# Assessing the Impact of Corrosion Control and Increased Dissolved Oxygen Levels on GVRD Member Municipality Distribution and Premise Plumbing Systems

By

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# ABSTRACT

A study of the water quality, of water distributed within the Greater Vancouver Regional District (GVRD) was carried out. The effectiveness of previously implemented corrosion control plans on the amount of observed metal concentration at the tap, in the warmest and coldest months of the year was evaluated. The effect of different primary disinfectants at the Seymour and Coquitlam water source was also investigated.

The GVRD was divided into four distribution areas, to isolate the effects of water coming from Capilano, Seymour and Coquitlam watersheds, and the Newton Reservoir, on the observed metal concentrations at the tap. The Capilano water has no corrosion control treatment. Seymour, Coquitlam and Newton waters are treated with soda ash, targeting a pH of 6.8, 6.9 and 8.1 resulting in alkalinity levels of 8.2, 6.8, and 20.0 mg/L as CaCO<sub>3</sub>, respectively.

Standing cold water, and running hot and cold water samples were collected during two samplings sessions from houses within the GVRD study area. Samples were analyzed at the UBC laboratory for their lead, copper and zinc concentrations and the averages compared.

The amount of lead coming out at the taps does not appear to be influenced by the source water treatment. Copper appeared to be influenced by the source water treatment, with the highest concentrations found in the water with the lowest pH (Capilano) and the lowest concentrations in the water with the highest pH (Newton). The source water treatment influenced the concentration of zinc in the samples. Samples collected in the

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Newton distribution area had significantly lower zinc levels than samples collected in the Capilano, Coquitlam and Seymour distribution areas.

Samples collected during the warmest month of the year had similar metal levels as samples collected during the coldest months of the year. This suggests that the temperature fluctuations of the water in the GVRD, as a result of changing seasons, don't affect the metal concentrations in the water.

The use of ozone, which can increase the dissolved oxygen concentration of the water, as opposed to chlorine as a primary disinfectant, didn't appear to affect the amount of lead, copper or zinc in the samples collected at the tap.

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# **1 INTRODUCTION**

The results of a study on the quality of water being distributed throughout the Greater Vancouver Regional District (GVRD) are presented in this thesis. Internal corrosion of the water distribution pipes is one of the major problems faced by utilities today, as it results in both the continual failure of the pipes that make up the distribution system, as well as causing unwanted changes in the water quality (Rompre *et al*, 1997).

Currently, the GVRD is in the process of designing a combined treatment facility for the Seymour and Capilano water sources that will include filtration, disinfection and corrosion control measures. This study focused on determining the optimum corrosion control strategy to be used in the new facility.

### **1.1 Objectives and Scope**

The GVRD wishes to assess the impact of the previously implemented corrosion control strategies at the Seymour, Coquitlam and Newton reservoir in order to determine optimal pH and alkalinity values which can be used in the design of the new Seymour/Capilano combined water treatment facility. The following issues will be addresses in this study.

- The effect that ozonation of the Coquitlam water source has on the corrosion control measures implemented at the treatment plant.
- Evaluate the effectiveness of the current levels of soda ash addition at Seymour and Coquitlam sources.

- Evaluate the pH stability, at the various pH levels, from the source to end-user to determine if the pH or alkalinity needs to be adjusted to maintain a desired end-user target level.
- Determine optimum pH and Alkalinity levels for the new combined Seymour/Capilano water sources.

#### 1.2 Thesis Overview

Presented in Chapter 2 is a short literature review on the corrosion process and factors affecting the rate of corrosion. In addition some corrosion control measures are discussed, along with potential health, environmental, economic and aesthetic impacts of corrosion. Finally, there is a short section on various current drinking water regulations. In Chapter 3, background material on the GVRD water distribution system is presented, along with the potential sources of metal in the GVRD drinking water. Chapter 4 outlines the analytical methods used for analyzing the collected samples. Chapter 5 is a presentation of the results along with a discussion about their potential implications. In Chapter 6, a summary of the results and the conclusions are presented, along with some recommendations for future work.

# **2** LITERATURE REVIEW

# 2.1 Principles of Corrosion

Corrosion has been defined by the American Water Works Association as the destructive attack of a metal as a result of electron transfer reactions (AWWARF, 1996). Although corrosion can also be a result of other chemical reactions taking place, only the electrochemical process will be considered, as virtually all corrosion of metals in an aqueous environment is as a result of electrochemical processes, (Obrecht and Pourbaix, 1967).

## 2.1.1 Electrochemical cell

In order for corrosion to occur, an electrochemical cell, made up of four distinct components, as seen in Figure 2-1, must be present (AWWARF, 1996).

The four critical elements are:

- Anode here the metal is released into solution as a result of oxidation, generating electrons which travel to the cathode
- Cathode electrons are accepted in the form of reduction reactions with corrosive substances such as dissolved oxygen (DO), chlorine and hydrogen ions. Typical reactions are

Eq 2-1  $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ 

Eq 2-2 HOCL +  $H^+$  + 2e<sup>-</sup>  $\rightarrow$  Cl<sup>-</sup> + H<sub>2</sub>O

Eq 2-3  $2H^+ + 2e^- \rightarrow H_2$ 

- 3. Conductor connection between the anode and the cathode, and permits the transfer of electrons from the anode to the cathode.
- 4. Electrolyte Solution medium in which the electron acceptors are found, completes the circuit.

If any of these components are absent, no corrosion will occur (AWWARF, 1996). Simply put, the total current generated by the oxidation of the anodic metal must equal the total current produced as a result of the cathodic reactions, and therefore the process can be controlled by either anodic or cathodic reactions (AWWARF, 1996).



Figure 2-1 Corrosion Cell Showing the Anodic and Cathodic Regions

The corrosion cell is not necessarily a stationary entity, as the anodic and cathodic sites can change, depending on the type of corrosion that is taking place. What determines the anodic and cathodic sites is the reactivity of different parts of the metal. When water is passed through distribution pipes, the more reactive areas of the surface, such as metal-crystal grain boundaries, become anodes and the less reactive areas, such as the grains, become cathodic areas (AWWARF, 1996).

The undesirable changes in the water quality can be attributed to the release of corrosion by-products, which is different than the actual corrosion process (AWWARF, 1996; Broo *et al*, 1999). Corrosion products are formed through the corrosion process, and the by-product release is mainly controlled by dissolution/precipitation equilibrium (Broo *et al*, 1999). Often, the inside of the pipes in the drinking water distribution system are covered with corrosion products, and the chemistry of these surface complexes can either facilitate the dissolution of the corrosion products, or hinder corrosion as a result of an inhomologous oxide layer (Broo *et al*, 1999). Overall, the corrosion potential of a specific metal in a defined water type is a function of the concentration of aqueous solutions species, which are involved in the reaction, as well as the characteristics of the metal (AWWARF, 1996).

It is important to know which process is the slowest step in order to be able to accurately control the rate of corrosion. The slowest step, or the rate-controlling step, will depend on the conditions within the distribution system, and a change in these conditions could lead to a change in the rate-controlling step and consequently differences in the metal concentration in the water (AWWARF, 1996). Since there are many different processes at work when corrosion is taking place, reactants and products are being

transported to and from the liquid, as well as adsorption and desorption reactions, this can be a difficult thing to determine.

#### 2.1.2 Factors Affecting Corrosion Rates

The physiochemical interactions between a metal and its environment, corrosion, are governed by chemical, physical and microbiological factors (AWWARF, 1996). Any chemical, physical or microbial change in the water system could potentially alter the corrosion rate. The exact nature of the corrosion process that will occur depends on both the types of metals involved and the chemistry of the water (AWWARF, 1996). Although there are many potential contributing factors to the corrosion process, the factors that appear to enhance the progression of corrosion in drinking water distribution systems are low pH values, low alkalinity levels, the presence of strong oxidizing agents such as oxygen and chlorine, the length of time the water is stagnant in the pipes, and the age of the pipes (Lee *et al*, 1989; Schock, 1989; AWWARF, 1996). In addition, the manner in which all of these mentioned factors interact will also dictate the type and rate of corrosion occurring in any particular distribution system (AWWARF, 1996).

#### 2.1.2.1 <u>Metal</u>

How susceptible a metal is to corrosion will depend on the type of metal and whether or not it has a tendency to passivate<sup>\*</sup> in the water in which it is being used (AWWARF, 1996). The tendency of a metal to passivate in water is also a function of the

<sup>\*</sup> Passivation: physical interference with the operation of corrosion cells by deliberately causing a protective scale to be formed, blocking contact between the electrolyte, anodes and cathodes.

pH of the water, and will subsequently be affected by any reactions that alter the pH of the system (AWWARF, 1996; Reiber, 1991).

Passivation of a metal may occur in two ways; either the corrosion surface develops a protective layer, consisting in part of corrosion by-products (scale), which physically shield the underlying metal from electrolyte contact or the surface adapts electrochemically in such a way as to reduce the thermodynamic driving force for electron exchange (Reiber, 1991). Passivated surfaces will continue to corrode; they simply corrode at rates lower than would be anticipated based on thermodynamic considerations for clear surfaces (Reiber, 1991).

More noble metals, such as copper, tend to be less susceptible to corrosion as often they provide the cathode in the corrosion reaction (AWWARF, 1996).

## 2.1.2.2 <u>pH</u>

The pH of the water is one of the most important characteristics to consider when looking at the rate of metal dissolution in drinking water (Schock, 1989; Lee *et al*, 1989). pH is inversely proportional to the concentration of hydrogen ions in water, and because hydrogen ions act as the electron acceptor in the corrosion reaction, lower pH means more hydrogen ions, which promotes corrosion, as seen in Equation 2-1 (AWWARF, 1996; Mays, 2000). Changing the pH of the water can influence the corrosion rate in at least three ways; by altering the equilibrium potential of the oxygen reduction halfreactions, changing the dominant metal species in solution, or by affecting the stability and protective qualities of the passivating film (Reiber 1989). It has been shown that

lower pH values enhance the solubility of metals, resulting in an increase in the corrosion rate (Schock, 1989).

In addition to promoting the solubility of metals, waters with low pH values create an environment that makes it difficult to form a protective film on the surface of the pipe, thus potentially leaving the entire surface of the pipe exposed to the water (Reiber, 1989; Mays, 2000).

# Eq 2-4 $Me + O_2 + 4H^+ \leftrightarrow Me^+ + 2H_2O$

#### 2.1.2.3 <u>Alkalinity</u>

Alkalinity is a measure of water's ability to neutralize acids and is related to the concentration of hydroxides (OH<sup>-</sup>), carbonates ( $CO_3^{2^-}$ ) and bicarbonates ( $HCO_3^{-}$ ) in the water (Singley *et al*, 1985).

Alkalinity can affect the overall metal concentration in a water distribution system in a number of ways. Indirectly, it affects the corrosion rate in the distribution line by controlling the production of a protective film on the pipe walls (Singley *et al*, 1985). In order for a protective film to form, the products that make up the film, such as calcium carbonate, must be present in excess of their saturation value. However, if there is too much alkalinity present in the system, it can cause the protective film to slough off, leaving the surface exposed and unprotected, resulting in higher metal concentrations in solution (Schock, 1989). Consequently it has been suggested that that lower carbonate levels can mean lower and possibly more consistent lead levels, because there is no sloughing off of corrosion by-products that have adhered to the wall. (AWWARF, 1996)

Alkalinity has a more direct effect on corrosion rates in soft water systems, where it isn't always possible to achieve the levels of calcium and carbonate alkalinity necessary for calcium carbonate precipitation and scale protection. In these systems, alkalinity is important because it can provide buffer capacity to maintain pH stability, which is important in reducing metal levels in soft water systems (DeZuane, 1990; Churchill *et al*, 2000). Waters that contain little alkalinity have proven to be more sensitive to pH changes, while waters with a lot of alkalinity are less sensitive to changes in pH and will most likely require a different corrosion control method to reduce the metal concentrations in the water (Sheiham and Jackson, 1981).

# 2.1.2.4 Oxidizing Agents

Dissolved oxygen (DO) and chlorine act as electron acceptors in the corrosion process, making them the two most powerful oxidants found in drinking water (Reiber, 1989; DeZuane, 1990; Hong and Macauley, 1998). Consequently, the higher their concentrations, the more aggressive the water tends to be (Reiber, 1989). In addition to being an electron acceptor, DO also reacts with the hydrogen ions released at the cathode, to form water, preventing excess hydrogen ion build up which could otherwise potentially slow down further corrosion reactions from taking place (DeZuane, 1990; Mays, 2000).

Earlier studies on the corrosion of copper by chlorinated drinking water, determined that free chlorine is the agent chiefly responsible for corrosion, and that oxygen only plays a minor role (Atlas *et al*, 1982). Atlas (1982) concluded that the free chlorine level should be maintained below 2 mg/L, and the pH above 7, to reduce the

amount of copper corrosion occurring in the distribution system of chlorinated drinking water. Recent studies have suggested that the presence of chlorine, at levels as low as 0.1mg/L can establish a reduction reaction potential that supersedes the oxygen couple (Reiber, 1989; Hong and Macauley, 1998; Boulay and Edwards, 2001).

Studies conducted by Reiber (1989) concluded that corrosion currents will increase linearly with free chlorine residual concentrations, so long as the residual concentration are in the range of typical water treatment practices, establishing a different redox system that is independent of the oxygen half cell (Reiber, 1989).

## 2.1.2.5 Period of Stagnation

The amount of time that water is allowed to remain stationary in the distribution pipes can adversely affect the quality of the water by increasing the metal concentrations. Kuch and Wagner (1983) derived a theoretical relationship between lead concentration and contact time for flowing and stagnant conditions for various lead pipe diameters. Practically, it has been shown that the concentration of metals in flowing waters is considerably less than what is typically found in stagnant waters (Lee *et al*, 1989; Schock, 1980; Lythe and Schock, 1997). Studies have also shown that corrosion rates can vary exponentially with time, being comparatively high at first, and then decreasing as a result of an accumulation of scale or corrosion byproducts on the surface of the pipe (Clement *et al*, 2000). In addition, when water remains immobile for long periods of time, changes in pH, oxygen and carbon dioxide concentration and precipitation of calcium solids may induce different compounds to precipitate (Lagos *et al*, 2001). Overall, the effect that stagnation time will have on the concentration of metal in the

water will depend on the water quality, oxidizing agent present, material age and alloy composition (Lythe and Schock, 1997).

## 2.1.2.6 Age of Plumbing

Corrosion rates can decrease over time as a result of the formation of a protective scale on the inner walls of the distribution pipes (MacQuarrie *et al*, 1997). Over time, the inner surface of the distribution pipe can get covered with corrosion by-products, impeding corrosion reactions from occurring at the pipe surface (Reiber, 1989). Even within the first 24 hours of running water through a new pipe, a reduction in the corrosion rate, by up to 50% has been observed, and attributed to the formation of a protective film (Reiber, 1989). Studies have shown that older plumbing systems contribute less lead to drinking water than new systems (Lee, 1989). Neff (1985) showed that it could take several months to attain stable concentration values in newly installed plumbing systems. Another evaluation on the impact of the age of plumbing systems on the observed metal concentrations showed that the metal concentrations went down with time, being unacceptably high during the first 5 years of use (Lovell *et al*, 1978).

Aged surfaces also appear to be less sensitive to pH changes, which can help reduce the corrosion rate at the surface (Reiber, 1989).

### 2.1.2.7 Other Factors

There is little consensus on the potential role that temperature might play in the corrosion process. Some studies show that lead levels tend to decrease with increasing alkalinity in both hot and cold water, suggesting that temperature may have no significant effect on the amount of lead released (Dodrill and Edwards, 1994). Other studies have argued that it may not be possible to observe an increase in the corrosion rate at higher temperatures, if there is a lot of calcium carbonate present in the system. This is due to the fact that, at higher temperature, a greater amount of calcium carbonate will precipitate out of solution, acting as a protective scale, thus preventing oxygen and chlorine from reaching the inner surface of the pipe and corroding it (Mays, 2000). In addition, at higher temperatures, the saturation concentration for dissolved gasses is less. Since both oxygen and chlorine are present as dissolved gasses, in hotter water there saturation concentration will be lower, resulting in potentially less corrosive water (Mays, 2000).

Still other studies have shown that lower corrosion rates appear to occur in colder temperatures (Boulay and Edwards, 2001; Clement *et al*, 2000, MacQuarrie *et al*, 1997). However, because the pH can change due to intrinsic solution properties as water is heated or cooled; the temperature could have an indirect effect on the solubility of metals to some degree (Schock, 1989).

Physical characteristics of the distribution system can also enhance the corrosion process by creating an environment that scours the pipes, removing any protective film that may have developed. High water velocity or turbulent water flow can erode protective scales, leaving the underlying pipe exposed. High Velocity water also increases the amount of oxidants coming into contact with the pipe surfaces, while low

velocity water can cause stagnation, which can also increase the amount of metals dissolved in solution (DeZuane, 1990; Mays, 2000). Turbulent water can cause even the most adherent scales or protective films to come loose, leaving the underlying surface bare, and susceptible to oxidation (DeZuane, 1990; Clement *et al*, 2000; Mays, 2000). Clement *et al* (2000) also showed that in flowing water, surface flux at any instant can also depend on the alkalinity and pH of the water.

Broo *et al* (1999) found that in the presence of natural organic matter (NOM), corrosion rates appear to increase. Metals often form complexes with NOM, which removes free metal ions from solution, encouraging the dissolution of the metal.

It has been suggested that the presence of many other ions in solution, such as chloride, sulfide, silicates, natural organic mater, magnesium, and calcium, may also contribute to the corrosion rate in the distribution system (Boulay and Edwards, 2001). However, the role that each of these factors might potentially play, and the significance of their possible contributions to the overall corrosion rate has not yet been established. The general consensus for most is that their influence on the rate of corrosion, compared to the previously mentioned factors is, for all practical purposes, negligible (Sheiham and Jackson, 1981).

# 2.1.3 Lead Corrosion

Lead is a naturally occurring, bluish-gray metal found in small amounts in the earth's crust, and can be found in all parts of our environment. Lead was used quite extensively in the past in water distribution systems because of the ease with which it could be worked, and it's relatively durable nature (Sorg and Bell, 1986).

The corrosion of lead is a complicated process that involves many interconnected reactions, all of which can be occurring at the same time (Vinci and Sarapata, 1992; Schock, 1989). Although a lot of research has been done to try and understand the processes involved in the corrosion of lead, there are still a number of variables that aren't well understood. Several models have been proposed to determine the expected concentration of lead in drinking water; however these models have not always been able to accurately predict what occurs in the real world (Edwards *et al*, 1991).

In general, the lead concentration in any given water system will be dictated by both the stability and solubility of the various lead species formed in that particular water (AWWARF, 1996). Understanding which forms of lead are the most stable in any given water system can be difficult as it will be a function of the ions present, the pH and the redox potential of the involved species (USEPA, 2002b). Typically, as the pH rises, lead complexes formed with hydroxide and carbonate ions become insoluble and greatly slow down the rate of metal dissolution (Clement *et al*, 2000).

The concentration of oxidizing agents will also affect the observed lead concentration, as lead is easily attacked by water that contains either oxygen or chlorine, unless compounds are present to help form a protective film (Sheiham and Jackson, 1981). The formation of an effective protective film will also depend on the pH and alkalinity of the water (Schock, 1989). Typically, lead solubility appears to be at a minimum when pH is 9.8 and alkalinity at 28 mg/L as <sup>(Schock, 1989)</sup>.

Sheiham (1981) observed the following trends in lead solubility with respect to pH and alkalinity.

- 1. At low alkalinity, total lead concentration is highly sensitive to pH changes and lead solubility decreases with increasing pH at a fixed alkalinity.
- 2. The predicted lead concentration is insensitive to changes in pH and/or alkalinity at pH 6.5 to 8.0 and alkalinity above 100mg/L
- 3. The effect of changing the alkalinity of a water source depends on the stable lead carbonate solid. Increasing alkalinity reduces lead concentration when PbCO<sub>3</sub> is stable, whereas the trend is reversed when Pb<sub>3</sub>(OH)<sub>2</sub>(CO<sub>3</sub>)<sub>2</sub> is stable.

Dodrill *et al* (1994) concluded that when the natural alkalinity of the water is low, either the pH must be raised above 8.4, or the alkalinity needs to be adjusted to between 30-74 mg/L as CaCO<sub>3</sub>, in order to get any significant improvement in the quality of the water.

A number of different models have been proposed for calculating the expected lead concentrations in water and these models have shown that theoretically it is possible to reduce the solubility of lead by up to 50 times just by increasing the pH and alkalinity (Vinci and Sarapata, 1992). In practice, the observed lead levels are often lower than the computer models have predicted, because the models aren't able to take all of the influencing variables into consideration, and so some of the solids predicted to form in different systems, based on thermodynamic consideration, do not do so in reality (Schock, 1989). The main problem with these models is that they are limited, not only by the accuracy of solubility and complexation constants used, but also by a poor understanding of the specific scale types that form and the nature of the transition

between scale types along with the relative importance of other mechanisms of corrosion by-product release (Sheiham and Jackson, 1989; Edwards *et al*, 1999).

#### 2.1.4 Copper Corrosion

Copper is a light red metal, and is soft, malleable and ductile. It is highly conductive toward electricity and heat and is resistant to oxidation, making it impervious to corrosion (Sorg and Bell, 1986). Copper is often a more noble metal than others used in plumbing and therefore is less likely to corrode as a result of galvanic action; in the complete absence of oxidized substances, copper is immune to corrosion because of its noble nature (Edwards *et al*, 1994). However, all waters that contain oxidizing agents, such as oxygen or chlorine, are corrosive to copper to some degree. Copper is susceptible to oxidation by both chlorine and oxygen, due to the positive cell potential for copper oxidation. As a result, copper will continue to corrode until the oxidizing agent present is depleted or a protective oxide film precipitates (Edwards *et al*, 1994). Overall, copper corrosion is a complex non-equilibrium process driven by at least three chemical subprocesses: metal oxidation, fixation of dissolved copper in the corrosion scale, and solubility equilibrium (Merkel *et al*, 2002).

Direct oxidation of copper metal by oxygen and free chlorine is thermodynamically viable, and therefore, the amount of copper in solution will be determined by the amount of oxidant available, and the solubility limits of formed copper mineral solids (Hong and Macauley, 1998). In addition to affecting the corrosion rate of copper, both oxygen and residual chlorine may alter the crystalline characteristics and porosity of the oxide corrosion product film produced at the pipe surface. Consequently,

considerable uncertainty remains regarding the thermodynamic properties of all copper species, and much more research is needed in order to improve understanding and control of cuprosolvency (USEPA, 2003c).

Oxidation of copper is also supported by low pH values and too little or too much alkalinity, as the highest copper levels are seen in waters that have a low pH with either very low alkalinity or very high alkalinity levels (AWWARF, 1996). Corrosion increases rapidly as the pH drops below 6 and at these low pH values corrosion is almost always of a generalized nature (Boulay and Edwards, 2001; Reiber, 1989). When the pH is too elevated, the corrosion problems are usually associated with a non-uniform process (Broo *et al*, 1997; Edwards *et al*, 1994). Increases in the alkalinity concentrations have been shown to cause significant increases in copper solubility in the pH range of 7 to 10. However, a certain level of alkalinity must be maintained to ensure adequate buffering intensity in the finished water (AWWARF, 1996).

Calcium carbonate scale formation has been found to protect copper and reduce copper release under favorable conditions (AWWARF, 1996). The nature of the insoluble scales that form on copper is strongly dependent on water chemistry and the type of scale that forms will influence the extent of protection offered and the magnitude of the associated corrosion by-product release (AWWARF, 1996). Dissolution of these scales is one of the primary mechanisms by which copper is liberated into drinking water (Lagos *et al*, 2001).

In addition to the already mentioned factors affecting the solubility of copper, a few other potentially influencing water parameters are the presence of NOM, chlorides, and sulfate (Edwards *et al*, 1999). It has been shown that copper forms strong complexes

with NOM, and that the solubility of copper corrosion increases with increasing NOM content (Broo *et al*, 1999). Low chloride content appears to inhibit the corrosion of copper, implying that the chloride ions take an active part in the reaction mechanisms (Broo *et al*, 1999). Sulfate also appears to assist in controlling cuprosolvency under some chemical conditions, or may interfere with the formation of a protective film under mildly alkaline conditions (Broo *et al*, 1997). Experimental studies have shown that soft treated drinking water can develop rather high concentrations of copper when the system is not operating and that repeated flushing of the system may be required to bring the copper level down to a palatable level (AWWARF, 1996).

#### 2.1.5 Zinc Corrosion

Although zinc is a fairly reactive metal, and may initially corrode rapidly, the corrosion rate slows down quickly as a result of the formation of a protective film (Slunder and Boyd, 1971). As with copper and lead, the behavior of zinc within a distribution system will depend on the type of water that it is in contact with (Slunder and Boyd, 1971). In addition, zinc is an amphoteric metal, making it resistant to corrosion in waters that have a pH near neutral (Porter, 1994). Water hardness, will also affect the observed corrosion rate in the system. Typically harder water is less corrosive than soft water, because of the protective scales that deposit on the metallic surface (Porter, 1994).

One of the main mechanisms by which zinc enters the drinking water is through a process called dezincification. High pH and the presence of both free chlorine and sulfate ions tend to increase the rate of dezincification (Schock and Neff, 1988).

## 2.2 Types of Corrosion

There are several different forms of corrosion, and the one that predominates will depend on the material being used for the construction of the system, scale and oxide film formation and the hydraulic conditions (AWWARF, 1996). Since corrosion involves the generation of electrons at the anode, which migrate to the cathode (where they are discharged) the distribution of anodic and cathodic areas over the corroding metal will also influence the form of corrosion that is taking place (AWWARF, 1996).

#### 2.2.1 Uniform

Uniform corrosion occurs on surfaces and is characterized by very small anodic and cathodic sites that are situated in close proximity to one another. This has the effect of creating an environment where the rate of corrosion is equal over the entire surface (Edwards *et al*, 1994). The surface of the corroding material may be described as a polyelectrode, because any one site may be anodic one moment and cathodic the next making the rate of metal loss over the metal surface relatively uniform. This type of corrosion often occurs on metal surfaces that are made up of one single metal and are characterized by an unvarying surface; thus, the corrosion cell develops as a result of differences in the potential between different areas on the metal surface. Differences in potential can be attributed to variations in the crystal structure, imperfections in the metal, or differences in the concentration of oxidants and reductants in solution (AWWARF, 1996: Edward *et al*, 1994). Perforation of the pipe wall and associated

failure are rare under true uniform attack, and the corrosion rates are commonly expressed as pipe penetration rates in milli-inches per year (Edwards *et al*, 1994).

High uniform corrosion rates are most commonly associated with waters of low pH and low alkalinity that are deemed incapable of forming films (or scale) that can protect the metal surface from attack (Edwards *et al*, 1994). Corrosion by-product release under this condition is more troublesome, especially upon stagnation (Edwards *et al*, 1994).

#### 2.2.2 Galvanic

Galvanic corrosion occurs when the cathode and anode of the electrochemical cell are fixed. This can occur when there are two different metals in contact with one another or as a result of differences in oxygen concentration between one place on a pipe surface and another (AWWARF, 1996). When two different metals are in contact with one another, one will operate as the anode, and be oxidized and consequently deteriorate, while the other metal will serve as the cathode (AWWARF, 1996). Any metal can serve as either the anode or the cathode and the nature of the metals involved will determine which one serves as which. The more noble metal will serve as the cathode, while the less noble metal will act as the anode. The greater the potential difference between the two metals, the greater the rate of galvanic corrosion. The rate of corrosion is also influenced by a larger cathodic area compared to the anodic area, the physical closeness of the two metals, and the conductivity of the water (AWWARF, 1996).

The galvanic current is greatly influenced by pH, especially on the apparent ultimate extent of passivation achievable relative to the base-line water quality conditions

(Reiber, 1991). At lower pH values, the degree of passivation is substantially less than that observed at values of 7 and higher. The extent of surface passivation is clearly linked to the pH of the water and probably relates to the solubility of the protective lead and tin oxide scales. (Reiber, 1991)

In general, galvanic corrosion is most often a problem where brass, bronze or copper is in direct contact with aluminum, galvanized iron or iron. (AWWARF, 1996)

## 2.2.3 Localized Corrosion

Localized corrosion can occur as a result of a single metal system or with galvanic corrosion, and may result in pitting. There are several factors that can contribute to localized corrosion, either imperfections in the metal oxide film (or scale), or due to the presence of a region of high stress. Imperfections in the metal, or areas of high stress are usually anodic, and the potential difference between them and the rest of the metal surface is enough to ensure that the anode remains stationary (AWWARF, 1996). The anodic region is often much smaller than the cathodic region, resulting in the potential for rapid failure of the pipe due to corrosion (AWWARF, 1996). This type of corrosion often appears at random in a distribution system (Edwards *et al*, 1994).

Three distinct types of pitting corrosion with respect to copper tubing have been identified by Edwards *et al* (1994) and are as follows:

Type I: cold water pits are relatively deep and narrow with a film of reddish brown glassy cuprite sandwiched between the copper surface and an exterior scale layer of basic copper salts, most commonly malachite. These kinds of pits are usually formed in well waters of relatively high conductivity, hardness, alkalinity and sulfate
concentration and of low organic carbon. Most common cause of copper pipe failures, and can occur within months.

- Type II: hot water pits are narrower than type I with a film of crystalline cuprous oxide sandwiched between the copper surface and an exterior scale layer invariably containing bronchantite. These types of pits are usually formed in waters with a pH less than 7, temperature greater than 60°C and a low bicarbonate-to sulfate ratio. Usually takes several years to occur.
- Type III: soft water pits are fairly wide and shallow with a film of crystalline reddishbrown cuprite sandwiched between the attacked cooper surface and an exterior scale layer containing bronchantite, malachite or both. Characterized by the persistent release of voluminous insoluble corrosion products that contaminate the water supply or actually cause pipe blockage. Water supporting soft water pitting is cold, of low conductivity, low alkalinity, and relatively high pH.

# 2.2.4 Concentration Cell Corrosion

Concentration cell corrosion involves the corrosion of a single metal as a result of different portions of the metal being exposed to different aqueous environments (Singh, 1990). The corrosion process always occurs in such a way as to equalize the potential differences between the anode and the cathode (AWWARF, 1996). The most common cause of this type of corrosion is differences in the dissolved oxygen concentration or hydrogen ions at different sites along the metal surface (Singh, 1990). Oxygen can become depleted at particular locations on the metal as a result of the corrosion reactions, reactions between oxygen and the corrosion by-products or because of biological activity

in the area (Singh, 1990). Resistance to the diffusion of oxygen to these locations by the slimes, chemical precipitates, deposits of debris, or simply distance of transport (into a crevice, or to pipe threads, for example) and a sufficient supply of oxygen to adjacent cathodic sites can maintain the oxygen concentration cell and allow the corrosion reactions to continue to take place (AWWARF, 1985).

Other differences that can cause this type of corrosion are differences in either pH or anion concentration (Singh, 1990). Alternatively, it can also be as a result of only part of the surface being protected from oxygen by rust or another type of coating (Singh, 1990).

#### 2.2.5 Microbiologically Mediated Corrosion

The development of a biofilm on the inside surface of distribution pipes is not only a problem because of the possible health concerns associated with bacteria in drinking water, but can also enhance the corrosion rate within the distribution system. Factors that influence whether or not a system is going to be susceptible to microbially influenced corrosion (MIC) are plumbing design, installation, and commission, along with the water quality and water temperature.

The presence of dead ends and long horizontal runs of pipe that are susceptible to sediment accumulation are common plumbing design features associated with MIC. Sediment accumulation increases the surface area for microbial colonization and growth and can promote the development of anaerobic conditions that are conducive to growth of sulphur-reducing bacteria and other potentially corrosive anaerobic species. Poor soldering practices, which result in irregular internal surfaces, can encourage biofilm

growth in the resulting flow eddies. Water predisposed to MIC tends to be soft, and weakly buffered, with neutral or neutral-alkaline pH and minimal chlorine concentrations (Bremer *et al*, 2001).

Three possible mechanisms for microbiologically mediated corrosion have been identified and are as follows: the production of acidic metabolites on the metal surface, the binding of copper by microbially produced extra cellular polysaccharides, and the alteration of the nature and porosity of the oxide film from the incorporation of cell and polymers (Bremer *et al*, 2001).

## 2.3 Corrosion Control

Corrosion control strategies can be complicated because of the many interdependent reactions that are occurring simultaneously, and not all of which are well understood (Schock, 1989). Although many models have been generated to try and predict the metal concentration in the water, to date, none have been able to consistently predict the concentration seen in reality (Shcok, 1989; Sheiham and Jackson, 1981; Dodrill and Edwards, 1994; Clement *et al*, 2000). The main objective of the models is to describe an environment where, theoretically, the solubility of the metal is lowest. This often involves adjusting the pH, alkalinity and the concentration of oxidants in the water (Edward *et al*, 1991). Although many other factors have been identified as potentially influencing the corrosion process, not all of them are involved in every water distribution system and the amount of influence they have on the corrosion process varies from system to system.

The problem with the models is that the metal concentration in the water appears to be governed not only by the solubility of the metal, but by physical characteristics of the distribution system, as well as various chemical mechanisms (Schock, 1980). Accordingly, prior to designing and implementing any corrosion control measures, it is important that all the factors contributing to the metal concentration in the water be evaluated.

The intensity of plumbing corrosion is dependent on both the pipe surface quality and the water chemistry. Therefore, the first line of defense in mitigating the corrosion problem in the water distribution line is in choosing the type of material that will be used to make up the water distribution system (Clement *et al*, 2000). In order to determine which pipe material will be best for a particular water distribution system, the chemistry of the water will need to be determined. The distribution system can then be designed to minimize the occurrence of corrosion by-products by employing material that is the most resistant to corrosion and altering the water chemistry to create the least corrosive environment.

The chemistry of the water will dictate both the solubility and which corrosion processes will be occurring, making it very important to understand the type of water that the corrosion control plan is being designed for. Most corrosion control measures used aim to create an environment that results in low metal solubility in the water by encouraging the formation of a protective barrier, while discouraging the dissolution of the metals. The formation of an effective protective film depends on pH and dissolved inorganic carbon (DIC), and occurs as a result of precipitates depositing on the inner surface of the pipes. This reduces the intensity of corrosion at the active zone (Schock,

1989; Clement *et al*, 2000). The presence of a polarization layer, which will result in the consumption of reactive species near the electrode, can also contribute to overall lower metal levels in the water (Clement *et al*, 2000).

Scale solubility considerations are either kinetic or thermodynamic in nature and will determine the maximum concentration of soluble metals (Schock, 1980). The kinetics of dissolution of the pipe material, the precipitation of the solids of interests and the rate of mass transport into solution will all determine the metal concentration in the water, if the solubility limit has not been reached. Unfortunately, incomplete knowledge of the chemical composition and crystalline structure of the solids that make up the scale have made it difficult to accurately predict the amount of corrosion that will take place in a given system after corrosion control plans have been implemented (AWWARF, 1996).

What complicates things is that so many of corrosion reactions taking place are interdependent and are not only affected by the chemistry of the water, but may in turn alter the quality of the water by releasing by-products. In addition, the sloughing off of the protective layer can often result in the presence of temporary high metal concentrations, called "spikes". In order to reduce the occurrence of these "spikes", the water distributor should try to create an environment that will allow for the formation of adherent passivation films (Schock, 1989).

Another factor that needs to be taken into consideration, when designing a corrosion control plan, is the form that the metals are going to be in, either dissolved or particulate, and in what ratio. To determine which portion is due to the dissolved metal, the solubility of the scale can be used. To determine the amount of metal in the particulate matter, the manner in which the particles are formed needs to be determined.

Particles containing corrosion products may be the result of precipitation after being transported away from the pipe wall or from breakup of the scale itself. Loosely deposited scales may be scoured from the pipe surface during high flow and differential thermal expansion properties of the scales may lead to its fragmentation as the pipe undergoes temperature changes. Therefore, control measures used to limit the concentration of metals in solution cannot be expected to work if the primary cause of high metal concentration is a result of the formation of particulates (AWWARF, 1996)

# 2.3.1 pH and Alkalinity Adjustment

Adjusting the pH and alkalinity is often the first corrosion control method tried because it can efficiently control corrosion without negatively impacting other aspects of water quality (Vinci and Sarapata, 1992). It is a simple and effective strategy that involves adding inorganic compounds, such as soda ash, or sodium hydroxide, to alter the pH and/or alkalinity of the water, thus minimizing the solubility of various metals (AWWARF, 1996). This process is based on the assumption that if the solubility of the metals can be minimized, then a minimal amount of corrosion by-products will be released into the system (Vinci and Sarapata, 1992; AWWARF, 1996).

pH and alkalinity adjustment can result in water that is able to promote the formation of protective films on the inner surface of the distribution pipes. This film can either consist of a dense oxide layer or a layer of corrosion products, both of which can substantially reduce the rate of corrosion by decreasing the rate of oxygen transport to the metal surface (Reiber, 1991).

Depending on whether or not the water being treated is hard or soft, the addition of some form of carbonate will offer one of two possible advantages. If the water is considered to be hard, increasing the carbonate concentration can increase the pH and promote the precipitation of calcium carbonate, which can form a protective barrier on the inside of the pipe (Churchill *et al*, 2000; Volk *et al*, 2000). If the water is considered to be soft, it is not always possible to achieve the levels of calcium and carbonate alkalinity necessary for calcium carbonate precipitation and scale protection. Elevated alkalinity levels, however, can provide sufficient buffer capacity to maintain pH stability, which is important in reducing metal levels (Churchill *et al*, 2000; Schock, 1980).

The main drawback of this method is that the calcium and carbonates found in the water will limit the amount that the pH can be changed without causing excessive amount of calcium carbonate to precipitate (AWWARF, 1996). Additional studies have shown that the use of soda ash alone may not be able to achieve the desired alkalinity without exceeding the maximum pH, in which case sodium bicarbonate may also be needed to achieve the desired alkalinity (Johnson *et al*, 1993). However, raising alkalinity is only justified where the natural reduction in pH between the treatment works and the consumer is large enough to prevent the specified pH being achieved at the tap. Although the value may change for specific metals, in general, minimum corrosion occurs when the pH is in the range of 7.5-8.5, which corresponds to maximum bicarbonate ion species (Vinci and Sarapata, 1992).

Overall, pH and alkalinity adjustment is an effective corrosion control system that is environmentally sensible and creates a stable chemical balance in the water supply (Vinci and Sarapata, 1992).

## 2.3.1.1 Disinfection By-Product Formation

Although increasing the pH can help decrease the amount of corrosion in the distribution system, it has also been shown to increase the concentration of disinfection by-products (DBP) formed (Schock, 1989; DeZuane, 1990; Kawamura, 1991; Churchill *et al*, 2000; Kim *et al*, 2002). Other studies, however have not been able to support an increase in DBP formation with an increase in pH (Korshin *et al*, 2002). Consequently there is still a lot of uncertainty about factors affecting the formation of DBP's and how these factors might interact with one another.

## 2.4 Impacts of Corrosion

# 2.4.1 Health

One of the biggest concerns about implementing corrosion control plans is the formation of disinfection by-products (DBP), specifically trihalomethanes (THM), and haloacetic acids (HAA). In addition, there can be a possible decrease in the disinfection efficiency of chlorinating programs, once a corrosion control plan is put in place (Churchill *et al*, 2000; Schock, 1989). However, not implementing a corrosion control plan can also have some serious consequences, with respect to potential health concerns.

# 2.4.1.1 Lead

Lead is persistent in nature, and when found in water as either a dissolved or finely divided solid; it can easily be transferable into the blood, compared to the

dissolution of solid lead in the stomach, or inhaling lead bearing particles (Body *et al*, 1991). Even though roughly only 20% of human exposure to lead is through drinking water, the form in which the lead presents itself in the body is the most significant.

The greatest risk is to children and pregnant women as lead interferes with red blood cell chemistry and the neurological and physical development of babies and young children (Health Canada, 2003b). It can also result in slight deficits in attention span, as well as hearing and learning disabilities in children (USEPA, 2003b). Over time, lead can build up in the body and cause damage to the brain, and kidneys as well as increased blood pressure in adults (Apostoli and Boffetta, 2000).

An association has been documented linking chronic low-level lead exposure to a variety of public health concerns including strokes, kidney disease, cancer, and vitamin D metabolism (ATSDR, 2003a). Even low lead levels in the blood can result in alterations of physiological functions and some generalized impairment of organs and systems (Apostoli and Boffetta, 2000).

# 2.4.1.2 Copper

Although copper is an essential nutrient, excessive amounts of it can have some adverse health effects. The very properties that make it useful also make it potentially toxic when too much is present (Camakaris *et al*, 1999). This is because copper will cycle between stable oxidized Cu(II) and unstable reduced Cu(I), and the enzymes used in this redox reaction can generate reactive oxygen species, such as super peroxide radicals and hydroxyl radicals which can damage the cell (Camakaris *et al*, 1999). Copper can also

bind, with affinity to histidine, cystein and methionine residues of proteins, denaturing them.

Long-term exposure to copper dust can irritate your nose, mouth, and eyes, and cause headaches, dizziness, nausea, and diarrhea. Drinking water with higher than normal copper levels can cause stomach and intestinal distress leading to nausea and vomiting, as well as liver and kidney damage (Camakaris *et al*, 1999; ATSDR, 2003b; Health Canada, 2003c; USEPA, 2003c;).

