SIGNIFICANCE OF BUILDING AND PLUMBING SPECIFICS ON TRACE METAL CONCENTRATIONS IN DRINKING WATER

by

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ABSTRACT

Samples were taken from 72 high-rise apartment suites (6 suites in 12 individual high-rise towers) and 60 single-family houses located within the Greater Vancouver Regional District. The influence of the following factors on trace metal concentrations in 1-L first-flush drinking water samples and running hot water samples was investigated: building height, location, plumbing age, type of plumbing and type of building. Results of this survey show that with the exception of building height, all factors had a correlation with one or more of the trace metals investigated. The trace metals examined were lead, copper, iron and zinc. Lead was influenced primarily by building type, copper by plumbing age and type of plumbing and iron by location. Elevated lead levels were associated with high-rise samples. New copper plumbing systems resulted in high copper levels. Highest iron levels in the drinking water were measured in the East location. Zinc did not show a distinct correlation with any of the factors investigated.

Brass faucets were the primary source of zinc in tap water. They also contributed substantially to the lead detected in the 1-L first-flush sample. Metal concentrations measured in high-rise and house samples were compared with U.S. Environmental Protection Agency's (USEPA) maximum contaminant levels (MCLs) and the proposed no-action level for lead[1]. In high-rise samples, the 0.01 mg/L "no-action" proposed for lead was exceeded in 43% of the samples and 62% of the samples exceeded the current 1.0 mg/L MCL standard for copper. In single-family house samples, these values were

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[1] Compliance with the proposed 0.01 mg/L no action limit for lead is based on a sample average. Individual samples may exceed this value and still be in compliance.

47% and 73%, respectively. The average lead concentration for all high-rise samples was 0.020 mg/L and 0.013 mg/L for house samples. Regulatory levels stated above would still be exceeded in 6% of the cases for lead and 9% of the cases for copper, even after prolonged flushing of the tap in a high-rise building. In all cases associated with single-family houses, flushing the cold water tap for 5 minutes was successful in achieving compliance levels.

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1. INTRODUCTION

1.1 Background Information

The Greater Vancouver Regional District (GVRD) supplies drinking water to the lower mainland from the Capilano, Seymour and Coquitlam watersheds (Figures 1-1 to 1-3). The degree of purity of this water is very high. However, its low pH, high dissolved oxygen content, lack of alkalinity and lack of hardness makes it very corrosive (aggressive) to the metallic distribution network. The consequence of supplying corrosive water is deleterious from both an economic, aesthetic and health stand-point. Major economic factors are listed below: (Hanson et. al., 1987)

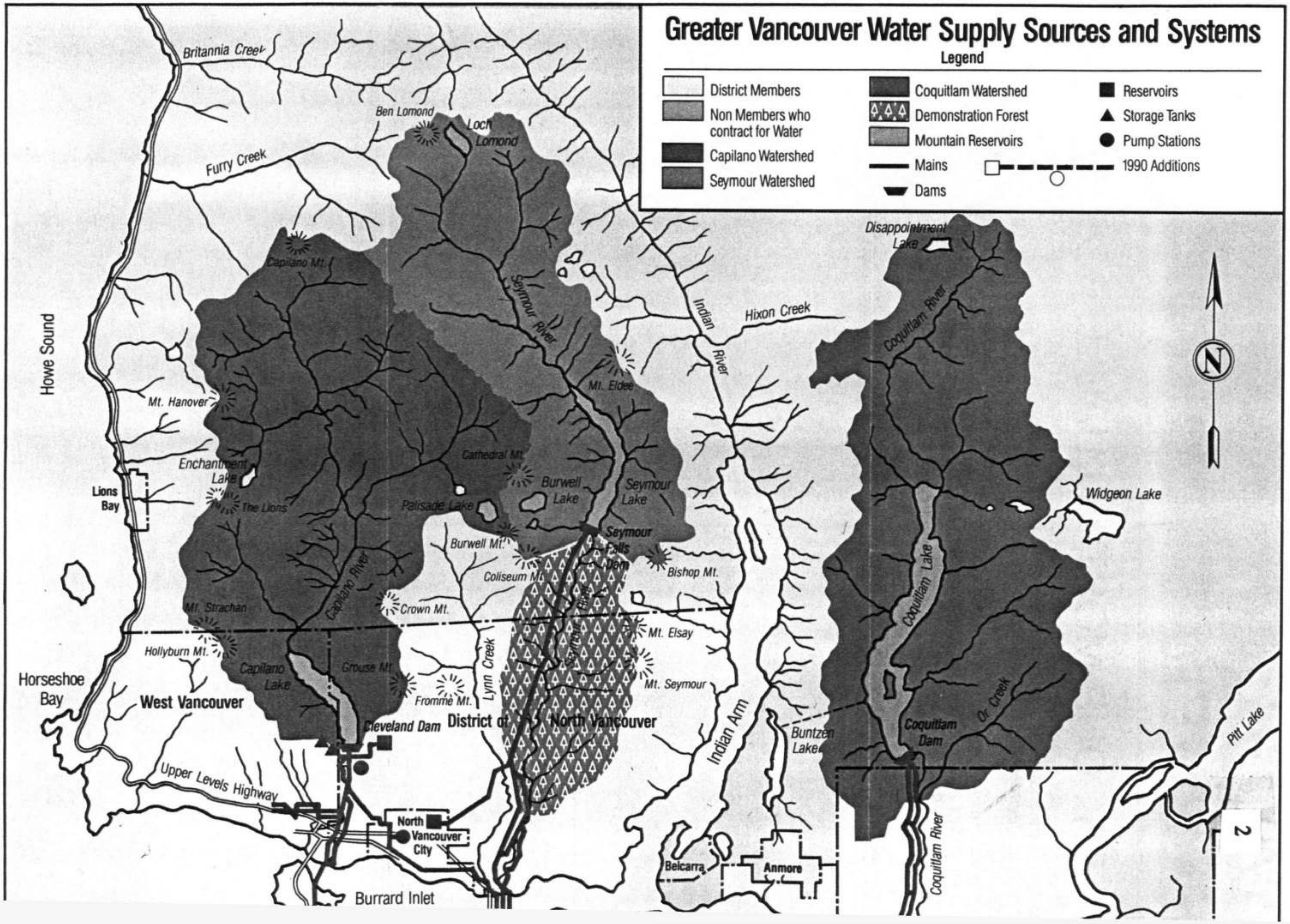
1) Increased pumping costs as a result of the accumulation of corrosion products and tuberculation that restrict water flow;

2) Accelerated corrosion rates that lead to the more rapid replacement of water mains and associated distribution infrastructure, and house plumbing;

3) Necessity of responding to customer complaints of coloured water, stains, or bad taste, which requires flushing programs and other remedial measures to mitigate water quality problems;

4) Need for treatment facilities and treatment practices to minimize system-wide deterioration of distribution waters.

Excessive levels of copper, iron and zinc are primarily of concern due to the aesthetic concerns of taste, colour and staining characteristics. Currently, consideration is being given by regulatory agencies in the United States and Canada, to regulate copper using a health risk criterion. The adverse health effects of lead, however, are well established


Greater Vancouver Water Supply Sources and Systems
Legend
District Members
Non Members who contract for Water
Capilano Watershed
Seymour Watershed
Coquitlam Watershed
Demonstration Forest
Mountain Reservoirs
Mains
Dams
■ Reservoirs
▲ Storage Tanks
● Pump Stations
1990 Additions
N
Britannia Creek
Ben Lomond
Loch Lomond
Furry Creek
Capilano Mt.
Seymour River
Indian River
Hixon Creek
Disappointment Lake
Coquitlam River
Howe Sound
Mt. Hanover
Mt. Eldee
Enchantment Lake
Cathedral Mt.
Burwell Lake
Seymour Lake
Lions Bay
The Lions
Palisade Lake
Widgeon Lake
Burwell Mt.
Seymour Falls Dam
Bishop Mt.
Coliseum Mt.
Coquitlam Lake
Capilano River
Crown Mt.
Mt. Strachan
Mt. Elsay
Hollyburn Mt.
Lynn Creek
Seymour River
Capilano Lake
Grouse Mt.
Mt. Seymour
Horseshoe Bay
West Vancouver
Fromme Mt.
Indian Arm
Or Creek
Pitt Lake
Cleveland Dam
District of North Vancouver
Buntzen Lake
Coquitlam Dam
Upper Levels Highway
North Vancouver City
Coquitlam River
Belcarra
Anmore
Burrard Inlet

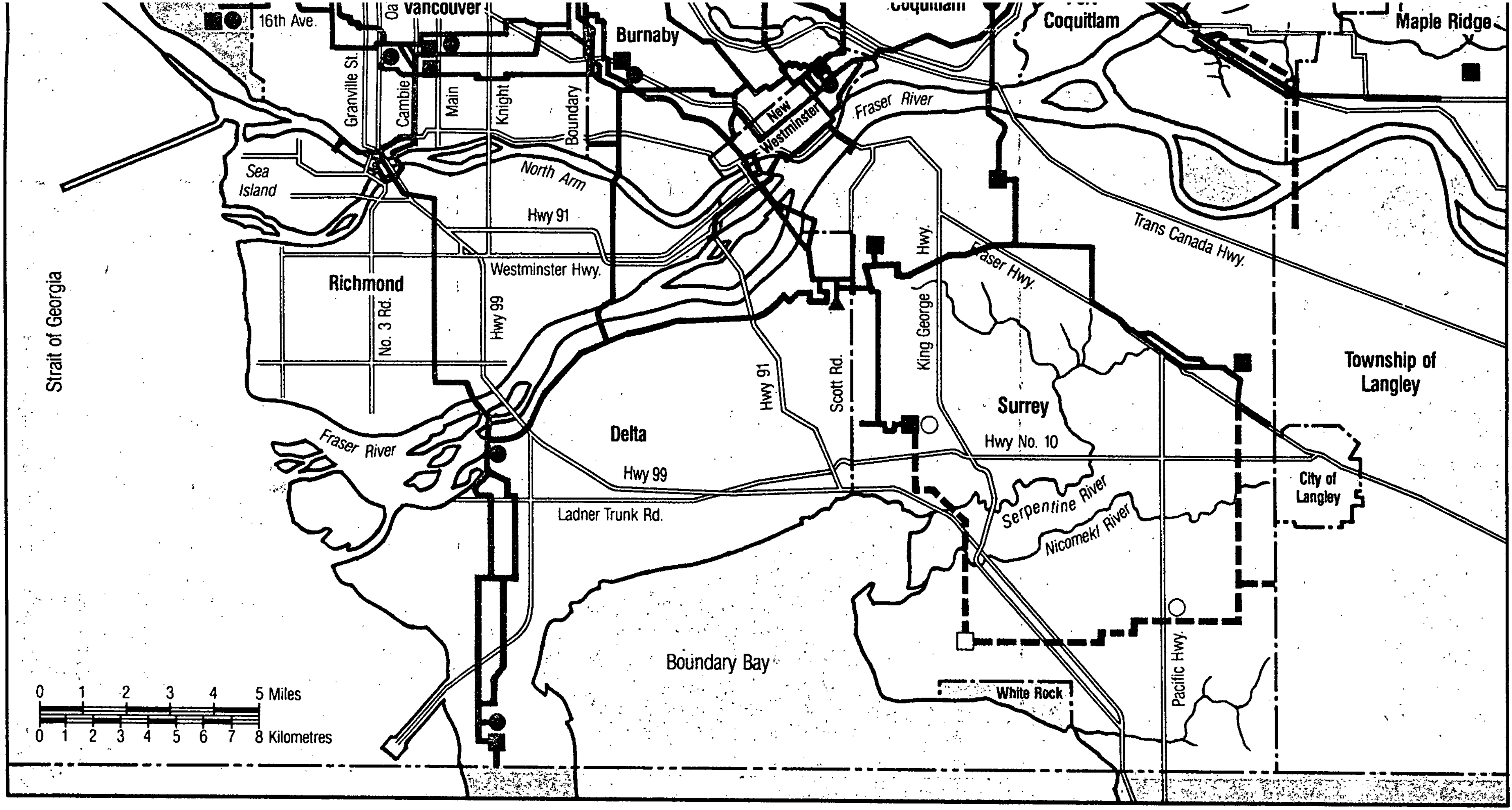


Figure 1-1. The Greater Vancouver Region's Water System

Figure 1-2. Seymour Reservoir.

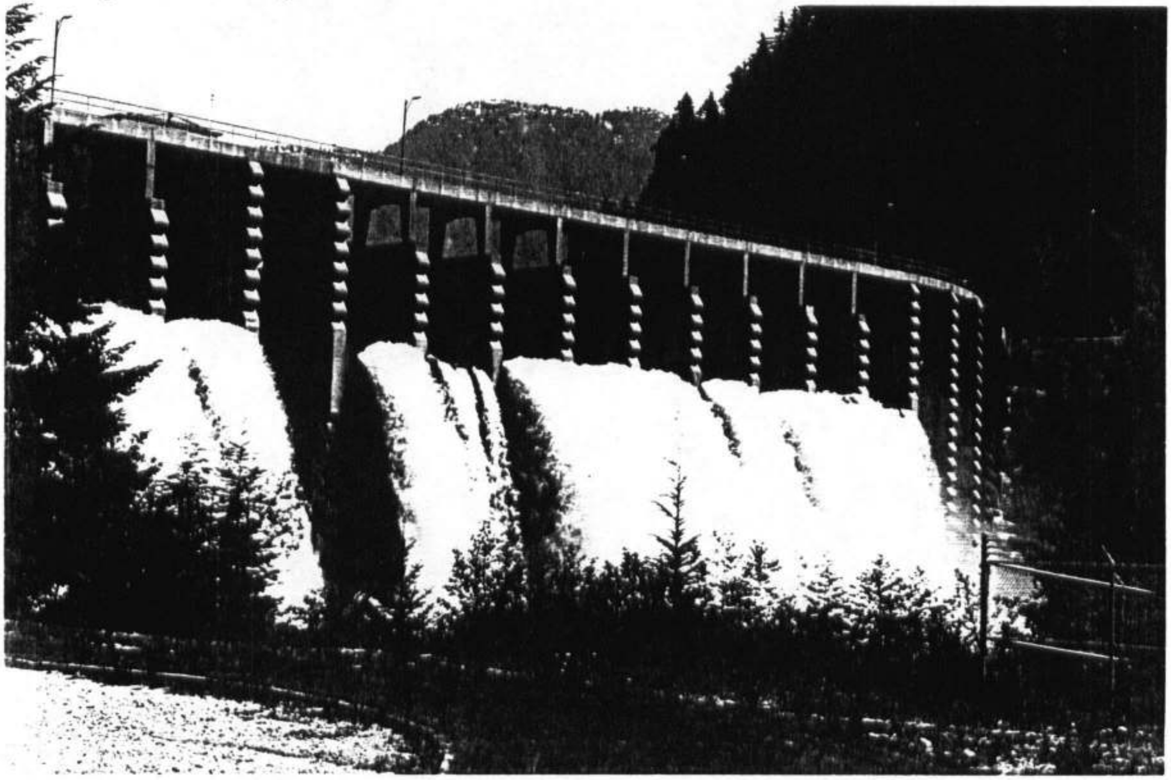


Figure 1-3. Seymour Falls Dam.

and regulations are continually being upgraded to safeguard public health from unacceptable exposure.

With a low pH and low alkalinity water supply, corrosion problems are made worse, since there is no possibility of forming a protective film of calcium carbonate on the inside of distribution pipes. Furthermore, pH and carbonate concentrations are low enough that a protective coating of insoluble corrosion products are also not usually formed (Ferguson, 1985). In fact, the corrosion products are released directly to the tap water.

Geographic factors are largely responsible for the corrosive nature of GVRD's water supply. The region receives large amounts of rainfall, which contributes to a significant mountain runoff, with little opportunity for dissolution of soil minerals. Also, bedrock formations in the region are poorly soluble and have low amounts of mineral salts that could produce alkalinity, if dissolved. In addition, a gradual increase in the acidity of rainfall (acid rain) may also be contributing to low alkalinity found in the reservoirs.

1.2 Objective and Scope

The primary objective of this study was to investigate the correlation of a limited number of key factors on the concentrations of trace metals measured in drinking water samples obtained from high-rise apartments and single-family houses. This investigation was conducted under field conditions and consequently, affirmative conclusions could not always be made due to intangibles and uncontrollable factors. In reviewing this report, the reader must be aware of analytical complications posed by unknown or missing variables, lack of control of the variables and interactions among the many variables.

2. LITERATURE REVIEW

2.1 Principles of Metallic Corrosion

Corrosion has been defined by Uhlig and Revie (1985) as "the destructive attack of a metal by chemical or electrochemical reaction with its environment." Also, he noted that the term "rusting" applies to the corrosion of iron or iron-base alloys with formation of corrosion products consisting largely of hydrous ferric oxides. Therefore, non ferrous metals can corrode, but not rust.

2.1.1 The Electrochemical Potential

Metals will corrode in water if the corrosion products are at a lower free energy level than the metal itself. The driving force of the reaction is the difference in free energy levels.

At the phase boundary of a metal (electrode) in an electrolyte, a potential difference exists between the solution and the electrode surface. This potential is the result of the tendency of a metal to go to the equilibrium state with the electrolyte. Therefore, the following reaction can be written:

$$\mathrm{Me} \rightleftharpoons \mathrm{Me}^{2+} + 2^{e-1}$$

This equation indicates that the metal corrodes, or dissolves, as the reaction goes to the right. This reaction will proceed until the metal is in equilibrium with the electrolyte containing ions of this metal. As the reaction goes to the right, oxidation takes place with the production of free electrons. At equilibrium, the forward reaction proceeds at the same rate as the reverse reaction and thus, no net corrosion occurs at equilibrium.

The velocity of an electrochemical reaction is strongly influenced by the potential difference. Figure 2-1 shows schematically the dependency of the electric current, which is equal to the velocity of the reaction, on the electrode potential (Snoeyink & Kuch, 1985). The solid curve represents the sum of the current produced by the oxidation and reduction half-reactions. The net current is zero when the rate of reduction is equal to the rate of oxidation, and the system is in equilibrium. Figure 2-2 gives a qualitative picture of the charge distribution in the phase boundary of such a metal electrode.

2.1.2 Forms of Corrosion

The study of corrosion has shown that there are many different types or forms of corrosion. The kind of attack depends on the material, the construction of the system, the scale and oxide film formation, and the hydraulic conditions (Snoeyink & Kuch, 1985). The corrosion forms range from uniform to intense localized attack. The basis for understanding most of the processes is the "corrosion cell."

2.1.2.1 The Corrosion Cell

For any type of corrosion to occur, an electrochemical cell must exist. Components of an electrochemical cell include an anode, a cathode, an external circuit, or a connection between the anode and cathode for electron transport, and an internal circuit, or an electrolyte solution that will conduct ions between the anode and cathode (Figure 2-3). If any one of these components are absent, a corrosion cell does not exist and

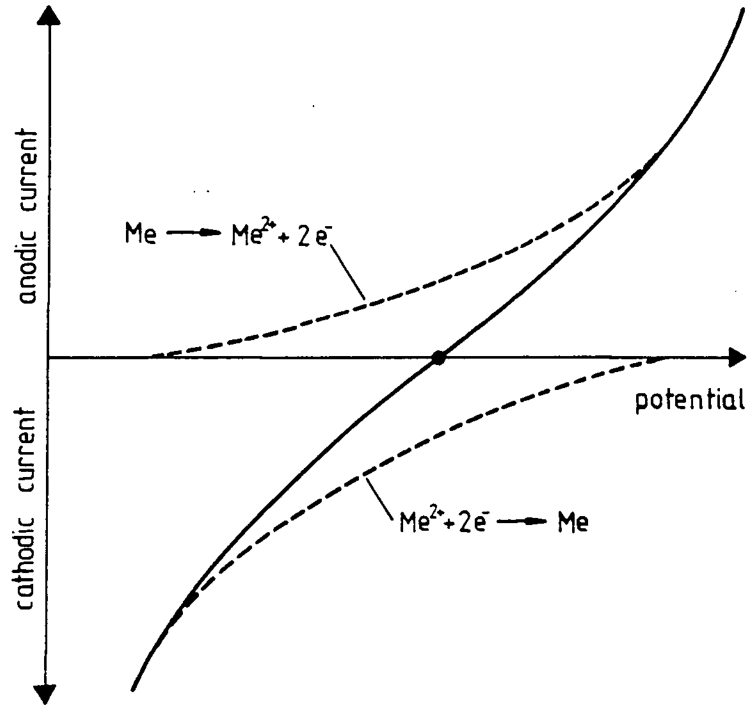


Figure 2-1. Potential Versus Current for an Electrochemical Reaction from (Adapted from Snoeyink & Kuch, 1985)

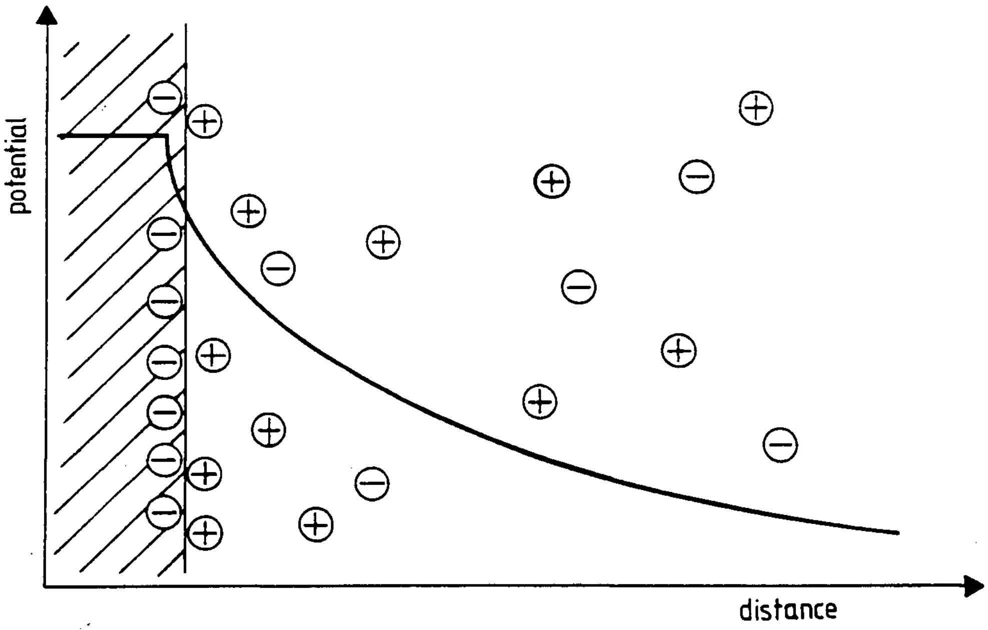


Figure 2-2. Potential Distribution at an Electrode Surface (Adapted from Snoeyink & Kuch, 1985)

corrosion will not occur. A difference in potential exists between the anode and cathode, resulting in a migration of electrons from the anode (where oxidation and dissolution of the metal takes place) to the cathode. At the cathode, electrons are discharged to a suitable electron acceptor, such as oxygen. The positive ions generated at the anode will tend to migrate to the cathode and the negative ions generated at the cathode will tend to migrate to the anode. This occurs in response to the concentration gradients and to maintain an electrically neutral solution.

The different forms of corrosion are primarily influenced by the distribution of anodic and cathodic areas over the corroding material. If the areas are microscopic and very close together, corrosion may be relatively uniform over the entire surface. However, if the areas are scattered and especially if the potential difference is large, pits may form, sometimes with the irregular deposits called "tubercles" (Larson, 1975).

2.1.2.2 **Uniform Corrosion**

Uniform corrosion takes place at a generally equal rate over the surface. In this situation, any one site on the metal surface may be anodic one instant and cathodic the next. The rate of loss of metal is relatively uniform over the metal surface, because anodic sites shift or creep about the surface.

There are a number of reasons why corrosion cells can develop on a single metal. The single metals themselves may be heterogeneous, with possible difference in potential existing between different areas because of differences in crystal structure, or imperfections in the metal. Also, the concentrations of oxidants and reductants in

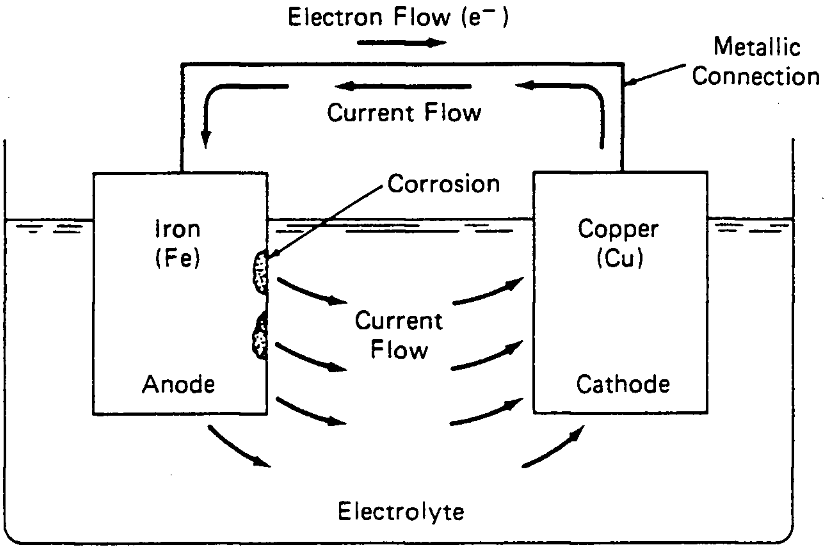


Figure 2-3. Corrosion Cell (Adapted from Smith, 1989)

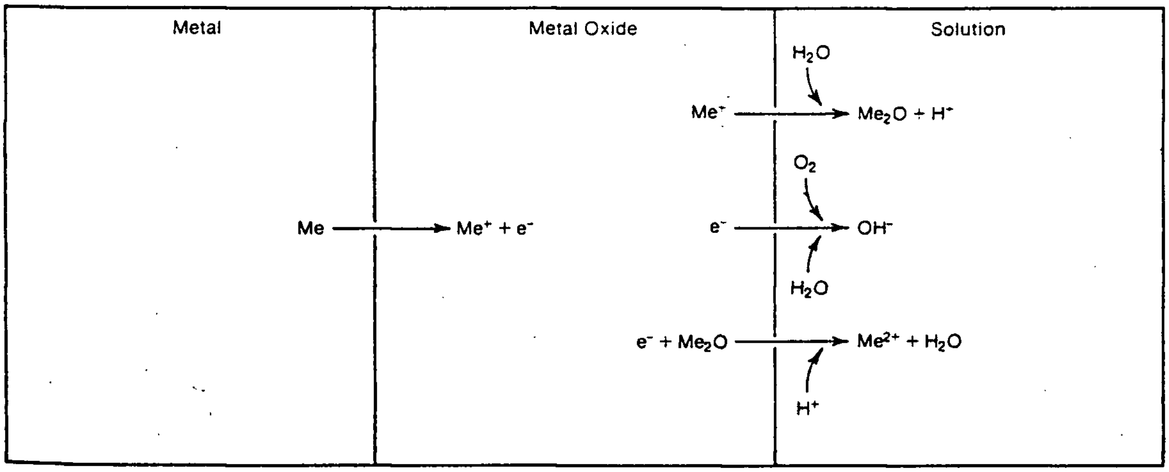


Figure 2-4. Uniform Corrosion of a Metal (Adapted from Snoeyink & Kuch, 1985)

solutions may be different, thus causing momentary differences in potential (Snoeyink & Kuch, 1985)

An alternative model for uniform corrosion is pictured in Figure 2-4. In this model, oxidation at the metal surface is accompanied by electron transport through an adherent film. Oxygen is reduced at the film surface and ions are transported to and away from the oxide film. The overall rate of corrosion is controlled by the presence and properties of the film or by transport of reaction products, especially hydroxide ion, away from the film-solution interface.

2.1.2.3 Galvanic Corrosion

Galvanic corrosion occurs when two different types of metals or alloys contact each other, and the elements of the corrosion cell are present. The less noble metal serves as the anode and deteriorates, while the other serves as the cathode and is, in effect, protected. Galvanic series tables can be used to predict the tendency of metal to corrode (Table 2-1). Thus, when zinc-coated (galvanized) iron corrodes, the zinc is sacrificed, preserving the iron. As pictured in Figure 2-5, large amounts of zinc corrosion products can form on the inside wall of galvanized pipes.

Table 2-1. Galvanic Series of Metals and Alloys.

Corroded end (anodic, or least noble)

Magnesium
Magnesium alloys

Zinc

Aluminum 2S

Cadmium

Aluminum 17ST

Steel or iron
Cast iron

Chromium-iron (active)

Ni-Resist

18-8 Cr-Ni-Fe (active)
18-8-3 Cr-Ni-Mo-Fe (active)

Hastelloy C

Lead-tin solders
Lead
Tin

Nickel (active)

Inconel (active)

Hastelloy A
Hastelloy B

Brasses
Copper
Bronzes
Copper-nickel alloys
Titanium
Monel

Silver solder

Nickel (passive)
Inconel (passive)

Chromium-iron(passive)
18-8 Cr-Ni-Fe (passive)
18-8-3 Cr-Ni-Mo-Fe(passive)

Silver

Graphite

Gold

Protected end (cathodic, or most noble)

(Adapted from Snoeyink & Kuch, 1985)

In the galvanic series table, the metals and alloys are arranged approximately in order of decreasing oxidation potentials with a few exceptions. This is because the corrosion behaviour of some metals is not dictated solely by differences in the electrode potential. For example, in Table 2-1, chromium-iron appears at two widely separated places on the list. At the higher position it carries the designation "passive." These metals become "active" (more subject to corrosion) when they are present in an oxygen-starved environment (the higher listing); they are passive (less subject to corrosion) when they are in an environment with oxygen present (the lower listing).

The rate of galvanic corrosion is increased by greater differences in potential between two metals. Also, the rate of corrosion is increased by large areas of cathode relative to the area of the anode (eg. copper pipe joined by lead solder) and it is generally increased by closeness of the two metals and by increased mineralization or conductivity of the water.

Galvanic corrosion is often problematic where brass or bronze faucets, or copper tubing is in direct contact with galvanized iron or iron. Copper-bearing metals are cathodic to zinc and iron and contact in the presence of water results in corrosion of the latter metals. Therefore, through careful selection of plumbing components, galvanic corrosion can be minimized.

2.1.2.4 **Localized (Pitting) Corrosion**

Localized corrosion is often referred to as pitting. In water containing dissolved oxygen, oxide corrosion products can deposit at the pitting site and form tubercles. Localized attack may occur in conjunction with both galvanic corrosion and with corrosion of a single-metal system. In the latter case, localized corrosion occurs if there are imperfections in the metal or its oxide film or scale. Regions of high stress in the metal are potential pitting sites. Imperfections in the metal or regions of high stress are usually anodic and the potential difference between these regions and the rest of the

Figure 2-5. Tuberculation Inside Corroded Galvanized Iron Pipe

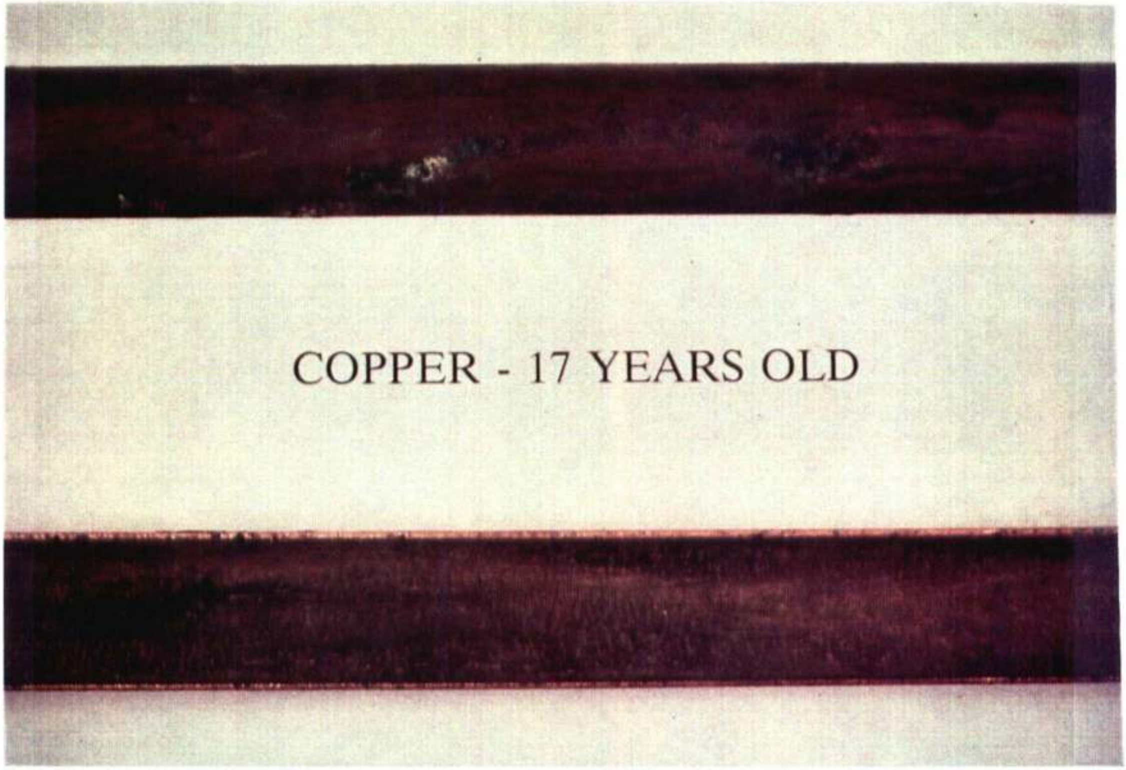


Figure 2-6. Failure of a Copper Water Supply Pipe due to Pitting

metal is such that the anode remains at the same location. Usually, the anode region is small compared to the cathode and a rapid localized corrosion occurs to the point of pipe failure through a pin-hole leak (Figure 2-6).

2.1.2.5 **Concentration Cell Corrosion**

This form of corrosion cell involves a single metal, but different portions of the metal are exposed to different aqueous environments. Such a cell could be generated by one region of an iron surface exposed to oxygen and another one nearly protected from oxygen by rust or other surface coatings. Similarly, differences in pH, metal, or anion concentrations could generate such a concentration cell (National Academy of Sciences, 1982).

One of the more common causes of corrosion is the presence of different concentrations of dissolved oxygen or hydrogen ion at different sites on a metal surface. For example, the Nernst equation for corrosion of iron with oxygen as the electron acceptor,

$$E = E^{\circ} + \left[\frac{0.059}{4}\right] \log\left[\frac{[Fe^{2+}]^2}{[O_{2(aq)}][H^+]^4}\right]$$

can be used to show that if two sites on an iron pipe have the same pH and Fe^{2+} concentration, but the O_2 concentration is 5 mg/L at one site and 0.1 mg/L at the other, the potential difference between the two sites will be 25 millivolts. Some of these situations are illustrated in Figure 2-7. Common areas for this type of corrosion are between two metal surfaces, such as under rivets, under washers, or in crevices.

Also, common to this type of corrosion are areas beneath a bacterial slime layer, a barnacle, or a piece of mill scale. Since oxygen is not produced by either the anodic of cathodic reaction, corrosion will proceed in such a way that the higher oxygen concentration is reduced (Uhlig & Revie, 1985). In this reaction, the part of metal in contact with the higher oxygen concentration will be the cathode and the metal in contact with the lower concentration will be the anode and will corrode. Therefore, corrosion will take place underneath adhesions on metal surfaces.

There are a number of ways for oxygen to be depleted at a particular location in a metal. This may occur because of the corrosion reaction, reaction of oxygen with the ionic metal corrosion product (ie Fe^{2+}), or possibly through microbiological reactions taking place within slime coatings. Resistance to the diffusion of oxygen to these locations and a sufficient supply of oxygen to adjacent cathodic sites maintain the oxygen concentration cell and the corrosion reaction. Slime growth, chemical precipitates, deposits of debris, or simply distance of transport (into a crevice, or to pipe threads, for example) are possible barriers to oxygen at these anodic sites. Eventually, this type of attack leads to pitting and the deepening of crevices and also the formation of tubercles, which appear as nodules on the scale. Figure 2-8 represents tuberculation of iron pipe caused by an oxygen concentration cell. According to this presentation, the H^+ produced from the reaction of the iron(II) corrosion products with oxygen can serve to neutralize the OH^- produced by the cathodic reaction and can accept electrons to form $H_{2(g)}$ within the pit (Obrecht and Pourbaix, 1967). Also, the iron (II) corrosion products reduce O_2,

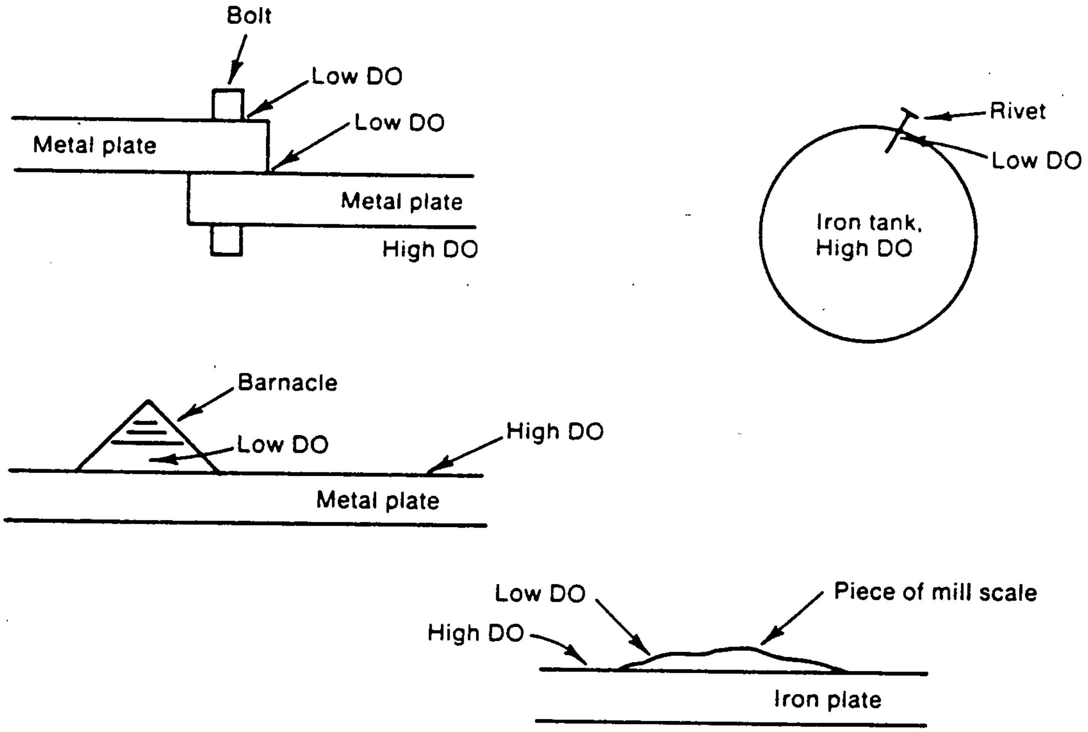


Figure 2-7. Examples of Differential Oxygenation Corrosion (Adapted from Snoeyink & Kuch, 1985)

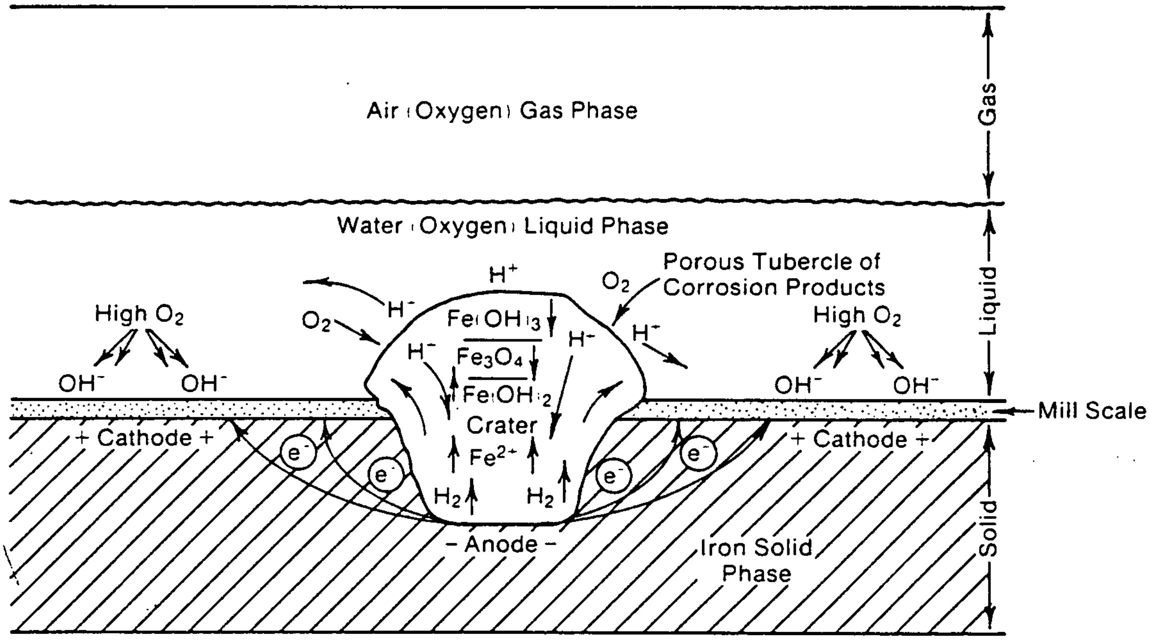


Figure 2-8. Pitting of Iron by Tuberculation and Oxygen-Concentration Cells (Adapted from Obrecht & Pourbaix, 1967)

thereby preventing oxygen from reaching the anodic sites, so the oxygen concentration cell is sustained.

$$O_2 + 4Fe^{2+} + 10H_2O \longrightarrow 4Fe(OH)_{3(s)} + 8H^+$$

2.1.2.6 Erosion Corrosion

Erosion corrosion can result when the protective (often oxide) film is removed by abrasion occurring in fast-moving waters (Figure 2-9). Normally, many metals in contact with water will form such a protective oxide coating. One example of erosion corrosion occurs near joints and elbows of copper pipes, when water flows at high velocities.

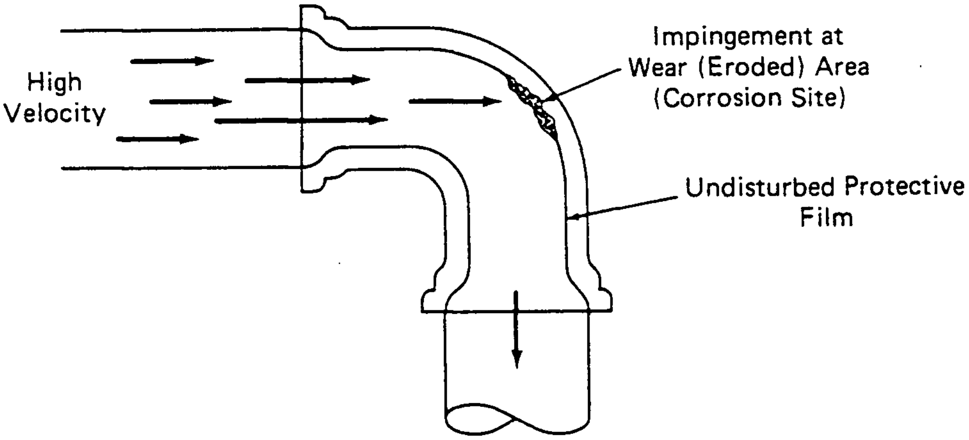


Figure 2-9. Erosion Corrosion (Adapted from Smith, 1989)

2.1.2.7 Biologically Mediated Corrosion

There is little doubt that microbial growths affect corrosion of metallic plumbing systems. There are numerous ways in which bacteria can increase corrosion rates. Slime growths of nitrifying (and other) organisms may produce acidity and consume oxygen in accordance with the following equations:

$$NH_4^+ + 3/2O_2 \longrightarrow NO_2^- + 2H^+ + H_2O$$

$$NH_4^+ + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O$$

Nitrifying microorganisms (eg, Nitrosomonas, Nitrobacter) consume oxygen to convert ammonia to nitrates and nitrites and possibly to oxidize biodegradable organic compounds and to oxidize iron in corrosion reactions. This results in the formation of oxygen concentration cells that cause localized pitting corrosion. For example, Lee, O' Connor, and Banerjii (1980), showed that much more localized corrosion occurred when a water with extensive biological activity was exposed to cast iron, compared to the same water under sterile conditions. Tuovinen et al. (1980) conducted a similar series of experiments in which iron coupons were immersed under various aqueous conditions. He also observed that the corrosive effects were less pronounced in sterile solutions.

