results for pH and conductivity are given in Table 7 along with data for the total suspended solids analysis. A correlation between the logarithm of the arsenic concentration and the pH gave an r value of 0.75 (α=0.05) for January, as show in Figure 4, and an r value of 0.78 for June. Many of the water samples are above the drinking water guideline value of 8.5 for pH. The sample with the highest conductivity also had the highest concentration of arsenic. A relationship was found between conductivity and arsenic, with an r value of 0.78 for the January samples (see Figure 4) and 0.91 for the June samples. The six samples that were tested for total suspended sediments (TSS) showed very low levels of TSS.

One of the cases found in the literature indicated that high levels of lithium may be found in some areas of elevated arsenic levels (Nimick, 1998). Lithium was not tested for in this study, but can be checked on previous analysis reports that may have included a test for Li. Selenium had also been mentioned as a possible metal of concern. Selenium was not specifically tested for in this study, but data available as a byproduct of the boron analysis indicated that selenium was not found above the DL of 0.05 ppm. However, the DL in this case was above the guideline value of 0.01 ppm. This means that selenium may or may not be above the guideline value, but it is certainly not severely elevated.

Table 7. pH and conductivity results.

		Jan/99		Jun-99	
Site	**pH**	**Conductivity (µS)**	**Total Suspended Sediments (mg/L)**	**pH**	**Conductivity (µS)**
SC-1	8.13	135		8.39	110
SC-2	9	267		9.1	230
SC-3	9.5	229		9.43	165
SC-4	9.22	490	< 0.4	9.47	400
SC-5	9.23	489			
SC-6	8.96	215	< 0.4	9.25	290
SC-7	9.03	412			
SC-8	8.83	2050		9.03	1700
SC-9	9.25	302	< 0.4	9.47	255
SC-10	6.45	106		7.33	205
PR-1	7.32	225		7.65	190
PR-2	7.54	200		7.81	165
PR-3	8.85	392	< 0.4	9.16	340
PR-4	9.08	305		9.21	255
PR-5	7.72	105	< 0.4	8.08	90
PR-6	9.3	412		9.58	310
PR-7	9.32	388			
PR-8	9.2	550	2.1		
PR-9	9.19	390		9.38	325
PR-10	8.48	204		8.63	190
PR-11	7.89	131		8.87	115
PR-13				8.32	240
Bowen Bay				8.1	218
Bluewater				8.69	335
Tunstall 1				6.69	146
Tunstall 3				7.71	267
Tunstall 6a				7.69	132



The 1994 study showed that elevated arsenic levels were mostly found in deep wells, however, not all deep wells had elevated arsenic levels. In the 1995 report by Carmichael et al, a deep well was arbitrarily defined as deeper than 20m. The results of the 1994 data indicated that this was a good boundary between deep and shallow wells. However, in this case, deep well refers to drilled wells that terminate in bedrock rather than absolute depth. The majority of wells sampled in this study were deep wells. In many cases the exact depths of wells was not known because well logs were not available. Many of the depths presented are based upon the owners best recollection.

The deepest well sampled had the highest arsenic levels (1.4 ppm). A well located in close proximity to the deepest well had an arsenic level 10 times lower. However, this level was still above 0.100 ppm. A significant correlation was not found between the depth of well and the arsenic concentration (r = 0.38). This is to be expected since arsenic is thought to travel through cracks in the bedrock, and the depth of a well may not be related to the number of cracks. The well yield may correlate with arsenic levels (M. Wei, BCMOE, personal communication) since well yield is related to the number of cracks a well intersects. The arsenic concentration may have a higher correlation with the depth of the major water bearing fractures. Since detailed well logs were not available for most of the wells sampled, it was not possible to perform this correlation.

A study on Bowen Island (Boyle et al, 1998) also found no correlation with depth, but the authors hypothesized that the number of fissures intercepted by a well would be a good indication of arsenic levels. They also mentioned that the age of the water may be related to the arsenic levels, since water softening occurs with age. The mechanism they proposed for introduction of arsenic into the water involved water softening initiating the dissolution of arsenic (see next section).

Two drilled wells within 10 m of each other were also sampled (PR-3 and PR-13). The depth is not known for certain, as the well logs differ from the owner's recollection. PR-3 is either 300 feet or 35 m deep and PR-13 is 105 feet deep. What is important is that the chemistry of the wells is very different. Arsenic levels differ by 4 to 10 times. The conductivity difference was 100 uS and a one unit difference was also found in the pH. Similar differences are seen in the boron and fluoride concentrations. The well logs did not indicate the depth of water bearing fractures, which may help explain the differences in water chemistry.

Relationships with other water quality parameters

A relationship between elevated arsenic levels and high levels of boron (B), fluoride (F), and pH was found in the 1994 study. This relationship was further examined in this study. This relationship has been reported in the literature (Levy et al, 1999, Boyle et al, 1998). Fluoride and boron results are given in Table 8. Fluoride results ranged from 5.2 to 0.04 ppm. Boron results ranged from 9.89 to <0.01 ppm. Three of the January results were above the drinking water guideline for fluoride. Fluoride is added to municipal waters to help fight cavities, and a level between 0.8-1 ppm is beneficial. Levels above 1.5 ppm can cause mottling of teeth. Four of the boron samples were also above the guideline value of 5 ppm in January.

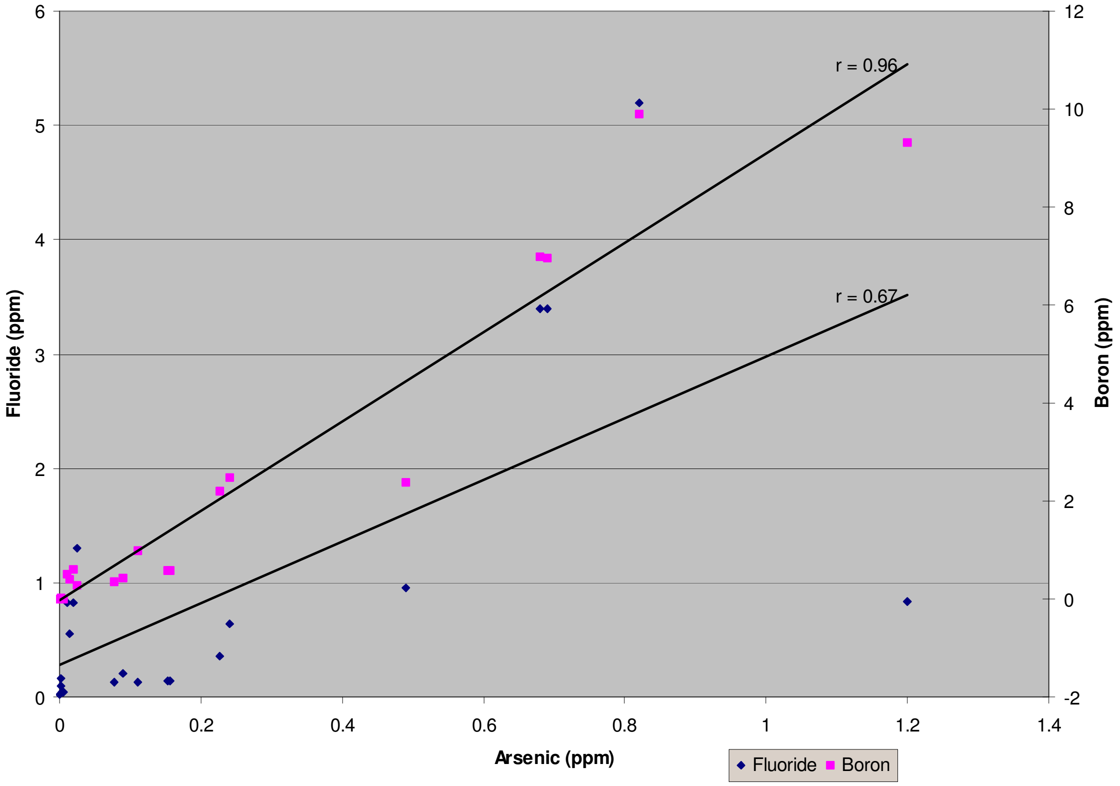
Table 8. Fluoride and boron results.

	Jan/99		Jun/99	
	F (ppm)	B (ppm)	F (ppm)	B (ppm)
SC-1	0.16	0.02	0.81	0.02
SC-2	0.82	0.61	0.64	0.64
SC-3	1.3	0.29	1	0.29
SC-4	0.14	0.57	0.15	0.69
SC-5	0.14	0.58	0.15	0.68
SC-6	0.36	2.2	0.38	2.4
SC-7	0.64	2.49		
SC-8	0.84	9.32	0.98	9.09
SC-9	0.13	1	0.12	1.07
SC-10	0.02	0.01	0.02	0.01
PR-1	0.1	0.01	0.08	0.01
PR-2	0.04	0	0.03	<0.01
PR-3	0.82	0.5	1.1	0.65
PR-4	0.55	0.4	0.62	0.4
PR-5	0.04	0	0.04	<0.01
PR-6	3.4	7	3.3	6.23
PR-7	3.4	6.97		
PR-8	5.2	9.89		
PR-9	0.95	2.37	0.81	2.58
PR-10	0.21	0.42	0.22	0.38
PR-11	0.13	0.35	0.19	0.51
PR-13			0.06	0.07

	May 1999	June 1999		Nov 1999
	B (ppm)	F (ppm)	B (ppm)	B (ppm)
Bowen Bay	0.11	0.21	0.12	0.12
Bluewater		0.12	0.03	<0.01
Tunstall 1	<0.01	0.03	<0.01	<0.01
Tunstall 3	0.07	0.02	0.06	0.26
Tunstall 6a	0.04	0.01	0.04	0.03

Figure 5 shows the results of a correlation analysis (α=0.05) performed on the relationship between arsenic, boron, and fluoride concentrations for the January samples. An excellent correlation was found between the boron and the arsenic concentrations (r=0.96). A significant (α=0.05) relationship was also found between fluoride and arsenic (r=0.67), As and Na (r=0.81), and As and S (r=.52). The June samples gave a As-B correlation with r=0.94 and As-F correlation with r=0.36. This fluoride correlation is lower than the January correlation, but this relationship still exists, as a good correlation was found between B and F (r=0.81 in January and r=0.62 in June). This type of correlation was also apparent in the data from Bowen Island (Boyle et al, 1998).

Figure 5. Arsenic, Fluoride and Boron relationships for January samples.



Speciation Results

Speciation results are summarized in Table 9. The January results indicate that most of the arsenic was in the As (V) form, however these results were of concern due to the length of time they were stored by PESC before analysis. Over time, As (III) oxidizes to As (V), especially in the presence of oxygen. In January, all of the samples from the Powell River area were in the As (V) form, along with most of the samples from the Sunshine Coast area. The only exceptions were SC-6, which had half the arsenic in each form and SC-8 and 9 which were all in the As (III) form. The June samples had a more even distribution between the two forms of arsenic. This is most likely due to better sample handling and shorter storage time, rather than any seasonal influence. For example, SC-3 had all of the arsenic in the (V) form in January, but had an even distribution of arsenic between the two species in June. Most of the other samples in June had 15-20% of the As in the (III) form, as opposed to none in January. Once again, it is not possible to tell if the level of As (V) is due to oxidation or the presence of that species in the water. The results give a general synopsis of arsenic speciation, however, a proper speciation study would require significantly higher amounts of funding.