# 2.4.1.3 <u>Zinc</u>

Zinc is also an essential element and too little zinc can cause health problems, but too much zinc can also be damaging to your health (ATSDR, 2003c). Harmful health effects generally begin at levels from 10-15 times the recommended daily average (RDA) (in the 100 to 250 mg/day range). Eating large amounts of zinc, even for a short time, can cause stomach cramps, nausea, and vomiting (Health Canada, 2003d). Taken longer, it can cause anemia, pancreas damage, and lower levels of high-density lipoprotein cholesterol (the good form of cholesterol).

It is not known if high levels of zinc affect human reproduction or cause birth defects. Rats that were fed large amounts of zinc became infertile or had smaller babies. Irritation was also observed on the skin of rabbits, guinea pigs, and mice when exposed to some zinc compounds. Skin irritation will probably occur in people (ATSDR, 2003c).

## 2.4.2 Environmental

Heavy metals are a common inorganic contaminant found in the environment and pose a significant threat to the environment as they are toxic to a broad range of species, from primary producers to top-level consumers. The toxicity will vary among metals, aquatic species and both the physical and chemical conditions of the water (Preston and Shackelford, 2002). Although they are released into the environment naturally, anthropogenic sources are usually the most significant source. Heavy metals can bioaccumulate or bioconcentrate since they do not degrade over time, making them persistent in either the water column or sediment (Preston and Shackelford, 2002).

Lead, copper and zinc are all potentially toxic to a broad range of trophic levels, from primary producers, such as phytoplankton, to top-level consumers such as predatory fish (Rand et al, 1995; Goyer, 1996; Keeling and Cater, 1998;Preston and Shackelford, 2002). Their toxicity is attributed to their ability to bind and interact with enzymes essential for metabolism (Preston and Shackelford, 2002).

# 2.4.2.1 Lead

The toxicity of lead is due to interactions with functional groups of enzymes as it has a strong affinity for metal binding proteins.(Leborans *et al.* 1998). The most toxic compounds are the organic forms of lead, while the most toxic chemical in water is the divalent cation.

In the environment, lead binds to soils and will not migrate, and consequently is retained in the upper 2-5 centimeters of soil; this is especially true if the soil contains at least 5% organic matter or is above pH 5. Over time, it will slowly

undergo speciation with sulfate, sulfide, oxide or phosphate, into one of the more insoluble salts (USEPA, 2003b).

In water, lead will bind to sediments and be removed from the water column predominantly via adsorption to organic matter, or clay minerals. In addition, lead is removed from the water column as a result of the precipitation of lead as an insoluble salt or reactions with hydrous irons and manganese oxides (USEPA, 2003b). Consequently, only a low portion of the metal will be found dissolved in the water column (Leborans *et al*, 1998).

# 2.4.2.2 <u>Copper</u>

Copper is a bacteriocide, and therefore can cause problems for both wastewater treatment plants as well as receiving waters. Also, to be able to use sludge from a wastewater treatment plant as a fertilizer, it is important that the copper level be as low as possible (Broo *et al*, 1997). Copper is toxic to fish in very small quantities, and can be a toxicant in the food chain due to its ability to bioaccumulate (MacQuarrie *et al*, 1997; Zyadah and Abdel-Baky, 2000).

Evidence suggests that, when copper and zinc are found in the same area, they affect one another antagonistically. This is attributed to substitution or competition for available sites during protein synthesis (Zyadah and Abdel-Baky, 2000).

# 2.4.2.3 <u>Zinc</u>

Although zinc is an essential element, it can be toxic to many different aquatic species. The extent to which it is toxic will depend on the species as well as certain water

quality parameters. Often, it will depend on the presence or absence of other heavy metals, as well as the hardness of the water. Evidence seems to suggest that, in softer waters, zinc is more toxic. The water quality will also determine the form that zinc will be present in, and this too will affect the actual toxicity of zinc in the water column.

### 2.4.3 Economic

Corrosion of pipes can be a major cause of poor system integrity, leading to breaks, reduced hydraulic capacity and poor water quality. The replacement of pipes can be a costly endeavor, for both municipalities and homeowners (Mays, 2000). For most municipalities, the distribution piping is the largest capital investment in a distribution system, and therefore the longer the life of the pipes, the less costly the system will be (Mays, 2000).

Homeowners are not only faced with potential increases in their municipal taxes as a result of pipe failure, but also have to deal with the effects of copper corrosion on their plumbing system. Although copper corrosion is usually a uniform process and rarely causes rapid failure of tubing, it can cause significant thinning and reduced service life (Edwards *et al*, 1994; Mays, 2000). Under specific conditions, the corrosion may be patchy or localized, resulting in pitting attack that can cause perforation of the copper pipes (Edwards *et al*, 1994).

# 2.4.4 Aesthetic

Green water from dislodged copper precipitates is a common manifestation of high corrosion rates. Related to green water is green staining, even a few mg/L of copper in

water can react with soap scums and cause green staining of plumbing fixtures and clothes. Staining has largely disappeared because detergents have replaced soaps; however, reductions in the corrosion rate in distribution systems have also contributed to a reduction in staining (Boulay and Edwards, 2001).

## 2.5 Current Drinking Water Guidelines

The primary concern in developing drinking water guidelines is the protection of human health. Although water supplies and water quality will vary from place to place, the acceptable water quality for drinking water standards for humans should be similar. Currently there is no single international organization responsible for establishing safe drinking water standards for all water purveyors around the world. Consequently there are a number of different established water quality standards. Ultimately, it is responsibility of the water purveyor to instill in their consumers the confidence that this task is being undertaken with responsibility and efficiency (WHO, 2003).

Contaminants in drinking water can come from a variety of sources including both naturally occurring and industrial effluents and emissions. Alternatively, some contaminants may be formed during the process of water treatment, such as trihalomethanes (THM) and haloacetic acids (HAA) (Neff *et all*, 1990; AWWARF, 1996). Substances such as lead, copper and zinc are often contaminants found in drinking water as a direct result of leaching of materials used to make up the distribution system (Neff et al, 1990; AWWARF, 1996; Health Canada, 2003a).

In order to establish safe drinking water criteria, it is essential to determine the potential effect that individual contaminants can have on human health. Scientists begin by examining available data to determine the relationship between dose and response, and to establish a level of exposure at which no adverse heath effects are observed in human or animal studies (Health Canada, 2003a). Limits are then set to protect the weakest individual in the population, usually children and the elderly.

# 2.5.1 Canadian Drinking Water Quality Guidelines (CDWQG)

The CDWQG were established in 1983 to ensure that Canadians were provided with clean, safe drinking water. CDWQG have been established for a variety of microbiological, chemical, physical and radiological parameters, and apply to drinking water from all private and municipal water sources (Health Canada, 2003a). These guidelines are recognized throughout Canada as the standard for water quality and provide a convenient, reliable yardstick against which water quality can be measured.

CDWQG are determined by calculating a maximum acceptable concentration (MAC), based on the no observed adverse effect levels (NOAEL). Generally the guideline is established by looking at long-term chronic or lifetime studies, as well as special studies on reproductive hazards, genetic damage, and potential to cause cancer (Health Canada, 2003a). In addition, aesthetic characteristics such as taste, odor, staining action, corrosiveness, turbidity and color are also considered. The process used in the development of CDWQG is well established and generally follows the approaches used internationally (Health Canada, 2003a).

To ensure that the guidelines are based on the most recent scientific data, they are reviewed twice a year by a federal committee (Health Canada, 2003a).

#### 2.5.2 US Environmental Protection Agency (USEPA) Drinking Water Standards

The USEPA establish the Safe Drinking Water Act (SDWA) in 1974, to protect public health. The SDWA has been revised and updated several times to reflect the most recent scientific evidence and available technology for the treatment of water. The USEPA works with its many regional offices in order to effectively implement the SDWA.

The SDWA has two different lists of water standards, National Primary Drinking Water Standards, and National Secondary Drinking Water Regulations. Contaminants that may pose health risks, and can possibly be present in public drinking water supplies are listed in the National Primary Drinking Water Standards, and are legally enforceable. Non-enforceable guidelines regulating contaminants that may cause cosmetic or aesthetic effects in drinking water are listed in the National Secondary Drinking Water Regulations (USEPA, 2003a).

#### 2.5.3 World Health Organization (WHO)

The WHO published the first edition of Guidelines for Drinking Water Quality in 1984. Each contaminant that was considered for the guidelines was evaluated for risks to human health from exposures to the contaminant in drinking water. Both Scientific institutions and selected experts assessed the toxicity of drinking water contaminants

based on published reports in the literature, information submitted by governments and other interested parties, as well as unpublished proprietary data (WHO, 2003).

#### 2.6 Case Studies

Corrosion problems faced by the GVRD have also been experienced by other water utilities in various parts of the world, some of which have similar water quality characteristics. Many have proceeded with various corrosion mitigation schemes, some being more successful than others. In coming up with the currently employed corrosion control plans, the GVRD has had the opportunity to benefit from the experience of these other water suppliers.

# 2.6.1 Fitchburg, Massachusetts

The city of Fitchburg supplies drinking water to approximately 39,000 people, and draws its water from 10 reservoirs, 5 of which water is drawn directly from, and 5 that are used as storage facilities. The raw water quality in all of the reservoirs is very similar, having an acidic pH (5.5-6.0), very little alkalinity (0-5 mg/L as CaCO<sub>3</sub>), and minimal mineral content. In order to address the corrosion problem, the city decided to use sodium hydroxide and raised the pH to between 7.8 and 8.0 and sodium bicarbonate was added to increase the alkalinity to 40mg/L as CaCO<sub>3</sub>. The water was then monitored over a period of several months, during which time there was a noticeable decrease in the metal concentrations in the water. The only problem that they encountered was a sudden increase in the amount of red water due to changes in the tuberculation of the cast iron

mains. They attributed this phenomenon to the pH adjustment with sodium hydroxide and were currently looking at a way of circumventing this problem (Judge, 1993).

#### 2.6.2 Boston

The water supplied to Boston, by the Metropolitan District Commission (MDC), is relatively acidic (pH = 6.7), low in hardness (12mg/L) and alkalinity (8 mg/L) and consequently corrosive to piping. Initially, a chemical inhibitor, zinc orthophosphate, was used to reduce the lead concentrations; however, it was unable to lower the levels to below 0.05 mg/L as was required by the USEPA. Next, sodium hydroxide was added to the system to elevate the pH and mitigate corrosion in the system; this was able to reduce the lead levels to below the maximum allowable concentration of 0.05mg/L at the time. In addition, it lowered the copper levels from an average of 0.35 mg/L to an average of 0.05 mg/L (Karalekas *et al* 1983).

# 2.6.3 Eastern Massachusetts

The Massachusetts Water Resources Authority (MWRA) supplies water to approximately 2.5 million people in 43 different communities. There are two main reservoirs, the Quabbin and Wachusett, both of which have aggressive water. The pH range is 6.3-7.3 and total alkalinity between 6 and 12 mg/L. Prior to implementing a more comprehensive corrosion control program, the MWRA tried a variety of treatments at the bench scale; however, they were unable to determine which method was more effective. They then proceeded to pilot scale testing where their results were varied. The biggest problem was going to be maintaining a stable pH throughout the distribution system,

particularly at the higher pH range. In the end, it was determined that the use of zinc orthophosphate or soda ash produced the best results (Johnson *et al*, 1993).

# **3 BACKGROUND**

#### 3.1 GVRD Water

The GVRD is responsible for acquiring, treating, and maintaining water quality throughout its distribution to the member municipalities. There are three watersheds, the Capilano, Seymour and Coquitlam, which cover over 585 square kilometers of forest area and supply approximately two million people with drinking water, through a network of mountain storage lakes, dams, reservoirs and over 500 km of supply mains. One of the biggest challenges faced by the GVRD is maintaining the quality of the water in the supply lines, which can be complicated because of the various chemical and physical reactions involved (Schock, 1980).

# 3.1.1 Source and Quality

All three watersheds are mountainous areas where the snowmelt, creeks and streams flow to the valley bottom into three large supply lakes (GVRD, 2003). The water is characteristically soft, with a low pH, poor buffering capacity, low mineral content and high dissolved oxygen saturation (Table 3-1). Consequently, the water is corrosive, and can have health, environmental, economic, and aesthetic impacts, including water leaks, corrosion products buildup, increased pumping costs and water quality deterioration (MacQuarrie *et al*, 1997; Volk *et al*, 2000).

Geographic factors are largely responsible for the corrosive nature of the water supply. High rainfall in the area has stripped the soil of its minerals, while the bedrock formation in the region is poorly soluble and contains low amounts of readily soluble mineral salts (Singh and Mavinic, 1991). Various factors are responsible corrosion in the

water distribution system, however the manner in which they interact isn't completely understood. Evidence suggests that corrosion of lead, copper and zinc is most affected by the pH, alkalinity, organic matter, and the concentration of free dissolved carbon dioxide (Broo *et al*, 1997; AWWARF, 1996; Mays, 2000).

| Source              | рН  | Alkalinity<br>(mg/L as<br>CaCO <sub>3</sub> ) | Dissolved<br>Oxygen<br>(mg/L) | Copper<br>(mg/L) | Lead<br>(mg/L) | Zinc<br>(mg/L) |
|---------------------|-----|---|-------------------------------|------------------|----------------|----------------|
| Capilano            | 6.1 | 1.4   | N/A                           | < 0.002          | 0.003          | < 0.002        |
| Seymour             | 6.9 | 6.5-9.6                                       | 11.1 <sup>†</sup>             | < 0.002          | < 0.001        | < 0.002        |
| Coquitlam           | 6.8 | 5.7-7.8                                       | 17.9                          | < 0.002          | < 0.001        | < 0.002        |
| Newton <sup>‡</sup> | 8.1 | $20^{\dagger}$                                | 11.1-17.9                     | < 0.002          | < 0.001        | < 0.002        |

Table 3-1 Water Quality Parameters of GVRD Water\*

<sup>†</sup>These values were calculated based on a number of grab samples and may not be the exact averages for the treated water.

<sup>‡</sup>The Newton Reservoir is fed by either the Seymour or the Coquitlam water sources, and therefore the DO and metal levels will fluctuate accordingly

For a more detailed list of all of the GVRD water quality parameters, see

Appendix A.

# 3.1.2 Previous Corrosion Studies Within the GVRD

In 1989-90, a study was conducted on the GVRD water distribution system to determine what factors were influencing the observed metal concentrations in the water. Lead, copper and iron levels in the drinking water were analyzed and it was determined that different variables were affecting the different metals individually. Lead

<sup>\*</sup> All values pertain to water quality characteristics after treatment, and not to source water characteristics (GVRD, 2003).

concentrations were most influenced by building types, while copper concentrations were affected by both plumbing age and type, and iron concentrations appeared to change, depending on the location (Singh and Mavinic, 1991). Elevated lead levels were associated with high-rise samples, new copper plumbing systems resulted in high copper concentrations, and iron did not show a distinct correlation with any of the factors investigated. Brass faucets were the primary source of zinc in the tap water, and they also contribute substantially to the lead detected in the 1-Litre first flush sample (Singh and Mavinic, 1991).

Following this study, another one was conducted in an attempt to determine the most effective and efficient ways of reducing the amount of lead and copper in the GVRD's drinking water. The results of the study indicated that adjusting the pH and alkalinity, through the addition of soda ash, should help to significantly reduce the amount of lead and copper leaching into the drinking water (MacQuarrie *et al*, 1997). Inhibitors offered no greater benefit for corrosion control than the adjustment of pH and alkalinity alone (MacQuarrie *et al*, 1997).

# 3.1.3 Current Water Treatment

The level of treatment used in the GVRD water distribution system was established based on the CDWQG, in accordance with the results of previous water quality studies done on GVRD source water. However, because the regulations pertaining to drinking water quality are constantly becoming more stringent, it is important to be aware of drinking water quality regulations that have been established by other organizations, which may have set out more restrictive limits. The CDWQG, USEPA

drinking water standards and the WHO drinking water guidelines for acceptable levels of lead, copper and zinc in drinking water are summarized in Table 3-2. These maximums were established based on either health concerns or aesthetic problems (Health Canada, 2001a; WHO, 2003; USEPA. 2003a).

**CDWQG<sup>1</sup> USEPA<sup>2</sup>** WHO<sup>1</sup> Metal (mg/L)(mg/L)(mg/L)Lead<sup>3</sup> 0.01 0.015 0.01 Copper<sup>4</sup> <1.0 1.3 2.0 Zinc<sup>4</sup> <5.0 5.0 3.0

Table 3-2 Drinking Water Guidelines for Lead, Copper and Zinc

CDWQG and WHO are for flushed samples, not water which has sat stagnant
USEPA are for the first litre flush

3. Maximum acceptable concentration for health reasons

4. Aesthetic Objective

The GVRD has chosen to implement corrosion control strategies involving the addition of soda ash, in an attempt to mitigate some of the health, environmental, economic and aesthetic problems associated with its corrosive water (GVRD, 2003). Currently, there are several different treatment strategies being employed in the area to treat the water, and these are summarized in Table 3-3.

| Primary             |                                   | Corrosion Control Plans |             |  |
|---------------------|-----------------------------------|-------------------------|-------------|--|
| Water Source        | Disinfectant Used                 | Chemical Added          | Targeted pH |  |
| Capilano            | Chlorine                          | None                    | N/A         |  |
| Coquitlam           | Ozone                             | Soda Ash                | 7           |  |
| Seymour             | Chlorine                          | Soda Ash                | 7           |  |
| Newton<br>Reservoir | Chlorine + Sodium<br>Hypochlorite | Soda Ash                | 8-8.5       |  |

# Table 3-3 Current Water Treatment Strategies Employed by the GVRD

The addition of soda ash increases the pH and alkalinity of the water, which helps decrease the concentration of dissolved metals in the water (Vinci and Sarapata, 1992).

## 3.1.3.1 Disinfection By-Product Formation

Samples collected in the Newton Distribution area, over the past couple of years have consistently had higher trihalomethane (THM) and haloacetic acid (HAA) concentration than samples collected from all three other sources. Historically Newton has the highest pH associated with it, which suggest that in the GVRD water distribution system, pH might be a factor in the formation of DBP's, specifically THM's and HAA's (Judy Smith, Water and Microbiology Quality Control Division, GVRD, Burnaby BC, pers. comm.). Other research has also supported the idea of an increased pH corresponding to an increased DBP formation, due to pH induced changes in the functional groups of the precursor molecules (Kawamura, 1991).

Although all samples collected to date have been in compliance with the current Canadian Drinking Water Quality Guidelines, which is a maximum concentration level (MCL) of 100µg/L for THM's, the USEPA is considering lowering the allowable THM

and haloacetic acids (HAA) concentrations from 80 and 60  $\mu$ g/L respectively, to 40 and 30  $\mu$ g/L in their stage 2 D-DBP rule (AWWA and ASCE, 1998). Consequently, the DBP concentration in samples collected in the Newton area over the past couples of years would exceed these new MCL levels for both THM's and HAA's. When looking at determining an optimum pH level for the new combined facilities, the potential benefits of adjusting the pH to 8-8.5 from 7 must be assessed, to justify targeting a pH of 8-8.5 for all GVRD water sources.

# 3.1.4 Water Distribution

The GVRD is responsible for acquiring, treating and delivering water to the municipalities. In order to do this, it needs to have a transmission system, which is composed of three major components: distribution piping, distribution storage, and pumping stations (Mays, 2000). The distribution piping is the most abundant element in a distribution system and is a combination of branched and looped pipe segments, which extend to all areas covered by the system. The pipes in the system will vary in their diameter, as well as in the type of material used to construct the pipes. The predominant materials used in the GVRD transmission system and the municipal distribution systems are:

- 1. Cast Iron: An iron alloy centrifugally cast in sand or metal molds.
- 2. Ductile iron: Cast iron product, magnesium is added to molten, low-sulfur base iron, causing the free graphite to form into spheroids and making it about as strong as steel (Mays, 2000).

- Polyvinyl Chloride (PVC): Polymer extruded under heat and pressure into a thermoplastic. Basic properties of PVC pipes can be found in ASTM 1784, while ASTM 3915 covers performance characteristics (Mays, 2000)
- Steel Pipe: Manufactured from a steel alloy, and should conform to AWWA C200 for drinking water distribution systems.
- Asbestos Cement (AC): made by mixing cement and asbestos fibers under pressure and heating it to produce a hard, strong, yet machinable product (Mays, 2000).

The GVRD is responsible for delivering water to the individual municipalities via its transmission system, and the municipalities are then responsible for delivering the water to the residents via their distribution systems (GVRD, 2003). Consequently, the material used to make up the GVRD water distribution system will vary from municipality to municipality.

The different municipalities and the types of material used in making up their distribution systems are listed in Table 3-4. Most of the new material being used to build water distribution systems in the various municipalities within the GVRD is ductile iron (Utilities Managers for GVRD municipalities pers. comm<sup>\*</sup>.). The general trend for most distribution systems is a move away from asbestos cement, cast iron and galvanized steel, and towards the use of ductile iron and plastics. All municipalities, within the GVRD, use

<sup>\*</sup> The following individuals provided information on the municipal distribution systems and in all further references will collectively be call Utility Managers; Chris Baber – City of Vancouver; Barry Davis – Burnaby; Tony Barber – North Vancouver; Chris Land – West Vancouver; Mike Carver – Coquitlam; Gary Gopp – Port Coquitlam; unknown – Port Moody.

copper almost exclusively for all of the service connections (Utilities Managers for Municipalities within the GVRD pers. comm.).

| Distribution System     | Material                          | % Composition |
|-------------------------|-----------------------------------|---------------|
|                         | Welded Steel                      | 91            |
| CVPD                    | Concrete Cylinders                | 7             |
| GVKD                    | AC                                | 1             |
|                         | Ductile/Cast Iron                 | 1             |
| Vancouver               | Cement lined cast or ductile iron | 50            |
| v ancouver              | Unlined cast iron                 | 50            |
|                         | Cast Iron                         | 65            |
| City of North Vancouver | Ductile Iron                      | 23            |
| City of North Vancouver | PVC                               | 7             |
|                         | Steel                             | 5             |
|                         | Ductile Iron                      | 80            |
| West Vancouver          | Cast Iron                         | 10            |
|                         | Galvanized Steel                  | 10            |
|                         | Cast Iron                         | 40            |
|                         | Ductile Iron                      | 36            |
| Coquitlam               | PVC                               | 18            |
|                         | AC                                | 2             |
|                         | Steel                             | 4             |
|                         | Ductile Iron                      | 48            |
| Port Coquitlam          | Cast Iron                         | 48            |
| I of t Coquitiani       | PVC                               | 2             |
|                         | AC                                | 2             |
| Port Moody              | Ductile Iron                      | 90            |
| 1 OI L MOUUY            | Cast Iron                         | 10            |
|                         | Ductile Iron                      | 80            |
| Burnaby                 | AC                                | 15            |
|                         | PVC                               | 5             |

# Table 3-4 Material Used in Current Water Distribution Systems Within the GVRD<br/>(Utilities Managers for Municipalities within the GVRD pers. comm.)

# 3.2 Sources of Metal

Water leaving the treatment facilities in the GVRD contains very low-level metal concentrations (GVRD, 2003). Unlike chemical contaminants that are present in the source water, metal contamination generally derives from the corrosion of materials comprising distribution system or residential plumbing (Reiber, 1991). Consequently, it stands to reason that the type of material used in the distribution and interior plumbing systems will dictate the types of metals found at the consumer's tap (Lee *et al*, 1989).

Metals can enter the environment from a variety of different sources, including as a result of the natural leaching of ores; however, the predominant sources are anthropogenic in nature, such as from atmospheric fallout, runoff and wastewater discharge (USEPA, 2003a). The leaching of lead, copper and zinc from plumbing material is the most significant source of metal in drinking water. Lead solder, service connections, brass fixtures and copper pipes can all contribute to the overall metal concentration in drinking water (Hong and Macauley, 1998).

# 3.2.1 Pipes

Within the GVRD there are a number of different distribution systems, and treated water must pass through these various distribution systems before arriving at individual homes. As a result, the water will potentially come into contact with a variety of different materials used in the distribution system, including pipes, valves, gaskets, fittings, seals, storage reservoirs and pumping stations (Mays, 2000). The material used to make up the GVRD transmission system can be quite different from the material used to

make up the municipalities distribution system; this is also different from the plumbing material used in the construction of single and multiple family housing units. Consequently, when trying to determine where the metals are coming from, it is important to examine all areas of possible metal leaching.

# 3.2.1.1 Distribution Systems

The current trend in material used to make up the distribution systems of most GVRD municipalities is ductile iron. This is being used in the construction of new water mains as well as replacing old mains, which can consist of cast iron, galvanized steel, or asbestos cement. As far as service connections go, they are predominantly made of copper. The GVRD water distribution system is not like the municipal distribution systems as it is made up mostly of lined welded steel. Overall, the contribution that these materials make to the observed concentration of lead, copper and zinc, is minimal (Hong and Macauley, 1997; Clement et al, 2000).

# 3.2.1.2 Interior Plumbing Systems

The interior plumbing systems of most houses is very different than the municipal distribution system, in terms of the type of material used. The majority of the houses being built today use copper tubing as the main water distribution material. Some houses use PVC, although this is not as common. Unlike the water in the distribution system that is virtually always moving, the water inside the house can remain stagnant in the pipes for 6 hours or more. Consequently, the material used to make up the interior pipes can contribute a significant amount of material to the water. Since most houses have at least

some copper tubing in them, this can be one of the most significant sources of copper in the drinking water (Broo *et al*, 1997).

#### 3.2.2 Solder

Solder can be used to join copper tubing and brass shut off valves in the household plumbing system (Reiber, 1991). In 1990, a change was made to the National Plumbing Code (NPC) limiting the amount of lead content in solder to 0.2% (Raman Chauhan, Technical Advisor, Canadian Codes Center, Ottawa pers. comm.). This effectively banned the use of 50:50 lead/ tin solder, which was previously the most widely used solder because of its low cost. Two alternatives to the lead/tin solder are tin/antimony and tin/silver, both of which can be considerably more expensive. Therefore, houses built prior to 1990 may contain significantly more of the lead/tin solder, which is a notable source of lead in drinking water (Reiber, 1991).

The lead/tin solder represents a particularly significant source of lead because of the electrochemical nature of the solder-copper joint. Copper is a more noble metal than lead, and when the two are placed side by side, it can create a galvanic cell; copper serves as the cathode, while the more electronegative lead solder serves as the anodic site and point of metal release (Reiber, 1991). The galvanic nature of the cells affects the solder anode by promoting electron exchange and thus inducing higher corrosion rates (Reiber,1991). Under air-saturated conditions, the reduction of dissolved oxygen on the copper surface can shift the copper potential in the positive direction producing an even larger electrochemical driving force for galvanic action (Reiber, 1991). Studies have

shown, that under certain water quality conditions, the soldered joints may continue to leach the metal for many years (Reiber, 1991).

#### 3.2.3 Faucets

The faucets can be a source of lead, copper and zinc in the water as it can leach into the water system as a result of solubility (Schock and Neff, 1988). The source of metals in systems that have initial elevated metal concentrations, where theoretically there shouldn't be any, has been attributed to the leaching of metals from the faucet while the water is standing (Schock and Neff, 1988). Dissolution of brass fittings can be a significant source of lead, copper, and zinc in tap water. The faucet appears to be a more significant source of metals in water samples where the water has been allowed to sit stagnant for a period of time, as opposed to running water (Schock and Neff, 1988; Lee *et al*, 1989). Metal concentration, in successive samples taken from the same faucet after the water was allowed to stand overnight, show a continual decrease, implying that the source is the faucet (Schock and Neff, 1988).

There is little difference in the types of material that goes into the construction of kitchen faucets. All of the major brands including, Delta, Waltec, Moen American Standard and Belanger, use a copper/brass alloy that contains very low lead levels and considered to be "lead free" (Dan Corrigan, Technical support, Delta Faucet, Canada, pers. comm.; Ivaless Santana, Sales assistant, American Standard, Canada, pers. comm.). The part of the faucets that comes into contact with the water is most often a copper tubing of the appropriate grade, and occasionally, some stainless steel is employed as fitting units, while neoprene may be used in making the seals (Dan Corrigan,

Technical support, Delta Faucet, Canada, pers. comm.). Tubing that connects the faucets and the plumbing system is usually copper, but sometimes it can be a plastic material. In summary, faucets are generally the major source of zinc in drinking water, and a potential source of lead and copper.

# 3.2.4 Hot Water Tanks

7

Most of the hot water tanks installed within the GVRD are glass lined. There may be some copper exposure where the water enters and leaves the tank, but as the water sits in the tank there is virtually no contact with any metals (Walter, Service department, Point Gray Plumbing and Heating Ltd., Vancouver, B.C., pers. comm.). Consequently, the hot water tank is not a very significant source of metal in the drinking water.

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# **4 EXPERIMENTAL METHODS**

# 4.1 Experimental Design

The objective of this research was to ascertain which of the 3 corrosion control plans currently in use within the GVRD is the most effective. It was also to determine what the effect of using ozone as opposed to chlorine, as the primary disinfectant, may have on the observed metal concentrations. The GVRD was divided into four distribution areas based on the predicted distribution of water from the Capilano, Seymour and Coquitlam watersheds, as well as the Newton reservoir. A significant number of households would need to be sampled in each of the distribution areas. All participants needed to be able to ensure that the water would remain stagnant in the plumbing system for a minimum of 6 hours.

It was also important to know if there was a significant difference in the amount of corrosion occurring in the summer months compared to the winter months. This involved taking samples during the warmest time of the year (sampling session 1), and during the coldest time of the year (sampling session 2). Traditionally the month of September is when the water in the distribution system is warmest, averaging 15°C, while January holds the record for the coldest temperatures, with an average of 6°C (GVRD, 2003).

During both sampling sessions, 4 water samples were taken at each sampling point (Table 4-1). Each water sample was to represent a different point in the water distribution system. The first sample taken, Cold #1, was a 50 ml sample, and was to contain the first 50 ml of water coming out of the tap after the water had been allowed to sit stagnant in

the household plumbing system for a minimum of 6 hours. This would represent the amount of metal in the drinking water as a result of the material used to make up the faucet (Reiber, 1989; Singh, 1990; Clement *et al*, 2000). Cold #2 sample was a 950 ml sample and was collected immediately after Cold #1. Theoretically, it should represent the amount of metal seen in the water as a result of the interior plumbing system in the house (Reiber, 1989; Singh, 1990; Clement *et al*, 2000). The third sample, Cold #3, was a sample of the running water, and would be used to determine the quality of the water reaching the participant's house.

The manner in which the Hot #1 sample was collected was different for the two sampling sessions. The Hot #1 sample was collected after the hot water had been allowed to run for a minute or two, during the first sampling session, and was indicative of the amount of metal in the drinking water as a result of the hot water tank used in the house. During the second sampling session, the Hot #1 sample was collected differently, and was the initial water coming out of the hot water tap after having sat overnight. This sample was used to examine the effect of leaving hot water sitting in the hot water pipes during the night.

Each house was also individually visited, between the two sampling sessions, to assess the pH, temperature, and DO levels in the water coming out at the tap.

| Sample  | Sample<br>Volume | Sample Taken                                      | Reason for Sampling   |  |
|---------|------------------|---|---|--|
| Cold #1 | 50 ml            | First water out of tap                            | Trace metal concentrations in the water as a result of faucet                 |  |
| Cold #2 | 950 ml           | Immediately following<br>Cold #1                  | Trace metal concentration in the<br>water as a result of building<br>plumbing |  |
| Cold #3 | 200 ml           | After cold water has been running for 5 minutes   | Background metal concentrations as a result of the GVRD mains.                |  |
| Hot #1  | 125 ml           | After hot water has been<br>running for 2 minutes | Trace metals in the water as a result<br>of hot water plumbing in houses.     |  |

# • Table 4-1 Sampling Program

# 4.1.1 Participants

103 participants were involved in the study. The participants were made up predominantly of GVRD employees, and people known to Gillian Knox. There were a few participants who were aware of the study as a result of knowing people who worked for the GVRD, but this only made up a small percentage of the participants.

In order to participate in the study, all people had to live within the GVRD and be served by the GVWD. In addition, all participants were asked to complete a questionnaire involving information about the age of their building, the material that was used in their plumbing system, the types of faucets used and whether or not they use a personal filtration unit. This information will be used to help determine if the observed metal concentration is a result of contaminants in the line, or due to the solubilization of the
plumbing pipes in the individual's home. A copy of the questionnaire and a summary of the results of the questionnaire can be seen in Appendix B.

# 4.1.1.1 Municipalities Involved

The participants involved in the study represented various municipalities served by the GVRD water distribution system (Table 4-2). Due to a lack of participants, some municipalities within the GVRD either didn't have any representation, or were only minimally represented in the study.

| Municipality   | Number of Participants | Source Water     |
|----------------|------------------------|------------------|
| Vancouver      | 22                     | Capilano         |
| Burnaby        | · 13                   | Seymour          |
| Coquitlam      | 10                     | Coquitlam        |
| Port Coquitlam | 11                     | Coquitlam        |
| Surrey         | 28                     | Coquitlam/Newton |
| N.Vancouver    | 9                      | Seymour          |

Table 4-2 Source Water Supplying Represented GVRD Municipalities

# 4.1.1.2 Study Number Designation

The participants were initially divided into 4 different categories, based on their predicted water source, Capilano (CAP), Coquitlam (COQ), Seymour (SEY), or Newton (NEW). The assigned water source was based on the geographic location, the predicted distribution of each of the 4 water sources and the corresponding pressure zone of the area in which the participant lived (Table 4-1). The Newton reservoir gets its water from

either the Seymour or the Coquitlam watershed, depending on the demand on the two watersheds and their respective flow rates. Once the water reaches the Newton reservoir, it is subsequently treated again with soda ash before being released back into the distribution system, and it is this released water that was of interest in this study.

Once the participants were divided into the 4 categories, they were organized in alphabetical order, by last name, and assigned a number. Therefore, every participant had a study number that consisted of 3 letters, to designate the source and a number. Ex. CAP 1, COQ10, SEY 22, NEW 13.

#### 4.1.2 Preparation

Based on previous water studies done in the area, the expected metal concentrations in the samples was low, in the parts per billion for lead, and parts per million for both copper and zinc (Singh, 1990). Therefore, it was imperative that the chance of any contamination be minimal. To minimize any cross contamination from the presence of trace metals in previously collected samples, only new bottles were used.

#### 4.1.2.1 Bottle Preparation

To minimize the possibility of contamination as a result of metals being present in the sampling containers, all bottles were acid washed using a 10% nitric acid solution (HNO<sub>3</sub>), and subsequently rinsed in distilled water. The last step in the procedure was a hand rinsing with deionized/distilled water, after which the bottles were capped and labeled. Although Standard Methods recommends a more labor intensive pretreatment of the sampling containers, a previous study done compared this method with the one used in this study and found that there was no significant difference in the observed metal concentrations (Chan, 1994). Samples of distilled/deionized water were analyzed for the presence of trace metals to ensure that the bottle preparation procedure was adequate (Appendix C). In addition, personal experience with collecting water samples with trace metal concentrations supported the decision to go with an acid wash, as opposed to the method outlined in Standard Methods.

## 4.1.2.2 <u>Sampling Kits</u>

The bottles were assembled in to sampling kits at the UBC lab. The kits consisted of a large Ziplock bag that contained one 1L bottle, one 250 ml bottle, one 125 ml bottle, one 65 ml bottle, and a 3 page instruction sheet which included some hints on how to get through the night without running the water (Appendix D).

The 65 ml bottle was labeled Cold #1 and was used to collect the initial 50 ml of water from the tap. The metal levels in this sample came primarily from the faucet used (Singh, 1990). The 1L bottle was labeled Cold #2 and was used to collect a 950ml sample. The observed metal concentration in this sample was a result of the metals leaching in to the water from the interior house plumbing system, and any solder joints (Singh, 1990). The 250ml bottle was labeled Cold#3 and was used to collect a 250ml sample. The observed metal concentrations in this sample came from the distribution system itself and were used to determine the background metal concentrations in the samples.

The 125ml bottle was labeled Hot #1 and was used to collect a 125ml sample. During the first session this sample contained water that came from the hot water tank and represented the metal concentration observed at the tap as a result of the hot water tank. During the second session, sampling was a little different and this sample represented hot water that was left to sit stagnant in the pipes. The metal concentration in this sample was as a result of metals leaching into the system from the interior hot water plumbing system, including any solder joints in that part of the system.

Taped to the outside of the ziplock bag was a summarized version of the instructions (Appendix D) along with an address label that gave the name of the participant, their address and their study number.

# 4.1.2.3 Drop-off and Pick-up

All sampling kits were personally delivered to the participants at their home, or at work. Employees of the GVRD agreed that they could pick up their sampling kits on the 12<sup>th</sup> floor reception area, where they were left in alphabetical order. Separate arrangements were made for people who didn't work at the GVRD head office, or were unable to pick them up at the specified time.

Samples were picked up the same day that they were taken. Pick up was done in the same manner as the drop-off, GVRD employees who worked at the head office dropped off their samples in a box in the reception area of the 12<sup>th</sup> floor. All other participants either left their completed sampling kits outside their front door, or at a prearranged location.

People who were doing duplicate samples were asked to take samples two mornings in a row. These samples were collected separately on the same day that they were taken.

#### 4.1.2.4 Instructions

All participants were given a detailed copy of the instructions in their sampling kits, as well as a summarized version taped to the outside of their sampling kits (Appendix D). Samples were to be taken from the kitchen tap, so long as there was no personal filtration device, or at least the means of bypassing it. The samples were to be taken immediately upon getting up in the morning, before any water was used. The water was to have been left to sit in the pipes overnight, between 6-8 hours.

Both surveys were identical in their instructions, except for the hot water sample. The manner in which the hot water sample was taken during sampling session #1 was different than for sampling session #2. During sampling session #1, participants were asked to run their hot water for a certain amount of time and then take the water sample. This sample was meant to contain water that had just come from the hot water tank. In the second sampling session, participants were asked to take the water sample from the hot water tap without letting it run. Consequently, the water in the sample was "cold"; however, it had been hot when it was initially left to sit in the pipes.

The reason that the instructions were changed was because the amount of metal being released into the water as a result of the hot water tank is minimal, since most of them are glass lined (Walter, Service department, Point Gray Plumbing and Heating Ltd, Vancouver BC pers. comm.). The second sampling session instructions was to determine

if leaving hot water in the plumbing system overnight would result in higher metal concentrations in the water compared to letting cold water sit in the plumbing system overnight. The fact that these samples were taken in a different manner should not have  $\int_{J}^{J}$  been affected by the initial temperature of the water entering the house, since no matter what the initial temperature of the water, the hot water tank will heat the water to a predetermined temperature.

## 4.1.2.5 Preservation

Once the samples were collected, they were immediately brought back to the UBC environmental lab and preserved using concentrated HNO<sub>3</sub>. To ensure that no metals were going to adsorb onto the walls of the sampling containers, all samples had their pH lowered to approximately 2 pH units on the same day that they were collected. The amount of acid added to each sample is shown in Table 4-3. The only exception was the Cold #3 sample, which wasn't immediately preserved, as both the pH and the alkalinity of the water needed to be determined before the sample could be preserved.

| Sample                        | HNO <sub>3</sub> Added |
|-------------------------------|------------------------|
| Cold #1 (50ml)                | 1 drop                 |
| Cold #2 (950 ml)              | 1 ml                   |
| Cold #3 (150ml <sup>*</sup> ) | 2 drops                |
| Hot #1 (125 ml)               | 1 drop                 |
| Field Blank (50ml)            | 1 drop                 |

| Fable 4-3 HI | NO <sub>3</sub> Added | to Each | Sample for | Preservation |
|--------------|-----------------------|---------|------------|--------------|
|              | 5                     |         |            |              |

\*This volume corresponds to the volume of sample left after the pH and alkalinity was determined

## 4.1.3 Home Visits

The house of every participant was visited to determine the pH and DO levels of the water as it comes out of the tap. Most houses were visited in the evening at the convenience of the participant. A portable pH meter was used to determine the pH, while biochemical oxygen demand (BOD) bottles were used to collect water samples for DO analysis at the lab. The observed DO levels in the water sample will be affected by the temperature of the water, and it's corresponding saturation level; therefore, temperature readings were taken at the same time as water samples.

#### 4.2 Analysis

All samples taken by the participants were analyzed for their lead, copper and zinc content. Cold #3 samples were analyzed to determine the alkalinity level in the water that reaches the house, as well as the pH. Samples collected during the home visit were analyzed to determine the pH and DO levels in the water reaching the tap.

#### 4.2.1 Metals

Standards were prepared using Fisher Scientific reference solutions and a 0.5% nitric acid dilution solution. All flasks and containers that were used in the process of preparing the standards were soaked in a 10% nitric acid (HNO<sub>3</sub>) solution overnight, rinsed with distilled water and finally rinsed with deionized/distilled water. The sample concentrations were expected to be low, and the standards were made up accordingly

(Table 4-4). Copper and zinc could be run on the atomic adsorption spectrometer (AAS) simultaneously, and their standards were made up in the same solution.

|           |        | Metals |        |
|-----------|--------|--------|--------|
| Standards | Lead   | Copper | Zinc   |
|           | (µg/L) | (mg/L) | (mg/L) |
| STD 1     | 10     | 0.5    | 0.5    |
| STD 2     | 50     | 1.0    | 1.0    |
| STD 3     | 100    | 2.0    | 2.0    |

Table 4-4 Standards Used for Metal Analysis

#### 4.2.1.1 <u>Lead</u>

Lead concentrations were determined on the Perkin Elmer Zeeman AAS model 4100 ZL, using Perkin Elmer THGA graphite tubes, according to Standard Methods (APHA 1995 Section 3113 B). The instrument recalibrated itself every 15 samples. In addition a test solution was made up and measured every 10 to 15 samples to ensure that the standards were accurate, and that the machine was maintaining its calibration. All samples were measured three times and only the average concentration was reported. For a complete list of all method parameters see appendix E.