The pipe surface, and pipe joints provide niches for the growth of many different microorganisms. Normal metabolic processes of these microorganisms can alter the chemical and physical habitat and produce conditions very different from those observed in the water passing through the pipe. Small microenvironments devoid of oxygen may result. Concentrations of organic matter promote the growth of aerobic microorganisms that deplete oxygen and create anaerobic conditions. Tuberculation, sediments, and pipe joints can yield protected environments in which neither dissolved oxygen nor disinfectant residuals can penetrate (National Academy of Sciences, 1982).

Under anaerobic conditions, sulfate-reducing bacteria play a significant role in pipe corrosion. Sulfate can act at the cathode in place of oxygen,

$$SO_4^{2-} + 8H^+ + 8e^{-1} \longrightarrow S^{2-} + 4H_2O$$

and the sulfate-reducing organisms apparently catalyze this reaction. Ainsworth, Oliphant, and Ridgway (1980) noted that sulfate-reducers have been found in the interior of tubercles. They noted that sulfate-reducers are often present regardless of whether the supply is aerated and that the activity of sulfate-reducers is controlled by TOC. Therefore, it has been suggested that a reduction in TOC should lessen their activity.

Uhlig (1971) suggested that an iron surface aids the process by which sulfate-reducing bacteria function. These anaerobic bacteria generally possess hydrogenase enzymes that act on hydrogen and require ferrous iron. Possible corrosion products of iron pipe are ferrous iron and hydrogen and sulfate reducers may remove these corrosion products through their metabolic processes (Lee and O'Connor, 1975). This, in effect, will shift the equilibrium of the corrosion reaction and drive the reaction to produce more end products.

Aerobic microorganisms have also been reported to contribute to corrosion. Gallionella, Sphaerotilus, and Leptothrix are the predominant members of the "iron bacteria" commonly found in water distribution systems (National Academy of Sciences, 1982). Iron bacteria derive energy from oxidation of soluble ferrous iron to ferric iron. Nuisance conditions often result because the ferric iron precipitates in the gelatinous sheaths of the microbial deposits and these can be sloughed off, giving rise to red water complaints.

Other microorganisms can remove iron from solutions directly. Strains of Pseudomonas, Aerobacter (Enterobacter), and Mycobacterium strains can form precipitates containing iron (Macrae and Edwards, 1972). Sulfur-oxidizing bacteria (Thiobacillus, Beggiatoa) may also contribute to corrosion under aerobic conditions.

This discussion of microbial effects on corrosion will be concluded with a brief mention of pipe cleaning. When a water distribution pipe is cleaned, highly reduced areas of the pipe are laid open and exposed to the oxidizing influence of the drinking water. The accelerated corrosion following pipe cleaning and the abundance of corrosion products, provides a variety of metabolic niches for different bacteria to establish themselves. To cope with this problem, sufficient flushing of the cleaned pipes is necessary and an additional dose of chlorine is useful. When the reduced areas are again covered by scales, bacterial problems diminish.

2.2 Corrosion Mitigation

There are a number of corrosion control strategies available to water utilities. One widely used method is to change water quality through classical treatment, using lime and soda ash to control pH and alkalinity. Also, if possible, another option is to mix different waters to make the supply less aggressive, overall. Furthermore, a switch can be made to more common corrosion resistant materials in piping systems.

The objective of using corrosion inhibitors is to minimize the deterioration of distribution piping, while maintaining the quality of the supplied water. There are a wide range of corrosion inhibitors available to control corrosion; however, only a small fraction are applicable to potable water systems.

2.2.1 Neutralization

Acid corrosion by a low pH water maybe effectively controlled by treatment with an alkaline material such as calcium carbonate (limestone), calcium hydroxide, sodium hydroxide, sodium carbonate, or sodium bicarbonate.

It is usually necessary to adjust pH to a range of 7.5 to 8.5, as determined by titration curves and consideration of the carbonate species (Ryder & Wagner, 1985). Increasing the pH of a water is very important in reducing lead and copper corrosion, but is much less significant in reducing iron corrosion rates. For zinc, an increase in pH may actually be detrimental. Optimum levels for pH are approximately 8.0 for copper, 9.0 for lead and 7.5 for steel and zinc (Economic & Engineering Services, 1988).

Calcium salts are generally much more economical than sodium salts for neutralization. However, they have relatively low solubility, and chemical handling and feeding costs are usually much more than those for sodium salts. Therefore, lime addition for neutralization is economical for large water systems, and sodium salts are preferred for smaller water systems. The use of limestone (Calcium Carbonate) requires high capital costs. This high cost is for the construction of granular bed filters that provide a minimum of 15-30 minutes of contact time. However, the high efficiency due to increasing buffering capacity and the lack of dosage problems to control final pH make operation costs relatively low.

There are however, a number of limitations associated with pH adjustment. Firstly, the use of sodium salts may not be desired, given the added potential of cardiovascular disease. High pH has the effect of increasing the trihalomethane (THM) reaction rate and reducing the effectiveness of chlorine disinfection. Another factor in buffered, soft, low mineralized water is the reduction of pH due to carbon dioxide adsorption, when the water stands still in open reservoirs. Therefore, the delivered pH may be substantially less than the pH of the water following neutralization. Also, there may be problems with excessive hardness and scale formation in pipelines. This problem is not likely with very soft waters, such as the GVRD supply.

2.2.2 Phosphate Inhibitors

Phosphates react with and precipitate as iron, calcium, and zinc salts on the metal surfaces, resulting in a relatively insoluble barrier of metal orthophosphate salts. The phosphate inhibitors are much more effective on iron than on zinc, copper, or aluminum. In the presence of enough oxygen, a ferric phosphate ($FePO_4$) layer is produced on the anodes, preventing anodic dissolution. Increasing the pH decreases the solubility of calcium salts and much of the inhibition decreases above a pH of 7.0. Zinc orthophosphate inhibitors are more versatile and protect copper and lead, as well as iron, at suitably high pH levels (Ryder & Wagner, 1985).

It is important to note that an insufficient concentration of anodic inhibitor will not sufficiently cover anodic areas on the metal. As a result, the uncovered anode sites become more active and severe pitting can quickly lead to pipe leaks. Therefore, it is advisable to conduct a thorough pilot scale investigation to determine the effective dosage and most effective type of inhibitor for a specific water supply. Otherwise, an insufficient inhibitor can accelerate corrosion deterioration and an excess will result in uneconomical chemical usage.

The use of phosphate inhibitors, however, can also have a negative effect on water quality. Phosphate is a nutrient that can stimulate algal and bacterial growth in reservoirs, in pipelines and in receiving wastewater discharges. The orthophosphate form is the most effective in stimulating algal growth in open reservoirs. Therefore, it is not advisable to use phosphate inhibitors to treat waters which are phosphorous nutrient limiting. This is probably the case for the GVRD water supply, where complications with bacterial regrowth is a definite concern.

2.2.3 **Silicate Inhibitors**

Silicates form a thin film layer over a layer of corroded metal. Sodium silicates are most effective against corrosion of steel and have little beneficial effects on copper or lead. Being slightly negatively charged, silica is attracted to the positively charged anodic metal surface (Ryder & Wagner, 1985). Film deposition depends on the presence of small quantities of corrosion products in order for metal-silicate compounds to form. Therefore, silicates are beneficial in reducing corrosion of existing iron, steel and galvanized steel transmission mains. Film formation is self-limiting and thick layers are not built up. The silica films will gradually breakdown and protection will cease if the dosage is stopped.

The use of silicate inhibitors also has negative effects. Silicates can stimulate the growth of certain diatom species in low mineralized waters. Usually, diatoms are not significant in causing water quality problems except in some instances where filter clogging may occur (Ryder, 1978). More importantly, the use of sodium silicates can increase the incidence of cardiovascular disease, due to an increased sodium intake. A similar concern is raised when adding soda ash (Na_2CO_3) to increase alkalinity.

2.3 Point-of-Use Treatment

In general, a consumer of drinking water supplied by a water utility can rely upon its quality and safety. It is the utilities mandate to provide water which meets the local drinking water regulations. Even so, no one can prove beyond a shadow of a doubt that the drinking water is entirely harmless. There are those consumers who may doubt the purity of their municipal water supply and wish to protect themselves from even the slightest risk over the long term. In this circumstance, a point-of-use treatment system may be installed. There are a wide variety of water purification devices available and the purpose of this discussion will be to point out the different technologies utilized and their effectiveness in reducing specific contaminants.

2.3.1 Adsorptive Filters

The most common adsorptive filter utilizes granular activated carbon (GAC). These filters reduce common taste and odours, some turbidity, residual chlorine and many organic contaminants (Rozelle, 1987). GAC filters are not effective in removing trace metals from drinking water. One of the major drawbacks of carbon is the fact that it can be an excellent breeding ground for bacteria. Trapped in a dark and warm environment, some bacteria may feed on the organic materials filtered by the carbon and reproduce rapidly (de Cotret, 1988).

2.3.2 Reverse Osmosis

Reverse osmosis (RO) is very effective in reducing dissolved inorganic contaminants and higher molecular weight organic contaminants. RO filters contain a semi-permeable membrane (most commonly used are cellulose acetate and polyamide), whose pores are so small (0.0005 microns) that they block almost all foreign bodies in the water. Only volatile gases or organic substances with low molecular weights such as chlorine derivatives pass through.

There is a constant water flow around a reverse osmosis system and at least 75% of water entering must be drained off as waste. Also, the RO membranes cannot tolerate the presence of chlorine and turbidity. Therefore, a carbon and sediment pre-filter is also needed on most systems.

2.3.3 Distillation

Distillation operates on a very simple principle, which has historically been known to produce contaminant-free water. Water is brought to a boil and the escaping steam is then condensed. In this way, all substances whose boiling point is higher than that of water can be eliminated, including minerals, heavy metals and most synthetic chemical pollutants. Distillers also eliminate all microbes (de Cotret, 1988).

A number of substances will boil at a lower temperature than water. Chloroform, for example, can escape in steam and may actually be concentrated in the treated water (Tobin, 1987). To eliminate these substances a carbon post-filter can be installed. This combination results in an extremely pure water. The biggest drawback of distillers is their electricity consumption.

2.3.4 **Ozonation**

Ozone is being used extensively in Europe and to a lesser extent in North America to oxidize organic matter and disinfect drinking water. Ozone (O_3) is a gas obtained from oxygen by passing a strong electric field or ultraviolet wave through air. Ozone is 13 times more soluble in water than the O_2 form and has an oxidation potential 15 times that of chlorine. Portable ozonators are available for home treatment and are relatively cheap to operate. They will not affect minerals or metals in the water and are primarily aimed at reducing taste, odour, colour and bacteriological problems.

Table 2-2 summarizes effective uses and drawbacks of purification principles previously discussed. As mentioned in the opening of this discussion, the need for a purification device for ones tap is a personal choice. The following quote from de Cotret, however, should be remembered:

> "If you do not drink a lot of water, if you live in a big city with a good water treatment system, if you live in an area close to major pollution (refineries, etc.), if you smoke, if you eat only highly refined foods, if your house is very airtight, or if you do not normally take the trouble to maintain equipment that you use, buying a water filter will make no difference to the pollution dangers you face."

Table 2-2. Uses and Drawbacks of Various Water Purification Principles.

Purification Principle	Effective against...	Drawbacks
Carbon (granulated, powder or block)	Bad Taste Organic pollutants	Difficult to determine when carbon is saturated. Effectiveness extremely variable depending on design.
Membrane (0.45 to 0.1 u)	Bacteria	Clogs rapidly without effective pre-filter.
Silver	Growth of bacteria	Possibility of excessive silver released in water. Long contact time
Ceramic	Sediment Bacteria	Low flow rate. Clogs easily. Frequent cleaning required.
Ultraviolet light	Bacteria Viruses	Requires built-in safety system. Permanent installation
Ozone and carbon	Sediment Bad taste Organic pollutants Bacteria, Viruses	High price. Small quantities produced.
Reverse osmosis and carbon	Sediment Bad taste Organic pollutants Minerals Bacteria Viruses	High price. Effective pre-filter essential. Min. water pressure of 40 psi required. Very low flows. Drain required. 3 L wastewater for each litre purified
Distillation and carbon	Sediment Bad taste Organic Pollutants Minerals Bacteria	High price. Time-consuming and frequent cleaning necessary. Produces large amounts of heat. Air-cooled models noisy. Produces hot water. Very low flow rate. High energy consumption.

(Adapted from de Cotret, 1988)

2.4 Case Histories

Corrosion problems faced by the Greater Vancouver Water District (GVWD) have been experienced by several water utilities in various parts of the world. Many utilities have proceeded with corrosion mitigation schemes and some have been more successful than others. Faced with its own need to address corrosion, the GVRD can benefit greatly from the experiences of other water suppliers.

2.4.1 Seattle, Washington

The Seattle Water Department (SWD) began looking at corrosion problems in 1970. Seattle obtains its water from two main sources. These are the Cedar and Tolt rivers whose headwaters originate on the Cascade Range. In a situation similar to Vancouver, the source waters are soft, have a low pH and have little buffering capacity. The services of Kennedy Engineers were retained by the SWD to define the corrosion problems, determine the degree of corrosion damage and to come up with a mitigation scheme. The report identified the extensive aesthetic, economic and health problems created due to the corrosion of galvanized steel and copper pipe in home plumbing systems. Some specific impacts related to metal leaching are summarized below (Chapman, Hoyt and Kirmeyer, 1989):

2.4.1.1 Aesthetic Problems

- Red water, a condition associated with "standing" water in galvanized pipes occurred in the majority of homes in Seattle. The number of complaints directed to the Water Department represents only a small fraction of the population affected.

- Metal leaching surveys indicated that over 65-75% of the "standing" water samples exceeded the 0.3 mg/L secondary standard for iron.
- The average iron content in "standing" samples was over twice the 0.3 mg/L secondary level on the Cedar and over four times this level on the Tolt.
- Copper was leached from copper plumbing and could result in objectionable taste and blue-green stains on fixtures.
- Data from various metal leaching surveys indicated that about 11% of the "standing" water samples exceeded the secondary standard of 1 mg/L for copper.
- Complaint records and corrosion tests indicated that copper leaching was a problem throughout the Seattle service area and that Tolt water was more aggressive towards copper than the Cedar supply.

2.4.1.2 Health Concerns

- Results of several metal leaching surveys were analyzed and these indicated that 13% of Tolt and 14% of Cedar "standing" water exceeded the MCL of 0.05 mg/L for lead.
- There was a higher incidence of lead above the MCL in large buildings as compared to smaller ones - probably due to the extended contact time.
- Preliminary metal leaching data indicated that about 2% of the "standing" water samples exceeded the MCL of 0.01 mg/l for Cadmium.

The end result of Seattle's corrosion study was to investigate corrosion treatment at the Cedar and Tolt sources. Treatment consists of the addition of calcium oxide (CaO) at both sources plus sodium carbonate (Na_2CO_3) on the Tolt supply. The consequence is an increase in the pH and the total alkalinity of the finished water. The treatment program was designed primarily as a means of controlling copper, lead and zinc corrosion. Protection for iron (including galvanized iron) was expected to be minimal.

Seattle's "Residential Water Quality Monitoring Program" (RWQM) was established to monitor metal concentrations in tap water to evaluate the effectiveness of treatment. Both "standing" (morning first flush) and fully flushed (for 5 minutes) samples were collected. The results of this survey are shown in Tables 2-3 and 2-4.

Table 2-3. Cedar River Supply: Metal Levels Before and After Treatment.

	No. of Samples		Max. (ug/L)		Avg. (ug/L)		Percent reduction
	Before	After	Before	After	Before	After	
Lead:							
Standing	163	214	137	47.5	9.52	3.68	61
Running	163	214	16.5	11	1.54	0.55	64
Copper:							
Standing	171	214	1050	750	140	70	50
Running	171	214	220	110	34	15	56
Iron:							
Standing	171	214	6380	9000	1041	860	17
Running	171	214	3500	4540	202	153	24
Zinc:							
Standing	171	214	3100	2950	537	317	41
Running	171	214	650	90	84	38	55
Cadmium:							
Standing	166	214	5.8	10	0.77	0.48	38
Running	163	214	1.1	1	0.18	0.05	72

(Adapted from Chapman, Hoyt & Kirmeyer, 1989)

Table 2-4. South Fork Tolt River Supply: Metal Levels Before and After Treatment.

	No. of Samples		Max. (ug/L)		Avg. (ug/L)		Percent
	Before	After	Before	After	Before	After	reduction
Lead:							
Standing	136	165	133	62	11.84	3.82	68
Running	133	165	16.5	6.5	1.91	0.37	81
Copper:							
Standing	143	165	2550	730	456	118	74
Running	143	165	1880	210	125	22	82
Iron:							
Standing	143	165	11400	6650	1417	1051	26
Running	143	165	2450	2100	242	166	31
Zinc:							
Standing	143	165	4450	1890	670	310	54
Running	143	165	2100	810	144	35	76
Cadmium:							
Standing	144	165	6.0	2.4	0.69	0.29	58
Running	144	165	5.3	1	0.16	0.03	81

(Adapted from Chapman, Hoyt & Kirmeyer, 1989)

Major findings of this survey include: (Chapman, Hoyt and Kirmeyer, 1989).

1) All five metals, copper, lead, zinc, iron and cadmium were in significantly lower concentrations following corrosion treatment.

2) Standing tap water lead levels have been reduced by approximately 61%-68%.

3) Cadmium levels have been reduced by about 38%-58% in the overnight standing samples.

4) Copper levels, a cause of numerous complaints because of fixture staining, have been reduced by 50%-74% in standing samples. Blue-green staining complaints have disappeared.

5) Iron, Seattle's main aesthetic metal problem, is improved, but remains a problem. Average iron reduction is about 17%-26% in standing samples.

6) Zinc levels have been reduced by about 41%-54% in standing samples.

2.4.2 **Glasgow, Scotland**

Fortunately, in most parts of North America, the use of lead piping for water distribution has been limited. Such is not the case in many parts of Scotland. Water from the Scottish uplands is usually of low alkalinity and acidic, making it aggressive to metal piping. Unfortunately, until the late 60's, it was traditional to use lead for domestic plumbing, and consequently, there are many parts of Scotland where excessive amounts of lead can be detected in drinking water (Richards, W.N.; Moore, M.R., 1984). Since 1970, the Glasgow District Council has removed all lead piping to the taps used to supply water for human consumption in houses being modernized. Also, individual property owners are strongly encouraged to replace all lead lines whenever pipe replacement or repair is undertaken.

Loch Katrine is a major drinking water source for Glasgow and the surrounding area. The pH of the raw water is about 6.3. In one study, tap water sampling of 232 properties selected at random throughout Glasgow, had revealed some shocking results, thus prompting remedial water treatment. "Random daytime" samples (1-L first flush samples taken any time in the day) were taken from houses. Before remedial treatment was introduced, approximately 50% of water samples had a lead content exceeding 100 ug/L and it was not uncommon for individual samples to contain greater than 1000 ug

Pb/L. The mean lead value was 244 ug/L and one sample contained 2000 ug Pb/L (Richards, W.N.; Moore, M.R., 1984). The European Community drinking water directive gives a maximum admissible concentration of 50 ug Pb/L in running water. However, in cases in which there are lead pipes and the lead content exceeds 100 ug/L, either "frequently or to an appreciable extent," measures must be taken to reduce the consumers' exposure to lead.

In 1978, after laboratory and pilot-scale testing, a lime-dosing system was put in place. With the addition of a small quantity of lime (approximately 4 mg lime/L), the pH of the water entering the distribution system was raised from 6.3 to 7.8. Subsequent sampling indicated that this had reduced lead levels to the extent that 80% of random daytime samples contained < 100 ug Pb/L.

In April 1980, the pH of the water from Loch Katrine was gradually raised to 9.0 and current samples taken from the distribution system usually have pH values between 8 and 9. It is estimated that at least 95% of random daytime samples now have lead concentrations <100 ug/L (Richards, W.N; Moore, M.R., 1984). A few values, however, still exceed 100 ug Pb/L by an appreciable extent.

Unsatisfactorily high levels of Pb are still obtained from houses with long lengths of lead piping and from houses where the kitchen faucet is supplied from a lead-lined cistern. In Glasgow, it was common to install a lead-lined storage tank to supply water for all domestic purposes. A lead cistern allows for a large surface area of lead to be in contact with the water for extended periods and also allows the water to absorb carbon dioxide from the atmosphere, depressing the pH.

2.4.3 Plastic Pipe Alternative

Recently, there has been a move to using plastic pipe in new residential plumbing. Based on a GVRD survey of plumbers, it is estimated that 50 to 75% of all new residential housing contains polybutylene plumbing (Economic & Engineering Services, 1988). In the remaining cases, copper is most popular. Plastic pipe was brought into use to provide low-cost pipe material that was not subject to corrosion. Within the past few years, however, there has been some concern over possible leaching of organic compounds and other constituents of plastic pipe into the water. Most of the testing conducted on this subject have been carried out with polyvinyl chloride (PVC) pipe.

Plastic pipe is composed principally of polymerized organic compounds, but there can be residual unpolymerized monomer present. This is important in PVC pipe, since the vinyl chloride monomer is known to be carcinogenic in humans and animals (National Academy of Sciences, 1980). PVC pipe is made by extrusion of thermoplastic PVC at temperatures of 150^0C to 200^0C. Heat stabilizers and internal and external lubricants must be added during this process, since PVC is unstable at temperatures about 120^0C (Health and Welfare Canada, 1983). Lead or tin compounds are the most common stabilizers added to PVC. Another source of concern in the use of PVC pipe are solvent residues. The smaller diameters of PVC pipe are joined by using a solvent composed of PVC dissolved in a mixture of solvents, such as tetrahydrofuran and cyclohexanone. Both of the solvents are toxic; however, they do not pose a health hazard to the water consumer, provided the piping is adequately flushed after installation (Health and Welfare Canada, 1983).

An extensive testing of PVC pipe has been conducted under the direction of the California Department of Health Services. One of the goals of the study was to determine the health risks, if any, posed by the use of plastic pipe systems in homes. Laboratory tests were conducted by James M. Montgomery Consulting Engineers in 1980 under both static and usage simulation conditions of a typical two-bedroom house.

In these tests, 32 volatile halogenated aromatic organic compound identified as priority pollutants by the EPA were analyzed by gas chromatography/mass spectrometry (GC/MS). Several volatile, halogenated organic compounds were detected at levels higher than those found in the raw water, suggesting that they had leached from the PVC pipe. Concentrations of chloroform in the 2 week stagnant CPVC samples were 5 to 11 times greater than those in the raw water. Levels of carbon tetrachloride were 52 to 125 times higher than the concentration in the raw water. Highest levels were those associated with surfaces bonded with excess cement and primer.

Dressman and McFarren (1978), measured vinyl chloride monomer concentrations up to 1.3 ug/L in samples taken from a new PVC distribution system in Georgetown, Texas. The newest and longest system appeared to have the highest chloride concentration.

2.5 Health Impacts of Metal Ingestion

It has been shown that corrosion of plumbing systems increases the concentrations of trace metals in drinking water. The health implications of ingesting limited quantities of lead, copper, iron and zinc in drinking water are not fully understood. Furthermore, when research data is available, the health effects of metal intake specifically through drinking water consumption is not available.

Exposure to trace metals takes place via the air we breathe, the food we eat as well as the water we drink. The following discussion will elaborate on the health affects of lead, copper, iron and zinc (presently, only lead is recognized as a health concern in the Canadian Drinking Water Guidelines, 1989).

2.5.1 Lead

Lead is potentially poisonous, accumulates in the body and has no known physiological functions. The concern of lead in tap water is related to the long-term effects from exposure to lead in amounts too small to give rise to classical lead poisoning.

1. **Absorption/Metabolism**

Studies of humans have demonstrated that infants and young children are more susceptible than adult females, who are more susceptible than adult males to the biochemical effects of lead (National Academy of Sciences, 1982). Of the lead ingested from food and water, about 5-10% is absorbed in the adult and 40-50% is absorbed in children 2-3 years old (National Academy of Sciences, 1977). No data is available for very young infants, but animal data indicate that the percentage absorbed is age-related and may be higher in early infancy. Absorbed lead is excreted through both the kidneys and the intestinal tract. Some of the lead is deposited in soft tissues, nails and hair, but most finds its way into the skeleton (Depart. of the Environment, 1977). Bone lead content may increase with age up to the age of 40 or 50 years. Bone is the storage site for at least 90% of the total lead body burden in adults and approximately 70% in growing children (National Academy of Sciences, 1977). The respective half-lives of lead in blood, soft tissues and bone have been estimated to be 2-4 weeks, 4 weeks, and 27.5 years (World Health Organization, 1984).

Of the lead inhaled from the atmosphere, the proportion absorbed through the lungs averages 15% to 33% (Dept. of the Environment, 1977). At present, most of the airborne lead in non-industrialized cities comes from motor vehicle traffic.

Estimates of weekly intake and uptake of lead by the body in adults have been provided by Drill (1979). In Table 2-5, a few simplified examples are given, where the last two columns give an estimate of the relative contribution of water to the total intake of lead and to the uptake of lead by the body. It is assumed that an average person consumes 2 litres of water per day and breathes air at the rate of 20 m^3/day. Absorption from food and water is assumed to be 10% of the intake and there is assumed to be complete absorption of the 10% retained from inhalation.

Table 2-5. Relative Contribution of Water to Total Lead Intake and Uptake.

Daily intake of 100 ug of lead per day in food;
1.0 ug of lead per m^3 of air

Lead Conc. in water	weekly intake of lead (mg) water only	air only	food only	total	Intake ratio: water/tot. (%)	Uptake ratio: water/tot. (%)
20 ug/L	0.28	0.14	0.70	1.12	25	18
50 ug/L	0.70	0.14	0.70	1.54	47	35
100 ug/L	1.40	0.14	0.70	2.24	63	52

(Adapted from World Health Organization, 1984)

Therefore, given the current maximum acceptable concentration (MAC) for lead of 50 ug/L, a significant proportion of the total lead intake (47%) may be provided through tap water consumption.

2. Health Effects

No beneficial effects of lead for the functioning of biological systems has yet been found. Acute lead poisoning is extremely rare, however, some symptoms are tiredness, lassitude, slight abdominal discomfort, irritability, anaemia and in the case of children, behaviourial changes (World Health Organization, 1984). The main chronic adverse effects of lead are those produced in the haematopoietic system (organs producing blood), the nervous systems and the kidneys (National Academy of Sciences, 1982). In most cases, recommended maximum daily intakes of lead are based on studies of the monitoring of lead concentrations in blood. The MAC of 50 ug Pb/L in drinking water was designed to protect people against blood levels over 40 ug/dL (dL=100 mL). At the time, it was thought that blood levels below 40 ug/dL were not harmful to health. Recent USEPA draft proposals have recommended that a blood lead level of 10 ug/dL be adopted as the threshold for adverse effects (U.S. Public Health Service, 1988).

2.5.2 Copper

1. Absorption/Metabolism

Under the present Canadian Drinking Water Guidelines (1989) and the new proposed Lead and Copper Rule of the USEPA, the classification of copper as an aesthetic concern is under review. Unlike lead, however, copper is recognized as an essential element for both plants and animals. It is a component of several enzymes that perform important physiologic functions. These involve the metabolism of iron and the rate of cell synthesis in the bone marrow (National Academy of Sciences, 1982). Copper also has a role in the central nervous system and in the formation of connective tissue (World Health Organization, 1984).

The absorption of copper, like all essential elements, from the gastrointestinal tract is limited. About 32% of the daily intake of copper is absorbed. The net absorption is about 5% after fecal and urine excretion (National Academy of Sciences, 1977).

2. Health Effects

Intake of excessively large doses of copper by man leads to severe mucosal irritation and breakdown, widespread capillary damage, hepatic (liver) and renal damage and central nervous system irritation followed by depression (World Health Organization, 1984). Severe gastrointestinal irritation and possible cell damage in the liver and kidneys could occur. However, copper poisoning is rare in man and higher animals owing to the inducement of vomiting upon ingestion of large doses.

The available evidence does not support chronic toxicity in people attributed to long-term intake of low concentrations of copper by mouth (National Academy of Sciences, 1977). Therefore, the recommended guideline value for copper is 1.0 mg/L to avoid excessive staining of laundry and plumbing fixtures. Also, this limit is below the taste threshold for most people, which varies from 1-5 mg/L.

2.5.3 Iron

1. Absorption/Metabolism

Iron is an essential element in human nutrition. It is contained in a number of biologically significant proteins and also in many oxidization-reduction enzymes. Individual iron requirements (which depend on age, sex, and physiological state) regulate the amount of iron absorbed from the diet, the amount varying from 1% to 20% (World Health Organization, 1984). Losses in faeces, urine and perspiration amount to 1 mg per day. The primary storage areas for iron are in the liver, bone marrow and spleen.

2. Health Effects

Iron ingestion in large quantities results in a condition known as haemochromatosis (normal regulatory mechanisms do not operate effectively), which results in tissue damage from iron accumulation. This condition rarely develops from simple dietary overloading (World Health Organization, 1984).

3. Other Aspects

The presence of iron in drinking water is objectionable for primarily aesthetic reasons. Precipitation of iron salts often produces unpalatable water which stains laundry and plumbing fixtures. The iron settles out in the distribution system, and gradually reduces water flow. Iron also promotes the growth of "iron bacteria". These microorganisms derive their energy from the oxidation of ferrous iron to ferric iron, and in the process deposit a slimy coating on the pipe wall.

2.5.4 Zinc

1. Absorption/Metabolism

Zinc is considered an essential trace element in human and animal nutrition. As far as human health in the general population is concerned, the major concern is not with toxicity, but rather with marginal or deficient zinc intake. Zinc is necessary for the functioning of various enzymatic systems. Zinc is distributed throughout the body, including the bone, and urinary excretion of zinc is generally less than 1 mg/day.

2. Health Effects

Zinc may be considered nontoxic. The low toxicity of zinc and efficient homeostatic control mechanisms make chronic zinc toxicity from drinking water and dietary sources an unlikely hazard in man (World Health Organization, 1984). Symptoms of zinc toxicity in humans include vomiting, dehydration, electrolyte imbalance, abdominal pain, nausea, lethargy, dizziness and lack of muscular coordination (Prasad, A.S. and Oberleas, D., 1976). There have been reports of human cases of zinc poisoning associated with the prolonged consumption of water from galvanized pipes. In two adults, irritability, muscular stiffness and pain, loss of appetite and nausea were reported when the water contained zinc in a concentration of 40 mg/L; this is well above the current secondary drinking water standard of 5 mg/L (National Academy of Sciences, 1977). Also, animal research data suggests that zinc is protective against lead toxicity.

3. Other Aspects

Zinc gives water an undesirable astringent taste and water containing zinc, at concentrations in excess of 5.0 mg/L, may appear opalescent and develop a greasy film on boiling.

3. EXPERIMENTAL METHODS

3.1 Survey Design

Two separate surveys were conducted in the course of this research. The first survey was conducted during the months of July and August, 1989 (Figure 3-1). During this survey, tap water samples were collected from high-rise apartment towers located in two specific clusters called East and West (LOCATION effect) and analyzed for the following metals: lead, copper iron and zinc. The East apartments are fed by water from the Seymour reservoir and the West apartments by the Capilano reservoir. Water quality parameters at these two locations are essentially identical with the exception of the free chlorine residual. Higher free chlorine residuals were measured in the West apartments due to their proximity to a chlorine booster station (0.60 to 0.76 mg/L). By contrast, the East location showed free chlorine residuals ranging from 0.04 to 0.64 mg/L. Within each location, a selection was made of new and old apartment buildings (AGE effect). In the East, new apartments ranged from 0.8 to 4.0 years and old apartments ranged from 7 to 18 years. In the West, new apartments were 0.8 to 2.0 years old and old apartments were 17 to 25 years old. The third parameter to be investigated was the effect of building height. Within each building, samples were collected from both the lower and upper floors. Building heights ranged from 16 to 32 stories.

The second survey was conducted during the month of January, 1990. Samples were collected from single-family houses (Figure 3-2) and analyzed for lead, copper and zinc. Iron was dropped because high-rise sampling showed that iron levels in the drinking

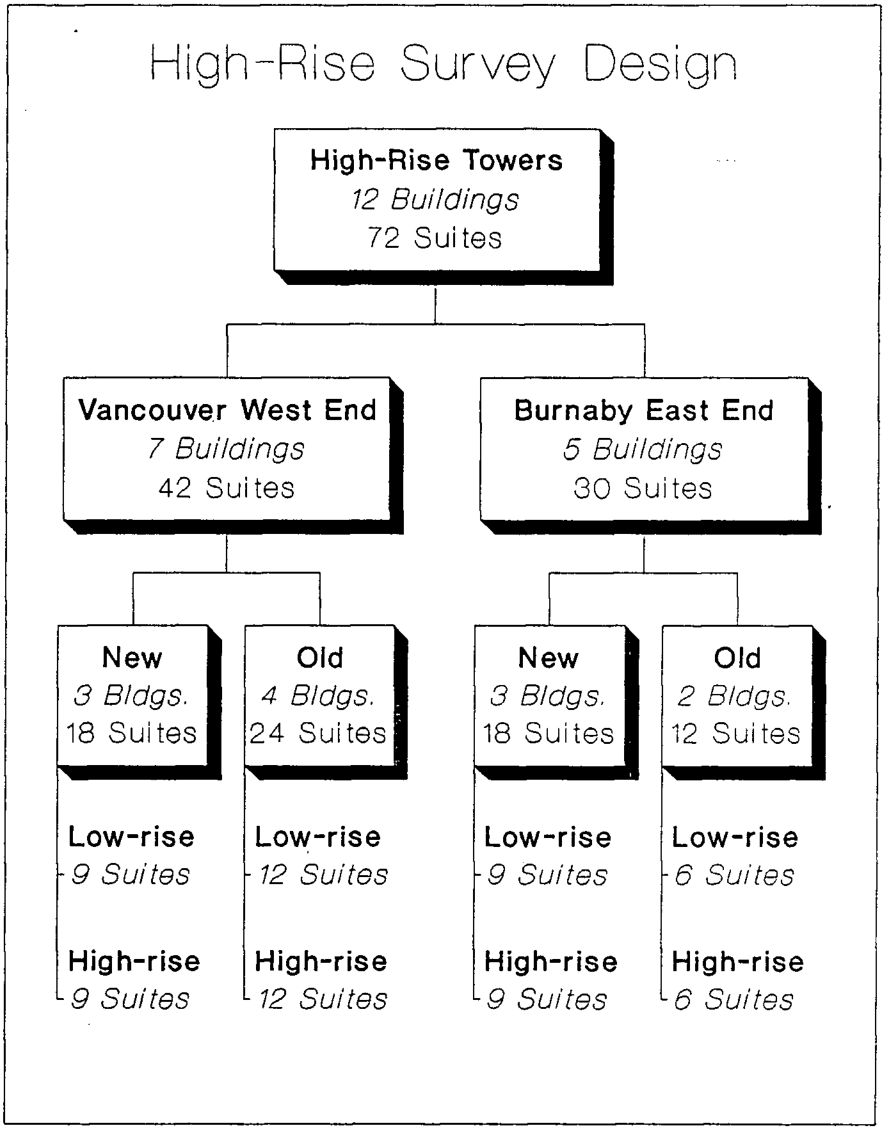


Figure 3-1. Survey Design for Sampling High-Rise Apartment Towers

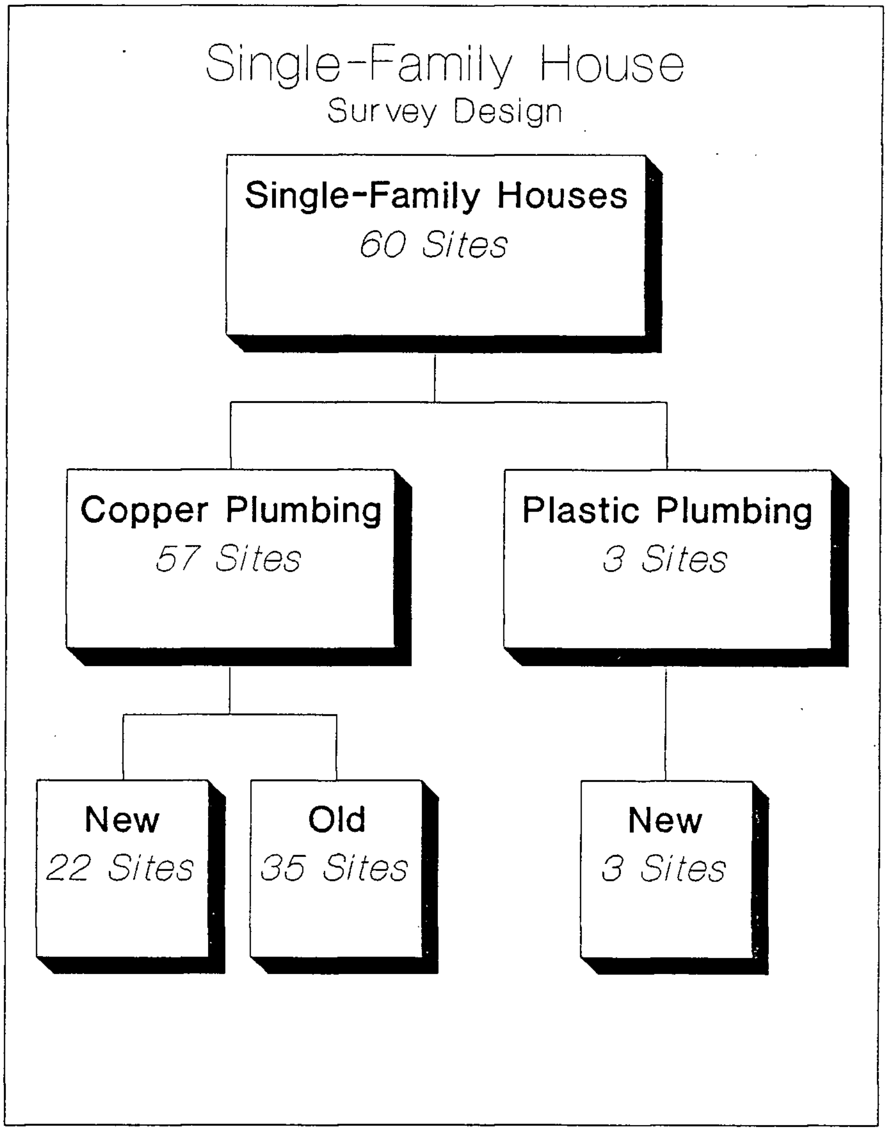


Figure 3-2. Survey Design for Sampling Single-Family Houses

water were influenced only by LOCATION. Since houses involved in the second survey had either copper or plastic plumbing systems, only background iron concentrations were expected. In this case, a random selection was made of 60 houses, receiving water from the Seymour and Capilano watersheds. The predominant type of home plumbing system material was copper (57 sites), with 3 houses containing plastic (PVC) systems. Consequently, only a qualitative evaluation can be made regarding the effect of plumbing system material on trace metal contamination of drinking water. New houses ranged from 0.5 to 11 years of age and old houses ranged from 12 to 43 years. In old homes, where complete plumbing refits were conducted, a "new house" classification was issued.

3.2 Sampling Protocol

In order to obtain first flush overnight standing samples, it was necessary that the individual homeowner and high-rise tenant conduct the actual sampling. Homeowners were contacted by telephone about the upcoming sampling and were individually informed of the sampling procedure. Arrangements were made with high-rise tenants through the building manager. Sampling kits with instructions (see Appendix A) were prepared and delivered prior to the sampling date. The sampling kit contained 5 bottles:

50 ml - COLD#1 - 1st flush cold
200 ml - COLD#2 - 2nd flush cold
750 ml - COLD#3 - 3rd flush cold
125 ml - COLD#4 - Running Cold (5 min.)
125 ml - HOT#1 - Running Hot (2 min.)

This protocol was also used to evaluate compliance with proposed USEPA regulations. The current USEPA protocol establishes a one litre standing sample for compliance monitoring and the equation used for calculating the 1 litre concentration (LCOLD) is:

```
Conc. of LCOLD = 0.05 x (Conc. of COLD#1)
               + 0.20 x (Conc. of COLD#2)
               + 0.75 x (Conc. of COLD#3)
```

3.3 Analytical Procedures

3.3.1 Trace Metals

Bottle Preparation: To ensure that the possibility of contamination was kept to a minimum, a rigorous bottle preparation technique was employed. Bottles were machine washed with soap, followed by a dionized rinse. Sample bottles were then soaked in a acid bath (5% nitric acid solution) overnight. The last step in the procedure was a final hand rinsing with deionized water after which the bottles were capped and labelled.

Sample Preservation: Samples were preserved immediately on the date of sampling or first thing the next morning with DPD assured nitric acid. A 2.5% acid/sample matrix was utilized. This is far in excess of that required to maintain a pH < 2.0 (standard methods); however, it was felt that a higher acid concentration would compensate to some degree for the digestion step, which was not practised, due to the number of samples to be processed.

Atomic Absorption: Copper, iron and zinc were analyzed using a Thermo Jarrel Ash Atomic Absorption Spectrophotometer with lean acetylene fuel conditions. Atomic absorption with graphite furnace was used for lead analysis. Azide ammonium matrix modifier was used to eliminate chloride interferences. Instruments were frequently recalibrated and EPA test solutions were run to monitor instrument performance. Samples which were outside of the linear range of the instruments were diluted and re-analyzed. All samples were run in duplicate and if values did not agree, the samples were repeated. Atomic absorption samples were aspirated directly out of the sample bottles. Lead samples were run on an autoanalyzer on the graphite furnace and sampling cups were acid soaked and D.I. rinsed prior to use.

Quality Control: For the high-rise sampling program, 10 percent of all samples were cross-checked and verified by the GVRD (Greater Vancouver Regional District) laboratory. The complete set of cross-check results are included in Appendix B. If discrepancies were noted, samples were re-analyzed until the "first analysis = re-checked analysis". There was good correlation between analysis conducted at the UBC and the GVRD lab.

3.3.2 Water Quality Parameters

Free Chlorine Residuals: DPD (diethyl-p-phenylene diamine) colorimetric method was selected for testing free chlorine residuals in the field. A Hack portable test kit was used.

pH: A Fisher glass electrode was used with a Bechman pH meter. Due to the low ionic strength of the water being tested, an Orion buffer solution was added to the samples.

Total Alkalinity: Total alkalinity was determined according to Standard Methods (APHA 1985, Section 403). For alkalinities less than 20 mg/L, the low alkalinity procedure was used.

Total Hardness: The calculation method (APHA 1985, Section 314A) was used to determine total hardness. In this method, hardness is computed from the results of separate determinations of calcium and magnesium using flame atomic absorption.

3.4 Data Evaluation

Groupings of data were initially examined and interpreted using Tukey box plot diagrams (Figure 3-3). This type of presentation conveys to the reader the medians and percentiles, minimum, maximum and outlier values. The 95% confidence interval about the median was determined based on methodology outlined by McGill, Tukey and Larsen, (1978).

One-way (one factor) analysis of variance was utilized for analysis of the house data (SYSTAT, 1988). Statistical differences between the mean metal concentrations associated with new and old copper plumbing were evaluated.

General Mixed Model of Variance was utilized for analysis of high-rise data (BMDP Statistical Software, 1988). The statistical analysis was based on a 2x2 Split-Plot Factorial experiment blocked by RUN. AGE and LOCATION are the factorial treatments and the FLOOR parameter is nested within each building. Lead data was log transformed, prior to running the analysis, due to its skewed nature (bunching of data points close to the instrument detection limit). A two-tail probability of $p<0.050$ represents a significant effect. An example of BMDP control language and output used for data analysis are presented in Appendix C.

