GVWD CORROSION CONTROL INITIATIVE - PHASE II INHIBITOR CHEMICAL TESTING AT SEYMOUR DAM

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

Department of Civil Engineering

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

MARCH 1993

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ABSTRACT

Greater Vancouver Regional District (GVRD) waters have some of the highest corrosion potentials in North America. A previous pilot study determined that copper corrosion could be reduced by 60 to 80 percent and lead corrosion could be reduced by 10 to 60 percent by disinfecting with chloramine instead of chlorine and by adjusting pH and alkalinity to 8-8.5 and 20 mg/L as calcium carbonate ($CaCO_3$) respectively. The study also recommended that further corrosion control pilot testing be carried out with chemical inhibitors as an adjunct to pH and alkalinity adjustments. The purposes of the inhibitor testing would be to determine their effectiveness in further reducing lead levels at the tap, reducing iron pipe deterioration in some of the older municipal systems, and to determine the impact of inhibitors on re-growth potential.

A literature search, and extensive discussion with chemical suppliers determined that zinc orthophosphate and Type N sodium silicate offered the best potential as corrosion inhibitors with GVWD type waters. Thus it was decided to evaluate (within the limitations that the seven loop pilot plant would allow) zinc orthophosphate, type N sodium silicate and a commercial blend of the two. pH and alkalinity were adjusted by the addition of lime [$Ca(OH)_2$] and sodium bicarbonate ($NaHCO_3$) respectively, and the water was disinfected with 2.5 mg/L of monochloramine (NH_2Cl).

The copper and cast iron corrosion rates were measured over the course of 12 months on pipe inserts removed at 3 month intervals. The removed inserts were measured for weight loss, pitting corrosion, and interior biofilm was monitored. In addition, corrosion rates were monitored weekly using an electrical resistance measuring device. Standing water samples taken regularly from lead/tin solder jointed soft copper

plumbing coils, submerged free standing coils of 50/50 lead/tin solder, and from faucets on each loop were measured for lead, zinc and copper leaching.

The results of the weight loss determinations from the pipe inserts and the weekly resistance measurements indicate that all of the inhibitors, particularly the zinc orthophosphate, work very favorably with copper, but they offer negligible additional benefit over that obtained from the pH and alkalinity adjustments alone in the case of the cast iron coupons.

Some very high metal levels were measured in some of the leaching samples. It is postulated that these high levels were due to the redissolution and sloughing (during the 24-hour standing period) of some of the protective scale that formed during periods when the water was flowing. Previous studies have shown that inhibitors such as phosphates and silicates work best in a constant flowing situation. A further suggestion of this sloughing was demonstrated by the appearance of sediment in the samples even though the water was clear prior to isolation of the standing samples. The protective scale which is formed by inhibitors is generally a metal and silicate combination or a metal, phosphate and zinc combination. Thus if the scale sloughs off, more metal will be in the sample when it is digested.

Another problem which can occur with zinc orthophosphate at pH above about 7.5 is that the zinc orthophosphate can precipitate out before forming a protective scale (EEC 1990). Sometimes, zinc levels were found to be a great deal higher than can be attributed to the feed itself (0.37 mg/L). It seems likely that these high zinc levels were due to a combination of precipitation and sloughing. The occurrence of sediment further corroborates this hypothesis.

Generally, in the leaching samples from the solder coils, the lowest lead levels occurred in the raw water. It could be that the lead reacted adversely to all of the treatments tried.

Peak metals levels occurred in several loops at the same time. The reason for these coincidental peaks is not clear. There is no obvious pattern. It may be that the degree of scale dissolution and sloughing is dependent on pH and/or alkalinity levels and/or fluctuations, or it may be due to some other factors or combinations of factors. During the standing period the scale appears to weaken but it may not come off until several weeks later. There did not appear to be a correlation between metal levels and total chlorine levels. More work is needed in this area to try and ascertain what causes the extremely high metal levels at certain times and not others. The scale formed seems to be very much a dynamic and ever evolving component in the corrosion situation.