# 4.2.1.2 Copper

Copper was analyzed on the Varia SprectrAA 220 FS machine using the direct air-acetylene flame method outlined in Standard Methods Section 3111 B (APHA *et al*, 1995). The instrument calibration was checked every 10 samples by the AA, which checked the standard curve by resloping it using one of the supplied standards. In

addition, a test solution was analyzed every 10 to 15 samples to ensure that the machine was in the correct range, and correctly calibrated. For a complete list of all method parameters see Appendix E.

#### 4.2.1.3 <u>Zinc</u>

Zinc was analyzed on the Varia SprectrAA 220 FS machine using the direct airacetylene flame method outlined in Standard Methods, Section 3111 B (APHA *et al*, 1995). The instrument calibration was checked every 10 samples as the AA reanalyzed and resloped the calibration curve using one of the supplied standards. A separate test solution was also measured every 10 to 15 samples to ensure that the machine was in the correct range, and maintaining its calibration. For a complete list of all method parameters, see Appendix E.

#### 4.2.2 Alkalinity

Cold#3 sample was the only one to be analyzed for its alkalinity levels, as it was meant to represent the quality of the water that is delivered to the house, as opposed to the alkalinity of the water after it had sat stagnant in the pipes during the night. The alkalinity in the water samples can deteriorate quickly and needed to be determined before the remainder of the sample was preserved; therefore, alkalinity was measured on the day the sample was taken, or as close to it as possible. All samples were expected to have low alkalinity levels (GVRD 2001), and were therefore determined using the low alkalinity procedure outlined in Standard Methods, Section 2320 B (APHA *et al*, 1995).

## 4.2.3 Dissolved Oxygen

The dissolved oxygen concentration was only measured in the samples taken during the home visit. Samples were collected in a BOD bottle, and brought back to the lab where they were fixed according to Standard Methods, Section 4500-0 C (APHA *et al*, 1995). A Winkler titration was then performed on the samples to determine the DO levels in the water.

## 4.2.3.1 <u>Temperature</u>

The DO saturation will fluctuate with the temperature of the water. When the DO sample was being collected the temperature of the water was also recorded, in degrees Celsius, using a Fisher brand thermometer. Before collecting the sample for DO analysis, water was collected in a beaker and the temperature reading was taken from there.

#### 4.2.4 pH

The pH was determined for the Cold #3 samples, as this represented the pH of the water reaching the house and not the pH of the water after it was left to sit in the pipes over the night. Since the pH of the tap water can also change quickly after sampling, it was measured on the day the sample was collected, or as close to it as possible to avoid any errors in the reading as a result of elapsed time. pH measurements were also taken during the house visits. All pH measurements were taken according to Standard Methods, Section 4500-H, and the same pH probe was used for all pH measurements, VWR Scientific symphony probe (APHA *et al*, 1995).

#### 4.2.4.1 <u>Lab</u>

The pH of Cold #3 was determined in the lab using a Horiba D-13 pH meter. The pH meter was calibrated every time prior to being used. In between samples, the probe was rinsed with distilled water to avoid any errors in reading as a result of contamination. A 100ml sample of Cold#3 was used to determine the pH of the water. The sample was continuously stirred until the measurement stabilized.

# 4.2.4.2 Home

A portable Oaklon WD-35615 series pH meter was used to determine the pH of the water at the tap during the home visits. The tap water in the GVRD area is expected to have low ionic strength, consequently an Orion buffer solution was added to the sample to give it a more stable reading (GVRD 2001). 1ml of the buffer solution was added to a 100ml sample of water taken from the tap prior to having the pH measured. While the pH was being read, the sample was continuously stirred to ensure an accurate and stable reading.

The pH meter was calibrated, using solutions that contained the Orion buffer solution, prior to being used in the field.

## 4.3 Quality Control

To ensure that the reported measurements were as accurate as possible, and to eliminate any errors as a result of the analysis procedure, quality control measures were put in place. This included sending samples to the GVRD lab for cross-referencing with

the results obtained in the UBC lab. In addition, participants were asked to take duplicate samples to check for precision. Test samples were also made up to gauge the accuracy of the standards used in the analysis. Also, a number of different blanks were used to see if there was any outside source of metal contamination that may affect the observed metal concentrations.

# 4.3.1 Method Detection Limits

The atomic adsorption (AA) machines come with a recommended detection limit; however, samples were analyzed to determine what the actual detection limit of the machine was, and whether or not it corresponded to the manufacturer's preset detection limit.

Ten low-level samples were analyzed, in sequence, on both AA machines and a method detection limit was set accordingly (Table 4-5).

| Metal  | Detection Limit (mg/L) |
|--------|------------------------|
| Lead   | 0.005                  |
| Copper | 0.03                   |
| Zinc   | 0.01                   |

**Table 4-5 Method Detection Limits for Atomic Adsorption Spectrometry** 

#### 4.3.2 Repeats

5 participants in each area, roughly 20%, were randomly chosen to take repeat samples during both sampling sessions 1 and 2. Those chosen to take repeat samples in the first sampling session were also asked to take repeat samples in the second sampling session. There were, however, a few people who moved between the sampling sessions and were unable to participate in the second sampling session making it necessary to choose new participants to take repeat samples. These participants were asked to take water samples two mornings in a row, following two nights of not running the water.

#### 4.3.3 GVRD

All samples that were done in duplicate, were also sent to the GVRD lab at Annacis Island, where ICP techniques were used to determine the lead, copper and zinc concentrations in the samples. The detection limits of the ICP, used in the GVRD lab, were 1  $\mu$ g/L for copper and lead, and 2  $\mu$ g/L for zinc, which is lower than the detection limit for the AA machines used at the UBC lab which were 5 $\mu$ g/L for lead, 30  $\mu$ g/L for copper and 10  $\mu$ g/L for zinc. These results were then compared to the results obtained in the UBC lab.

## 4.3.4 Test Samples

Test samples were made up for the lead, copper and zinc analysis. The source of the metal was different than what was used to make up the standards. These solutions were also made up using the same dilution water as the standards and were measured between the samples. Every 10 to 15 samples measured in the atomic adsorption was a test sample. This was done to give an idea as to the potential variability in the measurements.

# 4.3.5 Blanks

Field blanks were placed in approximately 20% of all sampling kits, 5 from each different source. Participants were then asked to remove the lid of the field blank for 5 seconds and then replace the lid. This was to assess the potential risk of contamination from any airborne particulate matter in the houses of the participants.

Blank samples were also used in the lab, while some of the analysis was being performed to determine if there was any potential contamination risk from the air in the lab.

Blanks that contained distilled deionized water and a drop of the HNO<sub>3</sub> used to preserve the samples, were sent to the GVRD for analysis. This was done to see if the acid used to preserve the samples contained any trace metal concentrations, or if the acid wash technique used to clean the sample containers adequately removed all trace metals.

# 4.4 Data Evaluation

The data was initially evaluated based on the alkalinity and pH measurements taken at each participant's house. The participants were then grouped according to their source water based on the pH, alkalinity and geographic locations.

The current USEPA protocol uses a standing one-litre sample for compliance monitoring because their water quality standards are based on the first litre flush. The Canadian Drinking Water Quality Guidelines (CDWQG) and the World Health Organization (WHO) drinking water standards are based on running water concentrations. In order to compare results with all three organizations water quality

standards, a calculated first-litre flush metal concentration was established by combining metal concentrations in samples Cold #1 and Cold #2 (Eq 4-1).

Eq 4-1 Concentration in 1<sup>st</sup> Litre Flush =  $0.05 \times (\text{concentration of Cold #1})$ + 0.95 x (concentration of Cold #2)

The calculated first-litre flush was used for most of the analysis done since it was more important to see the overall trends in the total amount of metal leaching into the drinking water, as opposed to the exact location in the household system the metals were coming from.

The aggressiveness of each of the water sources was then evaluated based on observed metal concentrations in the calculated first-litre flush. All values that were below the detection limit were assigned a value of half the detection limit in calculating averages. The measured average metal concentration for each of the sources was then compared to determine which water was the most corrosive and to see if the effect of the corrosiveness of the water was different for each metal.

In order to determine the mass loading of metals to the drinking water, Equation 4-2 was used.

**Eq 4-2** Sample Concentration (mg/L) \* Volume (L) = Amount (mg)

The error bars in the graphs represent the 95% confidence intervals and were calculated using methodology outlines in Freund (Freund and Perles 1999).

One-way (one-factor) analysis of variance was utilized for analysis of the house data (S-PLUS). Statistical differences between the mean metal concentrations, associated with each of the source waters, were evaluated. All p-values that exceed 0.05, (95% confidence interval) were considered not to be statistically significant. The percent difference between duplicate samples was calculated using equation 4-3:

73

Eq. 4-3 1-(smaller number/larger number)\*100 = % Difference

# **5 RESULTS**

#### 5.1 Source Water Allocation

The GVRD was divided into four areas based on the predicted distribution of water from the Capilano, Seymour, and Coquitlam watersheds, as well as the Newton reservoir. Throughout the year, the distribution of each of the source waters changes, depending on the demand, supply and weather conditions. Consequently, it is not possible to accurately predict which areas will be receiving water from which source on any given day. Since the purpose of the study was to determine the effect of the different corrosion control plans currently implemented in the GVRD, it was important to determine which areas the treated source waters were being distributed to on the day of sampling. This was determined not only by looking at the geographic location and the pressure zones surrounding the residence of the participants in the study, but also by examining the pH and alkalinity of the water reaching their homes.

Initially, all participants were divided into 4 different groups based on their geographic location, the pressure zone surrounding their residence and the predicted water distribution of each of the four treated source waters. However, after collecting the samples it was obvious that a number of people had been assigned incorrectly. Participants were redistributed into the four source categories, based on pH and alkalinity measurements from sample Cold #3, and their geographic location (Table 5-1). The distribution of each water source categories after each sampling session (Table 5-1). The number of participants who successfully collected samples in each of the four designated

areas after being reassigned based on pH and alkalinity measurements of their water is summarized in Table 5-1.

During the first sampling session, of the 104 sampling kits assembled and delivered, 101 were returned. Three people were unable to complete the samples because of personal conflicts with the dates. Of the 101 sampling kits returned, only one was rejected because the correct sampling protocol was not followed.

During the second sampling session, there were fewer participants than during the first because some had moved and others were unavailable during the time of the sampling. Of the 101 participants who successfully participated in sampling session 1, only 86 were able to participate in the second sampling session. All 86 participants returned their sampling kits; however, three of them were rejected because they had had some recent plumbing work done which affected the metal concentration in the water samples collected, specifically the lead concentration.

| Source    | Initial Designation | Sampling Session 1<br>(Sept. 2002) | Sampling Session 2<br>(Jan. 2003) |  |  |
|-----------|---------------------|------------------------------------|-----------------------------------|--|--|
| Capilano  | 21                  | 19                                 | 13                                |  |  |
| Seymour   | 27                  | 29                                 | 20                                |  |  |
| Coquitlam | 36                  | 34                                 | 35                                |  |  |
| Newton    | 17                  | 18                                 | 15                                |  |  |
| Total     | 101                 | 100                                | 83                                |  |  |

Table 5-1 Number of Participants in Each Source Category

## 5.1.1 Water Quality Parameters

Distributed Capilano water has the lowest pH and alkalinity levels of all of the source waters. Seymour and Coquitlam are both treated with soda ash, targeting a pH of 6.8 and 6.9, resulting in alkalinity levels of 8.2 mg/L and 6.8 mg/L as CaCO<sub>3</sub>, respectively. Newton water is also treated with soda ash; however, a pH of 8.1 is targeted resulting in an alkalinity of 14.3 mg/L as CaCO<sub>3</sub>.

To determine the source water of the samples being taken, both pH and alkalinity were measured from sample Cold #3, which should have contained water coming directly from the distribution system and be characteristic of the source water.

# 5.1.1.1 <u>pH</u>

The pH of the water in samples Cold #3 was determined the same day that samples were collected, before being preserved. The range of pH values for each of the source areas during both of the sampling sessions is shown in Figure 5-1. Water sampled from the Capilano distribution system had the lowest pH values, averaging 5.8 and 6.1 in the two sampling sessions (Table 5-2). Newton water samples had the highest pH values, averaging 7.2 and 7.3 in the two sampling sessions (Table 5-2). This trend was expected since there is no corrosion control treatment for the Capilano water, while the Newton water is treated to target the highest pH in the GVRD (Doug MacQuarrie, Engineering and Construction Department, GVRD, Burnaby BC, pers.comm.).

It was not possible to distinguish between the Seymour and Coquitlam watersheds in terms of pH, as they have similar pH values, upon leaving the treatment facilities, of 6.8 and 6.9 respectively (GVRD, 2003). The average pH for the Seymour water samples collected in this study was less than the average for the Coquitlam samples, as seen in

Figure 5-1. The distribution areas for the Seymour and Coquitlam sources can possibly explain the difference in average pH values of the waters. The distribution area of the Seymour water is adjacent the distribution area of the Capilano water system, which has a lower pH value associated with it, and therefore if the two mix, it would lower the observed pH value for Seymour samples collected. The Coquitlam water, however, is distributed to areas surrounding the Newton reservoir, which has the highest pH value associated with it, and if these two sources were to mix, it could raise the pH value of the collected samples. However, because it was not possible to determine whether this was the case, no conclusions can be drawn about the observed difference in the average pH values for the Seymour and Coquitlam water sources.

The average pH of the four treated source waters, during both sampling sessions is summarized in Table 5-2. There was very little change in the observed pH values obtained in the Cold#3 samples, suggesting that the temperature difference in the water due to changing seasons, has little effect on the pH of the water.

| Source    | рН            |               |  |  |  |
|-----------|---------------|---------------|--|--|--|
| Source    | Session 1     | Session 2     |  |  |  |
| Capilano  | $5.8 \pm 0.5$ | $6.1 \pm 0.5$ |  |  |  |
| Seymour   | $6.3 \pm 0.2$ | $6.4 \pm 0.1$ |  |  |  |
| Coquitlam | $6.8 \pm 0.1$ | $6.8 \pm 0.2$ |  |  |  |
| Newton    | $7.2 \pm 0.1$ | $7.3 \pm 0.2$ |  |  |  |

 Table 5-2 Average pH Values of Water in Cold #3 Sample



Figure 5-1 pH Values of Samples Collected in the 4 Source Areas



A) Samples collected during the first sampling session





# 5.1.1.2 <u>Alkalinity</u>

The alkalinity of the water in sample Cold #3 was determined the same day that the sample was collected, before being preserved, and is summarized in Table 5-3. The range of alkalinity measurements from each of the four treated source waters is shown in Figure 5-2. As expected, the Capilano distribution system had the lowest alkalinity levels, averaging 2.5 and 0.6 mg/L as CaCO<sub>3</sub> in each of the sampling sessions, while Newton had the highest alkalinity measurements, averaging 13.8 and 10.9 mg/L as CaCO<sub>3</sub> in each of the sampling sessions. This trend was expected since there is no corrosion control treatment for the Capilano water, while the Newton water is treated to target the highest pH, resulting in the highest alkalinity level. Although the alkalinity of the water leaving the treatment facility is different for the Seymour and the Coquitlam water sources, 8.2 and 6.8 mg/L as CaCO<sub>3</sub> respectively, the average measured alkalinity in the collected samples was similar.

The trend seen, with respect to changes in the alkalinity levels during both sampling sessions, implies that during the colder months, less alkalinity is in the water than in the warmer months (Table 5-3). This may be because in colder temperatures the dissolution reactions, which are responsible for releasing alkalinity into the water system, are slower, and consequently less alkalinity is able to accumulate (Mays, 2000).

| Source    | Treated Water                 | Alka<br>(mg/L as | linity<br>5 CaCO3) |  |
|-----------|-------------------------------|------------------|--------------------|--|
|           | (Ing/L as CaCO <sub>3</sub> ) | Session 1        | Session 2          |  |
| Capilano  | 1.4*                          | 2.5              | 0.6                |  |
| Seymour   | 8.2*                          | 7.8              | 5.6                |  |
| Coquitlam | 6.8*                          | 6.7              | 5.8                |  |
| Newton    | 14.3†                         | 13.8             | 10.9               |  |

Table 5-3 Treated GVRD Alkalinity Values Compared to Alkalinity in Cold #3

\*Average alkalinity values reported by the GVRD

<sup>†</sup>Average alkalinity value based on analysis of grab samples



Figure 5-2 Alkalinity Values of Samples Collected in the 4 Source Areas

A) Samples collected during the first sampling session



B) Samples collected during the second sampling session

#### 5.2 Sources of Metal Contamination in the GVRD Drinking Water Supply

The quality of the water leaving the treatment facilities within the GVRD has been well documented, and it has been concluded that the metal concentration in the water is below the detection limits, and is summarized in Table 5-4 (GVRD, 2003). When the water is dispensed at the taps, however, the observed metal concentration is considerably greater than when it left the treatment facility (Table 5-5).

Table 5-4 Average Metal Concentration in GVRD Water After Treatment

| Matal  | Source   |         |           |                     |  |  |  |  |
|--------|----------|---------|-----------|---------------------|--|--|--|--|
| Wittai | Capilano | Seymour | Coquitlam | Newton <sup>*</sup> |  |  |  |  |
| Lead   | < 0.001  | < 0.001 | < 0.001   | < 0.001             |  |  |  |  |
| Copper | <0.02    | < 0.02  | <0.02     | < 0.02              |  |  |  |  |
| Zinc   | < 0.01   | < 0.01  | < 0.01    | < 0.01              |  |  |  |  |

The Newton Reservoir is fed by either the Seymour or Coquitlam watersheds.

The sampling scheme used to collect samples from the participants houses allowed for a rough estimate of where the metal in the drinking water was coming from. The average metal concentrations, from both sampling session, from each of the four treated source areas is expressed in terms of mg/L, and is summarized in Table 5-5, along with the Canadian Drinking Water Quality Guidelines (CDWQG) for the metals of interest. A summary of all of the collected data used to calculate averages presented below can be found in Appendix F. Only one sample has an average that exceeds the CDWQG, and that is the calculated first-litre flush for the copper concentration in the Capilano distribution area. However, because the CDWQG specifies that the collected sample must be from a flushed tap, which is not the case in the calculated first-litre flush, it can be stated that all measured metal levels in all collected samples are in compliance with the CDWQG (Health Canada, 2002(a)).

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Table 5-5 Average Metal Concentration in all Collected Samples Compared to the Canadian Drinking Water Quality

Guidelines

|                     |                   |                         |                  |                 |                   | Source (n       | ıg/L)               |             |             |             |
|---------------------|-------------------|-------------------------|------------------|-----------------|-------------------|-----------------|---------------------|-------------|-------------|-------------|
| Metal               | CDWQG             | Sample                  | Capi             | lano            | Seym              | iour            | Coqui               | tlam        | New         | vton        |
|                     |                   |                         | S 1              | S 2             | S 1               | S 2             | S 1                 | S 2         | S 1         | S 2         |
|                     |                   | 1 St T                  | 0.008            | 0.004           | 0.008             | 0.004           | 0.005               | 0.004       | 0.006       | 0.005       |
|                     |                   |                         | (ND-0.036)       | (ND-0.007)      | (ND-0.031)        | (ND-0.012)      | (ND-0.024)          | (ND-0.016)  | (ND-0.017)  | (ND-0.029)  |
| I and <sup>1</sup>  | 100               | Cold#3                  | QN               | Ð               | ND                | Q               | 0.003               | 0.003       | QN          | QN          |
| rcan                | 10.0              |                         | (all<0.005)      | (all<0.005)     | (all<0.005)       | (all<0.005)     | (ND-0.011)          | (ND-0.008)  | (all<0.005) | (all<0.005) |
|                     |                   | Hot #1                  | 0.003            | 0.003           | 0.003             | Ð.              | 0.003               | 0.005       | 0.003       | 0.005       |
|                     |                   |                         | (ND-0.007)       | (ND-0.014)      | (ND-0.007)        | (all<0.005)     | (ND-0.005)          | (ND-0.061)  | (ND-0.006)  | (ND-0.019)  |
|                     |                   | $1^{st}L$               | 1.33             | 1.24            | 0.68              | 0.67            | 0.51                | 0.56        | 0.21        | 0.16        |
| -                   |                   |                         | (0.11-2.94)      | (0.44-1.86)     | (ND-1.24)         | (0.08-1.31)     | (0.03-1.57)         | (ND-1.74)   | (ND-0.41)   | (ND-0.35)   |
| Copper              | -<br>-<br>        | Cold#3                  | 0.13             | 0.28            | 0.11              | 0.16            | 0.13                | 0.10        | 0.03        | 0.02        |
| 4                   | 0.17              |                         | (ND-0.65)        | (0.03-1.18)     | (ND-0.53)         | (ND-0.85)       | (ND-1.32)           | (ND-1.40)   | (ND-0.05)   | (ND-0.04)   |
|                     |                   | Hot #1                  | 0.47             | 0.77            | 0.28              | 0.30            | 0.19                | 0.23        | 0.07        | 0.08        |
|                     |                   |                         | (0.04-1.48)      | (0.10-1.72)     | (ND-0.99)         | (0.07-0.67)     | (ND-0.75)           | (0.03-0.56) | (ND-0.21)   | (ND-0.26)   |
| _                   |                   | $1^{st}L$               | 0.11             | 0.13            | 0.08              | 0.08            | 0.06                | 0.06        | 0.02        | 0.02        |
|                     |                   |                         | (0.01 - 0.31)    | (ND-0.44)       | (ND-0.2)          | (ND-0.18)       | (0.01-0.32)         | (0.01-0.17) | (ND-0.03)   | (ND-0.05)   |
| 7 in c <sup>3</sup> | 082               | Cold#3                  | 0.009            | 0.01            | QN                | 0.01            | 0.01                | 0.01        | QN          | Q           |
|                     | 2.7               |                         | (ND-0.02)        | (ND-0.03)       | (all<0.01)        | (ND-0.07)       | (ND-0.16)           | (ND-0.05)   | (all<0.01)  | (all<0.01)  |
|                     |                   | Hot #1                  | 0.04             | 0.05            | 0.01              | 0.03            | 0.01                | 0.04        | QN          | 0.01        |
|                     |                   |                         | (ND-0.43)        | (ND-0.15)       | (ND-0.03)         | (ND-0.13)       | (ND-0.04)           | (ND-0.19)   | (all<0.01)  | (ND-0.04)   |
| 1. Dete             | stion Limit for l | $ead = 0.005 m_{\rm s}$ | g/L 2. Detection | Limit for Coppe | r = 0.03  mg/L 3. | Detection Limit | for $Zinc = 0.01 n$ | ıg/L        |             |             |

ND = Not Detected, all samples below the detection limit

#### 5.2.1 Source of Lead

The measured lead concentration in the collected samples, along with the lead concentration in the water leaving the various treatment facilities is summarized in Table 5-6. The distribution of lead concentrations in the collected samples from all 4-source areas, for both sampling sessions, showed similar trends, as seen in Figure 5-3.

Household plumbing systems appear to be the primary source of lead in the GVRD drinking water, as lead concentrations in the Cold #1 sample were consistently above the detection limit compared to the other samples which were either at or below the detection limit. This is supported by other research which has shown that a large portion of the lead in drinking water can come from lead leaching into the water if the water is allowed to sit stagnant over night (Lee *et al*, 1989; Clement *et al*, 2000).

The concentration of lead in the Cold #2 sample was invariably less than in Cold #1, but greater than the Cold #3 sample in all samples collected from all 4 treated source areas, during both sampling sessions. Cold #2 samples reflect the amount of metal allowed to dissolve into the water as a result of sitting stagnant in the household plumbing system for the duration of a night. The source of lead in the Cold #2 sample is most likely due to the use of lead tin solder in the plumbing systems of the older houses (Lee *et al*, 1987; Reiber, 1991).

All collected Cold #3 samples, for all 4-source areas, during both sampling sessions, had average lead concentrations below the value of the detection limit. This sample should have been representative of the quality of water reaching the participants home, as it should contain water coming directly from the distribution main. There is nothing to suggest that the water in the GVRD transmission system, or the municipal distribution systems comes into contact with any material containing lead, and therefore

the similarity between the lead concentration in the Cold #3 sample and the water leaving the treatment facility is expected (Table 5-6).

The Hot #1 sample also had low lead concentrations, below the detection limit, suggesting that there is nothing in connection with the hot water tank that could potentially be a source of lead.

Table 5-6 Average Lead Concentration of Collected Samples and Treated Water

| Source    | Treatment<br>Facility | Cold #1<br>(mg/L) |       | Col<br>(m | l <b>d #2</b><br>g/L) | <b>Cold #3</b><br>(mg/L) |         | Hot<br>(mg | t #1<br>g/L) |
|-----------|-----------------------|-------------------|-------|-----------|-----------------------|--------------------------|---------|------------|--------------|
| , vv ater | (mg/L)                | <b>S</b> 1        | S2    | <b>S1</b> | S2                    | <b>S</b> 1               | S2      | <b>S</b> 1 | S2           |
| Cap       | < 0.001               | 0.011             | 0.007 | 0.008     | < 0.005*              | < 0.005                  | < 0.005 | < 0.005    | < 0.005      |
| Sey       | < 0.001               | 0.013             | 0.006 | 0.007     | < 0.005               | < 0.005                  | < 0.005 | < 0.005    | < 0.005      |
| Coq       | < 0.001               | 0.007             | 0.006 | < 0.005   | < 0.005               | < 0.005                  | < 0.005 | < 0.005    | < 0.005      |
| New       | < 0.001               | 0.010             | 0.009 | 0.006     | < 0.005               | < 0.005                  | < 0.005 | < 0.005    | < 0.005      |

\* Average is below the value set as the detection limit (0.005mg/L)



Figure 5-3 Average Lead Concetrations in the Collected Samples\*

A) Samples collected during the first sampling session



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B) Samples collected during the second sampling session

\* All samples with values below the detection limit were assigned a value of half the detection limit for calculations

# 5.2.2 Source of Copper

The measured copper concentration in the collected samples, along with the copper concentration in the water after leaving the treatment facility is summarized in Table 5-7. The trend was similar to what was seen with the lead concentrations, as seen in Figure 5-4.

Samples Cold #1 and Cold #2 both had the highest copper concentrations of the collected samples, in all sampling areas, during both sampling sessions. This suggests that the interior plumbing system is the primary source of copper in the GVRD drinking water. This is supported by other research, which has suggested that copper tubing inside houses is the most significant source of copper in drinking water (AWWARF, 1996; Hong and Macauley, 1997).

The Cold #3 sample collected in all 4-source areas, during both sampling sessions, had the lowest copper concentrations. The difference in the observed copper concentrations in the Cold #3 sample, compared to the copper concentration in the water leaving the different treatment facilities, shows that the water accumulates copper as it travels through the distribution system (Table5-7). The accumulation of copper in the distribution system could be attributed to both the use of copper service connections in the municipal distribution systems within the GVRD, as well as the significant use of copper tubing in interior plumbing systems (Utilities Managers of Municipalities within the GVRD, pers.comm; Neff *et al*, 1987; AWWARF, 1996).

On average, the length of copper tubing from the main distribution line into the house is greater than any service connection used in the distribution system. However, in terms of surface area, the diameter of the service connections is significantly greater than the diameter of the copper tubing used in the interior of the house. Therefore, the copper

collected in the water as it travels from the source to the individual homes, is as likely to be as a result of exposure to the large surface areas of the copper service connections, as it is to the exposure to the long length of copper tubing inside the home (Jim Atwater, Department of Civil Engineering, UBC, Vancouver, BC pers. comm).

Copper concentrations in the Hot #1 samples collected during both sampling sessions, were greater than in the Cold #3 sample, however significantly less than in the Cold #1 and Cold #2 samples (Table 5-7). Although the Hot #1 sample was collected differently during both sampling session, the results suggests that both the hot water tank, and the tubing connecting the hot water tank and the faucet, can contribute a small amount of copper to the drinking water.

Most hot water tanks used in the GVRD are glass lined, and have a small amount of copper tubing, leading into and out of the hot water tank, that can be exposed to the water inside the hot water tank (Walter, Service department, Point Gray Plumbing and Heating Ltd., Vancouver, B.C., pers. comm.). This would allow for the potential of some copper dissolution in to the water and might explain the slightly elevated copper levels in the Hot #1 sample collected during the first sampling session, compared to the Cold #3 samples. Most tubing used to connect the hot water tank to the faucet is also made of copper, and would provide a source of copper to explain the copper concentration in the Hot #1 sample collected during the second sampling session.

| Source | Treatment | Col        | d #1 | Col        | d #2        | Col       | ld #3  | Ho         | t #1 |
|--------|-----------|------------|------|------------|-------------|-----------|--------|------------|------|
| Water  | Facility  | (mg        | g/L) | (mg        | g/L)        | (m        | g/L)   | (m)        | g/L) |
|        | (mg/L)    | <b>S</b> 1 | S2   | <b>S</b> 1 | . <b>S2</b> | <b>S1</b> | S2     | <b>S</b> 1 | S2   |
| Cap    | < 0.02    | 0.93       | 0.86 | 1.35       | 1.26        | 0.13      | 0.28   | 0.47       | 0.77 |
| Sey    | < 0.02    | 0.53       | 0.51 | 0.69       | 0.68        | 0.11      | 0.16   | 0.28       | 0.30 |
| Coq    | <0.02     | 0.38       | 0.47 | 0.51       | 0.57        | 0.13      | 0.10   | 0.19       | 0.23 |
| New    | <0.02     | 0.18       | 0.16 | 0.21       | 0.16        | 0.03      | <0.03* | 0.07       | 0.08 |

 Table 5-7 Copper Concentration in Collected Samples and Treated Water

Average in below the value set as the detection limit (0.03 mg/L)



Figure 5-4 Average Copper Concentrations in the Collected Samples<sup>\*</sup>

A) Samples collected during the first sampling session



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B) Samples collected during the second sampling session

\* All samples with values below the detection limit were assigned a value of half the detection limit for calculations

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# 5.2.3 Source of Zinc

The measured zinc concentration in the collected samples, along with the zinc concentrations in the water after leaving the treatment facility is summarized in Table 5-8. The trend seen in terms of zinc concentrations in the various samples collected is different from both the copper and the lead trends, as seen in Figure 5-5.

The only sample that contained a significant amount of zinc was sample Cold #1. This suggests that the major source of zinc in drinking water is the faucet, most of which are predominantly made of a copper/brass alloy, (Dan Corrigan, Technical support, Delta Faucet, Canada, pers. comm.; Ivaless Santana, Sales assistant, American Standard, Canada, pers. comm.). The brass portion of the faucet can contain a significant amount of zinc, and has subsequently been shown to be the predominant source of zinc in drinking water (Schock, 1989; Singh and Mavinic 1991). The only source of zinc in the remainder of the interior plumbing system is the shut off valves, which are mostly made of brass (Jayson Leonard, Plumbing Supplies Department, Home Depot, Vancouver BC, pers.comm.).

There is virtually no zinc in the water coming from the distribution system, and the zinc levels measured in most Cold #3 samples were similar to the zinc concentration of the water leaving the treatment facility (Table 5-8). Since there is nothing to suggest that there is any source of zinc in either the GVRD transmission system or the various municipalities' distribution systems, it is not surprising that the amount of zinc in the water reaching the homes is negligible (Figure 5-5).

Hot #1 samples collected during the first sampling session had zinc concentrations that were also similar to the treated source water, suggesting that the hot

water tank doesn't contribute any zinc to the drinking water (Table 5-8). Hot #1 collected during the second sampling session, had average zinc concentrations that were greater than the treated source water (Table 5-8). This is most likely due to zinc leaching out of brass shut of valves between the hot water tank and the faucet. In addition, brass faucets or fixtures might also be contributing to the zinc concentrations in this sample. It should also be noted that, although the Hot #1 samples collected during the second sampling session did contain higher concentrations of zinc than the treated source water, the concentrations were significantly lower than the Cold #1 (Table 5-8).

| Source<br>Water | Treatment | Cold #1    |           | Cold #2   |      | Cold #3    |        | Hot #1     |      |
|-----------------|-----------|------------|-----------|-----------|------|------------|--------|------------|------|
|                 | Facility  | (mg/L)     |           | (mg/L)    |      | (mg/L)     |        | (mg/L)     |      |
|                 | (mg/L)    | <b>S</b> 1 | <b>S2</b> | <b>S1</b> | S2   | <b>S</b> 1 | S2     | <b>S</b> 1 | S2   |
| Cap             | < 0.01    | 0.77       | 0.94      | 0.07      | 0.09 | < 0.01*    | 0.01   | 0.04       | 0.05 |
| Sey             | < 0.01    | 0.60       | 0.61      | 0.05      | 0.05 | < 0.01     | 0.01   | 0.01       | 0.03 |
| Coq             | < 0.01    | 0.38       | 0.46      | 0.04      | 0.04 | 0.01       | 0.01   | 0.01       | 0.04 |
| New             | < 0.01    | 0.11       | 0.12      | 0.01      | 0.02 | < 0.01     | < 0.01 | < 0.01     | 0.01 |

**Table 5-8 Zinc Concentration in Collected Samples and Treated Water** 

\*Average is below the value set as the detection limit (0.01 mg/L)


Figure 5-5 Average Zinc Concentrations in the Collected Samples\*

Sample

A) Samples collected during the first sampling session



# □ Capilano Seymour Coquitlam Newton

B) Samples collected during the second sampling session

\* All samples with values below the detection limit were assigned a value of half the detection limit for calculations

## 5.3 Effect of Treated Source Water on Metal Concentration in Drinking Water

The effect of targeting various pH levels on the observed metal concentration in the drinking water of the GVRD was investigated by collecting samples of water from various locations around the GVRD. The highest metal concentrations in GVRD drinking waters are associated with waters that have sat stagnant in the household plumbing system, thus allowing metals to leach from the plumbing material, into the drinking water (samples Cold #1 and Cold #2). As the water travels from the various treatment facilities, to the GVRD residences, and through the interior plumbing system, there is no observable accumulation of metals, with the exception of copper (sample Cold #3). Consequently, most figures below will only show the calculated metal concentrations in the calculated first-litre flush, and how the results from the different sources compare.

From an environmental perspective, corrosion of lead and zinc in the water distribution system isn't a major source of these metals to the municipal wastewater treatment plants (WWTP), and consequently this won't be discussed. The corrosion of copper in the water distribution system, however, has shown to be the predominant source of copper in the municipal WWTP influent. This has both environmental and economic implications, both of which will be discussed.

Although disinfection by-products (DBP) weren't looked at in this study, other studies have suggested that there may be a link between pH levels and the formation of DBPs (Kim et al, 2002; Chang et al, 2000). In addition, the trihalomethane (THM) and haloacetic acid (HAA) concentration in samples collected, over the past couple of years in the GVRD water distribution system, have been significantly greater in samples collected in the Newton distribution area, which also has the highest pH associated with

it, compared to samples collected in the other three distribution areas, which have lower pH values associated with them (Judy Smith, Water and Microbiology Quality Control Division, GVRD, Burnaby BC, pers. Comm.). This suggest that in the GVRD water distribution system, pH might be a factor in the formation of DBP's, specifically THM's and HAA's.

Although all samples collected have been in compliance with the current Canadian Drinking Water Quality Guidelines, which is a maximum concentration level (MCL) of 100 $\mu$ g/L for THM's, the USEPA is considering lowering the allowable THM and HAA concentrations from 80 and 60  $\mu$ g/L to 40 and 30  $\mu$ g/L respectively (AWWA and ASCE, 1998). Consequently, the DBP concentration in samples collected in the Newton area over the past couples of years would exceed these new MCL levels for both THM's and HAA's. Therefore targeting a pH greater than the current pH of 7 in the Seymour and Coquitlam water supply may have negative impacts on the quality of the distributed water.

## 5.3.1 Lead

The average lead concentration, in the calculated first-litre flush, for each of the four treated sources sampled is summarized in Table 5-9. There is no trend seen with respect to lead concentrations in the distributed water from all 4 sources, as seen in Figure 5-6. The average calculated first-litre flush concentration is similar in all water coming from all four different source areas, and statistically, there is no difference in the observed lead concentrations between all four treated sources (statistical analysis data can be found in Appendix G).

All source waters are similar in their water quality after treatment, except for the pH and alkalinity, which are adjusted differently for the various water sources (Appendix A). Capilano has the lowest pH at 6.1, while Seymour and Coquitlam have a pH of 6.8 and 6.9 respectively, and Newton has a pH of 8.1 (GVRD, 2003). The results of the lead analysis suggests that increasing the pH of the water from a pH of 6, to a pH of 7, or 8, doesn't affect the amount of corrosion control obtained with respect to lead. This is supported by other research, which concluded that, in waters with low alkalinity, such as the GVRD treated source waters, the pH needs to be adjusted to above 8.4 before any significant reduction in the amount of lead in the water at the tap is observed (Sheiham, 1981; Lee, 1989; Schock, 1989; Reiber, 1991; Dodrill and Edwards 1994). However, any benefit achieved as a result of elevating the pH to above 8.4 in the GVRD water distribution system, would only be seen in the first-litre flush samples, as these were the only samples that had lead levels above the detection limit.

Hot #1 samples collected suggest that the contribution of lead made to the observed drinking water sample as a result of the hot water tank or hot water pipes is very minimal and the same trend is seen in samples collected in all 4-source areas.

During the first sampling session, the Hot #1 sample would have represented the amount of lead in the drinking water as a result of the hot water tank, and the pipes leading into the hot water tank. Analysis of these results indicates that the hot water tank doesn't contribute any lead to the drinking water.

The Hot #1 samples collected during the second sampling session were representative of the pipes connecting the hot water tank and the faucet. Analysis of these results indicates that the pipes don't contribute any lead to the drinking water either.

|           | Samples (mg/L)                       |      |            |           |           |           |  |  |
|-----------|--------------------------------------|------|------------|-----------|-----------|-----------|--|--|
| Source    | Source 1 <sup>st</sup> Litre Cold #3 |      | d #3       | Hot #1    |           |           |  |  |
|           | <b>S</b> 1                           | S2   | <b>S</b> 1 | <b>S2</b> | <b>S1</b> | <b>S2</b> |  |  |
| Capilano  | 0.008                                | NDV* | NDV        | NDV       | NDV       | NDV       |  |  |
| Seymour   | 0.008                                | NDV  | NDV        | NDV       | NDV       | NDV       |  |  |
| Coquitlam | 0.005                                | NDV  | NDV        | NDV       | NDV       | NDV       |  |  |
| Newton    | 0.006                                | NDV  | NDV        | NDV       | NDV       | NDV       |  |  |

 Table 5-9 Average Lead Concentrations in Collected Samples

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\*NDV = Non-Detect Value, average below the value set as the detection limit

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Figure 5-6 Average Lead Concentration in the Calculated First-Litre Flush

A) Samples collected during the first sampling session



B) Samples collected during the second sampling session

## 5.3.1.1 Plumbing Age

Theoretically, older houses will have a greater lead content in their water because of the use of lead tin solder, which was prohibited in 1990 (Canadian Commission of Building and Fire Codes, 1995). To determine whether or not restricting the use of lead based material in household plumbing systems had any effect on the observed lead concentration in the collected samples, all source areas were also divided into two subcategories, old and new. Houses were considered old if they were built before 1990, while houses considered to be new were either built after 1990, or had major plumbing work done, which would involve replacing lead tin solder, after 1990. The lead concentration measured in samples Cold #1 and Cold #2, in both old and new houses is shown in Figure 5-7.

As expected, older houses had higher lead concentration in both Cold #1 and Cold #2 samples compared to newer houses. This suggests that in time, as older plumbing systems are repaired or replaced, there should be a reduction in the amount of lead being released at the tap, as there should be fewer sources of lead within the GVRD distribution system. Most new plumbing systems are made up of copper tubing that is soldered together with a 95/5 tin:antimony mixture. This is a lead free solder and will therefore not introduce any lead into the system, leaving only the faucet as a potential source of lead (John McNeil, Plumber, TDH plumbing, Port Moody, BC, pers. comm.).

**Figure 5-7** Average Lead Concentration in Old and New Houes

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# 5.3.2 Copper

The average copper concentration in the collected samples, for each of the 4 sources sampled, is summarized in Table 5-10. Copper concentrations, in the calculated first-litre flush, appeared to be influenced by the source water treatment, as seen in Figure 5-8. The different treated source waters correspond with different pH and alkalinity levels, both of which have been shown to significantly impact the amount of corrosion occurring in the distribution system (Reiber, 1989; Broo, 1997; Hong and Macauley, 1997; Boulay and Edwards, 2001).

The differences observed in terms of the copper concentration in the calculated first-litre flush from each of the four areas could be attributed to either the different corrosion control measures of each of the source waters or differences in the type of plumbing material used in the houses representing the four areas. All participants were asked to indicate the predominant plumbing material used in their plumbing systems, if known, so that it could be determined if the plumbing material used was different in the 4-source areas and consequently affecting the results (Appendix B). Most participants were able to answer the question and the predominant material used, in all 4-source areas was copper. Accordingly, differences in the observed copper concentration between source areas are most likely a reflection of the different pH and alkalinity levels of the treated water in the distribution system and not the type of plumbing material used.