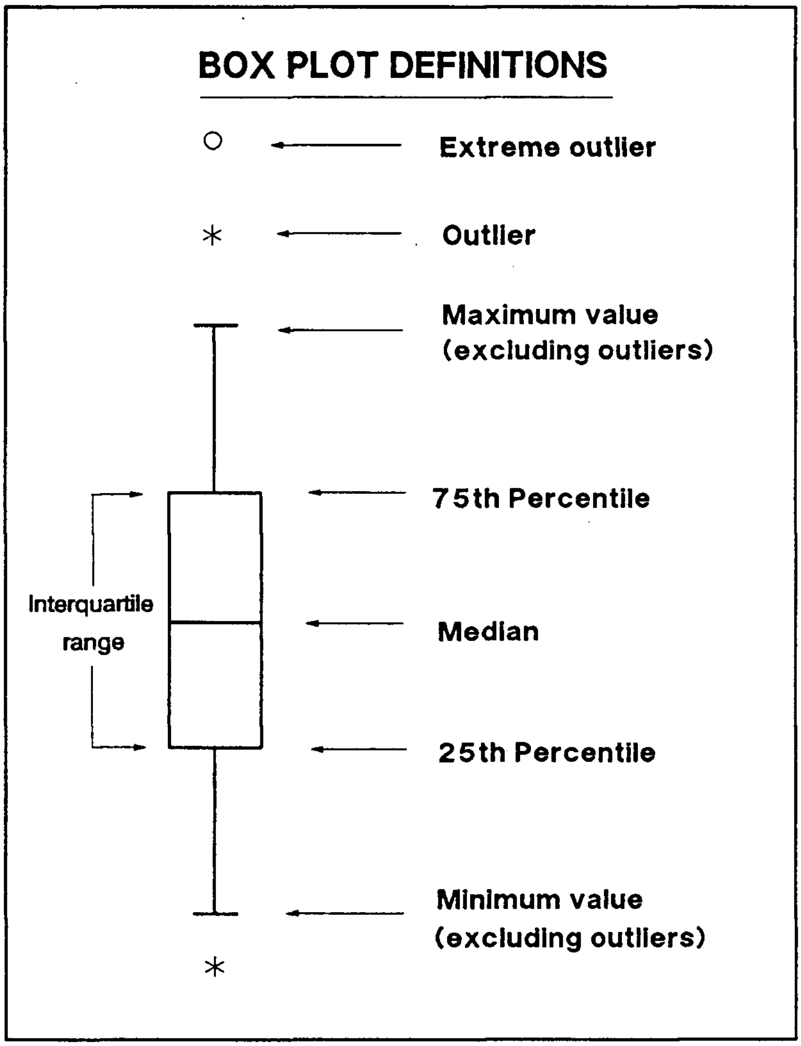


Figure 3-3. Guide to Tukey Box Plots

4. RESULTS AND DISCUSSION

4.1 Water Quality Characteristics

Greater Vancouver's water is derived almost entirely from rainfall and snow melt and it exhibits typical characteristics of a corrosive water: soft, low pH, poor buffering capacity, low mineral content and dissolved oxygen saturation. Table 4-1 summarizes the water quality parameters monitored during the course of this study.

Table 4-1. Water Quality Characteristics of GVRD Tap Water.

	pH	Total Alk.	Total Hardness	Cond.	Free Chlorine
High-Rise (West)	5.9-6.0	1.1-1.5	3.10-3.93	11-14	0.60-0.76
High-Rise (East)	6.1-6.3	1.9-3.7	4.31-5.38	14-17	0.04-0.64
House (All samples)	5.5-6.1	0.6-2.9	2.16-4.39	N/A	N/A

Units are: Tot. Alkalinity, Tot. Hardness: (mg/L) as $CaCO_3$.
Conductivity (umhos/cm); Free Chlorine (mg/L).

Rain water normally has a pH close to 5.5, resulting from the solution of atmospheric carbonic gas (Millette & Mavinic, 1988). Low pH is recognized as one of the most important factors influencing corrosion problems. The pH of GVRD tap water is well below the neutral pH value of 7.0 and was consistent throughout the sampled in this study.

Low alkalinity and low hardness lead to conditions which favour the dissolution of metals from the distribution piping. Alkalinity is a measure of a water's capacity to neutralize acids and, at the pH values encountered in GVRD water, it takes the form of bicarbonate alkalinity (HCO_3^-). The buffering capacity of GVRD water is very poor and alkalinity values measured were very close to the instrument detection limit. Hardness is caused primarily by divalent metallic cations and the principal cations in the GVRD water supply are calcium and magnesium. According to Sawyer and McCarty (1978), a soft water has a total hardness between 0 and 75 mg/L as $CaCO_3$. GVRD water, with an average hardness less than 5 mg/L as $CaCO_3$, is extremely soft, by this standard.

4.2 Factors Investigated

Statistical results are based on the 1-L first flush sample (weighted average of bottles COLD#1, COLD#2 & COLD#3) obtained from the cold water tap and the running sample (HOT#1) collected from the hot tap. High-rise samples were used to study the effect of building height (low-rise vs. high-rise), building location (East vs. West) and plumbing age (new vs. old) on trace metal concentrations in drinking water. Samples collected from single-family houses were used to evaluate the influence of plumbing age (new vs. old) and plumbing type (copper vs. plastic) on metal levels. Average metal levels were compared between the two building types (high-rise vs. single-family). Median concentration levels are represented on box plots and bar graphs represent the mean concentrations for the same groupings of data (Figures 4.1 to 4.14 inc.).

Also, trends associated with consecutive flushes from the cold water tap (bottles COLD#1 through to COLD#4) were investigated to obtain a better understanding of the source of trace metals measured. In addition to tap water sampling, a survey questionnaire was distributed. The goal was to establish the degree of consumer complaints related to their tap water and their perception of its quality. A comparison was made between the response from high-rise buildings and single-family houses.

4.2.1 **Building Height** (Low-Rise vs. High-Rise)

4.2.1.1 **Cold First-Flush**

The effect of building height on metal concentrations was investigated by collecting 1/2 of the samples from low-rise suites and the other half from high-rise suites. In most cases, this involved the lower three and upper three apartment levels. Building height proved to be statistically insignificant for lead, copper, iron and zinc concentrations measured in the 1-L first-flush samples obtained from the cold tap.

4.2.1.2 **Running Hot**

A similar analysis conducted on the running hot sample showed that the height was marginally significant ($p=0.042$) in influencing lead concentrations measured at the tap. BMDP statistical analysis conducted on both the 1-L first-flush cold and running hot samples may be suspect, due to their skewed distribution. It should be noted that log transformation of the lead data may not have completely compensated for this non-normal distribution. From Figures 4-1a and 4-1b, it's evident that a distinct trend does not exist between lead concentrations measured from low-rise compared to high-rise suites.

On the other hand, Figures 4-2a and 4-2b reveal that low-rise suites had higher levels of copper than high-rise suites. Statistically, however, this was not significant ($p=0.716$). The cause of this apparent difference may be influenced by temperature differences within the hot water recirculation system. Low-rise apartment suites are the first to draw off water immediately leaving the boiler. The high temperature of this water may result in rapid dissolution of copper. As the water reaches high-rise suites, it has cooled to a lower temperature and as a result, the potential to leach copper is reduced.

Building height proved to be statistically insignificant for iron and zinc concentrations measured in the running hot water samples.

4.2.2 **Building Location** (East vs. West)

4.2.2.1 **Cold First-Flush**

Sampling was conducted from two distinct zones - Vancouver (West) and Burnaby (East). The areas were chosen to monitor the effect of LOCATION (eg. 2 different free chlorine residual levels) on metal concentrations. The West zone is supplied with water from the Capilano watershed and the East zone is supplied from the Seymour watershed. It was suspected that metal concentrations in the West apartments would be higher due to the greater free chlorine residual. This was not the case. Lead showed a strong LOCATION by AGE interaction ($p=0.006$), which is apparent from Figure 4-1b. Low lead levels were associated with the EASTxOLD groupings.

Copper also showed a LOCATION by AGE interaction (P=0.036). This is reflected in the higher copper concentrations detected in new apartment buildings in the East (Figures 4-2a & 4-2b). This has probably resulted from a building specific phenomena and generalities should not be inferred.

A distinct LOCATION effect was detected for iron (p=0.000). The box plot and bar graph clearly show the higher iron values in apartments located in the East over those in the West (Figures 4-3a & 4-3b). Since the primary plumbing material in most apartments sampled was copper, the buildings themselves could not have caused these differences. Higher iron levels in the East may be due to unlined cast iron pipes or fittings in the East area distribution system. More likely, however, the cause was the higher iron concentration in the Seymour source water supplying the East. The iron levels at the Seymour reservoir intake averaged 0.10 mg/L, peaking at 0.30 mg/L in August; levels at the Capilano intake averaged only 0.08 mg/L over the same sampling period. The greater variability of iron concentrations in the East also reflect the greater fluctuation of iron concentration measured at the Seymour intake. Zinc levels were not found to be influenced by LOCATION (p=0.220) (Figures 4-4a & 4-4b).

4.2.2.2 **Running Hot**

Levels of lead measured in the running hot water sample do not appear to be influenced by LOCATION. Also, the copper concentrations were not influenced by location (p=0.719). Similar to the case with the 1-L cold first-flush sample, a distinct LOCATION effect was detected for iron (p=0.000), where apartments in the East showed higher levels than those in the West (Figures 4-7a & 4-7b). Zinc showed a strong LOCATION by AGE interaction (p=0.000). From Figure 4-8b, it can be seen that high zinc levels measured in old apartments in the West accounted for this interaction. The median value for this grouping (WESTxOLD) is consistent with the others; however, outliers associated with the WESTxOLD group resulted in mean levels to be significantly greater that the other groupings.

4.2.3 **Plumbing Age** (New vs. Old)

4.2.3.1 **Cold First-Flush**

The effect of plumbing AGE was not as pronounced as initially anticipated. The high-rise sampling program showed LOCATION by AGE interactions for lead and copper. As a consequence, it can not be absolutely concluded as to which parameter was the most significant. However, it can be estimated from the box plots and bar charts (Figures 4-1a to 4-2b), that AGE was the influencing factor, with newer plumbing systems giving rise to higher copper and lead concentrations. AGE had shown up as being marginally significant in the iron analysis (p=0.021). From Figure 4-3a, an apparent difference is not evident; however, Figure 4-3b indicates that older buildings contributed more iron to the drinking water. The predominent type of plumbing used in both the new and old high-rise buildings sampled was copper. The likely existence of galvanized iron pipe in some of the older buildings may have been a potential source of iron. Zinc was not influenced by plumbing age (p=0.317).

The AGE parameter was also investigated utilizing the trace metal data obtained from single-family houses. Iron was not analyzed in this data set. However, AGE strongly influenced copper concentrations (p=0.003). AGE had a marginal effect on lead (p=0.083) and did not influence zinc concentration (p=0.254). In the case of copper and lead, newer copper plumbing systems had the greater metal concentrations (Figures 4-9 to 4-11).

4.2.3.2 Running Hot

The effect of plumbing AGE was more evident when the hot water samples were analyzed, especially in the case of apartments located in the East. New buildings resulted in greater levels of lead (Figures 4-5a & 4-5b). When copper was analyzed, a very pronounced AGE effect was detected (p=0.000). Figures (4-6a & 4-6b) show that new apartments resulted in significantly greater copper levels in comparison to older apartments. This was the case in both the East and West locations.

A similar analysis conducted on running hot water samples obtained from single-family houses showed lead (p=0.705) and copper (p=0.827) concentrations to be unaffected by AGE. From Figures 4-12 and 4-13, it can be seen that there is no discernable difference between the mean or median levels of lead and copper obtained from NEWxCOPPER vs. OLDxCOPPER plumbing systems.

This leads to the conclusion that the recirculation system in a high-rise apartment building is a major contributor to the contamination of the hot water supply by lead and copper. The combination of a new plumbing system and hot water recirculation appears to result in a greater potential to leach trace metals.

For iron measured in high-rise apartments, a marginal LOCATION by AGE interaction (p=0.080) existed. This is not very significant, however, and as discussed previously, location of the building was the main factor influencing iron levels measured in high-rise apartments.

In both high-rises and houses, AGE was not significant in influencing zinc concentrations in the running hot samples.

4.2.4 **Plumbing Type** (Copper vs. Plastic)

4.2.4.1 **Cold First-Flush**

Plumbing material TYPE was investigated for single-family houses. It should be noted that differences cannot be statistically justified, since the data for the plastic pipe grouping is composed of only 3 sampling sites. A qualitative significance can be recognized from the box plots. Copper concentration levels associated with plastic pipe plumbing were well below those associated with copper plumbing (Figure 4-10). The only potential source of copper in a plastic system is that leached from the brass fixtures or background levels associated with the source water. Median lead and zinc concentrations do not appear to be different between copper or plastic plumbing systems (Figures 4-9 & 4-11).

4.2.4.2 **Running Hot**

In the running hot water sample, plastic plumbing systems also resulted in significantly lower copper concentrations compared to copper plumbing systems (Figure 4-13). Lead and zinc levels measured in the hot water were not discernably different between the two types of plumbing.

4.2.5 **Building Type** (High-Rise vs. Single-Family House)

4.2.5.1 **Cold First-Flush**

High-rise samples were collected during the summer months and single-family houses were sampled in January. Since water quality parameters which affect corrosion rates may have been significantly different, a detailed analytical comparison between house and high-rise samples may be suspect. Despite this caution, high-rise samples showed much greater concentrations of lead than the house samples. The mean lead concentrations for all 1-L first-flush high-rise and single-family house samples were 0.020 mg/l and 0.013 mg/l, respectively. This difference is probably due to the greater number of soldered connections in a high-rise plumbing system, allowing for a greater leaching potential of lead. Copper and zinc concentrations in 1-L first-flush samples did not appear to show any marked differences between building types. It is important to note that in the "running" cold sample, the mean high-rise copper concentration was 0.33 mg/L, compared with the single-family house level of 0.17 mg/L. This reveals that increased contact time associated with longer pipe runs is significant in influencing copper leaching. Table 4-2 summarizes the mean concentrations of all samples collected, as well as the recommended guidelines for Canadian Drinking Water (1989).

4.2.5.2 **Running Hot**

A difference in lead concentrations between high-rise and single-family house samples was not apparent in the running hot water. The mean lead level for apartments was 0.009 mg/L and for houses, 0.007 mg/L. The most significant difference was between

Table 4-2. Trace Metal Concentrations Measured in High-Rises vs. Single-Family Houses (mg/L).

Sample Bottle	Lead	Copper	Iron	Zinc
High-Rise Apartment Buildings[1]				
Cold#1 (50 ml)	0.041	1.31	0.08	0.91
Cold#2 (200 ml)	0.034	1.76	0.09	0.21
Cold#3 (750 ml)	0.014	1.30	0.10	0.04
Cold#4 (Running)	<0.005	0.33	0.11	<0.02
LCOLD (1000 ml)	0.020	1.39	0.09	0.12
Hot#1 (Running)	0.009	1.01	0.11	0.03
Single-Family Houses[2]				
Cold#1 (50 ml)	0.017	1.06	N/A	0.98
Cold#2 (200 ml)	0.028	1.76	N/A	0.20
Cold#3 (750 ml)	0.009	1.34	N/A	0.03
Cold#4 (Running)	<0.005	0.17	N/A	<0.02
LCOLD (1000 ml)	0.013	1.41	N/A	0.11
Hot#1 (Running)	0.007	0.47	N/A	0.02
Canadian Drinking Water Guidelines (1989)[3]				
MAC (mg/L)	0.010	1.00	0.30	5.00

[1] Sampled from 72 individual suites located in 12 high-rise buildings (represents average of 3 sampling runs)
[2] Sampled from 60 individual homes (randomly chosen)
[3] Guidelines are based on lead samples taken from a flushed tap

copper concentrations. The mean copper level for high-rises was 1.01 mg/L and for houses, 0.47 mg/L. The main factors influencing the elevated copper in high-rises were probably a higher boiler temperature, increased contact time, and hot water recirculation; previous discussion has shown the significance of each of these factors in accelerating corrosion. It should be noted that synergistic effects may be taking place amongst these variables; however, these effects cannot be isolated, given the scope of this analysis. Since the hot sample was obtained from a flushed tap (vs. standing), both building types showed zinc levels close to the detection limit (Figures 4.8a & 4.14).

HIGH-RISE APARTMENTS

1-L Cold First-Flush

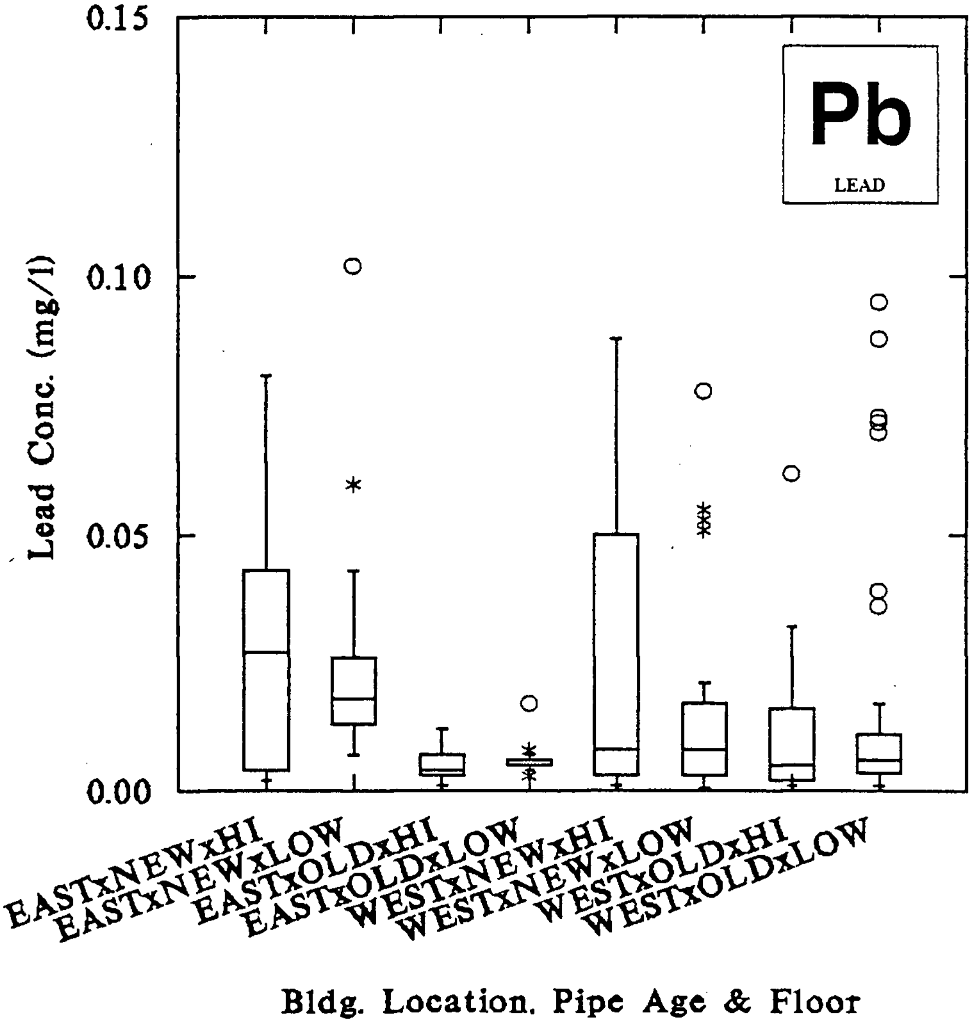


Figure 4-1a. Box Plot of Lead Levels in 1-L Cold First-Flush Samples from High-Rises (For Guide to Tukey Box Plots, see Section 3.4)

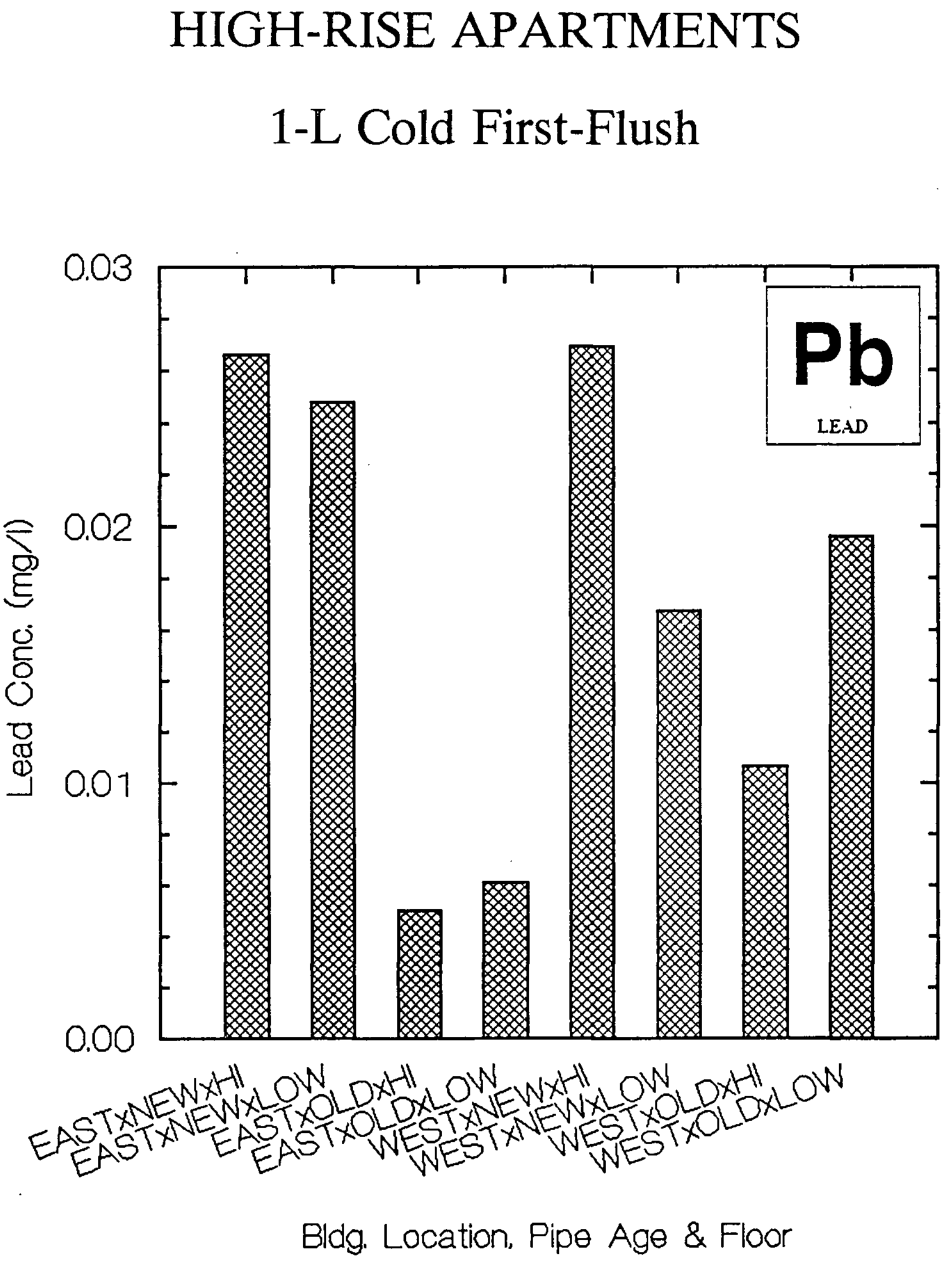


Figure 4-1b. Mean Lead Concentrations in 1-L Cold First-Flush Samples from High-Rises

HIGH-RISE APARTMENTS

1-L Cold First-Flush

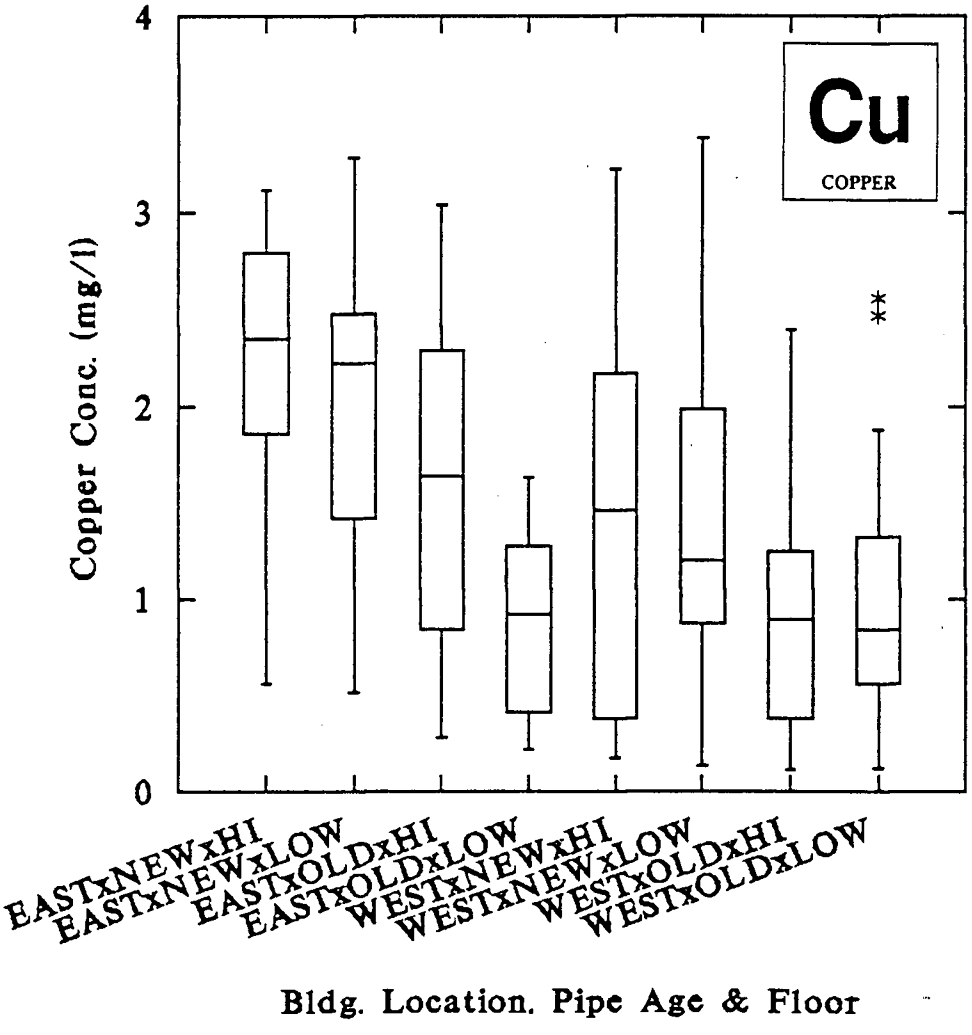


Figure 4-2a. Box Plot of Copper Levels in 1-L Cold First-Flush Samples from High-Rises

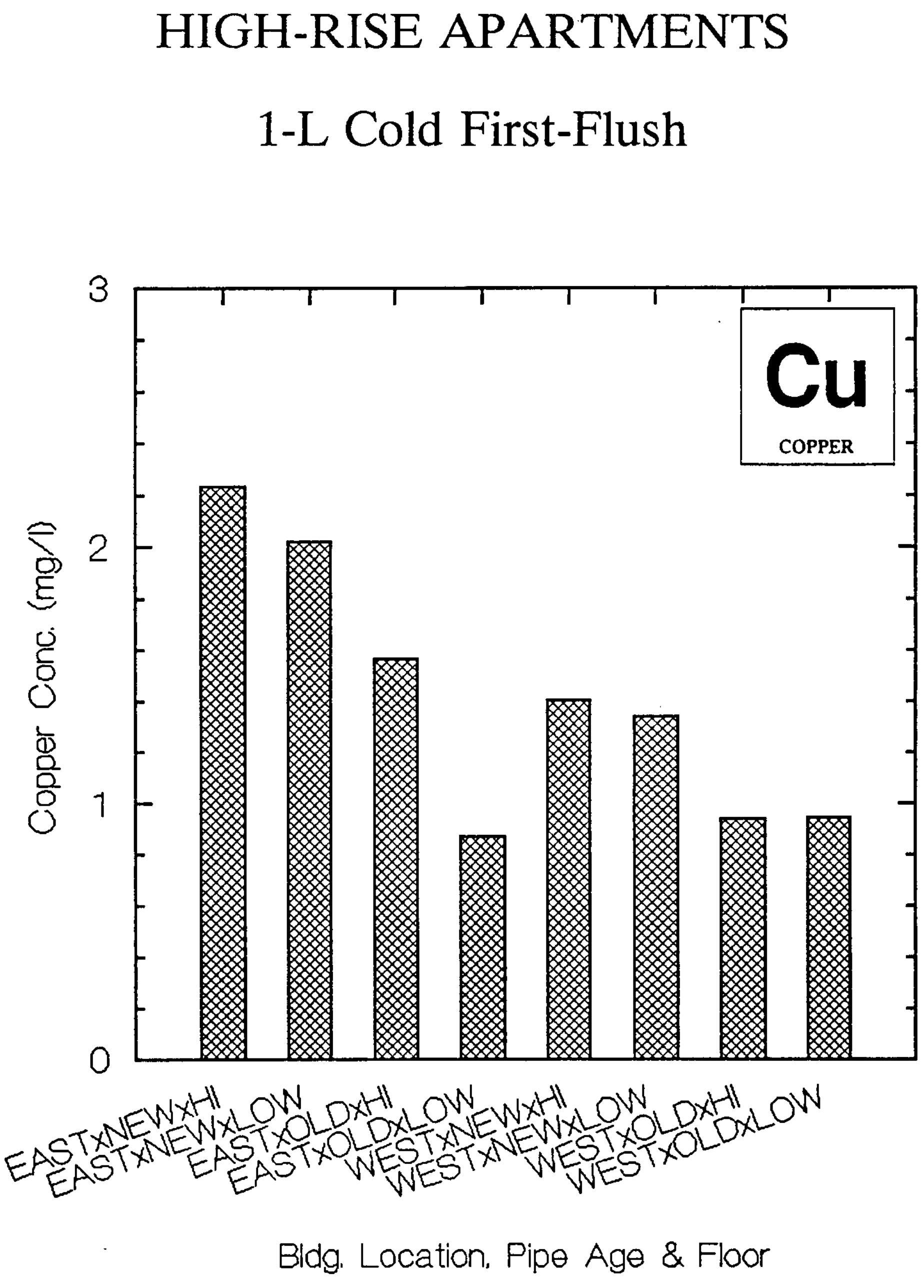


Figure 4-2b. Mean Copper Concentrations in 1-L Cold First-Flush Samples from High-Rises

HIGH-RISE APARTMENTS

1-L Cold First-Flush

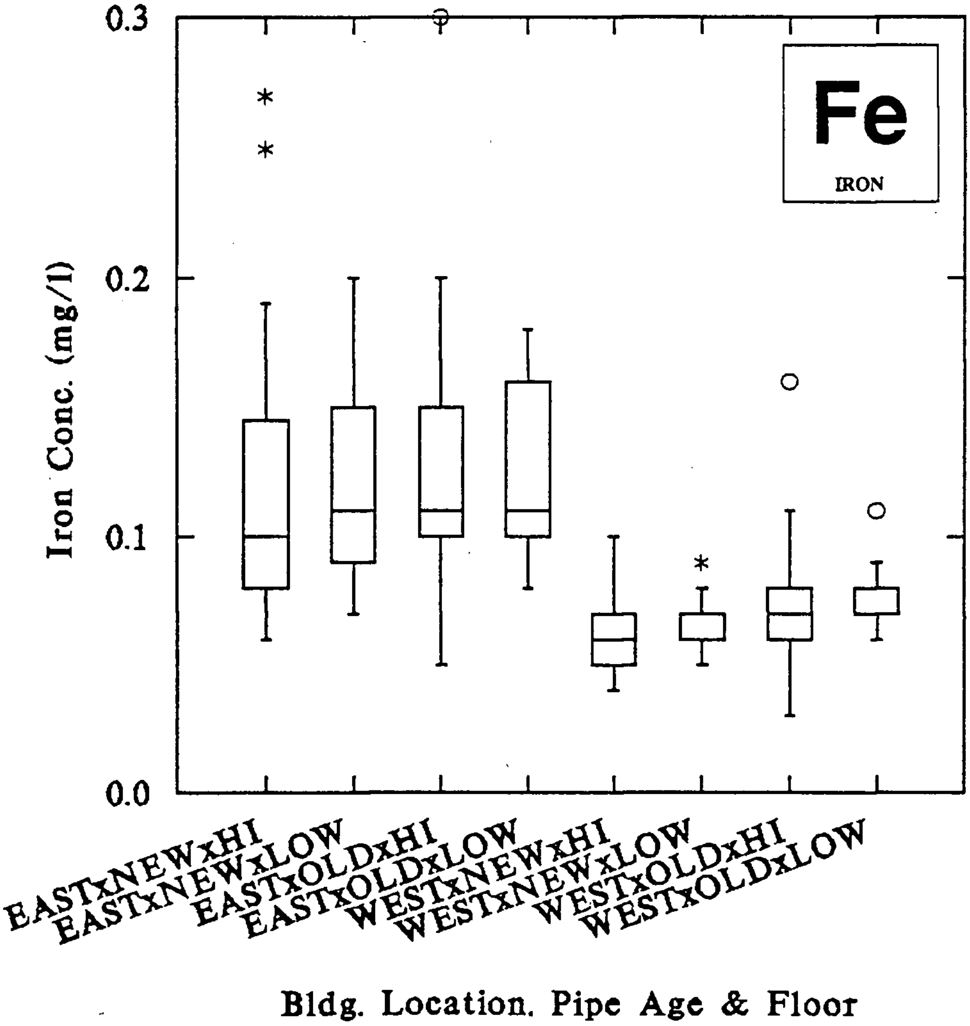


Figure 4-3a. Box Plot of Iron Levels in 1-L Cold First-Flush Samples from High-Rises

HIGH-RISE APARTMENTS

1-L Cold First-Flush

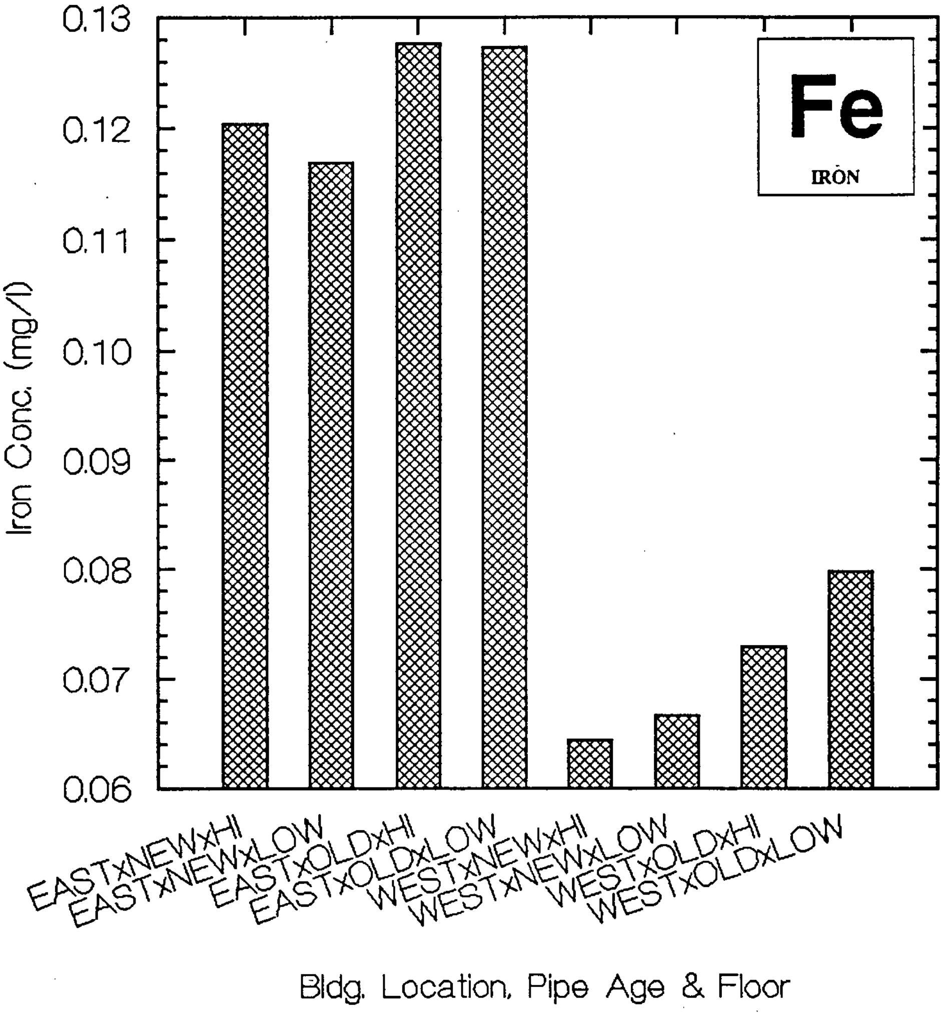


Figure 4-3b. Mean Iron Concentrations in 1-L Cold First-Flush Samples from High-Rises

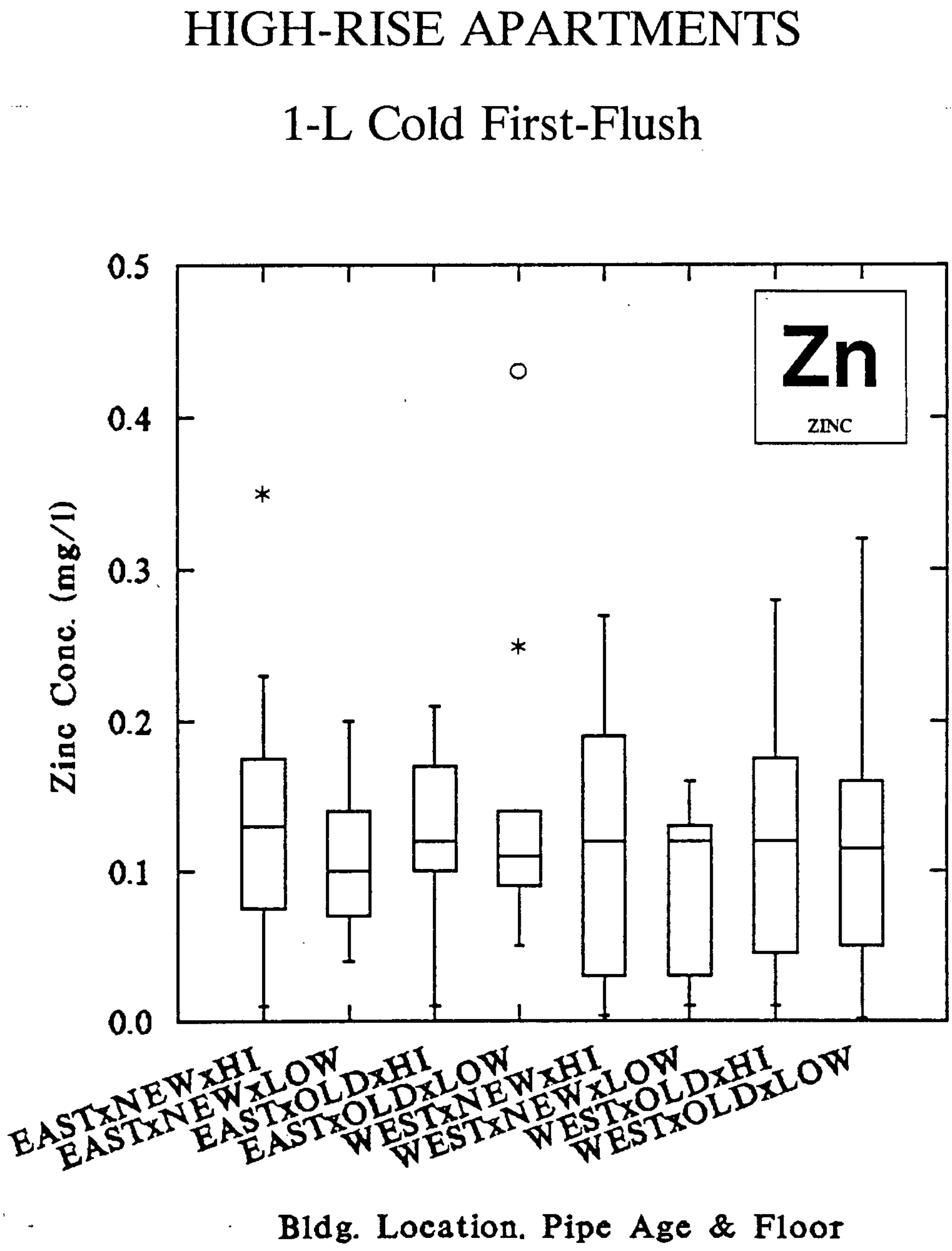


Figure 4-4a. Box Plot of Zinc Levels in 1-L Cold First-Flush Samples from High-Rises

HIGH-RISE APARTMENTS

1-L Cold First-Flush

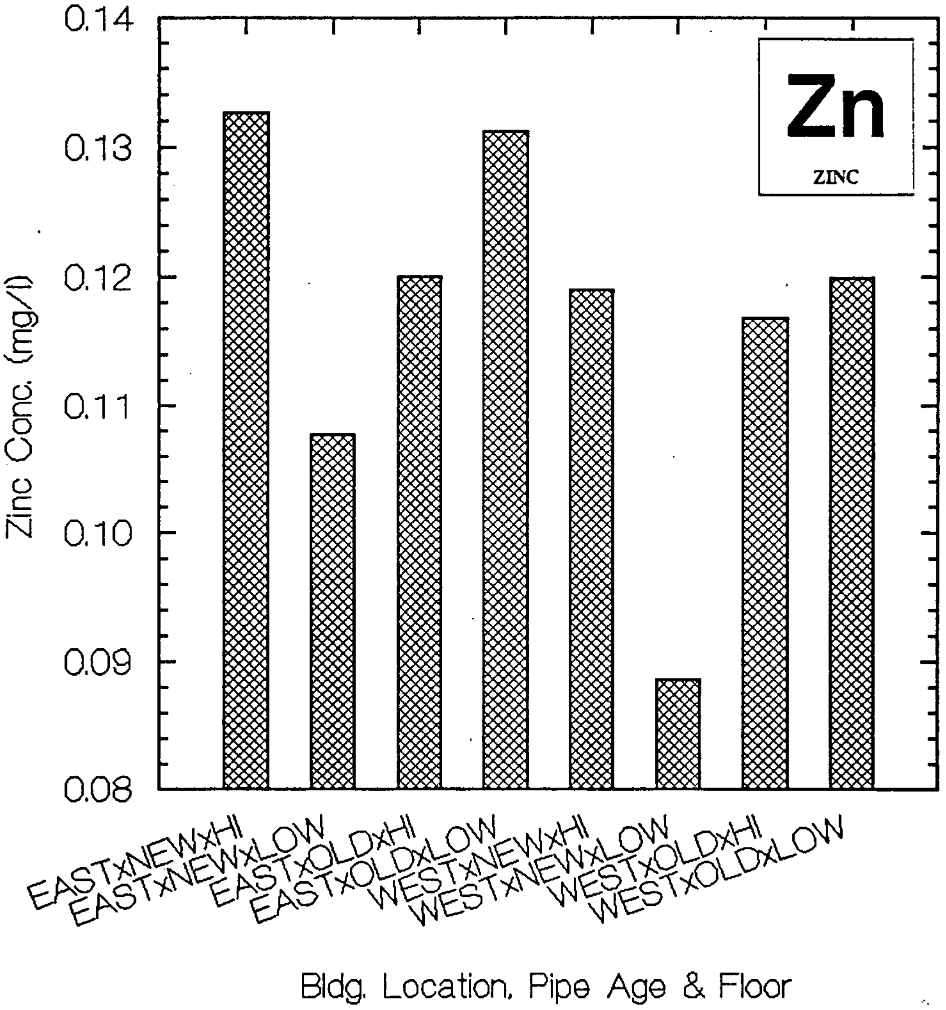


Figure 4-4b. Mean Zinc Concentrations in 1-L Cold First-Flush Samples from High-Rises