The biofilm examinations showed no significant differences between loops with the copper coupons, but higher growth levels were found with the cast iron coupons in the loops with the zinc orthophosphate feed.

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1. INTRODUCTION

1.1 Background Information

Most consumers in greater Vancouver are quite pleased with the pristine nature of the water available to them at the tap. Most of the time, the water is colour and odour free, and it is very soft which makes it a pleasure to bathe in and ideal for laundry purposes. Unfortunately, these same qualities give the water one of the highest corrosion potentials in North America. The corrosivity is due to the following main factors:

- Low pH - All of the water consumed by the Greater Vancouver Water District (GVWD) comes from surface sources. The rainfall in the British Columbia lower mainland area is acidic [pH 5 or less (House of Commons Sub-committee on Acid Rain, 1991)] and the granitic rock in the watershed does little to buffer it. The raw water pH range is 6.0 to 6.3, and after chlorination it is 5.4 to 5.9.

- Low alkalinity and buffering capacity - Raw water total alkalinity range is 1.5 to 3.7 mg/L as $CaCO_3$, and after chlorination it is 0.5 to 2.0.

- Low mineral content - Total dissolved solids range is 12 to 16 mg/L.

- High dissolved oxygen content - Typically the water is at or close to DO saturation.

- Disinfection with chlorine - Chlorine is not only an aggressive oxidizer in itself, but it also lowers the pH of the water even further, as mentioned.

The impact of corrosion is felt in terms of economics, health, and aesthetics.

1.2 Costs of Corrosion

The following are some of the cost considerations resulting from corrosivity in drinking water:

- Technical support of utility staff and consultants;

- Corrosion control measures;

- Replacement, maintenance, and repair of plant, equipment and material;

- Plant shutdowns for repairs and replacement;

- Special processing;

- Corrosion allowance;

- Process upsets resulting from corrosion;

- Product contamination;

- Product loss from corroded vessels;

- Overdesign to allow for corrosion and inability to use otherwise desirable materials;

- Cooling requires excessive water use because heat transfer is retarded by deposits of corrosion products;

- Flow Impairment. Tuberculation can result in severe reduction in flow capacity. In water mains this decreases the effective value of the system and increases pumping costs due to reduction of the open area in the pipe and increased resistance due to tubercle build-up;

- Clogging meters due to corrosion products;

- Extra cleaning requirements due to staining of fixtures;

- Water damage and insurance; and

- Health care costs.

Ryder (1980) defines direct costs as those which result in a loss to the economy and indirect costs as those resulting from the consumption of energy and materials that would not otherwise be required. In 1975 In the United States, annual corrosion costs were estimated at $70 billion of which the direct costs were approximately 25 percent. Ryder estimated that corrosion control measures could have reduced the direct costs by 15 percent or $2.6 billion.

In 1976, plumbing contractors estimated that the cost of replacing the accessible parts of a single family home hot and cold water system at $500 for small one bath homes and $1000 for larger one and a half and two bath homes. The cost to replace piping enclosed in walls and ceilings would be much higher due to the requirement for other trades to cut and replace these finishes. Kirmeyer and Logsdon (1983) estimated the cost of replacing all of the plumbing in a home to be at least $2000 to $3000 US.

According to Ryder (1980), in Seattle, pH and alkalinity adjustments to suppress corrosion reduced overall corrosion related costs by 25 percent. And for newer buildings, the relative savings may be as much as 75 percent because the effects of corrosion are much more severe on new piping systems which have not had any protective scale build-up.

1.3 Metal Levels and Regulatory Concerns

Metals which are leached from distribution and plumbing systems can be consumed causing health problems. Health factors led the United States Environmental Protection Agency (EPA) in 1991 to mandate that US utilities take specified corrective action when standing water lead levels exceed 0.015 mg/L or copper levels exceed 1.3 mg/L in more than 10 percent of samples taken at the tap. In his study which sampled overnight standing tap water in 36 Vancouver homes, Singh (1990) determined that the first 1/4 L samples had levels that exceeded the EPA action levels 64 percent of the time for copper and 24 percent of the time for lead.

The Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1989) proposed maximum acceptable concentration (MAC) for lead is 0.01 mg/L, but that is for a "thoroughly flushed" sample. Presently, there is no Canadian MAC for copper but there is an aesthetic objective (AO) of ≤ 1.0 mg/L, presumably to reduce blue-green staining of plumbing fixtures and laundry. There is no specification whether the copper sample should be flushed or not, so presumably, the AO could be applied to a

standing sample. The objective for copper is under review. Singh (1990) found that even after prolonged flushing of the taps sampled in high-rise buildings, the Canadian MAC for lead and the AO for copper were exceeded in 6 percent and 9 percent of the cases, respectively. However, with single family dwellings, after 5 minutes of flushing, cold water samples were within both EPA and Canadian compliance levels.

Plumbing age has a direct effect on metal levels, particularly in waters not treated for corrosivity. Electrical grounding also increases metal levels but plumbing age is more significant Lee et al., (1989). Lead levels from lead soldered copper plumbing are highest within the first 24 months of construction after which they level off (Boffardi, 1988). In a study of lead soldered copper pipe in age groups of 0 to 1 year, 1 to 5 years, and 6 to 20 years, at a pH of 7.5 the average lead levels 10 seconds after first flush were 100 μg/L, 40 μg/L and 4 μg/L respectively (Murrell, 1988).

Lead levels increase substantially in standing water, exceeding 50 μg/L in 1.5 to 2 hours and continue to increase for 6 hours or more (Boffardi, 1988; Bailey et al., 1986). Brass faucets will contribute one third of lead levels in the first 1 litre draw sample (Lee et al., 1989). In a first draw sample from a faucet, 60 to 75 percent of the lead is picked up in the first 125 ml. After 200 to 250 ml of water has flowed, 95 percent or more of the lead has normally been flushed from the faucet. (Gardels and Sorg, 1989). Unfortunately, flushing the tap before consumption takes time and wastes water. To save time and water the consumer may not flush; indeed he may not even be aware that he should flush. Regardless of any other measures taken, a serious effort must be made on the part of municipalities to ensure consumer awareness of the health implications of metal ingestion at the tap.[1]

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[1]There are, of course, other sources of lead besides the tap, such as the air we breathe due to leaded gasoline (no longer a problem in Canada, but still a serious one in most other countries including the United States). Lead based paints and soils are important sources for small children; and, surprisingly, the lead crystal found in many home china cabinets can leach significant levels of lead. Any effort to foster public awareness of the health hazard posed by lead should also consider these other sources.

1.4 Health, Aesthetic, and Other Effects

1.4.1 Lead

Lead has been used to convey water since the days of the Roman Empire and only recently has it been banned for use as a drinking water conduit. As recently as 1979, lead service lines were still being installed in some areas of the U.S. (Patterson and O'Brien, 1979). Its popularity was due to the fact that certain naturally forming salts can form adherent passivation scales that make lead highly resistant to corrosion and attack by natural waters. However, soft water is corrosive to lead due to the high solubility of lead oxide (ibid.). Corrosion rarely causes lead pipe failure because the actual amount of the metal that is corroded away is very small. Rather the problem is health related because, being a cumulative poison, even minute ingested quantities of dissolved or particulate lead salts can be toxic over time. There are no known beneficial effects from lead ingestion. Toxic effects (Patterson and O'Brien, 1979) in children include learning disabilities and even mental retardation, hyperactivity, motor and behavioral problems, renal insufficiency, and hypoglycemia. In adults, symptoms include diarrhea, headaches, chest pains, frequent fatigue, and hypertension.

In Scotland, lead was used traditionally for domestic plumbing until the late 1960's (Richards and Moore, 1984). The lead problem was further exacerbated by the common practice in home construction of including a lead lined storage tank to supply water for all domestic use. The European Community drinking water directive, which came into effect in July 1985, specified that where lead plumbing is installed and lead levels frequently exceed 100 µg/L, "measures must be taken to reduce the consumers' exposure to lead". Prior to any measures being taken to reduce corrosivity, lead levels in Ayr (population 49,000) water were very high. In 112 samples from dwellings, the mean lead level was 466 µg/L, 72 percent of the samples exceeded 100 µg/L and 14 percent

exceeded 1000 µg/L. After a treatment program was instituted, in which pH was adjusted to 9, 95 percent of samples had less than 100 µg/L and the majority had less than 50 µg/L. More importantly, lead blood levels decreased by 40 percent after water treatment was instituted.