Water samples taken in the Capilano distribution area had the most copper in the calculated first-litre flush, averaging 1.33 and 1.24 mg/L for each of the two sampling sessions; this also corresponds to the water source with the lowest pH and alkalinity levels. The Seymour and Coquitlam distribution systems, both of which target a pH close

to 7, had averages of 0.68 and 0.51 mg/L during the first sampling session and 0.67 and 0.56 mg/L respectively, in the second sampling session. Water samples taken from the Newton distribution system, which has the highest pH and alkalinity adjustment, had the lowest copper concentrations, averaging 0.21 and 0.16 mg/L during the first and second sampling session.

These results suggest that waters treated to target higher pH and alkalinity levels will result in lower copper corrosion rates or interior plumbing systems. This could potentially result in a significant amount of financial savings for homeowners, who will not have to replace their in-house copper pipes as often. However, increasing the pH of GVRD water to 8 as opposed to 7 will be a financial burden on the GVRD, as more soda ash will need to be added to the water, resulting in greater chemical costs for the water system.

|           | Samples (mg/L)        |           |      |      |            |      |  |  |
|-----------|-----------------------|-----------|------|------|------------|------|--|--|
| Source    | 1 <sup>st</sup> Litre |           | Cold | l #3 | Hot #1     |      |  |  |
|           | <b>S1</b>             | <b>S2</b> | S1   | S2   | <b>S</b> 1 | S2   |  |  |
| Capilano  | 1.33                  | 1.24      | 0.13 | 0.28 | 0.47       | 0.77 |  |  |
| Seymour   | 0.68                  | 0.67      | 0.11 | 0.16 | 0.28       | 0.30 |  |  |
| Coquitlam | 0.51                  | 0.56      | 0.13 | 0.10 | 0.19       | 0.23 |  |  |
| Newton    | 0.21                  | 0.16      | 0.03 | NDV* | 0.07       | 0.08 |  |  |

 Table 5-10 Average Copper Concentrations in the Collected Samples

NDV = Non-Detect Value, average below the value set as the detection limit



Figure 5-8 Average Copper Concentration in Ca;cu;ated First-Litre Flush

Source

A) Samples collected during the first sampling session



B) Samples collected during the second sampling session

The association between pH values and copper concentrations in the calculated first-litre flush can be seen in Figure 5-9. The manner in which the copper concentrations in the calculated first-litre flush, of the samples collected, was influenced by alkalinity levels can be seen in Figure 5-10. Both pH and alkalinity levels have a similar effect on the observed copper concentrations, with lower pH and alkalinity levels resulting in higher copper concentrations. This is supported by other research that found that lower pH values and alkalinity levels correspond to higher corrosion rates and greater by-product release (Reiber, 1989; Broo, 1997; Hong and Macauley, 1997; Boulay and Edwards, 2001).







Figure 5-4 Measured Alkalinity Levels and Copper Concentration in the Calculated First-Litre Flush

Copper concentrations in the Cold #3 sample also appeared to be influenced, to a lesser extent, by the different source water treatment, as seen in Figure 5-11. There was no observable trend in the copper concentrations of the collected samples in the Capilano, Seymour and Coquitlam distribution areas during the first sampling session, ranging from 0.12 mg/L to 0.13 mg/L (Table 5-10). The Cold #3 sample collected in Newton, however, had significantly less copper than the other three sources, during the first sampling session, averaging 0.03 mg/L. During the second sampling session, Capilano had the

highest copper concentration, averaging 0.28mg/L, while Seymour had 0.16 mg/L and Coquitlam averaged 0.08 mg/L. Although there was a trend, with respect to the copper concentrations, the differences between these three differently treated sources, was not statistically significant. Newton again had the lowest copper concentration, averaging 0.02 mg/L, and this difference was statistically significant compared to the other three sources (Figure 5-11).

The results of the copper analysis of Cold #3 samples indicates that either the different pH and alkalinity's of the source waters, after treatment, is affecting the dissolution of copper into the drinking water as it travels through the distribution network, or that each treated source water comes into contact with different amounts of copper as it travels through the distribution system. However, because there is nothing to suggest that there is a significant difference in the amount of copper used in each of the distribution systems, the differences in the observed copper concentrations are most likely due to the different pH and alkalinity adjustments of the four source waters.

Although the copper concentrations in Cold #3 samples were low, and therefore pose no potential health concern for humans, it could have significant environmental consequences. This is because copper, although an essential nutrient can also be toxic to aquatic organisms if present in excess amounts.

It has been shown that the majority of the copper reaching wastewater treatment plants can be a direct result of copper corrosion by-products being released into drinking water, and subsequently flushed down the drain into the sewer systems (Broo *et al*, 1997). The Cold #3 sample is characteristic of most of the water coming out at the tap, and therefore can potentially be the source of the majority of the copper, in terms of mass

loading, going to the municipal wastewater treatment plants (WWTP) (Table 5-11). Comparing the copper concentration in Cold #3 with the average copper concentration in the influent of the WWTP, it can be seen in Table 5-12, that flushed, running water is the predominant source of copper in the WWTP influent. Since copper can be toxic to aquatic species, these concentrations may impact the receiving waters of the GVRD WWTP. Based on these results, water treated to target the highest pH value, offers the lowest copper concentrations in flushed running water, and may subsequently result in less copper going to the GVRD WWTP.

Table 5-11 Mass Loading of Copper in GVRD Drinking Water per Day<sup>†</sup>

| Source  | Cold #1*  |           | Cold #2*   |      | Hot #1*    |    | Cold #3 <sup>‡</sup> |       |
|---------|-----------|-----------|------------|------|------------|----|----------------------|-------|
| Water   | (ug)      |           | (ug)       |      | (ug)       |    | (ug per capita)      |       |
| ,, ater | <b>S1</b> | <b>S2</b> | <b>S</b> 1 | S2   | <b>S</b> 1 | S2 | <b>S1</b>            | S2    |
| Cap     | 47        | 43        | 1283       | 1197 | 59         | 96 | 43680                | 94080 |
| Sey     | 27        | 26        | 656        | 646  | 35         | 38 | 36960                | 53760 |
| Coq     | 19        | 24        | 485        | 542  | 24         | 29 | 43680                | 33600 |
| New     | 9         | 8         | 200        | 152  | 9          | 10 | 10080                | 5040  |

<sup>†</sup>All ND's were assigned a value of half the detection limit in calculating the mass loading

<sup>‡</sup> Mass loading calculations for Cold #3 were based on Average Daily Per Capita Water Consumption in the GVRD, 336 L per day per person. (GVRD, 2003)

\*Mass loading calculations for these samples were based on the volume of the sample collected, and are not per capita, but per day.

### Copper Concentrations in Collected Cold #3 Samples Compared to **Table 5-12** Influent Copper Concentrations for Greater Vancouver Regional **District Wastewater Treatment Plants**

| GVRD<br>WWTP            | Influent Copper<br>Conc. (mg/L) | GVRD Source<br>Water | Average Copper Conc. In Cold<br>#3 (mg/L) |      |  |
|-------------------------|---------------------------------|----------------------|---|------|--|
|                         |                                 |                      | SS1                                       | SS2  |  |
| Lions Gate <sup>1</sup> | 0.21                            | Capilano             | 0.13                                      | 0.28 |  |
| Iona <sup>2</sup>       | 0.15                            | Seymour              | 0.11                                      | 0.16 |  |
| Annacis <sup>3</sup>    | 0.17                            | Coquitlam            | 0.13                                      | 0.10 |  |
| Lulu <sup>4</sup>       | 0.22                            | Newton               | 0.03                                      | 0.02 |  |

<sup>1</sup>Lions Gate WWTP influent from Capilano

<sup>2</sup>Iona WWTP influent from Capilano and Seymour <sup>3</sup>Annacis WWTP influent from Seymour, Coquitlam and Newton

<sup>4</sup>Lulu WWTP Influent from Newton



Figure 5-11 Average Copper Concentration in Cold #3 Samples

A) Samples collected during the first sampling session



B) Samples collected during the second sampling session

The copper concentration in the Hot #1 sample appeared to be influenced by the treated source water as well (Figure 5-12). The Hot #1 sample was taken differently during each of the 2 sampling sessions. During the first sampling session, the Hot #1 sample represented the amount of copper in the drinking water as a result of the hot water tank. The copper concentration in these samples was greatest in those collected in the Capilano area, while the Newton area had the lowest copper concentrations (Table 5-10). This trend follows the expected change in copper concentrations with the different pH and alkalinity levels of the various treated source waters.

During the second sampling session, the same trend was observed, with respect to the highest copper concentrations being found in the water with the lowest pH, Capilano, and the lowest copper concentrations were in the source water with the highest pH, Newton. However, during the second sampling session, the manner in which the Hot #1 sample was taken was different, and therefore different factors might have influenced the results. The elevated copper concentrations in these samples is most likely due to the fact that the water was left sitting in copper tubing (which connects the hot water tank to the faucet) overnight.



Figure 5-12 Average Copper Concentration in Hot #1 Samples

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A) Samples collected during the first sampling session



⊡ Capilano ⊞ Seymour ⊠ Coquitlam ⊟ Newton

B) Samples collected during the second sampling session

Typically, it would be expected that newer houses, less than 5 years old, would have greater copper concentrations in their water than older houses, greater than 5 years old. This is because it takes time to develop a protective film on the surface of copper tubing, especially in water that is as soft as the GVRD water (Reiber, 1989; Lagos, 2001). However, in this study, there weren't enough new homes to divide the participants up in groups based on age, and therefore it isn't possible to comment on whether or not the age of the house played a role in the observed copper concentrations. Had there been more new homes sampled in the study, the observed copper concentration in the drinking water might have been significantly greater.

## 5.3.3 Zinc

The average zinc concentration in the collected samples, for each of the 4 sources sampled, is summarized in Table 5-13. The effect of source water treatment on the concentration of zinc in the calculated first-litre flush was similar to the trend seen with both lead and copper concentrations (Figure 5-13). Capilano had the highest zinc concentrations in the calculated first-litre flush followed by Seymour and Coquitlam, while Newton had the lowest. This trend is consistent with adjustments in the pH and alkalinity levels of the source waters. Statistically, however, there was no difference between Capilano, Seymour and Coquitlam zinc concentrations. The difference between these three sources and the zinc concentration in the Newton sample, however, was statistically significant.

The Hot #1 samples collected during the first sampling session represented the amount of zinc that may be in the drinking water as a result of the hot water tank. All

samples taken had similar zinc concentrations as the water leaving the treatment facility. This suggests that either the source water treatment has no affect on the amount of zinc entering the drinking water, or else there is no source of zinc in the plumbing system.

During the second sampling session, the zinc concentrations in all of the Hot #1 samples collected were similar to the zinc concentration in the water as it leaves the treatment facility at the source. This suggests that the source treatment of the water has no significant effect on the amount of zinc corrosion occurring in the distribution system.

|           | Samples (mg/L)        |      |            |      |                 |      |  |  |
|-----------|-----------------------|------|------------|------|-----------------|------|--|--|
| Source    | 1 <sup>st</sup> Litre |      | Cold #3    |      | Hot #1          |      |  |  |
|           | <b>S</b> 1            | S2   | <b>S</b> 1 | S2   | <b>S1</b>       | S2   |  |  |
| Capilano  | 0.11                  | 0.13 | ND*        | 0.01 | 0.04            | 0.05 |  |  |
| Seymour   | 0.08                  | 0.08 | ND*        | 0.01 | 0.01            | 0.03 |  |  |
| Coquitlam | 0.06                  | 0.06 | 0.01       | 0.01 | 0.01            | 0.04 |  |  |
| Newton    | 0.02                  | 0.02 | ND*        | ND*  | ND <sup>*</sup> | 0.01 |  |  |

 Table 5-13 Average Zinc Concentrations in the Collected Samples

\*ND = Not Detected, Below the detection limit



Figure 5-13 Average Zinc Concentration in the Calculated First-Litre Flush

Source

A) Samples collected during the first sampling session





B) Samples collected during the second sampling session

# 5.4 Effect of Using Ozone or Chlorine as a Primary Disinfectant on the Metal Concentration in GVRD Drinking Water

The focus of the study was to investigate various factors responsible for corrosion in the GVRD, including the potential role that primary disinfectants might play in enhancing corrosion in the distribution system. Treated Seymour and Coquitlam water are very similar in terms of their water quality parameters, with the exception of the dissolved oxygen concentration Water coming from the Coquitlam watershed, is treated with ozone as a primary disinfectant, as opposed to Seymour water which is treated with chlorine. Consequently, the dissolved oxygen concentration of the treated Coquitlam water is greater than the dissolved oxygen level of treated Seymour water, therefore any observed differences in the metal concentrations can possibly be attributed to the different dissolved oxygen levels of the two treated waters, as a result of the primary disinfectants used. Chlorine and oxygen are both strong oxidants, and can potentially enhance the aggressiveness of the water, so the observed metal concentrations in samples collected from each of the two watersheds was compared to see if there were any significant differences (Hong and Macauley, 1997).

Much of the recent research has stated that chlorine is a much stronger oxidant than oxygen, even when present at levels as low as 0.1 mg/L, chlorine will often be the dominant oxidant in the system (Woodside *et al*, 1966; Atlas *et al*, 1982; Fuji *et al*, 1984; Reiber, 1989; Edwards *et al*, 1994; Hong and Macauley, 1998; Bremer, 2001). Since chlorine is used as a secondary disinfectant throughout the GVRD water distribution system, combined with the fact that all GVRD water is naturally close to saturation in terms of oxygen levels, the potential effect of elevated oxygen levels, as a result of using

ozone as a primary disinfectant, may not be observable in this system. Therefore, even if the use of either ozone or chlorine as a primary disinfectant could potentially enhance the corrosion process in the distribution system, it might not be possible to determine since chlorine is used as a secondary disinfectant in the system.

## 5.4.1 Lead

The average lead concentration in each of the samples collected in both the Seymour and the Coquitlam distribution areas are shown in Figure 5-14. The average lead concentration for all samples collected in the 2 areas can be seen in Table 5-5, with averages ranging from <0.005 to 0.008 mg/L. There was no significant difference in the observed lead concentrations in either the calculated first-litre flush, Cold #3, or Hot #1 samples collected in the Seymour and Coquitlam areas during both sampling sessions. These results suggest that there is little difference in the amount of lead in the drinking water, as a result of the primary disinfectant used.



# Figure 5-14 Average Lead Concentration in Samples Collected in the Seymour and Coquitlam Distribution Areas

E) Hot #1, first sampling session

F) Hot #1, second sampling session

## 5.4.2 Copper

The average copper concentration in each of the samples collected in both the Seymour and the Coquitlam distribution areas are shown in Figure 5-15. The average copper concentration for all samples collected in the 2 areas can be seen in Table 5-5, with averages ranging from <0.03 to 1.33 mg/L. There was no significant difference in the observed copper concentrations in either the calculated first-litre flush, Cold #3, or Hot #1 samples collected in the Seymour and Coquitlam areas during both sampling sessions. These results suggest that there is little difference in the amount of copper in the drinking water, as a result of the primary disinfectant used.

### 5.4.3 Zinc

The average zinc concentration in each of the samples collected in both the Seymour and Coquitlam distribution areas are shown in Figure 5-16. The average zinc concentration for all samples collected can be seen in Table 5-5, with averages ranging from <0.01 to 0.13 mg/L. There were no observed differences in the amount of zinc in the drinking water from samples collected in either the Seymour or the Coquitlam distribution areas. Since the only significant difference in the two water sources is the primary disinfectant used, the results suggests that the use of different primary disinfectants has no significant impact on the amount of zinc released into the drinking water.



# Figure 5-15 Average Copper Concentration in Samples Collected in the Seymour and Coquitlam Distribution Areas



F) Hot #1, second sampling session



Figure 5-16 Average Zinc Concentration in Samples Collected in the Seymour and Coquitlam Distribution Areas

E) Hot #1, first sampling session

F) Hot #1, second sampling session

## 5.5 Effect of Temperature on Metal Concentration in GVRD Drinking Water

Adjusting the pH of any water system can be expensive, and therefore, if there are times during the year that it is not needed, it would be economically beneficial to reduce the treatment of the water. In order to determine if the changes in water temperature, over the course of the year, had a significant effect on the observed metal concentration, samples were collected at two different times of the year. The range of temperature values, for the water samples collected during the first sampling session was 12-14°C, while the range of temperature values, for water samples collected during the second sampling session was 5-6°C (Judy Smith, Quality Control Department, GVRD, Vancouver, BC pers.comm..)

The average metal concentration for each of the samples collected in all 4-source areas during both sampling sessions is displayed in Table 5-5 above. Overall, there was little difference in the metal concentrations in any of the 4-source areas between samples taken during the warmest month of the year, and those taken during the coldest month of the year.

The only trend seen, with respect to differences in concentration in samples collected during the two sampling sessions, was in the calculated first-litre flush. Cold #3 samples collected during both sampling sessions were similar, and it wasn't possible to compare the Hot #1 samples taken at the two different times of the year, as they were each collected differently in both sampling sessions. Therefore, the figures shown will only contain the calculated first-litre flush concentrations for temperature comparisons.

The Hot #1 samples, collected during the second sampling session, were compared to the Cold #2 sample collected, to see if the initial temperature of the water had any significant effect on the observed metal concentration in the samples. The Cold #2 and Hot #1 samples could be compared because both involved sampling water that had been allowed to sit, stagnant, in the interior pipes for the duration of a night. The difference between these two samples was the initial temperature of the water in the pipes at the beginning of the stagnation time. It was not possible to make the sampling technique for both Cold #2 and Hot #1 identical, as one had to be sampled before the other. Consequently, the Cold #2 sample might contain some residual water that had been in the faucet overnight, as opposed to the interior pipes of the house, while the Hot #1 sample might contain some of the residual Cold #3 sample, left in the faucet prior to collecting the Hot #1. However, because the potential volumes of these residual waters in the faucet are significantly smaller than the volume of the sample taken, the concentrations in the two samples can be compared, and any differences observed discussed.

# 5.5.1 Lead

The trend seen in Figure 5-17 is that the lead concentration in the calculated firstlitre flush was greater in the samples collected in the first sampling session, which also corresponds to the warmest months. This trend was seen to some degree, in samples collected from all 4-source areas. Statistically, however, there was no difference in the observed metal concentrations from the two sampling sessions, as shown by the error bars on the graphs (Appendix G). This is most likely due to the fact that the lead

concentrations are so low, below  $10\mu g/L$ , making the standard error calculated very sensitive to small changes. Since the standard error is used to determine the statistical significance of the two means, the results do not appear to be statistically significant.

Figure 5-17 Difference in Average Lead Concentrations in the Collected Samples



### 5.5.1.1 Effect of Initial Water Temperature on Observed Metal Concentrations

Cold #2 and Hot #1 samples collected during the second sampling session were compared to see if there was a difference in the metal concentration in the drinking water, depending on whether cold or hot water were left sitting stagnant in the pipes for the duration of a night. The Cold #2 sample had a higher lead concentration than the Hot #1 samples collected in the Capilano and Seymour distribution areas, while samples collected in the Coquitlam distribution area had higher lead concentrations in the Hot #1 sample compared to the Cold #2 sample. Samples collected in the Newton distribution area had similar lead concentrations in the Hot #1 and Cold #2 samples collected. Consequently, there was no trend with respect to the lead levels in the Cold #2 and Hot #1 samples collected, as seen in Figure 5-18.

The potential effect of temperature on the rate of corrosion is a factor with many arguments. Some studies have suggested that increased temperature can result in an increased corrosion rate, based on kinetics (Boulay and Edwards, 2001; Clement *et al*, 2000). Other studies have suggested that higher temperatures might mean lower corrosion rates because of the lower saturation values for dissolved gasses. Since the most predominant oxidizing agents are oxygen and chlorine, both of which are dissolved gasses, higher temperatures would result in lower concentration values. In addition, elevated temperatures often promote the precipitation of calcium and magnesium carbonates, which can form a protective film, and decrease the rate of corrosion. Since there is no trend with respect to the lead concentrations in the Cold #2 and Hot #1 samples, no conclusions can be drawn about the effect of temperature on the corrosion of lead in the GVRD drinking water system.

Figure 5-18 Average Lead Concentration in Cold #2 and Hot #1



D) Newton

C) Coquitlam

# 5.5.2 Copper

The difference in the copper concentration in samples collected in all four of the source areas, during both sampling sessions, was not significant, as seen in Figure 5-19. All four treated source waters had similar average copper concentration in the samples collected during sampling session 1, the warmest time of the year, compared to samples collected during the second sampling session, the coldest time of the year. This suggests that temperature fluctuations in the GVRD water don't affect the amount of copper leaching into the drinking water. This does not mean that the temperature doesn't affect the corrosion rate, just simply that the change in temperature with in the GVRD water distribution system isn't significant enough to affect the corrosion rate.

## 5.5.2.1 Effect of Initial Water Temperature on Observed Metal Concentrations

Hot #1 samples collected during the second sampling session were compared to the Cold #2 samples collected, to see whether or not the elevated temperature of the water would influence the amount of copper in the water, after a night of sitting stagnant in the household plumbing system (Figure 5-20).

In samples collected from all four treated source waters, the copper concentration was greatest in the Cold #2 sample (Figure 5-20). This suggests that although both samples contained water which had sat stagnant in the interior plumbing system, the water sampled in the Hot #1 sample was less corrosive than the water sampled in the Cold #2 sample. This might be due to the hot water pipes being better able to form a protective film on the copper tubing as opposed to the cold water as it has been shown that carbonates, such as calcium and magnesium carbonate are less soluble in hotter waters, and will therefore precipitate out of solution contributing to the formation of a

protective film on the copper tubing (AWWARF, 1996; Mays, 2000). The levels of carbonate needed in the water to allow for the precipitation of a protective film are much greater than what is normally found in treated GVRD water, and therefore this is most likely not responsible for the observed trend. Alternatively, the lower copper concentrations in the Hot #1 sample might be attributed to the decrease in the concentration of oxidizing agents in the water as a result of lower saturation concentration for dissolved gasses in hot water compared to cold water, making the water less corrosive.

The observed differences are not statistically significant, however they do suggest that the initial elevated temperature of the Hot#1 sample doesn't increase the amount of copper in the drinking water at the tap.
Figure 5-19 Difference in Average Copper Concentrations in the Collected Samples

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Figure 5-20 Average Copper Concentration in Cold #2 and Hot #1



#### 5.5.3 Zinc

The difference in the zinc concentrations in samples collected from all four treated source waters, during both sampling sessions, isn't significant. There was little difference in the average zinc concentrations in each of the samples collected during both sampling sessions, as seen in Figure 5-21.

The average zinc concentration in the samples collected during sampling session 1, the warmest time of the year, are very similar to the average zinc concentrations in the samples collected during the second sampling session, the coldest time of the year. This suggests that temperature fluctuations in the GVRD water don't affect the amount of zinc leaching into the drinking water. This does not mean that the temperature doesn't affect the corrosion rate, just simply that the change in temperature within the GVRD water distribution system might not be significant enough to affect the corrosion rate.

## 5.5.3.1 Effect of Initial Water Temperature on Observed Metal Concentrations

Hot #1 samples collected during the second sampling session were compared to the Cold #2 samples collected, to see whether or not the elevated temperature of the water would influence the amount of zinc in the water, after a night of sitting stagnant in the household plumbing system (Figure 5-22).

In samples collected from all four treated source waters, the zinc concentration was greatest in the Cold #2 sample (Figure 5-22). This suggests that although both samples contained water that had sat stagnant in the interior plumbing system, the water sampled in the Hot #1 sample was less corrosive than the water sampled in the Cold #2 sample. This might be due to the hot water pipes being better able to form a protective

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film, as opposed to the cold water. It has been shown that carbonates, such as calcium and magnesium carbonate are less soluble in hotter waters, and will therefore precipitate out of solution, which could contribute to a protective film on the copper tubing (AWWARF, 1996; Mays, 2000). The levels of carbonate needed in the water to allow for the precipitation of a protective film are much greater than what is normally found in treated GVRD water, and therefore this is most likely not responsible for the observed trend. Alternatively, the lower zinc concentrations in the Hot #1 sample can be attributed to the decrease in the concentration of oxidizing agents in the water as a result of lower saturation concentration for dissolved gasses in hot water compared to cold water, making the water less corrosive.

The observed differences are not statistically significant, however they do suggest that the initial elevated temperature of the Hot#1 sample results in a decrease in the zinc concentration in the sample, which might be attributed to the lower concentrations of oxidizing agents in water with higher temperatures, making it less corrosive.



Figure 5-21 Difference in Average Zinc Concentrations in the Collected Samples

Sample Sample B) Seymour 0.16 0.00 (mqq) noitration (ppm) 4 5 9 9 9 9 9 4 6 9 9 9 9 9 4 7 9 9 9 9 9 9 0.16 0.00 因 Hot #1 日 Cold #2 ١ Sample Sample A) Capilano 0.10 0.12 0.08 0.06 0.16 0.14 0.04 0.02 0.00 0.16 0.14 0.02 0.00 Concentration (ppm)

Figure 5-22 Average Zinc Concentration in Cold #2 and Hot #1

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C) Coquitlam

D) Newton

## 5.6 Stability of the Targeted pH Values Within the GVRD

pH is one of the most influential factors in any corrosion control plan, even in waters that contain little alkalinity and are unable to produce any type of scale. Maintaining a stable pH can greatly enhance the ability of the water to reduce the amount of corrosion occurring (Churchill *et al*, 2000; Schock, 1980). pH measurements were taken both at the tap of all participants in the study and from the Cold #3 sample on the day the samples were collected during both of the sampling sessions. The measured pH values were then compared to the average pH of the treated water entering the distribution system. The collected pH data is summarized in Table 5-14.

The average pH for each of the four treated source waters remained constant during both sampling sessions. It must be noted that the average pH values obtained in this-study were approximately 0.5 pH units less than what is regularly measured at the tap by the GVRD. This is most likely due to different techniques being used for measuring the pH at the tap. It can be difficult to get an accurate pH measurement of GVRD water because of the low solute concentration in the water and therefore differences in the pH values in this study, compared to the GVRD values for the same area are attributed to this.

The pH values measured during the home visits were consistently higher than the values obtained in the lab, suggesting that the pH of the water, once out of the tap, has to adjust. This is not surprising, as the environment inside the distribution system is different than the environment outside the distribution system. Once the water leaves the tap, the chemistry of the water will have to adjust as it is exposed to the air and can affect

the pH of the water (AWWARF, 1996).

The stability of the pH is not only important for corrosion purposes, but economic ones as well. If the pH of the water is changing dramatically during distribution, and returns to its more aggressive state by the time it reaches the plumbing systems of the individuals (where corrosion is the biggest problem) then the benefit of adjusting the pH at the source is reduced. The pH of the water measured both at the tap and in the lab, from sample Cold #3, are compare to the average pH value of the treated water in Figures 5-23, 5-24, 5-25, 5-26.

| Source    | Average pH<br>after Treatment | Measurement             | рН            |  |
|-----------|-------------------------------|-------------------------|---------------|--|
|           | 6.1                           | pH at the tap           | $6.8 \pm 0.3$ |  |
| Capilano  |                               | pH in Cold #3 Session 1 | $5.8 \pm 0.5$ |  |
|           |                               | pH in Cold #3 Session 2 | $6.3 \pm 0.1$ |  |
| Seymour   | 6.8                           | pH at the tap           | $6.9 \pm 0.1$ |  |
|           |                               | pH in Cold #3 Session 1 | $6.3 \pm 0.1$ |  |
|           |                               | pH in Cold #3 Session 2 | $6.4 \pm 0.2$ |  |
| Coquitlam | 6.9                           | pH at the tap           | $7.1 \pm 0.3$ |  |
|           |                               | pH in Cold #3 Session 1 | $6.8 \pm 0.2$ |  |
|           |                               | pH in Cold #3 Session 2 | $6.8 \pm 0.1$ |  |
| Newton    | 8.1*                          | pH at the tap           | $7.8 \pm 0.3$ |  |
|           |                               | pH in Cold #3 Session 1 | $7.2 \pm 0.2$ |  |
|           |                               | pH in Cold #3 Session 2 | $7.2 \pm 0.2$ |  |

Table 5-14 Summary of Collected pH Data

\*Average pH for Newton was calculated based on in-line pH data collected over a year

## 5.6.1 Capilano

It was difficult to get the home visits in the Capilano distribution area completed, as the Capilano watershed is frequently offline due to turbidity events. The measured pH values in the Capilano distribution system were done over a longer period of time, compared to the other source waters, and show greater fluctuations in the measured values than the other three sources (Figure 5-23).

The average pH of the water coming out of the taps in the Capilano distribution area was 6.8, which is considerably higher than the pH of the Capilano water after treatment, which is 6.1. This difference in the measured pH values at the tap, compared to the pH of the water after treatment could be due to a number of different factors. Theoretically, it is possible that the presence of cement lined distribution pipes contributed a significant amount of alkalinity to the system, which could increase the pH (AWWARF, 1996). However, since there is nothing to suggest that there is a greater amount of cement lined pipes in the Capilano distribution system, compared to the other distribution systems. Alternatively, since there is no way of precisely defining the distribution of each of the source waters, combined with the fact that the Seymour and Capilano distribution areas are adjacent to one another, the elevated pH values measured at the taps, in the predicted Capilano distribution system might correspond to distributed Seymour water, as opposed to Capilano water (Dan Donnelly, Operations and Maintenance Department, GVRD, Burnaby BC, pers.comm.). In conclusion, although the results of the measured pH values at the tap, in the Capilano area, suggest that the pH is unstable as it travels through the distribution system, it is not possible to define the reasons for the apparent instability.

The pH values measured in the Cold #3 sample, during the first sampling sessions, were lower than the measured value of the Capilano water entering the distribution system, averaging 5.8, while the average pH of the Cold #3 sample collected during the second sampling session was greater, 6.1. Compared to the measured pH at the tap, however, they were considerably closer to the initial pH value of the water. One of the reasons that the pH measured in the lab is different than the value as the water leaves the treatment facility, is because once the water leaves the tap, it enters a new environment and the chemistry of the water must adjust accordingly, which could include a change in the pH, as a result of being exposed to air (AWWARF, 1996).







#### 5.6.2 Seymour

All of the pH measurements of samples collected in the Seymour distribution area and how they compare to the pH of the water leaving the treatment facility are shown in Figure 5-24.

The average pH of the water coming out at the taps in the Seymour distribution area was  $6.9 \pm 0.2$ , which is similar to the average pH of the water coming from the Seymour source, after treatment (pH=6.8). This suggests that the pH of treated Seymour water remains stable as it travels through the distribution system. The pH of sample Cold #3 was determined in the lab on the same day the samples were taken during both sampling session 1 and 2, and the average pH for these samples was 6.3, and 6.4, respectively. This suggests that the pH of the water is influenced by the conditions of the sampling container, which are different than the conditions of the distribution system.





## 5.6.3 Coquitlam

All of the pH measurements for the Coquitlam area, and how they compare to the pH of the water leaving the treatment facility are shown in Figure 5-25. There is little difference in the observed pH values measured at the tap, or from Cold #3, compared to the pH of the water entering the distribution system.

The average pH of the water coming out at the taps in the Coquitlam distribution area was  $7.1\pm 0.3$ , which is similar to the average pH of the Coquitlam source water, after treatment (pH=6.9). This suggests that the pH of the water coming out of the Coquitlam watershed is reasonably stable as it travels through the distribution system. The pH of sample Cold #3 was determined in the lab on the same day the samples were taken during both sampling sessions and the average pH for these samples was 6.8 for both sampling session. The average pH of the treated Coquitlam water is 6.9, which also indicates that the pH of this water is stable as it travels through the distribution system to the residents.

Figure 5-7 Measured pH of Samples Collected in the Coquitlam Distribution Area



## 5.6.4 Newton

All of the pH data collected from samples collected in the Newton distribution area and how they compare to the average measured pH of the water leaving the Newton reservoir are shown in Figure 5-26. There is little difference in the observed pHs at the tap, or measured pHs in Cold #3, compared to the pH of the water entering the distribution system at the source.

The average pH of the water at the taps in the Newton distribution area was  $7.8 \pm$ 0.3, which is similar to the pH of the water leaving the Newton reservoir (pH = 8.1). This suggests that the water coming out of the Newton reservoir is also stable, delivering water to the consumer at approximately the same pH as the water leaving the reservoir. The pH of Cold #3 was determined in the lab, on the same day the samples were collected. The average pH for these samples was 7.2 and 7.3, which is lower than the pH of the water entering the distribution system at the source. This difference is greater than what was seen in the Coquitlam and Seymour samples, suggesting that the water from the Newton reservoir may not be as stable at the higher pH. Since the Newton reservoir distribution area is considerable smaller than the Coquitlam and Seymour distribution areas, combined with the possibility that both Coquitlam and Seymour distribution areas border on the Newton distribution area, it is possible that some mixing of the water occurs. The Coquitlam and Seymour waters have a lower pH value associated with them than the Newton reservoir, and therefore, if they were to mix with the Newton water, they could lower the pH of the water. This could possibly explain the lower pH value in the Cold #3 sample collected in the Newton area, compared to the pH value of the water after treatment. In addition, the water in Cold #3 will adjust as a result of being exposed to the

air, after leaving the tap, and may fluctuate to a greater degree than the Seymour or Coquitlam sources.



Figure 5-8 Measured pH of Samples Collected in the Newton Distribution Area

## 5.7 Quality Control

Several Quality Control measures were put in place to ensure that the measured values were accurate. All data for calculations below can be found in Appendix C.

## 5.7.1 Repeats

Participants in each of the 4-source areas were randomly selected to take repeat samples, on two consecutive mornings. The average percent difference between repeats is summarized in Table 5-15, and ranged from 3% to 26% in the first sampling session and 4% to 35% in the second sampling session. Measured lead and zinc concentrations were below or close to the detection limit, which corresponded to the greatest variation in percent differences between samples, as small differences translate into large variations. Conversely, copper concentrations were mostly well above the detection limit, and therefore the calculated percent differences aren't as sensitive to small changes. Consequently, there didn't appear to be a major flaw in the sampling procedure used.

Table 5-15 Average Percent Difference Between Repeat Samples Collected

| Metal  | Cold #1 |     | Cold #2 |     | Cold #3 |     | Hot #1 |     |
|--------|---------|-----|---------|-----|---------|-----|--------|-----|
|        | SS1     | SS2 | SS1     | SS2 | SS1     | SS2 | SS1    | SS2 |
| Lead   | 14      | 35  | 14      | 30  | 0*      | 4   | 3      | 4   |
| Copper | 12      | 18  | 15      | 20  | 9       | 16  | 15     | 20  |
| Zinc   | 18      | 19  | 26      | 28  | 11      | 31  | 21     | 32  |

<sup>\*</sup>All samples collected were below the detection limit

## 5.7.2 GVRD

Samples were sent to the GVRD laboratory for analysis of lead, copper and zinc concentrations. In the first sampling session, the percent difference between the concentrations reported by the GVRD and those reported by analysis at the UBC lab were 28% for lead, 8% for copper and 26% for zinc. During the second sampling session, they percent differences were 27% for lead, and 20% for both copper and zinc. These results are in accordance with standard methods, and suggest that the analysis technique used to analyze all of the samples at the UBC laboratory was satisfactory (APHA *et al*, 1995).

The largest difference was seen in the lead levels measured at the two labs. This is likely due to the fact that the levels being measured are very low, usually below  $10 \ \mu g/L$  and therefore small differences in measurement can equate to a large variance.

#### 5.7.3 Test Sample

To ensure that the Atomic Absorption machines were maintaining their calibration, a test solution was analyzed every 10 to 15 samples. Whenever the measured concentrations of the given test solution was either greater than or less than the expected value, the machine was stopped and recalibrated before continuing the analysis of the remaining samples. Whenever the test sample came back too high or too low, all samples analyzed before that and after that were reanalyzed, once the machine was recalibrated.

During the first sampling session, there was less than 1% variation in the average test sample measured and the actual test sample concentration (Table 5-16). In the second sampling session, there was greater difference between the test samples measured and the actual concentration of the test sample. There was a 6% difference in the lead test sample, 3% difference in the copper test sample and a 4% difference in the zinc test sample. Overall, the machine was able to maintain its calibration during the run, and therefore all measured concentration values at the UBC lab should be representative of their actual concentrations.

|        | Sampling Session 1  |                   |                 | Sampling Session 2  |                   |                 |
|--------|---------------------|-------------------|-----------------|---------------------|-------------------|-----------------|
| Metal  | Calculated<br>Conc. | Measured<br>Conc. | %<br>Difference | Calculated<br>Conc. | Measured<br>Conc. | %<br>Difference |
|        |                     |                   | ·····           |                     |                   |                 |
| Lead   | 30                  | 30                | < 1%            | 30                  | 32                | 6%              |
| (µg/L) | 50                  | 50                | < 170           | 50                  | 52                | 070             |
| Copper | 1.4                 | 1.4               | < 10/           | 2.5                 | 2.4               | 20/             |
| (mg/L) | 1.4                 | 1.4               | < 1%            | 3.5                 | 3.4               | 3%              |
| Zinc   | 1.0                 | 1.0               | < 1%            | 26                  | 2.5               | 10/             |
| (mg/L) | 1.0                 | 1.0               | ~ 1 70          | 2.0                 | 2.5               | +/0             |

Table 5-16 Comparison of the Calculated and Measured Test Concentrations

## 5.7.4 Blanks

Blank samples were used to determine if there was any source of contamination during any of the procedures used to process the samples. Field blanks were sent home with 25% of the participants, to determine if there was a possibility of any metal contamination during the sampling. In the UBC laboratory, blanks were used to see if there was any way that the samples could be contaminated when opened in the lab. Finally, blank samples that contained only deionized water and the preserving acid were analyzed to determine if the acid used to preserve the samples was a potential source of contamination. All blanks analyzed in the UBC lab came back showing concentrations less than the detection limit for lead (<0.005 mg/L), copper (< 0.03 mg/L) and zinc (<0.01 mg/L). This suggests that the sampling procedure, as well as the manner in which

the samples were handled at the lab, weren't sources of contamination.

Blanks, sent to the GVRD lab, contained 50 mL of deionized water and 2 drops of the preserving acid from the UBC lab. Two blanks were sent for the first sampling session, and both had copper concentrations of 0.011 mg/L and zinc concentrations of 0.018 and 0.013 mg/L. Two blanks were again sent during the second sampling session, and had copper concentrations of 0.011 and 0.012 mg/L and zinc concentrations of 0.012 and 0.010 mg/L. None of eh blanks contained any detectable levels of lead (Appendix C).

Although these results indicate either the deionized water, or the preserving acid used might have contained trace amount of copper and zinc, the concentrations were low enough to be considered negligible. The observed copper and zinc concentration in most Cold #1 samples collected, was considerably greater than the concentration in the blanks sent to the GVRD for analysis, and therefore it was concluded that they didn't contribute a very significant amount to the observed concentrations in these samples.

## 5.7.5 Sources of Error

Quality control measures were put in place to try and reduce the number of possible sources of error, however some of the sources were unavoidable. The most significant source of error was the sampling protocol, which relied on people not running their water for a night; however, there was no way to determine if all participants complied with the specified protocol. Consequently, it is possible that a number of the observed sample concentrations were lower than the actual concentrations. The effect that this might have had on the results, aside from lowering the average metal concentration for a given source area, is that the calculated error in the samples would be greatly increased, as a

result of the increased range in concentration for a given source. This would have had the greatest effect on the observed lead concentrations, because the levels that were being measured were very low; this would make the calculated error very sensitive to small changes, and might have resulted in the observed concentration levels not being statistically significant.

## 6 CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 Major Findings

The purpose of this project was to determine the optimum pH level for GVRD drinking water, based on previously implemented corrosion control measures. In addition, the potential impact of using ozone, as opposed to chlorine, on the amount of corrosion occurring, as well as any potential difference seen with respect to the temperature of the water and the observed metal release, was also assessed.

Samples were collected from all four treated source water distribution areas accordingly, and analyzed for their metal content. The results of the analysis were then compared to the Canadian Drinking Water Quality Guidelines to see whether or not they were in compliance. In addition, potential environmental, aesthetic and economic impacts were addressed.

## 6.1.1 Source of Metals

The results of the metal analysis on the individual samples suggested that the majority of the metal contamination was as a result of corrosion in the household plumbing system, as opposed to the distribution system. The concentration of metal in the samples taken for background measurements were similar for samples collected in all source water distribution areas. This indicates that the water in the distribution system is contributing very little metal to the drinking water.

• The highest lead concentrations were found in the first two samples taken, Cold #1 and Cold #2, implying that both the faucet and the interior plumbing

system of the house contributed significant amounts of lead to the drinking water.

- The higher lead concentrations were also associated with older houses, which could contain substantially more lead tin solder than newer houses.
- The highest copper concentrations were found in Cold #2, suggesting that the interior plumbing system was the most significant source of copper in drinking water.
- The zinc concentration in Cold #1 was significantly greater than the zinc concentration in any of the other collected samples, suggesting that the main source of zinc in the GVRD drinking water is the faucets, which are predominantly made of brass.

## 6.1.2 Treated Source Water

The results of the metal concentrations measured in samples taken from each of the four source water distribution areas, suggests that the different pH and alkalinity levels of the different treated waters impacts the amount of metal observed in the drinking water of GVRD residents. The most significant differences between the four treated source waters were with respect to copper concentrations.

- No trend was seen with respect to lead concentrations in samples collected from all four treated source waters.
- There was a trend in the amount of copper in the collected samples between the four treated source waters, which was statistically significant.
  - The highest copper concentrations were collected in the Capilano

distribution area, which corresponds to the most aggressive water.