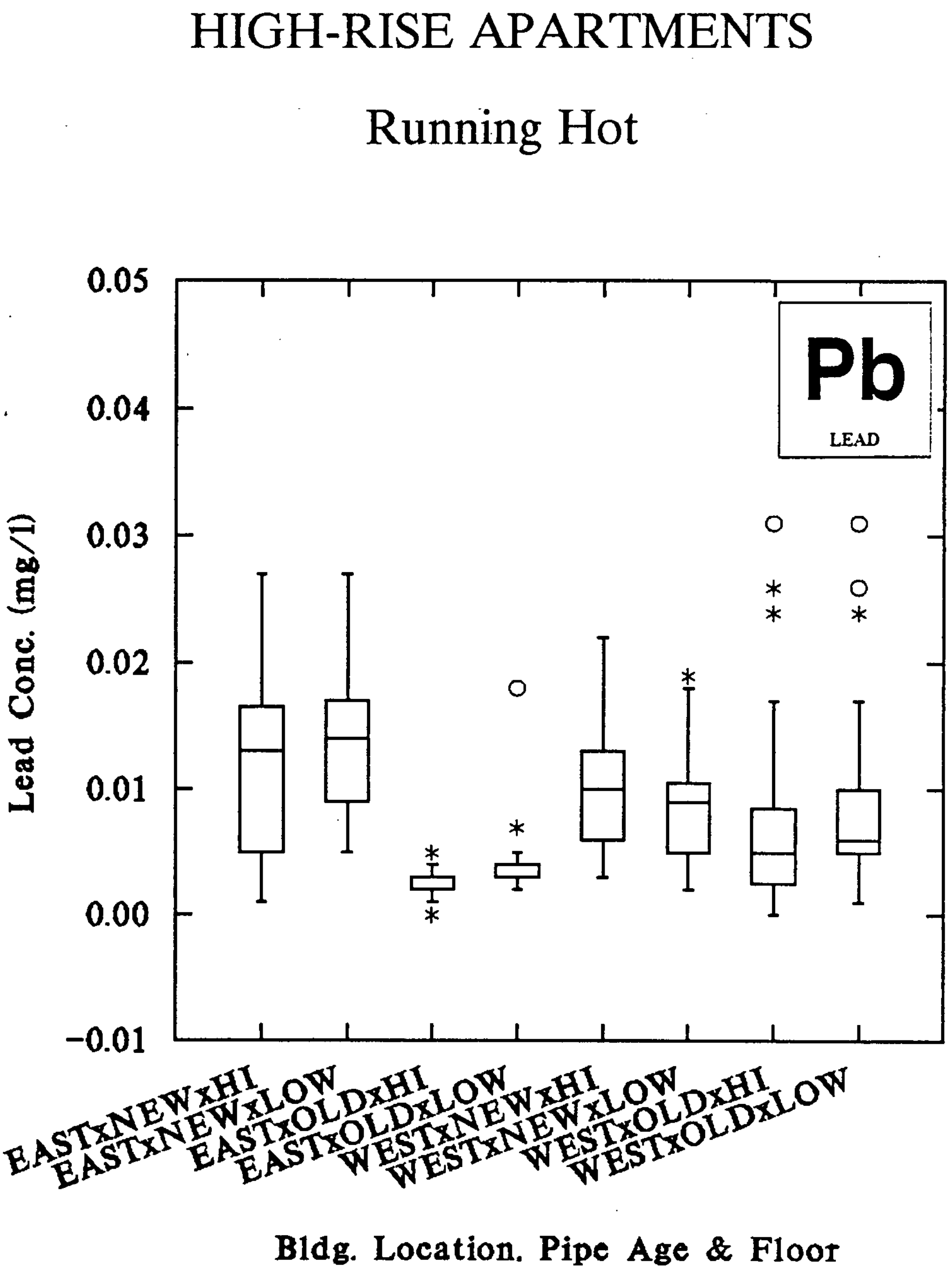
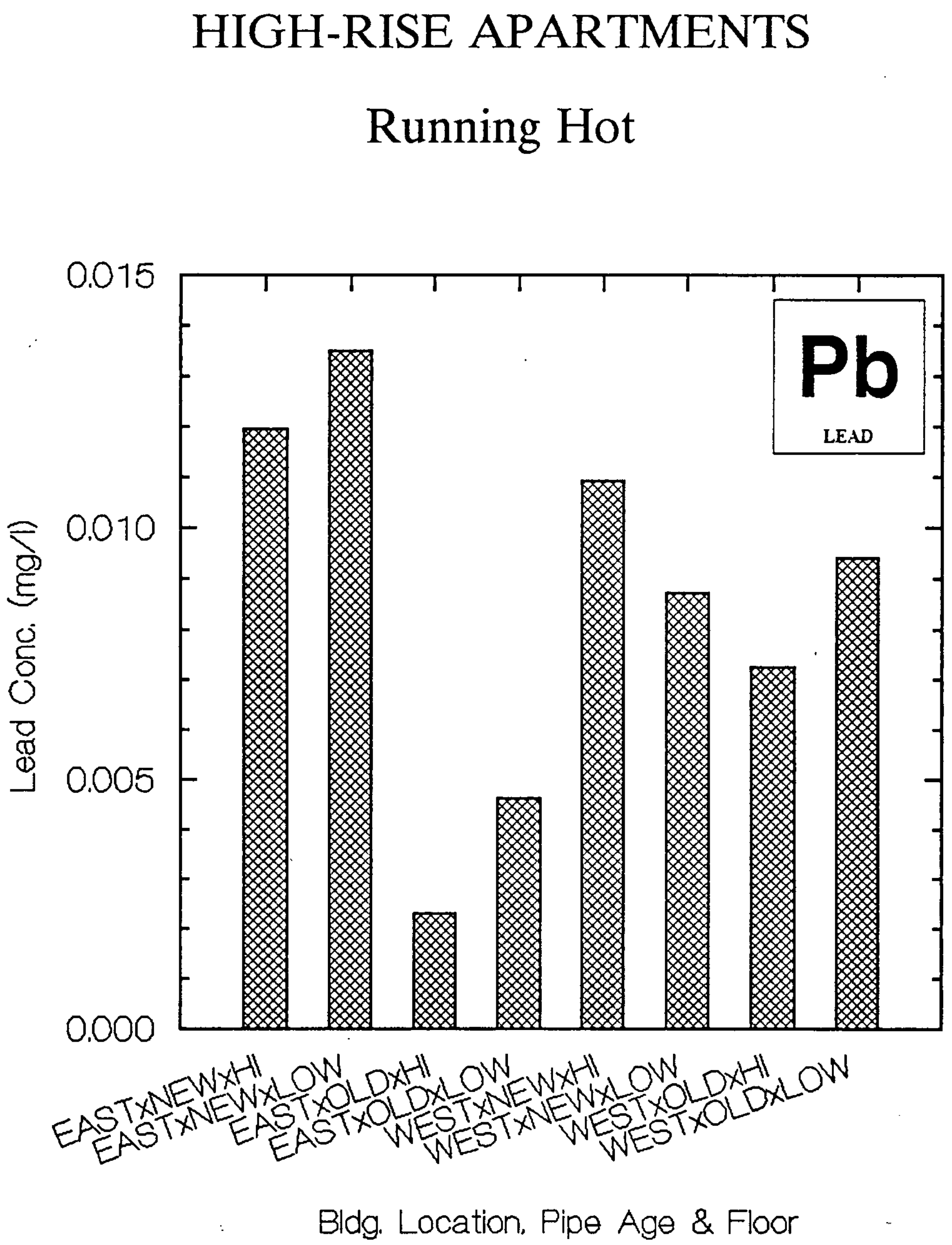


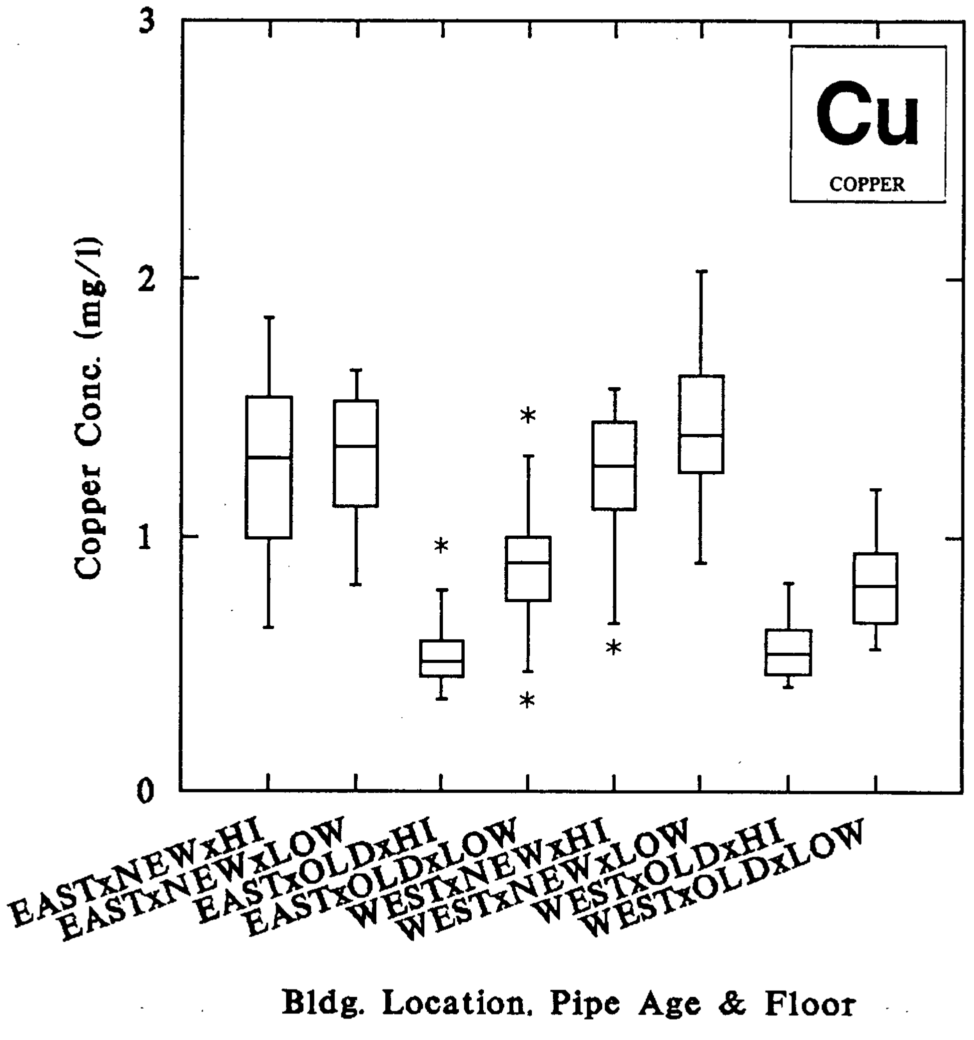
Figure 4-5a. Box Plot of Lead Levels in Running Hot Samples from High-Rises



HIGH-RISE APARTMENTS

Running Hot

Figure 4-5b. Mean Lead Concentrations in Running Hot Samples from High-Rises



HIGH-RISE APARTMENTS

Running Hot

Figure 4-6a. Box Plot of Copper Levels in Running Hot Samples from High-Rises

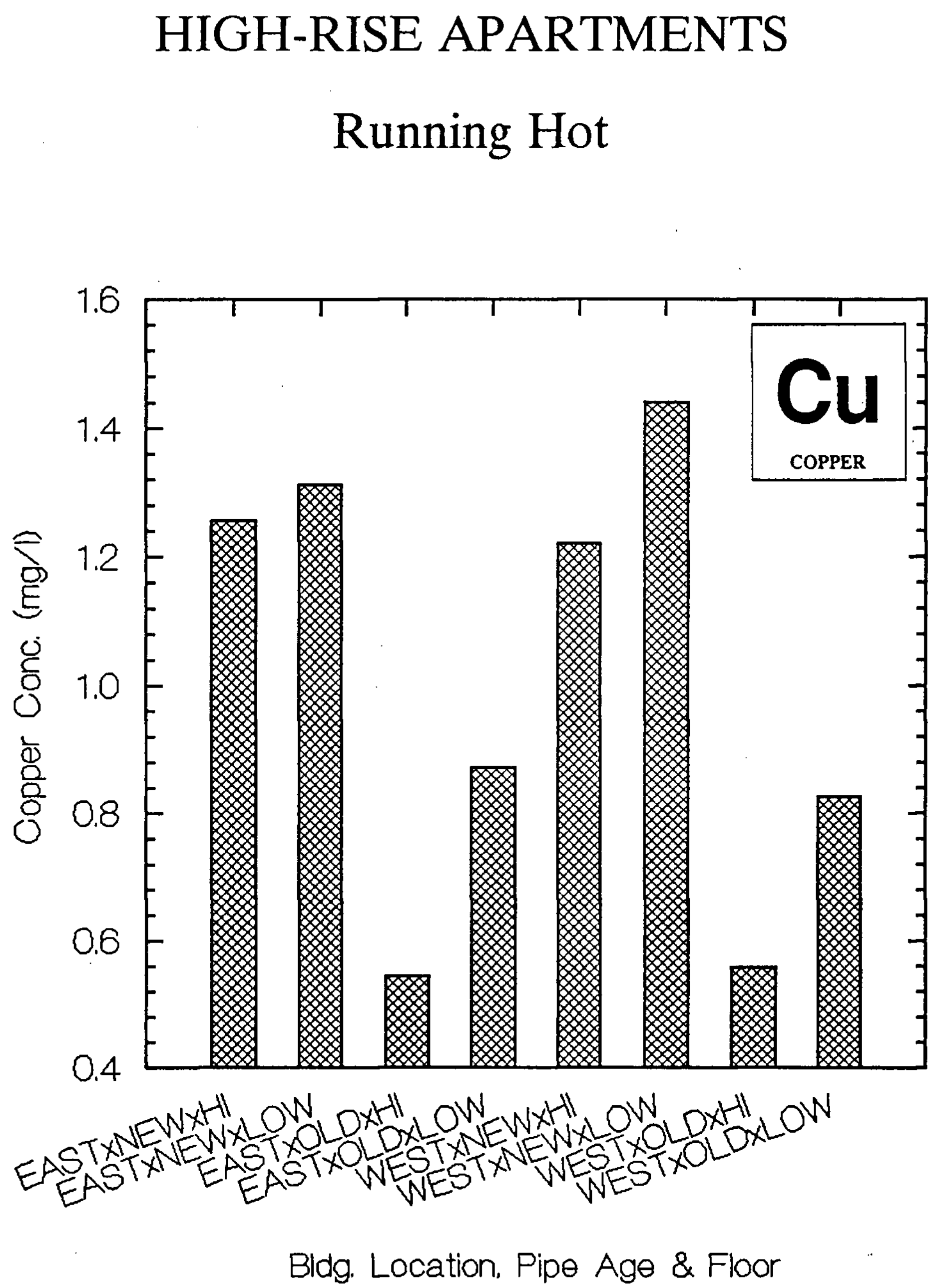


Figure 4-6b. Mean Copper Concentrations in Running Hot Samples from High-Rises

HIGH-RISE APARTMENTS

Running Hot

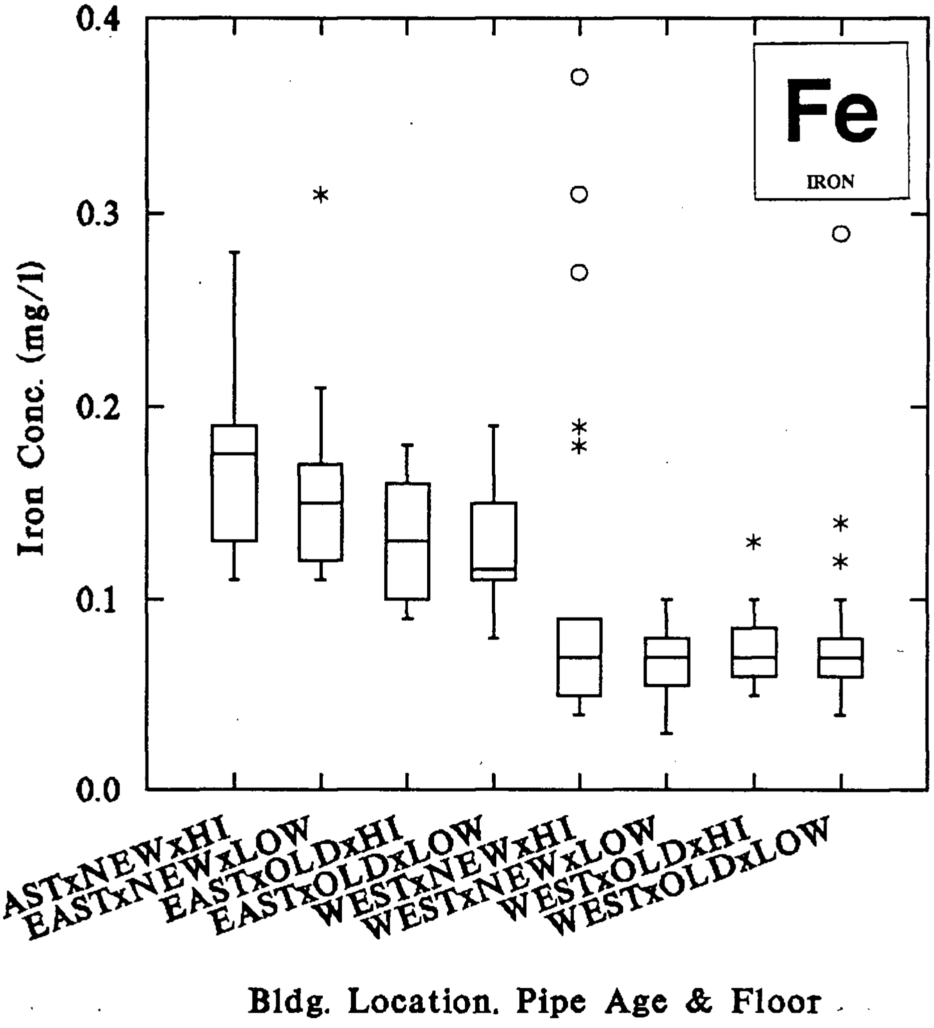
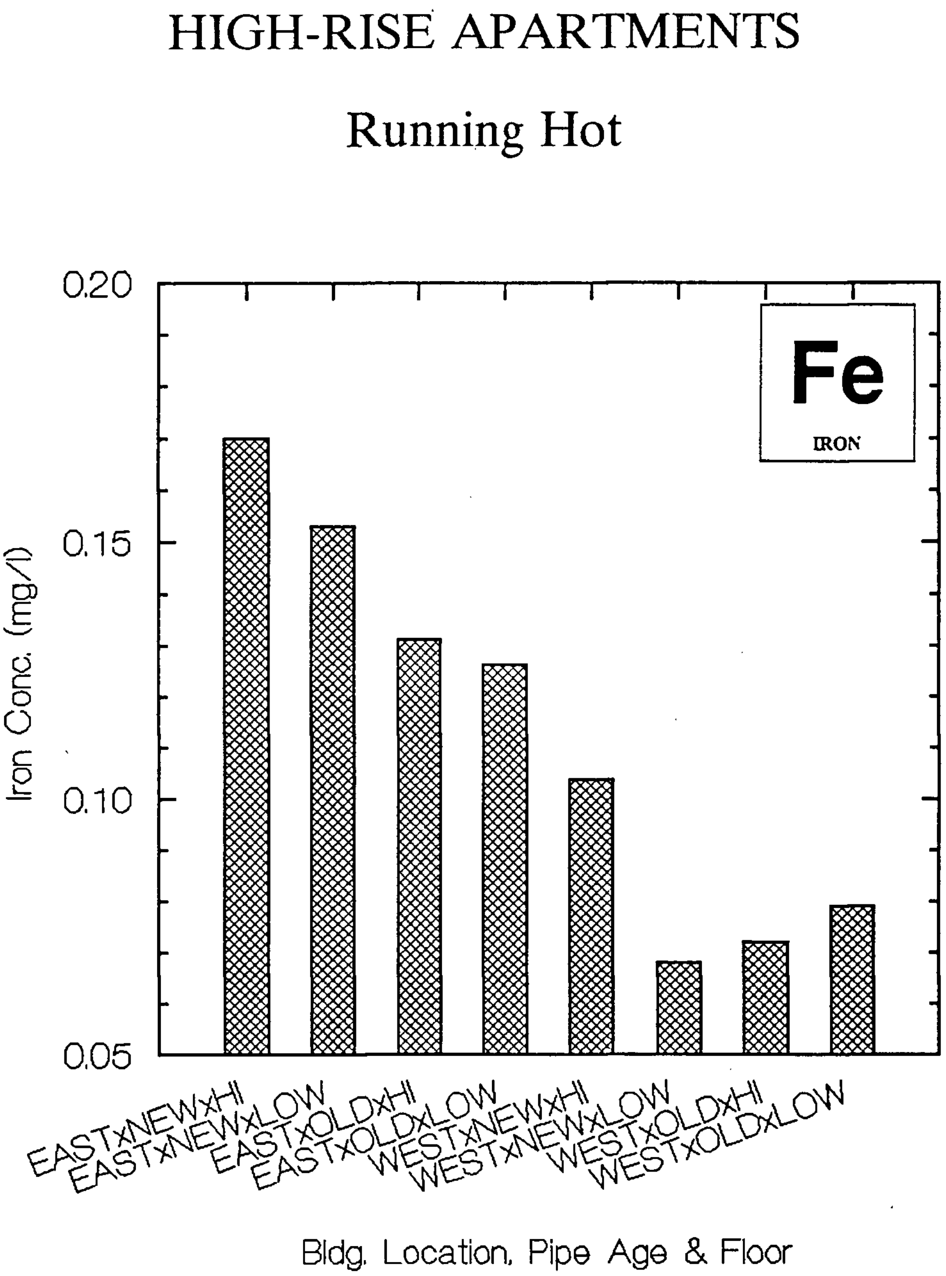


Figure 4-7a. Box Plot of Iron Levels in Running Hot Samples from High-Rises


HIGH-RISE APARTMENTS

Running Hot

Figure 4-7b. Mean Iron Concentrations in Running Hot Samples from High-Rises

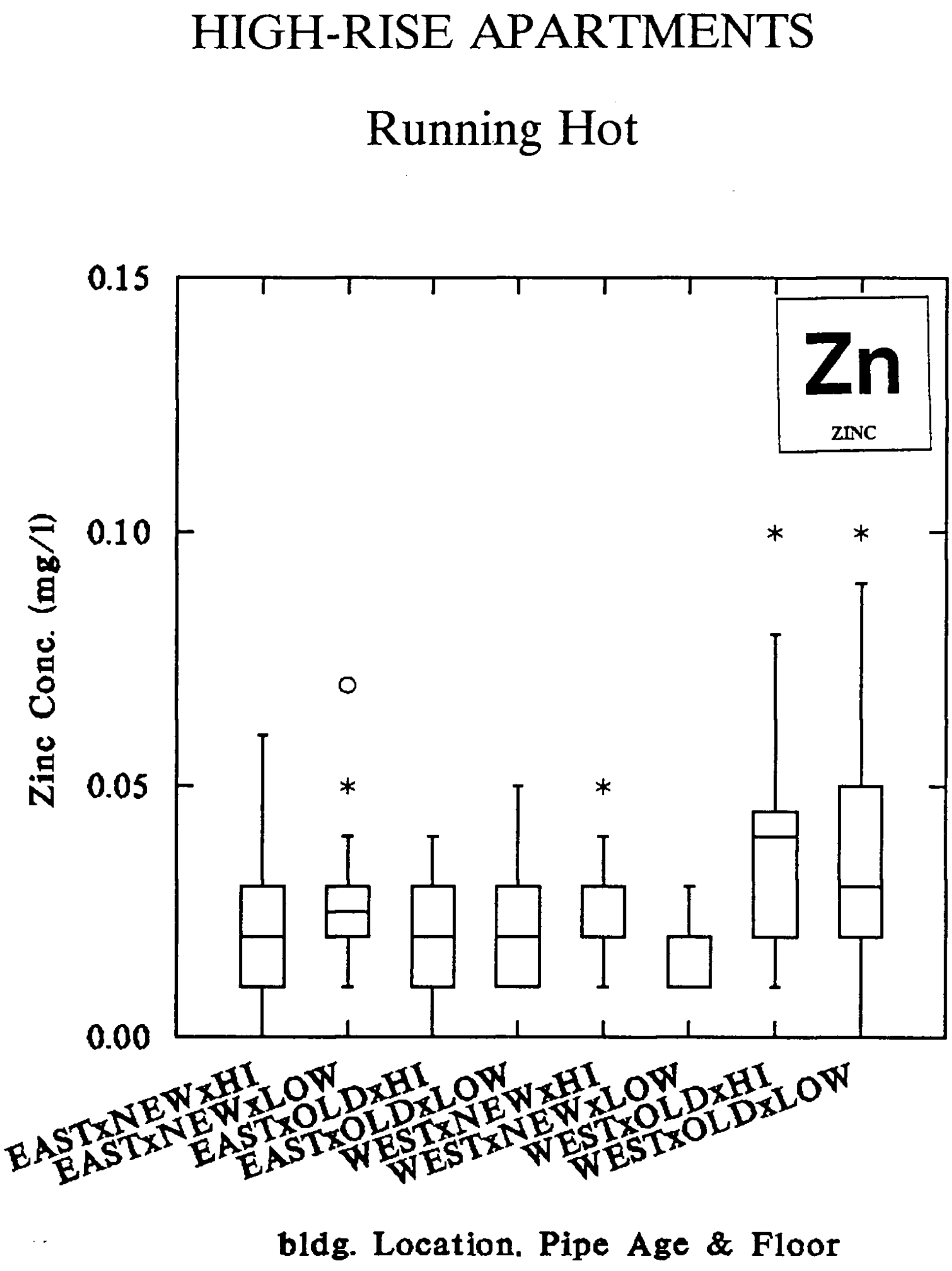
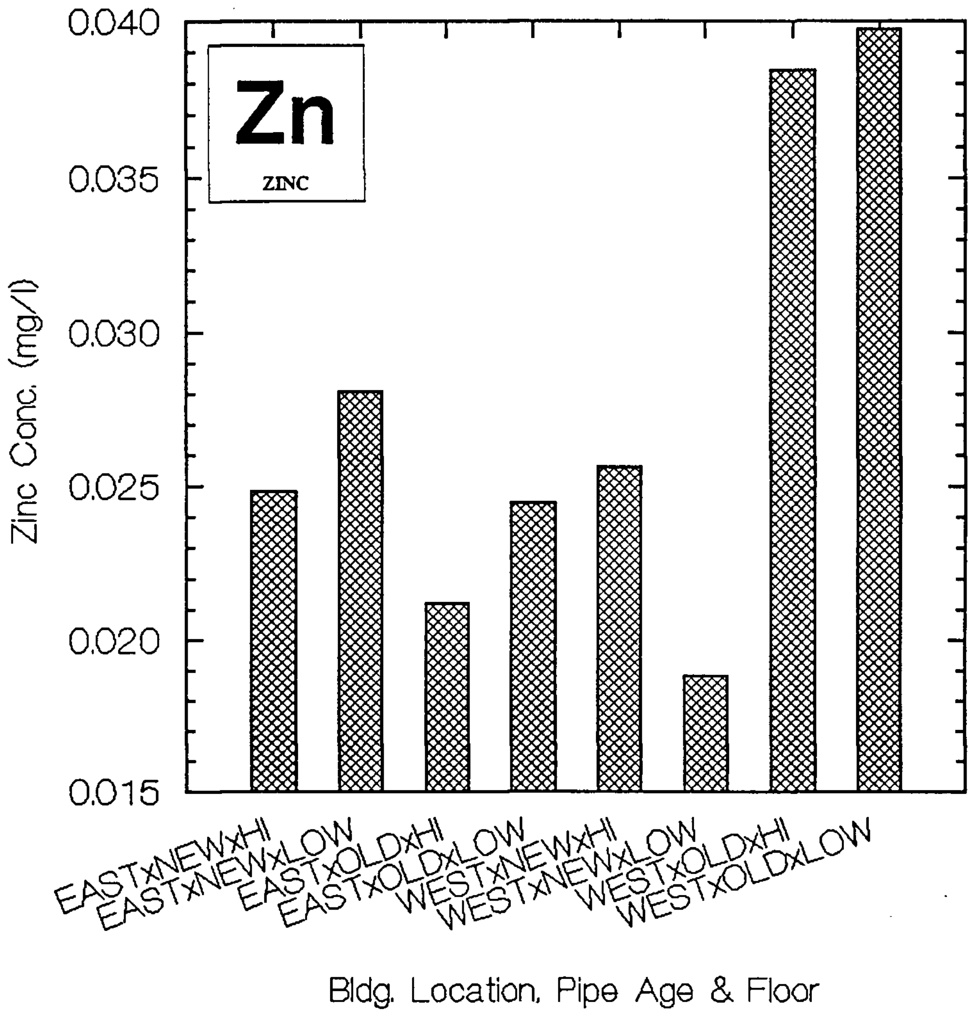


Figure 4-8a. Box Plot of Zinc Level in Running Hot Samples from High-Rises



HIGH-RISE APARTMENTS

Running Hot

Figure 4-8b. Mean Zinc Concentrations in Running Hot Samples from High-Rises

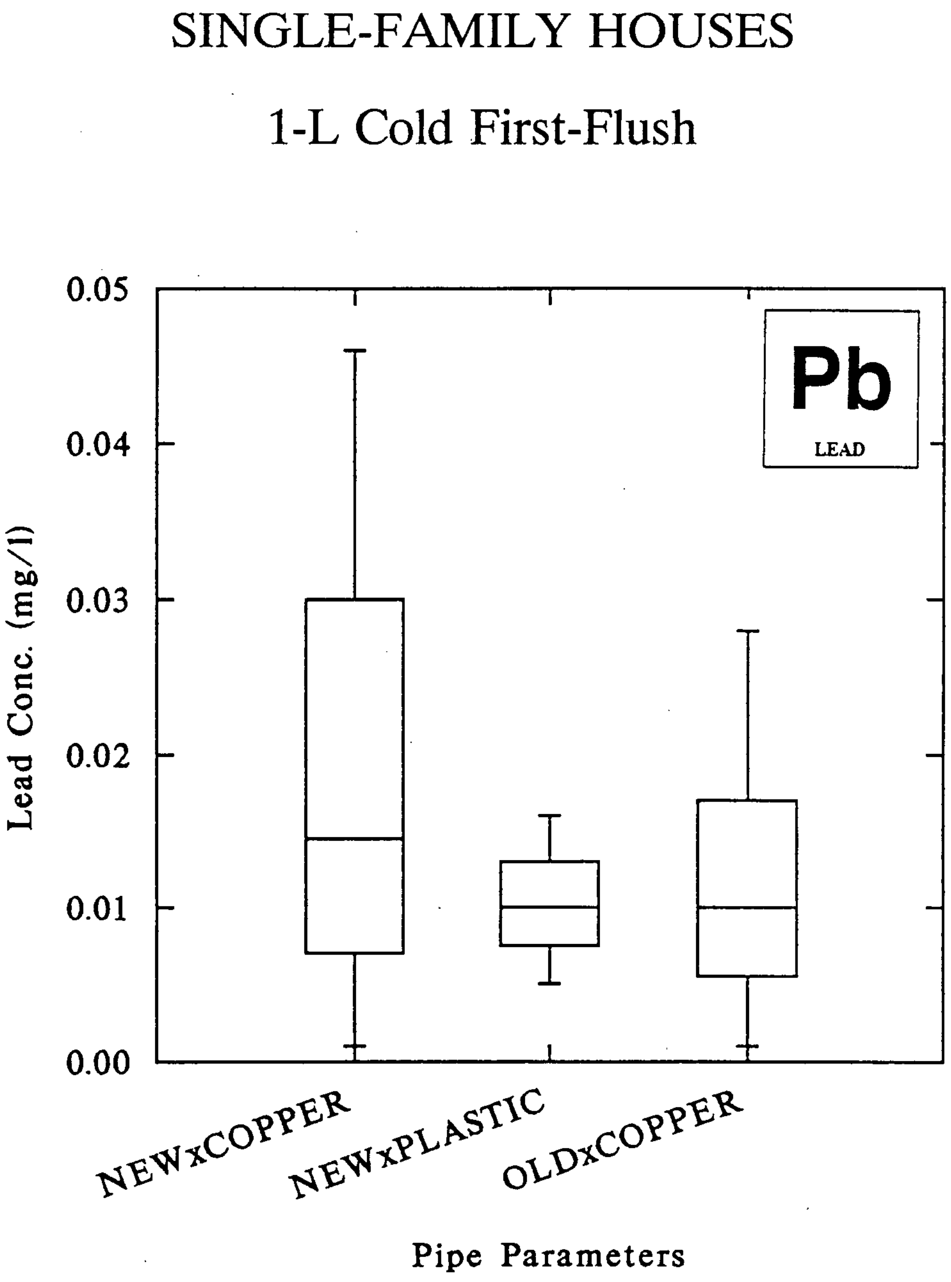


Figure 4-9. Box Plot of Lead Levels in 1-L Cold First-Flush Samples from Single-Family Houses

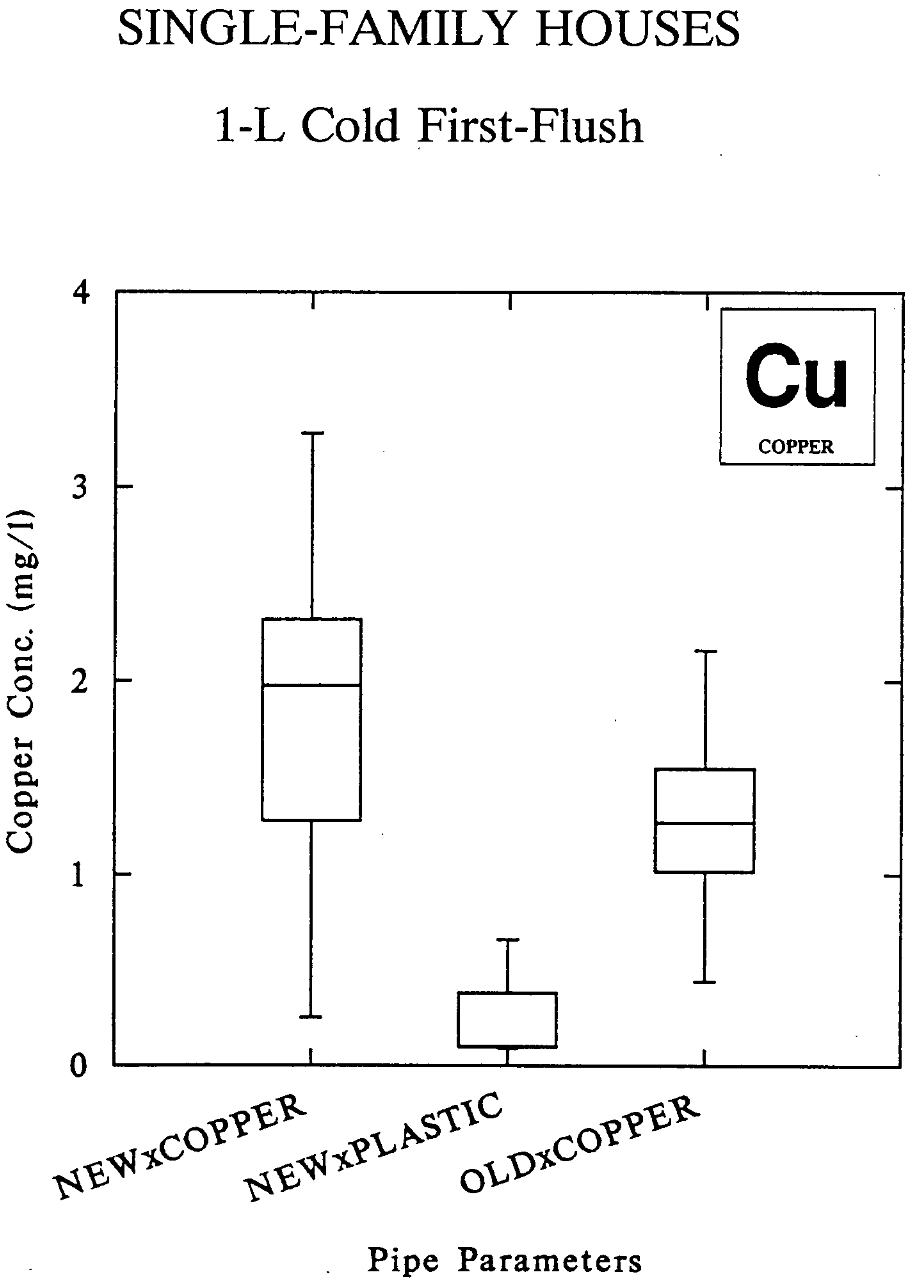


Figure 4-10. Box Plot of Copper Levels in 1-L Cold First-Flush Samples from Single-Family houses

SINGLE-FAMILY HOUSES

1-L Cold First-Flush

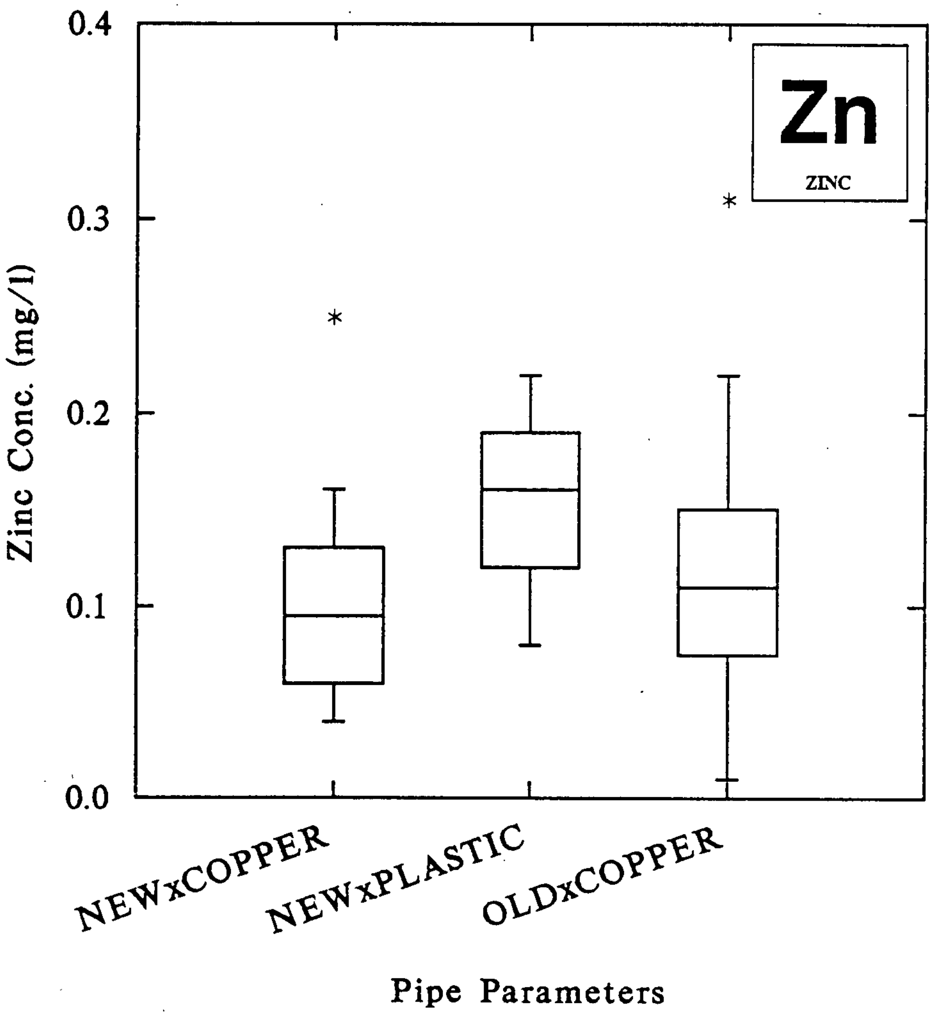


Figure 4-11. Box Plot of Zinc Levels in 1-L Cold First-Flush Samples from Single-Family Houses

SINGLE-FAMILY HOUSES

Running Hot

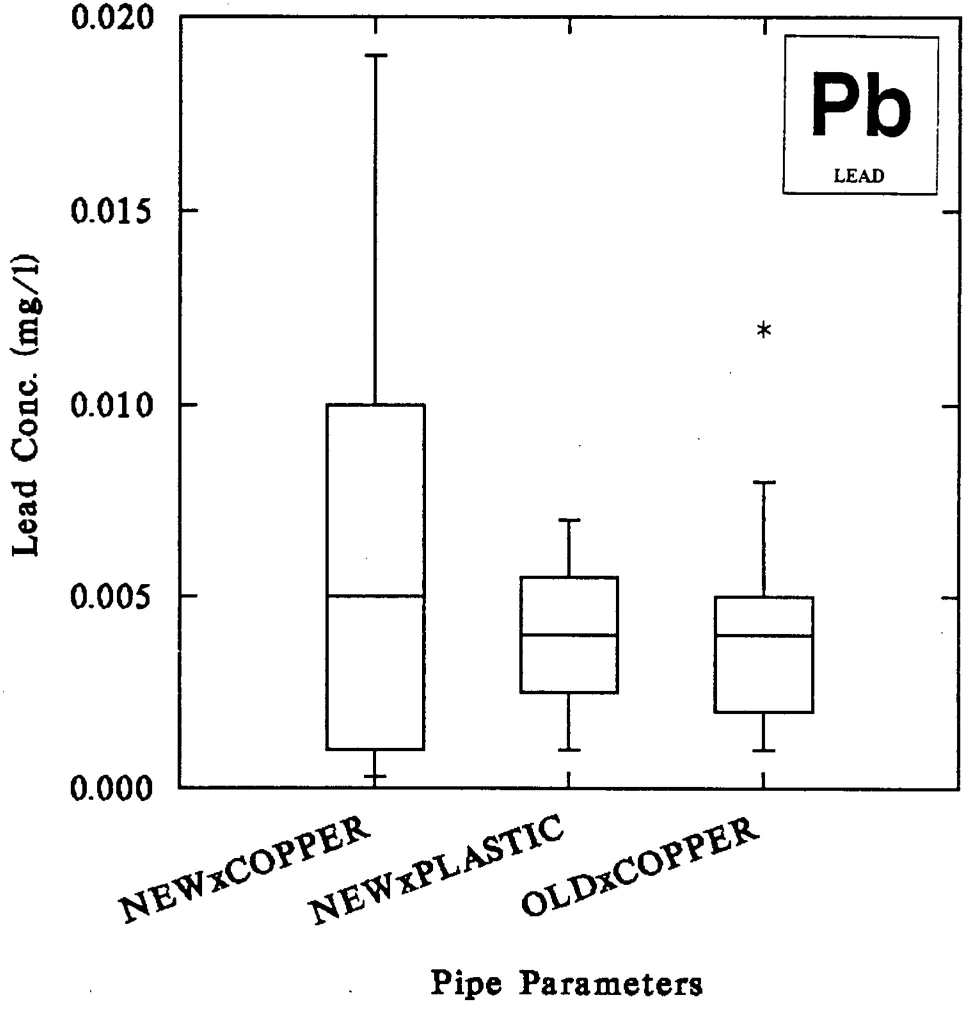


Figure 4-12. Box Plot of Lead Levels in Running Hot Samples from Single-Family Houses

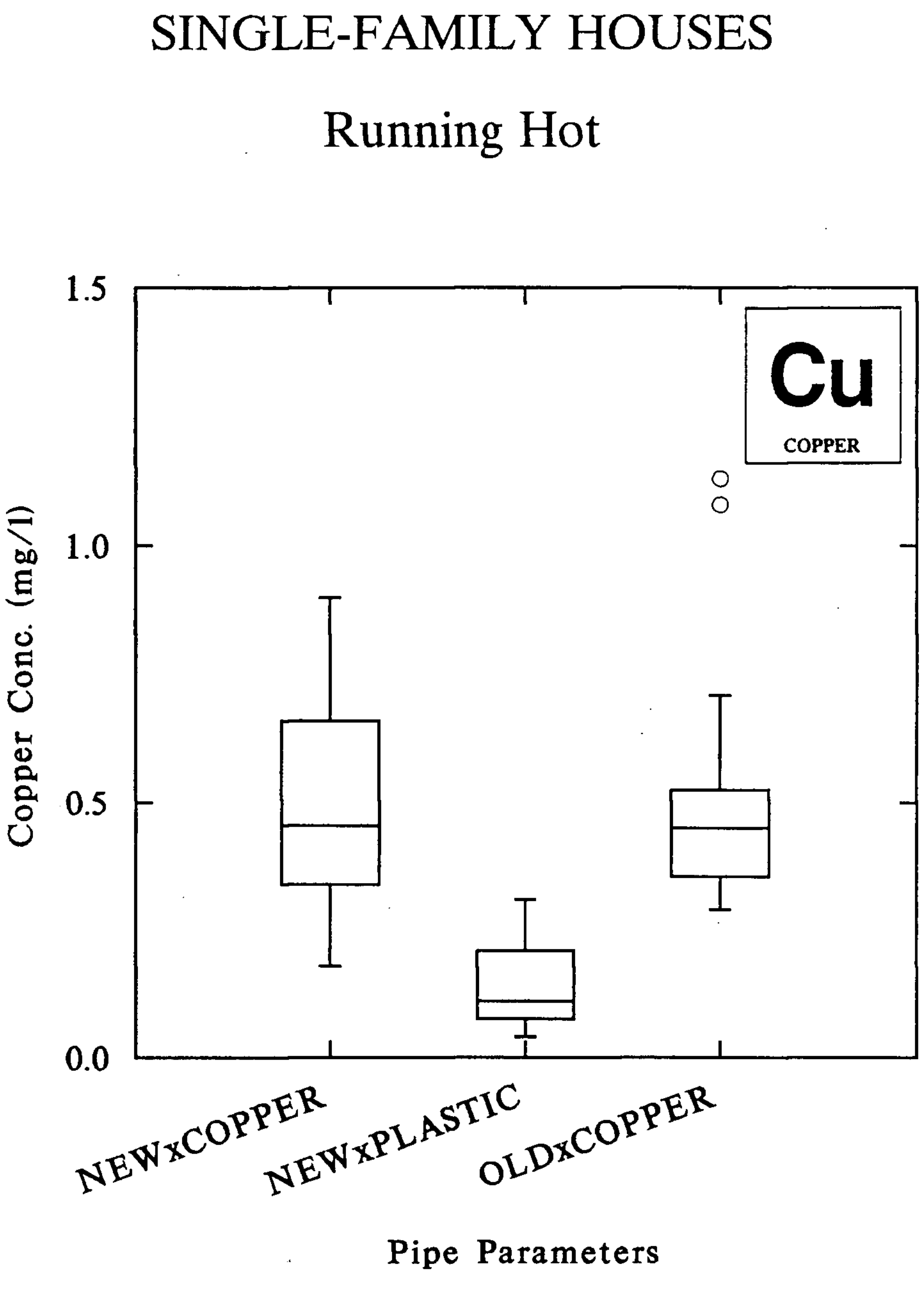


Figure 4-13. Box Plot of Copper Levels in Running Hot Samples from Single-Family Houses

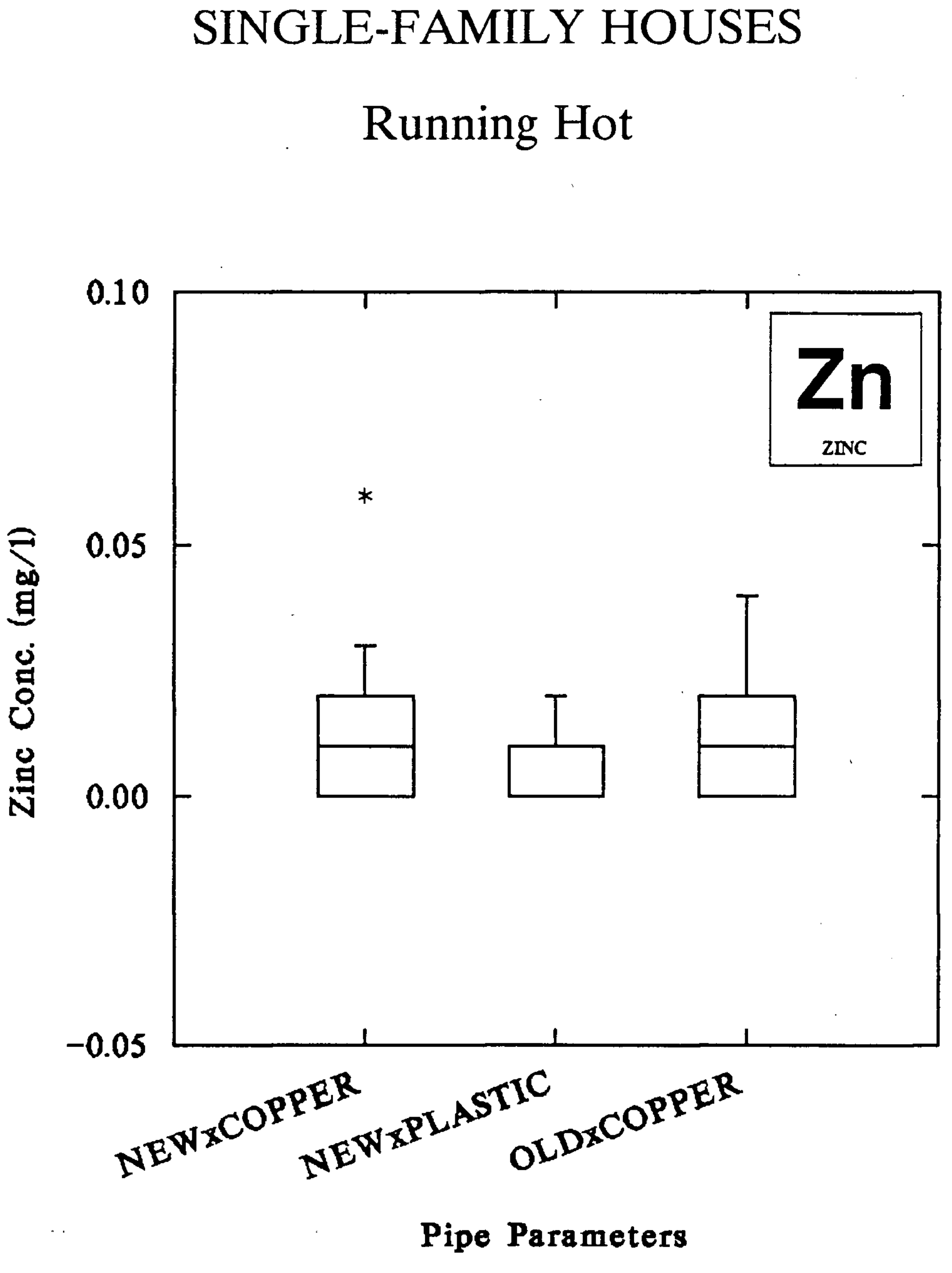


Figure 4-14. Box Plot of Zinc Levels in Running Hot Samples from Single-Family Houses

4.2.6 **Flushing Trends** (Contamination Sources)

The bottle scheme used for sampling was designed to obtain a better understanding of the contribution that various parts of the distribution system made to metal concentrations measured in tap water. Cold#1 was representative of the faucet. Cold#2 and Cold#3 represented consecutive flushes from the building plumbing and any residual from the faucet. Cold#4 allowed for the water to be run long enough to access background levels from the city main. Lastly, Hot#1 gave a representation of trace metals leached from the hot water plumbing in houses and the hot water recirculation system in high-rises. A weighted average of bottles Cold#1, Cold#2, and Cold#3 was used to calculate a concentration for a 1-L cold first-flush sample (for comparison with USEPA lead and copper regulations, see section 4.3 Compliance Issues).