Even though lead pipe is no longer used for new pipe installations, it is still in existence in many municipal distribution systems. Moreover, as already mentioned, significant quantities of lead can be leached from the solder and from the brass fixtures in most premises plumbing. Even though 50/50 lead/tin solder has been banned from plumbing use in British Columbia (in favour of 95/5 tin/antimony solder) since 1989, it still exists in most of the homes built prior to that date.

1.4.2 Copper

Copper has been used to convey drinking water since the early days of civilization, but only in the past 75 years or so has it been widely used in domestic plumbing (Rambow and Holmgren 1966). Its popularity is due to its relative durability. Naturally forming copper scale consists mainly of cuprous and cupric oxides and hydroxides. It is thin (<0.1 mm), is uniformly distributed, dense, adherent, forms rapidly and it is resistant to abrasion, unlike the scale that usually forms on iron or galvanized surfaces. Young copper scales weighing less than 0.1 mg/cm^2 are remarkably protective (Reiber, 1989). Nevertheless, soft waters are very corrosive to copper, which can lead to premature failure of the pipe. Although localized attack (pitting) is rare on copper surfaces, where it does occur, the intensity of the attack along with the thinness of the copper pipe can reduce the copper pipe service life from decades to months (ibid.)

In contrast to lead, copper is an essential nutrient to both plants and animals. However, in humans, extremely large doses can lead to severe mucosal irritation and breakdown, capillary damage, liver and renal damage, central nervous system irritation and depression (World Health Organization, 1984). Due to its tendency to induce vomit-

ing if ingested in large quantities, copper poisoning in humans is rare and there is no evidence of chronic toxicity due to long term ingestion at low levels. Copper is a bactericide and is toxic to fish at quite low levels, so it can pose a threat to sewage treatment plants and/or receiving waters.

Copper salts can cause blue green staining of plumbing fixtures, laundry, and bleached hair. Stained bathroom fixtures are very common in Greater Vancouver.

1.4.3 Ferrous Metals

Cast iron and steel pipe have been used to transport water for centuries. These materials are cheap and durable from a structural point of view. Of all materials used for water conveyance purposes, ferrous metals are the most subject to corrosion but failure of the pipe due to leakage or breakage is rare due to the thickness of the material used. Generally, the most serious result of ferrous pipe corrosion is loss of flow capacity due to tuberculation and scale accumulation. Schneider and Stumm (1956) showed that a cast iron pipe can lose 15 percent of its flow capacity within one month. If 2.5 percent of the thickness of a one inch ferrous pipe is corroded away, the pipe may be completely filled with corrosion products (Smith, undated). Studies by Curry and Wright (1975) in some southern Illinois communities found arterial mains having only 20 to 30 percent of their original capacity because of corrosion product build-up.

Ferrous pipe is often protected from corrosion by application of protective coatings, cement linings etc., or by cathodic protection; by galvanizing or using zinc or magnesium alloy anodes.

Since significant quantities of iron are required in the human diet on a daily basis, deleterious health effects from ingestion of dissolved or particulate iron are rare. Ingestion of very large quantities of iron can cause a condition known as haemochromatosis (a condition wherein normal body regulatory mechanisms fail to function correctly), but such occurrences are extremely rare.

Iron salts in drinking water can make the water less palatable, and can cause red staining of plumbing fixtures and clothing during laundering.