- The lowest copper concentrations were in samples collected in the Newton distribution area, which is treated to be the least aggressive water type in the GVRD water distribution system.
- Copper corrosion in the drinking water distribution system is the predominant source of copper in the GVRD wastewater treatment plant influent.
- The trend seen in terms of the zinc concentrations in the collected samples was the same as the copper concentrations.
  - The highest zinc concentrations were in samples from the Capilano distribution area, while the lowest zinc concentrations were in samples from the Newton distribution system.
  - The difference in the zinc concentrations between samples collected in the Capilano, Seymour, and Coquitlam distribution areas isn't statistically significant.
  - The difference between the zinc concentration in samples collected in the Newton area, and samples collected from all three of the other source waters was, however, statistically significant.

## 6.1.3 Primary Disinfectant

The results of metal analysis on samples collected in both the Seymour and Coquitlam distribution areas suggest that the use of either ozone or chlorine as a primary disinfectant has little effect on the metal concentration in the drinking water of the GVRD. The average metal concentrations in samples collected from both of these areas showed similar trends.

## 6.1.4 Temperature Effects

Metal concentrations in samples taken during the warmest month of the year were not significantly different from the metal concentrations in samples taken during the coldest month of the year. This suggests that the corrosion rate isn't greatly affected by the temperature fluctuations of the water within the GVRD.

- Lead concentrations in samples collected during the first sampling session, the warmest time of the year, were consistently greater than the lead concentrations in samples collected during the second sampling session, the coldest time of the year. Although there was an observed trend, the differences were not statistically significant.
- There was no trend or statistically significant difference in either the zinc and copper concentrations in samples collected during the warmest month of the year, compared to samples collected during the coldest month of the year.

## 6.1.5 pH stability

The results of the pH measurements taken at the tap, compared to the average pH of water coming from the four treated source areas, suggest that the pH is stable.

- Distributed Capilano water appears to increase in pH as it travels throughout the water distribution system; reasons for the observed increase in pH is unknown at this time, however it is most likely due to infiltration of treated Seymour water into the predicted Capilano distribution area.
- Distributed Seymour, Coquitlam and Newton water, all appear to maintain their pH throughout the distribution system.

## 6.2 Recommendations

Due to the observed reduction in copper concentrations in samples taken from the Capilano distribution area compared to the Seymour, Coquitlam and Newton areas, adjusting the pH of GVRD to a targeted value of 7 is recommended. Targeting a pH of 7, as opposed to 8, is recommended due to the uncertainty of DBP formation in GVRD water, and the more stringent USEPA regulations with respect to THM and HAA concentrations in drinking water. However, since copper can be toxic to aquatic organisms, it would be environmentally beneficial to reduce the amount of copper being released into the receiving waters of the GVRD wastewater treatment plants (WWTP) by reducing the amount of copper going to the GVRD WWTP. Therefore targeting a pH that results in a reduction in the amount of copper in the drinking water will also be environmentally beneficial.

There is little difference in the observed lead and zinc concentrations in samples collected from all four treated source waters and they are all in compliance with the CDWQG, therefore there is no need to adjust the pH to lower their presence in the GVRD drinking water and ensure the protection of public health.

Using ozone, which will increase the dissolved oxygen concentration in the water, as opposed to chlorine as the primary disinfectant in GVRD water doesn't appear to be an influencing factor in the observed metal concentrations in the collected samples. Therefore, no recommendation on the type of primary disinfectant used is made at this time.

It is recommended that the pH adjustments remain the same throughout the year, as temperature does not appear to play a role in the corrosion rates in the GVRD water distribution system.

#### 6.3 Recommendations for Future Research

Due to the increasingly more stringent drinking water guidelines, it might be necessary to reexamine the amount of corrosion occurring within the GVRD water distribution system. Based on this study, as well as previous studies, there is good reason to take no more than two samples on the sampling day, the calculated first-litre flush and a background sample. It has already been well established where in the distribution system the majority of the metals are coming from, and therefore it shouldn't be necessary to break up the first sample. In addition, the amount of metal introduced into the drinking water, as a result of the hot water system, is negligible.

Given the findings of this research, there are a couple of areas that have been identified as needing further investigation

- The association between the production of disinfection by-products, and elevated pH levels.
- The formation of protective films using distributed GVRD water since there is limited understanding about how soft waters, with low alkalinity is able to form a protective film on the interior surface of the distribution pipes.

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# Appendix A: GVRD Water Quality


# Physical and Chemical Analysis of Water Supply Greater Vancouver Water District

## 2002 - Capilano Water System

| Man an anna an anna an an an an an an an | Untreated |                 | Treated         |                 |                   |                    |
|--|-----------|-----------------|-----------------|-----------------|-------------------|--------------------|
| D  |           |                 |                 | Days            | <u>Canadian</u>   | Reason             |
| Parameter                                | Average   | Average         | Kange           | <u>Exceeded</u> | Limit             | <u>Established</u> |
|  |           |                 |                 |                 |                   | S. Statistics      |
| Alkalinity as CaCO3 (mg/L)               | 2.8       | 1.1             | 0.7 to 1.7      |                 | none              |                    |
| Aluminium Dissolved (mg/L)               | 0.06      | 0.05            | 0.03 to 0.07    |                 | none              |                    |
| Aluminium Total (mg/L)                   | 0.12      | 0.08            | 0.05 to 0.11    |                 | none              |                    |
| Antimony Total (mg/L)                    | <0.002    | <0.002          | < 0.002         | 0               | 0.006             | health             |
| Arsenic Total (mg/L)                     | <0.001    | <0.001          | < 0.001         | 0               | 0.025             | health             |
| Barium Total (mg/L)                      | 0.003     | 0.003           | 0.003           | Ó               | 1.0               | health             |
| Boron Total (mg/L)                       | 0.02      | 0.02            | 0.02            | 0               | 5.0               | health             |
| Cadmium Total (mg/L)                     | <0.0005   | < 0.0005        | < 0.0005        | 0               | 0.005             | health             |
| Calcium Total (mg/L)                     | 1.27      | 1.24            | 1.09 to 1.43    |                 | none              |                    |
| Carbon Organic Dissolved (mg/L)          | 1.8       | 1.7             | 1.1 to 2.5      |                 | none              |                    |
| Carbon Organic Total (mg/L)              | 1.9       | 1.6             | 1.2 to 2.6      |                 | none              |                    |
| Chloride Total (mg/L)                    | 0.5       | 1.6             | 1.5 to 1.8      | 0               | _ ≤ 250           | aesthetic          |
| Chromium Total (mg/L)                    | <0.001    | <0.001          | < 0.001         | 0               | 0.05              | health             |
| Color Apparent (ACU)                     | 13        | 6               | 4 to 12         |                 | none              |                    |
| Color True (TCU)                         | 11        | 4               | 2 to 8          | 0               | ≤ 15              | aesthetic          |
| Conductivity (umhos/cm)                  | 11        | 12              | 11 to 14        |                 | none              |                    |
| Copper Total (mg/L)                      | 0.005     | N.A.            | N.A.            | 0               | ≤ 1.0             | aesthetic          |
| Cyanide Total (mg/L)                     | <0.005    | <0.005          | < 0.005         | 0               | 0.2               | health             |
| Fluoride (mg/L)                          | <0.05     | <0.05           | < 0.05          | 0               | 1.5               | health             |
| Hardness as CaCO <sub>3</sub> (mg/L)     | 3.80      | 3.74            | 3.30 to 4.39    |                 | none              |                    |
| Iron Dissolved (mg/L)                    | 0.02      | 0.02            | <0.02 to 0.03   |                 | none              |                    |
| Iron Total (mg/L)                        | 0.06      | 0.06            | 0.03 to 0.08    | 0               | $\leq 0.3$        | aesthetic          |
| Lead Total (mg/L)                        | <0.001    | <0.001          | < 0.001         | 0               | 0.01              | health             |
| Magnesium Total (mg/L)                   | 0.15      | 0.14            | 0.13 to 0.17    |                 | none              |                    |
| Manganese Dissolved (mg/L)               | 0.003     | 0.003           | <0.001 to 0.006 |                 | none              | ı                  |
| Manganese Total (mg/L)                   | 0.005     | 0.004           | 0.002 to 0.007  | - 0             | ≤ 0.05            | aesthetic          |
| Mercury Total (mg/L)                     | < 0.00005 | < 0.00005       | < 0.00005       | 0               | 0.001             | health             |
| Nickel Total (mg/L)                      | <0.001    | < 0.001         | < 0.001         |                 | none              |                    |
| Nitrogen - Ammonia as N (mg/L)           | <0.01     | < 0.01          | <0.01 to 0.01   |                 | none              |                    |
| Nitrogen - Nitrate as N (mg/L)           | 0.11      | 0.10            | 0.07 to 0.17    | 0               | 10                | health             |
| Nitrogen - Nitrite as N (mg/L)           | <0.01     | < 0.01          | < 0.01          | 0               | 1.0               | health             |
| pH                                       | 6.5       | 5.9             | 5.6 to 6.1      | 182             | $\leq$ 6.5 to 8.5 | aesthetic          |
| Phenols (mg/L)                           | <0.005    | < 0.005         | < 0.005         |                 | none              |                    |
| Phosphorus Total (mg/L)                  | <0.005    | < 0.005         | <0.005 to 0.016 |                 | none              |                    |
| Potassium Total (mg/L)                   | 0.16      | 0.13            | 0.13            |                 | none              |                    |
| Residue Total (mg/L)                     | 15        | 15              | 15              |                 | none              |                    |
| Residue Total Dissolved (mg/L)           | 15        | 15 <sup>,</sup> | 14 to 15        | 0               | ≤ 500             | aesthetic          |
| Residue Total Fixed (mg/L)               | 8         | 8               | 7 to 9          |                 | none              |                    |
| Residue Total Volatile (mg/L)            | 6         | 7               | 6 to 8          |                 | none              |                    |
| Selenium Total (mg/L)                    | < 0.001   | < 0.001         | < 0.001         | 0               | 0.01              | health             |
| Silica as $SiO_2$ (mg/L)                 | 3.1       | 2.8             | 2.6 to 3.3      |                 | none              |                    |
| Silver Total (mg/L)                      | <0.001    | <0.001          | < 0.001         |                 | none              |                    |
| Sodium Total (mg/L)                      | 0.53      | 0.47            | 0.40 to 0.60    | 0               | ≤ 200             | aesthetic          |
| Sulphate (mg/L)                          | 0.9       | 0.9             | 0.7 to 1.0      | · ·             | ≤ 500             | aesthetic          |
| Turbidity (NTU)                          | 0.79      | 0.62            | 0.38 to 1.4     | 0               | ≤ 5               | aesthetic          |
| Turbidity (NTU)                          | 0.79      | 0.62            | 0.38 to 1.4     | 9               | 1                 | health             |
| UV254 (Abs/cm)                           | 0.065     | 0.044           | 0.023 to 0.077  | 2               | none              |                    |
| UV272 (Abs/cm)                           | 0.055     | 0.035           | 0.018 to 0.061  |                 |                   |                    |
| Zinc Total (mg/L)                        | <0.01     | <0.01           | <0.01           | 0               | ≤ 5.0             | aesthetic          |

These figures are average values from a number of laboratory analyses done throughout the year. Where the range is a single value no variation was measured for the samples analysed. Methods and terms are based on those of "Standard Methods of Water and Waste Water", 20th Edition 1998. Less than (<) denotes not detectable with the technique used for determination. Untreated water is from the intake prior to chlorination, treated water is from a sample line after 10 minutes chlorine contact time. Guidelines are taken from "Guidelines for Canadian Drinking Water Quality - Stath Edition" Health and Welfare Canada 1996, updated to April 2002. Capilano source water is treated with chlorine for disinfection. Capilano source water was distributed for only 182 days. The Intake was taken out of service from Jan 1 to June 2 due to East abutment upgrade, and Nov 19 to Dec 18 due to high turbidity. Summary does not include data from Jan. 1 to Jun. 3.

N.A. Not available, There are no results for copper in the treated water as there was interference in the sample from the copper sample line.



# 2002 - Seymour Water System

|   | Untreated      |                | Treated              |                               |  |  |
|---|----------------|----------------|----------------------|-------------------------------|--|--|
| <u>Parameter</u>  | <u>Average</u> | <u>Average</u> | <u>Range</u>         | Days<br>Guideline<br>Exceeded | <u>Canadian</u><br><u>Guideline</u><br>Limit | <u>Reason</u><br><u>Guideline</u><br>Established |
|   |                |                |                      |                               |  |  |
| Alkalinity as CaCO <sub>3</sub> (mg/L)                  | 3.7            | 7.4            | 5.5 to 9.0           |                               | none   |  |
| Aluminium Dissolved (mg/L)                              | 0.06           | 0.06           | 0.01 to 0.08         | ,                             | none   |  |
| Aluminium Total (mg/L)                                  | 0.13           | 0.13           | 0.06 to 0.25         |                               | none   |  |
| Antimony Total (mg/L)                                   | <0.002         | <0.002         | < 0.002              | 0                             | 0.006  | health   |
| Arsenic Total (mg/L)                                    | <0.001         | <0.001         | < 0.001              | 0                             | 0.025  | health   |
| Barium Total (mg/L)                                     | 0.003          | 0.003          | 0.003                | 0                             | 1.0  | health   |
| Boron Total (mg/L)                                      | <0.02          | <0.02          | < 0.02               | 0                             | 5.0  | health   |
| Bromate (mg/L)  | <0.01          | <0.01          | < 0.01               | 0                             | 0.01   | health   |
| Cadmium Total (mg/L)                                    | <0.0005        | < 0.0005       | < 0.0005             | 0                             | 0.005  | health   |
| Calcium Total (mg/L)                                    | 1.8            | 1.8            | 1.4 to 2.3           |                               | none   |  |
| Carbon Organic Dissolved (mg/L)                         | 1.9            | 1.9            | 1.3 to 2.9           |                               | none   |  |
| Carbon Organic Total (mg/L)                             | 2.0            | 1.9            | 1.3 to 2.9           |                               | none   |  |
| Chloride Total (mg/L)                                   | 0.4            | 2.2            | 1.8 to 3.1           | 0                             | ≤ 250  | aesthetic  |
| Chromium Total (mg/L)                                   | <0.001         | < 0.001        | < 0.001              | 0                             | 0.05   | health   |
| Color Apparent (ACU)                                    | 20             | 13             | 6 to 48              |                               | none   |  |
| Color True (TCU)  | 13             | 7              | 5 to 24              | 7                             | < 15   | aesthetic  |
| Conductivity (umbos/cm)                                 | 14             | 27             | 16 to 38             |                               | none   |  |
| Copper Total (mg/L)                                     | <0.02          | < 0.02         | <0.02                | 0                             | < 1.0  | aesthetic  |
| Cvanide Total (mg/L)                                    | <0.005         | < 0.005        | < 0.005              | 0                             | 0.2  | health   |
| Fluoride (mg/L)   | <0.05          | <0.05          | <0.05                | Ő                             | 1.5  | health   |
| Hardness as $CaCO_2$ (mg/L)                             | 51             | 51             | 4 1 to 6 5           | Ũ                             | none   |  |
| Iron Dissolved (mg/L)                                   | 0.07           | 0.07           | 0.02 to 0.26         |                               | none   |  |
| Iron Total (mg/L)                                       | 0.26           | 0.26           | 0.02 to 0.16         | 78                            | < 03   | aesthetic  |
| Lead Total (mg/L)                                       | <0.001         | <0.001         | <0.001               | , e<br>0                      | 0.01   | health   |
| Magnesium Total (mg/L)                                  | 0.16           | 0.16           | 0.13 to 0.18         | U                             | none   | iteatui  |
| Manganese Dissolved (mg/L)                              | 0.02           | 0.10           | 0.002 to 0.11        |                               | none   |  |
| Manganese Total (mg/L)                                  | 0.02           | 0.02           | 0.002 to 0.11        | 30                            | < 0.05                                       | aesthetic  |
| Mangariese Total (mg/L)                                 | <0.000         | <0.00          | <0.000100.10         | 50                            | 0.001  | health   |
| Nickel Total (mg/L)                                     | <0.00005       | <0.00005       | <0.00005             | U .                           | none   | ncanur   |
| Nitrogen - Ammonia as N (mg/L)                          | 0.02           | <0.001         | <0.001               |                               | none   |  |
| Nitrogen - Nitrote es N (mg/L)                          | 0.02           | 0.01           | 0.06 to 0.16         | 0                             | 10   | haalth   |
| Nitrogen - Nitrite es N (mg/L)                          | <0.03          | <0.01          | <0.01                | 0                             | 10   | health   |
| nH  | 64             | 6.8            | <0.01<br>6 4 to 7 2  | 3                             | 65 to 85                                     | aesthetic  |
| Phenols (mg/I)  | <0.005         | <0.0           | <0.005               | 5                             | 0.5 10 8.5                                   | acsuictie  |
| Phosphorus Total (mg/L)                                 | <0.005         | <0.005         | <0.005               |                               | none   |  |
| Potassium Total (mg/L)                                  | 0.15           | 0.15           | 0 14 to 0 16         |                               | none   |  |
| Posidue Total (mg/L)                                    | 18             | 25             | 22 to 28             |                               | none   |  |
| Residue Total (Ing/L)<br>Residue Total Dissolved (mg/L) | 18             | 23             | 23 to 28             | 0                             | 100e   | oosthatia  |
| Residue Total Dissolved (Ing/L)                         | 17             | 17             | 21 to 23             | U                             | ≤ 500  | acsulctic  |
| Residue Total Fixed (Ing/L)                             | 12             | 9              | 13 to 20             |                               | none   |  |
| Selenium Total (mg/L)                                   | /<br><0.001    | <0.001         | <0.001               | 0                             | 0.01   | health   |
| Silies as SiQ (mg/L)                                    | ~0.001         | ~0.001         | <0.001<br>2.8 to 2.0 | U                             | 0.01   | nçalul   |
| Sinca as SIO <sub>2</sub> (mg/L)                        | 3.2            | 3.2            | 2.8 10 3.9           |                               | none   |  |
| Silver Total (mg/L)                                     | <0.001         | <0.001         | <0.001               |                               | none   |  |
| Socium I otal (mg/L)                                    | 0.57           | 3.58           | 2.9 to 4.3           | U                             | $\geq 200$                                   | aestnetic  |
| Sulphate (mg/L)   | 1.5            | 1.5            | 1.1 to 1.9           |                               | ≤ 500  | aestnetic  |
| Turbidity (NTU)   | 1.3            | 1.3            | 0.34 to 7.5          | 15                            | $\leq 5$                                     | aesthetic  |
| Turbidity (NTU)   | 1.3            | 1.3            | 0.34 to 7.5          | 116                           | 1  | health   |
| $\cup V254$ (Abs/cm)                                    | 0.74           | 0.49           | 0.022 to 0.083       |                               | none   |  |
| UVZ/2. (Abs/cm)   | 0.59           | 0.4            | 0.020 to 0.067       | _                             | none   |  |
| Zinc Total (mg/L)                                       | <0.002         | <0.002         | <0.002 to 0.002      | 0                             | $\geq 5.0$                                   | aesthetic  |

These figures are average values from a number of laboratory analyses done throughout the year. Where the range is a single value no variation was measured for the samples analysed. Methods and terms are based on those of "Standard Methods of Water and Waste Water" 20th Edition 1998. Less than (<) denotes not detectable with the technique used for determination. Untreated water is from the intake prior to chlorination, treated water is from a single site in the GVRD distribution system downstream of chlorination. Guidelines are taken from "Guidelines for Canadian Drinking Water Quality - Sixth Edition" Health and Welfare Canada 1996, updated to April 2002. Seymour source water is treated with chlorine for disinfection and soda ash to increase pH and alkalinity.



# Physical and Chemical Analysis of Water Supply Greater Vancouver Water District

## 2002 - Coquitlam Water System

|  | Untreated  | A Made         | Treated             | and the second                       |                                       | at the                                    |
|--|--|----------------|---------------------|--------------------------------------|---------------------------------------|---|
| Parameter                              | Average  | <u>Average</u> | Range               | <u>Days</u><br>Guideline<br>Exceeded | <u>Canadian</u><br>Guideline<br>Limit | <u>Reason</u><br>Guideline<br>Established |
|  | Salar de la constante de la co | 1. St. 62      | Child Cale and Cale |                                      | kint                                  |   |
| Alkalinity as CaCO <sub>3</sub> (mg/L) | 1.6  | 6.2            | 5.5 to 7.6          |                                      | none                                  |   |
| Aluminium Dissolved (mg/L)             | 0.06   | 0.05           | 0.03 to 0.06        |                                      | none                                  |   |
| Aluminium Total (mg/L)                 | 0.09   | 0.08           | 0.05 to 0.08        |                                      | none                                  |   |
| Antimony Total (mg/L)                  | <0.002   | <0.002         | < 0.002             | 0                                    | 0.006                                 | health                                    |
| Arsenic Total (mg/L)                   | <0.001   | <0.001         | < 0.001             | 0                                    | 0.025                                 | health                                    |
| Barium Total (mg/L)                    | 0.003  | 0.005          | 0.003 to 0.006      | 0                                    | 1.0                                   | health                                    |
| Boron Total (mg/L)                     | 0.02   | 0.02           | 0.02                | 0                                    | 5.0                                   | health                                    |
| Bromate (mg/L)                         |  | <0.01          | < 0.01              | 0                                    | 0.01                                  | health                                    |
| Cadmium Total (mg/L)                   | <0.0005  | <0.0005        | < 0.0005            | 0                                    | 0.005                                 | health                                    |
| Calcium Total (mg/L)                   | 0.98   | 0.95           | 0.82 to 1.06        |                                      | none                                  |   |
| Carbon Organic Dissolved (mg/L)        | 1.7  | 1.5            | 1.2 to 2.2          |                                      | none                                  |   |
| Carbon Organic Total (mg/L)            | 1.8  | 1.6            | 1.2 to 2.2          |                                      | none                                  |   |
| Chloride Total (mg/L)                  | 0.5  | 1.8            | 1.5 to 2.0          | 0                                    | ≤ 250                                 | aesthetic                                 |
| Chromium Total (mg/L)                  | <0.001   | <0.001         | < 0.001             | 0                                    | 0.05                                  | health                                    |
| Color Apparent (ACU)                   | 13   | 4              | 2 to 8              |                                      | none                                  |   |
| Color True (TCU)                       | 10   | 3              | 1 to 12             | 0                                    | ≤ 15                                  | aesthetic                                 |
| Conductivity (umhos/cm)                | 9  | 23             | 21 to 26            |                                      | none                                  |   |
| Copper Total (mg/L)                    | 0.005  | <0.002         | <0.002 to 0.007     | 0                                    | 1.0                                   | aesthetic                                 |
| Cyanide Total (mg/L)                   | <0.005   | <0.005         | < 0.005             | 0                                    | 0.2                                   | health                                    |
| Fluoride (mg/L)                        | <0.05  | <0.05          | <0.05               | 0                                    | 1.5                                   | health                                    |
| Hardness as CaCO <sub>3</sub> (mg/L)   | 2.83   | 2.81           | 2.52 to 3.10        | ,                                    | none                                  |   |
| Iron Dissolved (mg/L)                  | 0.02   | 0.03           | <0.02 to 0.04       |                                      | none                                  |   |
| Iron Total (mg/L)                      | 0.06   | 0.06           | 0.04 to 0.10        | 0                                    | $\leq 0.3$                            | aesthetic                                 |
| Lead Total (mg/L)                      | <0.001   | <0.001         | < 0.001             | 0                                    | 0.01                                  | health                                    |
| Magnesium Total (mg/L)                 | 0.11   | 0.11           | 0.08 to 0.16        |                                      | none                                  |   |
| Manganese Dissolved (mg/L)             | 0.005  | 0.004          | 0.003 to 0.006      |                                      | none                                  |   |
| Manganese Total (mg/L)                 | 0.006  | 0.005          | 0.003 to 0.006      | 0                                    | $\leq 0.05$                           | aesthetic                                 |
| Mercury Total (mg/L)                   | <0.00005   | < 0.00005      | < 0.00005           | 0                                    | 0.001                                 | health                                    |
| Nickel Total (mg/L)                    | <0.001   | <0.001         | <0.001              |                                      | none                                  |   |
| Nitrogen - Ammonia as N (mg/L)         | <0.01  | < 0.01         | < 0.01              |                                      | none                                  |   |
| Nitrogen - Nitrate as N (mg/L)         | 0.13   | 0.13           | 0.09 to 0.18        | 0                                    | 10                                    | health                                    |
| Nitrogen - Nitrite as N (mg/L)         | <0.01  | < 0.01         | <0.01               | 0                                    | 1.0                                   | health                                    |
| pH                                     | 6.3  | 6.8            | 6.6 to 7.1          | 0                                    | 6.5 to 8.5                            | aesthetic                                 |
| Phenols (mg/L)                         | <0.005   | <0.005         | <0.005              |                                      | none                                  |   |
| Phosphorus Total (mg/L)                | <0.005   | <0.005         | <0.005              |                                      | none                                  |   |
| Potassium Total (mg/L)                 | 0.12   | 0.13           | 0.12 to 0.13        |                                      | none                                  |   |
| Residue Total (mg/L)                   | 12   | 22             | 20 to 23            | 0                                    | none                                  |   |
| Residue Total Dissolved (mg/L)         |  | 21             | 19 to 22            | U                                    | $\simeq 500$                          | aesthetic                                 |
| Residue Total Fixed (mg/L)             | 6  | 14             | 13 to 15            |                                      | none                                  |   |
| Residue Total Volatile (mg/L)          | 5  | 8              | 0 10 8              | 0                                    | none                                  | 1 141.                                    |
| Selenium Total (mg/L)                  | <0.001   | <0.001         | <0.001              | U                                    | 0.01                                  | nealth                                    |
| Silica as SiO <sub>2</sub> (mg/L)      | 2.4  | 2.4            | 2.1 to 2.6          |                                      | none                                  |   |
| Silver Total (mg/L)                    | <0.001   | <0.001         | <0.001              |                                      | none                                  |   |
| Sodium Total (mg/L)                    | 0.42   | 3.70           | 3.4 to 3.9          | 0                                    | $\geq 200$                            | aesthetic                                 |
| Sulphate (mg/L)                        | 0.9  | 0.9            | 0.7 to 1.0          |                                      | $\leq 500$                            | aesthetic                                 |
| Turbidity (NTU)                        | 0.64   | 0.57           | 0.22 to 2.9         | 0                                    | . = 5                                 | aesthetic                                 |
| I UFDIGITY (NIU)                       | 0.04   | 0.57           | 0.22 to 2.9         | 16                                   | I I                                   | nealth                                    |
| $\cup v 254$ (ADS/CM)                  | 0.060  | 0.019          | 0.011 to 0.045      |                                      | none                                  |   |
| $\cup v \ge i \ge (AOS/CM)$            | 0.050  | 0.014          |                     | <u>_</u>                             | none                                  | e anthat's                                |
| Zine rotal (mg/L)                      | <b>~0.00</b> 2   | <0.002         | ~0.002 to 0.002     | U                                    | ≤ <b>5.0</b>                          | aesinetic                                 |

These figures are average values from a number of laboratory analyses done throughout the year. Where the range is a single value no variation was measured for the samples analysed. Methods and terms are based on those of "Standard Methods of Water and Waste Water" 20th Edition 1998. Less than (<) denotes not detectable with the technique used for determination. Untreated water is from the intake prior to chlorination, treated water is from a single site in the GVRD distribution system downstream of chlorination. Guidelines are taken from "Guidelines for Canadian Drinking Water Quality - Sixth Edition" Health and Welfare Canada 1996, updated to April 2002. Coquitlam water is treated with ozone for primary disinfection, chlorine for secondary disinfection, and soda ash to increase the pH and alkalinity.

**Appendix B: Questionnaire and Summarized Results** 

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|    | Name:  |
|----|--|
|    | Address:   |
|    |  |
|    |  |
|    |  |
|    | Water Quality Sampling Program Questionnaire   |
| 1. | Do you utilize a water purification device on your drinking tap?                           |
|    | Type of Unit: Activated Carbon   |
|    | Reverse Osmosis  |
|    | Distiller  |
|    | Other  |
| •  |  |
| 2. | Describe any blue/green staining problems on porcelain fixtures and files:                 |
|    |  |
|    | ·  |
| 3. | Do you notice a brown-colored discharge when opening your taps first thing in the morning? |
|    | If yes, how often?   |
|    |  |
| 4. | Does your tap water have a metallic aftertaste?  |
|    | If yes, when do you notice this problem?   |
| 5. | Do you let your water run prior to drinking it?  |
|    | If yes, how long?  |

6. Type of plumbing within your house/building:

.

|                              | Copper   |                                |
|------------------------------|--|--------------------------------|
|                              | Galvanized Iron                                    |                                |
|                              | Plastic  |                                |
|                              | Other  |                                |
|                              | If a combination is used please                    | describe:                      |
|                              |  |                                |
|                              |  |                                |
| 7.                           | Age of the house:                                  |                                |
| 8.                           | Describe any major refits under                    | taken and when they were done: |
|                              |  | · ·                            |
|                              |  |                                |
| 9.                           | Type of material and age of the                    | hot water tank:                |
|                              |  |                                |
| 10.                          | Make of faucets installed in the                   | building:                      |
|                              |  |                                |
|                              |  |                                |
| Thank                        | you for your cooperation.                          |                                |
| Gillian<br>Gradua<br>Civil F | Knox<br>ite Student<br>Engineering Department, UBC |                                |
|                              | $0$ $0$ $1$ $\cdots$ $,$ $2$ $=$ $0$               |                                |

| Study #      | Staining | Taste<br>Problem | Plumbing<br>Material | House<br>Age | Plumbing<br>Work Done | Hot Water<br>Tank Age |  |  |  |
|--------------|----------|------------------|----------------------|--------------|-----------------------|-----------------------|--|--|--|
| CAP1         |          |                  |                      |              |                       |                       |  |  |  |
| CAP2         | N        | N                | Plastic              | 70           | Unknown               | Unknown               |  |  |  |
| CAP3         | N        | N                | Plastic              | 15           | Unknown               | Unknown               |  |  |  |
| CAP4         | unknown  | Ν                | Unknown              | unknow       | Unknown               | Unknown               |  |  |  |
|              |          |                  |                      | n            |                       |                       |  |  |  |
| CAP5         | some     | <u>N</u>         | Unknown              | 5            | N                     | NEW                   |  |  |  |
| CAP7         | yes      | N                | Copper               | 30           | Unknown               | Unknown               |  |  |  |
| CAP8         | some     | <u>N</u>         | Copper               | old          |                       |                       |  |  |  |
| CAP9         | N        | N                | Copper               | 74           | 1987                  | 2                     |  |  |  |
| CAP10        | N        | <u>N</u>         | Unknown              | 40-50        | Unknown               | Unknown               |  |  |  |
| CAP11        | some     | N                | Copper               | 40           | 20 yrs                | NEW                   |  |  |  |
| CAP12        |          |                  |                      | `            |                       |                       |  |  |  |
| CAP13        |          |                  |                      |              |                       |                       |  |  |  |
| CAP14        | N        | N                | Copper               | old          |                       | t                     |  |  |  |
| CAP15        | some     | <u> </u>         | Copper               | 37           | Some                  | 7                     |  |  |  |
| CAP16        | yes      | <u>N</u>         | Copper               | 35           | None                  | Unknown               |  |  |  |
| CAP17        |          |                  |                      |              |                       |                       |  |  |  |
| CAP18        | N        | <u>N</u>         | Copper               | 54           | Unknown               | 2                     |  |  |  |
| CAP19        |          |                  |                      |              |                       |                       |  |  |  |
| CAP20        | N        | N                | Copper               | 80           | 20 yrs                | 5                     |  |  |  |
| CAP21        | Y        | <u>N</u>         | Copper               | 53           | None                  | Unknown               |  |  |  |
| CAP22        | Y        | N                | Copper               | 50           | Unknown               | Unknown               |  |  |  |
| COQ1         | N        | N                | Copper               | 24           | Unknown               | 6                     |  |  |  |
| COQ2         | some     | N                | Plastic              | 6            | N                     | Unknown               |  |  |  |
| COQ3         | some     | N                |                      |              |                       |                       |  |  |  |
| COQ4         | some     | N                | Cu/plastic           | 10           | None                  | 10                    |  |  |  |
| COQ5         | Ν        | N                | Unknown              | 11           | minor pipes           | 5                     |  |  |  |
| COQ6         | N        | N                | Plastic              | 15           | None                  | 1                     |  |  |  |
| COQ7         | Ν        | N                | Copper               | 44           | None                  | <8                    |  |  |  |
| COQ8         | Y        | N                | Copper               | 18           | N                     | 3                     |  |  |  |
| COQ9         |          |                  |                      |              |                       |                       |  |  |  |
| COQ10        | N        | N                | Unknown              | 22           | None                  | 2                     |  |  |  |
| COQ11        | N        | N                | Copper               | 16           | Ν                     | 15                    |  |  |  |
| COQ13        | Ν        | N                | Unknown              | 12           | None                  | 3                     |  |  |  |
| COQ14        | some     | N                | Plastic              | 20           | None                  | 12                    |  |  |  |
| COQ15        | some     | N                | Cu/plastic           | 22           | Uknown                | 4                     |  |  |  |
| COQ16        | N        | N                | Unknown              | 2            | None                  | 2                     |  |  |  |
| <b>COQ17</b> | some     | Y                | Copper               | 40           | None                  | 4                     |  |  |  |
| COQ18        | Ν        | N                | Cu/Plastic           | 27           | None                  | 7                     |  |  |  |

# Summarized results of the questionnaire

| COQ19 | N        | N        | Plastic    | 2    | None     | 3       |  |  |
|-------|----------|----------|------------|------|----------|---------|--|--|
| COQ20 | N        | N        | Copper     | 35+  | Unknown  | Unknown |  |  |
| COQ21 | Ν        | N        | Copper     | 13   | None     | 13      |  |  |
| COQ22 | some     | N        | Copper     | 14   | None     | 14      |  |  |
| COQ23 | N        | N        | Cu/Plastic | 8    | None     | 8       |  |  |
| COQ24 | . N      | N        | Copper     | 9    | None     | 9       |  |  |
| COQ25 | Ν        | N        | Copper     | 25   | None     | 4       |  |  |
| COQ26 | Y        | N        | Unknown    | 6    | Unknown  | 5       |  |  |
| COQ27 | Ν        | N        | Copper     | 35   | None     | 15      |  |  |
| COQ28 | Ν        | N        | Plastic    | 13   | 2        | 2       |  |  |
| COQ29 | N        | N        | Plastic    | 0.17 | None     | NEW     |  |  |
| COQ30 | N        | N        | Plastic    | 9    | None     | 4       |  |  |
| COQ31 | Y        | N        | Copper     | 80   | 30       | 10      |  |  |
| COQ32 | N        | <u> </u> | Cu/Plastic | 40   | Unknown  | 8       |  |  |
| COQ33 | Y        | <u>N</u> | Cu/Plastic | 2.5  | 30       | 2.5     |  |  |
| COQ34 | N        | N        | Plastic    | 37   | 5        | 5       |  |  |
| COQ35 | N        | N        | Plastic    | 4    | N        | 4       |  |  |
| COQ36 | some     | N        | Copper     | 22   | None     | 12      |  |  |
| COQ37 | some     | N        | Copper     | 37   | None     | NEW     |  |  |
| NEW1  | N        | N        | Copper     | 7    | N        | 7       |  |  |
| NEW2  | some     | N        | Cu/Plastic | 19   | <u>N</u> | 1       |  |  |
| NEW3  | N        | <u>N</u> | Cu/plastic | 22   | N        | Unknown |  |  |
| NEW4  | N        | some     | Copper     | 20   | N        | 3       |  |  |
| NEW5  | N        | N        | Cu/plastic | 1    | N        | 1       |  |  |
| NEW6  | N        | N        | Copper     | 48   | Unknown  | 6       |  |  |
| NEW7  | N        | <u>N</u> | Copper     | 30   | N        | NEW     |  |  |
| NEW8  | N        | N        | Cu/plastic | 20   | Unknown  | 3       |  |  |
| NEW10 | <u>N</u> | <u>N</u> | Plastic    | 15   | None     | 3       |  |  |
| NEW9  | <u> </u> | <u>N</u> | Copper     | 9    | · N      | 9       |  |  |
| NEW11 | <u>N</u> | <u>N</u> | Copper     | 27   | None     | 3       |  |  |
| NEW12 | <u> </u> | <u> </u> | Copper     | 25   | None     | 5       |  |  |
| NEW13 | <u>N</u> | <u>N</u> | Copper     | 14   | None     | 1       |  |  |
|       | some     | N        |            | 27   | Unknown  | Unknown |  |  |
| NEW15 | <u>N</u> | IN .     | Plastic    | 13   | INONE    | 4       |  |  |
| NEW10 | NI       | N 1      | 0          | 4.4  | Nene     |         |  |  |
|       | IN       | IN N     | Copper     | 11   | INONE    | Unknown |  |  |
| SET1  | some     | N        | Copper     | 33   | <u>N</u> | 12      |  |  |
| JETZ  |          |          |            |      |          |         |  |  |
| SEIJ  | NI       | NI NI    | Diastia    |      | NI       | 7       |  |  |
| SEVE  | IN       | IN<br>NI | Plastic    | (    |          |         |  |  |
| SEVO  | some     | IN NI    |            | 30   |          |         |  |  |
| SE10  |          |          | Copper     | 14   | J        |         |  |  |
|       | N        |          | Copper     | 20U  |          |         |  |  |
| SEY8  |          |          | Uu/plastic | 80   | Unknown  | Unknown |  |  |

| SEY9  | Y    | N              | Copper     | 50 | 40      | 2       |  |  |
|-------|------|----------------|------------|----|---------|---------|--|--|
| SEY10 | Ν    | N              | Copper     | 65 | >20 yr  | 9       |  |  |
| SEY11 | Ν    | N              | Copper     | 14 | Unknown | 1       |  |  |
| SEY12 | Y    | N              | unknown    | 5  | None    | 5       |  |  |
| SEY13 |      |                |            |    |         |         |  |  |
| SEY14 |      |                |            |    |         |         |  |  |
| SEY15 | some | N              | Copper     | 80 | Unknown | 10      |  |  |
| SEY16 | some | N              | Copper     | 46 | Unknown | 13      |  |  |
| SEY17 | N    | N              | unknown    | 30 | None    | 5       |  |  |
| SEY18 |      |                |            |    |         |         |  |  |
| SEY19 | N    | N              | Copper     | 30 | Unknown | 10      |  |  |
| SEY20 |      |                |            |    |         |         |  |  |
| SEY21 | some | some           | Copper     | 42 | 7       | 9       |  |  |
| SEY22 | some | N              | Copper     | 30 | None    | Unknown |  |  |
| SEY23 | N    | N              | Copper     | 35 | 5       | 12      |  |  |
| SEY25 | Ý    | N              | Copper     | 2  | None    | 2       |  |  |
| SEY26 | some | Y              | Copper     | 28 | None    | Unknown |  |  |
| SEY27 |      |                |            |    |         |         |  |  |
| SEY28 | Y    | N <sup>1</sup> | Cu/plastic | 22 | N       | Unknown |  |  |