The speciation results indicate that it is not appropriate to assume that all of the As is in the (V) form, as some water treatment companies have suggested. This has important implications for treatment, as the (III) form is not charged and is much more difficult to remove from water. In terms of health effects the speciation of arsenic may be of concern because As (III) may be somewhat more toxic than As (V).

Table 9. Arsenic speciation results.

		Jan/99			Jun/99	
	As III (ppm)	As V (ppm)	As total (ppm)	As III (ppm)	As V (ppm)	As total (ppm)
SC-1	<0.005	<0.005	0.0012	<0.005	<0.005	0.0009
SC-2	0.011	0.012	0.023	0.008	0.014	0.022
SC-3	<0.005	0.027	0.027	0.013	0.012	0.0253
SC-4	<0.005	0.177	0.177	0.036	0.15	0.19
SC-5	<0.005	0.156	0.156	0.033	0.14	0.17
SC-6	0.11	0.110	0.22	0.13	0.2	0.33
SC-7	<0.005	0.390	0.39			
SC-8	1.4	<0.005	1.36	1.1	0.3	1.36
SC-9	0.12	<0.005	0.111	0.09	0.03	0.118
SC-10	<0.005	<0.005	0.0002	<0.005	<0.005	0.0007
PR-1	<0.005	<0.005	0.0004	<0.005	<0.005	0.0003
PR-2	<0.005	<0.005	0.0031	<0.005	<0.005	0.0037
PR-3	<0.005	0.011	0.011	0.005	0.012	0.0169
PR-4	<0.005	0.014	0.014	<0.005	0.012	0.0137
PR-5	<0.005	<0.005	0.0047	<0.005	<0.005	0.005
PR-6	<0.005	0.840	0.84	0.19	0.24	0.43
PR-7	<0.005	0.790	0.79			
PR-8	0.005	0.895	0.9			
PR-9	<0.005	0.480	0.48	<0.005	0.53	0.53
PR-10	<0.005	0.088	0.088	<0.005	0.078	0.079
PR-11	<0.005	0.068	0.068	0.01	0.096	0.106
PR-13				<0.005	<0.005	0.0046
Bowen Bay				<0.005	<0.005	0.0018
Bluewater				<0.005	0.01	0.014
Tunstall 1				<0.005	<0.005	<0.002
Tunstall 3				<0.005	<0.005	<0.002
Tunstall 6a				<0.005	<0.005	<0.002

Bowen Island Results

In general arsenic concentrations in wells on Bowen Island are relatively low, with only the Bluewater well being near the 0.025 ppm arsenic guideline. However there seems to be quite a bit of variation in the concentrations of arsenic and other metals over time. This may be due to sampling or to the actual arrangement of wells as some of these wells are linked together. Some samples indicated other metals such as lead were above drinking water guidelines. These results can be found in the appendices. Speciation results for Bowen Island can not be interpreted because of the low concentrations of arsenic.

Chemical processes responsible for high arsenic levels

There are many theories as to the process which causes high arsenic levels in groundwater. While an exact mechanism had not been elucidated, work on Bowen Island by the Geological Survey of Canada (Boyle et al, 1998) presents a possible mechanism. They hypothesize that water softening with increased residence time, leads to water of higher pH and anion exchange capacity. This allows arsenic to be exchanged to the water. Concurrent with this, arsenic desorbs from iron and aluminum oxyhydroxide minerals in veins present in fissures due to the higher pH. Arsenic and sulfur also enters the water from the oxidation of arsenic bearing minerals such as arsenopyrite.

Conclusions

The current IMAC of 0.025 ppm for arsenic may be lowered in the next few years. The EPA is expected to propose a preliminary guideline for arsenic in mid May, which may influence other regulatory bodies to change their guideline for arsenic as well.

A variety of management tools exist by which proposed new development in areas of high arsenic concentrations may be approved or regulated. These tools include; the status quo of using the GCDWQ to approve water supplies, allowing the use of treatment devices below certain arsenic concentrations, or allowing development in all areas with restrictive covenants on property titles. The possible introduction of groundwater legislation by the provincial government at some time in the future may also affect the management frameworks for dealing with arsenic in private water supplies.

There are many treatment devices on the market, however, no single technology is perfect. Each well contains water with a unique chemical composition which must be considered when choosing a treatment method. With the conditions present in the study area, pretreatment of water may be required. All devices require routine maintenance and monitoring in order to be safe and effective. The best available technology at this point in time may be reverse osmosis. However, a number of new treatment methods are in development, especially for the massive arsenic problem in Bangladesh. These devices should be available in the next few years.

No significant seasonal variability was found in arsenic concentrations, but significant variability was observed in the samples over the year. While no spatial patterns were detected in the study, some clusters of high arsenic concentrations were observed. The spatial distribution of arsenic is most likely regulated by the fracture patterns in the bedrock which are almost impossible to map.

Over half of the 21 wells had arsenic concentrations above the GCDWQ. Results ranged from 1.4 to <0.0005 ppm. Approximately 20% of the samples had fluoride and boron levels above guidelines. Speciation analysis for arsenic was not fully conclusive, but demonstrated that both forms of arsenic are present, with most of the arsenic in the As (V) form, with a few samples mainly in the As (III) form.

QA/QC results indicate that the analytical procedures for fluoride and boron do not have a great deal of variability. Significant analytical variability is present in routine arsenic analysis. The results from duplicate and reference samples indicate that up to 25% error can be expected in arsenic analysis.

Significant relationships were found between the arsenic concentrations and the concentrations of fluoride (r=0.67) and boron (r=0.96) in the water. pH and conductivity also correlated well with the arsenic concentrations (r=0.78 and 0.91 respectively). No significant correlation was found between arsenic and well depth.

The source of the high levels of arsenic in groundwater is thought to be mineralization deposits in fissures that are present in the bedrock. Water passing through these cracks dissolves and transports the arsenic from the precipitates into the wells.

Scientists from the University of Waterloo and Environment Canada are interested in applying for grants to study the arsenic problem in this area in greater detail. They may be able to provide more insight into the sources and methods of arsenic movement. The Geological Survey of Canada has a few scientists who may be interested in coordinating some of their work with any future projects involving arsenic in this region.

The results of this study should help guide approvals of new developments by providing an estimate of the error associated with measuring arsenic in water, along with a measure of the spatial and temporal variations in arsenic concentrations.

Recommendations for Further Work

During the course of this study, a number of topics for further research were identified. These avenues of research were beyond the scope of the current study. However, if funding is available in the future, investigation of the following options may provide useful information.

1. On-going monitoring of arsenic concentrations should be performed, perhaps in conjunction with the BC Ministry of Environment-Groundwater Section. This may help build a database that could be used to monitor trends in arsenic concentrations. There is relatively little work involved in obtaining well identification numbers from the MOE which would allow data from water chemistry analysis to be entered into their databases automatically. A set of wells could be chosen for long term study in conjunction with MOE. The costs for this would be negligible if community wells that are currently monitored were used for the study.

2. A thorough analysis of the depths of water bearing fractures should be done if detailed well logs can be located. A correlation of bedrock types and mineralization deposits with arsenic concentrations may reveal geochemical patterns that may be of use in determining where high levels of arsenic may be found. Collaboration with the Geological Survey of Canada may be possible on this project.

3. A review of treatment technologies should be conducted in a few years. The technologies which are currently in the research and development stage should be available on the market in a few years and may be much more effective in removing arsenic at a lower cost than the devices that are presently available. The removal of different species of arsenic by these methods should also be considered. This could

be incorporated into a study involving detailed arsenic speciation analysis of groundwater.

4. The proposed guideline that will be made public by the EPA in mid May should be a good indication of safe levels of arsenic in water, as it will be based on the most comprehensive arsenic study ever undertaken. This should be taken into consideration when considering a management strategy.

5. Communication should be initiated with other Health Units to determine the extent of high arsenic concentrations in groundwater in the province. This could be part of a provincial strategy to deal with groundwater containing high levels of arsenic. Other Health units may not be aware of high arsenic levels, as arsenic is often not tested for in water quality tests. Data from previous water quality analysis could be re-examined to determine if arsenic is a problem in other health regions.

6. Contact should be maintained with those in academia, government, and industry who are interested in arsenic research. They may be able to conduct high quality research in the region at little or no cost to the Health Unit and help provide valuable data.

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List of Abbreviations

As	Arsenic
As (III)	Arsenic III
As(V)	Arsenic V
B	Boron
ASL	Analytical Service Laboratories LTD, Vancouver
AWWA	American Water Works Association
CGHU	Coast Garibaldi Health Unit
DL	Detection Limit
EPA	Environmental Protection Agency (USA)
F	Fluoride
GCDWQ	Guidelines for Canadian Drinking Water Quality
GF	Graphite furnace
IMAC	Interim Maximum Acceptable Concentration
Li	Lithium
MAC	Maximum Acceptable Concentration
MOTH	BC Ministry of Transportation and Highways
Na	Sodium
PESC	Pacific Environmental Science Center - Environment Canada
POE	Point of Entry
POU	Point of Use
PPM	Parts per million (mg/L)
PR	Powell River
QA/QC	Quality Assurance/Quality Control
RO	Reverse Osmosis
S	Sulphur
SC	Sunshine Coast
SFU	Simon Fraser University
TSS	Total suspended sediments
UBC	University of British Columbia

Appendix 1. Complete analytical data.

	Jan/99			Jun-99	
Site	pH	Conductivity (uS)	Total Suspended Sediments (mg/L)	pH	conductivity (uS)
SC-1	8.13	135		8.39	110
SC-2	9	267		9.1	230
SC-3	9.5	229		9.43	165
SC-4	9.22	490	< 0.4	9.47	400
SC-5	9.23	489			
SC-6	8.96	215	< 0.4	9.25	290
SC-7	9.03	412			
SC-8	8.83	2050		9.03	1700
SC-9	9.25	302	< 0.4	9.47	255
SC-10	6.45	106		7.33	205
PR-1	7.32	225		7.65	190
PR-2	7.54	200		7.81	165
PR-3	8.85	392	< 0.4	9.16	340
PR-4	9.08	305		9.21	255
PR-5	7.72	105	< 0.4	8.08	90
PR-6	9.3	412		9.58	310
PR-7	9.32	388			
PR-8	9.2	550	2.1		
PR-9	9.19	390		9.38	325
PR-10	8.48	204		8.63	190
PR-11	7.89	131		8.87	115
PR-13				8.32	240
Bowen Bay				8.1	218
Bluewater				8.69	335
Tunstall 1				6.69	146
Tunstall 3				7.71	267
Tunstall 6a				7.69	132