1.5 Previous Study

Phase I of the Greater Vancouver Water District (GVWD) Corrosion Control Initiative was a 1988-1990 pilot scale study by Economic and Engineering Services (EES) of Olympia WA (March 1990), which compared the effects of disinfection with chloramine versus chlorine in raw and pH and alkalinity adjusted water. The study concluded that copper corrosion could be reduced by 60 to 80 percent and lead corrosion could be reduced by 10 to 60 percent over corrosion levels of the normal chlorinated water currently produced by the GVWD, by disinfecting with chloramine instead of chlorine and by adjusting pH and alkalinity to 8-8.5 and 20 mg/L respectively. It was recommended that further corrosion control pilot testing be carried out with chemical inhibitors as an adjunct to pH and alkalinity adjustments. The inhibitor testing should attempt to determine their effectiveness in further reducing lead levels at the tap, reducing iron pipe deterioration in some of the older municipal systems, and the impact of inhibitors on re-growth potential.

1.6 Objective and Scope

The objective of this study was to evaluate the corrosion inhibition capability (within the limitations that the pilot plant allowed) of zinc orthophosphate, type N sodium silicate and a commercial blend of the two, with concurrent adjustment of pH and alkalinity. Due to the limited number of loops available for testing, this study could not lead to outright acceptance or rejection of a particular inhibitor. At best it was hoped to determine an idea of the effectiveness of the inhibitors tested relative to raw water, pH and alkalinity adjusted water, and each other. Further, it was expected that enough in-

formation could be gained to give an indication of the direction to be taken for further study.

2. BACKGROUND AND LITERATURE SEARCH

2.1 Basic Corrosion Theory

The word corrode which comes from the Latin "rodere", meaning to gnaw, is defined by *Webster's Encyclopedic Dictionary of the English Language*[2] as "to eat away gradually as if by gnawing, especially by chemical action".

During the smelting and manufacturing process, a great deal of energy is expended to remove bound oxygen and moisture from ore to produce a finished metal. The finished metal is highly stressed due to stored energy. If the metal comes into contact with oxygen and moisture some of the stored energy may be released resulting in corrosion. Usually the greater the energy input in the manufacture the greater the tendency for the metal to corrode.

According to U.R. Evans (Obrecht and Pourbaix 1967) practically all corrosion of metals in aqueous environments is due to electrochemical processes. How readily an electrochemical reaction can take place at the interface of a metal and an electrolyte depends on the relative values of the electrode potential, E, of the metal and the thermodynamic equilibrium potential, E_0, of the reaction. Oxidation can only occur if the electrode potential of the metal is greater than the equilibrium potential of the reaction. Conversely, a reduction reaction can only proceed if the electrode potential of the metal is less than the equilibrium potential.

In order for corrosion to occur, a corrosion cell consisting of four critical elements must be formed as shown in Figure 2.1.

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[2]Portland House. New York. 1989.

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Conducting Solution (Electrolyte)

Ion Migration

$M \longrightarrow M^+ + e^-$

Anodic area where metal
dissolves and
passivation film forms

$A + e^- \longrightarrow A^-$

Cathodic area where
reduction of oxygen,
chlorine, etc., takes place

e^-

Conducting Metal
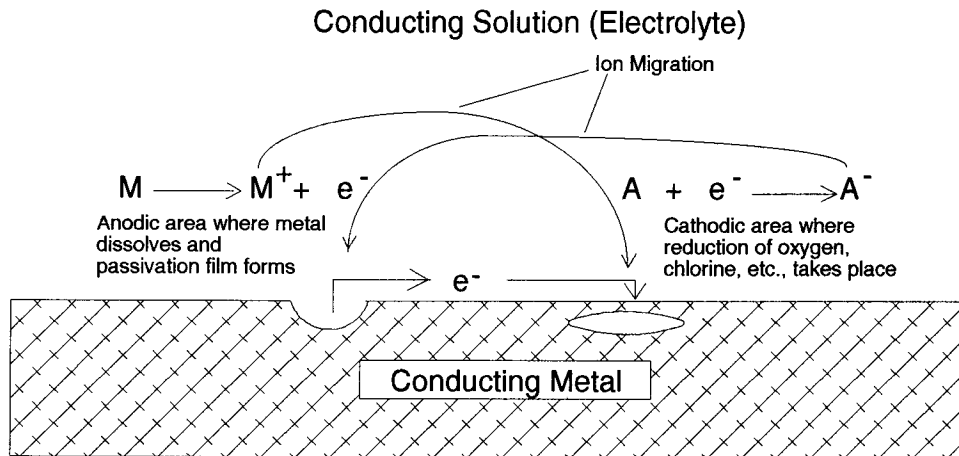
Corrosion Cell Showing Anodic and Cathodic Regions