Appendix C: Quality Assurance and Quality Control Data

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|         |         | %     |         | 8     | 1       | ~     | I       | ~     | 1       | ~     |         | ~     |         | ~     |         | ~     |         | %     |         | ~      | 1       | %     |         | %      |         | %     |         | ~     |         | ~     |         | %     |         | %     |         | %     |         | ~     | %         |
|---------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|---------|--------|---------|-------|---------|--------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|-----------|
| % Diff. |         | 11.19 |         | 10.09 |         | 20.0% |         | 0.0   |         | 50.09 |         | 0.0%  |         | 33.39 |         | 33.3% |         | 50.0% |         | 100.09 |         | 50.0% |         | 0.0%   |         | 60.0  |         | 60.0  |         | 0.0%  |         | 50.0% |         | 0.0%  |         | 60.03 |         | 33.3% | 25.4%     |
| uΖ      | 0.08    | 0.09  | 0.09    | 0.10  | 0.04    | 0.05  | 0.06    | 0.06  | 0.02    | 0.01  | 0.04    | 0.04  | 0.02    | 0.03  | 0.02    | 0.03  | 0.01    | 0.02  | 0.02    | 0.01   | 0.01    | 0.02  | 0.02    | 0.02   | 0.01    | 0.01  | 0.01    | 0.01  | 0.10    | 0.10  | 0.01    | 0.02  | 0.03    | 0.03  | 0.01    | 0.02  | 0.04    | 0.06  |           |
| % Diff. |         | 4.7%  |         | 14.2% |         | %0.0  |         | 2.3%  |         | 17.5% |         | 28.6% |         | 36.7% |         | 3.8%  |         | 42.9% |         | 44.4%  |         | 20.0% |         | 4.3%   |         | 20.0% |         | 6.9%  |         | 11.1% |         | 0.0%  |         | 5.8%  |         | 0.0%  |         | 12.2% | 14.6%     |
| cn      | 2.15    | 2.05  | 2.04    | 1.75  | 0.66    | 0.66  | 1.73    | 1.69  | 0.85    | 1.03  | 0.10    | 0.14  | 0:30    | 0.19  | 0.52    | 0.50  | 0.08    | 0.14  | 60.0    | 0.05   | 0.04    | 0.05  | 0.23    | 0.22   | 0.04    | 0.05  | 0.29    | 0.27  | 0.80    | 06.0  | 0.02    | 0.02  | 1.63    | 1.73  | 1.00    | 1.00  | 0.65    | 0.74  |           |
| % Diff. |         | %0'0  |         | %0.0  |         | %0.0  |         | 18.2% |         | 33.3% |         | %0.0  |         | %0'0  |         | 12.5% |         | %0'0  |         | 50.0%  |         | 84.4% |         | 14.3%  |         | %0'0  |         | 10.0% |         | 14.3% |         | %0.0  |         | 0.0%  |         | 10.0% |         | 16.7% | 13.7%     |
| qd      | 0.003   | 0.003 | 0.003   | 0.003 | 0.018   | 0.018 | 0.009   | 0.011 | 0.027   | 0.018 | 0.003   | 0.003 | 0.003   | 0.003 | 0.007   | 0.008 | 0.003   | 0.003 | 0.006   | 0.003  | 0.003   | 0.016 | 0.014   | 0.012  | 0.003   | 0.003 | 0.009   | 0.010 | 0.006   | 0.007 | 0.003   | 0.003 | 0.003   | 0.003 | 0.009   | 0.010 | 0.005   | 0.006 |           |
| Type    | Cold #2 |        | Cold #2 |       | Cold #2 |        | Cold #2 |       | Cold #2 |       | Cold #2 |       | Cold #2 |       | Cold #2 |       | Cold #2 |       | Cold #2 |       |           |
| % Diff. |         | 7.3%  |         | 3.1%  |         | 27.2% |         | 33.3% |         | %0.0  |         | 8.3%  |         | %0'0  |         | 67.0% |         | 15.9% |         | 3.8%   |         | 33.3% |         | 13.3%  |         | %0'0  |         | 20.0% |         | 8.1%  |         | 48.3% |         | 8.1%  |         | 25.0% |         | 18.3% | 17.9%     |
| uZ      | 1.24    | 1.15  | 1.23    | 1.27  | 1.03    | 1.31  | 0.24    | 0.16  | 0.20    | 0.20  | 0.11    | 0.12  | 0.03    | 0.03  | 0.29    | 0.88  | 0.37    | 0.44  | 0.26    | 0.25   | 0.02    | 0.03  | 0.26    | 0.30   | 0.15    | 0.15  | 0.04    | 0.05  | 1.36    | 1.48  | 0.15    | 0.29  | 0.37    | 0.34  | 0.27    | 0.36  | 0.76    | 0.93  |           |
| % Diff. |         | 8.5%  |         | 3.1%  |         | 12.9% |         | 9.4%  |         | 1.5%  |         | 4.2%  |         | 9.8%  |         | 35.1% |         | 2.5%  |         | 6.7%   |         | 0.0%  |         | 17.4%  |         | %0.0  |         | 0.0%  |         | 13.2% |         | 80.6% |         | 12.0% |         | 9.9%  |         | 5.1%  | 12.6%     |
| υu      | 0.82    | 0.75  | 0.95    | 0.98  | 0.54    | 0.62  | 1.15    | 1.27  | 0.66    | 0.67  | 0.23    | 0.24  | 0.37    | 0.41  | 0.37    | 0.24  | 0.40    | 0.39  | 0.14    | 0.15   | 0.05    | 0.05  | 0.19    | 0.23   | 0.12    | 0.12  | 0.26    | 0.26  | 0.46    | 0.53  | 0.06    | 0.31  | 0.92    | 0.81  | 0.71    | 0.64  | 0.37    | 0.39  |           |
| % Diff. |         | %0.0  |         | %0.0  |         | 42.9% |         | 19.3% |         | 9.1%  |         | %0.0  |         | %0.0  |         | 50.0% |         | %0.0  |         | %0.0   |         | %0.0  |         | 41.7%  |         |       |         | 9.1%  |         | 12.5% |         | 52.6% |         | 0.0%  |         | 24.0% |         | 0.0%  | 15.4%     |
| Ър      | 0.016   | 0.016 | 0.003   | 0.003 | 0.008   | 0.014 | 0.057   | 0.046 | 0.010   | 0.011 | 0.003   | 0.003 | 0.003   | 0.003 | 0.034   | 0.017 | 0.003   | 0.003 | 0.003   | 0.003  | 0.003   | 0.003 | 0.007   | .0.012 | 0.005   | 0.005 | 0.010   | 0.011 | 0.008   | 0.007 | 0.009   | 0.019 | 0.003   | 0.003 | 0.025   | 0.019 | 0.014   | 0.014 | % Differe |
| Type    | Cold#1  |        | Cold#1  |       | Cold#1  |        | Cold#1  |       | Cold#1  |       | Cold#1  |       | Cold#1  |       | Cold#1  |       | Cold#1  |       | Cold#1  |       | Average   |
| #       | 5       |       | 7       |       | ი       |       | 13      |       | 14      |       | 4       |       | 8       |       | 15      |       | 23      |       | e       |        | 5       |       | 7       |        | 12      |       | 14      | •     | 6       |       | 11      |       | 14      |       | 16      |       | 21      |       |           |
| Source  | Cap     |       | Cod     |       | Coq     |       | Coq     |       | Coq     |       | New     |        | New     |       | New     |        | New     |       | New     |       | Sey     |       | Sey     |       | Sey     |       | Sey     |       | Set.    | '6    |           |

| Sessio |            |  |
|--------|------------|--|
| Metal  | Duplicates |  |

|        | 0 %     |
|--------|---------|
|        | ວັ      |
|        | % Diff. |
|        | Pp      |
| sion 1 | Type    |
| Ses    | #       |

| 23.15%  |      | 15.27%  |      | 2.78%   |       |        | 11.11%  |      | 8.92%   |      | %00.0   |       | Average |          |        |
|---------|------|---------|------|---------|-------|--------|---------|------|---------|------|---------|-------|---------|----------|--------|
| 50.00%  | 0.01 | 10.00%  | 0.20 | 0.00%   | 0.003 |        | 0.00%   | 0.01 | 10.00%  | 0.10 | 0.00%   | 0.003 |         |          |        |
|         | 0.01 |         | 0.18 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.09 |         | 0.003 | Cold#3  | 5        | Sey    |
| 0.00%   | 0.01 | 5.41%   | 0.35 | 0.00%   | 0.003 | # 101  | 0.00%   | 0.01 | 0.00%   | 0.12 | 0.00%   | 0.003 | 24nnoo  | 2        | oey    |
| 0.00%   | 0.01 | 2.17%   | 0.46 | %00.0   | 0.003 | 1      | 50.00%  | 0.01 | 6.45%   | 0.29 | 0.00%   | 0.003 | 0#11-0  |          | ć      |
|         | 0.01 |         | 0.45 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.31 |         | 0.003 | Cold#3  | 4        | Sey    |
| 50.00%  | 0.01 | 16.67%  | 0.06 | 0.00%   | 0.003 |        | %00'0   | 0.01 | 0.00%   | 0.02 | 0.00%   | 0.003 |         |          |        |
|         | 0.01 |         | 0.05 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.02 |         | 0.003 | Cold#3  | 11       | Sey    |
| 50.00%  | 0.01 | 52.73%  | 0.26 | 0.00%   | 0.003 |        | 0.00%   | 0.01 | 10.00%  | 0.10 | 0.00%   | 0.003 |         |          |        |
|         | 0.02 |         | 0.55 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.09 |         | 0.003 | Cold#3  | 9        | Sey    |
| %00.0   | 0.01 | 23.08%  | 0.26 | %00'0   | 0.003 |        | %00'0   | 0.01 | %00'0   | 0.04 | %00'0   | 0.003 |         |          |        |
|         | 0.01 |         | 0.20 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.04 |         | 0.003 | Cold#3  | 14       | New    |
| 0.00%   | 0.01 | 25.00%  | 0.04 | %00.0   | 0.003 |        | %00'0   | 0.01 | 0.00%   | 0.02 | 0.00%   | 0.003 |         |          |        |
|         | 0.01 |         | 0.03 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.02 |         | 0.003 | Cold#3  | 12       | New    |
| %00.0   | 0.01 | 11.11%  | 0.08 | 0.00%   | 0.003 |        | 0.00%   | 0.01 | 20.00%  | 0.04 | 0.00%   | 0.003 |         |          |        |
| × 00.0  | 0.01 | %,00.0  | 60.0 | %.00.0  | 0.003 | Hot #1 | %,nn.n  | 0.01 | *nn.u4  | 0.05 | % ^^^   | 0.003 | Cold#3  | ~        | New    |
|         | 0.01 |         | 0.03 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.03 |         | 0.003 | Cold#3  | £        | New    |
| %00.0   | 0.01 | 25.00%  | 0.06 | %00:0   | 0.003 |        | %00'0   | 0.01 | %00.0   | 0.02 | 0.00%   | 0.003 |         |          |        |
|         | 0.01 |         | 0.08 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.02 |         | 0.003 | Cold#3  | e        | New    |
| 50.00%  | 0.01 | 56.52%  | 0.10 | %00.0   | 0.003 |        | 50.00%  | 0.01 | %00'0   | 0.02 | 0.00%   | 0.003 |         |          |        |
|         | 0.01 |         | 0.23 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.02 |         | 0.003 | Cold#3  | 53       | Cod    |
| 50.00%  | 0.01 | %00.0   | 0.18 | 50.00%  | 0.005 |        | %00'0   | 0.01 | 12.50%  | 0.07 | 0.00%   | 0.003 |         |          |        |
|         | 0.01 |         | 0.18 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.08 |         | 0.003 | Cold#3  | 15       | Cod    |
| 50.00%  | 0.01 | 6.90%   | 0.27 | %00:0   | 0.003 | 1      | 0.00%   | 0.01 | %00'0   | 0.03 | 0.00%   | 0.003 |         |          |        |
|         | 0.01 |         | 0.29 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.03 |         | 0.003 | Cold#3  | ω        | ğ      |
| 00.0%   | 0.01 | 35.71%  | 0.14 | %00.0   | 0.003 |        | 0.00%   | 0.01 | %00.0   | 0.02 | %00.0   | 0.003 |         |          |        |
|         | 0.01 |         | 0.09 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.02 |         | 0.003 | Cold#3  | 4        | Cod    |
| 50.00%  | 0.01 | 3.33%   | 0.29 | %00:0   | 0.003 |        | 50.00%  | 0.01 | %00.0   | 0.07 | %00.0   | 0.003 |         |          |        |
|         | 0.01 |         | 0:30 |         | 0.003 | Hot #1 |         | 0.01 | 2       | 0.07 |         | 0.003 | Cold#3  | 4        | Cap    |
| 50.00%  | 0.01 | 5.41%   | 0.37 | %00.0   | 0.003 |        | 0.00%   | 0.01 | 0.00%   | 0.20 | %00.0   | 0.003 |         |          |        |
|         | 0.01 |         | 0.35 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.20 |         | 0.003 | Cold#3  | 13       | Cap    |
| %00.0   | 0.01 | %00.0   | 0.25 | 0.00%   | 0.003 |        | 50.00%  | 0.01 | 20.00%  | 0.05 | %00.0   | 0.003 |         |          |        |
|         | 0.01 |         | 0.25 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.04 |         | 0.003 | Cold#3  | <u>о</u> | Cap    |
| 33.33%  | 0.03 | 1.25%   | 0.80 | 0.00%   | 0.003 |        | %00.0   | 0.02 | 28.57%  | 0.14 | %00.0   | 0.003 |         |          |        |
|         | 0.02 |         | 0.79 |         | 0.003 | Hot #1 |         | 0.02 |         | 0.10 |         | 0.003 | Cold#3  | ~        | Cap    |
| 33.33%  | 0.03 | 4.62%   | 0.65 | 0.00%   | 0.003 |        | 0.00%   | 0.01 | 23.08%  | 0.10 | %00.0   | 0.003 |         |          |        |
|         | 0.02 |         | 0.62 |         | 0.003 | Hot #1 |         | 0.01 |         | 0.13 |         | 0.003 | Cold#3  | 5        | Cap    |
| % Diff. | υZ   | % Diff. | Си   | % Diff. | qd    | Type   | % Diff. | Zn   | % Diff. | си   | % Diff. | Pb    | Type    | #        | Source |

| GVRD                  | Lead   |         |         | Coppe  |        |         | Zinc  |       |         |
|-----------------------|--------|---------|---------|--------|--------|---------|-------|-------|---------|
| All Cold <sup>1</sup> | #2     |         |         |        |        |         |       |       |         |
|                       |        |         |         |        |        |         |       |       |         |
| Sample                | GVRD   | Study   | % diff. | GVRD   | Study  | % diff. | GVRD  | Study | % diff. |
| Blank                 | <0.001 | <0.005  |         | <0.001 | <0.03  |         | 0.002 | <0.01 |         |
|                       |        |         |         |        |        |         |       |       |         |
| CAP 5                 | 0.005  | 0.0025  | 50.0%   | 2.20   | 215.0% | 2.27%   | 0.10  | 0.09  | 10.00%  |
| CAP 7                 | 0.003  | 0.0025  | 16.7%   | 1.56   | 175.0% | 10.86%  | 0.12  | 0.1   | 14.53%  |
| CAP 9                 | 0.021  | 0.018   | 14.3%   | 0.738  | 66.0%  | 10.57%  | 0.07  | 0.05  | 29.58%  |
| <b>CAP 13</b>         | 0.013  | 0.011   | 15.4%   | 1.83   | 173.0% | 5.46%   | 0.06  | 0.06  | 4.76%   |
| <b>CAP 14</b>         | 0.022  | 0.018   | 18.2%   | 1.13   | 103.0% | 8.85%   | 0.02  | 0.02  | 5.00%   |
|                       |        |         |         |        |        |         |       |       |         |
| COQ 4                 | 0.003  | 0.0025  | 16.7%   | 0.128  | 14.0%  | 8.57%   | 0.06  | 0.04  | 27.27%  |
| COQ 8                 | 0.003  | 0.0025  | 16.7%   | 0.196  | 19.0%  | 3.06%   | 0.04  | 0.03  | 14.29%  |
| COQ 15                | 0.009  | 0.008   | 11.1%   | 0.521  | 52.0%  | 0.19%   | 0.04  | 0.03  | 30.23%  |
| COQ 23                | 0.003  | 0.0025  | 16.7%   | 0.144  | 14.0%  | 2.78%   | 0.04  | 0.02  | 47.37%  |
| COQ 34                | 0.003  | 0.0025  | 16.7%   | 0.227  | 25.0%  | 9.20%   | 0.10  | 0.08  | 15.79%  |
|                       |        |         |         |        |        |         |       |       |         |
| NEW 3                 | 0.004  | 0.0025  | 37.5%   | 0.058  | 5.0%   | 13.79%  | 0.01  | 0.01  | 28.57%  |
| NEW 5                 | 0.001  | 0.0025  | 150.0%  | 0.036  | 4.0%   | 10.00%  | 0.03  | 0.02  | 37.50%  |
| NEW 7                 | 0.014  | 0.014   | %0.0    | 0.204  | 22.0%  | 7.27%   | 0.03  | 0.005 | 80.00%  |
| <b>NEW 12</b>         | 0.002  | 0.0025  | 20.0%   | 0.049  | 5.0%   | 2.00%   | 0.02  | 0.01  | 20.00%  |
| <b>NEW 14</b>         | 0.011  | 0.01    | 9.1%    | 0.285  | 29.0%  | 1.72%   | 0.01  | 0.005 | 37.50%  |
|                       |        |         |         |        |        |         |       |       |         |
| SEY 6                 | 0.007  | 0.006   | 14.3%   | 0.974  | 80.0%  | 17.86%  | 0.12  | 0.12  | 2.50%   |
| SEY 11                | 0.001  | 0.0025  | 60.0%   | 0.028  | 2.0%   | 28.57%  | 0.03  | 0.02  | 33.33%  |
| SEY 14                | 0.002  | 0.0025  | 20.0%   | 1.87   | 173.0% | 7.49%   | 0.04  | 0.03  | 18.92%  |
| SEY 16                | 0.011  | 0.01    | 9.1%    | 1.08   | 100.0% | 7.41%   | 0.02  | 0.02  | 16.67%  |
| SEY 21                | 0.001  | 0.0025  | 60.0%   | 0.792  | 74.0%  | 6.57%   | 0.08  | 0.06  | 21.05%  |
|                       |        | average | 28.6%   |        |        | 8.23%   |       |       | 26.24%  |

|            | Test Sa  | nples    |          |
|------------|----------|----------|----------|
|            | Lead     | Copper   | Zinc     |
| Test Conc. | 30 ppb - | 1.40 ppm | 1.03 ppm |
|            | 30.00    | 1.39     | 1.00     |
|            | 29.00    | 1.40     | 1.04     |
|            | 30.00    | 1.41     | 1.03     |
|            | 27.00    | 1.43     | 1.05     |
|            | 27.00    | 1.42     | 1.05     |
|            | 26.00    | 1.36     | 1.01     |
|            | 39.00    | 1.39     | 1.04     |
|            | 32.00    | 1.41     | 1.04     |
|            | 30.00    | 1.37     | 1.03     |
|            | 26.00    | 1.38     | 1.04     |
|            | 34.00    | 1.43     | 1.05     |
|            | 30.00    | 1.40     | 1.02     |
|            | 30.00    | 1.42     | 1.03     |
|            | 27.00    | 1.41     | 1.04     |
|            | 28.00    | 1.40     | 1.05     |
|            | 32.00    | 1.37     | 1.00     |
|            | 27.00    | 1.34     | 0.92     |
|            | 30.00    | 1.39     | 1.01     |
|            | 24.00    | 1.34     | 1.01     |
|            | 39.00    | 1.35     | 1.03     |
|            | 33.00    | 1.37     | 0.98     |
|            | 29.00    | 1.31     | 0.91     |
|            | 26.00    | 1.37     | 0.99     |
|            | 35.00    | 1.36     | 1.00     |
|            | 37.00    | 1.39     | 1.03     |
|            | 30.00    | 1.37     | 1.04     |
|            | 31.00    | 1.39     | 1.01     |
|            | 30.00    | 1.35     | 1.04     |
|            | 30.00    | 1.33     | 1.01     |
|            | 30.28    | 1.34     | 1.03     |
|            |          | 1.37     | 1.04     |
|            |          | 1.37     | 1.01     |
|            |          | 1.38     | 1.03     |
|            |          | 1.37     | 1.01     |
|            |          | 1.27     | 0.98     |
|            |          | 1.54     | 1.08     |
|            |          | 1.40     | 0.93     |
|            |          | 1.54     | 1.06     |
| Average    | 30.28    | 1.39     | 1.02     |

| ion 1 | llanks (mg/L) | <br>Copper Zinc | i <0.03 <0.01 | <pre>&lt; &lt; 0.03 &lt; 0.01</pre> | 6 <0.03 <0.01 | i <0.03 <0.01 | <pre>&lt; &lt; 0.03 &lt; 0.01</pre> | 6 <0.03 <0.01 | i <0.03 <0.01 | 6 < 0.03 < 0.01 | i <0.03 <0.01 | i <0.03 <0.01 | <pre>&lt; &lt; 0.03 &lt; 0.01</pre> | <0.03  <0.01 | 6 <0.03 <0.01 |
|-------|---------------|-----------------|---------------|-------------------------------------|---------------|---------------|-------------------------------------|---------------|---------------|-----------------|---------------|---------------|-------------------------------------|--------------|---------------|
| Sessi | Field BI      | Lead            | <0.005        | <0.005                              | <0.005        | <0.005        | <0.005                              | <0.005        | <0.005        | <0.005          | <0.005        | <0.005        | <0.005                              | <0.005       | <0.005        |

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Metal Session 2 Duplicates

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| Source | #  | Type   | Ч     | % Diff. | J    | % Diff. | Zn   | % Diff. | Type    | Чd    | % Diff. | υ    | % Diff. | Zn   | % Diff. |
|--------|----|--------|-------|---------|------|---------|------|---------|---------|-------|---------|------|---------|------|---------|
| Cap    | 5  | Cold#1 | 0.012 | 29.4%   | 0.78 | 7.9%    | 1.22 |         | Cold #2 | 0.016 |         | 1.80 |         | 0.09 |         |
|        |    |        | 0.017 |         | 0.85 |         | 0.96 | 21.7%   |         | 0.005 | 68.8%   | 1.50 | 16.9%   | 0.04 | 48.2%   |
| Cap    | 7  | Cold#1 | 0.003 | 77.3%   | 1.13 | 12.3%   | 1.19 | 4.6%    | Cold #2 | 0.003 | 83.3%   | 2.29 | 0.4%    | 0.07 |         |
|        |    |        | 0.011 |         | 1.29 |         | 1.25 |         |         | 0.015 |         | 2.30 |         | 0.07 | 1.4%    |
| Cap    | 6  | Cold#1 | 0.003 | %0.0    | 0.30 |         | 1.00 | 1.1%    | Cold #2 | 0.006 |         | 0.55 |         | 0.05 |         |
|        |    |        | 0.003 |         | 0.29 | 2.6%    | 1.01 |         |         | 0.003 | 58.3%   | 0.49 | 10.9%   | 0.04 | 8.7%    |
| Cap    | 14 | Cold#1 | 0.017 | 29.2%   | 0.48 | 13.5%   | 0.22 |         | Cold #2 | 0.009 |         | 0.79 |         | 0.01 | 0.0%    |
|        |    |        | 0.024 |         | 0.56 |         | 0.19 | 11.6%   |         | 0.003 | 72.2%   | 0.15 | 81.0%   | 0.01 |         |
| Coq    | 4  | Cold#1 | 0.005 |         | 0.25 | 7.4%    | 0.10 |         | Cold #2 | 0.003 | 0.0%    | 0.10 | 14.9%   | 0.02 | 28.3%   |
|        |    |        | 0.003 | 50.0%   | 0.27 |         | 0.06 | 40.0%   |         | 0.003 |         | 0.12 |         | 0.03 |         |
| Coq    | 8  | Cold#1 | 0.006 |         | 0.46 |         | 0.71 | 26.0%   | Cold #2 | 0.003 | %0.0    | 0.40 | 23.5%   | 0.02 | 59.8%   |
|        |    |        | 0.003 | 58.3%   | 0.42 | 8.7%    | 0.96 |         |         | 0.003 |         | 0.52 |         | 0.06 |         |
| Coq    | 11 | Cold#1 | 0.005 | 64.3%   | 0.77 |         | 0.05 | %0'0    | Cold #2 | 0.008 |         | 1.50 |         | 0.06 |         |
|        |    |        | 0.014 |         | 0.64 | 16.9%   | 0.05 |         |         | 0.003 | 68.8%   | 0.26 | 82.5%   | 0.02 | 67.1%   |
| Coq    | 15 | Cold#1 | 0.006 | 33.3%   | 0.43 |         | 0.45 |         | Cold #2 | 0.005 | 0.0%    | 0.44 |         | 0.03 | 12.8%   |
|        |    |        | 0.009 |         | 0.16 | 62.8%   | 0.19 | 57.8%   |         | 0.005 |         | 0.38 | 14.6%   | 0.04 |         |
| Cod    | 23 | Cold#1 | 0.003 | %0.0    | 0.36 | 21.7%   | 0.57 | %0'0    | Cold #2 | 0.003 | 82.1%   | 0.08 |         | 0.02 | 34.2%   |
|        |    |        | 0.003 |         | 0.46 |         | 0.57 |         |         | 0.014 |         | 0.08 | 6.5%    | 0.03 |         |
| New    | 3  | Cold#1 | 0.003 | %0.0    | 0.15 |         | 0.29 |         | Cold #2 | 0.003 | %0.0    | 0.10 |         | 0.04 |         |
|        |    |        | 0.003 |         | 0.14 | 6.7%    | 0.22 | 24.1%   |         | 0.003 |         | 0.07 | 22.2%   | 0.02 | 35.9%   |
| New    | 5  | Cold#1 | 0.003 | %0'0    | 0.15 |         | 0.23 |         | Cold #2 | 0.003 | %0.0    | 0.01 | 49.3%   | 0.02 | 88.8%   |
|        |    |        | 0.003 |         | 0.02 | 80.0%   | 0.19 | 17.4%   |         | 0.003 |         | 0.02 |         | 0.16 |         |
| New    | 7  | Cold#1 | 0.005 |         | 0.09 | 18.2%   | 0.09 | 18.2%   | Cold #2 | 0.003 | %0.0    | 0.08 | 3.7%    | 0.01 | 39.2%   |
|        |    |        | 0.003 | 20.0%   | 0.11 |         | 0.11 |         |         | 0.003 |         | 0.08 |         | 0.02 |         |
| New    | 12 | Cold#1 | 0.006 |         | 0.16 |         | 0.14 |         | Cold #2 | 0.003 | 0.0%    | 0.18 | 0.1%    | 0.02 |         |
|        |    |        | 0.003 | 58.3%   | 0.11 | 31.3%   | 0.02 | 85.7%   |         | 0.003 |         | 0.18 |         | 0.01 | 52.1%   |
| New    | 14 | Cold#1 | 0.009 |         | 0.29 |         | 0.08 | 11.1%   | Cold #2 | 0.003 | %0.0    | 0.29 |         | 0.01 | 0.0%    |
|        |    |        | 0.006 | 33.3%   | 0.28 | 3.4%    | 0.09 |         |         | 0.003 |         | 0.28 | 2.5%    | 0.01 |         |
| Sey    | 9  | Cold#1 |       |         | 0.45 |         | 1.16 |         | Cold #2 | 0.012 | %0'0    | 0.81 | 3.0%    | 0.07 |         |
|        |    |        |       |         | 0.42 | 6.7%    | 1.15 | %6'0    |         | 0.012 |         | 0.83 |         | 0.07 | 2.2%    |
| Sey    | 14 | Cold#1 |       |         | 0.46 | %0.0    | 0.31 | 3.1%    | Cold #2 | 0.003 | %0'0    | 1.04 | 0.2%    | 0.04 | 8.2%    |
|        |    |        |       | 1       | 0.46 |         | 0.32 |         |         | 0.003 |         | 1.04 |         | 0.04 |         |
| Sey    | 16 | Cold#1 |       |         | 0.71 | 13.4%   | 0.41 |         | Cold #2 | 0.011 |         | 0.73 | 26.8%   | 0.02 | 2.4%    |
|        |    |        |       |         | 0.82 |         | 0.38 | 7.3%    |         | 0.006 | 45.5%   | 0.99 |         | 0.02 |         |
| Sey    | 21 | Cold#1 |       |         | 0.32 | 3.0%    | 0.75 |         | Cold #2 | 0.006 |         | 0.69 |         | 0.04 | 8.0%    |
|        |    |        |       |         | 0.33 |         | 0.69 | 8.0%    |         | 0.003 | 58.3%   | 0.65 | 6.8%    | 0.04 |         |

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|---------|-------|--------|------|--------|------|--------|--------|-------|--------|------|--------|------|--------|
| Type    | Ч     |        | Сu   |        | μZ   |        | Type   | Ч     |        | nD   |        | Zn   |        |
| Cold#3  | 0.003 | 0.00%  | 0.23 |        | 0.02 |        | Hot #1 | 0.003 | %00.0  | 1.72 | 7.89%  | 0.15 |        |
|         | 0.003 |        | 0.13 | 42.48% | 0.01 | 68.75% |        | 0.003 |        | 1.86 |        | 0.13 | 13.79% |
| Cold#3  | 0.003 | %00.0  | 0.13 | 8.76%  | 0.02 |        | Hot #1 | 0.003 | %00.0  | 0.93 | 4.79%  | 0.13 |        |
|         | 0.003 |        | 0.14 |        | 0.01 | 66.67% |        | 0.003 |        | 0.98 |        | 0.13 | %62.0  |
| Cold#3  | 0.003 | 0.00%  | 0.03 | 93.17% | 0.01 | %00'0  | Hot #1 | 0.003 | 0.00%  | 0.25 |        | 0.01 | 0.00%  |
|         | 0.003 |        | 0.41 |        | 0.01 |        |        | 0.003 |        | 0.25 | 2.76%  | 0.01 |        |
| Cold#3  | 0.003 | %00.0  | 0.05 | 16.95% | 0.01 | 16.67% | Hot #1 | 0.003 | 0.00%  | 0.45 |        | 0.01 | 70.59% |
|         | 0.003 |        | 0.06 |        | 0.01 |        |        | 0.003 |        | 0.43 | 3.34%  | 0.02 |        |
| Cold#3  | 0.003 | 0.00%  | 0.02 | 0.00%  | 0.01 | 5.66%  | Hot #1 | 0.003 | %00.0  | 60.0 | 39.86% | 0.02 |        |
|         | 0.003 |        | 0.02 |        | 0.01 |        |        | 0.003 |        | 0.14 |        | 0.01 | 42.86% |
| Cold#3  | 0.003 | 0.00%  | 0.02 | 0.00%  | 0.02 |        | Hot #1 | 0.007 |        | 0.35 |        | 0.02 | 1.74%  |
|         | 0.003 |        | 0.02 |        | 0.01 | 22.67% |        | 0.003 | 64.29% | 0.25 | 28.12% | 0.02 |        |
| Cold#3  | 0.008 |        | 0.23 |        | 0.03 |        | Hot #1 | 0.003 | 0.00%  | 0.16 | 23.67% | 0.01 | 12.74% |
|         | 0.003 | 68.75% | 0.19 | 16.50% | 0.02 | 37.08% |        | 0.003 |        | 0.21 |        | 0.02 |        |
| Cold#3  | 0.003 | 0.00%  | 0.03 | 8.46%  | 0.02 |        | Hot #1 | 0.003 | 0.00%  | 0.17 | 6.21%  | 0.02 | 16.35% |
|         | 0.003 |        | 0.03 |        | 0.01 | 71.59% |        | 0.003 |        | 0.18 |        | 0.02 |        |
| Cold#3  | 0.003 | 0.00%  | 0.02 | 0.00%  | 0.01 | %00.0  | Hot #1 | 0.003 | 0.00%  | 0.05 | 4.17%  | 0.01 | 33.33% |
|         | 0.003 |        | 0.02 |        | 0.01 |        |        | 0.003 |        | 0.05 |        | 0.01 |        |
| Cold#3  | 0.003 | 0.00%  | 0.02 | 0.00%  | 0.01 | %00.0  | Hot #1 | 0.003 | 0.00%  | 0.05 | 26.91% | 0.03 | 18.56% |
|         | 0.003 |        | 0.02 |        | 0.01 |        |        | 0.003 |        | 0.07 |        | 0.04 |        |
| Cold#3  | 0.003 | 0.00%  | 0.02 | 0.00%  | 0.01 | 97.24% | Hot #1 | 0.003 | %00.0  | 0.02 | 0.00%  | 0.02 |        |
|         | 0.003 |        | 0.02 |        | 0.18 |        |        | 0.003 |        | 0.02 |        | 0.02 | 7.69%  |
| Cold#3  | 0.003 | 0.00%  | 0.02 | 0.00%  | 0.01 | 0.00%  | Hot #1 | 0.003 | 0.00%  | 0.02 | 0.00%  | 0.01 |        |
|         | 0.003 |        | 0.02 |        | 0.01 |        |        | 0.003 |        | 0.02 |        | 0.01 | 53.70% |
| Cold#3  | 0.003 | 0.00%  | 0.02 | %00.0  | 0.01 | %00'0  | Hot #1 | 0.003 | 0.00%  | 0.07 |        | 0.02 |        |
|         | 0.003 |        | 0.02 |        | 0.01 |        |        | 0.003 |        | 0.04 | 36.66% | 0.01 | 76.19% |
| Cold#3  | 0.003 | 0.00%  | 0.04 |        | 0.01 | %00.0  | Hot #1 | 0.003 | 0.00%  | 0.16 | 19.01% | 0.02 |        |
|         | 0.003 |        | 0.04 | 5.03%  | 0.01 |        | -      | 0.003 |        | 0.20 |        | 0.02 | 15.92% |
| Cold#3  | 0.003 | 0.00%  | 0.20 |        | 0.01 | 80.58% | Hot #1 | 0.003 | 0.00%  | 0.58 |        | 0.01 | 80.58% |
|         | 0.003 |        | 0.12 | 39.08% | 0.06 |        |        | 0.003 |        | 0.34 | 41.80% | 0.06 |        |
| Cold#3  | 0.003 | 0.00%  | 0.37 | 11.87% | 0.03 | 25.42% | Hot #1 | 0.003 | %00.0  | 0.41 |        | 0.03 | 25.42% |
|         | 0.003 |        | 0.42 |        | 0.04 |        |        | 0.003 |        | 0.04 | 89.48% | 0.04 |        |
| Cold#3  | 0.003 | 0.00%  | 0.24 |        | 0.01 | 28.99% | Hot #1 | 0.003 | 0.00%  | 0.29 |        | 0.01 | 63.77% |
|         | 0.003 |        | 0.12 | 47.69% | 0.01 |        |        | 0.003 |        | 0.25 | 15.23% | 0.01 |        |
| Cold#3  | 0.003 | %00.0  | 0.10 |        | 0.04 | 37.70% | Hot #1 | 0.003 | 0.00%  | 0.21 | 11.24% | 0.04 | 37.70% |
|         | 0.003 |        | 0.09 | 1.56%  | 0.06 |        |        | 0.003 |        | 0.24 |        | 0.06 |        |
| Average |       | 3.82%  |      | 16.20% |      | 31.06% |        |       | 3.57%  |      | 20.06% |      | 31.76% |

|            | Test Sa | mples   |         | GVRD    | All cold 2   | Repeats |       |        |       |        |      |        |        |
|------------|---------|---------|---------|---------|--------------|---------|-------|--------|-------|--------|------|--------|--------|
|            | Lead    | Copper  | Zinc    | Sample  | Lead         |         |       | Copper |       |        | Zinc |        |        |
| Test Conc. | 30 ppb  | 3.5 ppm | 2.6 ppm |         | GVRD         | study   |       | GVRD   | study |        | GVRD | study  |        |
|            | 33.00   | 3.78    | 2.61    | Cap 5   | 0.4%         |         |       | 1.28   | 1.50  | 14.55% | 0.06 | 0.044  | 31.25% |
|            | 34.00   | 3.34    | 2.27    | Cap 7   | 0.2%         |         |       | 1,44   | 2.30  | 37.39% | 0.08 | 0.07   | 7.89%  |
|            | 28.00   | 3.37    | 2.40    | Cap 9   | 1.2%         |         |       | 0.656  | 0.49  | 25.15% | 0.07 | 0.042  | 39.13% |
|            | 28.00   | 3.35    | 2.42    | Cap 14  | 1.5%         |         |       | 0.974  | 0.15  | 84.60% | 0.03 | 0.005  | 82.76% |
|            | 30.00   | 3.40    | 2.48    |         |              |         |       |        |       |        |      |        |        |
|            | 29.00   | 3.45    | 2.52    | Coq 4   | %£.0         | 0.0025  | 0.167 | 0.139  | 0.12  | 15.04% | 0.04 | 0.0297 | 27.56% |
|            | 29.00   | 3.31    | 2.53    | Coq 8   | 0.2%         | 0.0025  | 0.200 | 0.572  | 0.52  | 8.88%  | 0.07 | 0.0585 | 11.36% |
|            | 30.00   | 3.21    | 2.25    | Coq 11  | 0.7%         | 0.008   | 0.143 | 0.293  | 0.26  | 10.24% | 0.02 | 0.0194 | 3.00%  |
|            | 31.00   | 3.26    | 2.52    | Coq 15  | 1.0%         | 0.005   | 0.500 | 0.422  | 0.38  | 10.69% | 0.04 | 0.0391 | 9.07%  |
|            | 37.00   | 3.27    | 2.41    | Coq 23  | <0.001       | 0.0025  |       | 0.092  | 0.08  | 9.02%  | 0.02 | 0.0269 | 18.22% |
|            | 36.00   | 3.22    | 2.46    |         |              |         |       |        |       |        |      |        |        |
|            | 37.00   | 3.34    | 2.53    | New 3   | 0.2%         | 0.0025  | 0.200 | 0.089  | 0.09  | 6.02%  | 0.02 | 0.023  | 8.70%  |
|            | 34.00   | 3.43    | 2.53    | New 5   | <0.001       | 0.0025  |       | 0.004  | 0.01  | 75.00% | 0.21 | 0.1634 | 20.29% |
|            | 34.00   | 3.37    | 2.31    | New 7   | <b>%9</b> .0 | 0.0025  | 0.583 | 0.099  | 0.08  | 16.06% | 0.01 | 0.0104 | 3.85%  |
|            | 36.00   | 3.40    | 2.42    | New 12  | 0.4%         | 0.0025  | 0.375 | 0.203  | 0.18  | 9.26%  | 0.02 | 0.0217 | 17.05% |
|            | 32.00   | 3.31    | 2.43    | New 14  | <b>%9</b> .0 | 0.014   | 0.571 | 0.305  | 0.28  | 7.84%  | 0.01 | 0.0082 | 25.45% |
|            | 35.00   | 3.40    | 2.45    |         | •            |         | ,     |        |       |        |      |        |        |
|            | 35.00   | 3.37    | 2.51    | Sey 6   | 1.3%         | 0.012   | 0.077 | 0.902  | 0.83  | 7.87%  | 60.0 | 0.072  | 21.74% |
|            | 29.00   |         |         | Sey 14  | 0.2%         | 0.0025  | 0.200 | 1.12   | 1.04  | 7.05%  | 0.05 | 0.0389 | 18.96% |
|            | 34.00   |         |         | Sey 16  | %9.0         | 0.006   | 0.000 | 1.08   | 0.99  | 8.03%  | 0.02 | 0.0249 | 3.61%  |
|            | 32.00   |         |         | Sey 21  | 0.5%         | 0.004   | 0.200 | 0.697  | 0.65  | 7.20%  | 0.05 | 0.0437 | 15.96% |
|            | 26.00   |         |         | average |              |         | 0.268 |        |       | 19.99% |      |        | 20.33% |
|            | 31.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 31.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 31.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 37.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 38.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 37.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 35.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 33.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 30.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 31.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 28.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 33.00   |         |         |         |              |         |       |        |       |        |      |        |        |
|            | 29.00   |         |         |         |              |         |       |        |       |        |      |        |        |
| Average    | 32.37   | 3.37    | 2.45    |         |              |         |       |        |       |        |      |        |        |
| %Diff      | 7.9%    | 2.4%    | 6.2%    |         |              |         |       |        |       |        |      |        |        |

|        |           | Zinc   | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  | <0.01  |
|--------|-----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| n 2    | inks      | Copper | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  | <0.03  |
| Sessic | Field Bla | Lead   | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |

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**Appendix D: Sampling Instructions for Participants** 

#### **Instructions for Winter 2003 Corrosion Study Sampling**

#### Purpose

The main purpose of the study is to compare the effects of corrosion on standing water in household plumbing systems from different water sources under varying corrosion control strategies.

#### **General Guidelines**

#### <u>Step #1</u>

As the purpose of the study is to monitor standing water, under worst case conditions please try not to use any water after going to bed on the eve of the sampling (i.e. No flushing of toilets or running water in the middle of the night).

#### <u>Step #2</u>

Sampling must be done first thing in the morning after the water has sat during the night in the plumbing (6-8 hours). **It is most imperative that no other water is run before this sampling**. This means grab the samples before flushing any toilet, running any water for the morning coffee, or taking that morning shower. This may be out of the ordinary for your habits but it is essential for the purpose of the study.

#### <u>Step #3</u>

Sampling. A total of 4 samples will be taken. Three of the samples involve cold water, while only one sample is to be taken from the hot water tap. Table 1 shows what volumes are to be collected in each sample. For those sampling kits that have a fifth bottle, the field blank, all that needs to be done is that the cap be taken off, exposing the contents to the environment and then the cap is to be replaced on the bottle.

| <b>_</b>            | Cold #1        | 50 ml  |
|---------------------|----------------|--------|
| Cold Water Samples  | Cold #2        | 950 ml |
|                     | Cold #3        | 250 ml |
|                     |                |        |
| Hot Water Samples   | Hot #1         | 125 ml |
| Field Blank Samples | Field Blank #1 | 50 ml  |

**Table 1.** Size for each sample to be collected

#### **Sampling Procedure**

All samples are to be taken from the kitchen tap first thing in the morning before any water is used in the house.

- Set bottles out on the counter in order, ready to take samples: Cold #1, Cold #2, Cold #3, and then Hot #1
- 2 Take bottle Cold #1 and have bottle Cold #2 ready with the cap off. Place bottle Cold #1 under tap and slowly turn the cold water on. Don't let it flow too fast. Only fill to mark!!
- 3 Immediately as Cold #1 is filled to the mark switch to bottle Cold #2 and fill this bottle to the mark. **Don't allow any of this first flow to miss the first two bottles**.
- 4 Increase the tap water flow and let the water run for 5 minutes. Fill bottle Cold #3 to the top. Turn off cold water tap.
- 5 Place bottle HOT #1 under the tap and slowly turn on the hot water. Again don't let it flow too fast and fill to top.
- 6 Cap all bottles tight and place in the Ziploc bag provided. If you have a field blank bottle, remove the cap from the field blank, and then recap it after 5 seconds.
- 7 Have the filled sample bottles ready for pick-up and post yourself a reminder for the next sampling, if you were chosen for repeats. You will be sent a reminder email the day before the second sampling.

#### Notes

- If on a particular day you were unable to get the first morning flush, sample the following day and make a note of it on your label. Please contact Gillian Knox to let her know that your samples will not be available for pick up on the predetermined day (Contact Information is below).
- If no water was used in the house for longer than just the one night, please specify on your label

If you have any questions please contact Gillian Knox at 604-341-6843 or via email at <u>gknox@civil.ubc.ca</u>.