		Jan/99			Jun/99	
	As III (ppm)	As V (ppm)	As total (ppm)	As III (ppm)	As V (ppm)	As total (ppm)
SC-1	<0.005	<0.005	0.0012	<0.005	<0.005	0.0009
SC-2	0.011	0.012	0.023	0.008	0.014	0.022
SC-3	<0.005	0.027	0.027	0.013	0.012	0.0253
SC-4	<0.005	0.177	0.177	0.036	0.15	0.19
SC-5	<0.005	0.156	0.156	0.033	0.14	0.17
SC-6	0.11	0.110	0.22	0.13	0.2	0.33
SC-7	<0.005	0.390	0.39			
SC-8	1.4	<0.005	1.36	1.1	0.3	1.36
SC-9	0.12	<0.005	0.111	0.09	0.03	0.118
SC-10	<0.005	<0.005	0.0002	<0.005	<0.005	0.0007
PR-1	<0.005	<0.005	0.0004	<0.005	<0.005	0.0003
PR-2	<0.005	<0.005	0.0031	<0.005	<0.005	0.0037
PR-3	<0.005	0.011	0.011	0.005	0.012	0.0169
PR-4	<0.005	0.014	0.014	<0.005	0.012	0.0137
PR-5	<0.005	<0.005	0.0047	<0.005	<0.005	0.005
PR-6	<0.005	0.840	0.84	0.19	0.24	0.43
PR-7	<0.005	0.790	0.79			
PR-8	0.005	0.895	0.9			
PR-9	<0.005	0.480	0.48	<0.005	0.53	0.53
PR-10	<0.005	0.088	0.088	<0.005	0.078	0.079
PR-11	<0.005	0.068	0.068	0.01	0.096	0.106
PR-13				<0.005	<0.005	0.0046
Bowen Bay				<0.005	<0.005	0.0018
Bluewater				<0.005	0.01	0.014
Tunstall 1				<0.005	<0.005	<0.002
Tunstall 3				<0.005	<0.005	<0.002
Tunstall 6a				<0.005	<0.005	<0.002

	Jan/99		Jun/99	
	F	B	F	B
SC-1	0.16	0.02	0.81	0.02
SC-2	0.82	0.61	0.64	0.64
SC-3	1.3	0.29	1	0.29
SC-4	0.14	0.57	0.15	0.69
SC-5	0.14	0.58	0.15	0.68
SC-6	0.36	2.2	0.38	2.4
SC-7	0.64	2.49		
SC-8	0.84	9.32	0.98	9.09
SC-9	0.13	1	0.12	1.07
SC-10	0.02	0.01	0.02	0.01
PR-1	0.1	0.01	0.08	0.01
PR-2	0.04	0	0.03	<0.01
PR-3	0.82	0.5	1.1	0.65
PR-4	0.55	0.4	0.62	0.4
PR-5	0.04	0	0.04	<0.01
PR-6	3.4	7	3.3	6.23
PR-7	3.4	6.97		
PR-8	5.2	9.89		
PR-9	0.95	2.37	0.81	2.58
PR-10	0.21	0.42	0.22	0.38
PR-11	0.13	0.35	0.19	0.51
PR-13			0.06	0.07

Bowen Bay	0.21	0.12
Bluewater	0.12	0.03
Tunstall 1	0.03	<0.01
Tunstall 3	0.02	0.06
Tunstall 6a	0.01	0.04

Environment Canada -Laboratories
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North Vancouver, B.C.
V7H 1V2 (604)924-2500

Lab Reference #
990396

13:45 18-Feb-99

PRELIMINARY REPORT

Identification: SUNSHINE COAST POWELL RIVER MATTU GEVAN

Flagged: DRAFT

Type of Sample: Fresh Water

Submitted by: YEE,STEWART
PESC SC.SUPPORT
SCIENTIFIC SUPP
PESC
ENV CONSERVATION

Logged in: 28-Jan-99 (28 samples)

Completed: <incomplete>

Charged to: 7020-9
+HB-HEALTH-COAST GARIB-11

Analyzed for: INORGANICS, METALS
X-MISC. NON-ANAL

Authorized by: ____________________

Notes:

[1] -extractable metals: use graphite furnace (GF) results, where reported, in preference to ICP results due to better precision and accuracy.
[2] -Hardness, Ca+Mg, and hardness, total, are expressed as mg equivalent CaCO3/L.