4.2.6.1 **High-Rise Sampling**

Lead: It has been shown in other surveys (Lee, 1989) that lead-based solder and brass faucets contribute substantially to lead in first-draw samples. In representing flushing trends (Figures 4-15 to 4-18), metal concentration data from low-rise and high-rise suites were combined for clarity (building height was not a significant factor in influencing first-flush metal concentrations). It was shown by Gardels (1989), that after 200 to 250 ml of water had flowed, 95% or more of the lead had normally been flushed from the faucet (study was conducted under laboratory conditions with plastic plumbing leading up to the faucet). Lee (1989) concluded that lead-based solder is the most significant source of lead at the tap and that brass faucets were found to contribute substantially to the lead in the first-draw samples (based on a field study). Sampling from high-rise apartments supports this conclusion. For lead, the highest concentration was detected within the first two flushes (Cold#1 and Cold#2 - total volume of 250 ml). On average, 47% of the lead was contributed from Cold#1 and Cold#2. In accordance with Gardels, the subsequent third-flush should be close to background levels; however, a significant contribution of 32% resulted. It should be noted that the 21% percent contribution of lead from background (Cold#4 -Running) may be unfairly biased due to cases where "overnight standing samples" were not correctly taken (may have been flushed). Therefore, mean levels for cold flush #1, #2 and #3 were probably higher than those portrayed in Figure 4-15.

It is clear then, that lead is leaching out of brass and bronze faucets and fittings. Water standing in the pipes near the faucet may have high lead levels due to the presence of numerous lead-soldered joints close to the faucet. Until a recent change in the City of Vancouver plumbing code, which now specifies 95/5 Tin/Antimony solder, 50/50 lead-tin solder had been extensively used as an industry standard. The leaching process can also be accelerated due to the galvanic cell established between the copper pipe and lead-tin solder.

Copper: It was found that the greatest concentration of copper did not occur in the first-flush (COLD#1), but rather in the second (COLD#2) (Figure 4-16). The water in contact with the copper plumbing, immediately after the faucet, was the most contaminated. Also, it is important to note that bottle Cold#3 (750 ml), with a much greater dilution volume over bottles Cold#1 and Cold#2, still maintained a relatively high copper concentration. Flushing the system for copper was not as effective as for lead.

Iron: Iron concentrations were generally higher in consecutive flushes, with the peak levels measured in Cold#4 (running water from the city main) (Figure 4-17). Iron in tap water was not found to be correlated with plumbing materials within the apartment buildings, but was a result of iron from the source reservoir and from the city distribution main. The step wise increase in iron concentration from Cold#1 to Cold#4 could be a result of precipitation reactions occurring in the building pipe overnight and the deposition of the iron as oxide scales. As a consequence, the iron concentration associated with the initial draw is gradually increased as fresh water, with higher iron concentration, is drawn from the city main. Eventually, the iron concentrations measured at the tap do level off to normal background values.

Zinc: The highest zinc concentration was associated with the first 50 ml draw, representative of water sitting in the faucet (Figure 4-18). Subsequent flushing rapidly diluted the zinc concentration. Therefore, it is evident that the copper-zinc alloy used in the production of tap fixtures and other fittings is the primary source of contamination. These brass alloys may contain 40 to 50% zinc and any simple brass containing more than about 15% zinc is susceptible to "dezincification" (Cruse, 1985). Loss of zinc from brass is readily observed, since the corroded alloy is reddish or copper coloured rather than the normal yellow. Also, the presence of a large area of copper adjacent to a brass fixture may encourage dezincification; this occurs through a galvanic acceleration of the corrosion process, where by the less noble zinc component is sacrificed (Cruse, 1985).

4.2.6.2 Single-Family House Sampling

Lead: Figures 4-19 to 4-21 represent flushing trends associated with samples obtained from single-family houses. The general trend is very similar to that associated with high-rise sampling. Bottles COLD#1 and COLD#2 contained the highest lead concentrations. The lead contribution of these first 2 flushes (250 ml total volume) was again 47%. The subsequent third-flush (750 ml), contributed 44% of the lead. Therefore, in a 1-L first-flush sample, 9% of the lead can be attributed to background levels. In high-rise samples, the background lead contribution was 21% of the total in a 1-L first flush. Clearly, homeowners conducted sampling more carefully than high-rise tenants, who may have partially flushed their taps in a number of cases prior to obtaining samples.

Copper: Flushing of copper from copper plumbing systems in houses (Figure 4-20) closely parallels the trends observed in high-rise apartments. The highest copper concentration was associated with the second draw (250 ml). The flushing trend associated with plastic plumbing systems reveals that the faucet is not only a source of lead, but also of copper. As the tap is flushed, copper levels drop off well below those observed in copper plumbing systems.

Zinc: The rapid drop in zinc concentrations from bottles COLD#1 to COLD#4 clearly reveals leaching from the faucet. The flushing trend of zinc from both copper and plastic plumbing systems was identical. This is further evidence that the primary source of zinc is the faucet and not the piping.

HIGH-RISE APARTMENTS

Flushing Trends

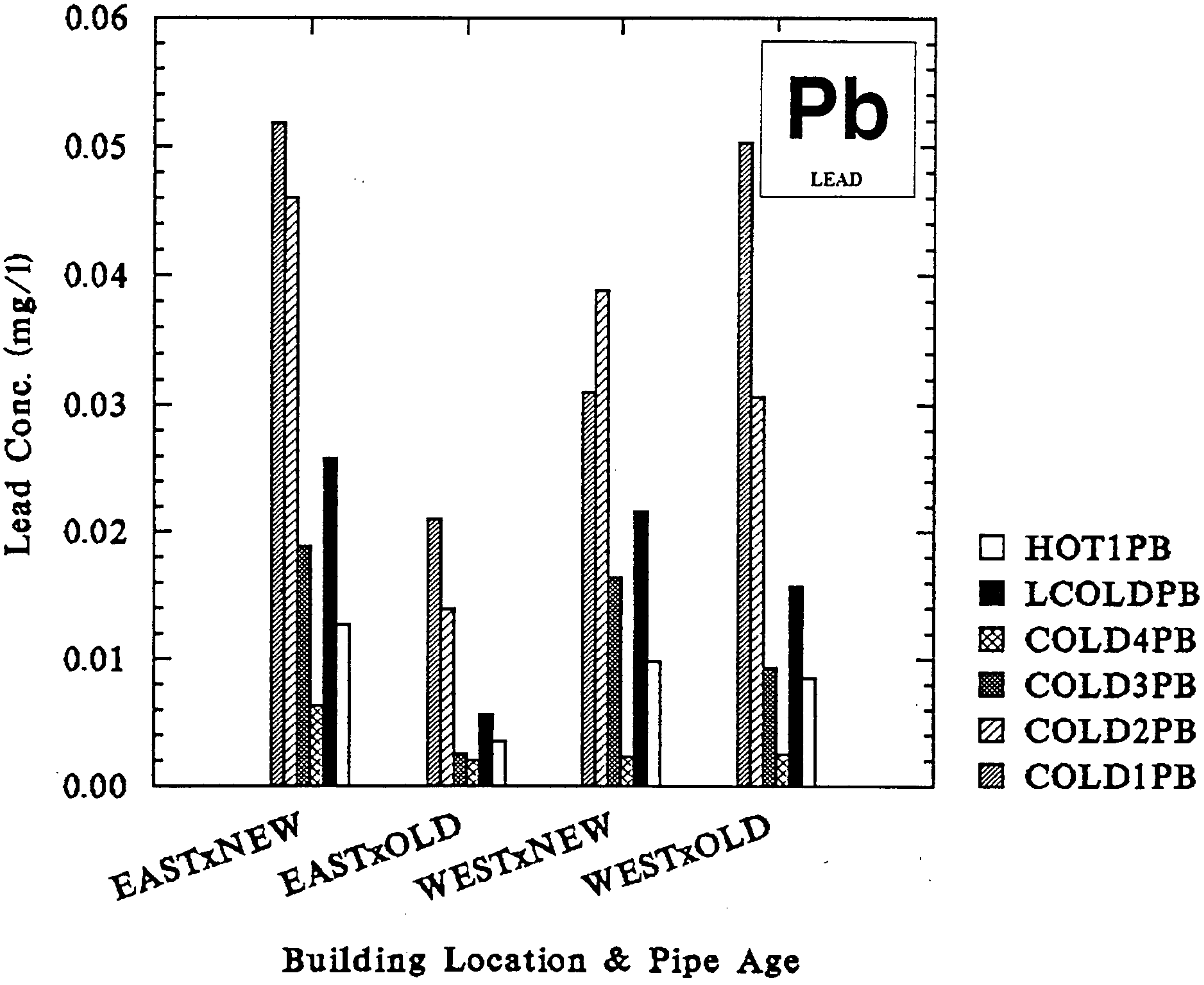


Figure 4-15. Flushing of Lead from Drinking Water Taps in High-Rises

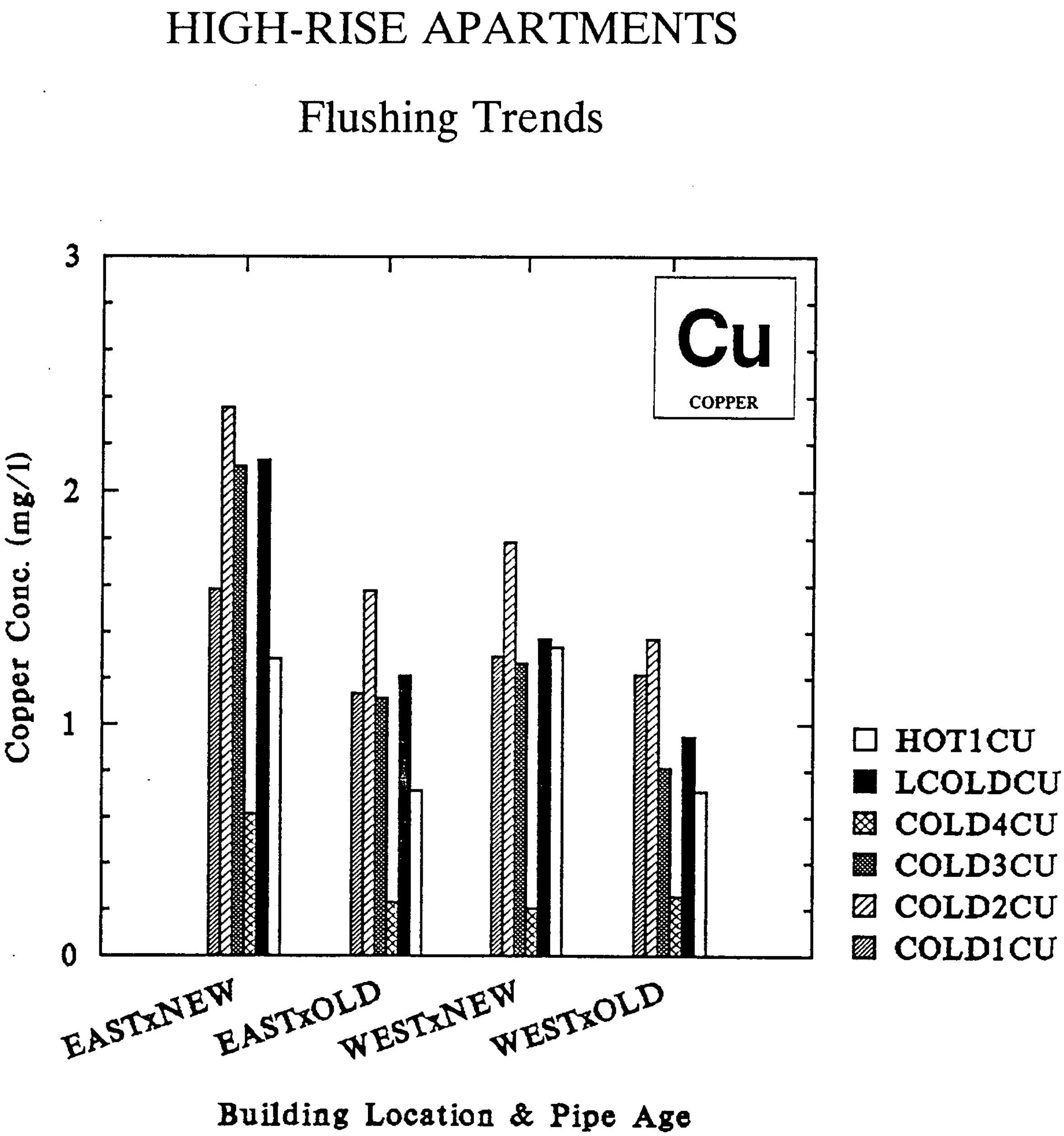
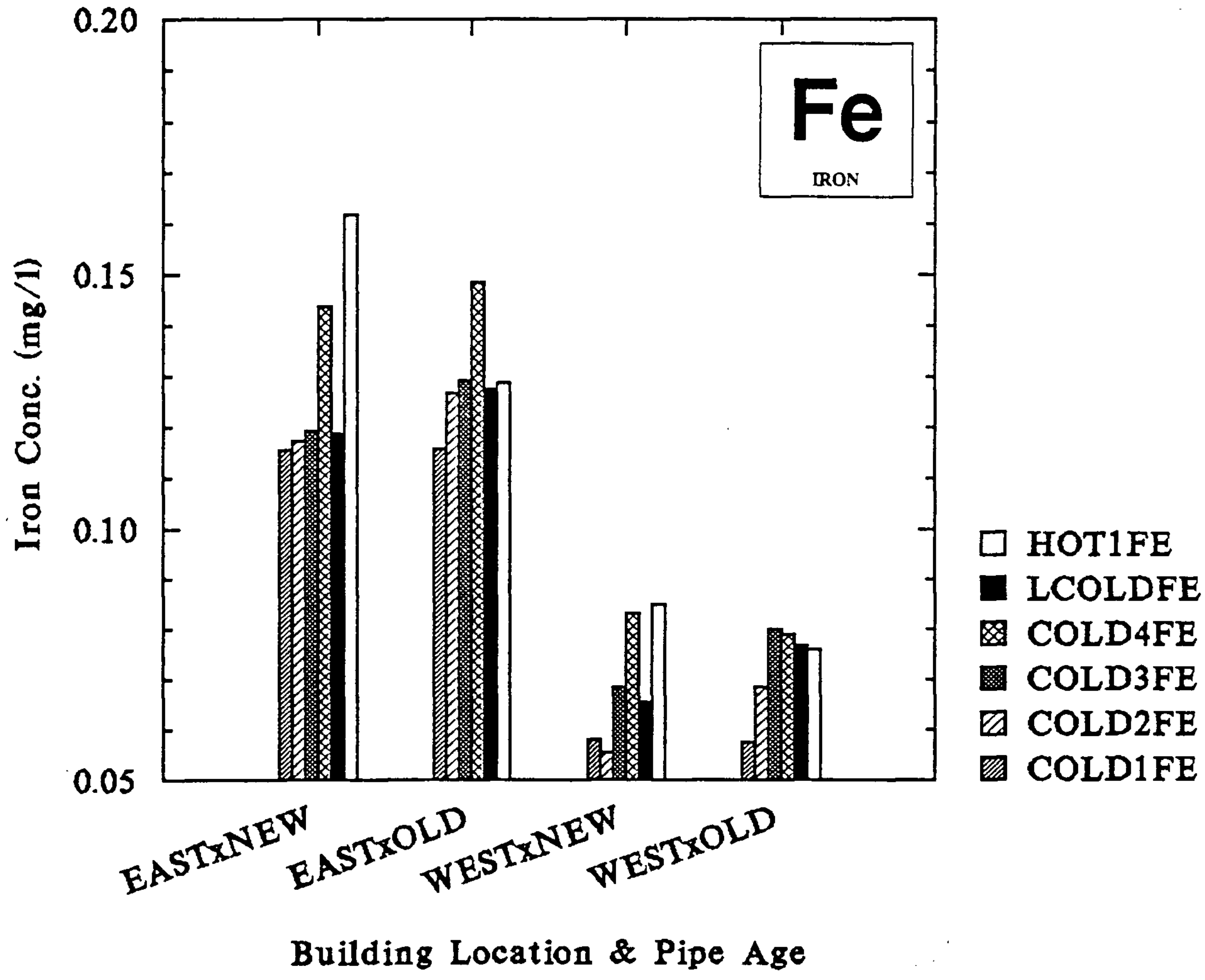


Figure 4-16. Flushing of Copper from Drinking Water Taps in High-Rises



HIGH-RISE APARTMENTS

Flushing Trends

Figure 4-17. Flushing of Iron from Drinking Water Taps in High-Rises

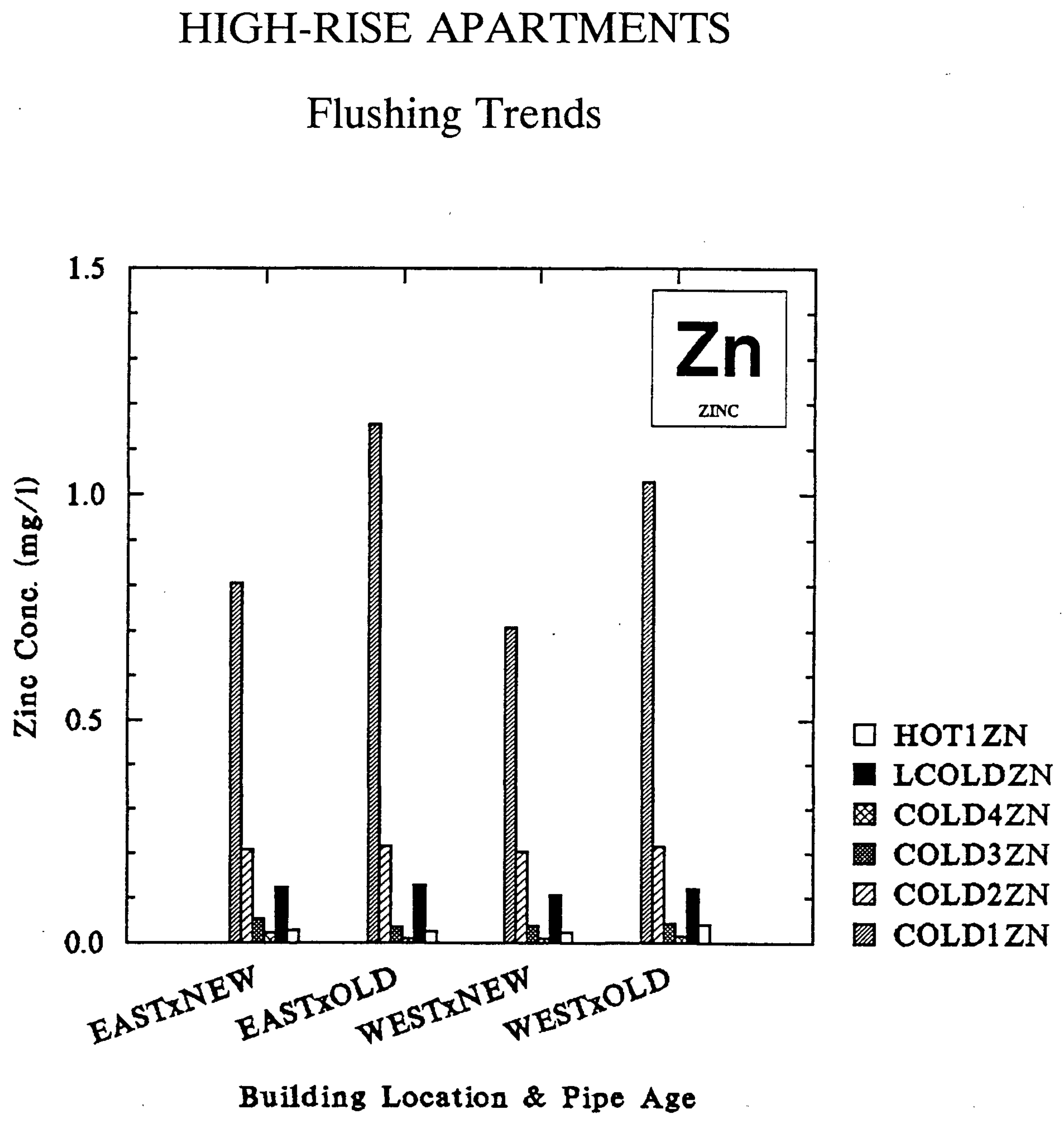
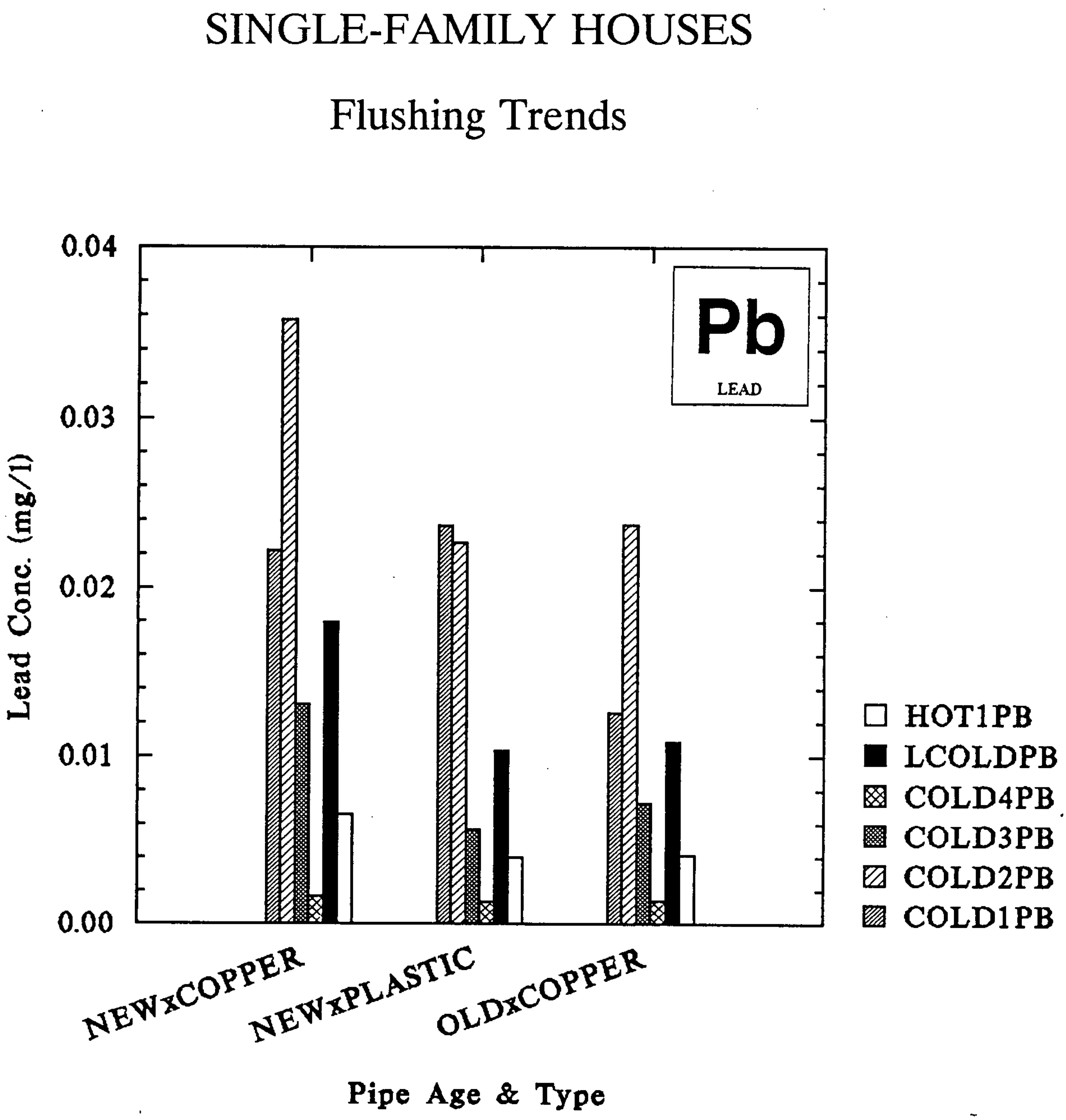


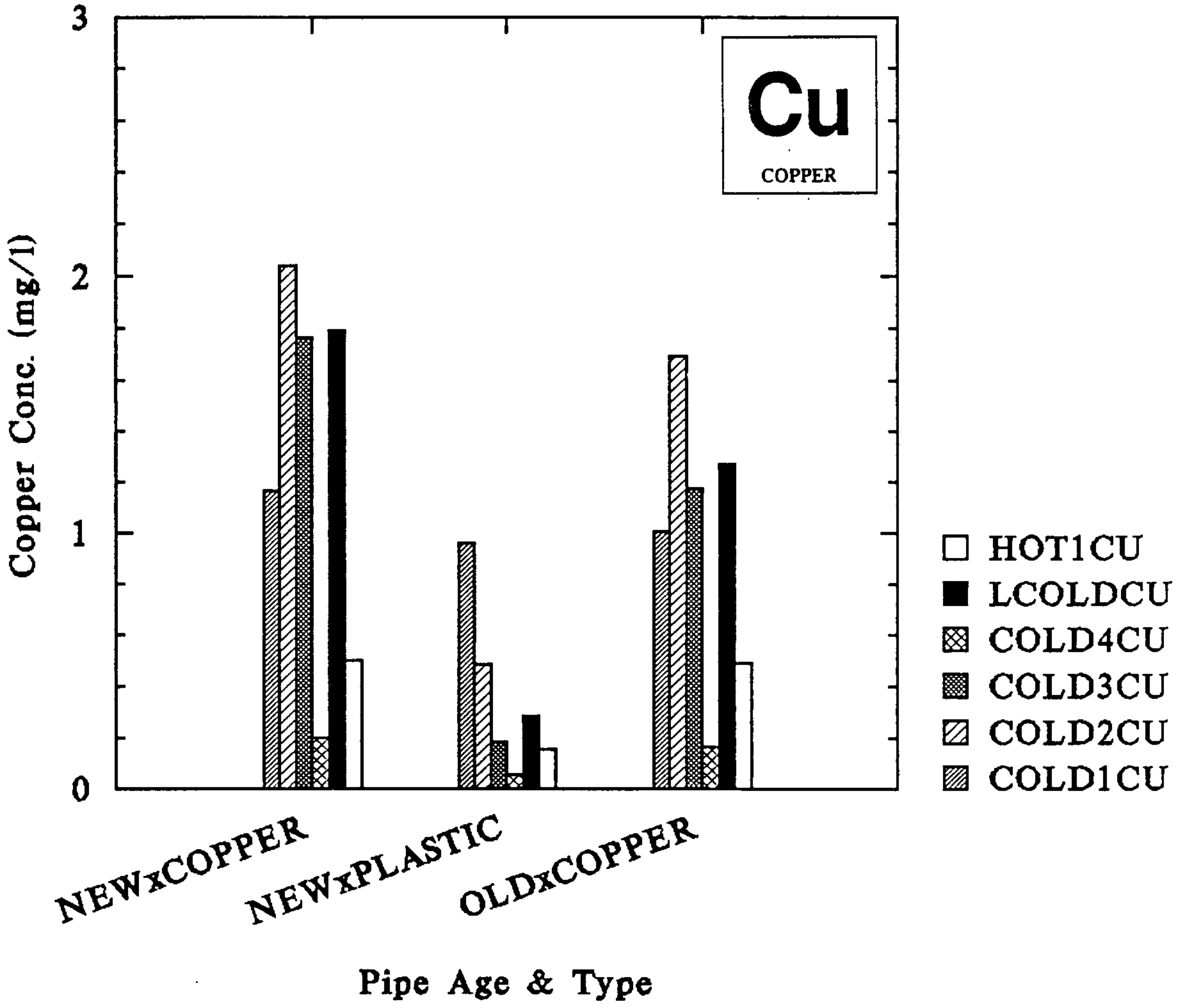
Figure 4-18. Flushing of Zinc from Drinking Water Taps in High-Rises



SINGLE-FAMILY HOUSES

Flushing Trends

Figure 4-19. Flushing of Lead from Drinking Water Taps in Single-Family Houses



SINGLE-FAMILY HOUSES

Flushing Trends

Figure 4-20. Flushing of Copper from Drinking Water Taps in Single-Family Houses

SINGLE-FAMILY HOUSES

Flushing Trends

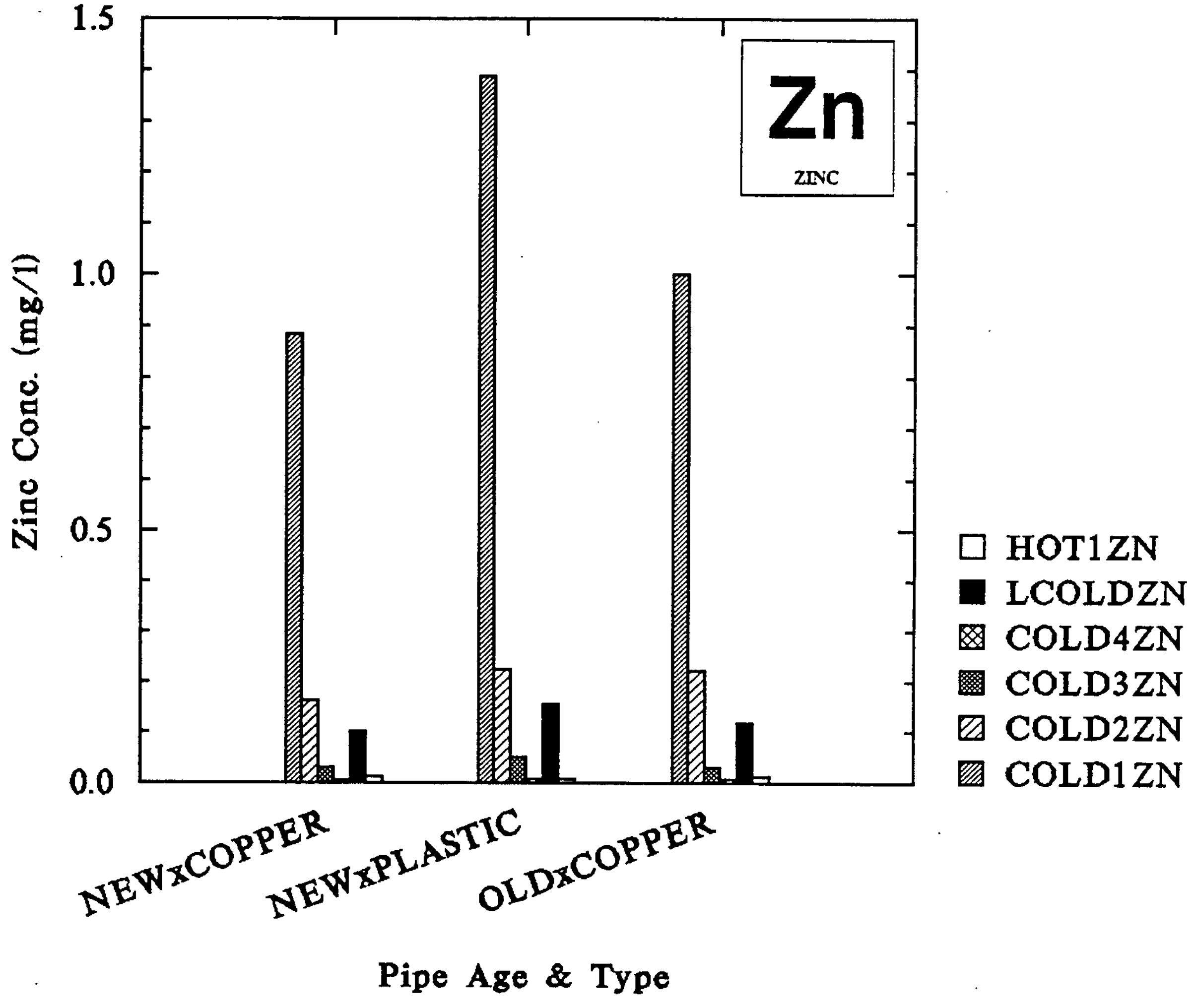


Figure 4-21. Flushing of Zinc from Drinking Water Taps in Single-Family Houses

4.3 Compliance Issues

Guidelines for Canadian Drinking Water Quality (1978), issued by Health and Welfare Canada, stipulates lead as a health related concern and the maximum acceptable concentration (MAC) is set at 0.05 mg/L (50 ug/L). The usefulness of these guidelines is severely limited, however, since the sampling protocol is not specified. It is unclear whether these limits apply to an absolute ceiling, or an average. Other questions left open include: Are samples to be taken from the consumers' tap, from the distribution system or at the source?; Do these guidelines require first-flush standing samples?; If so, for how long?. Also, sample size is not fixed; it is clear from Table 4-3 that this will dramatically effect lead levels measured in the water.

The 1989 Canadian guidelines have just been released and a new MAC (Maximum Acceptable Concentration) of 0.01 mg/L has been proposed for lead. This proposal requires faucets to be thoroughly flushed before water is taken for consumption or analysis. Presently, USEPA Drinking Water regulations are better formulated and will be used to evaluate sample results in this study.

EPA standards specify a 1-L first-flush overnight standing sample from the consumers' tap. Samples must be collected from a cold-water kitchen tap and must represent water that has stood in the service line and plumbing for 8 to 18 hours (Pontius, 1990). Maximum contaminant levels (MCLs) are currently set at 0.05 mg/L for lead, 1.0 mg/L for copper, 0.3 mg/L for iron and 5.0 mg/L for zinc. Current regulations are under review and proposed is the new "Lead & Copper rule" and "no-action levels" for lead and copper. Based on the sample results for one year, a water system is in compliance and will require no action if:

1) the average lead level is less than or equal to 0.01 mg/L,
2) no more than 5 percent of samples contain more than 1.3 mg/L of copper, and
3) no more than 5 percent of samples have a pH less than 8.0.

Currently, copper is an aesthetic concern, with limits set at 1.0 mg/L. Consideration is being given to upgrade this to a 1.3 mg/L health related maximum level. Publication of the final lead and copper rule is scheduled for November, 1990 (Pontius, 1990).

Table 4-3. Percentage of Cold Flush Samples Exceeding EPA Maximum Contaminant Levels.

MCL (mg/L)	Lead 0.05	Lead[1] 0.01	Copper 1.0	Iron 0.3	Zinc 5.0
High-Rise Apartment Buildings[2]					
Cold#1 (50 ml)	22	78	68	0	0
Cold#2 (200 ml)	20	61	74	1	0
Cold#3 (750 ml)	9	38	55	1	0
Cold#4 (Running)	3	6	9	0	0
LCOLD (1000 ml)	15	43	62	1	0
Single-Family Houses[3]					
Cold#1 (50 ml)	5	45	42	N/A	0
Cold#2 (200 ml)	15	70	90	N/A	0
Cold#3 (750 ml)	0	32	58	N/A	0
Cold#4 (Running)	0	0	0	N/A	0
LCOLD (1000 ml)	0	47	73	N/A	0

[1] EPA proposed maximum average lead level (based on a 1-L first-flush, this is not an MCL value)

[2] Sampled from 72 individual suites located in 12 high-rise buildings (representing the worst case of 3 sampling runs)

[3] Sampled from 60 individual homes (randomly chosen)

In reviewing Table 4-3, it must be noted that individual lead results are being compared to the 0.01 mg/L "no-action level" for lead. Compliance with the proposed 0.01 mg/L regulatory limit would be based on the average of a large number of samples. The population served by the water system determines the number of samples to be taken and the frequency of monitoring. The purpose of Table 4-3 is to reveal the percentage of individual cases exceeding the proposed "no-action" lead levels and does not necessarily imply that GVRD water would be noncompliant for lead under the new rule. GVRD tap water samples which exceed MCL values, however, would be in noncompliance.

Based on a 1-L first-flush sample, 15% of the high-rise samples exceeded the current 0.05 mg/L MCL level for lead and 43% exceeded the proposed limit of 0.01 mg/L. One litre, first-flush samples, taken from single-family houses, were all below the 0.05 mg/L limit for lead; however, 47% would exceed the proposed 0.01 mg/L level. The average lead concentration of all samples taken from 72 high-rise suites and 60 single-family houses was 0.020 and 0.013 mg/L, respectively (Table 4-2).

The secondary standard for copper of 1.0 mg/L was exceeded in 62% of the high-rise samples and 73% of the single-family house samples.

Only 1% of the high-rise samples exceeded the MCL for iron and all single-family house samples were in compliance. Zinc concentrations were well within acceptable levels for both building types.

Therefore, this sampling program indicates that the GVRD water supply may not comply completely with acceptable lead and copper levels in drinking water based on an

EPA sampling protocol. An alternative to treatment of the water supply to comply with regulatory guidelines, might be to encourage the public not to drink first-flush tap water. This may safeguard dwellers of single-family houses; however, there is still a concern for those living in high-rise apartments. This sampling program has shown that 3% of high-rise samples exceeded the 0.05 mg/L lead level and 6% exceeded the 0.01 mg/L proposed "no-action level" for lead in the "running" cold sample bottle. Also, the "running" cold sample exceeded the 1.0 mg/L MCL for copper in 9% of the high-rise samples. This indicates that flushing may not be the final solution to achieving acceptable lead and copper levels in specific high-rise apartment towers.

4.4 Water Quality Sampling Program Questionnaire

In conjunction with the sampling bottles, a questionnaire was distributed to high-rise tenants and residents of single-family houses. The purpose of this questionnaire was to evaluate the consumer practices of water users and determine plumbing impacts. Conclusions are based on a return of 48 questionnaires from high-rise tenants and 56 from houses and results have been summarized in Table 4-4.

The survey showed that high-rise dwellers have a much greater concern for the purity of their tap water than those living in houses. Thirteen percent of high-rise tenants indicated that they utilized a water purification device on their taps, compared with only 2% of house residents. In high-rise apartments, 69% of the tenants indicated that they flushed the tap for more than 30 seconds prior to drinking from it (Figure 4-22). In single-family houses, this value was 45%. This did not seen to influence the number of glasses consumed by high-rise tenants in an average day; only 21% consumed 2 glasses or less (Figure 4-23).

Tap water testing had shown significantly higher concentrations of lead and copper in the hot water line. This survey showed that 40% of high-rise tenants and 38% of house residents do obtain drinking water (for tea kettle or cooking) from the hot water tap. Although the quantity of water used for such purposes is relatively small, the hot water should not be used for consumption.

It can be seen that blue/green staining of porcelain fixtures and tiles was very prevalent; 85% of high-rise tenants and 70% of house dwellers indicated staining problems. Also, those surveyed from high-rises (particularly new buildings) responded with severe staining complaints.

People were also questioned on whether they could detect a metallic aftertaste in their tap water. A positive response was obtained from 35% of high-rise tenants and 13% of house dwellers. The higher percentage associated with high-rise dwellers is probably related to the greater severity of copper staining problems in high-rise towers.

It was also questioned, as to whether a brown-coloured discharge was noticed when opening the tap first thing in the morning. A positive response was obtained from 17% of high-rise tenants and 16% of house dwellers. In most of the positive cases, this problem was only noticeable after the taps were left stagnant for a long time period (ie. over the weekend).

Table 4-4. Water Quality Sampling Program Questionnaire: Percent Positive Response.

	High-Rise	House
Do you utilize a water purification device on your drinking water tap?	13	2
Do you let your water run prior to drinking it?	92	91
Have you ever used the hot water tap to obtain drinking water (tea kettle or other)?	40	38
Do you have problems with blue/green staining of porcelain fixtures and tiles?	85	70
Does your tap water have a metallic aftertaste?	35	13
Do you notice a brown-coloured discharge when opening your taps 1st thing in the morning?	17	16

[1] Based on 48 respondents from high-rise buildings and 56 respondents from single-family houses.