#### **HELPFUL HINTS**

To help ensure that no water is run the night before, I have come up with some suggestions:

Place a note on your alarm clock reminding you of the morning that sampling is to take place, so that when you go to bed at night you remember that no water can be run that night and you make the proper preparations

- 2 Place a DO NOT FLUSH sign on your toilets before going to bed. This may go for some of your taps as well if you or any member of your household tends to get up and run the water in the night.
- 3 You may want to fill you bathroom sink with water so that you can wash your hands in the middle of the night if needed.
- 4 Pour a pitcher of water and place it on the counter or leave a note on the tap indicating that there is water in the fridge. This way you don't have to go thirsty in the middle of the night, and the sampling isn't compromised.
- 5 It is best if the samples are taken immediately upon getting up in the morning, as once they are taken you can proceed with your morning as usual, showering, making coffee, and just preparing for the day. Don't forget to either leave them out on the porch for me if no one is going to be at home during the day, or take them to the 12<sup>th</sup> floor reception at the GVRD, they are expecting you.

### **Sampling Instructions (Taped on outside of bag)**

All samples are to be taken from the kitchen tap first thing in the morning before any water is used in the house.

- 1. Set bottles out on the counter in order, ready to take samples: Cold #1, Cold #2, Cold #3, and then Hot #1
- 2. Take bottle Cold #1 and have bottle Cold #2 ready with the cap off. Place bottle Cold #1 under tap and slowly turn the cold water on. Don't let it flow too fast, fill to mark only!
- 3. Immediately as Cold #1 is filled to the mark switch to bottle Cold #2 and fill this bottle to the mark. Don't allow any of this first flow to miss the first two bottles.
- 4. Increase the tap water flow and let the water run for 5 minutes. Fill bottle Cold #3 to the top. Turn off cold water tap.
- 5. Place bottle HOT #1 under the tap and **slowly** turn on the **hot** water. Again don't let it flow too fast and fill to top.

Cap all bottles tight and place in the provided Ziploc bag. If you have a field blank bottle, remove the cap from the field blank, and then recap it after 5 seconds. Have bottles ready for pickup.

**Appendix E: Method Parameters for Metal Analysis** 

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#### LEAD

Element File: PB\_TAP.GEL

Element: Pb

Print Data: Main + Suppl. Print:

Remarks:

Analyst: Gillian Peak Storage: None

This element file is based on the 5100 PC Tutorial manual but modified for the 4100 ZL instrument.

Calibaration will be performed using three standards

| · · · · · · · · · · · · · · · · · · · | 0                      |               |  |
|---------------------------------------|------------------------|---------------|--|
| INSTRUMENT: 4100 ZL                   | Technique: HGA         | Version: 7.30 |  |
| Wavelength: 283.3 Peak                | Slit: 0.70 Low         |               |  |
| Signal Type: Seeman AA                | Signal Measurement: P  | Peak Area     |  |
| Read Time: 2.5                        | Read Delay: 0.5        | BOC Time: 3   |  |
| Sample Replicated: 2                  |                        |               |  |
| Standard Replicates: 3                | Spike Replicated: Same | e as Sample   |  |
| Calibration:                          |                        |               |  |

| Solutions    | ID      | Conc | Location | Volume | Diluent | Mod | lifier |
|--------------|---------|------|----------|--------|---------|-----|--------|
|              |         |      |          |        | Volume  | #1  | #2     |
| Calib. Blank | Blank   |      | 80       | 20     | 5       | 2   |        |
| Standard 1   | 10 ppb  | 10   | 79       | 20     | 5       | 2   |        |
| Standard 2   | 50 ppb  | 50   | 78       | 20     | 5       | 2   |        |
| Standard 3   | 100 ppb | 100  | 77       | 20     | 5       | 2   |        |
| Reslope Std. | 50 ppb  | 50   | 78       | 20     | 5       | 2   |        |
| Samples      |         |      |          | 20     | 5       | 2   |        |

Diluent Location: 80 Modifier #1 Location: 76 Calibration Units: µg/L Calibration Type: Nonlinear

Modifier #2 Location: Sample Units: µg/L

| Furnace Tin  | ne/Temperatu | ire Program: |            |          |              |          |
|--------------|--------------|--------------|------------|----------|--------------|----------|
| Step         | Temp         | Ramp         | Hold       | Gas Flow | Read         | Gas Type |
| 1            | 110          | 5            | 30         | 250      |              | Norm     |
| 2            | 150          | 5            | 5          | 250      |              | Norm     |
| 3            | 750          | 5            | 5          | 50       |              | Norm     |
| 4            | 850          | · 10         | 10         | 250      |              | Norm     |
| 5            | 1600         | 0            | 5          | 0        | *            | Norm     |
| 6            | 2000         | 2            | . 3        | 250      |              | Norm     |
| Injection Te | mp: 50       | Pipette S    | Speed: 50% | Extra    | ction Systen | n: On    |

**SEQUENCE:** 

Step Action and Paramters

1 Pipet sample/std + spike + diluent + modifier

2 Run HGA steps 1 to End

CHECKS: Recalibration Type: Reslope Locations: 20, 40, 60

Conc. Above Calibration Action: Dilute & Reanalyze After 1 Rep Alternate Sample Volumes ( $\mu$ L): 10, 5, 3 Run Alternate Volume Blanks: No

If % RSD> 30.0 and Concentrations > 20 the retry 1 time Check % RSD on: Samples + Standards

Recovery Measurements: 5 µL of 50 µg/L Standard at Location 2 Gives 12.500 µg/L Measure Recovery on Samples: 20, 40, 60 Add to QC Samples: No % Recovery Limits:

OC:

Matrix Check Calculations: % Difference for Dupls: No % Recovery for Spike: No

Locations: Locations:

Conc:

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# COPPER

| Analyst              | Gillian       |
|----------------------|---------------|
| Date Started         | 2/5/03 10:48  |
| Worksheet            | GKCCc22       |
| Comment              |               |
| Methods              | Cu,           |
| Method: Cu (Flame)   | ,             |
| Element - Matrix:    | Cu -          |
| Instrument Type:     | Flame         |
| Conc. Units:         | mg/L          |
| Instrument Mode:     | Absorbance    |
| Sampling Mode:       | Autonormal    |
| Calibration Mode:    | Concentration |
| Measurement Mode:    | Integrate     |
| Replicates Standard: | 3             |
| Replicates Sample:   | 3             |
| Expansion Factor:    | 1             |
| Minimum Reading:     | Disabled      |
| Smoothing:           | 5 point       |
| Conc. Dec. Places:   | 2             |
| Wavelength:          | 324.8 nm      |
| Slit Width:          | 0.5 nm        |
| Gain:                | 46%           |
| Lamp Current:        | 4.0 mA        |
| Lamp Position:       | 4             |
| Background           | BC Off        |
| Correction:          |               |
| STANDARD 1:          | 0.50 mg/L     |
| STANDARD 2:          | 1.00 mg/L     |
| STANDARD 3:          | 2.00 mg/L     |
| STANDARD 4:          | 5.00 mg/L     |

| · · ·                  |               |
|------------------------|---------------|
| Reslope Standard No.:  | 2             |
| Reslope Lower Limit:   | 75.00%        |
| Reslope Upper Limit:   | 125.00%       |
| Recalibration Rate:    | 100           |
| Calibration Algorithm: | New Rational  |
| Cal. Lower Limit:      | 20.00%        |
| Cal. Upper Limit:      | 150.00%       |
| SIPS:                  | Off           |
| Measurement Time:      | 5.0 s         |
| Pre-Read Delay:        | 5 s           |
| Flame Type:            | Air/Acetylene |
| Air Flow:              | 13.50 L/min   |
| Acetylene Flow:        | 2.00 L/min    |
| Burner Height:         | 13.5 mm       |
| Probe Height:          | 0 mm          |
| Rinse Rate:            | 1             |
| Rinse Time:            | 3 s           |
| CAL ZEROPos:           | 1             |
| STANDARD 1Pos:         | 2             |
| STANDARD 2Pos:         | 3             |
| STANDARD 3Pos:         | 4             |
| STANDARD 4Pos:         | 5             |

| Method: Zn (Flame)   |               |
|----------------------|---------------|
| Element - Matrix:    | Zn -          |
| Instrument Type:     | Flame         |
| Conc. Units:         | mg/L          |
| Instrument Mode:     | Absorbance    |
| Sampling Mode:       | Autonormal    |
| Calibration Mode:    | Concentration |
| Measurement Mode:    | Integrate     |
| Replicates Standard: | 3             |
| Replicates Sample:   | 3             |
| Expansion Factor:    | 1             |
| Minimum Reading:     | Disabled      |
| Smoothing:           | 5 point       |
| Conc. Dec. Places:   | 2             |
| Wavelength:          | 213.9 nm      |
| Slit Width:          | 1.0 nm        |
| Gain:                | 23%           |
| Lamp Current:        | 5.0 mA        |
| Lamp Position:       | 3             |
| Background           | BC Off        |
| Correction:          |               |
| STANDARD 1:          | 0.50 mg/L     |
| STANDARD 2:          | 1.00 mg/L     |
| STANDARD 3:          | 2.00 mg/L     |
| STANDARD 4:          | 5.00 mg/L     |

| Reslope Rate:          | 15            |
|------------------------|---------------|
| Reslope Standard       | 2             |
| No.:                   |               |
| Reslope Lower Limit:   | 75.00%        |
| Reslope Upper Limit:   | 125.00%       |
| Recalibration Rate:    | 100           |
| Calibration Algorithm: | New Rational  |
| Cal. Lower Limit:      | 20.00%        |
| Cal. Upper Limit:      | 150.00%       |
| SIPS:                  | Off           |
| Measurement Time:      | 5.0 s         |
| Pre-Read Delay:        | 5 s           |
| Flame Type:            | Air/Acetylene |
| Air Flow:              | 13.50 L/min   |
| Acetylene Flow:        | 2.00 L/min    |
| Burner Height:         | 13.5 mm       |
| Probe Height:          | 0 mm          |
| Rinse Rate:            | 1             |
| Rinse Time:            | 3 s           |
| CAL ZEROPos:           | 1             |
| STANDARD 1Pos:         | 2             |
| STANDARD 2Pos:         | 3             |
| STANDARD 3Pos:         | 4             |
| STANDARD 4Pos:         | 5             |

Appendix F: Collected Raw Data

| u <u>Z</u> u | <b>B</b> 020 | 0.005     | 0.005   | 0.005   | 0.005   | 0.005   | 0.010   | 0.010   | 0.010   | 0.010   | 0.010   | 0.010   | 0.005   | 0.010   | 0.005   | 0.010   | 0.020   | 0.010    | 0.010   | 0.010   | 0.010   | 0.010   | 0.005   | 0.020   | 0.005   | 0.010   | 0.040   | 0.020   | 0.005   | 0.010   | 0.030   | 0.005   | 0.010   | 33      | 0.011   | 0.008   | 0.001   |  |
|--------------|--------------|-----------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|----------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|--|
| Сu           | 0.22         | 0.26      | 0.09    | 0.12    | 0.09    | 0.19    | 0.29    | 0.14    | 0.26    | 0.27    | 0.14    | 0.11    | 0.18    | 0.75    | 0.33    | 0.13    | 0.04    | 0.14     | 0.17    | 0.23    | 0.23    | 0.34    | 0.12    | 0.53    | 0.13    | 0.07    | 0.03    | 0.07    | 0.12    | 0.10    | 0.05    | 0.17    | 0.21    | 33      | 0.192   | 0.144   | 0.025   |  |
| Pb           | 0.0025       | 0.0025    | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0050  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025   | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 33      | 0.0026  | 0.0004  | 0.0001  |  |
| Type         | Hot #1       | Hot #1    | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1   | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  | Hot #1  |  |
| Zn           | 0.005        | 0.005     | 0.005   | 0.005   | 0.005   | 0.005   | 0.005   | 0.010   | 0.005   | 0.040   | 0.005   | 0.010   | 0.005   | 0.005   | 0.010   | 0.005   | 0.010   | 0.160    | 0.005   | 0.005   | 0.010   | 0.005   | 0.005   | 0.050   | 0.005   | 0.005   | 0.010   | 0.010   | 0.005   | 0.005   | 0.020   | 0.005   | 0.005   | 33      | 0.014   | 0.028   | 0.005   |  |
| С            | 0.150        | 0.180     | 0.015   | 0.030   | 0.015   | 0.070   | 0.030   | 0.070   | 0.060   | 0.390   | 0.050   | 0.030   | 0.080   | 0.100   | 0.180   | 060.0   | 0.015   | 0.470    | 0.080   | 0.060   | 0.015   | 0:090   | 0.070   | 1.320   | 0.110   | 0.030   | 0.040   | 0.015   | 060.0   | 0.060   | 0.170   | 0.130   | 0.130   | 33      | 0.134   | 0.235   | 0.041   |  |
| đ            | 0.0025       | 0.0025    | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0110  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0060   | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 33      | 0.0029  | 0.0016  | 0.0003  |  |
| Type         | Cold #3      | Cold #3   | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3  | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 | Cold #3 |  |
| zn           | 0.01         | 0.06      | 0.04    | 0.04    | 0.07    | 0.04    | 0.02    | 0.05    | 0.02    | 0.03    | 0.01    | 0.10    | 0.03    | 0.09    | 0.05    | 0.02    | 0.13    | 0.05     | 0.03    | 0.04    | 0.03    | 0.06    | 0.02    | 0.08    | 0.01    | 0.01    | 0.03    | 0.11    | 0.02    | 0.11    | 0.32    | 0.03    | 0.04    | 33      | 0.055   | 0.057   | 0.010   |  |
| Cu           | 1.14         | 0.17      | 0.11    | 0.10    | 0.09    | 0.44    | 0:30    | 0.11    | 0.50    | 0.85    | 0.15    | 0.22    | 0.51    | 1.57    | 1.30    | 0.44    | 0.06    | 0.08     | 0.34    | 1.03    | 0.10    | 1.13    | 0.47    | 1.27    | 0.70    | 0.06    | 0.03    | 0.11    | 1.07    | 0.27    | 0.13    | 1.01    | 0.80    | 33      | 0.505   | 0.454   | 0.079   |  |
| Pb           | 0.0025       | 0.0029    | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0061  | 0.0161  | 0.0060  | 0.0049  | 0.0084  | 0.0027  | 0.0027  | 0.0060  | 0.0025  | 0.0029   | 0.0025  | 0.0051  | 0.0025  | 0.0026  | 0.0025  | 0.0032  | 0.0239  | 0.0027  | 0.0025  | 0.0026  | 0.0027  | 0.0031  | 0.0080  | 0.0099  | 0.0026  | 33      | 0.0047  | 0.0045  | 0.0008  |  |
| Type         | 1st L        | 1st L     | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L    | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   | 1st L   |  |
| Zu           | 0.010        | 0.030     | 0.040   | 0.030   | 0.020   | 0.040   | 0.020   | 0.020   | 0.010   | 0.030   | 0.010   | 0.060   | 0.020   | 0.050   | 0.040   | 0.010   | 0.100   | 0.005    | 0.020   | 0.030   | 0.010   | 0.030   | 0.020   | 0.070   | 0.010   | 0.010   | 0.030   | 0.070   | 0.010   | 0.080   | 0.280   | 0.010   | 0.030   | 33      | 0.038   | 0.049   | 0.009   |  |
| ло           | 1.180        | 0.160     | 0.100   | 0.100   | 0.080   | 0.450   | 0.300   | 0.100   | 0.510   | 0.860   | 0.150   | 0.220   | 0.520   | 1.610   | 1.320   | 0.440   | 0.060   | 0.060    | 0.340   | 1.060   | 0.080   | 1.160   | 0.480   | 1.300   | 0.730   | 0.050   | 0.030   | 0.100   | 1.090   | 0.250   | 0.130   | 1.040   | 0.810   | 33      | 0.511   | 0.470   | 0.082   |  |
| Pb           | 0.0025       | 0.0025    | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0060  | 0.0160  | 0.0060  | 0.0050  | 0.0070  | 0.0025  | 0.0025  | 0.0060  | 0.0025  | 0.0025   | 0.0025  | 0.0050  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0250  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0080  | 0.0100  | 0.0025  | 33      | 0.0046  | 0.0047  | 0.0008  |  |
| Type         | Cold #2      | Cold #2   | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2  | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 | Cold #2 |  |
| Zn           | 0.09         | 0.71      | 0.11    | 0.19    | 1.01    | 0.11    | 0.03    | 0.63    | 0.20    | 0.08    | 0.01    | 0.78    | 0.29    | 0.83    | 0.23    | 0.11    | 0.77    | 0.93     | 0.29    | 0.20    | 0.37    | 0.67    | 0.02    | 0.31    | 0.03    | 0.10    | 0.08    | 0.85    | 0.13    | 0.70    | 1.11    | 0.31    | 0.32    | 33      | 0.382   | 0.336   | 0.058   |  |
| С            | 0.320        | 0.260     | 0.230   | 060.0   | 0.360   | 0.290   | 0.370   | 0.350   | 0.330   | 0.650   | 0.060   | 0.290   | 0.370   | 0.810   | 0.850   | 0.360   | 0.130   | 0.440    | 0.380   | 0.510   | 0.400   | 0.520   | 0.180   | 0.660   | 0.200   | 0.320   | 0.070   | 0.230   | 0.670   | 0.560   | 0.140   | 0.490   | 0.700   | 33      | 0.382   | 0.208   | 0.036   |  |
| d d d        | 0.0025       | 0.0110    | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0025  | 0.0080  | 0.0180  | 0.0050  | 0.0025  | 0.0340  | 0.0070  | 0.0070  | 0.0050  | 0.0025  | 0.0110   | 0.0025  | 0.0070  | 0.0025  | 0.0050  | 0.0025  | 0.0160  | 0.0025  | 0.0070  | 0.0025  | 0.0050  | 0.0060  | 0.0150  | 0.0080  | 0.0070  | 0.0050  | 33      | 0.0067  | 0.0064  | 0.0011  |  |
| Type         | 1# plo:      | : 1# ploc | Cold #1  | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 | Cold #1 |  |
| ,<br>,, #    | -            | 2         | 4       | 5       | 9       | ~       | 8       | 6       | 10      | 7       | 13 0    | 14      | 15 (    | 16 (    | 17      | 18      | 19 (    | 20       | 21      | 22      | 23 (    | 24 (    | 25 (    | 26 (    | 27 (    | 28      | 29 (    | 30      | 32 (    | 34      | 35 (    | 36 (    | 37 (    | J       | 0       | 0       | 0       |  |
| Source       | со<br>Со     | Coq       | Cod     | Сод     | Сod     | Cod     | Cod     | Cod     | Cod     | Coq     | Cod     | Сод     | Cod     | Cod     | Cod     | Coq     | Cod     | бо<br>Со | Сод     | ы<br>Со | Сод     | Сод     | Сод     | Сод     | Сод     | Cod     | Cod     | Cod     | Cod     | Cod     | Сод     | Cod     | Cod     | count   | mean    | st dev  | st err  |  |
|              |              |           |         |         |         |         |         |         |         |         |         |         |         |         | •       |         |         |          |         |         |         |         |         |         |         |         |         |         |         |         |         |         | ,       |         |         |         |         |  |

Sampling Session 1 - September 2002

| Samplin     | g Sest  | sion 1 | - Sept | ember   | r 2002  |         |        |       |       |       |        |       |       |         |        |         |       |        |        |        |       |
|-------------|---------|--------|--------|---------|---------|---------|--------|-------|-------|-------|--------|-------|-------|---------|--------|---------|-------|--------|--------|--------|-------|
| Source      | # Ty    | /pe    | Pb     | с.<br>С | uZ<br>Z | Type    | Pb     | ទ     | Zn    | Type  | Pb     | ло    | Zn    | Type    | Pb     | Сu      | zn    | Type   | Pb     | Cu     | Żn    |
| New         | 1 Colc  | d #1 0 | 0025   | 0.130   | 0.14    | Cold #2 | 0.0025 | 0.300 | 0.005 | 1st L | 0.0025 | 0.29  | 0.01  | Cold #3 | 0.0025 | 0.030   | 0.005 | Hot #1 | 0.0025 | 0.03   | 0.005 |
| New         | 2 Colc  | d #1 0 | 0470   | 0.340   | 0.09    | Cold #2 | 0.0110 | 0.240 | 0.010 | 1st L | 0.0128 | 0.25  | 0.01  | Cold #3 | 0.0025 | 0:030   | 0.005 | Hot #1 | 0.0060 | 0.07   | 0.005 |
| New         | 3 Colc  | d #1 0 | 0025   | 0.140   | 0.26    | Cold #2 | 0.0060 | 0.090 | 0.020 | 1st L | 0.0058 | 0.09  | 0.03  | Cold #3 | 0.0025 | 0.030   | 0.005 | Hot #1 | 0.0025 | 0.08   | 0.005 |
| New         | 4 Colc  | d #1 0 | 0140   | 0.250   | 0.07    | Cold #2 | 0.0170 | 0.350 | 0.010 | 1st L | 0.0169 | 0.35  | 0.01  | Cold #3 | 0.0025 | 0.040   | 0.005 | Hot #1 | 0.0025 | 0.05   | 0.005 |
| New         | 5 Colc  | d #1 0 | 0025   | 0.050   | 0.02    | Cold #2 | 0.0025 | 0.040 | 0.010 | 1st L | 0.0025 | 0.04  | 0.01  | Cold #3 | 0.0025 | 0.030   | 0.005 | Hot #1 | 0.0025 | 0.03   | 0.005 |
| New         | 6 Colc  | d #1 0 | 0025   | 0.210   | 0.02    | Cold #2 | 0.0025 | 0.230 | 0.010 | 1st L | 0.0025 | 0.23  | 0.01  | Cold #3 | 0.0025 | 0.040   | 0.005 | Hot #1 | 0.0025 | 0.07   | 0.005 |
| New         | 7 Colc  | d #1 0 | 0.0070 | 0.190   | 0.26    | Cold #2 | 0.0140 | 0.230 | 0.020 | 1st L | 0.0137 | 0.23  | 0.03  | Cold #3 | 0.0025 | 0.050   | 0.005 | Hot #1 | 0.0025 | 0.09   | 0.005 |
| New         | 8 Colc  | d #1 0 | 0900.  | 0.160   | 0.01    | Cold #2 | 0.0050 | 0.150 | 0.005 | 1st L | 0.0051 | 0.15  | 0.01  | Cold #3 | 0.0025 | 0.040   | 0.005 | Hot #1 | 0.0025 | 0.06   | 0.005 |
| New         | 9 Colc  | d #1 0 | 0130   | 0.230   | 0.21    | Cold #2 | 0.0025 | 0.420 | 0.010 | 1st L | 0.0030 | 0.41  | 0.02  | Cold #3 | 0.0025 | 0.030   | 0.005 | Hot #1 | 0.0025 | 0.03   | 0.010 |
| New         | 10 Colc | d #1 0 | 0440   | 0.230   | 0.09    | Cold #2 | 0.0160 | 0.280 | 0.005 | 1st L | 0.0174 | 0.28  | 0.01  | Cold #3 | 0.0025 | 0.015   | 0.005 | Hot #1 | 0.0025 | 0.04   | 0.005 |
| New         | 11 Colc | d #1 0 | 0025   | 0.200   | 0.12    | Cold #2 | 0.0040 | 0.220 | 0.005 | 1st L | 0.0039 | 0.22  | 0.01  | Cold #3 | 0.0025 | 0.015   | 0.005 | Hot #1 | 0.0025 | 0.11   | 0.005 |
| New         | 12 Colc | d #1 0 | 0050   | 0.120   | 0.15    | Cold #2 | 0.0025 | 0.040 | 0.010 | 1st L | 0.0026 | 0.04  | 0.02  | Cold #3 | 0.0025 | 0.015   | 0.005 | Hot #1 | 0.0025 | 0.03   | 0.005 |
| New         | 13 Cold | d #1 0 | 0.0025 | 0.015   | 0.04    | Cold #2 | 0.0025 | 0.050 | 0.020 | 1st L | 0.0025 | 0.05  | 0.02  | Cold #3 | 0.0025 | 0.015 ~ | 0.005 | Hot #1 | 0.0025 | 0.015  | 0.005 |
| New         | 14 Colc | d #1 0 | 0.0100 | 0.260   | 0.04    | Cold #2 | 0.0090 | 0.290 | 0.005 | 1st L | 0.0091 | 0.29  | 0.01  | Cold #3 | 0.0025 | 0.040   | 0.005 | Hot #1 | 0.0025 | 0.20   | 0.005 |
| New         | 15 Cold | d #1 C | 0900.0 | 0.110   | 0.08    | Cold #2 | 0.0060 | 0.090 | 0.005 | 1st L | 0.0060 | 0.09  | 0.01  | Cold #3 | 0.0025 | 0.015   | 0.005 | Hot #1 | 0.0025 | 0.03   | 0.005 |
| New         | 16 Colc | d #1 C | 0.0025 | 0.200   | 0.02    | Cold #2 | 0.0025 | 0.320 | 0.005 | 1st L | 0.0025 | 0.31  | 0.01  | Cold #3 | 0.0025 | 0.040   | 0.005 | Hot #1 | 0.0025 | 0.06   | 0.010 |
| New         | 17 Cold | d #1 C | 0025   | 0.270   | 0.14    | Cold #2 | 0.0025 | 0.420 | 0.010 | 1st L | 0.0025 | 0.41  | 0.02  | Cold #3 | 0.0025 | 0.030   | 0.005 | Hot #1 | 0.0025 | 0.21   | 0.005 |
| ь<br>S      | 33 Cold | d #1 C | 0.0025 | 0.080   | 0.18    | Cold #2 | 0.0025 | 0.015 | 0.020 | 1st L | 0.0025 | 0.02  | 0.03  | Cold #3 | 0.0025 | 0.015   | 0.005 | Hot #1 | 0.0025 | 0.015  | 0.005 |
| count       | Colc    | d #1   | 18     | 18      | 18      | Cold #2 | 18     | 18    | 18    | 1st L | 18     | 18    | 18    | Cold #3 | 18     | 18      | 18    | Hot #1 | 18     | 18     | 18    |
| mean        | Colc    | d #1 C | 1.0097 | 0.177   | 0.108   | Cold #2 | 0.0061 | 0.210 | 0.010 | 1st L | 0.0063 | 0.208 | 0.015 | Cold #3 | 0.0025 | 0.029   | 0.005 | Hot #1 | 0.0027 | 0.0678 | 0.006 |
| st dev      | Colc    | d #1 C | 0135   | 0.084   | 0.081   | Cold #2 | 0.0051 | 0.132 | 0.006 | 1st L | 0.0053 | 0.128 | 0.008 | Cold #3 | 0.0000 | 0.011   | 0.000 | Hot #1 | 0.0008 | 0.0564 | 0.002 |
| st err      | Colc    | d #1 C | 0.0032 | 0.020   | 0.019   | Cold #2 | 0.0012 | 0.031 | 0.001 | 1st L | 0.0012 | 0.030 | 0.002 | Cold #3 | 0.0000 | 0.003   | 0.000 | Hot #1 | 0.0002 | 0.0133 | 0.000 |
| time St Err | Colc    | d #1 C | 0.0064 | 0.039   | 0.038   | Cold #2 | 0.0024 | 0.062 | 0.003 | 1st L | 0.0025 | 0.061 | 0.004 | Cold #3 | 0.0000 | 0.005   | 0.000 | Hot #1 | 0.0004 | 0.0266 | 0.001 |
|             |         |        |        |         |         |         |        |       |       |       |        |       |       |         |        |         |       |        |        |        |       |

| Sey 2                  |           | ć         |             | 1 > > 1                          | ł         | ī          | č        | i<br>i   |                  | č           | Ċ             | ŕ        |         | Ż                    | ċ       | 5            | ŀ          | ż               | ċ     | ř          |   |
|------------------------|-----------|-----------|-------------|----------------------------------|-----------|------------|----------|----------|------------------|-------------|---------------|----------|---------|----------------------|---------|--------------|------------|-----------------|-------|------------|---|
|                        | adki      | <b>Pb</b> | Cu<br>Deen  | Zn<br>2<br>2<br>2<br>2<br>2<br>2 | Type      | Pb<br>0050 | Cu<br>Cu | Zn T     | ⊂<br>÷ Abe       | Pb<br>0051  | o<br>G        |          | Type    | Р <b>b</b><br>0.0025 | Cu      | <b>7</b> 000 | Type       | 0.0055          | 300   | <b>n</b> 2 |   |
|                        |           |           |             |                                  |           |            |          |          |                  | 1000        | 1 2 2         |          |         | 0.0025               | 0.015   | 0.005        |            | 0.0025          | 0.015 | 0.005      |   |
| Sev J                  |           | 0.0140    | 0.470       |                                  |           | 1 2200.0   |          |          |                  | 10005       | 0.UZ          |          |         | 0.0025               |         | 0100         |            | 0.0025          | 000   | 0000       |   |
| Sev 1                  |           | 0.0025    | 0.710       | 2 80 F                           |           | 1 0025     |          | 060 15   | 0 c<br>          | 0025        | 1 07          | 210      |         | 0.0025               | 0.050   | 0.005        | Hot #1     | 0.0025          | 0.59  | 0.010      |   |
| Sev 6                  | Cold #1   | 0.0080    | 0.460       | 136                              |           | 1 0060 C   |          | 1001     |                  | 0061        | 0.78          | 0.16     | Cold #3 | 0.0025               | 060.0   | 0.010        | Hot #1     | 0.0025          | 0.55  | 0.020      |   |
| Sev 7                  | Cold #1   | 0.0220    | 0.510       | 0.88                             | Sold #2 C | 0.0025 0   | .430 0   | 050 15   | ж<br>Г Г         | 0035        | 0.43          | 60.0     | Cold #3 | 0.0025               | 0.040   | 0.005        | Hot #1     | 0.0025          | 0.11  | 0.010      |   |
| Sev 8                  | Cold #1   | 0.0480    | 1.040       | 1.09                             | Sold #2 C | 2 0600.0   | 020      | 040 15   | ير ا<br>۲        | 0110        | 1.97          | 0.09     | Cold #3 | 0.0025               | 0.130   | 0.010        | Hot #1     | 0.0050          | 0.38  | 0.020      |   |
| Sev 9                  | Cold #1   | 0.0140    | 0.510       | 0.55 (                           | Sold #2 C | 1.0160 C   | 0.390    | 050 15   | й<br>Т           | 0159        | 0.40          | 0.08     | Cold #3 | 0.0025               | 0.060   | 0.005        | Hot #1     | 0.0050          | 0.41  | 0.020      |   |
| Sev 10                 | Cold #1   | 0.0200    | 0.580       | 0.18                             | Sold #2 C | 0.0050 C   | 1.710 0  | 005 15   |                  | 0058        | 0.70          | 0.01     | Cold #3 | 0.0025               | 0.330   | 0.010        | Hot #1     | 0.0025          | 0.30  | 0.010      |   |
| Sev 11                 | Cold #1   | 0.0090    | 0.060       | 0.15 0                           | Sold #2 C | 0.0025 0   | 0.015 0  | 1.010 15 | x L 0            | 0028        | 0.02          | 0.02     | Cold #3 | 0.0025               | 0.015   | 0.005        | Hot #1     | 0.0025          | 0.05  | 0.005      |   |
| Sev 12                 | Cold #1   | 0.0025    | 0.300       | 0.04                             | Sold #2 C | 0.0025 0   | 1.210 (  | 040 1    | й<br>Т<br>С      | 0025        | 0.21          | 0.0      | Cold #3 | 0.0025               | 0.110   | 0.030        | Hot #1     | 0.0025          | 0.30  | 0.010      |   |
| Sey 13                 | Cold #1   | 0.0070    | 0.400       | 0.62 (                           | Sold #2 C | 0.0050 (   | 0.320 (  | 1:030 15 | st L O           | .0051       | 0.32          | 0.06     | Cold #3 | 0.0025               | 0.100   | 0.005        | Hot #1     | 0.0025          | 0.14  | 0.010      |   |
| Sey 15                 | Cold #1   | 0.0050    | 0.290       | 0.83 (                           | Sold #2 C | 0.0025 (   | .470 (   | 1:060 15 | st L O           | .0026       | 0.46          | 0.10     | Cold #3 | 0.0025               | 0.040   | 0.005        | Hot #1     | 0.0025          | 0.13  | 0.010      |   |
| Sey 16                 | Cold #1   | 0.0250    | 0.710       | 0.27 (                           | Cold #2 C | 0600.0     | 000.     | 0.010 15 | st L 0           | 8600.       | 0.99          | 0.02     | Cold #3 | 0.0025               | 0.120   | 0.005        | Hot #1     | 0.0025          | 0.37  | 0.005      |   |
| Sey 17                 | Cold #1   | 0.0110    | 0.400       | 0.22 (                           | Cold #2 ( | 0800.0     | .220 (   | 080 15   | st L 0           | .0082       | 1.18          | 0.09     | Cold #3 | 0.0025               | 0.330   | 0.010        | Hot #1     | 0.0025          | 0.17  | 0.005      |   |
| Sey 18                 | Cold #1   | 0.0230    | 0.550       | 0.23 (                           | Cold #2 C | 0.0310     | .280 (   | 1.200 15 | st L 0           | .0306       | 1.24          | 0.20     | Cold #3 | 0.0025               | 060.0   | 0.005        | Hot #1     | 0.0025          | 0.25  | 0.020      |   |
| Sey 19                 | · Cold #1 | 0.0120    | 0.420       | 0.18 (                           | Cold #2 C | 0.0080 (   | .520 (   | 040 1    | st L 0           | .0082       | 0.52          | 0.05     | Cold #3 | 0.0025               | 0.110   | 0.005        | Hot #1     | 0.0070          | 0.24  | 0.005      |   |
| Sey 20                 | Cold #1   | 0.0120    | 0.720       | 0.83 (                           | Cold #2 C | 0.0025 (   | .310 (   | ).020 15 | st L 0           | .0030       | 0.33          | 0.06     | Cold #3 | 0.0025               | 0.070   | 0.005        | Hot #1     | 0.0025          | 0.19  | 0.005      |   |
| Sey 21                 | Cold #1   | 0.0140    | 0.370       | 0.76 (                           | Cold #2 ( | 0.0050 (   | .650 (   | 0.040 15 | st L O           | .0055       | 0.64          | 0.08     | Cold #3 | 0.0025               | 060.0   | 0.005        | Hot #1     | 0.0025          | 0.18  | 0.010      |   |
| Sey 22                 | Cold #1   | 0.0130    | 0.470       | 1.54 (                           | Cold #2 ( | 0.0025 (   | ) 200 (  | 0.060 15 | st L 0           | .0030       | 0.69          | 0.13     | Cold #3 | 0.0025               | 0.110   | 0.010        | Hot #1     | 0.0025          | 0.45  | 0.020      |   |
| Sey 23                 | Cold #1   | 0.0080    | 0.360       | 0.65 (                           | Cold #2 ( | ).0270 (   | .880 (   | 0.060 1  | st L<br>St L     | .0261       | 0.85          | 0.09     | Cold #3 | 0.0025               | 0.070   | 0.005        | Hot #1     | 0.0025          | 0.21  | 0.005      |   |
| Sey 25                 | Cold #1   | 0.0025    | 0.680       | 0.69                             | Cold #2 ( | 0025 (     | ).760 (  | 0.110 1  | st L             | .0025       | 0.76<br>2 2 2 | 0.14     | Cold #3 | 0.0025               | 0.530   | 0.005        | Hot #1     | 0.0025          | 0.99  | 0.005      |   |
| Sey 26                 | Cold #1   | 0.0025    | 0.420       | 0.22                             | Cold #2 ( | ).0025 (   | .500 (   | ).020 14 | st L             | .0025       | 0.50          | 0.03     | Cold #3 | 0.0025               | 0.070   | 0.010        | Hot #1     | 0.0025          | 0.15  | 0.010      |   |
| Sey 27                 | Cold #1   | 0.0060    | 0.530       | 0.30                             | Cold #2 ( | ).0025 (   | .510 (   | 0.050 1  | st L             | .0027       | 0.51          | 0.06     | Cold #3 | 0.0025               | 0.030   | 0.005        | Hot #1     | 0.0025          | 0.19  | 0.005      |   |
| Sey 25                 |           | 0.0230    | 0.610       | 1.41                             | ) 24 plo( | 0.0025 (   | .540     | 0.140 1; | st L             | .0035       | 0.54          | 0.20     |         | 0.0025               | 0.080.0 | G00.0        |            | 0.0025          | 0.16  | c00.0      |   |
| Cap 14                 |           | 0.0100    | 0.660       |                                  |           | 0/2/0      | 0001     | 1.020.1  |                  | 2020        | 0.84          | 0.03     |         | GZUU.U               | 0.070   | 0.010        |            | 0.0025<br>10000 | 0.30  | 0.010      |   |
|                        |           | 0.0440    | 0.900       |                                  |           | 1 0900 1   |          | 1.000    | 0 0<br>          | 0000        | 50.1<br>2     | 6.0      |         | 0,0005               | 0.040   |              | - + +      | 0.0026          | 0.24  | 0.000      |   |
|                        |           | 0.0140    | 0:090<br>28 | 2 00<br>2 8                      | , 24 UIO  | 28         | 28       | 28 100.1 | ר<br>קור<br>יל ב | -000-<br>28 | 0.43<br>28    | - 0.<br> |         | 0.200.0<br>28        | 28      | 280          | Hot #1     | 0.0020<br>28    | 28    | 280        |   |
| neem                   | 000 #1    | 0.0120    | 0.530 0     | 1508 (                           | 2014 #2 C | 0072       | 1601     | 052 14   |                  | 0075 (      | 0.683         | 0.079    |         | 0.0055               | 0 111   | 0.008        | Hot #1     | 0 0028          | 772 0 | 0.011      |   |
| st dev                 | Cold #1   | 0.0099    | 0.227 (     | 0.439 (                          |           | 0.0081     | 1434 (   | 1.044 15 | 4 L C            | 0078 (      | 0.419         | 0.054 0  | Cold #3 | 0.0000               | 0.111   | 0.005        | Hot #1     | 0.0010          | 0.195 | 0.007      |   |
| st err                 | Cold #1   | 0.0019    | 0:043 (     | 0.083 (                          | Cold #2 C | 0015 (     | 0.082    | 0.008 1  | 37 L 0           | .0015 (     | 0.079         | 0.010    | Cold #3 | 0.0000               | 0.021   | 0.001        | Hot #1     | 0.0002          | 0.037 | 0.001      | / |
| time St Err            | Cold #1   | 0.0037    | 0.086       | 0.166 0                          | Cold #2 ( | 0.0031 (   | .164     | 017 1    | ы<br>тг<br>о     | .0029       | 0.158         | 0.020    | Cold #3 | 0.0000               | 0.042   | 0.002        | Hot #1     | 0.0004          | 0.074 | 0.003      |   |
| SummaryCou             | n Cold #1 | Pb        | 0<br>C      | Zn Z                             | Cold #2   | Pb         | Cu       | Zn 15    | зt Г             | Pb          | С             | ZnZ      | Cold #3 | Pb                   | Cu      | Zn           | Hot #1     | Pb              | Cu    | Zn         |   |
| CDWG                   |           | 0.0100    | 1.000       | 5.00                             | 5         | 0.0100     | 000.1    | 5.000    | 0                | .0100       | 1.00          | 5.00     |         | 0.0100               | 1.000   | 5.000        |            | 0.0100          | 1.00  | 5.000      |   |
| Average<br>Canilano 20 | Cold #1   | 0.0112    | 0 928       | ) 766 (                          | Jold #2   | 00800      | 349 (    | 1 074 14 |                  | 0081        | 1.328         | 0 108    | Cold #3 | 0 0025               | 0 134   | 0000         | Hot #1     | 0 0027          | 0.470 | 0 035      |   |
|                        |           |           | 0 2000      |                                  |           | 00000      | 0.00     | 1050 1   | , c              | 0075        | 0.600         |          |         | 0.0005               | 0 111   |              | ; #<br>; # |                 | 776.0 | 0.000      |   |
|                        | Cold #1   | 0.0067    | 0.382       | 382 (                            |           | ) 0046 (   | 1511 (   | 1 038 14 | 0 0<br>          | 10047       | 0.505         | 0.055 0  |         | 0.0029               | 0.134   | 0.014        | Hot #      | 0.0026          | 0 192 | 0.01       |   |
| Newton 18              | Cold #1   | 0.0097    | 0.177 (     | 0.108 (                          | Cold #2 ( | 0.0061     | .210 (   | 010 1    | at L             | .0063       | 0.208         | 0.015    | Cold #3 | 0.0025               | 0.029   | 0.005        | Hot #1     | 0.0027          | 0.068 | 0.006      |   |
|                        |           |           |             |                                  |           |            |          |          |                  |             |               |          |         |                      |         |              |            |                 |       |            |   |
|                        |           |           |             |                                  |           |            |          |          |                  |             |               |          |         |                      |         |              |            |                 |       |            |   |
|                        |           |           |             |                                  |           |            |          |          |                  |             |               |          |         | ŗ                    |         |              |            |                 |       |            |   |
|                        |           |           |             |                                  |           |            |          |          |                  |             |               |          |         |                      |         |              |            |                 |       |            |   |
|                        |           |           |             |                                  |           |            |          |          |                  |             |               |          |         |                      |         |              |            |                 |       |            |   |