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Environment Canada                               Lab# 990396  18-Feb-99  Page 2
          RESULTS FOR SUNSHINE COAST POWELL RIVER MATTU GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-1   |   SC-2   |   SC-3   |
       Parameter Analyzed       | Units |990396-001|990396-002|990396-003|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.16   |   0.82   |   1.3    |
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.0015 |   0.0195 |   0.025  |
           (WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |   <.05   |   <.05   |   <.05   |
                             AS | mg/l  |   <.05   |   <.05   |   <.05   |
                             B  | mg/l  |    .02   |    .61   |    .29   |
                             BA | mg/l  |   <.001  |    .01   |    .002  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |  14.3    |   2.2    |   1.7    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |    .005  |   <.005  |   <.005  |
                             CR | mg/l  |    .005  |   <.005  |    .012  |
                             CU | mg/l  |   <.005  |   <.005  |   <.005  |
                             FE | mg/l  |    .006  |   <.005  |    .017  |
                             K  | mg/l  |   .2     |    .2    |   <.1    |
                             MG | mg/l  |   2.5    |    .3    |   <.1    |
                             MN | mg/l  |    .01   |    .002  |    .002  |
                             MO | mg/l  |   <.01   |   <.01   |   <.01   |
                             NA | mg/l  |  11.2    |  63.1    |  54.6    |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |   .1     |   <.1    |   <.1    |
                             PB | mg/l  |   <.05   |   <.05   |   <.05   |
                             S  | mg/l  |   6.4    |   8.41   |   3.01   |
                             SB | mg/l  |   <.05   |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |  12.1    |   7.34   |   7.49   |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .026  |    .033  |    .025  |
                             TI | mg/l  |   <.002  |   <.002  |   <.002  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |    .065  |    .002  |   <.002  |
          .HARDNESS/CA+MG    HC | mg/l  |  46.1    |   6.7    |   4.5    |
                   /TOTAL    HT | mg/l  |  46.3    |   6.8    |   4.7    |
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Environment Canada                               Lab# 990396  18-Feb-99  Page 3
          RESULTS FOR SUNSHINE COAST POWELL RIVER MATTU GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-4   |   SC-5   |   SC-6   |
       Parameter Analyzed       | Units |990396-004|990396-005|990396-006|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.14   |   0.14   |   0.36   |
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.153  |   0.157  |   0.227  |
           (WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |   <.05   |   <.05   |   <.05   |
                             AS | mg/l  |    .13   |    .14   |    .2    |
                             B  | mg/l  |    .57   |    .58   |   2.2    |
                             BA | mg/l  |   <.001  |   <.001  |   <.001  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |   2.3    |   2.3    |    .2    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |   <.005  |
                             CR | mg/l  |    .007  |   <.005  |   <.005  |
                             CU | mg/l  |   <.005  |   <.005  |    .006  |
                             FE | mg/l  |    .026  |    .029  |    .015  |
                             K  | mg/l  |   1      |   1.1    |    .3    |
                             MG | mg/l  |    .5    |    .6    |    .2    |
                             MN | mg/l  |    .004  |    .005  |   <.001  |
                             MO | mg/l  |    .02   |    .01   |   <.01   |
                             NA | mg/l  | 119      | 119      |  49.4    |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |   <.1    |
                             PB | mg/l  |   <.05   |   <.05   |   <.05   |
                             S  | mg/l  |  36.1    |  38.1    |  10.9    |
                             SB | mg/l  |   <.05   |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |   7.51   |   7.51   |   4.03   |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .008  |    .008  |    .002  |
                             TI | mg/l  |   <.002  |   <.002  |   <.002  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |   <.002  |   <.002  |    .005  |
          .HARDNESS/CA+MG    HC | mg/l  |   7.9    |   8.1    |   1.2    |
                   /TOTAL    HT | mg/l  |   8      |   8.2    |   1.2    |
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Environment Canada                               Lab# 990396  18-Feb-99  Page 4
          RESULTS FOR SUNSHINE COAST POWELL RIVER MATTU GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-7   |   SC-8   |   SC-9   |
       Parameter Analyzed       | Units |990396-007|990396-008|990396-009|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.64   |   0.84   |   0.13   |
METALS/EXT.(WATER-GF)        AS | mg/l  |     -    |     -    |   0.110  |
           (WATER-ICP SCAN)  AG | mg/l  |  <.01    |  <.01    |  <.01    |
                             AL | mg/l  |    .08   |  <.05    |  <.05    |
                             AS | mg/l  |    .24   |   1.2    |    .13   |
                             B  | mg/l  |   2.49   |   9.32   |   1      |
                             BA | mg/l  |    .002  |    .005  |   <.001  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |   3.7    |  20.5    |   2.4    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |    .008  |   <.005  |   <.005  |
                             CR | mg/l  |    .023  |   <.005  |    .008  |
                             CU | mg/l  |   <.005  |    .006  |   <.005  |
                             FE | mg/l  |    .112  |    .189  |   <.005  |
                             K  | mg/l  |    .8    |   2      |   1.1    |
                             MG | mg/l  |   1.3    |   1.4    |    .4    |
                             MN | mg/l  |    .012  |    .005  |   <.001  |
                             MO | mg/l  |   <.01   |    .03   |    .02   |
                             NA | mg/l  |  92.9    | 436      |  68      |
                             NI | mg/l  |  <.02    |  <.02    |  <.02    |
                             P  | mg/l  |  <.1     |  <.1     |  <.1     |
                             PB | mg/l  |  <.05    |  <.05    |  <.05    |
                             S  | mg/l  | 105      |  36.9    |  10.2    |
                             SB | mg/l  |  <.05    |  <.05    |  <.05    |
                             SE | mg/l  |  <.05    |  <.05    |  <.05    |
                             SI | mg/l  |   8.7    |   6.6    |   9.57   |
                             SN | mg/l  |  <.05    |  <.05    |  <.05    |
                             SR | mg/l  |    .021  |    .147  |    .014  |
                             TI | mg/l  |    .002  |   <.002  |   <.002  |
                             V  | mg/l  |  <.01    |  <.01    |  <.01    |
                             ZN | mg/l  |   <.002  |   <.002  |   <.002  |
          .HARDNESS/CA+MG    HC | mg/l  |  14.7    |  57      |   7.6    |
                   /TOTAL    HT | mg/l  |  15.2    |  57.7    |   7.6    |
--------------------------------+-------+----------+----------+----------+
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Environment Canada                               Lab# 990396  18-Feb-99  Page 5
          RESULTS FOR SUNSHINE COAST POWELL RIVER MATTU GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-10  |   PR-1   |   PR-2   |
       Parameter Analyzed       | Units |990396-010|990396-011|990396-012|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.02   |   0.1    |   0.04   |
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.0008 |   0.0009 |   0.0037 |
           (WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |    .1    |   <.05   |   <.05   |
                             AS | mg/l  |   <.05   |   <.05   |   <.05   |
                             B  | mg/l  |    .01   |    .01   |   <.01   |
                             BA | mg/l  |    .004  |    .118  |    .109  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |  11.4    |  30.7    |  26.9    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |    .007  |   <.005  |   <.005  |
                             CR | mg/l  |    .007  |    .018  |   <.005  |
                             CU | mg/l  |    .106  |   <.005  |    .01   |
                             FE | mg/l  |    .04   |    .597  |    .019  |
                             K  | mg/l  |    .4    |    .7    |    .2    |
                             MG | mg/l  |   1.7    |   8.5    |   7.1    |
                             MN | mg/l  |    .002  |    .186  |    .048  |
                             MO | mg/l  |   <.01   |   <.01   |   <.01   |
                             NA | mg/l  |   7.8    |   9.4    |   9.3    |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |   <.1    |
                             PB | mg/l  |   <.05   |   <.05   |   <.05   |
                             S  | mg/l  |    .9    |   2.19   |   1.98   |
                             SB | mg/l  |   <.05   |   <.05   |    .05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |   5.45   |  13.3    |   9.71   |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .036  |    .174  |    .125  |
                             TI | mg/l  |   <.002  |   <.002  |   <.002  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |    .009  |    .018  |    .006  |
          .HARDNESS/CA+MG    HC | mg/l  |  35.2    | 111      |  96.5    |
                   /TOTAL    HT | mg/l  |  35.9    | 113      |  97      |
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Environment Canada                              Lab# 990396  18-Feb-99  Page 6
          RESULTS FOR SUNSHINE COAST POWELL RIVER MATTU GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   PR-3   |   PR-4   |   PR-5   |
       Parameter Analyzed       | Units |990396-013|990396-014|990396-015|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.82   |   0.55   |   0.04   |
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.0107 |   0.0138 |   0.0048 |
           (WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |   <.05   |    .07   |   <.05   |
                             AS | mg/l  |   <.05   |   <.05   |   <.05   |
                             B  | mg/l  |    .5    |    .4    |   <.01   |
                             BA | mg/l  |   <.001  |    .002  |    .004  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |   3.8    |   1.8    |  12.7    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |    .007  |   <.005  |   <.005  |
                             CR | mg/l  |    .007  |    .012  |   <.005  |
                             CU | mg/l  |   <.005  |    .006  |   <.005  |
                             FE | mg/l  |    .022  |    .026  |    .452  |
                             K  | mg/l  |    .7    |    .3    |   1.6    |
                             MG | mg/l  |    .9    |    .3    |   3.1    |
                             MN | mg/l  |    .003  |    .004  |    .248  |
                             MO | mg/l  |   <.01   |    .01   |   <.01   |
                             NA | mg/l  |  94.3    |  74.5    |   6.2    |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |    .1    |
                             PB | mg/l  |   <.05   |   <.05   |   <.05   |
                             S  | mg/l  | 112      |   8.71   |    .06   |
                             SB | mg/l  |   <.05   |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |   9.09   |   8.07   |  12.8    |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .023  |    .011  |    .068  |
                             TI | mg/l  |   <.002  |    .005  |   <.002  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |   <.002  |    .002  |    .007  |
          .HARDNESS/CA+MG    HC | mg/l  |  12.9    |   5.9    |  44.6    |
                   /TOTAL    HT | mg/l  |  13.1    |   6.2    |  46      |
--------------------------------+-------+----------+----------+----------+
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Environment Canada                                Lab# 990396  18-Feb-99  Page 7
          RESULTS FOR SUNSHINE COAST POWELL RIVER MATTU GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   PR-6   |   PR-7   |   PR-8   |
       Parameter Analyzed       | Units |990396-016|990396-017|990396-018|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   3.4    |   3.4    |   5.2    |
METALS/EXT.(WATER-GF)        AS | mg/l  |     -    |     -    |     -    |
           (WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |   <.05   |   <.05   |   <.05   |
                             AS | mg/l  |    .68   |    .69   |    .82   |
                             B  | mg/l  |   7      |   6.97   |   9.89   |
                             BA | mg/l  |    .006  |    .008  |    .022  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |   1.2    |   1.2    |   2.1    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |   <.005  |
                             CR | mg/l  |    .008  |   <.005  |   <.005  |
                             CU | mg/l  |   <.005  |   <.005  |   <.005  |
                             FE | mg/l  |    .032  |    .022  |    .06   |
                             K  | mg/l  |    .3    |    .3    |    .7    |
                             MG | mg/l  |   <.1    |   <.1    |    .1    |
                             MN | mg/l  |    .002  |    .002  |    .005  |
                             MO | mg/l  |   <.01   |   <.01   |   <.01   |
                             NA | mg/l  | 102      | 101      | 131      |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |    .1    |    .1    |   <.1    |
                             PB | mg/l  |   <.05   |   <.05   |   <.05   |
                             S  | mg/l  | 140      | 137      |  87.5    |
                             SB | mg/l  |   <.05   |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |   4.51   |   4.46   |   3.86   |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .017  |    .018  |    .046  |
                             TI | mg/l  |   <.002  |   <.002  |   <.002  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |   <.002  |   <.002  |    .956  |
          .HARDNESS/CA+MG    HC | mg/l  |   2.9    |   3.1    |   5.6    |
                   /TOTAL    HT | mg/l  |   2.9    |   3.3    |   7.3    |
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Environment Canada                              Lab# 990396  18-Feb-99  Page 8
          RESULTS FOR SUNSHINE COAST POWELL RIVER MATTU GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   PR-9   |   PR-10  |   PR-11  |
       Parameter Analyzed       | Units |990396-019|990396-020|990396-021|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.95   |   0.21   |   0.13   |
METALS/EXT.(WATER-GF)        AS | mg/l  |    -     |   0.0900 |   0.0772 |
           (WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |   <.05   |   <.05   |   <.05   |
                             AS | mg/l  |    .49   |    .08   |    .07   |
                             B  | mg/l  |   2.37   |    .42   |    .35   |
                             BA | mg/l  |    .027  |    .212  |    .052  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |   1.1    |  10.5    |   5.6    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |   <.005  |
                             CR | mg/l  |    .006  |   <.005  |   <.005  |
                             CU | mg/l  |    .006  |   <.005  |    .007  |
                             FE | mg/l  |    .024  |    .023  |    .167  |
                             K  | mg/l  |    .7    |   2.2    |   2.1    |
                             MG | mg/l  |   <.1    |   1.4    |   1      |
                             MN | mg/l  |    .002  |    .007  |    .007  |
                             MO | mg/l  |   <.01   |   <.01   |   <.01   |
                             NA | mg/l  | 100      |  38.4    |  23.3    |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |   <.1    |
                             PB | mg/l  |   <.05   |   <.05   |   <.05   |
                             S  | mg/l  |   9.99   |   8.38   |   2.38   |
                             SB | mg/l  |   <.05   |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |   4.39   |   6.9    |   6.67   |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .019  |    .17   |    .062  |
                             TI | mg/l  |   <.002  |   <.002  |   <.002  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |   <.002  |   <.002  |    .12   |
          .HARDNESS/CA+MG    HC | mg/l  |   3      |  31.9    |  18.1    |
                   /TOTAL    HT | mg/l  |   3.1    |  32.3    |  18.7    |
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Environment Canada                               Lab# 990396  18-Feb-99  Page 9
          RESULTS FOR SUNSHINE COAST POWELL RIVER MATTU GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-11  |   SC-12  |   SC-13  |
       Parameter Analyzed       | Units |990396-022|990396-023|990396-024|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |     -    |     -    |     -    |
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.0030 |   0.0006 |  <0.0005 |
           (WATER-ICP SCAN)  AG | mg/l  |     -    |     -    |     -    |
                             AL | mg/l  |     -    |     -    |     -    |
                             AS | mg/l  |     -    |     -    |     -    |
                             B  | mg/l  |     -    |     -    |     -    |
                             BA | mg/l  |     -    |     -    |     -    |
                             BE | mg/l  |     -    |     -    |     -    |
                             CA | mg/l  |     -    |     -    |     -    |
                             CD | mg/l  |     -    |     -    |     -    |
                             CO | mg/l  |     -    |     -    |     -    |
                             CR | mg/l  |     -    |     -    |     -    |
                             CU | mg/l  |     -    |     -    |     -    |
                             FE | mg/l  |     -    |     -    |     -    |
                             K  | mg/l  |     -    |     -    |     -    |
                             MG | mg/l  |     -    |     -    |     -    |
                             MN | mg/l  |     -    |     -    |     -    |
                             MO | mg/l  |     -    |     -    |     -    |
                             NA | mg/l  |     -    |     -    |     -    |
                             NI | mg/l  |     -    |     -    |     -    |
                             P  | mg/l  |     -    |     -    |     -    |
                             PB | mg/l  |     -    |     -    |     -    |
                             S  | mg/l  |     -    |     -    |     -    |
                             SB | mg/l  |     -    |     -    |     -    |
                             SE | mg/l  |     -    |     -    |     -    |
                             SI | mg/l  |     -    |     -    |     -    |
                             SN | mg/l  |     -    |     -    |     -    |
                             SR | mg/l  |     -    |     -    |     -    |
                             TI | mg/l  |     -    |     -    |     -    |
                             V  | mg/l  |     -    |     -    |     -    |
                             ZN | mg/l  |     -    |     -    |     -    |
          .HARDNESS/CA+MG    HC | mg/l  |     -    |     -    |     -    |
                   /TOTAL    HT | mg/l  |     -    |     -    |     -    |
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Environment Canada                              Lab# 990396  18-Feb-99  Page 10
          RESULTS FOR SUNSHINE COAST POWELL RIVER MATTU GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-14  |   SC-15  |   SC-16  |
       Parameter Analyzed       | Units |990396-025|990396-026|990396-027|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |     -    |   1      |   0.05   |
METALS/EXT.(WATER-GF)        AS | mg/l  |     -    |     -    |     -    |
           (WATER-ICP SCAN)  AG | mg/l  |   <.01   |     -    |   <.01   |
                             AL | mg/l  |   <.05   |     -    |   <.05   |
                             AS | mg/l  |   <.05   |     -    |   <.05   |
                             B  | mg/l  |   4.75   |     -    |   <.01   |
                             BA | mg/l  |   <.001  |     -    |    .004  |
                             BE | mg/l  |   <.001  |     -    |   <.001  |
                             CA | mg/l  |   <.1    |     -    |   1.3    |
                             CD | mg/l  |   <.005  |     -    |   <.005  |
                             CO | mg/l  |   <.005  |     -    |   <.005  |
                             CR | mg/l  |   <.005  |     -    |   <.005  |
                             CU | mg/l  |   <.005  |     -    |    .539  |
                             FE | mg/l  |   <.005  |     -    |    .04   |
                             K  | mg/l  |   <.1    |     -    |    .2    |
                             MG | mg/l  |   <.1    |     -    |    .2    |
                             MN | mg/l  |    .001  |     -    |    .004  |
                             MO | mg/l  |   <.01   |     -    |   <.01   |
                             NA | mg/l  |   <.1    |     -    |    .1    |
                             NI | mg/l  |   <.02   |     -    |   <.02   |
                             P  | mg/l  |   <.1    |     -    |   <.1    |
                             PB | mg/l  |   <.05   |     -    |   <.05   |
                             S  | mg/l  |   <.05   |     -    |    .47   |
                             SB | mg/l  |   <.05   |     -    |   <.05   |
                             SE | mg/l  |   <.05   |     -    |   <.05   |
                             SI | mg/l  |   <.05   |     -    |   1.48   |
                             SN | mg/l  |   <.05   |     -    |   <.05   |
                             SR | mg/l  |   <.001  |     -    |    .006  |
                             TI | mg/l  |   <.002  |     -    |   <.002  |
                             V  | mg/l  |   <.01   |     -    |   <.01   |
                             ZN | mg/l  |    .003  |     -    |    .024  |
          .HARDNESS/CA+MG    HC | mg/l  |   <.4    |     -    |   3.9    |
                   /TOTAL    HT | mg/l  |   <.4    |     -    |   5      |
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Environment Canada                              Lab# 990396  18-Feb-99  Page 11
          RESULTS FOR SUNSHINE COAST POWELL RIVER MATTU GEVAN SAMPLES