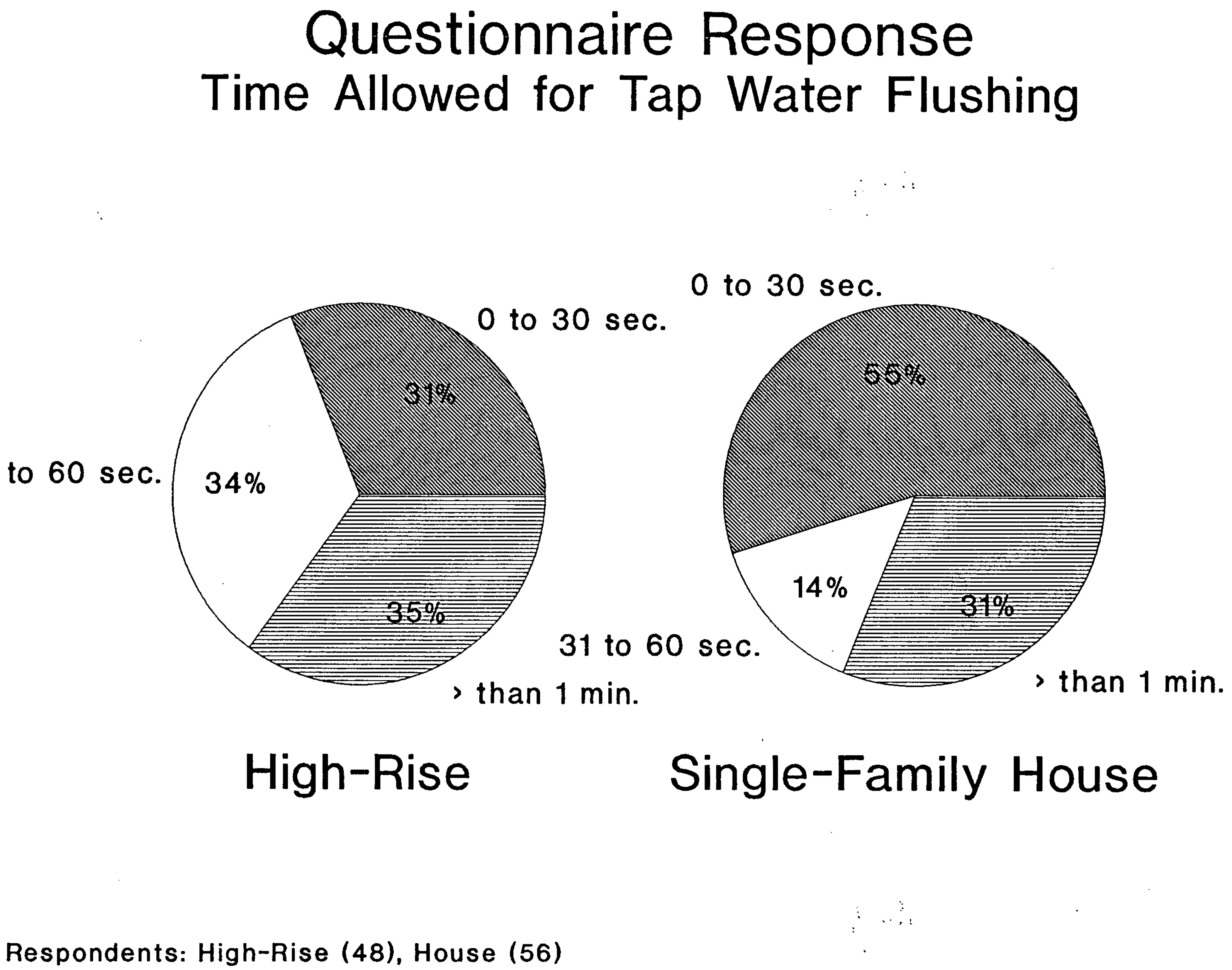


Figure 4-22. Questionnaire Response: Time Allowed for Tap Water Flushing

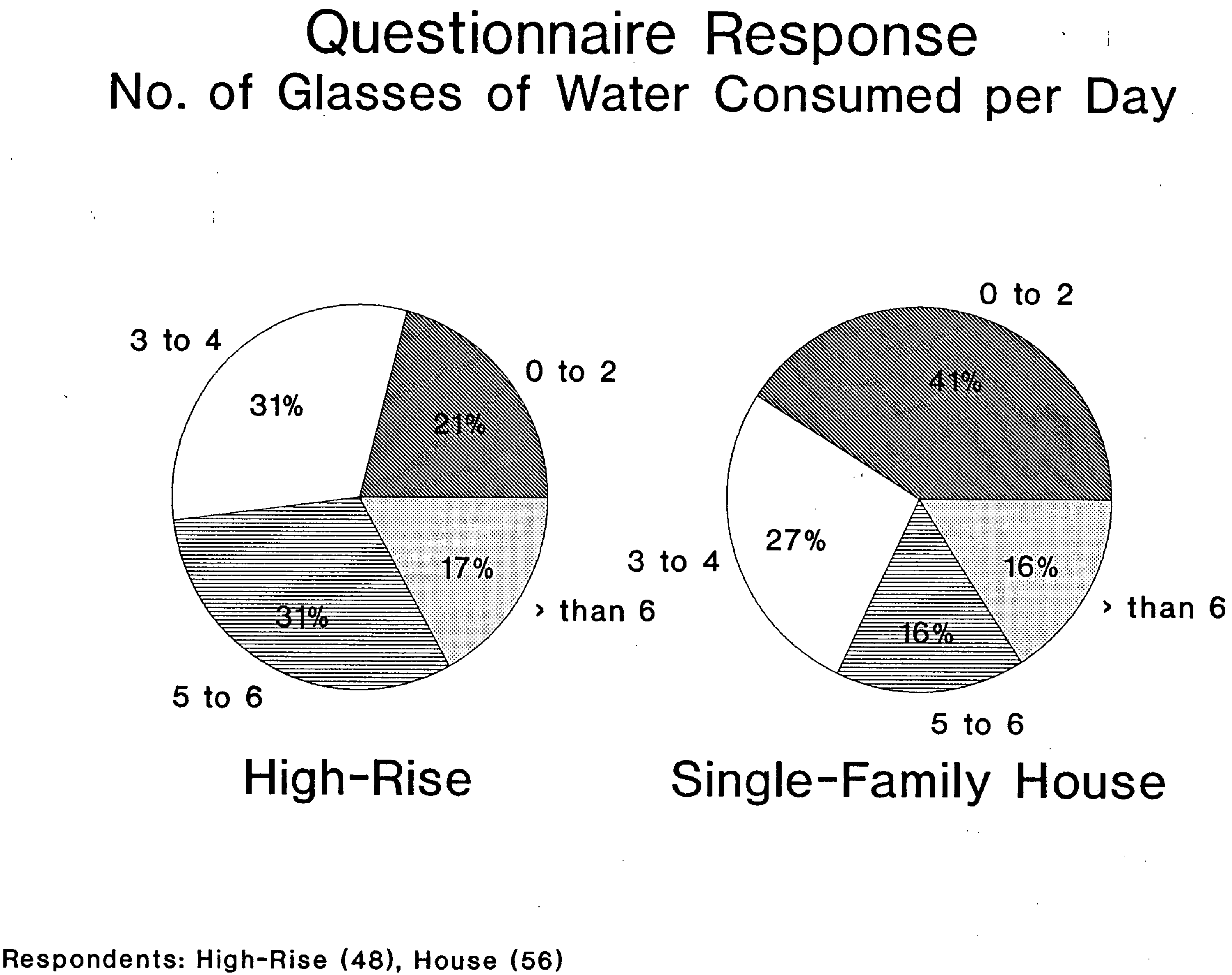


Figure 4-23. Questionnaire Response: No. of Glasses of Water Consumed per Day

5. SUMMARY AND CONCLUSIONS

5.1 Major Findings

The main purpose of this study was to determine the correlation of a limited number of key factors on the trace metal concentrations measured in drinking water samples obtained from high-rise apartments and single-family houses. This study did not determine the processes which were producing these metal levels, but the various possible processes are reviewed in Section 2.1.

Corrosion mitigation has also been reviewed, but again, this report is not intended to recommend treatments for the Greater Vancouver water supply. However, Section 2.2 shows that water treatment must be undertaken carefully, since some chemical treatments may have adverse corrosion effects on specific metals. It is advisable to conduct a thorough pilot scale investigation, to determine the effective dosage and type of chemicals to be used on a specific water supply.

In 1-L cold, first-flush water samples, taken within the Greater Vancouver Regional District, it was determined that there was no statistical significance between the mean metal concentrations of lead, copper, iron and zinc measured from high-rise, compared to low-rise suites. Iron concentrations measured in East high-rises were significantly greater than those detected in the West, for 1-L cold first-flush and running hot water samples. This was probably a reflection of the higher levels of iron in the source water supplying buildings in the East.

Plumbing AGE did not appear to be significant in effecting zinc concentrations; however, AGE did strongly affect copper measured in cold water samples taken from single-family houses. Newer homes resulted in higher concentrations. Analysis of the running hot water samples revealed that AGE was very significant in contributing to elevated lead and copper levels in high-rise buildings. The hot water recirculation system, utilized by most apartment towers, appeared to accelerate corrosion rates.

Houses with plastic, as opposed to copper plumbing systems, had a very significant reduction in copper measured in the cold and hot water, while lead and zinc levels did not show a significant difference. The potential for lead contamination was found to be much greater in high-rise apartments suites, in general, as compared to single-family houses, for both the 1-L first-flush cold and running hot sample. Also, very high copper concentrations were measured in the hot water supply of high-rise buildings, due primarily to high boiler temperatures, lengthy contact times, and hot water recirculation.

In high-rise apartments, lead-tin solder and brass fixtures contributed to most of the lead leached into drinking water. On average, the first 250 ml of water drawn from the cold tap contributed 47% of the lead and the next 750 ml contributed 32% of the lead measured in the 1-L first-flush sample. As much as 24% of the 1-L first-flush copper was contributed by background levels. This background copper in "running" samples was much higher than concentrations measured in the GVRD mains. It appears that city water flowing through apartment building plumbing readily picks up copper; therefore, flushing of taps in high-rise apartments may only be partially effective in reducing copper levels. The majority of zinc contamination was from the faucets, as shown by a 70%

contribution made by the first 250 ml of sample. Tap water flushing results for single-family houses closely resembled those from high-rise buildings.

Current Canadian Drinking Water Guidelines are ambiguous; therefore, 1-L first-flush samples were compared with the current and proposed USEPA Drinking Water Regulations. Compliance with the proposed EPA 0.01 mg/L regulatory limit for lead is based on a sample average. Individual samples may exceed this value and still be in compliance. For both high-rises and single-family houses, iron and zinc pose no regulatory concerns. Under the current MCL of 0.05 mg/L for lead, 15% of high-rise samples exceeded this value; however, all single-family house samples complied. Under the proposed 0.01 mg/L "no-action level" for lead, 43% of high-rise samples and 47% of house samples exceeded the recommended concentration. The average lead concentration for all high-rise samples was 0.020 mg/L and, for house samples, 0.013 mg/L. The secondary MCL for copper of 1.0 mg/L was exceeded in 62% of the high-rise and 73% of the house samples. It should be noted that flushing of the drinking water taps in high-rise suites did not achieve totally acceptable levels of lead and copper; 3% still exceeded the 0.05 mg/l limit for lead and 9% still exceeded the 1.0 mg/l limit for copper.

Sample testing has revealed that first-flush samples exceed acceptable limits for lead and copper in a significant percentage of cases, particularly in high-rise buildings. The response to the survey questionnaire echoes these findings. In high-rise buildings, 85% of people surveyed indicated problems with blue-green staining. A metallic aftertaste associated with their tap water was reported by 35% of respondents. Taste and staining problems are a reflection of excessive levels of copper

5.2 Recommendations for Future Research

Corrosion of metal distribution systems by aggressive water has been extensively investigated, yet there are still many unanswered questions. Contradictory results are common in the literature and there is the need to clarify these discrepancies through more studies. Contributing to this confusion is the fact that the mechanisms of corrosion are complex and vary with a large number of physical, chemical, and biological parameters. In order to mitigate against the deleterious attack on the materials of concern, the factors affecting corrosion must be identified and investigated both under laboratory and field conditions. The following are suggestions for research areas needing further investigation, given the findings of this report:

1) Determination of whether chloramine disinfection results in reduced metal dissolution compared with maintaining a free chlorine residual.

2) Sampling of a more comprehensive range of buildings to determine the relative levels of metal contamination from different plumbing systems. Hospitals, schools, office towers, as well as houses and apartments, should be sampled using a standard sampling protocol.

3) Seasonal effects of water quality changes on metal levels detected in the consumer's drinking water should be studied.

4) A detailed investigation of factors that initiate pitting at the surface of copper tubing. Carbon deposits, corrosion products, lubricant residuals, scratches, and metal impurities

all contribute to pit initiation and propagation. The significance of each of these factors and the importance of manufacturing defects needs investigation.

5) The contribution of lead from brass, bronze, and the faucet materials needs further investigation. The effect of lead solubility control practices and important water chemistry variables on lead leaching from different components of the water distribution system needs study.

6) The formation of protective films of metal oxides, oxyhydroxides, carbonates, phosphates and other solids should be investigated. In low alkalinity waters, where treatment is necessary to provide protection, this information would be valuable.

7) Methods should be developed for preconditioning newly installed copper plumbing systems to minimize the potential health risks associated with the consumption of water containing excessive trace metal concentrations. For example, pipe materials could be treated by the manufacturer, or after installation, to form protective films on the surface.

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APPENDIX A

SAMPLING INSTRUCTIONS & QUESTIONNAIRES

environmental
engineering
ubc

January 02, 1990.

Dear Sir or Madam,

At the University of British Columbia, we are undertaking a water quality sampling program. The major purpose of this study is to examine the corrosion effects of "standing water" in household plumbing systems.

Sampling kits with instructions will be delivered prior to the sampling dates of Jan. 09 and Jan. 11. Sampling must be carried out first thing in the morning and will take no longer than 8 minutes.

Also, one site visit will be required at a time most convenient to you. Your co-operation in this study will be much appreciated.

Yours Truly,

I. Singh
Graduate Student
Dept. of Civil Engineering, UBC

Instructions for Corrosion Study Sampling

Purpose

The major purpose of this study is to examine the corrosion effects of "standing water" in household plumbing systems.

General Guidelines

Step #1

As the purpose of the study is to monitor "standing water" under worst case conditions please try not to use any water after retiring on the eve of sampling (ie. no flushing of toilets or running water in the middle of the night).

Step #2

Sampling must be done first thing in the morning after the water has sat during the night in the plumbing. It is most imperative that no other water is run before this sampling. This means grab the samples before flushing any toilet, running the 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 purposes of the study.

Step #3

	The Sampling Kit contains **5** bottles:	
for Cold Water--	Cold #1	125 mls size
	Cold #2	250 mls size
	Cold #3	1 litre size
	Cold #4	125 mls size
for Hot Water---	Hot #1	125 mls size

Sampling

All samples are to be taken from the kitchen tap first thing in the morning.

1) Lay bottles out on the counter in order, ready to take samples: Cold #1, Cold#2, Cold#3, Cold#4 and then Hot #1.

2) Take bottle Cold#1 and have bottle Cold #2 and Cold#3 ready with the caps off. Place bottle Cold #1 under tap and slowly turn the cold water on.

3) Immediately as Cold #1 is filled to the mark switch to bottle Cold #2 and fill this bottle to the mark, followed by bottle Cold #3. Don't allow any of this first flow to miss the first three bottles.

Continued next page...

APPENDIX B

HIGH-RISE CROSS-CHECKS

First Set of Highrise Apartment Metals Cross-Check

Lab.#: 890963												
Project Name: Apartment Hi Rise Study Cross Checks												
Date Received: 89/11/14												
Abstract: First set of samples for cross checks from Inder Singh												
(all results mg/L)												
		GVRD	Inder		GVRD	Inder		GVRD	Inder		GVRD	Inder
Apartment	Sample	Copper	Copper		Iron	Iron		Lead	Lead		Zinc	Zinc
1-W1-0201	-C1	1.31	1.31		0.05	0.05		0.014	0.015		0.78	0.85
	-C2	2.15	2.32		0.06	0.07		0.011	0.023		0.22	0.24
	-C3	0.49	0.48		0.59	0.61		<0.005	<0.010		0.04	0.04
	-C4	0.11	0.09		0.24	0.21		<0.005	<0.010		<0.01	<0.02
	-H1	1.65	1.85		0.12	0.10		0.009	0.010		0.02	0.02
1-W4-0505	-C1	1.56	1.59		0.05	0.04		0.37	0.40		0.88	0.94
	-C2	2.06	2.21		0.05	0.04		0.17	0.18		0.27	0.29
	-C3	1.45	1.50		0.06	0.06		0.026	0.022		0.02	0.02
	-C4	0.24	0.24		0.07	0.09		0.005	<0.010		<0.01	<0.02
	-H1	0.85	0.97		0.07	0.09		0.020	0.017		0.02	0.02
1-W4-0606	-C1	3.30	3.33		0.12	0.11		0.36	0.37		1.46	1.46
	-C2	1.53	1.62		0.34	0.34		0.086	0.099		0.15	0.16
	-C3	0.59	0.60		0.23	0.22		0.068	0.076		0.06	0.07
	-C4	0.35	0.35		0.08	0.09		0.15	0.16		0.02	0.02
	-H1	0.75	0.83		0.08	0.08		0.010	0.016		0.13	0.14
1-W7-0308	-C1	1.52	1.57		0.05	0.05		0.053	0.051		0.52	0.57
	-C2	2.75	2.92		0.06	0.04		0.088	0.095		0.25	0.25
	-C3	1.76	1.85		0.07	0.06		0.042	0.042		0.04	0.04
	-C4	0.20	0.21		0.07	0.09		<0.005	<0.010		0.02	<0.02
	-H1	1.40	1.55		0.07	0.05		0.014	0.017		0.03	0.03
1-E1-2601	-C1	1.23	1.26		0.15	0.16		0.008	<0.010		0.23	0.25
	-C2	2.78	2.95		0.09	0.09		0.011	0.012		0.21	0.23
	-C3	3.13	3.18		0.08	0.09		<0.005	<0.010		0.05	0.05
	-C4	0.57	0.59		0.14	0.15		<0.005	<0.010		0.01	<0.02
	-H1	0.50	0.56		0.10	0.11		<0.005	<0.010		0.03	0.03

1-E2-1904	-C1	1.28	1.32		0.07	0.07		0.067	0.070		1.81	1.90
	-C2	2.48	2.63		0.08	0.08		0.076	0.087		0.29	0.32
	-C3	1.89	1.95		0.10	0.08		0.020	0.023		0.06	0.06
	-C4	0.22	0.22		0.14	0.13		<0.005	<0.010		0.01	<0.02
	-H1	1.00	1.17		0.15	0.16		0.014	0.013		0.03	0.03
1-E3-0103	-C1	0.94	0.98		0.10	0.10		0.040	0.044		1.56	1.65
	-C2	2.02	2.12		0.10	0.10		0.054	0.059		0.26	0.28
	-C3	2.05	2.11		0.11	0.11		0.015	0.008	<-	0.07	0.07
	-C4	0.13	0.13		0.12	0.11		<0.005	<0.010		0.03	0.03
	-H1	1.49	1.76	<-	0.11	0.13		0.020	0.017		0.04	0.04
1-E5-0301	-C1	1.97	2.03		0.07	0.06		0.042	0.039		0.92	0.99
	-C2	2.93	3.04		0.08	0.08		0.068	0.069		0.23	0.25
	-C3	3.42	3.43		0.12	0.07		0.016	0.009	<-	0.03	0.03
	-C4	0.31	0.32		0.11	0.11		0.005	<0.010		0.03	<0.02
	-H1	1.41	1.62	<-	0.12	0.14		0.019	0.012	<-	0.03	0.02

Lab.#: 891034

Project Name: Apartment Hi Rise Study Cross Checks

Date Received: 89/12/05

Abstract: Second set of samples for cross checks from Inder Singh.

(all results mg/L)

		GVRD	Inder		GVRD	Inder		GVRD	Inder		GVRD	Inder	
Apartment	Sample	Copper	Copper		Iron	Iron		Lead	Lead		Zinc	Zinc	
2-W1-1850	-C1	1.49	1.53		0.04	0.04		0.094	0.087		1.25	1.34	
	-C2	2.50	2.58		0.04	0.04		0.19	0.18		0.52	0.57	
	-C3	1.72	1.75		0.06	0.07		0.064	0.062		0.12	0.12	
	-C4	0.17	0.18		0.07	0.08		<0.005	<0.010		<0.01	<0.02	
	-H1	0.74	0.74		0.07	0.09		0.016	0.021		0.03	0.03	
2-W2-2401	-C1	1.60	1.67		0.05	0.04		0.19	0.17		0.13	0.14	
	-C2	2.85	2.95		0.04	<0.04		0.18	0.17		0.25	0.27	
	-C3	0.30	0.29		0.08	0.09		0.027	0.027		0.03	0.03	
	-C4	0.18	0.17		0.07	0.08		<0.005	<0.010		<0.01	<0.02	
	-H1	0.63	0.64		0.06	0.07		0.014	0.017		0.03	0.03	
2-W4-0504	-C1	1.08	1.10		0.06	0.07		0.27	0.28		3.08	3.04	
	-C2	2.60	2.75		0.08	0.06		0.31	0.31		1.57	1.64	
	-C3	1.06	1.09		0.13	0.07		0.064	0.064		0.18	0.19	
	-C4	0.18	0.16		0.08	0.13		0.012	0.015		0.01	<0.02	
	-H1	0.88	0.91		0.07	0.08		0.035	0.031		0.07	0.07	
2-W4-3106	-C1	1.51	1.56		0.08	0.07		0.027	0.031		0.66	0.66	
	-C2	2.30	2.43		0.06	0.05		0.040	0.042		0.09	0.10	
	-C3	0.85	0.87		0.07	0.07		0.013	0.017		0.03	0.03	
	-C4	0.15	0.14		0.07	0.07		<0.005	<0.010		<0.01	<0.02	
	-H1	0.55	0.55		0.10	0.09		0.009	0.010		0.04	0.03	
2-W6-0301	-C1	1.05	1.09		0.06	0.12	<-	<0.005	<0.010		0.03	0.55	<-
	-C2	0.79	0.80		0.06	0.06		<0.005	<0.010		0.02	0.02	
	-C3	0.58	0.58		0.07	0.08		<0.005	<0.010		0.01	<0.02	
	-C4	0.10	0.10		0.08	0.06		<0.005	<0.010		<0.01	<0.02	
	-H1	1.35	1.42		0.05	<0.04		<0.005	<0.010		0.01	<0.02	

Second Set of Highrise Apartment Metals Cross-Checks

		GVRD	Inder		GVRD	Inder		GVRD	Inder		GVRD	Inder	
Apartment	Sample	Copper	Copper		Iron	Iron		Lead	Lead		Zinc	Zinc	
2-W7-0308	-C1	1.69	1.72		0.05	0.05		0.054	0.051		0.85	0.86	
	-C2	2.88	2.98		0.05	0.06		0.094	0.084		0.3	0.30	
	-C3	1.79	1.87		0.07	0.07		0.050	0.048		0.03	0.04	
	-C4	0.18	0.17		0.08	0.07		<0.005	<0.010		<0.01	<0.02	
	-H1	1.27	1.32		0.07	0.06		0.011	0.014		0.01	0.02	
2-W7-1703	-C1	2.13	2.20		0.06	0.06		0.096	0.091		0.77	0.81	
	-C2	3.14	3.22		0.05	0.04		0.062	0.063		0.07	0.07	
	-C3	2.12	2.21		0.07	0.05		0.026	0.023		0.03	0.04	
	-C4	0.15	0.15		0.08	0.07		0.005	<0.010		<0.01	<0.02	
	-H1	1.33	1.36		0.08	0.08		0.013	0.013		0.05	0.05	
2-E3-1602	-C1	1.34	1.36		0.08	0.08		0.033	0.027		0.88	0.92	
	-C2	2.09	2.13		0.10	0.10		0.14	0.14		0.35	0.36	
	-C3	2.51	2.56		0.09	0.08		0.072	0.069		0.08	0.08	
	-C4	0.27	0.27		0.14	0.15		<0.005	<0.010		<0.01	0.02	
	-H1	1.32	1.35		0.14	0.14		0.019	0.017		0.04	0.04	
2-E5-0201	-C1	2.58	2.60		0.07	0.07		0.35	0.35		0.46	0.49	
	-C2	1.52	1.55		0.08	0.09		0.015	0.014		0.03	0.03	
	-C3	1.54	1.57		0.08	0.08		0.014	0.013		0.02	0.02	
	-C4	1.50	1.54		0.09	0.09		0.006	<0.010		<0.01	<0.02	
	-H1	0.83	0.84		0.13	0.15		0.024	0.027		0.03	0.03	

Lab.#: 891088 | Date Sampled: 89/12/22

Project Name: Apartment Hi Rise Study Cross Checks

Date Received: 89/12/22

Abstract: Third set of samples for cross checks for Inder Singh at UBC.
Samples are from a study he is doing of corrosion in hi-rises.

(all results mg/L)

		GVRD Copper	Inder Copper		GVRD Iron	Inder Iron		GVRD Lead	Inder Lead		GVRD Zinc	Inder Zinc
3-W1-0402	-C1	1.22	1.21		0.06	0.06		0.013	0.014		1.32	1.35
	-C2	2.04	2.07		0.08	0.07		0.017	0.017	->	0.20	0.25
	-C3	1.86	1.91		0.08	0.06		0.008	0.008		0.05	0.06
	-C4	0.18	0.17		0.09	0.08		<0.005	<0.005		<0.01	<0.02
	-H1	1.93	2.03		0.08	0.08		0.009	0.009		0.02	0.02
3-W1-1850	-C1	1.47	1.47		0.07	0.06		0.023	0.023		1.02	1.07
	-C2	2.29	2.32		0.06	0.05		0.17	0.179	->	0.65	0.75
	-C3	2.11	2.17		0.07	0.06		0.064	0.062		0.07	0.08
	-C4	0.21	0.20		0.08	0.07		<0.005	<0.005		<0.01	<0.02
	-H1	0.80	0.82		0.08	0.09		0.014	0.012		0.02	0.02
3-W3-0701	-C1	1.20	1.20		0.06	0.06		0.013	0.015		0.74	0.79
	-C2	1.22	1.23		0.07	0.07		0.006	0.005		0.12	0.14
	-C3	0.35	0.33		0.08	0.09		<0.005	<0.005		0.03	0.04
	-C4	0.11	0.11		0.08	0.07		<0.005	<0.005		<0.01	<0.02
	-H1	0.75	0.78		0.06	0.06		0.006	0.005		0.05	0.06
3-W4-0505	-C1	1.99	2.05		0.06	0.06		0.38	0.412		0.48	0.52
	-C2	0.71	0.72		0.08	0.08		0.031	0.031		0.03	0.04
	-C3	0.47	0.48		0.08	0.08		0.014	0.012		<0.01	<0.02
	-C4	0.31	0.31		0.08	0.07		<0.005	<0.005		<0.01	<0.02
	-H1	0.76	0.75		0.25	0.29		0.023	0.024		0.02	0.02
3-W5-0306	-C1	0.92	0.91		0.07	0.07		0.007	0.008		0.50	0.55
	-C2	1.20	1.23		0.06	0.06		0.018	0.016	->	0.27	0.33
	-C3	1.34	1.35		0.07	0.08		0.005	<0.005		0.03	0.04
	-C4	0.09	0.09		0.08	0.07		<0.005	<0.005		<0.01	<0.02
	-H1	0.77	0.77		0.07	0.07		0.007	0.007		0.02	0.02

(all results mg/L)												
		GVRD Copper	Inder Copper		GVRD Iron	Inder Iron		GVRD Lead	Inder Lead		GVRD Zinc	Inder Zinc
3-W7-1805	-C1	1.28	1.27		0.06	0.07		0.023	0.030	<-	1.46	1.47
	-C2	3.13	3.22		0.05	0.04		0.100	0.081	<-	0.50	0.60
	-C3	3.30	3.35		0.04	0.04		0.054	0.047		0.08	0.08
	-C4	0.25	0.23		0.08	0.09		<0.005	<0.005		0.02	<0.02
	-H1	1.55	1.58		0.06	0.07		0.012	<0.005	<-	0.02	0.02
3-E3-1403	-C1	2.14	2.18		0.07	0.08		0.29	0.299		2.53	2.42
	-C2	4.34	4.34		0.06	0.07		0.088	0.080		0.27	0.30
	-C3	2.33	2.43		0.12	0.14		0.053	0.050		0.21	0.22
	-C4	0.50	0.49		0.14	0.15		0.005	0.006		0.03	0.03
	-H1	1.18	1.18		0.15	0.18		0.014	0.014		0.03	0.03
3-E4-0208	-C1	1.48	1.48		0.14	0.15		0.024	0.029		0.46	0.49
	-C2	1.29	1.27		0.16	0.16		0.019	0.014		0.23	0.25
	-C3	0.77	0.76		0.17	0.18		<0.005	<0.005		0.02	0.02
	-C4	0.11	0.09		0.16	0.18		<0.005	<0.005		0.01	<0.02
	-H1	1.47	1.48		0.13	0.15		<0.005	<0.005		0.03	0.03
3-E5-0201	-C1	2.26	2.31		0.13	0.15		0.36	0.037		0.49	0.51
	-C2	2.32	2.34		0.15	0.14		0.22	0.231		0.07	0.07
	-C3	1.50	1.48		0.16	0.18		0.057	0.049		0.03	0.03
	-C4	0.27	0.26		0.18	0.17		<0.005	<0.005		<0.01	<0.02
	-H1	0.97	0.97		0.19	0.21		0.073	0.070		0.03	0.03

APPENDIX C

STATISTICAL COMMAND LANGUAGE AND SAMPLE OUTPUT

```
Screen Output will be written to file A:PB_L_3V.OUT

BMDP Instructions will be read from file A:PB_L_3V.INP

PAGE   1  BMDP3V

BMDP3V - GENERAL MIXED MODEL ANALYSIS OF VARIANCE
Copyright 1977, 1979, 1981, 1982, 1983, 1985, 1987, 1988
         BMDP Statistical Software, Inc.

         BMDP Statistical Software, Inc.| Statistical Software, Ltd.
         1440 Sepulveda Blvd            | Cork Technology Park, Model Farm Rd
         Los Angeles, CA 90025 USA      | Cork, Ireland
                                        |
         Phone (213) 479-7799           | Phone +353 21 542722
         Fax   (213) 312-0161           | Fax   +353 21 542822
         Telex 4972934 BMDP UI          | Telex 75659 SSWL EI

Version: 1988    (IBM PC/DOS)
 Manual: BMDP Manual Vol. 1 (August, 1988); Vol. 2 (December, 1988).
         Use 1983 or 1985 edition until 1988 becomes available.
 Digest: BMDP User's Digest (4th edition), plus addendum.
Updates: State NEWS. in the PRINT paragraph for summary of new features.

   DATE:11/28/89            AT 20:02:37

PROGRAM INSTRUCTIONS

/INPUT          TITLE IS ' LITRE COLD LEAD ANALYSIS - COVARIATE (YEAR)'.
                VARIABLES ARE 6.
                FORMAT IS FREE.
                FILE IS 'B:LCOLD_PB.DAT'.

/VARIABLE       NAMES ARE RUN, LOCN, AGE, FLOOR, CONC, YEAR.

/GROUP          LEVEL(RUN) = 2.
                LEVEL(LOCN) = 2.
                LEVEL(AGE) = 2.
                LEVEL(FLOOR) = 2.

/DESIGN         DEPENDANT = CONC.
                FIXED = LOCN.
                FIXED = AGE.
                FIXED = LOCN, AGE.
                FIXED = LOCN, AGE, FLOOR.
                FNAMES = LOCN, AGE, 'LOCNAGE', 'LA(F)'.
                RANDOM =RUN.
                COVARIATE = YEAR.
                METHOD = REML.

/END
PAGE   2  BMDP3V  LITRE COLD LEAD ANALYSIS - COVARIATE (YEAR)


PROBLEM TITLE IS
 LITRE COLD LEAD ANALYSIS - COVARIATE (YEAR)

NUMBER OF VARIABLES TO READ IN. . . . . . . . .       6
```

```
NUMBER OF VARIABLES ADDED BY TRANSFORMATIONS. .        0
TOTAL NUMBER OF VARIABLES . . . . . . . . . . .        6
CASE WEIGHT VARIABLE. . . . . . . . . . . . . .
CASE LABELING VARIABLES . . . . . . . . . . . .
NUMBER OF CASES TO READ IN. . . . . . . . . . . TO END
MISSING VALUES CHECKED BEFORE OR AFTER TRANS. . NEITHER
BLANKS ARE. . . . . . . . . . . . . . . . . . . MISSING
INPUT FILE. . .B:LCOLD_PB.DAT
REWIND INPUT UNIT PRIOR TO READING. . DATA. . .     YES
NUMBER OF WORDS OF DYNAMIC STORAGE. . . . . . .   16298

VARIABLES TO BE USED
     1 RUN          2 LOCN          3 AGE           4 FLOOR         5 CONC
     6 YEAR

INPUT FORMAT IS
FREE

MAXIMUM LENGTH DATA RECORD IS   80 CHARACTERS.

*** DATA ERROR ***  CASE NO.    145 WILL BE DELETED.
WHILE READING VARIABLE     1,    2 RECORD(S) WOULD BE READ.
AS DEFINED BY CASE ONE, THERE MUST BE    1 RECORD(S) PER CASE.



   VARIABLE            STATED VALUES FOR                GROUP CATEGORY     INTERVALS
  NO.   NAME     MINIMUM MAXIMUM MISSING      CODE   INDEX   NAME       .GT.    .LE.
  ---- --------  ------- ------- -------     ------ ----- --------    ------ -------

   2  LOCN                                   0.000     1  *0
                                             1.000     2  *1

   3  AGE                                    0.000     1  *0
                                             1.000     2  *1

   4  FLOOR                                  0.000     1  *0
                                             1.000     2  *1

   1  RUN                                    0.000     1  *0
                                             1.000     2  *1

NOTE: CATEGORY NAMES BEGINNING WITH * WERE CREATED BY THE PROGRAM.
------------------------------------------------------------------------------


NUMBER OF CASES READ. . . . . . . . . . . . . . .      145
   CASES WITH USE SET TO NEGATIVE VALUE . . . .          1
      REMAINING NUMBER OF CASES . . . . . . . .        144
   CASES WITH DATA MISSING OR BEYOND LIMITS . .          3
      REMAINING NUMBER OF CASES . . . . . . . .        141
PAGE    3  BMDP3V  LITRE COLD LEAD ANALYSIS - COVARIATE (YEAR)



CELL INFORMATION FOR VARIABLE CONC

 CELL          MEAN        ST.DEV.      COEF. OF      COUNT      GROUPING  VARIABLES
                                        VARIATION                LOCN        AGE
```

```
Y 1 1 1       0.01694     0.02224     1.31225     18.00000     *0         *0
  1 1 2       0.02650     0.03112     1.17437     18.00000     *0         *0
  1 2 1       0.02165     0.03512     1.62190     26.00000     *0         *1
  1 2 2       0.01157     0.01498     1.29473     21.00000     *0         *1
  2 2 1       0.00550     0.00131     0.23896     12.00000     *1         *1
  2 2 2       0.00509     0.00298     0.58570     11.00000     *1         *1
  2 1 1       0.04024     0.06933     1.72323     17.00000     *1         *0
  2 1 2       0.02794     0.02499     0.89438     18.00000     *1         *0


CELL INFORMATION FOR VARIABLE YEAR

 CELL           MEAN        ST.DEV.     COEF. OF     COUNT      GROUPING  VARIABLES
                                        VARIATION               LOCN       AGE

1 1 1          1.26667     0.54015     0.42644     18.00000     *0         *0
1 1 2          1.26667     0.54015     0.42644     18.00000     *0         *0
1 2 1         21.53846     2.81753     0.13081     26.00000     *0         *1
1 2 2         21.42857     3.13961     0.14652     21.00000     *0         *1
2 2 1         12.00000     6.26680     0.52223     12.00000     *1         *1
2 2 2         11.45455     6.26680     0.54710     11.00000     *1         *1
2 1 1          2.10588     1.45665     0.69171     17.00000     *1         *0
2 1 2          2.03333     1.44629     0.71129     18.00000     *1         *0
```

PERTINENT OUTPU

```
DEPENDENT VARIABLE CONC

PARAMETER         ESTIMATE       STANDARD      EST/ST.DEV.   TWO-TAIL PROBABILITY
                                 DEVIATION                   (ASYMPTOTIC THEORY)

 ERR.VAR.          0.001          0.000
 YEAR              0.002          0.001            1.877          0.061
 CONSTANT          0.004          0.009            0.447          0.655
 LOCN             -0.004          0.004           -1.170          0.242
 AGE               0.021          0.007            2.872          0.004
 LOCNAGE          -0.001          0.004           -0.372          0.710
 LA(F)            -0.004          0.003           -1.600          0.110
 RAND( 1)          0.000          0.000

-2*LOG(MAXIMUM LIKELIHOOD)       -540.08380000
PAGE   4  BMDP3V  LITRE COLD LEAD ANALYSIS - COVARIATE (YEAR)


ASYMPTOTIC VARIANCE-COVARIANCE MATRIX OF THE PARAMETERS


                    ERR.VAR.       YEAR          CONSTANT       LOCN          AGE

                        1             2              3             4
ERR.VAR.     1      0.0000
YEAR         2      0.0000        0.0000
CONSTANT     3      0.0000       -0.0000        0.0001
LOCN         4      0.0000       -0.0000        0.0000        0.0000
AGE          5      0.0000        0.0000       -0.0001       -0.0000        0.
LOCNAGE      6      0.0000        0.0000       -0.0000       -0.0000        0.
LA(F)        7      0.0000       -0.0000        0.0000        0.0000       -0.
RAND( 1)     8      0.0000        0.0000        0.0000        0.0000        0.

TESTS OF FIXED EFFECTS BASED ON ASYMPTOTIC VARIANCE-COVARIANCE MATRIX
```

```
 SOURCE          F-STATISTIC   DEGREES OF    PROBABILITY
                                 FREEDOM

COVARIATE            3.52       1    135       0.06271
CONSTANT             0.20       1    135       0.65578
LOCN                 1.37       1    135       0.24422
AGE                  8.25       1    135       0.00474
LOCNAGE              0.14       1    135       0.71084
LA(F)                2.56       1    135       0.11195


CELL    GROUPING VARIABLES                              DUMMY VARIABLES
            LOCN      AGE       FLOOR
1 1 1    *0        *0        *0              1.  1.  1.  1.  1.
1 1 2    *0        *0        *1              1.  1.  1.  1. -1.
1 2 1    *0        *1        *0              1.  1. -1. -1. -1.
1 2 2    *0        *1        *1              1.  1. -1. -1.  1.
2 2 1    *1        *1        *0              1. -1. -1.  1.  1.
2 2 2    *1        *1        *1              1. -1. -1.  1. -1.
2 1 1    *1        *0        *0              1. -1.  1. -1. -1.
2 1 2    *1        *0        *1              1. -1.  1. -1.  1.


CELL          OBSERVED     PREDICTED     SD.DEV.
                MEAN         MEAN         PRED.
1 1 1          0.0169       0.0320       0.0099
1 1 2          0.0265       0.0408       0.0099
1 2 1          0.0217       0.0013       0.0118
1 2 2          0.0116      -0.0075       0.0120
2 2 1          0.0055      -0.0021       0.0075
2 2 2          0.0051       0.0068       0.0076
2 1 1          0.0402       0.0518       0.0094
2 1 2          0.0279       0.0429       0.0094
PAGE    5  BMDP3V  LITRE COLD LEAD ANALYSIS - COVARIATE (YEAR)


VARIANCE-COVARIANCE MATRIX OF PREDICTED CELL MEANS


                        1 1 1         1 1 2         1 2 1         1 2 2         2 2

                             1             2             3             4
1 1 1       1          0.0001
1 1 2       2          0.0001        0.0001
1 2 1       3         -0.0001       -0.0001        0.0001
1 2 2       4         -0.0001       -0.0001        0.0001        0.0001
2 2 1       5         -0.0000       -0.0000        0.0000        0.0000        0.
2 2 2       6         -0.0000       -0.0000        0.0000        0.0000        0.
2 1 1       7          0.0000        0.0001       -0.0001       -0.0001       -0.
2 1 2       8          0.0001        0.0000       -0.0001       -0.0001       -0.


PAIRWISE TESTS FOR PREDICTED CELL MEANS


                        1 1 1         1 1 2         1 2 1         1 2 2         2 2

                             1             2             3             4
```

```
1 1 1      1        0.0000
1 1 2      2        1.6000        0.0000
1 2 1      3       -1.5031       -2.0007       0.0000
1 2 2      4       -2.0007       -2.3457      -1.6000       0.0000
2 2 1      5       -2.6382       -3.0606      -0.2597       0.4459       0.0
2 2 2      6       -1.7925       -2.6382       0.4459       1.0528       1.6
2 1 1      7        2.0604        1.4032       2.6428       2.9640       3.9
2 1 2      8        1.4032        0.2218       2.1076       2.6428       3.6
PAGE    6  BMDP3V  LITRE COLD LEAD ANALYSIS - COVARIATE (YEAR)


RESIDUAL ANALYSIS

CELL          OBSERVED    PREDICTED    ST.DEV.     OBSERVED-     ST.DEV.   (O-P)/
              CONC        CONC         PRED.       PREDICTED       O-P     ST.DEV.
1 1 1           0.008       0.019       0.006       -0.011        0.032     -0.328
1 1 1           0.014       0.019       0.006       -0.005        0.032     -0.142
1 1 1           0.014       0.019       0.006       -0.005        0.032     -0.142
1 1 2           0.016       0.027       0.006       -0.011        0.032     -0.354
1 1 2           0.010       0.027       0.006       -0.017        0.032     -0.541
1 1 2           0.088       0.027       0.006        0.061        0.032      1.885
1 2 1           0.006       0.022       0.005       -0.016        0.032     -0.495
1 2 1           0.008       0.022       0.005       -0.014        0.032     -0.433
1 2 1           0.007       0.022       0.005       -0.015        0.032     -0.464
1 2 1           0.003       0.022       0.005       -0.019        0.032     -0.587
1 2 2           0.002       0.013       0.006       -0.011        0.032     -0.345
1 2 2           0.016       0.013       0.006        0.003        0.032      0.089
1 2 1           0.002       0.022       0.005       -0.020        0.032     -0.618
1 2 1           0.003       0.022       0.005       -0.019        0.032     -0.587
1 2 1           0.005       0.022       0.005       -0.017        0.032     -0.526
1 2 2           0.002       0.013       0.006       -0.011        0.032     -0.345
1 2 2           0.001       0.013       0.006       -0.012        0.032     -0.376
1 2 2           0.005       0.013       0.006       -0.008        0.032     -0.252
1 2 1           0.088       0.027       0.006        0.061        0.032      1.896
1 2 1           0.073       0.027       0.006        0.046        0.032      1.429
1 2 1           0.095       0.027       0.006        0.068        0.032      2.114
1 2 2           0.018       0.018       0.006        0.000        0.032     -0.007
1 2 2           0.028       0.018       0.006        0.010        0.032      0.304
1 2 2           0.016       0.018       0.006       -0.002        0.032     -0.070
1 2 1           0.001       0.013       0.007       -0.012        0.032     -0.389
1 2 1           0.002       0.013       0.007       -0.011        0.032     -0.358
1 2 1           0.007       0.013       0.007       -0.006        0.032     -0.201
1 2 2           0.003       0.005       0.007       -0.002        0.032     -0.050
1 2 2           0.001       0.005       0.007       -0.004        0.032     -0.113
1 2 2           0.002       0.005       0.007       -0.003        0.032     -0.082
1 1 1           0.001       0.017       0.006       -0.016        0.032     -0.493
1 1 1           0.001       0.017       0.006       -0.016        0.032     -0.493
1 1 1           0.004       0.017       0.006       -0.013        0.032     -0.399
1 1 2           0.001       0.026       0.006       -0.025        0.032     -0.768
1 1 2           0.003       0.026       0.006       -0.023        0.032     -0.705
1 1 2           0.007       0.026       0.006       -0.019        0.032     -0.581
1 1 1           0.053       0.017       0.006        0.036        0.032      1.135
1 1 1           0.014       0.017       0.006       -0.003        0.032     -0.078
1 1 1           0.078       0.017       0.006        0.061        0.032      1.912
1 1 2           0.002       0.025       0.006       -0.023        0.032     -0.726
1 1 2           0.050       0.025       0.006        0.025        0.032      0.767
1 1 2           0.067       0.025       0.006        0.042        0.032      1.295
2 2 1           0.004       0.012       0.009       -0.008        0.031     -0.246
2 2 1           0.003       0.012       0.009       -0.009        0.031     -0.278
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2 2 1         0.006       0.012       0.009       -0.006       0.031     -0.183
2 2 2         0.002       0.021       0.009       -0.019       0.031     -0.592
2 2 2         0.004       0.021       0.009       -0.017       0.031     -0.528
2 2 2         0.004       0.021       0.009       -0.017       0.031     -0.528
2 1 1         0.014       0.036       0.006       -0.022       0.032     -0.694
2 1 1         0.013       0.036       0.006       -0.023       0.032     -0.725
2 1 1         0.013       0.036       0.006       -0.023       0.032     -0.725
PAGE   7  BMDP3V  LITRE COLD LEAD ANALYSIS - COVARIATE (YEAR)

2 1 2         0.016       0.027       0.006       -0.011       0.032     -0.357
2 1 2         0.038       0.027       0.006        0.011       0.032      0.328
2 1 2         0.027       0.027       0.006        0.000       0.032     -0.014
2 1 1         0.018       0.037       0.006       -0.019       0.032     -0.596
2 1 1         0.020       0.037       0.006       -0.017       0.032     -0.534
2 1 1         0.025       0.037       0.006       -0.012       0.032     -0.378
2 1 2         0.035       0.028       0.006        0.007       0.032      0.208
2 1 2         0.055       0.028       0.006        0.027       0.032      0.830
2 1 2         0.054       0.028       0.006        0.026       0.032      0.799
2 2 1         0.004      -0.009       0.009        0.013       0.031      0.403
2 2 1         0.006      -0.009       0.009        0.015       0.031      0.467
2 2 1         0.005      -0.009       0.009        0.014       0.031      0.435
2 2 2         0.009       0.000       0.009        0.009       0.031      0.281
2 2 2         0.003       0.000       0.009        0.003       0.031      0.091
2 2 2         0.005       0.000       0.009        0.005       0.031      0.154
2 1 1         0.060       0.042       0.006        0.018       0.032      0.569
2 1 1         0.023       0.042       0.006       -0.019       0.032     -0.584
2 1 1         0.043       0.042       0.006        0.001       0.032      0.039
2 1 2         0.002       0.033       0.006       -0.031       0.032     -0.963
2 1 2         0.004       0.033       0.006       -0.029       0.032     -0.900
2 1 2         0.004       0.033       0.006       -0.029       0.032     -0.900
1 1 1         0.003       0.019       0.006       -0.016       0.032     -0.484
1 1 1         0.005       0.019       0.006       -0.014       0.032     -0.421
1 1 1         0.010       0.019       0.006       -0.009       0.032     -0.266
1 1 2         0.008       0.027       0.006       -0.019       0.032     -0.603
1 1 2         0.003       0.027       0.006       -0.024       0.032     -0.759
1 1 2         0.086       0.027       0.006        0.059       0.032      1.823
1 2 1         0.005       0.022       0.005       -0.017       0.032     -0.526
1 2 1         0.010       0.022       0.005       -0.012       0.032     -0.371
1 2 1         0.004       0.022       0.005       -0.018       0.032     -0.556
1 2 1         0.003       0.022       0.005       -0.019       0.032     -0.587
1 2 2         0.002       0.013       0.006       -0.011       0.032     -0.345
1 2 2         0.062       0.013       0.006        0.049       0.032      1.516
1 2 1         0.004       0.022       0.005       -0.018       0.032     -0.556
1 2 1         0.005       0.022       0.005       -0.017       0.032     -0.526
1 2 1         0.003       0.022       0.005       -0.019       0.032     -0.587
1 2 2         0.001       0.013       0.006       -0.012       0.032     -0.376
1 2 2         0.001       0.013       0.006       -0.012       0.032     -0.376
1 2 1         0.070       0.027       0.006        0.043       0.032      1.336
1 2 1         0.123       0.027       0.006        0.096       0.032      2.985
1 2 1         0.017       0.027       0.006       -0.010       0.032     -0.314
1 2 2         0.012       0.018       0.006       -0.006       0.032     -0.194
1 2 2         0.032       0.018       0.006        0.014       0.032      0.429
1 2 2         0.023       0.018       0.006        0.005       0.032      0.148
1 2 1         0.002       0.013       0.007       -0.011       0.032     -0.358
1 2 1         0.006       0.013       0.007       -0.007       0.032     -0.233
1 2 1         0.011       0.013       0.007       -0.002       0.032     -0.077
1 2 2         0.005       0.005       0.007        0.000       0.032      0.012
1 2 2         0.006       0.005       0.007        0.001       0.032      0.043
1 2 2         0.005       0.005       0.007        0.000       0.032      0.012
1 1 1         0.001       0.017       0.006       -0.016       0.032     -0.493
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1 1 1        0.000      0.017      0.006      -0.017      0.032     -0.524
1 1 1        0.003      0.017      0.006      -0.014      0.032     -0.431
1 1 2        0.001      0.026      0.006      -0.025      0.032     -0.768
1 1 2        0.001      0.026      0.006      -0.025      0.032     -0.768
1 1 2        0.003      0.026      0.006      -0.023      0.032     -0.705
1 1 1        0.055      0.017      0.006       0.038      0.032      1.197
PAGE   8  BMDP3V  LITRE COLD LEAD ANALYSIS - COVARIATE (YEAR)

1 1 1        0.021      0.017      0.006       0.004      0.032      0.140
1 1 1        0.020      0.017      0.006       0.003      0.032      0.109
1 1 2        0.031      0.025      0.006       0.006      0.032      0.176
1 1 2        0.034      0.025      0.006       0.009      0.032      0.269
1 1 2        0.066      0.025      0.006       0.041      0.032      1.264
2 2 1        0.006      0.012      0.009      -0.006      0.031     -0.183
2 2 1        0.006      0.012      0.009      -0.006      0.031     -0.183
2 2 1        0.008      0.012      0.009      -0.004      0.031     -0.119
2 2 2        0.001      0.021      0.009      -0.020      0.031     -0.624
2 2 2        0.006      0.021      0.009      -0.015      0.031     -0.465
2 1 1        0.012      0.036      0.006      -0.024      0.032     -0.757
2 1 1        0.008      0.036      0.006      -0.028      0.032     -0.881
2 1 2        0.005      0.027      0.006      -0.022      0.032     -0.699
2 1 2        0.032      0.027      0.006       0.005      0.032      0.141
2 1 2        0.020      0.027      0.006      -0.007      0.032     -0.232
2 1 1        0.024      0.037      0.006      -0.013      0.032     -0.409
2 1 1        0.012      0.037      0.006      -0.025      0.032     -0.783
2 1 1        0.022      0.037      0.006      -0.015      0.032     -0.472
2 1 2        0.056      0.028      0.006       0.028      0.032      0.861
2 1 2        0.081      0.028      0.006       0.053      0.032      1.639
2 1 2        0.062      0.028      0.006       0.034      0.032      1.048
2 2 1        0.006     -0.009      0.009       0.015      0.031      0.467
2 2 1        0.006     -0.009      0.009       0.015      0.031      0.467
2 2 1        0.006     -0.009      0.009       0.015      0.031      0.467
2 2 2        0.011      0.000      0.009       0.011      0.031      0.345
2 2 2        0.004      0.000      0.009       0.004      0.031      0.123
2 2 2        0.007      0.000      0.009       0.007      0.031      0.218
2 1 1        0.030      0.042      0.006      -0.012      0.032     -0.366
2 1 1        0.304      0.042      0.006       0.262      0.032      8.172
2 1 1        0.043      0.042      0.006       0.001      0.032      0.039
2 1 2        0.002      0.033      0.006      -0.031      0.032     -0.963
2 1 2        0.005      0.033      0.006      -0.028      0.032     -0.869
2 1 2        0.005      0.033      0.006      -0.028      0.032     -0.869
HYPOTHESIS OPTION NOT AVAILABLE IF REML IS USED.

CPU TIME USED    166.860 SECONDS

PAGE   9  BMDP3V

BMDP3V - GENERAL MIXED MODEL ANALYSIS OF VARIANCE

   DATE:11/28/89            AT 20:05:22

PROGRAM INSTRUCTIONS


NO MORE CONTROL LANGUAGE.

PROGRAM TERMINATED
```