| Sampli<br>Source | s gn<br># | esion   | 2 - Jan<br>Pb | uary 2<br>Cu | 2003<br>Zn | Tvpe     | ,<br>P | Cu    | z        | Tvpe  | ą      | C     | ,<br>Z   | Type     | P     | C     | Zn<br>Tve   | e<br>Pb        | Cu      | Zn       |    |
|------------------|-----------|---------|---------------|--------------|------------|----------|--------|-------|----------|-------|--------|-------|----------|----------|-------|-------|-------------|----------------|---------|----------|----|
|                  |           |         |               |              |            |          |        |       |          |       |        |       |          |          |       |       | :           |                |         |          |    |
| Cap              | 0<br>5    | :0ld #1 | 0.0050        | 0.571        | 0.788 C    | old #2 ( | 0.0070 | 0.680 | 0.032    | 1st L | 0.0069 | 0.675 | 0.070 C  | old #3 0 | .0025 | 0.184 | 0.013 Hot 3 | #1 0.002       | 25 0.19 | 90.0     | 05 |
| Cap              | 5<br>C    | old #1  | 0.0120        | 0.783        | 1.220 C    | old #2 ( | 0.0050 | 1.800 | 0.085    | 1st L | 0.0054 | 1.749 | 0.142 C  | old #3 0 | .0025 | 0.226 | 0.016 Hot 3 | #1 0.003       | 25 1.71 | 6 0.1    | 45 |
| Cap              | 7 C       | old #1  | 0.0025        | 1.135        | 1.193 C    | old #2 ( | 0.0025 | 2.291 | 0.071    | 1st L | 0.0025 | 2.233 | 0.127 C  | old #3 0 | .0025 | 0.125 | 0.015 Hot 3 | #1 0.002       | 25 0.93 | 4 0.1    | 26 |
| Cap              | 8         | bld #1  | 0.0025        | 0.377        | 0.560 C    | old #2 ( | 0.0025 | 0.445 | 0.012    | 1st L | 0.0025 | 0.442 | 0.039 C  | old #3 0 | .0025 | 0.053 | 0.008 Hot 3 | #1 0.003       | 25 0.18 | 2 0.0    | 3  |
| Cap              | ი<br>ი    | old #1  | 0.0025        | 0.302        | 1.001 C    | old #2 ( | 0.0060 | 0.551 | 0.046    | 1st L | 0.0058 | 0.539 | 0.094 C  | old #3 0 | .0025 | 0.015 | 0.005 Hot 3 | #1 0.002       | 25 0.25 | 4 0.0    | 33 |
| Cap              | 10<br>C   | old #1  | 0.0050        | 0.473        | 1.950 C    | old #2 ( | 0.0060 | 0.692 | 0.360    | 1st L | 0.0060 | 0.681 | 0.440 C  | old #3 0 | .0025 | 0.838 | 0.030 Hot 3 | #1 0.00        | 25 0.31 | 1 0.0    | 83 |
| Cap              | 1<br>C    | old #1  | 0.0050        | 0.384        | 1.304 C    | old #2 ( | 0.0025 | 0.516 | 0.125    | 1st L | 0.0026 | 0.509 | 0.184 C  | old #3 0 | .0025 | 0.035 | 0.005 Hot i | #1 0.002       | 25 0.05 | 0.0 6    | 4  |
| Cap              | 12 C      | :old #1 | 0.0140        | 1.127        | 0.953 C    | old #2 ( | 0.0025 | 0.506 | 0.040    | 1st L | 0.0031 | 0.537 | 0.086 C  | old #3 0 | .0025 | 0.157 | 0.005 Hot 3 | #1 0.00        | 25 1.06 | 3 0.0    | 05 |
| Cap              | 15 C      | bld #1  | 0.0025        | 0.969        | 1.594 C    | old #2 ( | 0.0025 | 1.654 | 0.104    | 1st L | 0.0025 | 1.620 | 0.179 C  | old #3 0 | .0025 | 0.308 | 0.016 Hot i | #1 0.002       | 25 1.60 | 0.0      | 12 |
| Cap              | 19 C      | bld #1  | 0.0070        | 0.719        | 0.974 C    | old #2 ( | 0.0070 | 1.197 | 0.157    | 1st L | 0.0070 | 1.173 | 0.198 C  | old #3 0 | .0025 | 0.152 | 0.007 Hot 3 | #1 0.00        | 25 0.13 | 7 0.0    | 58 |
| Cap              | 20<br>C   | :old #1 | 0.0140        | 1.747        | 0.190 C    | old #2 ( | 0.0025 | 1.130 | 0.005    | 1st L | 0.0031 | 1.161 | 0.014 C  | old #3 0 | .0025 | 0.190 | 0.005 Hot 3 | <b>#1 0.01</b> | t0 1.4ε | 6 0.0    | 13 |
| Cap              | 22 C      | :0ld #1 | 0.0080        | 1.407        | 0.086 C    | old #2 ( | 0.0070 | 2.931 | 0.049    | 1st L | 0.0071 | 2.855 | 0.051 C  | old #3 0 | .0025 | 0.205 | 0.005 Hot : | #1 0.00        | 25 0.84 | 4 0.1    | 8  |
| Sey              | 14<br>C   | >old #1 | 0.0050        | 1.173        | 0.433 C    | old #2 ( | 0.0025 | 2.041 | 0.035    | 1st L | 0.0026 | 1.998 | 0.055 C  | old #3 0 | .0025 | 1.183 | 0.005 Hot : | #1 0.00        | 25 1.16 | 4<br>0.0 | 48 |
|                  |           |         |               |              |            |          |        |       |          |       |        |       |          |          |       |       |             |                |         |          |    |
| count            |           |         | 13            | 13           | 13         |          | 13     | 13    | 13       |       | 13     | 13    | 13       |          | 13    | 13    | 13          |                | 13      | e        | 13 |
| mean             | J         | :old #1 | 0.0065        | 0.859        | 0.942 C    | old #2 ( | 0.0043 | 1.264 | 0.086 1  | st L  | 0.0044 | 1.244 | 0.129 Co | old #3 0 | .0025 | 0.282 | 0.010 Hot # | 1 0.00         | 34 0.76 | 8 0.0    | 45 |
| st dev           |           |         | 0.0043        | 0.445        | 0.536      | Ŭ        | 0.0021 | 0.810 | 0.094    |       | 0.0020 | 0.784 | 0.110    | 0        | 0000  | 0.340 | 0.007       | 0.00           | 32 0.60 | 3 0.0    | 49 |
| st err           |           |         | 0.0012        | 0.123        | 0.149      | 0        | 0.0006 | 0.225 | 0.026    |       | 0.0005 | 0.217 | 0.031    | 0        | 0000  | 0.094 | 0.002       | 0.00           | 09 0.16 | 0.0      | 4  |
| 2 time St        | Er        | >old #1 | 0.0024        | 0.247        | 0.297 C    | old #2 ( | 0.0011 | 0.450 | -0.052 1 | st L  | 0.0011 | 0.435 | 0.061 C  | old #3 0 | 0000  | 0.189 | 0.004 Hot # | 1 0.00         | 18 0.33 | 5 0.0    | 27 |

| Sampli      | bu | Sesion  | ı 2 - Jan | iuary i | 2003          |        |       |         |       |        |        |            |           |       |              |        |       |       |
|-------------|----|---------|-----------|---------|---------------|--------|-------|---------|-------|--------|--------|------------|-----------|-------|--------------|--------|-------|-------|
| Source      | #  | Type    | Ър        | ы       | Zn Type       | Pb     | อื    | Zn      | Type  | Pb     | 5<br>C | Zn Tyr     | oe Pb     | S     | Zn Type      | РЬ     | 5     | Zn    |
| Сod<br>Cod  | -  | Cold #1 | 0.0025    | 0.490   | 0.090 Cold #2 | 0.0025 | 1.326 | 0.014   | 1st L | 0.0025 | 1.284  | 0.018 Cold | #3 0.0025 | 0.104 | 0.005 Hot #1 | 0.0025 | 0.337 | 0.028 |
| Сod         | 2  | cold #1 | 0.0070    | 0.340   | 1.060 Cold #2 | 0.0025 | 0.145 | 0.049   | 1st L | 0.0027 | 0.155  | 0.099 Cold | #3 0.0025 | 0.105 | 0.005 Hot #1 | 0.0025 | 0.189 | 0.105 |
| Б<br>С      | ო  | Cold #1 | 0.0025    | 0.160   | 1.520 Cold #2 | 0.0025 | 0.089 | 0.079   | 1st L | 0.0025 | 0.093  | 0.151 Cold | #3 0.0025 | 0.015 | 0.005 Hot #1 | 0.0025 | 0.305 | 0.037 |
| Cod         | 4  | Cold #1 | 0.0050    | 0.250   | 0.100 Cold #2 | 0.0025 | 0.101 | 0.021   | 1st L | 0.0026 | 0.108  | 0.025 Cold | #3 0.0025 | 0.015 | 0.005 Hot #1 | 0.0025 | 0.086 | 0.021 |
| Cod         | ß  | Cold #1 | 0.0025    | 0.110   | 0.140 Cold #2 | 0.0025 | 0.050 | 0.022   | 1st L | 0.0025 | 0.053  | 0.028 Cold | #3 0.0025 | 0.015 | 0.005 Hot #1 | 0.0025 | 0.110 | 0.068 |
| Сод         | 9  | Cold #1 | 0.0070    | 0.350   | 1.100 Cold #2 | 0.0025 | 0.059 | 0.069   | 1st L | 0.0027 | 0.074  | 0.120 Cold | #3 0.0025 | 0.015 | 0.005 Hot #1 | 0.0025 | 0.128 | 0.043 |
| Сод         | 2  | Cold #1 | 0.0025    | 0.340   | 0.070 Cold #2 | 0.0025 | 0.721 | 0.065   | 1st L | 0.0025 | 0.702  | 0.065 Cold | #3 0.0025 | 0.054 | 0.012 Hot #1 | 0.0610 | 0.390 | 0.061 |
| Cod         | œ  | Cold #1 | 0.0060    | 0.460   | 0.710 Cold #2 | 0.0025 | 0.399 | 0.024   | 1st L | 0.0027 | 0.402  | 0.058 Cold | #3 0.0025 | 0.015 | 0.015 Hot #1 | 0.0070 | 0.345 | 0.023 |
| Сod         | ი  | Cold #1 | 0.0050    | 0.440   | 0.560 Cold #2 | 0.0025 | 0.105 | 0.022   | 1st L | 0.0026 | 0.122  | 0.049 Cold | #3 0.0025 | 0.015 | 0.020 Hot #1 | 0.0025 | 0.032 | 0.005 |
| б           | 9  | Cold #1 | 0.0060    | 0.440   | 0.210 Cold #2 | 0.0025 | 0.592 | 0.022   | 1st L | 0.0027 | 0.584  | 0.031 Cold | #3 0.0025 | 0.035 | 0.011 Hot #1 | 0.0025 | 0.241 | 0.010 |
| бо<br>Со    | 7  | Cold #1 | 0.0050    | 0.770   | 0.050 Cold #2 | 0.0080 | 1.504 | 0.059   | 1st L | 0:0079 | 1.467  | 0.059 Cold | #3 0.0080 | 0.228 | 0.033 Hot #1 | 0.0025 | 0.158 | 0.014 |
| бо<br>Со    | 13 | Cold #1 | 0.0330    | 1.190   | 0.260 Cold #2 | 0.0090 | 0.275 | 0.042   | 1st L | 0.0102 | 0.321  | 0.053 Cold | #3 0.0025 | 0.015 | 0.013 Hot #1 | 0.0070 | 0.466 | 0.111 |
| Бо          | 4  | Cold #1 | 0.0025    | 0.270   | 0.460 Cold #2 | 0.0025 | 0.173 | 0.048   | 1st L | 0.0025 | 0.178  | 0.069 Cold | #3 0.0025 | 0.015 | 0.024 Hot #1 | 0.0025 | 0.065 | 0.085 |
| бо<br>Со    | 15 | Cold #1 | 0.0060    | 0.430   | 0.450 Cold #2 | 0.0050 | 0.441 | 0.034   | 1st L | 0.0051 | 0.441  | 0.055 Cold | #3 0.0025 | 0.015 | 0.018 Hot #1 | 0.0025 | 0.166 | 0.017 |
| Cod         | 16 | Cold #1 | 0.0025    | 0.680   | 1.430 Cold #2 | 0.0025 | 1.794 | 0.103   | 1st L | 0.0025 | 1.738  | 0.169 Cold | #3 0.0025 | 0.082 | 0.014 Hot #1 | 0.0025 | 0.576 | 0.029 |
| Сод         | 18 | Cold #1 | 0.0025    | 0.460   | 0.120 Cold #2 | 0.0025 | 0.441 | 0.020   | 1st L | 0.0025 | 0.441  | 0.025 Cold | #3 0.0025 | 0.062 | 0.005 Hot #1 | 0.0025 | 0:364 | 0.005 |
| Сod         | 19 | Cold #1 | 0.0070    | 0.230   | 1.050 Cold #2 | 0.0025 | 0.063 | 0.122   | 1st L | 0.0027 | 0.071  | 0.169 Cold | #3 0.0025 | 0.015 | 0.027 Hot #1 | 0.0025 | 0.053 | 0.031 |
| Сod         | 20 | Cold #1 | 0.0025    | 0.340   | 0.730 Cold #2 | 0.0025 | 0.222 | 0.060   | 1st L | 0.0025 | 0.228  | 0.094 Cold | #3 0.0025 | 0.032 | 0.005 Hot #1 | 0.0025 | 0.189 | 0.036 |
| Сod         | 21 | Cold #1 | 0.0025    | 0.460   | 0.300 Cold #2 | 0.0025 | 0.383 | 0.031   | 1st L | 0.0025 | 0.386  | 0.044 Cold | #3 0.0025 | 0.049 | 0.005 Hot #1 | 0.0025 | 0.195 | 0.005 |
| Сod         | 23 | Cold #1 | 0.0060    | 0.640   | 0.160 Cold #2 | 0.0025 | 0.886 | 0.025   | 1st L | 0.0027 | 0.873  | 0.032 Cold | #3 0.0025 | 0.063 | 0.005 Hot #1 | 0.0025 | 0.275 | 0.005 |
| Сод         | 53 | Cold #1 | 0.0025    | 0.360   | 0.570 Cold #2 | 0.0025 | 0.084 | 0.018   | 1st L | 0.0025 | 0.098  | 0.045 Cold | #3 0.0025 | 0.015 | 0.005 Hot #1 | 0.0025 | 0.046 | 0.005 |
| соd<br>С    | 24 | Cold #1 | 0.0050    | 0.530   | 0.750 Cold #2 | 0.0025 | 1.210 | 0.034   | 1st L | 0.0026 | 1.176  | 0.069 Cold | #3 0.0025 | 0.062 | 0.016 Hot #1 | 0.0025 | 0.341 | 0.022 |
| Coq         | 25 | Cold #1 | 0.0100    | 0.540   | 0.170 Cold #2 | 0.0025 | 0.596 | 0.024   | 1st L | 0.0029 | 0.593  | 0.031 Cold | #3 0.0025 | 0.063 | 0.005 Hot #1 | 0.0180 | 0.122 | 0.005 |
| Сод         | 26 | Cold #1 | 0.0110    | 1.180   | 0.340 Cold #2 | 0.0025 | 1.485 | 0.054   | 1st L | 0.0029 | 1.470  | 0.068 Cold | #3 0.0025 | 1.402 | 0.047 Hot #1 | 0.0025 | 0.559 | 0.025 |
| Сод         | 27 | Cold #1 | 0.0025    | 0.380   | 0.060 Cold #2 | 0.0170 | 0.814 | 0.021   | 1st L | 0.0163 | 0.792  | 0.023 Cold | #3 0.0025 | 0.085 | 0.005 Hot #1 | 0.0025 | 0.236 | 0.014 |
| Сод         | 28 | Cold #1 | 0.0060    | 0.370   | 0.100 Cold #2 | 0.0025 | 0.093 | 0.020   | 1st L | 0.0027 | 0.107  | 0.024 Cold | #3 0.0025 | 0.015 | 0.005 Hot #1 | 0.0025 | 0.035 | 0.005 |
| Сoq         | 29 | Cold #1 | 0.0050    | 0.050   | 0.040 Cold #2 | 0.0025 | 0.015 | 0.024   | 1st L | 0.0026 | 0.017  | 0.025 Cold | #3 0.0025 | 0.015 | 0.005 Hot #1 | 0.0025 | 0.077 | 0.104 |
| Сод         | 30 | Cold #1 | 0.0025    | 0.310   | 0.610 Cold #2 | 0.0025 | 0.104 | 0.055   | 1st L | 0.0025 | 0.114  | 0.083 Cold | #3 0.0025 | 0.015 | 0.005 Hot #1 | 0.0025 | 0.135 | 0.019 |
| Сод         | 32 | Cold #1 | 0.0050    | 0.720   | 0.070 Cold #2 | 0.0025 | 1.277 | 0.005   | 1st L | 0.0026 | 1.249  | 0.008 Cold | #3 0.0025 | 0.064 | 0.005 Hot #1 | 0.0025 | 0.353 | 0.010 |
| Сod         | 34 | Cold #1 | 0.0025    | 0.380   | 0.120 Cold #2 | 0.0025 | 0.224 | 0.063   | 1st L | 0.0025 | 0.232  | 0.065 Cold | #3 0.0025 | 0.036 | 0.005 Hot #1 | 0.0025 | 0.133 | 0.106 |
| Сod         | 35 | Cold #1 | 0.0070    | 0.230   | 1.000 Cold #2 | 0.0025 | 0.064 | 0.119   | 1st L | 0.0027 | 0.072  | 0.163 Cold | #3 0.0025 | 0.015 | 0.016 Hot #1 | 0.0025 | 0.112 | 0.185 |
| Сод         | 36 | Cold #1 | 0.0050    | 0.470   | 0.320 Cold #2 | 0.0070 | 1.265 | 0.012   | 1st L | 0.0069 | 1.225  | 0.028 Cold | #3 0.0025 | 0.102 | 0.005 Hot #1 | 0.0025 | 0.252 | 0.005 |
| Cod         | 37 | Cold #1 | 0.0025    | 0.660   | 0.720 Cold #2 | 0.0025 | 0.984 | 0.038   | 1st L | 0.0025 | 0.968  | 0.072 Cold | #3 0.0025 | 0.121 | 0.005 Hot #1 | 0.0025 | 0.338 | 0.038 |
| New         | თ  | Cold #1 | 0.0110    | 0.230   | 0.440 Cold #2 | 0.0025 | 0.518 | 0.026   | 1st L | 0.0029 | 0.503  | 0.046 Cold | #3 0.0025 | 0.031 | 0.005 Hot #1 | 0.0025 | 0.121 | 0.026 |
| New         | 17 | Cold #1 | 0.0025    | 1.090   | 0.090 Cold #2 | 0.0025 | 1.351 | 0.043   | 1st L | 0.0025 | 1.338  | 0.045 Cold | #3 0.0025 | 0.412 | 0.005 Hot #1 | 0.0025 | 0.449 | 0.005 |
| count       |    | Cold #1 | 35        | 35      | 35            | 35     | 35    | 35      |       | 35     | 35     | 35         | 35        | 35    | 35           | 35     | 35    | 35    |
| mean        |    | Cold #1 | 0.0056    | 0.467   | 0.456 Cold #2 | 0.0035 | 0.567 | 0.042 1 | lst L | 0.0036 | 0.562  | 0.063 Cold | #3 0.0027 | 0.098 | 0.011 Hot #1 | 0.0049 | 0.228 | 0.037 |
| steev       |    | st dev  | 0.0054    | 0.270   | 0.414         | 0.0029 | 0.531 | 0.029   |       | 0.0028 | 0.514  | 0.044      | 0.000     | 0.239 | 0.010        | 0.0102 | 0.149 | 0.041 |
| Ling Series |    | st err  | 0.0009    | 0.046   | 0.070         | 0.0005 | 060.0 | 0.005   |       | 0.0005 | 0.087  | 0.007      | 0.0002    | 0.040 | 0.002        | 0.0017 | 0.025 | 0.007 |
| 2 time St   | Б  | Cold #1 | 0.0018    | 0.091   | 0.140 Cold #2 | 0.0010 | 0.180 | 0.010 1 | lst L | 0.0009 | 0.174  | 0.015 Cold | #3 0.0003 | 0.081 | 0.003 Hot #1 | 0.0034 | 0.050 | 0.014 |

| Samplir    | ng S   | sion    | 2 - Jan | uary 2 | 2003    |           |        |       |         |       |        |       |         |           |         |       |          |       |        |       |       |
|------------|--------|---------|---------|--------|---------|-----------|--------|-------|---------|-------|--------|-------|---------|-----------|---------|-------|----------|-------|--------|-------|-------|
| Source     | #      | Type    | Рb      | CL     | Zn      | Type      | Pb     | Cu    | zn      | Type  | Pb     | c     | Zn      | Type      | Pb      | Cu    | L<br>Z   | Lype  | Pb     | Сu    | Zn    |
| New        | 5      | Cold #1 | 0.0070  | 0.190  | 0.330 C | Cold #2 ( | 0.0025 | 0.066 | 0.017   | 1st L | 0.0027 | 0.073 | 0.032 C | old #3 (  | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0025 | 0.176 | 0.005 |
| New        | с<br>Э | Cold #1 | 0.0025  | 0.150  | 0.290 C | Cold #2 ( | 0.0025 | 0.095 | 0.036   | 1st L | 0.0025 | 0.097 | 0.049 C | >old #3 ( | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0025 | 0.053 | 0.033 |
| New        | 4      | Cold #1 | 0.0090  | 0.210  | 0.090 C | Cold #2 ( | 0.0090 | 0.329 | 0.014   | 1st L | 0.0090 | 0.323 | 0.017 C | old #3 (  | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0025 | 0.127 | 0.010 |
| New        | 5      | Cold #1 | 0.0025  | 0.150  | 0.230 C | Cold #2 ( | 0.0025 | 0.015 | 0.018   | 1st L | 0.0025 | 0.022 | 0.029 C | old #3 (  | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0025 | 0.015 | 0.025 |
| New        | 9      | Cold #1 | 0.0025  | 0.250  | 0.020 C | Cold #2 ( | 0.0025 | 0.273 | 0.017   | 1st L | 0.0025 | 0.272 | 0.017 C | Sold #3 ( | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0025 | 0.073 | 0.010 |
| New        | 2      | Cold #1 | 0.0050  | 060.0  | 0.090 C | Cold #2 ( | 0.0025 | 0.080 | 0.010   | 1st L | 0.0026 | 0.081 | 0.014 C | Sold #3 ( | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0025 | 0.015 | 0.011 |
| New        | 8      | Cold #1 | 0.0100  | 0.200  | 0.010 C | Cold #2 ( | 0.0025 | 0.173 | 0.005   | 1st L | 0.0029 | 0.174 | 0.005 C | Sold #3 ( | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0025 | 0.112 | 0.042 |
| New        | 10     | Cold #1 | 0.0630  | 0.270  | 0.090 C | Cold #2 ( | 0.0270 | 0.325 | 0.012   | 1st L | 0.0288 | 0.322 | 0.016 C | Sold #3 ( | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0025 | 0.257 | 0.005 |
| New        | 1      | Cold #1 | 0.0025  | 0.100  | 0.030 C | Cold #2 ( | 0.0025 | 0.057 | 0.005   | 1st L | 0.0025 | 0.059 | 0.006 C | Cold #3 ( | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0025 | 0.046 | 0.005 |
| New        | 12 (   | Cold #1 | 0.0060  | 0.160  | 0.140 C | Cold #2 ( | 0.0025 | 0.184 | 0.022   | 1st L | 0.0027 | 0.183 | 0.028 C | Sold #3 ( | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0060 | 0.067 | 0.021 |
| New        | 13 (   | Cold #1 | 0.0025  | 0.015  | 0.010 C | Cold #2 ( | 0.0025 | 0.015 | 0.032   | 1st L | 0.0025 | 0.015 | 0.030 C | Sold #3 ( | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0025 | 0.015 | 0.005 |
| New        | 14 (   | Cold #1 | 0.0090  | 0.290  | 0.080 C | Cold #2 ( | 0.0025 | 0.288 | 0.005   | 1st L | 0.0028 | 0.288 | 0.009 C | Cold #3 ( | 0.0025  | 0.044 | 0.005 H  | ot #1 | 0.0025 | 0.163 | 0.025 |
| New        | 15 (   | Cold #1 | 0600.0  | 0.120  | 0.100 C | Cold #2 ( | 0.0025 | 0.117 | 0.011   | 1st L | 0.0028 | 0.117 | 0.015 C | Sold #3 ( | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0140 | 0.062 | 0.005 |
| New        | 16 (   | Cold #1 | 0.0060  | 0.100  | 0.030 C | Cold #2 ( | 0.0025 | 0.359 | 0.014   | 1st L | 0.0027 | 0.346 | 0.015 C | Sold #3 ( | 0.0025  | 0.036 | 0.005 H  | ot #1 | 0.0190 | 0.065 | 0.005 |
| Сод        | 33 (   | Cold #1 | 0.0025  | 0.120  | 0.320 C | Cold #2 ( | 0.0025 | 0.034 | 0.037   | 1st L | 0.0025 | 0.038 | 0.052 C | ) E# plo; | 0.0025  | 0.015 | 0.005 H  | ot #1 | 0.0025 | 0.015 | 0.010 |
|            |        |         |         |        |         |           |        |       |         |       |        |       |         |           |         |       |          |       |        |       |       |
| count      | 0      | Cold #1 | 15      | 15     | 15      |           | 15     | 15    | 15      |       | 15     | 15    | 15      |           | 15      | 15    | 15       |       | 15     | 15    | 15    |
| mean       | 0      | Cold #1 | 0.0093  | 0.161  | 0.124 C | Cold #2 ( | 0.0046 | 0.161 | 0.017 1 | st L  | 0.0048 | 0.161 | 0.022 C | old #3 (  | 0.0025  | 0.018 | 0.005 Ho | ot #1 | 0.0046 | 0.084 | 0.014 |
| st dev     |        | st dev  | 0.0151  | 0.075  | 0.114   | -         | 0.0064 | 0.124 | 0.011   |       | 0.0017 | 0.116 | 0.015   | 5         | 0.000.0 | 0.009 | 0.000    |       | 0.0050 | 0.071 | 0.012 |
| st err     |        | st err  | 0.0039  | 0.019  | 0.029   | -         | 0.0017 | 0.032 | 0.003   |       | 0.0004 | 0.030 | 0.004   | 5         | 0000.0  | 0.002 | 0.000    |       | 0.0013 | 0.018 | 0.003 |
| time St Er | -      | Cold #1 | 0.0078  | 0.039  | 0.059 C | Cold #2 ( | 0.0033 | 0.064 | 0.005 1 | stL   | 0.0009 | 0.060 | 0.008 C | ;old #3 ( | 0000.0  | 0.005 | 0.000 Ho | ot #1 | 0.0026 | 0.036 | 0.006 |

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| Sampli  | , gui | Sesion   | 2 - Jan | uary 2 | 003           |        |        |         |       |        |       |           |             |       |              |        |       |       |
|---------|-------|----------|---------|--------|---------------|--------|--------|---------|-------|--------|-------|-----------|-------------|-------|--------------|--------|-------|-------|
| Source  | #     | Type     | d<br>d  | ū      | Zn Type       | 4<br>G | 5<br>C | Zn      | Type  | Pb     | Cu    | Zn        | pe Pb       | Cu    | Zn Type      | 4<br>G | Сu    | zn    |
| Sey     | -     | Cold #1  | 0.0025  | 0.490  | 0.280 Cold #2 | 0.0025 | 0.128  | 0.017   | 1st L | 0.0025 | 0.146 | 0.030 Col | d #3 0.0025 | 0.033 | 0.005 Hot #1 | 0.0025 | 0.540 | 0.005 |
| Sey     | 2     | Cold #1  | 0.0025  | 0.620  | 0.390 Cold #2 | 0.0025 | 0.530  | 0.030   | 1st L | 0.0025 | 0.535 | 0.048 Col | 1#3 0.0025  | 0.060 | 0.010 Hot #1 | 0.0025 | 0.270 | 0.010 |
| Sey     | 4     | Cold #1  | 0.0025  | 0.340  | 0.950 Cold #2 | 0.0025 | 1.356  | 0.077   | 1st L | 0.0025 | 1.305 | 0.120 Col | 1#3 0.0025  | 0.058 | 0.005 Hot #1 | 0.0025 | 0.214 | 0.038 |
| Sey     | S     | Cold #1  | 0.0025  | 0.670  | 1.450 Cold #2 | 0.0025 | 1.268  | 0.088   | 1st L | 0.0025 | 1.238 | 0.156 Col | 1#3 0.0025  | 0.087 | 0.005 Hot #1 | 0.0025 | 0.668 | 0.132 |
| Sey     | 9     | Cold #1  | 0.0025  | 0.450  | 1.160 Cold #2 | 0.0120 | 0.806  | 0.074   | 1st L | 0.0115 | 0.788 | 0.128 Col | d #3 0.0025 | 0.197 | 0.005 Hot #1 | 0.0025 | 0.578 | 0.011 |
| Sey     | 7     | Cold #1  | 0.0025  | 0.350  | 1.130 Cold #2 | 0.0025 | 0.428  | 0.083   | 1st L | 0.0025 | 0.424 | 0.136 Col | d #3 0.0025 | 0.015 | 0.005 Hot #1 | 0.0025 | 0.169 | 0.046 |
| Sey     | 10    | Cold #1  | 0.0120  | 0.630  | 0.190 Cold #2 | 0.0050 | 0.985  | 0.023   | 1st L | 0.0054 | 0.967 | 0.031 Col | 1#3 0.0025  | 0.189 | 0.005 Hot #1 | 0.0025 | 0.352 | 0.005 |
| Sey     | 12    | Cold #1  | 0.0180  | 0.370  | 0.050 Cold #2 | 0.0025 | 0.200  | 0.055   | 1st L | 0.0033 | 0.209 | 0.055 Col | d #3 0.0025 | 0.015 | 0.005 Hot #1 | 0.0025 | 0.154 | 0.058 |
| Sey     | 13    | Cold #1  | 0.0070  | 0.490  | 0.470 Cold #2 | 0.0025 | 0.361  | 0.017   | 1st L | 0.0027 | 0.367 | 0.040 Col | d #3 0.0025 | 0.088 | 0.005 Hot #1 | 0.0025 | 0.177 | 0.005 |
| Sey     | 15    | Cold #1  | 0.0120  | 0.380  | 1.450 Cold #2 | 0.0025 | 0.620  | 0.113   | 1st L | 0.0030 | 0.608 | 0.179 Col | 1#3 0.0025  | 0.058 | 0.005 Hot #1 | 0.0025 | 0.294 | 0.052 |
| Sey     | 16    | Cold #1  | 0.0130  | 0.710  | 0.410 Cold #2 | 0.0110 | 0.727  | 0.024   | 1st L | 0.0111 | 0.726 | 0.044 Col | 1#3 0.0025  | 0.238 | 0.005 Hot #1 | 0.0025 | 0.293 | 0.010 |
| Sey     | 17    | Cold #1  | 0.0070  | 0.690  | 0.270 Cold #2 | 0.0025 | 1.256  | 0.083   | 1st L | 0.0027 | 1.227 | 0.092 Col | d #3 0.0025 | 0.443 | 0.016 Hot #1 | 0.0025 | 0.143 | 0.005 |
| Sey     | 20    | Cold #1  | 0.0025  | 0.440  | 0.020 Cold #2 | 0.0025 | 0.103  | 0.016   | 1st L | 0.0025 | 0.119 | 0.016 Col | d #3 0.0025 | 0.311 | 0.017 Hot #1 | 0.0025 | 0.072 | 0.005 |
| Sey     | 21    | Cold #1  | 0.0025  | 0.320  | 0.750 Cold #2 | 0.0060 | 0.694  | 0.040   | 1st L | 0.0058 | 0.675 | 0.076 Col | d #3 0.0025 | 0.096 | 0.005 Hot #1 | 0.0025 | 0.211 | 0.039 |
| Sey     | 22    | Cold #1  | 0.0025  | 0.450  | 1.340 Cold #2 | 0.0025 | 0.715  | 0.065   | 1st L | 0.0025 | 0.701 | 0.129 Col | d #3 0.0025 | 0.120 | 0.005 Hot #1 | 0.0025 | 0.262 | 0.061 |
| Sey     | 25    | Cold #1  | 0.0025  | 0.650  | 0.700 Cold #2 | 0.0025 | 0.956  | 0.114   | 1st L | 0.0025 | 0.940 | 0.143 Col | d #3 0.0025 | 0.135 | 0.005 Hot #1 | 0.0025 | 0.299 | 0.063 |
| Sey     | 26    | Cold #1  | 0.0025  | 0.400  | 0.150 Cold #2 | 0.0025 | 0.065  | 0.005   | 1st L | 0.0025 | 0.081 | 0.012 Col | d #3 0.0025 | 0.854 | 0.069 Hot #1 | 0.0025 | 0.238 | 0.019 |
| Cap     | 4     | Cold #1  | 0.0050  | 0.480  | 0.216 Cold #2 | 0600.0 | 0.788  | 0.005   | 1st L | 0.0088 | 0.773 | 0.011 Col | d #3 0.0025 | 0.049 | 0.005 Hot #1 | 0.0025 | 0.449 | 0.005 |
| Cap     | 18    | Cold #1  | 0.0130  | 0.873  | 0.260 Cold #2 | 0.0025 | 1.155  | 0.005   | 1st L | 0.0030 | 1.141 | 0.022 Col | d #3 0.0025 | 0.088 | 0.005 Hot #1 | 0.0025 | 0.435 | 0.005 |
| Cap     | 3     | Cold #1  | 0.0080  | 0.505  | 0.617 Cold #2 | 0.0025 | 0.373  | 0.019   | 1st L | 0.0028 | 0.380 | 0.049 Col | d #3 0.0025 | 0.015 | 0.005 Hot #1 | 0.0025 | 0.186 | 0.070 |
| count   |       |          | 20      | 20     | 20            | 20     | 20     | 20      |       | 20     | 20    | 20        | 20          | 20    | 20           | 20     | 20    | 20    |
| mean    |       | Cold #1  | 0.0061  | 0.515  | 0.613 Cold #2 | 0.0040 | 0.676  | 0.048 1 | stL   | 0.0041 | 0.668 | 0.076 Col | 1#3 0.0025  | 0.157 | 0.010 Hot #1 | 0.0025 | 0.300 | 0.032 |
| stdev   |       |          | 0.0049  | 0.150  | 0.477         | 0.0030 | 0.403  | 0.036   |       | 0.0029 | 0.387 | 0.054     | 0.0000      | 0.197 | 0.014        | 0.0000 | 0.159 | 0.034 |
| erroe   |       |          | 0.0011  | 0.034  | 0.107         | 0.0007 | 060.0  | 0.008   |       | 0.0007 | 0.087 | 0.012     | 0.0000      | 0.044 | 0.003        | 0.0000 | 0.035 | 0.008 |
| 2xerror |       | Cold #1  | 0.0022  | 0.067  | 0.213 Cold #2 | 0.0014 | 0.180  | 0.016 1 | stL   | 0.0013 | 0.173 | 0.024 Col | 1 #3 0.0000 | 0.088 | 0.006 Hot #1 | 0.0000 | 0.071 | 0.015 |
|         |       |          |         |        |               |        |        |         |       |        |       |           |             |       |              |        |       |       |
| Summary | Ĕ     | otal Cou | 83      |        |               |        |        |         |       |        |       |           |             |       |              |        |       |       |

Zn 0.045 0.0321 0.0374 0.0144 **Cu** 0.768 0.3001 0.2279 0.084 **Pb** 0.003 0.0025 0.0049 0.0046 **Type** Hot #1 Hot #1 Hot #1 **Zn** 0.010 0.0096 0.0107 0.005 Cu 0.282 0.1574 0.0976 0.0183 
 Zn
 Type
 Pb

 0.129
 Cold #3
 0.003
 (

 0.0758
 Cold #3
 0.0025
 0

 0.0631
 Cold #3
 0.0027
 0

 0.0223
 Cold #3
 0.0027
 0
 **Cu** 1.244 0.6675 0.5621 0.1607 **Pb** 0.004 0.0036 0.0036 Type 1st L 1st L 1st L 1st L Cu Zn 1.264 0.086 0.676 0.0476 0.567 0.0424 0.161 0.0169 
 Type
 Pb

 Cold #2
 0.004
 1

 5
 Cold #2
 0.004
 0

 3
 Cold #2
 0.0035
 0

 Cold #2
 0.0035
 0
 0
 **Zn** 0.942 (0.6126 (0.4563 (0.124 (0.124 (0.124))) **Cu** 0.859 0.515 0.467 0.161 
 Type
 Pb

 Cold #1
 0.007
 (0.0061

 Cold #1
 0.0056
 (0.0056

 Cold #1
 0.0056
 (0.0056
 Summary Tc Average Source # Capilano Seymour Seymour Doquittam Newton

# Appendix G: Statistical Analysis Data
# LEAD

# Session 1

| Groups  | 1st Litre | Cold#1 | Cold #2 | Cold #3 | Hot #1 |
|---------|-----------|--------|---------|---------|--------|
| CAP/NEW | 0.347     | 0.680  | 0.334   | 0.055   | 0.162  |
| CAP/COQ | 0.040     | 0.078  | 0.045   | 0.943   | 0.257  |
| CAP/SEY | 0.783     | 0.581  | 0.736   | 0.171   | 0.413  |
| COQ/NEW | 0.309     | 0.318  | 0.335   | 0.277   | 0.511  |
| COQ/SEY | 0.056     | 0.003  | 0.080   | 0.431   | 0.849  |
| NEW/SEY | 0.454     | 0.315  | 0.489   | 0.235   | 0.479  |

## Session 2

| Groups  | 1st Litre | Cold#1 | Cold #2 | Cold #3 | Hot #1 |
|---------|-----------|--------|---------|---------|--------|
| CAP/NEW | 0.674     | 0.604  | 0.603   | 0.920   | 0.774  |
| CAP/COQ | 0.054     | 0.511  | 0.055   | 0.558   | 0.660  |
| CAP/SEY | 0.546     | 0.416  | 0.527   | 0.470   | 0.634  |
| COQ/NEW | 0.466     | 0.251  | 0.503   | 0.511   | 0.783  |
| COQ/SEY | 0.309     | 0.858  | 0.292   | 0.666   | 0.886  |
| NEW/SEY | 0.378     | 0.297  | 0.326   | 0.427   | 0.728  |

# COPPER

#### Session 1

| Groups  | 1st Litre | Cold#1 | Cold #2 | Cold #3 | Hot #1 |
|---------|-----------|--------|---------|---------|--------|
| CAP/NEW | 0.000     | 0.000  | 0.000   | 0.004   | 0.000  |
| CAP/COQ | 0.000     | 0.000  | 0.000   | 0.955   | 0.000  |
| CAP/SEY | 0.001     | 0.001  | 0.002   | 0.527   | 0.013  |
| COQ/NEW | 0.010     | 0.000  | 0.012   | 0.070   | 0.001  |
| COQ/SEY | 0.103     | 0.011  | 0.109   | 0.675   | 0.049  |
| NEW/SEY | 0.000     | 0.000  | 0.000   | 0.003   | 0.000  |

#### Session 2

| Groups  | 1st Litre | Cold#1 | Cold #2 | Cold #3 | Hot #1 |
|---------|-----------|--------|---------|---------|--------|
| CAP/NEW | 0.000     | 0.000  | 0.000   | 0.005   | 0.000  |
| CAP/COQ | 0.001     | 0.001  | 0.001   | 0.032   | 0.000  |
| CAP/SEY | 0.009     | 0.002  | 0.010   | 0.179   | 0.001  |
| COQ/NEW | 0.006     | 0.000  | 0.025   | 0.306   | 0.001  |
| COQ/SEY | 0.194     | 0.394  | 0.271   | 0.205   | 0.100  |
| NEW/SEY | 0.000     | 0.000  | 0.000   | 0.005   | 0.000  |

202

# ZINC

## Session 1

| Groups  | 1st Litre | Cold#1 | Cold #2 | Cold #3 | Hot #1 |
|---------|-----------|--------|---------|---------|--------|
| CAP/NEW | 0.000     | 0.000  | 0.000   | 0.000   | 0.146  |
| CAP/COQ | 0.626     | 0.868  | 0.461   | 0.619   | 0.148  |
| CAP/SEY | 0.139     | 0.254  | 0.150   | 0.197   | 0.170  |
| COQ/NEW | 0.112     | 0.187  | 0.076   | 0.137   | 0.001  |
| COQ/SEY | 0.836     | 0.789  | 0.888   | 0.285   | 0.686  |
| NEW/SEY | 0.000     | 0.000  | 0.000   | 0.012   | 0.000  |

#### Session 2

1

| Groups  | 1st Litre | Cold#1 | Cold #2 | Cold #3 | Hot #1 |
|---------|-----------|--------|---------|---------|--------|
| CAP/NEW | 0.001     | 0.000  | 0.009   | 0.001   | 0.027  |
| CAP/COQ | 0.005     | 0.002  | 0.017   | 0.675   | 0.584  |
| CAP/SEY | 0.105     | 0.048  | 0.196   | 0.569   | 0.261  |
| COQ/NEW | 0.001     | 0.004  | 0.002   | 0.013   | 0.045  |
| COQ/SEY | 0.153     | 0.224  | 0.199   | 0.618   | 0.461  |
| NEW/SEY | 0.000     | 0.000  | 0.003   | 0.100   | 0.091  |