--------------------------------+-------+----------+
                                |       |   SC-17  |
       Parameter Analyzed       | Units |990396-028|
--------------------------------+-------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.05   |
METALS/EXT.(WATER-GF)        AS | mg/l  |     -    |
           (WATER-ICP SCAN)  AG | mg/l  |   <.01   |
                             AL | mg/l  |   <.05   |
                             AS | mg/l  |   <.05   |
                             B  | mg/l  |   <.01   |
                             BA | mg/l  |    .002  |
                             BE | mg/l  |   <.001  |
                             CA | mg/l  |   <.1    |
                             CD | mg/l  |   <.005  |
                             CO | mg/l  |    .01   |
                             CR | mg/l  |   <.005  |
                             CU | mg/l  |    .006  |
                             FE | mg/l  |   <.005  |
                             K  | mg/l  |   <.1    |
                             MG | mg/l  |   <.1    |
                             MN | mg/l  |   <.001  |
                             MO | mg/l  |   <.01   |
                             NA | mg/l  |   <.1    |
                             NI | mg/l  |   <.02   |
                             P  | mg/l  |   <.1    |
                             PB | mg/l  |   <.05   |
                             S  | mg/l  |   <.05   |
                             SB | mg/l  |   <.05   |
                             SE | mg/l  |    .07   |
                             SI | mg/l  |   <.05   |
                             SN | mg/l  |   <.05   |
                             SR | mg/l  |    .001  |
                             TI | mg/l  |    .004  |
                             V  | mg/l  |   <.01   |
                             ZN | mg/l  |   <.002  |
          .HARDNESS/CA+MG    HC | mg/l  |   <.4    |
                   /TOTAL    HT | mg/l  |   <.4    |
--------------------------------+-------+----------+
```

Environment Canada -Laboratories
Pacific Environmental Science Centre
2645 Dollarton Hwy.
North Vancouver, B.C.
V7H 1V2 (604)924-2500

Lab Reference #
991828

08:56 14-May-99

FINAL REPORT

Identification: SUNSHINE COAST - MATTU, G. (JIM BROOKES)

Type of Sample: Fresh Water

Submitted by: YEE,STEWART
PESC SC.SUPPORT
SCIENTIFIC SUPP
PESC
ENV CONSERVATION

Logged in: 22-Apr-99 (3 samples)

Completed: 07-May-99 (3 results)

Charged to: 7020-9
+HB-HEALTH-COAST GARIB-11

Analyzed for: METALS

Authorized by: ____________________

Notes:

[1] -Results confirmed by ICP-MS
[2] -extractable metals: use graphite furnace (GF) results, where reported, in preference to ICP results due to better precision and accuracy.

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Environment Canada                          Lab# 991828  14-May-99  Page 2
          RESULTS FOR SUNSHINE COAST - MATTU, G. (JIM BROOKES) SAMPLES

----------------------------------+-------+----------+----------+----------+
                                  |       |   SC-1   |   SC-2   |   SC-3   |
                                  |       |                     |          |
       Parameter Analyzed         | Units |991828-001|991828-002|991828-003|
----------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)          AS | mg/l  |  0.0009  |  0.019   |  0.022   |
----------------------------------+-------+----------+----------+----------+

----------------------------------+-------+----------+----------+----------+
                                  |       |   SC-4   |   SC-6   |   SC-9   |

       Parameter Analyzed         | Units |991829-001|991829-002|991829-003|
----------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)          AS | mg/l  |  0.135   |  0.035   |  0.102   |
----------------------------------+-------+----------+----------+----------+


----------------------------------+-------+----------+----------+
                                  |       |   SC-10  |   SC-7   |
       Parameter Analyzed         | Units |991829-004|991829-005|
----------------------------------+-------+----------+----------+
METALS/EXT.(WATER-GF)          AS | mg/l  | <0.0005  |  0.255   |
----------------------------------+-------+----------+----------+


----------------------------------+-------+----------+----------+----------+
                                  |       |   PR-1   |   PR-2   |   PR-3   |
       Parameter Analyzed         | Units |991655-001|991655-002|991655-003|
----------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)          AS | mg/l  | <0.0005  |  0.0031  |  0.013   |
----------------------------------+-------+----------+----------+----------+


----------------------------------+-------+----------+----------+----------+
                                  |       |   PR-4   |   PR-5   |   PR-9   |
       Parameter Analyzed         | Units |991655-004|991655-005|991655-007|
----------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)          AS | mg/l  |  0.013   |  0.0037  |  0.436   |
----------------------------------+-------+----------+----------+----------+


----------------------------------+-------+----------+----------+
                                  |       |   PR-10  |   PR-11  |
       Parameter Analyzed         | Units |991655-008|991655-009|
----------------------------------+-------+----------+----------+
METALS/EXT.(WATER-GF)          AS | mg/l  |  0.072   |  0.085   |
----------------------------------+-------+----------+----------+
```

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Environment Canada -Laboratories                           Lab Reference #
Pacific Environmental Science Centre                         9 9 2 1 8 2
2645 Dollarton Hwy.
North Vancouver, B.C.                                      11:54 14-Jul-99
V7H 1V2  (604)924-2500
```

PRELIMINARY REPORT

Identification: BOWEN ISLAND MATTU,GEVAN

Flagged: DRAFT

Type of Sample: Fresh Water

Submitted by: YEE,STEWART
PESC SC.SUPPORT
SCIENTIFIC SUPP
PESC
ENV CONSERVATION

Logged in: 7 may-99 (5 samples)

Completed: <incomplete>

Charged to: 99-900
PESC - DIRECT BILLING

Analyzed for: CONTRACTED TESTS, INORGANICS
METALS

Authorized by: ______________________

Notes:

[1] -Hardness, Ca+Mg, and hardness, total, are expressed as mg equivalent CaCO3/L.
[2] -Result notations: "<inc>" test incomplete

```
Environment Canada                           Lab# 992182  7 may-99  Page 2
              RESULTS FOR BOWEN ISLAND  MATTU,GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |     #3 tunstall  #1 tunstall  6a tunstall

       Parameter Analyzed       | Units |992182-001|992182-002|992182-003|
--------------------------------+-------+----------+----------+----------+
                   As           | mg/l     0.0009     0.0023    0.0010
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |   <.05   |   <.05   |   <.05   |
                             AS | mg/l  |   <.05   |   <.05   |   <.05   |
                             B  | mg/l  |    .07   |   <.01   |    .04   |
                             BA | mg/l  |    .002  |    .004  |   <.001  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |  34.3    | 13.4     |  14.6    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |   <.005  |
                             CR | mg/l  |   <.005  |   <.005  |   <.005  |
                             CU | mg/l  |   <.005  |   <.005  |   <.005  |
                             FE | mg/l  |    .123  |   1.73   |    .065  |
                             K  | mg/l  |   <.1    |   1.5    |   <.1    |
                             MG | mg/l  |   2.6    |   4.2    |   1.5    |
                             MN | mg/l  |    .015  |     .01  |    .004  |
                             MO | mg/l  |    .01   |   <.01   |   <.01   |
                             NA | mg/l  |  15.6    |   6.7    |   9.4    |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |   <.1    |
                             PB | mg/l  |   <.05   |   <.05   |   <.05   |
                             S  | mg/l  |   4.12   |   1.22   |   2.15   |
                             SB | mg/l  |   <.05   |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |  7.47    |  16.6    |   5.25   |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .047  |    .107  |    .023  |
                             TI | mg/l  |   <.002  |   <.002  |   <.002  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |    4.08  |    .021  |    .464  |
          .HARDNESS/CA+MG    HC | mg/l  |  96.5    |  50.8    |  42.7    |
                  /TOTAL     HT | mg/l  |  103     |  54.1    |  43.7    |
```

```
Environment Canada                               Lab# 992182  7 may-99  Page 3
              RESULTS FOR BOWEN ISLAND MATTU,GEVAN SAMPLES

--------------------------------+-------+----------+
                                |       |bowen bay
                                |       |          |
       Parameter Analyzed       | Units |992182-004|
--------------------------------+-------+----------+
            As                  | mg/l     0.0019
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |   <.01   |
                             AL | mg/l  |   <.05   |
                             AS | mg/l  |   <.05   |
                             B  | mg/l  |    .11   |
                             BA | mg/l  |    .136  |
                             BE | mg/l  |   <.001  |
                             CA | mg/l  |  18.3    |
                             CD | mg/l  |   <.005  1
                             CO | mg/l  |    .007  |
                             CR | mg/l  |   <.005  |
                             CU | mg/l  |    .257  |
                             FE | mg/l  |    .053  |
                             K  | mg/l  |    .7    |
                             MG | mg/l  |   3.4    |
                             MN | mg/l  |    .003  |
                             MO | mg/l  |    .01   |
                             NA | mg/l  |  51.6    |
                             NI | mg/l  |   <.02   |
                             P  | mg/l  |   <.1    |
                             PB | mg/l  |   <.05   |
                             S  | mg/l  |   3.81   |
                             SB | mg/l  |   <.05   |
                             SE | mg/l  |   <.05   |
                             SI | mg/l  |   13.4   |
                             SN | mg/l  |   <.05   |
                             SR | mg/l  |    .099  |
                             TI | mg/l  |   <.002  |
                             V  | mg/l  |   <.01   |
                             ZN | mg/l  |   1.27   |
          .HARDNESS/CA+MG    HC | mg/l  |  59.9    |
                   /TOTAL    HT | mg/l  |  62.5    |
```

Environment Canada -Laboratories
Pacific Environmental Science Centre
2645 Dollarton Hwy.
North Vancouver, B.C.
V7H 1V2 (604)924-2500

Lab Reference #
993206

11:54 14-Jul-99

PRELIMINARY REPORT

Identification: BOWEN ISLAND JUNE 22 MATTU,GEVAN

Flagged: DRAFT

Type of Sample: Fresh Water

Submitted by: YEE,STEWART
PESC SC.SUPPORT
SCIENTIFIC SUPP
PESC
ENV CONSERVATION

Logged in: 24-Jun-99 (5 samples)

Completed: <incomplete>

Charged to: 99-900
PESC - DIRECT BILLING

Analyzed for: CONTRACTED TESTS, INORGANICS
METALS

Authorized by: ______________________

Notes:

[1] -Hardness, Ca+Mg, and hardness, total, are expressed as mg equivalent CaCO3/L.
[2] -Result notations: "<inc>" test incomplete