APPENDIX D

HIGH-RISE & SINGLE-FAMILY HOUSE SAMPLE ANALYSIS DATA

HIGH-RISE APARTMENT SAMPLING PROGRAM - Set No. 1
Metal Concentrations (mg/l)

Sample	Cold#1				Cold#2				Cold#3			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
1-W1-0201	1.31	0.05	0.015	0.85	2.32	0.07	0.023	0.24	0.48	0.61	<.005	0.04
1-W1-0203	0.39	0.07	0.020	0.05	0.45	0.07	0.008	0.02	0.45	0.07	0.015	<.02
1-W1-0402	1.70	0.04	0.025	0.68	0.40	0.06	0.014	0.22	1.85	0.08	0.013	0.05
1-W1-1604	1.23	0.05	0.016	1.50	2.29	0.07	0.016	0.16	2.03	0.08	0.016	0.06
1-W1-1703	0.86	0.05	0.024	1.43	1.08	0.07	0.023	0.21	0.16	0.08	0.005	0.03
1-W1-1850	1.33	0.05	0.029	0.82	2.04	0.05	0.164	0.55	2.08	0.07	0.072	0.06
1-W2-0301	2.04	0.05	0.011	0.34	1.67	0.08	0.006	0.06	0.68	0.08	0.006	0.03
1-W2-0601	0.99	0.04	0.012	1.96	1.42	0.07	0.012	0.35	1.31	0.08	0.007	0.14
1-W2-0602	1.01	0.05	0.013	1.35	1.31	0.08	<.005	0.09	1.05	0.07	0.007	0.05
1-W2-0702	1.37	0.09	<.005	0.05	1.37	0.08	<.005	0.03	1.29	0.09	<.005	0.03
1-W2-2204	0.90	0.05	0.018	1.02	0.43	0.06	<.005	0.18	0.18	0.05	<.005	<.02
1-W2-2401	3.31	0.05	0.125	0.11	0.22	0.07	0.013	0.03	0.15	0.05	0.009	0.02
1-W3-0502	0.96	0.05	0.008	0.77	0.16	0.08	<.005	0.04	0.14	0.07	<.005	0.03
1-W3-0505	0.19	0.07	0.007	0.12	0.22	0.07	<.005	0.09	0.09	0.06	<.005	0.03
1-W3-0701	0.96	0.04	0.009	1.17	1.62	0.05	0.010	0.29	1.43	0.06	<.005	0.08
1-W3-2108	0.62	0.07	<.005	0.02	1.37	0.07	<.005	0.02	0.78	0.05	<.005	0.02
1-W3-2302	0.18	0.08	<.005	0.09	0.11	0.07	<.005	0.03	0.10	0.05	<.005	0.03
1-W3-2303	0.69	0.06	0.023	1.45	0.61	0.07	0.008	0.48	0.48	0.06	<.005	0.07
1-W4-0405	1.58	0.05	0.073	0.78	2.45	0.04	0.268	0.31	2.54	0.05	0.041	0.02
1-W4-0505	1.59	0.04	0.398	0.94	2.21	0.04	0.182	0.29	1.50	0.06	0.022	0.02
1-W4-0606	3.33	0.11	0.367	1.46	1.62	0.34	0.099	0.16	0.60	0.22	0.076	0.07
1-W4-2109	1.39	<.04	0.072	3.76	1.75	0.19	0.029	0.15	1.13	0.10	0.011	0.07
1-W4-3105	0.48	0.07	0.063	2.72	2.73	0.04	0.026	0.23	1.21	0.06	0.026	0.07
1-W4-3106	0.98	0.07	0.022	2.88	1.97	0.06	0.026	0.18	0.74	0.06	0.013	0.05
1-W5-0101	1.07	0.06	0.007	0.21	0.73	0.07	<.005	0.03	0.48	0.07	<.005	<.02
1-W5-0306	0.96	0.07	0.007	0.05	0.43	0.07	<.005	<.02	0.47	0.07	<.005	<.02
1-W5-0403	1.13	0.05	0.027	0.15	1.77	0.05	0.020	0.33	0.57	0.07	<.005	0.04
1-W5-1902	1.10	0.05	<.005	0.82	1.66	0.04	0.009	0.31	1.84	0.05	<.005	0.03
1-W5-2001	1.91	0.05	0.016	0.57	2.64	0.04	<.005	0.12	0.61	0.07	<.005	0.02
1-W5-2101	1.56	0.05	0.007	0.91	2.51	0.04	<.005	0.16	2.43	<.04	<.005	0.05
1-W6-0301	1.14	0.06	<.005	0.02	1.27	0.06	<.005	0.03	0.75	0.06	<.005	0.02
1-W6-0305	0.35	0.06	0.006	0.13	0.12	0.06	<.005	0.02	0.12	0.06	<.005	<.02
1-W6-0404	1.35	0.04	0.016	1.00	2.33	0.04	0.007	0.24	1.91	0.06	<.005	0.04
1-W6-2003	1.05	0.06	0.012	0.19	0.31	0.06	<.005	<.02	0.35	0.06	<.005	<.02
1-W6-2103	1.34	0.06	0.020	1.09	0.81	0.05	0.005	0.13	0.29	0.05	<.005	0.04
1-W6-2303	1.53	0.05	0.029	1.08	1.85	0.04	0.018	0.48	0.94	0.05	<.005	0.05
1-W7-0308	1.57	0.05	0.051	0.57	2.92	0.04	0.095	0.27	1.85	0.06	0.042	0.04
1-W7-0309	0.22	0.07	<.005	<.02	2.76	<.04	0.024	0.06	0.68	0.07	0.012	0.03
1-W7-0406	1.85	0.05	0.109	1.11	3.08	<.04	0.197	0.25	3.11	0.06	0.044	0.03
1-W7-1609	0.35	0.07	0.007	<.02	0.18	0.05	<.005	<.02	0.16	0.06	<.005	<.02
1-W7-1703	1.21	0.05	0.042	1.48	2.76	<.04	0.121	0.30	2.35	0.05	0.031	0.04
1-W7-1805	2.44	0.05	0.117	0.25	2.96	<.04	0.097	0.08	2.85	0.05	0.056	0.04
1-E1-0103	0.72	0.12	0.006	0.05	0.10	0.11	<.005	<.02	0.96	0.10	<.005	0.06

1-E1-0205	0.61	0.09	0.017	3.42	0.52	0.10	0.013	1.04	0.13	0.11	<.005	0.07
1-E1-0301	1.23	0.09	0.042	1.01	2.39	0.08	0.012	0.12	0.97	0.11	<.005	0.02
1-E1-2501	0.53	0.11	0.011	2.09	1.11	0.10	<.005	0.31	1.30	0.10	<.005	0.06
1-E1-2505	1.09	0.10	0.020	1.39	0.81	0.11	0.013	0.37	0.44	0.12	<.005	0.03
1-E1-2601	1.26	0.16	0.008	0.25	2.95	0.09	0.012	0.23	3.18	0.09	<.005	0.05
1-E2-0101	1.93	0.09	0.015	0.44	3.39	0.06	0.023	0.18	2.88	0.08	0.012	0.02
1-E2-0206	2.46	0.09	0.012	0.08	2.56	0.07	0.011	0.08	2.46	0.09	0.013	0.07
1-E2-0307	1.54	0.08	0.013	1.05	2.66	0.07	0.025	0.19	2.37	0.09	0.010	0.03
1-E2-1802	0.44	0.15	0.007	0.02	0.51	0.13	0.061	0.03	0.86	0.13	0.005	<.02
1-E2-1904	1.32	0.07	0.070	1.90	2.63	0.08	0.087	0.32	1.95	0.08	0.023	0.06
1-E2-2002	1.27	0.08	0.038	1.24	2.21	0.07	0.048	0.28	2.05	0.09	0.021	0.05
1-E3-0102	2.58	0.09	0.055	0.14	1.10	0.12	0.047	0.33	0.54	0.13	0.008	0.07
1-E3-0103	0.98	0.10	0.044	1.65	2.12	0.10	0.059	0.28	2.11	0.11	0.014	0.07
1-E3-0303	1.31	0.11	0.031	1.28	1.96	0.11	0.047	0.25	1.13	0.12	0.019	0.07
1-E3-1403	1.62	0.08	0.065	1.16	3.51	0.09	0.044	0.11	1.71	0.10	0.031	0.06
1-E3-1602	1.89	0.08	0.139	0.67	2.65	0.10	0.043	0.15	2.88	0.08	0.052	0.07
1-E3-1604	1.75	0.09	0.015	0.80	2.80	0.08	0.071	0.55	2.97	0.09	0.052	0.10
1-E4-0101	1.56	0.10	0.012	0.89	2.62	0.09	0.011	0.19	1.00	0.10	<.005	0.04
1-E4-0208	1.14	0.09	0.005	0.92	1.62	0.09	0.023	0.28	1.21	0.11	<.005	0.02
1-E4-0308	0.97	0.09	0.008	1.35	1.53	0.10	0.021	0.29	0.61	0.11	<.005	0.02
1-E4-2102	1.71	0.08	0.014	1.42	1.20	0.11	0.033	0.13	0.34	0.10	<.005	0.02
1-E4-2202	1.80	0.08	0.012	0.47	0.60	0.11	0.005	0.03	0.66	0.10	<.005	0.02
1-E4-2401	1.04	0.08	0.006	1.01	2.86	0.09	0.018	0.17	2.79	0.08	<.005	0.03
1-E5-0201	1.71	0.08	0.101	1.33	2.93	0.08	0.215	0.23	1.76	0.09	0.016	0.06
1-E5-0301	2.03	0.06	0.039	0.99	3.04	0.08	0.069	0.25	3.43	0.07	0.014	0.03
1-E5-0401	1.35	0.08	0.033	1.13	2.23	0.09	0.049	0.39	2.60	0.07	0.042	0.04
1-E5-1701	1.00	0.09	0.007	0.73	2.32	0.09	0.005	0.18	1.68	0.08	<.005	0.03
1-E5-1801	1.44	0.07	0.009	1.21	3.34	0.09	0.007	0.16	3.16	0.08	<.005	0.05
1-E5-1901	2.18	0.06	0.022	0.83	2.94	0.08	0.008	0.19	2.88	0.07	<.005	0.04

Statistical Data Summary

	Cold#1				Cold#2				Cold#3			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
Mean	1.31	0.07	0.038	0.93	1.75	0.08	0.037	0.20	1.35	0.09	0.013	0.04
Std Dev	0.64	0.03	0.066	0.78	1.00	0.04	0.055	0.17	0.97	0.07	0.018	0.02
Max	3.33	0.16	0.398	3.76	3.51	0.34	0.268	1.04	3.43	0.61	0.076	0.14
Min	0.18	<.04	<.005	<.02	0.10	<.04	<.005	<.02	0.09	<.04	<.005	<.02

HIGH-RISE APARTMENT SAMPLING PROGRAM - Set No. 1
Metal Concentrations (mg/l)

Sample	Cold#4				Hot#1				1L-Cold (Calc.)			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
1-W1-0201	0.09	0.21	<.005	<.02	1.85	0.10	0.010	0.02	0.89	0.47	0.008	0.12
1-W1-0203	0.14	0.12	<.005	<.02	1.73	0.06	0.018	<.02	0.45	0.07	0.014	<.02
1-W1-0402	0.32	0.11	<.005	<.02	2.02	0.07	0.008	0.02	1.55	0.07	0.014	0.12
1-W1-1604	0.59	0.10	<.005	<.02	1.07	0.31	0.009	0.04	2.04	0.08	0.016	0.15
1-W1-1703	0.14	0.14	<.005	<.02	0.80	0.18	0.005	0.03	0.38	0.08	0.010	0.14
1-W1-1850	0.28	0.11	<.005	<.02	1.11	0.05	0.022	0.03	2.03	0.07	0.088	0.20
1-W2-0301	0.10	0.09	<.005	<.02	0.88	0.05	0.007	<.02	0.95	0.08	0.006	0.05
1-W2-0601	0.70	0.09	<.005	0.03	0.97	0.04	0.005	0.03	1.32	0.08	0.008	0.27
1-W2-0602	0.13	0.09	<.005	<.02	0.86	0.05	<.005	<.02	1.10	0.07	0.007	0.12
1-W2-0702	1.25	0.11	0.005	0.03	1.15	0.05	0.005	0.04	1.31	0.09	<.005	0.03
1-W2-2204	0.17	0.09	<.005	<.02	0.46	0.05	<.005	0.02	0.27	0.05	<.005	0.09
1-W2-2401	0.15	0.10	0.008	<.02	0.53	0.05	0.015	0.03	0.32	0.05	0.016	0.03
1-W3-0502	0.07	0.09	<.005	<.02	0.65	0.06	<.005	0.05	0.19	0.07	<.005	0.07
1-W3-0505	0.06	0.10	<.005	<.02	0.57	0.06	<.005	0.07	0.12	0.06	<.005	0.05
1-W3-0701	0.13	0.09	<.005	<.02	0.80	0.05	0.006	0.08	1.44	0.06	0.005	0.18
1-W3-2108	0.85	0.10	<.005	0.05	0.54	0.05	<.005	0.04	0.89	0.06	<.005	0.02
1-W3-2302	0.09	0.09	<.005	<.02	0.42	0.05	<.005	0.05	0.11	0.06	<.005	0.03
1-W3-2303	0.35	0.09	<.005	<.02	0.54	0.06	<.005	0.04	0.52	0.06	0.005	0.22
1-W4-0405	0.35	0.09	0.006	<.02	0.82	0.09	0.017	0.04	2.47	0.06	0.088	0.12
1-W4-0505	0.24	0.09	0.005	<.02	0.85	0.09	0.017	0.02	1.65	0.06	0.073	0.12
1-W4-0606	0.35	0.09	0.163	0.02	0.75	0.08	0.016	0.14	0.94	0.24	0.095	0.16
1-W4-2109	0.16	0.07	<.005	<.02	0.45	0.09	0.005	0.04	1.27	0.11	0.018	0.27
1-W4-3105	0.19	0.08	0.006	0.02	0.58	0.10	0.031	0.10	1.48	0.06	0.028	0.23
1-W4-3106	0.16	0.08	0.006	<.02	0.57	0.08	0.007	0.08	1.00	0.06	0.016	0.22
1-W5-0101	0.10	0.07	<.005	<.02	0.70	0.07	0.005	<.02	0.56	0.07	<.005	0.02
1-W5-0306	0.29	0.06	<.005	<.02	0.64	0.08	0.007	<.02	0.49	0.07	<.005	<.02
1-W5-0403	0.09	0.07	<.005	<.02	0.56	0.08	0.007	<.02	0.84	0.07	0.007	0.10
1-W5-1902	0.22	0.07	<.005	<.02	0.67	0.07	0.005	0.02	1.77	0.05	<.005	0.13
1-W5-2001	0.34	0.07	<.005	<.02	0.63	0.08	<.005	<.02	1.08	0.06	<.005	0.07
1-W5-2101	0.32	0.07	<.005	<.02	0.82	0.05	0.010	0.02	2.40	<.04	<.005	0.12
1-W6-0301	0.11	0.07	<.005	<.02	1.55	0.04	0.005	<.02	0.87	0.06	<.005	0.02
1-W6-0305	0.12	0.07	<.005	<.02	1.21	0.05	<.005	0.02	0.13	0.06	<.005	0.02
1-W6-0404	0.13	0.08	<.005	<.02	1.55	<.04	0.011	0.02	1.97	0.06	<.005	0.13
1-W6-2003	0.24	0.06	<.005	<.02	0.57	0.08	<.005	<.02	0.38	0.06	<.005	0.02
1-W6-2103	0.20	0.07	<.005	<.02	1.42	0.05	0.005	0.02	0.45	0.05	<.005	0.11
1-W6-2303	0.15	0.07	<.005	<.02	1.23	0.05	0.009	0.02	1.15	0.05	0.007	0.19
1-W7-0308	0.21	0.09	0.005	<.02	1.40	0.05	0.017	0.03	2.05	0.06	0.053	0.11
1-W7-0309	0.19	0.08	<.005	<.02	1.30	0.10	0.011	0.02	1.07	0.06	0.014	0.03
1-W7-0406	0.18	0.08	0.005	<.02	0.90	0.08	0.008	0.02	3.04	0.05	0.078	0.13
1-W7-1609	0.13	0.08	<.005	<.02	1.45	0.19	0.013	0.03	0.17	0.06	<.005	<.02
1-W7-1703	0.15	0.07	0.005	<.02	1.31	0.06	0.013	0.05	2.38	0.05	0.050	0.16
1-W7-1805	0.22	0.07	0.006	<.02	1.28	0.07	0.018	0.02	2.85	0.05	0.067	0.06
1-E1-0103	0.10	0.13	0.006	0.02	0.92	0.11	<.005	0.03	0.78	0.10	<.005	0.05

1-E1-0205	0.09	0.13	<.005	<.02	0.89	0.12	<.005	0.05	0.23	0.11	<.005	0.43
1-E1-0301	0.56	0.13	0.015	0.37	0.93	0.10	<.005	0.04	1.27	0.10	0.006	0.09
1-E1-2501	0.15	0.15	<.005	<.02	0.45	0.10	<.005	0.03	1.22	0.10	<.005	0.21
1-E1-2505	0.21	0.15	<.005	<.02	0.36	0.09	<.005	0.03	0.55	0.12	<.005	0.17
1-E1-2601	0.59	0.15	<.005	<.02	0.50	0.11	<.005	0.03	3.04	0.09	<.005	0.10
1-E2-0101	0.39	0.24	<.005	<.02	1.50	0.15	0.008	0.02	2.93	0.08	0.014	0.07
1-E2-0206	1.96	0.11	<.005	0.05	1.55	0.12	0.007	0.03	2.48	0.09	0.013	0.07
1-E2-0307	0.30	0.12	<.005	<.02	1.42	0.13	0.007	0.02	2.39	0.09	0.013	0.11
1-E2-1802	0.38	0.15	0.080	0.02	1.61	0.13	0.025	0.06	0.77	0.13	0.016	<.02
1-E2-1904	0.22	0.13	<.005	<.02	1.00	0.16	0.013	0.03	2.05	0.08	0.038	0.20
1-E2-2002	0.23	0.15	<.005	<.02	1.11	0.15	0.011	0.03	2.04	0.09	0.027	0.16
1-E3-0102	0.30	0.12	0.006	0.04	1.65	0.14	0.020	0.04	0.75	0.13	0.018	0.13
1-E3-0103	0.13	0.11	<.005	0.03	1.53	0.13	0.017	0.04	2.06	0.11	0.025	0.19
1-E3-0303	0.12	0.12	<.005	<.02	1.54	0.16	0.016	0.03	1.31	0.12	0.025	0.17
1-E3-1403	0.34	0.13	0.006	<.02	1.61	0.14	0.017	0.02	2.07	0.10	0.035	0.13
1-E3-1602	0.59	0.13	0.005	0.03	1.74	0.16	0.016	0.03	2.78	0.08	0.055	0.12
1-E3-1604	0.40	0.12	0.005	<.02	1.64	0.22	0.016	0.03	2.88	0.09	0.054	0.23
1-E4-0101	0.13	0.11	<.005	<.02	1.32	0.11	<.005	<.02	1.35	0.10	<.005	0.11
1-E4-0208	0.07	0.11	<.005	<.02	0.91	0.12	<.005	<.02	1.29	0.11	0.006	0.12
1-E4-0308	0.08	0.11	<.005	<.02	0.84	0.12	<.005	0.02	0.81	0.11	0.005	0.14
1-E4-2102	0.18	0.13	<.005	<.02	0.54	0.13	<.005	<.02	0.58	0.10	0.009	0.11
1-E4-2202	0.18	0.11	<.005	<.02	0.59	0.17	<.005	<.02	0.71	0.10	<.005	0.04
1-E4-2401	0.37	0.12	<.005	<.02	0.44	0.12	<.005	<.02	2.72	0.08	0.005	0.11
1-E5-0201	1.77	0.10	0.012	<.02	1.36	0.15	0.014	0.02	1.99	0.09	0.060	0.16
1-E5-0301	0.32	0.11	<.005	<.02	1.44	0.11	0.012	0.02	3.28	0.07	0.026	0.12
1-E5-0401	0.26	0.10	0.005	0.02	1.16	0.12	0.010	0.03	2.46	0.07	0.043	0.16
1-E5-1701	0.26	0.11	<.005	<.02	0.98	0.12	<.005	<.02	1.77	0.08	<.005	0.10
1-E5-1801	0.32	0.11	<.005	<.02	1.08	0.11	<.005	<.02	3.11	0.08	<.005	0.13
1-E5-1901	0.54	0.11	<.005	0.02	1.33	0.11	<.005	<.02	2.86	0.07	<.005	0.11

Statistical Data Summary

	Cold#4				Hot#1				1L-Cold (Calc.)			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
Mean	0.31	0.10	0.006	0.02	1.03	0.10	0.008	0.03	1.43	0.08	0.019	0.12
Std Dev	0.33	0.03	0.021	0.04	0.43	0.05	0.007	0.02	0.90	0.05	0.024	0.08
Max	1.96	0.24	0.163	0.37	2.02	0.31	0.031	0.14	3.28	0.47	0.095	0.43
Min	0.06	0.06	<.005	<.02	0.36	0.03	<.005	<.02	0.11	<.04	<.005	<.02

HIGH RISE APARTMENT SAMPLING PROGRAM - Set No. 2
Metal Concentrations (mg/l)

Sample	Cold#1				Cold#2				Cold#3			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
2-W1-0201	1.53	0.04	0.011	1.11	2.58	0.05	0.012	0.29	0.57	0.09	<.005	0.03
2-W1-0203	1.88	0.05	0.029	0.77	2.36	0.06	0.008	0.19	0.88	0.08	<.005	0.04
2-W1-0402	1.43	0.04	0.012	1.11	2.08	0.05	0.020	0.24	2.02	0.08	0.007	0.06
2-W1-1604	0.93	0.04	0.011	1.15	1.66	0.06	0.011	0.21	1.46	0.08	0.007	0.03
2-W1-1703	0.61	0.09	0.008	0.09	0.32	0.11	<.005	0.05	0.25	0.10	<.005	<.02
2-W1-1850	1.53	0.04	0.087	1.34	2.58	0.04	0.177	0.57	1.75	0.07	0.062	0.12
2-W2-0301	1.81	0.04	0.022	0.92	2.11	0.06	<.005	0.08	1.24	0.09	<.005	0.02
2-W2-0601	0.95	<.04	0.009	1.83	1.32	0.05	0.014	0.49	1.11	0.08	0.009	0.14
2-W2-0602	0.98	0.07	<.005	0.08	0.94	0.07	<.005	0.07	0.94	0.10	<.005	0.06
2-W2-0702	1.17	0.04	0.010	1.56	0.42	0.07	<.005	0.09	0.29	0.09	<.005	0.04
2-W2-2204	1.96	<.04	0.010	0.16	1.68	0.05	<.005	0.04	0.20	0.10	<.005	<.02
2-W2-2401	1.67	0.04	0.171	0.14	2.95	<.04	0.167	0.27	0.29	0.09	0.027	0.03
2-W3-0303	0.66	0.05	0.010	1.94	0.56	0.06	<.005	0.09	0.55	0.09	<.005	<.02
2-W3-0505	0.74	0.04	0.008	1.28	0.97	0.06	0.010	0.33	0.64	0.09	<.005	0.04
2-W3-0701	0.95	0.05	0.011	0.45	0.24	0.06	<.005	0.05	0.21	0.10	<.005	0.03
2-W3-2108	0.22	0.05	<.005	<.02	0.23	0.07	<.005	<.02	0.37	0.09	<.005	0.02
2-W3-2302	0.12	0.06	<.005	<.02	0.13	0.05	<.005	0.02	0.12	0.08	<.005	<.02
2-W3-2303												
2-W4-0405	1.66	0.06	0.058	0.74	2.73	0.04	0.207	0.33	1.67	0.07	0.034	0.02
2-W4-0504	1.10	0.06	0.283	3.04	2.75	0.07	0.306	1.64	1.09	0.13	0.064	0.19
2-W4-0505	1.11	0.06	0.017	<.02	1.09	0.06	0.027	<.02	0.53	0.08	0.014	<.02
2-W4-2106	1.55	0.06	0.080	1.72	1.13	0.06	0.016	0.12	0.62	0.07	0.006	0.04
2-W4-3105	0.91	<.04	0.167	2.46	2.31	0.04	0.050	0.13	0.72	0.07	0.018	0.05
2-W4-3106	1.56	0.07	0.031	0.66	2.43	0.05	0.042	0.10	0.87	0.07	0.017	0.03
2-W5-0101	0.27	0.07	<.005	0.03	0.23	0.07	<.005	<.02	0.19	0.08	<.005	<.02
2-W5-0306	0.76	0.05	0.016	0.18	0.84	0.05	0.009	0.06	0.60	0.06	<.005	<.02
2-W5-0403	1.20	0.08	0.025	1.27	1.69	0.06	0.024	0.81	0.33	0.08	0.006	0.04
2-W5-1902	1.25	0.05	0.006	0.76	1.63	0.05	0.008	0.36	1.38	0.06	<.005	0.02
2-W5-2001	3.16	0.06	0.016	1.23	3.74	0.05	0.014	0.59	0.17	0.06	<.005	0.05
2-W5-2101	1.76	0.04	0.033	0.91	1.65	0.06	0.007	0.11	0.37	0.07	<.005	<.02
2-W6-0301	1.09	0.06	<.005	0.03	0.80	0.06	<.005	0.02	0.58	0.08	<.005	<.02
2-W6-0305	0.77	0.07	<.005	0.05	0.33	0.07	<.005	0.07	0.25	0.07	<.005	0.03
2-W6-0404	1.78	0.05	0.013	0.79	2.18	0.04	0.005	0.26	1.96	0.07	<.005	0.04
2-W6-2003	0.58	0.07	<.005	0.02	0.41	0.07	<.005	<.02	0.31	0.08	<.005	<.02
2-W6-2103	0.37	0.06	<.005	0.05	0.24	0.06	<.005	0.03	0.22	0.07	<.005	0.02
2-W6-2303	1.22	0.04	0.016	0.22	0.72	0.07	0.005	0.04	0.34	0.07	<.005	<.02
2-W7-0308	1.72	0.05	0.051	0.86	2.98	0.06	0.084	0.30	1.87	0.07	0.048	0.04
2-W7-0309	1.34	0.06	0.025	1.02	2.51	0.04	0.041	0.24	1.12	0.07	0.016	0.04
2-W7-0406	1.75	0.07	0.024	0.04	1.42	0.05	0.021	0.03	1.47	0.06	0.019	0.03
2-W7-1609	2.24	0.06	0.086	0.64	3.10	0.04	0.047	0.05	0.97	0.06	0.023	0.02
2-W7-1703	2.20	0.06	0.091	0.81	3.22	0.04	0.063	0.07	2.21	0.05	0.023	0.04
2-W7-1805	1.30	0.06	0.030	0.67	2.62	0.05	0.122	0.23	2.88	0.05	0.054	0.05
2-E1-0103	0.67	0.10	0.027	1.48	0.54	0.13	0.014	0.20	0.36	0.12	<.005	0.03

2-E1-0205	2.96	0.10	0.044	0.59	2.75	0.08	0.008	0.07	0.32	0.12	<.005	<.02
2-E1-0301	0.86	0.08	0.027	1.15	1.84	0.08	0.020	0.25	1.00	0.11	<.005	0.03
2-E1-2501	0.57	0.09	0.012	2.03	1.02	0.11	<.005	0.28	1.24	0.10	<.005	0.06
2-E1-2505	1.08	0.30	0.028	1.20	1.79	0.35	0.011	0.19	1.85	0.29	<.005	0.03
2-E1-2601												
2-E2-0101												
2-E2-0206	2.30	0.14	0.028	0.54	2.84	0.23	0.024	0.05	2.15	0.20	0.008	0.04
2-E2-0307	1.47	0.11	0.019	0.75	2.38	0.10	0.017	0.14	2.21	0.11	0.005	0.04
2-E2-1802	0.43	0.23	0.006	0.04	0.41	0.23	<.005	0.02	1.59	0.17	0.006	0.03
2-E2-1904	1.38	0.14	0.057	0.92	2.38	0.11	0.069	0.16	1.87	0.14	0.020	0.05
2-E2-2002	1.31	0.14	0.021	1.36	2.07	0.12	0.050	0.25	2.05	0.13	0.012	0.06
2-E3-0102	1.69	0.08	0.032	0.09	0.91	0.09	0.065	0.43	0.51	0.12	0.013	0.08
2-E3-0103	1.89	0.08	0.019	0.10	1.74	0.09	0.015	0.07	1.59	0.08	0.011	0.04
2-E3-0303	1.12	0.08	0.016	1.24	1.57	0.09	0.041	0.42	0.99	0.11	0.018	0.07
2-E3-1403	1.38	0.09	0.069	0.85	2.39	0.09	0.092	0.30	1.55	0.09	0.045	0.06
2-E3-1602	1.36	0.08	0.027	0.92	2.13	0.10	0.139	0.36	2.56	0.08	0.069	0.08
2-E3-1604	1.43	0.07	0.020	0.92	2.57	0.08	0.073	0.48	2.84	0.07	0.062	0.10
2-E4-0101	1.30	0.08	0.006	0.77	2.07	0.09	0.012	0.19	1.53	0.08	<.005	0.03
2-E4-0208	0.89	0.08	0.005	0.71	1.04	0.10	0.021	0.18	0.26	0.13	<.005	<.02
2-E4-0308	0.71	0.08	<.005	0.96	0.78	0.11	0.017	0.20	0.17	0.11	<.005	0.02
2-E4-2102	0.84	0.07	0.010	1.15	1.54	0.10	0.039	0.24	0.65	0.12	<.005	0.02
2-E4-2202	1.85	0.08	<.005	0.03	1.90	0.07	0.005	0.02	1.84	0.07	<.005	0.02
2-E4-2401	0.81	0.05	0.007	0.87	2.39	0.06	0.016	0.14	2.36	0.05	0.005	0.04
2-E5-0201	2.60	0.07	0.353	0.49	1.55	0.09	0.014	0.03	1.57	0.08	0.013	0.02
2-E5-0301	1.90	0.08	0.034	1.00	2.82	0.09	0.063	0.25	3.20	0.07	0.386	0.03
2-E5-0401	1.16	0.10	0.018	0.18	2.24	0.11	0.059	0.32	2.60	0.08	0.041	0.04
2-E5-1701	1.03	0.08	0.006	0.57	2.24	0.08	<.005	0.09	1.48	0.07	<.005	0.02
2-E5-1801	1.20	0.08	0.010	0.13	3.13	0.10	0.006	0.13	2.98	0.07	0.005	0.04
2-E5-2001	1.34	0.07	0.006	1.19	2.29	0.08	0.011	0.36	2.65	0.06	<.005	0.04

Statistical Data Summary

	Cold#1				Cold#2				Cold#3			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
Mean	1.29	0.07	0.035	0.79	1.73	0.08	0.036	0.21	1.18	0.09	0.018	0.04
Std Dev	0.60	0.04	0.060	0.64	0.92	0.05	0.055	0.24	0.85	0.04	0.048	0.03
Max	3.16	0.30	0.353	3.04	1.73	0.35	0.306	1.64	3.20	0.29	0.386	0.19
Min	0.12	<.04	<.005	<.02	0.13	<.04	<.005	<.02	0.12	0.05	<.005	<.02

HIGH RISE APARTMENT SAMPLING PROGRAM - Set No. 2
Metal Concentrations (mg/l)

Sample	Cold#4				Hot#1				1L-Cold (Calc.)			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
2-W1-0201	0.09	0.09	<.005	<.02	1.97	0.09	0.009	0.02	1.02	0.08	<.005	0.14
2-W1-0203	0.10	0.09	<.005	<.02	1.33	0.10	0.008	0.02	1.23	0.07	0.005	0.11
2-W1-0402	0.10	0.08	<.005	<.02	1.95	0.08	0.010	0.02	2.00	0.07	0.010	0.15
2-W1-1604	0.56	0.09	<.005	<.02	1.21	0.37	0.010	0.02	1.47	0.07	0.008	0.12
2-W1-1703	0.14	0.09	<.005	<.02	0.66	0.09	0.012	0.03	0.28	0.10	<.005	0.02
2-W1-1850	0.18	0.08	<.005	<.02	0.74	0.09	0.021	0.03	1.91	0.06	0.086	0.27
2-W2-0301	0.13	0.09	<.005	<.02	1.09	0.07	0.006	0.02	1.44	0.08	0.005	0.08
2-W2-0601	0.11	0.08	<.005	<.02	1.07	0.06	0.008	0.05	1.14	0.07	0.010	0.29
2-W2-0602	0.13	0.08	<.005	<.02	1.04	0.07	0.006	0.02	0.94	0.09	<.005	0.06
2-W2-0702	0.12	0.08	<.005	<.02	0.86	0.07	0.007	0.03	0.36	0.08	<.005	0.13
2-W2-2204	0.22	0.08	<.005	<.02	0.60	0.07	<.005	<.02	0.58	0.09	<.005	0.02
2-W2-2401	0.17	0.08	0.005	<.02	0.64	0.07	0.017	0.03	0.89	0.08	0.062	0.08
2-W3-0303	0.54	0.07	<.005	0.07	0.56	0.06	<.005	0.05	0.56	0.08	<.005	0.12
2-W3-0505	0.53	0.07	0.005	0.07	0.70	0.08	0.005	0.10	0.71	0.08	0.005	0.16
2-W3-0701	0.10	0.07	<.005	<.02	0.68	0.06	<.005	0.05	0.25	0.09	<.005	0.06
2-W3-2108	0.20	0.07	<.005	<.02	0.52	0.06	<.005	0.05	0.33	0.08	<.005	0.02
2-W3-2302	0.09	0.05	<.005	<.02	0.43	0.06	<.005	0.04	0.12	0.07	<.005	<.02
2-W3-2303												
2-W4-0405	0.31	0.07	0.007	<.02	0.98	0.10	0.013	0.02	1.88	0.06	0.070	0.12
2-W4-0504	0.16	0.08	0.015	<.02	0.91	0.08	0.031	0.07	1.42	0.11	0.123	0.62
2-W4-0505	0.31	0.08	<.005	<.02	1.09	0.08	0.026	0.02	0.67	0.08	0.017	<.02
2-W4-2106	0.14	0.08	<.005	<.02	0.48	0.07	0.005	0.05	0.77	0.07	0.012	0.14
2-W4-3105	0.14	0.08	<.005	<.02	0.52	0.10	0.024	0.08	1.05	0.06	0.032	0.19
2-W4-3106	0.14	0.07	<.005	<.02	0.55	0.09	0.010	0.03	1.22	0.07	0.023	0.08
2-W5-0101	0.17	0.08	<.005	<.02	0.64	0.06	0.006	<.02	0.20	0.08	<.005	<.02
2-W5-0306	0.17	0.06	<.005	<.02	0.63	0.12	0.007	<.02	0.66	0.06	0.006	0.02
2-W5-0403	0.13	0.13	<.005	<.02	0.63	0.08	0.011	0.02	0.65	0.08	0.011	0.26
2-W5-1902	0.22	0.07	<.005	<.02	0.70	0.05	0.006	<.02	1.42	0.06	0.005	0.13
2-W5-2001	0.30	0.06	<.005	0.02	0.66	0.06	<.005	0.04	1.03	0.06	0.006	0.22
2-W5-2101	0.16	0.07	<.005	<.02	0.57	0.06	0.005	0.02	0.70	0.07	0.005	0.08
2-W6-0301	0.10	0.06	<.005	<.02	1.42	<.04	0.005	<.02	0.65	0.08	<.005	0.01
2-W6-0305	0.09	0.07	<.005	<.02	0.90	0.06	0.019	0.61	0.29	0.07	<.005	0.04
2-W6-0404	0.36	0.06	0.005	<.02	1.40	<.04	0.009	0.03	2.00	0.06	<.005	0.12
2-W6-2003	0.48	0.07	<.005	0.02	1.36	0.04	0.008	0.03	0.34	0.08	<.005	<.02
2-W6-2103	0.15	0.07	<.005	<.02	1.17	0.04	0.006	<.02	0.23	0.07	<.005	0.02
2-W6-2303	0.13	0.07	<.005	<.02	1.25	0.06	0.008	<.02	0.46	0.07	<.005	0.03
2-W7-0308	0.17	0.07	<.005	<.02	1.32	0.06	0.014	0.02	2.08	0.07	0.055	0.13
2-W7-0309	0.22	0.07	<.005	<.02	1.52	0.06	0.010	<.02	1.41	0.06	0.021	0.13
2-W7-0406	0.18	0.07	<.005	<.02	0.98	0.06	0.009	<.02	1.47	0.06	0.020	0.03
2-W7-1609	0.19	0.07	0.005	<.02	1.47	0.07	0.013	0.02	1.46	0.06	0.031	0.06
2-W7-1703	0.15	0.07	<.005	<.02	1.36	0.08	0.013	0.05	2.41	0.05	0.034	0.08
2-W7-1805	0.22	0.07	0.006	<.02	1.43	0.08	0.017	0.02	2.75	0.05	0.066	0.12
2-E1-0103	0.05	0.12	<.005	<.02	0.47	0.10	<.005	<.02	0.41	0.12	0.006	0.14