```
Environment Canada                               Lab# 993206  14-Jul-99  Page 2
              RESULTS FOR BOWEN ISLAND JUNE 22 MATTU,GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       | BOWEN BAY|BLUE WATER|TUNSTALL 1|
                                |       |          |          |          |
       Parameter Analyzed       | Units |993206-001|993206-002|993206-003|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.21   |   0.12   |   0.03   |
CONDUCTIVITY                    | uS/cm | 335      | 218      | 146      |
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |    .09   |    .05   |    .44   |
                             AS | mg/l  |   <.05   |   <.05   |   <.05   |
                             B  | mg/l  |    .12   |    .03   |   <.01   |
                             BA | mg/l  |    .144  |   <.001  |    .003  |
                             BE | mg/l  |    .001  |   <.001  |   <.001  |
                             CA | mg/l  |  17.4    |  24      |  14.8    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |   <.005  |
                             CR | mg/l  |    .006  |    .005  |   <.005  |
                             CU | mg/l  |   <.005  |   <.005  |    .247  |
                             FE | mg/l  |    .021  |    .718  |    .155  |
                             K  | mg/l  |   1      |    .5    |  2       |
                             MG | mg/l  |   3.6    |   1.9    |  4.5     |
                             MN | mg/l  |    .005  |    .031  |    .001  |
                             MO | mg/l  |   <.01   |   <.01   |   <.01   |
                             NA | mg/l  |  53.6    |  20.2    |  5.7     |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |   <.1    |
                             PB | mg/l  |   <.05   |   <.05   |    .62   |
                             S  | mg/l  |   4.05   |   4.97   |  1.45    |
                             SB | mg/l  |    .07   |    .05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |  13.9    |  11.5    |  19.7    |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .104  |    .097  |    .115  |
                             TI | mg/l  |   <.002  |   <.002  |   <.002  |
                             V  | mg/l  |    .01   |   <.01   |    .01   |
                             ZN | mg/l  |    .029  |    .049  |    .104  |
          .HARDNESS/CA+MG    HC | mg/l  |  58.1    |  67.7    |  55.3    |
                   /TOTAL    HT | mg/l  |  58.8    |  69.4    |  58.2    |
PH                              |Rel.U. |   8.69   |   8.10   |  6.69    |
--------------------------------+-------+----------+----------+----------+
ASL-ARSENIC 3+ SPECIATION       |       |   <inc>  |   <inc>  |   <inc>  |
            5+ SPECIATION       |       |   <inc>  |   <inc>  |   <inc>  |
--------------------------------+-------+----------+----------+----------+
```

```
Environment Canada                              Lab# 993206  14-Jul-99  Page 3
              RESULTS FOR BOWEN ISLAND JUNE 22 MATTU,GEVAN SAMPLES

--------------------------------+-------+----------+----------+
                                |       |TUNSTALL 3| TUNSTALL |
                                |       |          |    6A    |
       Parameter Analyzed       | Units |993206-004|993206-005|
--------------------------------+-------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.020  |   0.01   |
CONDUCTIVITY                    | uS/cm | 267      | 132      |
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |
                             AL | mg/l  |    .09   |    .11   |
                             AS | mg/l  |   <.05   |   <.05   |
                             B  | mg/l  |    .06   |    .04   |
                             BA | mg/l  |   <.001  |   <.001  |
                             BE | mg/l  |    .002  |    .002  |
                             CA | mg/l  |  36.9    |  15.7    |
                             CD | mg/l  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |
                             CR | mg/l  |   <.005  |   <.005  |
                             CU | mg/l  |   <.005  |    .372  |
                             FE | mg/l  |    .13   |    .065  |
                             K  | mg/l  |    .2    |    .2    |
                             MG | mg/l  |   2.8    |   1.6    |
                             MN | mg/l  |    .024  |   <.001  |
                             MO | mg/l  |   <.01   |   <.01   |
                             NA | mg/l  |  13.7    |   7.7    |
                             NI | mg/l  |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |
                             PB | mg/l  |   <.05   |    .11   |
                             S  | mg/l  |   4.59   |   2.35   |
                             SB | mg/l  |    .07   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |
                             SI | mg/l  |   6.39   |   6.49   |
                             SN | mg/l  |   <.05   |   <.05   |
                             SR | mg/l  |    .052  |    .025  |
                             TI | mg/l  |   <.002  |   <.002  |
                             V  | mg/l  |    .01   |    .01   |
                             ZN | mg/l  |   7.95   |    .346  |
         .HARDNESS/CA+MG     HC | mg/l  | 104      |  45.7    |
                  /TOTAL     HT | mg/l  | 117      |  47.4    |
PH                              |Rel.U. |   7.71   |   7.69   |
--------------------------------+-------+----------+----------+
ASL-ARSENIC 3+ SPECIATION       |       |   <inc>  |   <inc>  |
            5+ SPECIATION       |       |   <inc>  |   <inc>  |
--------------------------------+-------+----------+----------+
```

Environment Canada -Laboratories
Pacific Environmental Science Centre
2645 Dollarton Hwy.
North Vancouver, B.C.
V7H 1V2 (604)924-2500

Lab Reference #
993207

11:55 14-Jul-99

PRELIMINARY REPORT

Identification: SUNSHINE COAST/POWELL RIVER MATTU,G

Flagged: DRAFT

Type of Sample: Fresh Water

Submitted by: YEE,STEWART
PESC SC.SUPPORT
SCIENTIFIC SUPP
PESC
ENV CONSERVATION

Logged in: 25-Jun-99 (21 samples)

Completed: <incomplete>

Charged to: 99-900
PESC - DIRECT BILLING

Analyzed for: CONTRACTED TESTS, INORGANICS
METALS

Authorized by: ____________________

Notes:

[1] -Hardness, Ca+Mg, and hardness, total, are expressed as mg equivalent CaCO3/L.
[2] -Result notations: "<inc>" test incomplete

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Environment Canada                               Lab# 993207  14-Jul-99  Page 2
            RESULTS FOR SUNSHINE COAST/POWELL RIVER MATTU,G SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-1   |   SC-2   |   SC-3   |
       Parameter Analyzed       | Units |993207-001|993207-002|993207-003|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.81   |   0.64   |   1      |
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |   <.05   |   <.05   |   <.05   |
                             AS | mg/l  |   <.05   |   <.05   |   <.05   |
                             B  | mg/l  |    .02   |    .64   |    .29   |
                             BA | mg/l  |    .001  |    .01   |    .002  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |  14.4    |   2.2    |   1.6    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |   <.005  |
                             CR | mg/l  |    .009  |   <.005  |    .006  |
                             CU | mg/l  |   <.005  |   <.005  |   <.005  |
                             FE | mg/l  |    .008  |    .01   |    .007  |
                             K  | mg/l  |    .4    |    .2    |   <.1    |
                             MG | mg/l  |   2.6    |    .3    |   <.1    |
                             MN | mg/l  |    .012  |    .002  |    .002  |
                             MO | mg/l  |   <.01   |   <.01   |   <.01   |
                             NA | mg/l  |  10.8    |  61.1    |  52.3    |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |    .1    |   <.1    |   <.1    |
                             PB | mg/l  |   <.05   |   <.05   |   <.05   |
                             S  | mg/l  |   7.33   |   8.38   |   3.24   |
                             SB | mg/l  |   <.05   |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |  12.7    |   7.76   |   8      |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .026  |    .033  |    .024  |
                             TI | mg/l  |   <.002  |   <.002  |   <.002  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |    .033  |    .008  |   <.002  |
          .HARDNESS/CA+MG    HC | mg/l  |  46.6    |   6.7    |   4.5    |
                   /TOTAL    HT | mg/l  |  46.7    |   6.8    |   4.7    |
--------------------------------+-------+----------+----------+----------+
ASL-ARSENIC 3+ SPECIATION       |       |     -    |     -    |     -    |
            5+ SPECIATION       |       |     -    |     -    |     -    |
--------------------------------+-------+----------+----------+----------+
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Environment Canada                              Lab# 993207  14-Jul-99  Page 3
            RESULTS FOR SUNSHINE COAST/POWELL RIVER MATTU,G SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-4   |   SC-5   |   SC-6   |
       Parameter Analyzed       | Units |993207-004|993207-005|993207-006|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.15   |   0.15   |   0.38   |
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |   <.05   |   <.05   |    .05   |
                             AS | mg/l  |    .16   |    .17   |    .29   |
                             B  | mg/l  |    .69   |    .68   |   2.4    |
                             BA | mg/l  |   <.001  |   <.001  |    .001  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |   1.4    |   1.4    |   3.8    |
                             CD | mg/l  |   <.005  |   <.005  |    .005  |
                             CO | mg/l  |   <.005  |   <.005  |   <.005  |
                             CR | mg/l  |    .013  |   <.005  |   <.005  |
                             CU | mg/l  |   <.005  |   <.005  |   <.005  |
                             FE | mg/l  |    .026  |    .012  |    .06   |
                             K  | mg/l  |   1.1    |   1.3    |   1.1    |
                             MG | mg/l  |    .4    |    .4    |   1.4    |
                             MN | mg/l  |    .007  |    .009  |    .012  |
                             MO | mg/l  |    .01   |    .01   |   <.01   |
                             NA | mg/l  | 124      | 124      |  83.9    |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |   <.1    |
                             PB | mg/l  |   <.05   |   <.05   |   <.05   |
                             S  | mg/l  |  29.1    |  28.9    |  50.2    |
                             SB | mg/l  |   <.05   |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |   7.77   |   7.75   |   9.31   |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .008  |    .008  |    .021  |
                             TI | mg/l  |   <.002  |   <.002  |    .006  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |   <.002  |   <.002  |    .003  |
          .HARDNESS/CA+MG    HC | mg/l  |   4.9    |   5.1    |  15.5    |
                   /TOTAL    HT | mg/l  |   5.1    |   5.1    |  15.8    |
--------------------------------+-------+----------+----------+----------+
ASL-ARSENIC 3+ SPECIATION       |       |     -    |     -    |     -    |
            5+ SPECIATION       |       |     -    |     -    |     -    |
--------------------------------+-------+----------+----------+----------+
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Environment Canada                               Lab# 993207  14-Jul-99  Page 4
            RESULTS FOR SUNSHINE COAST/POWELL RIVER MATTU,G SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-8   |   SC-9   |   SC-10  |
       Parameter Analyzed       | Units |993207-007|993207-008|993207-009|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.98   |   0.12   |   0.02   |
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |   <.05   |   <.05   |   <.05   |
                             AS | mg/l  |   1.17   |    .1    |   <.05   |
                             B  | mg/l  |   9.09   |   1.07   |    .01   |
                             BA | mg/l  |    .004  |   <.001  |    .009  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |  20.4    |   2.4    |  28.6    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |   <.005  |
                             CR | mg/l  |   <.005  |    .014  |    .02   |
                             CU | mg/l  |   <.005  |    .018  |    .136  |
                             FE | mg/l  |    .242  |    .012  |    .009  |
                             K  | mg/l  |   2      |   1.1    |    .9    |
                             MG | mg/l  |   1.4    |    .4    |   5      |
                             MN | mg/l  |    .005  |    .001  |    .001  |
                             MO | mg/l  |    .03   |    .02   |    .01   |
                             NA | mg/l  | 454      |  65.9    |  17.4    |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |   <.1    |
                             PB | mg/l  |   <.05   |    .08   |   <.05   |
                             S  | mg/l  |  37.7    |  11.1    |  2.97    |
                             SB | mg/l  |   <.05   |    .06   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |   6.96   |  10      |  6.58    |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .152  |    .015  |    .091  |
                             TI | mg/l  |   <.002  |   <.002  |   <.002  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |   <.002  |    .003  |   <.002  |
          .HARDNESS/CA+MG    HC | mg/l  |  56.6    |   7.6    |  92      |
                   /TOTAL    HT | mg/l  |  57.3    |   7.8    |  92.4    |
--------------------------------+-------+----------+----------+----------+
ASL-ARSENIC 3+ SPECIATION       |       |     -    |     -    |     -    |
            5+ SPECIATION       |       |     -    |     -    |     -    |
--------------------------------+-------+----------+----------+----------+
```

```
Environment Canada                              Lab# 993207  14-Jul-99  Page 5
            RESULTS FOR SUNSHINE COAST/POWELL RIVER MATTU,G SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |  SC-11   |  SC-12   |  PR-1    |
       Parameter Analyzed       | Units |993207-010|993207-011|993207-012|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |    -     |    -     |   0.08   |
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |    -     |    -     |   <.01   |
                             AL | mg/l  |    -     |    -     |   <.05   |
                             AS | mg/l  |    -     |    -     |   <.05   |
                             B  | mg/l  |    -     |    -     |    .01   |
                             BA | mg/l  |    -     |    -     |    .118  |
                             BE | mg/l  |    -     |    -     |   <.001  |
                             CA | mg/l  |    -     |    -     |  28.3    |
                             CD | mg/l  |    -     |    -     |   <.005  |
                             CO | mg/l  |    -     |    -     |   <.005  |
                             CR | mg/l  |    -     |    -     |    .015  |
                             CU | mg/l  |    -     |    -     |    .005  |
                             FE | mg/l  |    -     |    -     |    .438  |
                             K  | mg/l  |    -     |    -     |    .7    |
                             MG | mg/l  |    -     |    -     |   7.9    |
                             MN | mg/l  |    -     |    -     |    .184  |
                             MO | mg/l  |    -     |    -     |    .01   |
                             NA | mg/l  |    -     |    -     |   8.4    |
                             NI | mg/l  |    -     |    -     |   <.02   |
                             P  | mg/l  |    -     |    -     |   <.1    |
                             PB | mg/l  |    -     |    -     |   <.05   |
                             S  | mg/l  |    -     |    -     |   1.76   |
                             SB | mg/l  |    -     |    -     |   <.05   |
                             SE | mg/l  |    -     |    -     |   <.05   |
                             SI | mg/l  |    -     |    -     |  13.8    |
                             SN | mg/l  |    -     |    -     |   <.05   |
                             SR | mg/l  |    -     |    -     |    .174  |
                             TI | mg/l  |    -     |    -     |   <.002  |
                             V  | mg/l  |    -     |    -     |   <.01   |
                             ZN | mg/l  |    -     |    -     |    .109  |
          .HARDNESS/CA+MG    HC | mg/l  |    -     |    -     | 103      |
                   /TOTAL    HT | mg/l  |    -     |    -     | 105      |
--------------------------------+-------+----------+----------+----------+
ASL-ARSENIC 3+ SPECIATION       |       |  <inc>   |  <inc>   |    -     |
            5+ SPECIATION       |       |  <inc>   |  <inc>   |    -     |
--------------------------------+-------+----------+----------+----------+
```

```
Environment Canada                               Lab# 993207  14-Jul-99  Page 6
            RESULTS FOR SUNSHINE COAST/POWELL RIVER MATTU,G SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   PR-2   |   PR-3   |   PR-13  |
       Parameter Analyzed       | Units |993207-013|993207-014|993207-015|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.03   |   1.1    |   0.06   |
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |   <.05   |   <.05   |   1.13   |
                             AS | mg/l  |   <.05   |   <.05   |   <.05   |
                             B  | mg/l  |   <.01   |    .65   |    .07   |
                             BA | mg/l  |    .111  |   <.001  |    .018  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |  25.8    |   2.8    |  18.7    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |   <.005  |
                             CR | mg/l  |    .012  |    .017  |    .009  |
                             CU | mg/l  |   <.005  |   <.005  |    .01   |
                             FE | mg/l  |    .02   |    .022  |    .368  |
                             K  | mg/l  |    .2    |    .7    |   1.8    |
                             MG | mg/l  |   6.8    |    .6    |   6.1    |
                             MN | mg/l  |    .05   |    .003  |    .03   |
                             MO | mg/l  |    .01   |    .01   |   <.01   |
                             NA | mg/l  |   8.5    |  95.5    |  42.8    |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |    .2    |
                             PB | mg/l  |   <.05   |    .06   |    .06   |
                             S  | mg/l  |   2.27   |  31.5    |   3.17   |
                             SB | mg/l  |   <.05   |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |  10.2    |   9.76   |  11      |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .13   |    .018  |    .107  |
                             TI | mg/l  |   <.002  |   <.002  |    .004  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |   <.002  |   <.002  |    .006  |
          .HARDNESS/CA+MG    HC | mg/l  |  92.6    |   9.4    |  71.6    |
                   /TOTAL    HT | mg/l  |  93      |   9.6    |  76.7    |
--------------------------------+-------+----------+----------+----------+
ASL-ARSENIC 3+ SPECIATION       |       |     -    |     -    |     -    |
            5+ SPECIATION       |       |     -    |     -    |     -    |
--------------------------------+-------+----------+----------+----------+
```

RESULTS FOR SUNSHINE COAST/POWELL RIVER MATTU,G SAMPLES

Parameter Analyzed		Units	PR-4 993207-016	PR-5 993207-017	PR-6 993207-018
ANIONS/IC - FLUORIDE		mg/l	0.62	0.04	3.3
METALS/EXT.(WATER-ICP SCAN)	AG	mg/l	<.01	<.01	<.01
	AL	mg/l	.05	<.05	<.05
	AS	mg/l	<.05	<.05	.52
	B	mg/l	.4	<.01	6.23
	BA	mg/l	.001	.005	.005
	BE	mg/l	<.001	<.001	<.001
	CA	mg/l	1.7	11.6	1
	CD	mg/l	<.005	<.005	<.005
	CO	mg/l	<.005	<.005	<.005
	CR	mg/l	<.005	.006	.018
	CU	mg/l	<.005	<.005	<.005
	FE	mg/l	.028	.441	.014
	K	mg/l	.4	1.5	.2
	MG	mg/l	.2	2.9	<.1
	MN	mg/l	<.001	.249	.001
	MO	mg/l	.01	<.01	<.01
	NA	mg/l	69.7	5.3	87.8
	NI	mg/l	<.02	<.02	<.02
	P	mg/l	<.1	.1	<.1
	PB	mg/l	<.05	<.05	<.05
	S	mg/l	8.08	<.05	100
	SB	mg/l	<.05	<.05	<.05
	SE	mg/l	<.05	<.05	<.05
	SI	mg/l	8.43	13.4	4.72
	SN	mg/l	<.05	<.05	<.05
	SR	mg/l	.011	.068	.015
	TI	mg/l	<.002	<.002	<.002
	V	mg/l	<.01	<.01	<.01
	ZN	mg/l	.004	.003	<.002
.HARDNESS/CA+MG	HC	mg/l	5.3	41.1	2.5
/TOTAL	HT	mg/l	5.6	42.5	2.6
ASL-ARSENIC 3+ SPECIATION			-	-	-
5+ SPECIATION			-	-	-

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Environment Canada                               Lab# 993207  14-Jul-99  Page 8
            RESULTS FOR SUNSHINE COAST/POWELL RIVER MATTU,G SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   PR-9   |   PR-10  |   PR-11  |
       Parameter Analyzed       | Units |993207-019|993207-020|993207-021|
--------------------------------+-------+----------+----------+----------+
ANIONS/IC - FLUORIDE            | mg/l  |   0.81   |   0.22   |   0.19   |
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |  <.01    |  <.01    |  <.01    |
                             AL | mg/l  |  <.05    |  <.05    |  <.05    |
                             AS | mg/l  |    .51   |    .07   |    .08   |
                             B  | mg/l  |  2.58    |    .38   |    .51   |
                             BA | mg/l  |    .028  |    .237  |    .048  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |   1      |  11.1    |   2.9    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |   <.005  |
                             CR | mg/l  |    .007  |   <.005  |    .005  |
                             CU | mg/l  |    .01   |    .023  |   <.005  |
                             FE | mg/l  |    .015  |    .021  |    .198  |
                             K  | mg/l  |    .6    |   2.4    |   1.3    |
                             MG | mg/l  |    .1    |   1.5    |    .4    |
                             MN | mg/l  |   <.001  |    .005  |    .012  |
                             MO | mg/l  |  <.01    |    .01   |   <.01   |
                             NA | mg/l  |  95.4    |  33.9    |  26.5    |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |  <.1     |   <.1    |   <.1    |
                             PB | mg/l  |    .05   |   <.05   |   <.05   |
                             S  | mg/l  |  10      |   3.69   |  2.35    |
                             SB | mg/l  |   <.05   |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |  4.68    |   7.37   |  7.42    |
                             SN | mg/l  |  <.05    |   <.05   |   <.05   |
                             SR | mg/l  |    .02   |    .193  |    .045  |
                             TI | mg/l  |   <.002  |   <.002  |   <.002  |
                             V  | mg/l  |  <.01    |   <.01   |   <.01   |
                             ZN | mg/l  |    .042  |   <.002  |    .044  |
          .HARDNESS/CA+MG    HC | mg/l  |   3.2    |  33.8    |   9      |
                   /TOTAL    HT | mg/l  |   3.5    |  34.4    |  9.7     |
--------------------------------+-------+----------+----------+----------+
ASL-ARSENIC 3+ SPECIATION       |       |     -    |     -    |     -    |
            5+ SPECIATION       |       |     -    |     -    |     -    |
--------------------------------+-------+----------+----------+----------+
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```
Environment Canada -Laboratories                              Lab Reference #
Pacific Environmental Science Centre                            9 9 5 3 3 8
2645 Dollarton Hwy.
North Vancouver, B.C.                                         16:54 27-Oct-99
V7H 1V2  (604)924-2500

                      P R E L I M I N A R Y   R E P O R T


            Identification: SUNSHINE COAST ARSENICS-MATTU,G

                   Flagged: DRAFT

            Type of Sample: Fresh Water

              Submitted by: YEE,STEWART
                            PESC SC.SUPPORT
                            SCIENTIFIC SUPP
                            PESC
                            ENV CONSERVATION

                 Logged in: 29-Sep-99  (9 samples)

                 Completed: 21-Oct-99  (9 results)

                Charged to: 7020-9
                            +HB-HEALTH-COAST GARIB-11

             Analyzed for: METALS, FIELD DATA



                                                 Authorized by: ____________________

Notes:

   [1] -extractable metals: use graphite furnace (GF) results, where reported, i
n
        preference to ICP results due to better precision and accuracy.
```

```
Environment Canada                              Lab# 995399  27-Oct-99  Page 2
              RESULTS FOR SUNSHINE COAST-MATTU,G 99/09/27 SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-1   |   SC-2   |   SC-3   |
       Parameter Analyzed       | Units |995399-001|995399-002|995399-003|
--------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.0010 |   0.0224 |   0.0240 |
--------------------------------+-------+----------+----------+----------+