2-E1-0205	0.09	0.11	<.005	<.02	0.57	0.09	0.018	0.04	0.94	0.11	0.006	0.05
2-E1-0301	0.09	0.14	<.005	<.02	0.75	0.11	<.005	0.02	1.16	0.10	0.008	0.13
2-E1-2501	0.15	0.15	<.005	<.02	0.51	0.10	<.005	0.02	1.16	0.10	<.005	0.20
2-E1-2505	0.55	0.14	<.005	<.02	0.37	0.10	<.005	0.03	1.80	0.30	0.006	0.12
2-E1-2601												
2-E2-0101												
2-E2-0206	0.38	0.24	<.005	<.02	1.60	0.47	0.014	0.02	2.30	0.20	0.012	0.07
2-E2-0307	1.96	0.12	0.029	0.08	1.60	0.15	0.009	0.02	2.21	0.11	0.008	0.10
2-E2-1802	0.44	0.22	0.005	0.04	1.50	0.20	0.013	0.02	1.30	0.19	0.005	0.03
2-E2-1904	0.30	0.25	<.005	0.02	1.27	0.19	0.021	0.03	1.95	0.13	0.032	0.12
2-E2-2002	0.25	0.18	<.005	<.02	1.31	0.17	0.013	0.02	2.02	0.13	0.020	0.16
2-E3-0102	0.15	0.15	0.006	0.02	1.34	0.11	0.020	0.05	0.65	0.11	0.024	0.15
2-E3-0103	0.11	0.12	<.005	<.02	1.25	0.12	0.019	0.03	1.64	0.08	0.012	0.05
2-E3-0303	0.10	0.14	<.005	<.02	1.10	0.12	0.015	0.03	1.11	0.10	0.023	0.20
2-E3-1403	0.25	0.13	<.005	<.02	1.85	0.48	0.027	<.02	1.71	0.09	0.056	0.15
2-E3-1602	0.27	0.15	<.005	0.02	1.35	0.14	0.017	0.04	2.41	0.08	0.081	0.18
2-E3-1604	0.29	0.11	<.005	<.02	1.34	0.19	0.018	0.03	2.72	0.07	0.062	0.22
2-E4-0101	0.10	0.12	<.005	<.02	1.01	0.11	0.005	<.02	1.63	0.08	0.006	0.10
2-E4-0208	0.09	0.14	<.005	<.02	1.00	0.08	<.005	<.02	0.45	0.12	0.006	0.08
2-E4-0308	0.10	0.12	<.005	<.02	0.80	0.11	<.005	0.02	0.32	0.11	0.006	0.10
2-E4-2102	0.16	0.13	<.005	<.02	0.55	0.12	<.005	<.02	0.84	0.11	0.011	0.12
2-E4-2202	0.19	0.13	<.005	<.02	0.79	0.10	<.005	<.02	1.85	0.07	<.005	0.02
2-E4-2401	0.26	0.14	<.005	<.02	0.45	0.13	<.005	<.02	2.29	0.05	0.007	0.10
2-E5-0201	1.54	0.09	0.006	<.02	0.84	0.15	0.027	0.03	1.62	0.08	0.030	0.05
2-E5-0301	0.27	0.14	<.005	0.02	0.94	0.13	0.016	<.02	3.06	0.07	0.304	0.12
2-E5-0401	2.67	0.09	0.014	0.04	0.81	0.11	0.013	0.02	2.46	0.09	0.043	0.10
2-E5-1701	0.21	0.13	<.005	<.02	0.64	0.13	0.005	0.00	1.61	0.07	<.005	0.06
2-E5-1801	0.26	0.14	<.005	<.02	0.70	0.12	<.005	<.02	2.92	0.08	0.005	0.06
2-E5-2001	0.48	0.14	<.005	0.02	0.99	0.13	<.005	<.02	2.51	0.06	0.006	0.16

Statistical Data Summary

	Cold#4				Hot#1				1L-Cold (Calc.)			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
Mean	0.29	0.10	<.005	<.02	0.98	0.11	0.010	0.03	1.30	0.09	0.023	0.11
Std Dev	0.41	0.04	0.004	0.02	0.40	0.08	0.007	0.07	0.77	0.04	0.042	0.09
Max	2.67	0.25	0.029	0.08	1.97	0.48	0.031	0.61	3.06	0.30	0.304	0.62
Min	0.05	0.05	<.005	<.02	0.37	<.04	<.005	<.02	0.12	0.05	<.005	<.02

HIGH RISE APARTMENT SAMPLING PROGRAM - Set No. 3
Metal Concentrations (mg/l)

Sample	Cold#1				Cold#2				Cold#3			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
3-W1-0201	1.45	0.04	0.007	1.08	2.60	0.05	0.014	0.31	0.58	0.07	<.005	0.03
3-W1-0203	1.54	0.07	0.019	0.58	1.90	0.07	0.011	0.35	0.67	0.07	<.005	0.03
3-W1-0402	1.21	0.06	0.014	1.35	2.07	0.07	0.017	0.25	1.91	0.06	0.008	0.06
3-W1-1604	0.96	0.06	0.011	1.23	1.92	0.05	0.012	0.18	1.90	0.07	0.007	0.04
3-W1-1703												
3-W1-1850	1.47	0.06	0.023	1.07	2.32	0.05	0.179	0.75	2.17	0.06	0.062	0.08
3-W2-0301	1.82	0.05	0.025	1.06	2.02	0.06	0.005	0.10	1.10	0.09	<.005	0.03
3-W2-0601	0.95	0.06	0.014	1.66	1.43	0.07	0.012	0.34	1.35	0.09	0.010	0.14
3-W2-0602	1.17	0.06	0.013	1.18	1.15	0.07	<.005	0.08	1.13	0.09	0.006	0.05
3-W2-0702	1.36	0.07	0.018	0.71	0.39	0.07	<.005	0.06	0.32	0.10	<.005	0.03
3-W2-2204	0.67	0.08	0.009	0.52	0.20	0.08	<.005	0.06	1.16	0.09	<.005	0.02
3-W2-2401	0.56	0.08	0.050	0.28	0.21	0.07	0.012	0.03	0.18	0.08	0.009	0.02
3-W3-0502	0.86	0.04	0.007	1.78	0.55	0.08	<.005	0.12	0.30	0.07	<.005	0.06
3-W3-0505	0.74	0.05	0.009	1.32	1.03	0.07	0.010	0.34	0.78	0.08	<.005	0.06
3-W3-0701	1.20	0.06	0.015	0.79	1.23	0.07	0.005	0.14	0.33	0.09	<.005	0.04
3-W3-2108												
3-W3-2302	0.23	0.08	<.005	0.08	0.14	0.08	<.005	0.02	0.14	0.08	<.005	0.02
3-W3-2303	0.88	0.06	0.014	1.50	0.45	0.08	<.005	0.02	0.39	0.06	<.005	0.02
3-W4-0405	1.40	0.08	0.053	0.65	1.87	0.07	0.195	0.58	2.82	0.06	0.041	0.03
3-W4-0504	1.66	0.05	0.259	2.38	2.62	0.05	0.059	0.58	0.66	0.07	0.019	0.11
3-W4-0505	2.05	0.06	0.412	0.52	0.72	0.08	0.031	0.04	0.48	0.08	0.012	<.02
3-W4-2109	1.45	0.07	0.047	2.04	0.25	0.10	<.005	0.05	0.25	0.10	<.005	0.04
3-W4-3105	1.20	0.06	0.202	2.10	1.67	0.07	0.034	0.11	0.43	0.11	0.011	0.06
3-W4-3106	0.65	0.06	0.018	1.69	2.29	0.06	0.054	0.10	0.82	0.09	0.022	0.04
3-W5-0101	0.86	0.08	<.005	0.03	0.35	0.08	<.005	0.03	0.28	0.08	<.005	<.02
3-W5-0306	0.91	0.07	0.008	0.55	1.23	0.06	0.016	0.33	1.35	0.08	<.005	0.04
3-W5-0403	0.88	0.06	0.023	1.92	1.29	0.05	0.016	0.77	0.49	0.08	<.005	0.08
3-W5-1902	1.22	0.06	0.008	0.74	1.79	0.11	0.010	0.34	1.80	0.18	<.005	0.02
3-W5-2001	2.63	0.05	0.020	2.32	4.07	0.05	0.007	0.50	1.33	0.09	<.005	0.09
3-W5-2101	1.57	0.05	<.005	0.87	2.16	0.05	0.007	0.50	2.47	0.07	<.005	0.05
3-W6-0301	0.37	0.08	<.005	0.03	0.29	0.08	<.005	0.04	0.27	0.08	<.005	0.02
3-W6-0305	1.30	0.08	0.029	0.26	0.18	0.07	<.005	0.08	0.12	0.09	<.005	0.02
3-W6-0405	1.41	0.08	<.005	0.03	0.92	0.07	<.005	0.04	0.82	0.07	<.005	0.02
3-W6-2003	0.29	0.08	<.005	<.02	0.33	0.07	<.005	0.03	0.31	0.08	<.005	<.02
3-W6-2103	0.97	0.06	0.012	1.36	1.10	0.06	0.009	0.36	0.36	0.08	<.005	0.06
3-W6-2303	1.07	0.05	0.017	1.92	1.81	0.05	0.014	0.46	1.02	0.08	<.005	0.06
3-W7-0308	1.70	0.06	0.049	0.84	2.98	0.06	0.078	0.32	1.92	0.07	0.046	0.04
3-W7-0309	2.00	0.06	0.053	0.69	2.65	0.06	0.014	0.08	0.76	0.08	0.011	0.03
3-W7-0406	3.12	0.05	0.237	0.68	3.76	0.05	0.062	0.18	3.29	0.06	0.035	0.08
3-W7-1609												
3-W7-1803	1.55	0.06	0.063	1.13	2.67	0.05	0.080	0.23	2.71	0.06	0.027	0.05
3-W7-1805	1.27	0.07	0.030	1.47	3.22	0.04	0.081	0.60	3.35	0.04	0.047	0.08
3-E1-0103	0.73	0.14	0.041	1.72	0.34	0.18	0.008	0.16	0.16	0.17	<.005	0.03

3-E1-0208	0.69	0.15	0.172	2.74	0.35	0.17	0.022	0.39	0.15	0.16	0.005	0.04
3-E1-0301	1.28	0.14	0.043	1.06	2.42	0.16	0.010	0.11	0.94	0.19	<.005	0.05
3-E1-2501	0.57	0.17	0.012	1.89	1.15	0.19	<.005	0.22	1.22	0.18	<.005	0.05
3-E1-2505	0.64	0.12	0.017	1.22	0.36	0.21	<.005	0.17	0.23	0.20	<.005	0.03
3-E1-2605	0.94	0.17	0.026	1.02	2.42	0.18	0.006	0.19	2.36	0.16	<.005	0.05
3-E2-0101	1.99	0.16	0.011	0.05	2.53	0.15	0.015	0.06	3.18	0.14	0.015	0.08
3-E2-0206	1.97	0.23	0.026	1.06	2.99	0.16	0.024	0.08	2.17	0.15	0.006	0.04
3-E2-0307	1.67	0.12	0.024	0.88	2.51	0.14	0.014	0.14	2.21	0.15	0.015	0.04
3-E2-1802	0.99	0.17	0.009	0.09	0.68	0.16	0.005	0.03	0.50	0.18	<.005	<.02
3-E2-1904	1.31	0.14	0.067	1.40	2.64	0.24	0.058	0.21	2.32	0.29	0.020	0.08
3-E2-2002	1.12	0.29	0.056	1.98	2.51	0.26	0.056	0.29	2.44	0.24	0.017	0.07
3-E3-0102	1.50	0.16	0.129	1.26	2.37	0.15	0.047	0.09	0.17	0.16	0.007	0.05
3-E3-0103	1.18	0.16	0.019	0.44	1.39	0.15	0.029	0.20	1.44	0.15	0.008	0.03
3-E3-0303	1.53	0.16	0.051	0.14	0.76	0.18	0.009	0.06	0.38	0.16	<.005	0.03
3-E3-1403	2.18	0.08	0.299	2.42	4.34	0.07	0.080	0.30	2.43	0.14	0.050	0.22
3-E3-1602	2.41	0.15	0.043	0.06	2.56	0.15	0.061	0.06	2.29	0.15	0.019	0.03
3-E3-1604	1.78	0.14	0.021	0.68	2.70	0.13	0.068	0.51	3.01	0.13	0.044	0.08
3-E4-0101	1.56	0.15	0.014	1.14	2.80	0.15	0.009	0.16	0.84	0.16	<.005	0.04
3-E4-0208	1.48	0.15	0.029	0.49	1.27	0.16	0.014	0.25	0.76	0.18	<.005	0.02
3-E4-0308	1.05	0.15	0.012	1.19	1.48	0.17	0.015	0.13	1.05	0.18	<.005	0.03
3-E4-2102	1.21	0.14	0.015	1.62	2.26	0.14	0.039	0.35	1.64	0.14	0.005	0.03
3-E4-2202	2.04	0.15	0.012	0.04	1.69	0.14	<.005	0.02	1.60	0.15	<.005	<.02
3-E4-2401	1.17	0.12	0.008	1.03	2.78	0.12	0.018	0.20	2.79	0.12	<.005	0.05
3-E5-0201	2.31	0.15	0.374	0.51	2.34	0.14	0.231	0.07	1.48	0.18	0.049	0.03
3-E5-0301	2.47	0.13	0.097	0.41	3.02	0.11	0.028	0.13	3.34	0.12	0.009	0.03
3-E5-0401	1.24	0.14	0.022	1.17	2.59	0.13	0.030	0.24	2.79	0.14	0.032	0.04
3-E5-1701	0.99	0.16	0.010	0.67	2.40	0.15	0.006	0.17	1.59	0.16	<.005	0.03
3-E5-1801	1.08	0.16	0.011	0.95	3.07	0.14	0.009	0.20	3.14	0.14	<.005	0.03
3-E5-2001	2.36	0.14	0.019	0.43	2.77	0.13	0.006	0.10	2.73	0.15	<.005	0.03

Statistical Data Summary

	Cold#1				Cold#2				Cold#3			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
Mean	1.33	0.10	0.051	1.02	1.79	0.11	0.029	0.21	1.36	0.12	0.011	0.05
Std Dev	0.58	0.05	0.085	0.68	1.05	0.05	0.044	0.18	1.00	0.05	0.015	0.03
Max	3.12	0.29	0.412	2.74	4.34	0.26	0.231	0.77	3.35	0.29	0.062	0.22
Min	0.23	0.04	<.005	<.02	0.14	0.04	<.005	0.02	0.12	0.04	<.005	<.02

HIGH RISE APARTMENT SAMPLING PROGRAM - Set No. 3
Metal Concentrations (mg/l)

Sample	Cold#4				Hot#1				1L-Cold (Calc.)			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
3-W1-0201	0.11	0.07	<.005	<.02	1.68	0.07	0.006	<.02	1.03	0.06	0.006	0.14
3-W1-0203	0.09	0.07	<.005	<.02	1.58	0.08	0.011	0.03	0.96	0.07	0.005	0.12
3-W1-0402	0.17	0.08	<.005	<.02	2.03	0.08	0.009	0.02	1.91	0.06	0.010	0.16
3-W1-1604	0.58	0.07	<.005	<.02	1.22	0.27	0.008	0.02	1.86	0.07	0.008	0.13
3-W1-1703												
3-W1-1850	0.20	0.07	<.005	<.02	0.82	0.09	0.012	0.02	2.17	0.06	0.083	0.26
3-W2-0301	1.04	0.07	<.005	0.03	1.19	0.06	0.009	0.04	1.32	0.08	0.005	0.10
3-W2-0601	0.41	0.07	<.005	0.02	1.08	0.06	0.005	0.03	1.35	0.08	0.011	0.26
3-W2-0602	0.12	0.06	<.005	<.02	1.08	0.07	0.005	0.02	1.14	0.08	0.006	0.11
3-W2-0702	0.30	0.06	<.005	0.05	0.84	0.07	0.006	0.05	0.39	0.09	<.005	0.07
3-W2-2204	0.15	0.11	<.005	<.02	0.43	0.07	<.005	0.03	0.94	0.09	<.005	0.05
3-W2-2401	0.25	0.04	0.006	0.02	0.51	0.07	0.013	0.03	0.21	0.08	0.012	0.04
3-W3-0502	0.06	0.08	<.005	<.02	0.75	0.08	0.004	0.06	0.38	0.07	<.005	0.16
3-W3-0505	0.76	0.08	<.005	0.06	0.88	0.08	0.005	0.12	0.83	0.08	<.005	0.18
3-W3-0701	0.11	0.07	<.005	<.02	0.78	0.06	0.005	0.06	0.55	0.08	0.005	0.10
3-W3-2108												
3-W3-2302	0.13	0.08	<.005	<.02	0.46	0.07	<.005	0.04	0.14	0.08	<.005	0.02
3-W3-2303	0.39	0.07	<.005	0.03	0.54	0.06	<.005	0.06	0.43	0.06	<.005	0.09
3-W4-0405	0.37	0.09	0.005	<.02	0.90	0.09	0.011	0.02	2.56	0.06	0.072	0.17
3-W4-0504	0.17	0.08	0.007	0.03	0.81	0.09	0.045	0.09	1.10	0.07	0.039	0.32
3-W4-0505	0.31	0.07	<.005	<.02	0.75	0.29	0.024	0.02	0.61	0.08	0.036	0.04
3-W4-2109	0.14	0.08	<.005	0.02	0.42	0.10	0.005	0.04	0.31	0.10	0.006	0.14
3-W4-3105	0.13	0.07	<.005	0.02	0.44	0.13	0.026	0.08	0.72	0.10	0.025	0.17
3-W4-3106	0.13	0.08	<.005	0.02	0.41	0.10	0.006	0.04	1.11	0.08	0.028	0.13
3-W5-0101	0.21	0.08	<.005	<.02	0.59	0.14	<.005	<.02	0.32	0.08	<.005	0.02
3-W5-0306	0.09	0.07	<.005	<.02	0.77	0.07	0.007	0.02	1.30	0.08	0.007	0.12
3-W5-0403	0.09	0.08	<.005	<.02	0.65	0.08	0.008	0.03	0.67	0.07	0.007	0.31
3-W5-1902	0.23	0.08	<.005	<.02	0.73	0.06	<.005	<.02	1.77	0.16	<.005	0.12
3-W5-2001	0.22	0.09	<.005	0.02	0.66	0.09	<.005	0.04	1.94	0.08	<.005	0.28
3-W5-2101	0.40	0.08	<.005	<.02	0.82	0.06	<.005	<.02	2.36	0.07	<.005	0.18
3-W6-0301	0.09	0.10	<.005	<.02	1.22	0.06	<.005	<.02	0.28	0.08	<.005	0.02
3-W6-0305	0.14	0.08	<.005	0.04	1.31	0.05	0.009	0.64	0.19	0.09	<.005	0.04
3-W6-0405	0.12	0.09	<.005	<.02	1.16	0.08	<.005	0.02	0.87	0.07	<.005	0.02
3-W6-2003	0.29	0.08	<.005	<.02	1.51	0.05	0.005	0.02	0.31	0.08	<.005	<.02
3-W6-2103	0.26	0.08	<.005	<.02	1.46	0.04	0.020	0.02	0.54	0.08	<.005	0.19
3-W6-2303	0.20	0.10	<.005	<.02	1.55	0.04	0.015	0.03	1.18	0.07	0.006	0.23
3-W7-0308	0.29	0.08	0.005	<.02	1.29	0.09	0.005	0.02	2.12	0.07	0.053	0.14
3-W7-0309	0.17	0.08	<.005	<.02	1.34	0.08	<.005	0.03	1.20	0.08	0.014	0.07
3-W7-0406	0.22	0.08	<.005	<.02	0.94	0.09	<.005	0.02	3.38	0.06	0.051	0.11
3-W7-1609												
3-W7-1803	0.17	0.08	<.005	<.02	1.47	0.07	<.005	0.04	2.64	0.06	0.039	0.14
3-W7-1805	0.23	0.09	<.005	<.02	1.58	0.07	<.005	0.02	3.22	0.04	0.053	0.25
3-E1-0103	0.08	0.21	<.005	<.02	0.60	0.17	<.005	0.03	0.22	0.17	0.005	0.14

3-E1-0208	0.03	0.16	<.005	<.02	0.36	0.14	<.005	0.05	0.22	0.16	0.017	0.25
3-E1-0301	0.08	0.18	<.005	<.02	0.83	0.17	0.005	0.03	1.25	0.18	0.007	0.11
3-E1-2501	0.16	0.21	<.005	<.02	0.65	0.16	<.005	0.03	1.17	0.18	<.005	0.18
3-E1-2505	0.17	0.19	<.005	0.02	0.39	0.16	<.005	0.04	0.28	0.20	<.005	0.12
3-E1-2605	0.43	0.28	<.005	0.03	0.49	0.16	0.005	0.04	2.30	0.16	<.005	0.13
3-E2-0101	1.61	0.15	0.006	0.06	1.51	0.17	0.007	0.02	2.99	0.14	0.015	0.07
3-E2-0206	0.65	0.15	<.005	0.02	1.38	0.31	0.008	0.03	2.32	0.16	0.011	0.10
3-E2-0307	2.27	0.14	0.006	0.05	1.57	0.16	0.005	0.02	2.24	0.15	0.015	0.10
3-E2-1802	0.29	0.17	<.005	0.02	1.59	0.18	0.008	0.02	0.56	0.18	<.005	0.02
3-E2-1904	0.23	0.17	<.005	0.02	1.34	0.23	0.015	0.05	2.33	0.27	0.030	0.17
3-E2-2002	0.53	0.16	<.005	<.02	1.19	0.28	0.014	0.04	2.39	0.25	0.027	0.21
3-E3-0102	0.13	0.16	0.007	0.03	1.32	0.17	0.017	0.07	0.68	0.16	0.021	0.12
3-E3-0103	0.16	0.16	<.005	0.03	1.35	0.19	0.018	0.04	1.42	0.15	0.013	0.08
3-E3-0303	0.11	0.17	<.005	<.02	1.33	0.17	0.013	0.02	0.51	0.16	0.007	0.04
3-E3-1403	0.49	0.15	0.006	0.03	1.18	0.18	0.014	0.03	2.80	0.12	0.068	0.35
3-E3-1602	2.05	0.15	0.017	0.04	1.56	0.19	0.019	0.04	2.35	0.15	0.029	0.04
3-E3-1604	0.35	0.16	<.005	<.02	1.53	0.25	0.015	0.04	2.89	0.13	0.048	0.20
3-E4-0101	0.13	0.17	<.005	<.02	1.07	0.19	0.007	<.02	1.27	0.16	<.005	0.12
3-E4-0208	0.09	0.18	<.005	<.02	1.48	0.15	<.005	0.03	0.90	0.17	0.006	0.09
3-E4-0308	0.09	0.16	<.005	<.02	0.94	0.17	<.005	0.02	1.14	0.18	0.005	0.11
3-E4-2102	0.19	0.17	<.005	<.02	0.61	0.15	<.005	0.02	1.74	0.14	0.012	0.17
3-E4-2202	1.66	0.15	<.005	<.02	0.58	0.18	<.005	0.02	1.64	0.15	<.005	<.02
3-E4-2401	0.32	0.16	<.005	<.02	0.97	0.15	<.005	0.02	2.71	0.12	0.007	0.13
3-E5-0201	0.26	0.17	<.005	<.02	0.97	0.21	0.070	0.03	1.69	0.17	0.102	0.06
3-E5-0301	0.33	0.15	0.005	0.04	1.12	0.17	0.015	0.02	3.23	0.12	0.017	0.07
3-E5-0401	2.76	0.12	0.027	0.06	0.93	0.17	0.010	0.02	2.67	0.14	0.031	0.14
3-E5-1701	0.20	0.15	<.005	0.02	0.77	0.18	0.005	0.02	1.72	0.16	<.005	0.09
3-E5-1801	0.30	0.16	<.005	0.03	0.81	0.18	0.005	<.02	3.02	0.14	<.005	0.11
3-E5-2001	0.92	0.16	<.005	0.03	0.88	0.18	<.005	0.02	2.72	0.15	<.005	0.06

Statistical Data Summary

	Cold#4				Hot#1				1L-Cold (Calc.)			
	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn	Cu	Fe	Pb	Zn
Mean	0.39	0.12	<.005	0.02	1.01	0.13	0.009	0.04	1.44	0.11	0.017	0.13
Std Dev	0.52	0.05	0.004	0.01	0.40	0.07	0.010	0.08	0.94	0.05	0.021	0.08
Max	2.76	0.28	0.027	0.06	2.03	0.31	0.070	0.64	3.38	0.27	0.102	0.35
Min	0.03	0.04	<.005	<.02	0.36	0.04	<.005	<.02	0.14	0.04	<.005	<.02

HIGH-RISE SAMPLING PROGRAM - Vancouver (West)
Water Quality Parameters

Bldg. Code	Week	pH	Alk.	Hardness Ca	Hardness Mg	T.H.	Cond	Free Chlorine
W1	1	5.9	1.30	1.10	0.14	3.32	12	0.70
	2	6.0	1.40	1.27	0.15	3.78	13	0.65
	3	6.0	1.40	1.27	0.16	3.83	12	0.60
W2	1	5.9	1.10	1.06	0.14	3.22	12	0.70
	2	6.0	1.30	1.22	0.15	3.66	13	0.70
	3	6.0	1.30	1.22	0.16	3.70	11	0.66
W4	1	6.0	1.40	1.03	0.14	3.14	12	0.70
	2	5.9	1.40	1.21	0.15	3.63	14	0.66
	3	6.0		1.25	0.16	3.78	13	0.72
W5	1	5.9	1.20	1.06	0.14	3.22	12	0.75
	2	6.0	1.40	1.20	0.15	3.61	13	0.75
	3	6.0	1.30	1.22	0.16	3.70	11	0.70
W6	1	6.0	1.20	1.03	0.13	3.10	11	0.70
	2	6.0	1.40	1.23	0.15	3.68	12	0.76
	3	6.1	1.40	1.31	0.16	3.93	13	0.74
W7	1	5.9	1.30	1.19	0.16	3.63	12	0.70
	2	6.0	1.40	1.23	0.15	3.68	13	0.72
	3	6.1	1.50	1.30	0.16	3.90	13	0.68

Statistical Data Summary

	pH	Alk.	Hardness Ca	Hardness Mg	T.H.	Cond	Free Chlorine
Number	18	17	18	18	18	18	18
Average	6.0	1.34	1.19	0.15	3.58	12	0.70
Std Dev	0.1	0.10	0.09	0.01	0.25	1	0.04
Max	6.1	1.50	1.31	0.16	3.93	14	0.76
Min	5.9	1.10	1.03	0.13	3.10	11	0.60

Units are:
Total Alkalinity (mg/L) as CaCO3
Calcium (mg/L)
Magnesium (mg/L)
Total Hardness (mg/L) as CaCO3
Conductivity (umhos/cm)
Free Chlorine (mg/L)

HIGH-RISE SAMPLING PROGRAM - Burnaby (East)
Water Quality Parameters

Bldg. Code	Week	pH	Alk.	Hardness Ca	Hardness Mg	T.H.	Cond	Free Chlorine
E1	1	6.2	2.40	1.68	0.13	4.72	14	0.18
	2	6.2	2.50	1.74	0.14	4.92	14	0.08
	3	6.2	2.60	1.77	0.14	4.99	16	0.08
E2	1	6.3	2.90	1.86	0.12	5.13	15	0.04
	2	6.3	2.60	1.82	0.14	5.11	17	0.05
	3	6.3	3.70	1.88	0.14	5.26	16	0.05
E3	1	6.3	2.70	1.54	0.13	4.38	14	0.50
	2	6.2	2.10	1.55	0.15	4.48	14	0.26
	3	6.2	2.70	1.75	0.15	4.98	15	0.14
E4	1	6.1	2.30	1.64	0.14	4.67	14	0.60
	2	6.1	1.90	1.48	0.15	4.31	14	0.36
	3	6.2	2.60	1.71	0.15	4.88	15	0.64
E5	1	6.2	2.40	1.62	0.13	4.57	14	0.44
	2	6.2	2.00	1.56	0.14	4.47	15	
	3	6.3	2.80	1.91	0.15	5.38	16	

Statistical Data Summary

	pH	Alk.	Hardness Ca	Hardness Mg	T.H.	Cond	Free Chlorine
Number	15	15	15	15	15	15	13
Average	6.2	2.55	1.70	0.14	4.82	15	0.26
Std Dev	0.1	0.42	0.13	0.01	0.32	1	0.21
Max	6.3	3.70	1.91	0.15	5.38	17	0.64
Min	6.1	1.90	1.48	0.12	4.31	14	0.04

Units are:
Total Alkalinity (mg/L) as CaCO3
Calcium (mg/L)
Magnesium (mg/L)
Total Hardness (mg/L) as CaCO3
Conductivity (umhos/cm)
Free Chlorine (mg/L)

HOUSE SAMPLING PROGRAM
Metal Concentrations (mg/l)

Sample	Cold#1			Cold#2			Cold#3		
	Cu	Pb	Zn	Cu	Pb	Zn	Cu	Pb	Zn
V1	0.63	0.007	1.50	1.37	0.047	0.45	1.36	0.009	<.02
V2	0.49	0.036	2.00	3.24	0.103	0.07	0.83	0.032	0.04
V3	0.37	0.014	0.48	0.37	0.020	0.85	1.57	0.016	0.16
V4	0.75	<.005	1.43	1.56	0.034	0.40	1.23	0.010	0.03
V5	1.16	0.031	0.99	2.41	0.101	0.14	0.98	0.026	0.03
V6	1.29	0.009	0.91	2.08	0.061	0.17	3.02	0.019	0.03
V7	1.31	0.023	0.71	1.78	0.049	0.07	1.24	0.010	<.02
V8	0.79	0.007	0.94	2.10	0.032	0.21	2.07	0.009	0.03
V9	1.41	0.039	0.33	1.37	0.042	0.52	1.45	0.011	0.05
V10	2.04	0.031	0.64	1.05	0.030	0.08	0.46	<.005	0.04
V11	1.52	0.015	0.90	1.30	0.068	0.18	0.14	0.006	<.02
V12	1.33	0.030	1.05	1.59	0.049	0.09	1.09	0.012	0.06
V13	1.63	0.014	0.37	2.43	<.005	0.02	0.92	<.005	<.02
V14	0.62	0.008	1.82	1.68	0.047	0.30	1.69	0.010	0.04
V15	1.80	0.034	0.11	1.77	0.017	0.02	0.83	0.009	0.02
V16	1.14	0.024	0.64	1.88	0.082	0.12	1.62	0.014	0.02
V17	0.75	0.011	0.54	1.95	0.007	0.09	0.19	<.005	<.02
V18	1.00	0.005	0.80	1.69	0.016	0.19	1.91	0.007	<.02
V19	1.46	0.153	0.38	1.88	0.068	0.19	2.49	0.015	0.02
V20	1.52	0.012	0.83	2.86	0.062	0.32	3.17	0.025	0.04
V21	0.96	0.008	0.90	1.86	0.024	0.22	2.02	0.025	0.07
V22	0.94	0.009	0.36	0.24	<.005	0.04	0.21	<.005	0.02
V23	1.55	0.014	1.59	2.62	0.044	0.57	2.76	0.021	0.07
V24	1.94	0.056	0.68	3.65	0.039	0.06	2.31	0.009	<.02
V25	0.93	0.007	0.94	1.33	0.014	0.13	1.50	0.007	0.02
V26	0.91	<.005	0.82	1.54	0.013	0.29	0.72	<.005	0.03
V27	1.37	0.018	0.46	1.04	0.006	0.05	0.96	<.005	0.02
V28	0.27	<.005	0.45	1.43	<.005	0.06	0.41	<.005	0.04
V29	0.77	0.010	1.87	1.79	0.008	0.43	0.98	<.005	0.05
V30	1.72	0.010	0.40	2.11	0.007	0.10	2.32	0.006	<.02
V31	1.00	0.013	1.30	2.93	0.009	0.17	2.17	0.016	0.03
V32	0.93	0.005	0.86	1.24	<.005	0.10	1.61	<.005	0.03
V33	0.69	0.007	2.06	2.13	0.006	0.08	1.46	<.005	0.03
V34	1.63	0.008	0.15	1.97	0.008	0.12	2.00	0.017	<.02
V35	1.70	0.045	0.43	2.18	0.012	0.06	0.39	<.005	<.02
V36	0.73	0.007	0.80	2.17	0.012	0.14	2.11	0.006	0.04
NV1	2.33	0.052	0.67	3.18	0.049	0.05	3.37	0.023	0.03
NV2	0.86	0.014	1.37	1.89	0.073	0.42	1.49	0.013	0.04
NV3	1.30	0.016	0.10	1.63	0.012	<.02	0.98	0.005	<.02
NV4	0.68	0.010	1.65	2.11	0.049	0.13	0.65	0.009	0.03
NV5	0.91	0.008	0.60	1.74	0.010	0.11	1.43	0.012	0.03
NV6	1.32	0.005	1.06	2.13	0.017	0.24	2.23	0.005	0.04
NV7	1.30	0.008	0.69	2.23	0.017	0.26	2.20	0.008	0.03

NV8	1.69	0.030	0.55	1.34	0.010	0.08	0.97	0.006	0.03
WV1	0.57	0.006	1.54	1.59	0.073	0.33	0.90	0.020	0.02
WV2	0.93	<.005	0.68	1.71	0.026	0.16	1.85	0.006	0.02
WV3	0.99	0.005	0.55	1.46	0.011	0.31	1.24	0.010	0.03
R1	0.35	0.013	1.57	0.26	0.008	0.26	0.03	<.005	0.04
R2	0.62	<.005	1.04	1.66	0.005	0.17	0.89	<.005	0.02
R3	0.45	<.005	1.76	1.24	0.013	0.13	0.76	0.010	0.02
R4	0.97	0.012	1.08	1.97	0.025	0.17	2.04	0.005	0.04
R5	0.48	0.027	1.95	0.14	0.030	0.33	0.06	0.011	0.07
R6	0.64	0.007	1.06	1.75	0.014	0.20	1.25	0.007	0.06
R7	0.30	<.005	0.81	0.85	0.016	0.13	0.71	<.005	0.02
B1	0.89	0.009	1.57	1.85	0.008	0.37	1.04	0.005	0.03
B2	0.71	0.010	1.64	2.52	0.019	0.21	1.44	0.006	<.02
B3	0.86	0.008	1.86	1.54	0.015	0.33	0.40	<.005	0.03
B4	1.11	0.005	1.48	2.09	<.005	0.03	1.29	<.005	<.02
B5	0.78	<.005	1.08	1.45	0.024	0.37	0.22	<.005	<.02
B6	1.48	0.015	0.71	0.62	0.009	0.08	0.80	0.013	0.03

Statistical Data Summary

		Cold#1			Cold#2			Cold#3	
	Cu	Pb	Zn	Cu	Pb	Zn	Cu	Pb	Zn
Mean	1.06	0.017	0.98	1.76	0.028	0.20	1.34	0.009	0.03
Std Dev	0.47	0.022	0.52	0.69	0.025	0.16	0.79	0.007	0.02
Max	2.33	0.153	2.06	3.65	0.103	0.85	3.37	0.032	0.16
Min	0.27	<.005	0.10	0.14	<.005	<.02	0.03	<.005	<.02

HOUSE SAMPLING PROGRAM
Metal Concentrations (mg/l)

Sample	Cold#4			Hot#1			1 Litre		
	Cu	Pb	Zn	Cu	Pb	Zn	Cu	Pb	Zn
V1	0.19	<.005	<.02	0.40	<.005	0.02	1.33	0.017	0.17
V2	0.16	<.005	<.02	0.73	0.013	<.02	1.30	0.046	0.14
V3	0.17	<.005	0.03	1.08	0.070	0.44	1.27	0.017	0.31
V4	0.16	<.005	<.02	0.50	<.005	0.02	1.27	0.014	0.17
V5	0.09	<.005	<.02	0.57	0.011	<.02	1.28	0.041	0.10
V6	0.14	<.005	<.02	0.45	0.005	<.02	2.75	0.027	0.10
V7	0.07	0.005	<.02	0.27	0.007	0.06	1.35	0.018	0.05
V8	0.25	<.005	<.02	0.68	<.005	<.02	2.01	0.014	0.11
V9	0.15	<.005	0.02	0.32	0.006	<.02	1.43	0.019	0.16
V10	0.15	<.005	<.02	0.31	<.005	<.02	0.66	0.010	0.08
V11	0.08	<.005	<.02	0.66	0.006	<.02	0.44	0.019	0.09
V12	0.12	<.005	<.02	0.59	0.005	0.02	1.20	0.020	0.12
V13	0.14	<.005	<.02	0.53	<.005	<.02	1.26	<.005	0.03
V14	0.14	<.005	<.02	0.41	0.005	<.02	1.63	0.017	0.18
V15	0.10	<.005	<.02	0.29	0.005	<.02	1.07	0.012	0.02
V16	0.20	<.005	<.02	0.40	0.005	<.02	1.65	0.028	0.07
V17	0.13	<.005	<.02	0.35	<.005	<.02	0.57	<.005	0.05
V18	0.14	<.005	<.02	0.63	<.005	<.02	1.82	0.009	0.09
V19	0.10	<.005	<.02	0.48	0.010	0.02	2.32	0.033	0.07
V20	0.33	<.005	0.02	0.77	0.018	0.03	3.03	0.032	0.14
V21	0.22	<.005	<.02	0.47	0.008	<.02	1.94	0.024	0.14
V22	0.06	<.005	<.02	0.31	<.005	<.02	0.25	<.005	0.04
V23	0.19	<.005	<.02	0.66	0.007	0.02	2.67	0.025	0.25
V24	0.09	<.005	<.02	0.46	0.019	<.02	2.56	0.017	0.05
V25	0.18	<.005	<.02	0.44	<.005	<.02	1.44	0.008	0.09
V26	0.11	<.005	<.02	0.36	<.005	0.03	0.89	0.005	0.12
V27	0.30	<.005	<.02	0.43	<.005	0.02	1.00	<.005	0.05
V28	0.12	<.005	<.02	0.27	<.005	0.02	0.61	<.005	0.06
V29	0.14	<.005	<.02	0.45	<.005	0.03	1.13	<.005	0.22
V30	0.31	<.005	<.02	0.87	<.005	<.02	2.25	0.006	0.05
V31	0.44	<.005	<.02	0.51	0.005	<.02	2.26	0.014	0.12
V32	0.18	<.005	<.02	0.33	<.005	<.02	1.50	<.005	0.09
V33	0.20	<.005	<.02	0.46	<.005	0.02	1.56	<.005	0.14
V34	0.19	<.005	<.02	0.81	0.061	<.02	1.98	0.015	0.04
V35	0.16	<.005	<.02	1.13	<.005	<.02	0.81	0.006	0.04
V36	0.13	<.005	<.02	0.36	<.005	<.02	2.05	0.007	0.10
NV1	0.25	<.005	<.02	0.90	0.016	0.02	3.28	0.030	0.07
NV2	0.20	<.005	<.02	0.48	<.005	0.03	1.54	0.025	0.18
NV3	0.15	<.005	<.02	0.32	0.012	<.02	1.13	0.007	<.02
NV4	0.14	<.005	<.02	0.39	0.008	0.04	0.94	0.017	0.13
NV5	0.15	<.005	<.02	0.52	<.005	<.02	1.47	0.011	0.07
NV6	0.26	<.005	<.02	0.43	<.005	<.02	2.17	0.007	0.13
NV7	0.24	<.005	<.02	0.71	0.008	<.02	2.16	0.010	0.11

NV8	0.16	<.005	<.02	0.35	<.005	<.02	1.08	0.008	0.07
WV1	0.17	<.005	<.02	0.34	<.005	<.02	1.02	0.030	0.16
WV2	0.16	<.005	<.02	0.54	<.005	<.02	1.78	0.010	0.08
WV3	0.19	<.005	<.02	0.46	<.005	<.02	1.27	0.010	0.11
R1	<.02	<.005	<.02	0.04	<.005	<.02	0.09	0.005	0.16
R2	0.12	<.005	<.02	0.46	<.005	<.02	1.03	<.005	0.10
R3	0.11	<.005	<.02	0.35	<.005	<.02	0.84	0.010	0.13
R4	0.14	<.005	<.02	0.47	<.005	<.02	1.97	0.009	0.12
R5	<.02	<.005	0.02	0.11	0.007	0.02	0.10	0.016	0.22
R6	0.09	<.005	<.02	0.27	<.005	<.02	1.32	0.008	0.14
R7	0.07	<.005	<.02	0.18	<.005	<.02	0.72	0.005	0.08
B1	0.15	<.005	0.02	0.32	0.006	0.02	1.19	0.006	0.18
B2	0.26	<.005	<.02	0.52	0.005	<.02	1.62	0.009	0.13
B3	0.12	<.005	<.02	0.39	<.005	0.04	0.65	0.006	0.18
B4	0.18	<.005	0.02	0.45	<.005	0.02	1.44	<.005	0.09
B5	0.06	<.005	<.02	0.31	0.005	<.02	0.49	0.007	0.14
B6	0.82	<.005	0.02	0.42	0.007	0.03	0.80	0.012	0.07

Statistical Data Summary

	Cold#4			Hot#1			1 Litre		
	Cu	Pb	Zn	Cu	Pb	Zn	Cu	Pb	Zn
Mean	0.17	<.005	<.02	0.47	0.007	0.02	1.41	0.013	0.11
Std Dev	0.11	0.001	0.01	0.21	0.012	0.06	0.70	0.010	0.06
Max	0.82	0.005	0.03	1.13	0.070	0.44	3.28	0.046	0.31
Min	<.02	<.005	<.02	0.04	<.005	<.02	0.09	<.005	<.02

HOUSE SAMPLING PROGRAM
Water Quality Parameters

Sample	pH	Alk.	Hardness		T.H.
			Ca	Mg	
V1			0.96	0.15	3.01
V2	5.9	2.13	0.99	0.14	3.04
V3			0.60	0.20	2.32
V4			0.96	0.15	3.01
V5			1.09	0.14	3.29
V6			0.95	0.15	2.99
V7	6.0	2.13	1.15	0.13	3.40
V8			0.94	0.15	2.96
V9	5.9	1.88	0.99	0.15	3.09
V10			0.93	0.15	2.94
V11	5.9	1.38	0.85	0.15	2.74
V12	5.5	0.75	0.57	0.18	2.16
V13			0.76	0.16	2.55
V14	6.0	1.88	1.02	0.14	3.12
V15	5.8	1.50	0.76	0.16	2.55
V16			0.60	0.18	2.24
V17	5.9	1.50	0.96	0.15	3.01
V18	5.8	1.13	0.68	0.17	2.40
V19	5.6	1.00	0.56	0.19	2.18
V20	5.6	0.63	0.62	0.18	2.29
V21	6.0	2.38	1.16	0.14	3.47
V22	5.9	1.88	0.92	0.15	2.91
V23			0.94	0.15	2.96
V24	5.9	1.88	1.01	0.15	3.14
V25			1.20	0.13	3.53
V26			0.98	0.15	3.06
V27	5.7	0.88	0.64	0.18	2.34
V28			0.91	0.15	2.89
V29			1.00	0.14	3.07
V30	5.9	2.13	1.07	0.14	3.24
V31	6.0	2.63	1.25	0.12	3.61
V32			1.08	0.13	3.23
V33			0.92	0.14	2.87
V34	5.6	1.00	0.62	0.16	2.20
V35			0.92	0.13	2.83
V36			0.95	0.13	2.90
NV1	6.0	2.50	1.07	0.13	3.20
NV2			0.65	0.16	2.28
NV3			1.38	0.11	3.89
NV4			0.94	0.14	2.92
NV5			0.65	0.15	2.24
NV6	6.0	2.88	1.58	0.11	4.39
NV7			1.26	0.11	3.59

NV8	5.8	1.88	0.94	0.15	2.96
WV1			0.61	0.17	2.22
WV2	5.8	1.38	0.80	0.15	2.61
WV3	5.7	0.88	0.62	0.18	2.29
R1			1.08	0.16	3.35
R2	6.0	1.88	0.94	0.15	2.96
R3	6.1	2.38	1.48	0.12	4.18
R4	5.7	1.38	0.61	0.18	2.26
R5	5.9	1.13	0.73	0.16	2.48
R6	6.0	1.88	0.89	0.15	2.84
R7			1.24	0.13	3.63
B1			1.01	0.14	3.09
B2			0.99	0.15	3.09
B3	5.8	1.75	0.97	0.15	3.04
B4			1.00	0.14	3.07
B5	6.0	2.38	1.17	0.13	3.45
B6			1.10	0.16	3.40

Statistical Data Summary

	pH	Alk.	Hardness		T.H.
			Ca	Mg	
Number	30	30	60	60	60
Average	5.8	1.70	0.94	0.15	2.95
Std Dev	0.1	0.59	0.23	0.02	0.50
Max	6.1	2.88	1.58	0.20	4.39
Min	5.5	0.63	0.56	0.11	2.16

Units are:
Total Alkalinity (mg/L) as CaCO3
Calcium (mg/L)
Magnesium (mg/L)
Total Hardness (mg/L) as CaCO3