--------------------------------+-------+----------+----------+----------+
                                |       |   SC-7   |   SC-8   |   SC-9   |
       Parameter Analyzed       | Units |995399-004|995399-005|995399-006|
--------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.86   |   1.12   |   0.10   |
--------------------------------+-------+----------+----------+----------+


--------------------------------+-------+----------+----------+----------+
                                |       |   SC-10  |     SC-4
       Parameter Analyzed       | Units |995399-007|     995461-001
--------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.0017 |      0.24
--------------------------------+-------+----------+----------+----------+



--------------------------------+-------+----------+----------+----------+
                                |       |    PR1   |    PR2   |    PR3   |
       Parameter Analyzed       | Units |995338-001|995338-002|995338-003|
--------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.0008 |   0.0041 |   0.016  |
--------------------------------+-------+----------+----------+----------+
BC COLLECTION START DATE        | y/m/d |99/08/27  |99/08/27  |99/08/27  |
--------------------------------+-------+----------+----------+----------+

--------------------------------+-------+----------+----------+----------+
                                |       |    PR4   |    PR5   |    PR6   |
       Parameter Analyzed       | Units |995338-004|995338-005|995338-006|
--------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.018  |   0.0054 |   0.50   |
--------------------------------+-------+----------+----------+----------+
BC COLLECTION START DATE        | y/m/d |99/08/27  |99/08/28  |99/08/27  |
--------------------------------+-------+----------+----------+----------+

--------------------------------+-------+----------+----------+----------+
                                |       |    PR9   |   PR10   |   PR11   |
       Parameter Analyzed       | Units |995338-007|995338-008|995338-009|
--------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.45   |   0.107  |   0.119  |
--------------------------------+-------+----------+----------+----------+
BC COLLECTION START DATE        | y/m/d |99/08/27  |99/08/27  |99/08/27  |
--------------------------------+-------+----------+----------+----------+
```

```
--------------------------------+-------+----------+----------+----------+
                                |       | BOWEN BAY| BLUEWATER|TUNSTALL 1|
                                |       |          |          |          |
       Parameter Analyzed       | Units |995385-001|995385-002|995385-003|
--------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.0037 |   0.019  |   0.0008 |
--------------------------------+-------+----------+----------+----------+


--------------------------------+-------+----------+----------+
                                |       |TUNSTALL 3|TUNSTALL 6|
                                |       |          |    A     |
       Parameter Analyzed       | Units |995385-004|995385-005|
--------------------------------+-------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.0068 |   0.0072 |
--------------------------------+-------+----------+----------+
```

Environment Canada –Laboratories
Pacific Environmental Science Centre
2645 Dollarton Hwy.
North Vancouver, B.C.
V7H 1V2 (604)924-2500

Lab Reference #
996578

11:54 24 nov-99

PRELIMINARY REPORT

Identification: BOWEN ISLAND nov 24 MATTU,GEVAN

Flagged: DRAFT

Type of Sample: Fresh Water

Submitted by: YEE,STEWART
PESC SC.SUPPORT
SCIENTIFIC SUPP
PESC
ENV CONSERVATION

Logged in: 24-nov-99 (5 samples)

Completed: <incomplete>

Charged to: 99-900
PESC – DIRECT BILLING

Analyzed for: CONTRACTED TESTS, INORGANICS
METALS

Authorized by: ______________________

Notes:

[1] –Hardness, Ca+Mg, and hardness, total, are expressed as mg equivalent $CaCO_3$/L.
[2] –Result notations: "<inc>" test incomplete

```
Environment Canada                               Lab# 996578  24 nov  Page 2
              RESULTS FOR BOWEN ISLAND nov 22 MATTU,GEVAN SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       | BOWEN BAY|BLUE WATER|TUNSTALL  |
                                |       |    #1    |   #2     |   1A     |
       Parameter Analyzed       | Units |996578-001|996578-002|996578-003|
--------------------------------+-------+----------+----------+----------+
                  As            | mg/l  |  <0.0005    <0.0005   <0.0005
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |   <.01   |
                             AL | mg/l  |   <.05   |   <.05   |    <.05  |
                             AS | mg/l  |   <.05   |   <.05   |   <.05   |
                             B  | mg/l  |    .12   |    <.01  |   <.01   |
                             BA | mg/l  |    .128  |   .003   |    .003  |
                             BE | mg/l  |   <.001  |   <.001  |   <.001  |
                             CA | mg/l  |  15.2    |   4.8    |  13.3    |
                             CD | mg/l  |   <.005  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |   <.005  |
                             CR | mg/l  |    .005  |   <.005  |   <.005  |
                             CU | mg/l  |   <.005  |   <.005  |    .051  |
                             FE | mg/l  |    .035  |    .11   |    .014  |
                             K  | mg/l  |     .8   |    .1    |   1.6    |
                             MG | mg/l  |   3.1    |     .7   |   4.3    |
                             MN | mg/l  |    .016  |    .003  |   <.001  |
                             MO | mg/l  |   <.01   |   <.01   |   <.01   |
                             NA | mg/l  |  170     |   2.3    |    6     |
                             NI | mg/l  |   <.02   |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |   <.1    |
                             PB | mg/l  |   <.05   |   <.05   |    .11   |
                             S  | mg/l  |   123    |   1.67   |   1.32   |
                             SB | mg/l  |   <.05   |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |   <.05   |
                             SI | mg/l  |  12.1    |    3     |  16      |
                             SN | mg/l  |   <.05   |   <.05   |   <.05   |
                             SR | mg/l  |    .092  |    .011  |    .104  |
                             TI | mg/l  |   <.002  |   <.002  |   <.002  |
                             V  | mg/l  |   <.01   |   <.01   |   <.01   |
                             ZN | mg/l  |    .06   |    .652  |    .017  |
          .HARDNESS/CA+MG    HC | mg/l  |  50.7    |  14.9    |  51.2    |
                   /TOTAL    HT | mg/l  |  51.2    |  16.1    |  51.6    |
```

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Environment Canada                               Lab# 996578  14-Jul-99  Page 3
              RESULTS FOR BOWEN ISLAND JUNE 22 MATTU,GEVAN SAMPLES

--------------------------------+-------+----------+----------+
                                |       |TUNSTALL6A| TUNSTALL |
                                |       |          |    3     |
       Parameter Analyzed       | Units |996578-004|996578-005|
--------------------------------+-------+----------+----------+
                  As            | mg/l  | 0.0018      0.0051
METALS/EXT.(WATER-ICP SCAN)  AG | mg/l  |   <.01   |   <.01   |
                             AL | mg/l  |    .1    |   <.05   |
                             AS | mg/l  |   <.05   |   <.05   |
                             B  | mg/l  |    .03   |    .26   |
                             BA | mg/l  |   <.001  |   <.001  |
                             BE | mg/l  |   <.001  |   <.001  |
                             CA | mg/l  |    14    |  12.4    |
                             CD | mg/l  |   <.005  |   <.005  |
                             CO | mg/l  |   <.005  |   <.005  |
                             CR | mg/l  |   <.005  |   <.005  |
                             CU | mg/l  |    .311  |   <.005  |
                             FE | mg/l  |    .13   |    .042  |
                             K  | mg/l  |    .1    |   <.1    |
                             MG | mg/l  |   1.5    |   1.8    |
                             MN | mg/l  |    .005  |   <.001  |
                             MO | mg/l  |   <.01   |   <.01   |
                             NA | mg/l  |    7.2   |   52.1   |
                             NI | mg/l  |   <.02   |   <.02   |
                             P  | mg/l  |   <.1    |   <.1    |
                             PB | mg/l  |    .15   |   <.05   |
                             S  | mg/l  |   1.99   |   5.32   |
                             SB | mg/l  |   <.05   |   <.05   |
                             SE | mg/l  |   <.05   |   <.05   |
                             SI | mg/l  |   5.2    |   6.99   |
                             SN | mg/l  |   <.05   |   <.05   |
                             SR | mg/l  |    .022  |    .033  |
                             TI | mg/l  |   <.002  |   <.002  |
                             V  | mg/l  |   <.01   |   <.01   |
                             ZN | mg/l  |   .375   |    .553  |
          .HARDNESS/CA+MG    HC | mg/l  | 41.1     |  38.4    |
                   /TOTAL    HT | mg/l  | 42.9     |  39.5    |
```

Environment Canada -Laboratories
Pacific Environmental Science Centre
2645 Dollarton Hwy.
North Vancouver, B.C.
V7H 1V2 (604)924-2500

Lab Reference #
996620

08:56 24 nov 99

FINAL REPORT

Identification: SUNSHINE COAST - MATTU, G.

Type of Sample: Fresh Water

Submitted by: YEE,STEWART
PESC SC.SUPPORT
SCIENTIFIC SUPP
PESC
ENV CONSERVATION

Logged in: 19 nov-99 (3 samples)

Completed: 23 nov-99 (3 results)

Charged to: 7020-9
+HB-HEALTH-COAST GARIB-11

Analyzed for: METALS

Authorized by: ____________________

Notes:

[1] -Results confirmed by ICP-MS
[2] -extractable metals: use graphite furnace (GF) results, where reported, in preference to ICP results due to better precision and accuracy.

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Environment Canada                              Lab# 996620  nov 99  Page 2
          RESULTS FOR SUNSHINE COAST - MATTU, G.) SAMPLES

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-1   |   SC-2   |   SC-3   |
                                |       |                     |          |
       Parameter Analyzed       | Units |
--------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.0011 |   0.020  |   0.026  |
--------------------------------+-------+----------+----------+----------+

--------------------------------+-------+----------+----------+----------+
                                |       |   SC-4   |   SC-7   |   SC-8   |

       Parameter Analyzed       | Units ||
--------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.168  |   0.97   |   1.43   |
--------------------------------+-------+----------+----------+----------+


--------------------------------+-------+----------+----------+
                                |       |   SC-9  |   SC-10   |
       Parameter Analyzed       | Units ||
--------------------------------+-------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.123  | <0.0005  |
--------------------------------+-------+----------+----------+


--------------------------------+-------+----------+----------+----------+
                                |       |   PR-1   |   PR-2   |   PR-3   |
       Parameter Analyzed       | Units |
--------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.0009 |   0.0031 |   0.020  |
--------------------------------+-------+----------+----------+----------+


--------------------------------+-------+----------+----------+----------+
                                |       |   PR-4   |   PR-5   |   PR-9   |
       Parameter Analyzed       | Units |
--------------------------------+-------+----------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.019  |   0.0043 |   0.84  |
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                                |       |   PR-10  |   PR-6  |
       Parameter Analyzed       | Units ||
--------------------------------+-------+----------+----------+
METALS/EXT.(WATER-GF)        AS | mg/l  |   0.097  |   1.01   |
--------------------------------+-------+----------+----------+
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Appendix 2

Health Canada Fact Sheet for Arsenic
From: http://www.hc-sc.gc.ca/ehp/ehd/catalogue/general/iyh/arsenic.htm

Appendix 3

EPA Treatment Technology Overview
From: http://www.epa.gov/OGWDW/ars/treat.html

Appendix 4

Maps of Arsenic Concentrations from this Study

Appendix 5

Maps of Arsenic Concentrations from the 1994 Study