Figure 2.1

The four critical elements are the:

a. anode - where the metal is oxidized and electrons are generated that flow through the metal and through the electrolyte to the cathode;

b. cathode - where the electrons flowing from the anode reduce corrosive substances such as dissolved oxygen, chlorine, and hydrogen ions; typical reduction reactions could be:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-; \qquad\qquad 2\text{-}1$$

$$HOCl + H^+ + 2e^- \rightarrow Cl^- + H_2O; \text{ and} \qquad\qquad 2\text{-}2$$

$$2H^+ + 2e^- \rightarrow H_2\uparrow \qquad\qquad 2\text{-}3$$
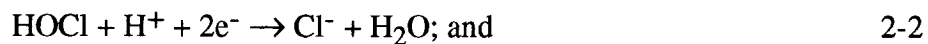
among many other possibilities;

c. conductor - between the two electrodes, i.e., the metal itself which will permit the transfer of electrons from the anode to the cathode; and

d. electrolyte - the other medium which will conduct various ions between the

   cathode and the anode and complete the circuit.

The corrosion cell is by no means static. The electrodes usually change location

continuously, and the distance between the anode and the cathode is often infinitesimal

and will vary continuously as well.

Some of the cations generated at the anode along with other cations present in the

electrolyte will tend to migrate to the cathode where the electrode potential is lower,

while some of the anions will tend to migrate to the higher potential at the anode. If pre-

sent, some of the ferrous ions that migrate to the anode will react as follows:

$$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2 \qquad\qquad\qquad 2\text{-}4$$

This reaction could also take place at the anode as a result of the migration of

some of the hydroxyl ions.

Some other reactions that may occur are:

$$Fe^{3+} + 3OH^- \rightarrow \underline{Fe(OH)_3}\downarrow; \qquad\qquad\qquad 2\text{-}5$$

$$Fe^{3+} + 2O_2 \rightarrow \underline{Fe_3O_4}\downarrow; \text{ and} \qquad\qquad\qquad 2\text{-}6$$

$$Fe^{2+} + CO_3^= \rightarrow \underline{FeCO_3}\downarrow \qquad \text{among numerous others.} \qquad 2\text{-}7$$
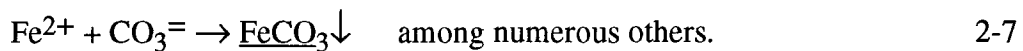
Some reactions can lead to a build-up of corrosion scale due to precipitation.

Since the overall corrosion rate is limited by the rate of the slowest step in the circuit,

that form of corrosion scale which tends to impede the migration of ions can assist in re-

ducing corrosion.

2.2 Types Of Corrosion

In a potable water system the following are the main types of corrosion that can occur.

2.2.1. Uniform corrosion

The corrosion attack is spread more or less equally giving a uniform depth of penetration over the entire surface. It normally occurs with acid solutions or in water with a high level of total dissolved solids (TDS) and high electrical conductivity. Uniform corrosion is most common in copper and lead pipe.

2.2.2. Galvanic corrosion

Galvanic corrosion arises from the uninsulated contact of two dissimilar metals of different electrode potentials. The less noble metal becomes the sacrificial anode while the nobler metal acts as the cathode and the area near the galvanic anode remains corrosion free as long as the anode and electrical conductivity continue to exist. Galvanic corrosion can occur in copper pipe with lead soldered joints, with the solder forming the anode. Oliphant (1983) found total lead levels of one to two orders of magnitude higher from lead soldered joints than would be expected from equilibrium solubility calculations.

2.2.3. Crevice corrosion

Crevice corrosion occurs in areas where there is poor circulation and usually oxygen depletion (e.g., where metal overlaps as with a rivet). Halides and sulfates tend to migrate into crevices and combine with the dissolved metal to form strong acids. For example, if there are chloride ions in the water, iron pipe crevices will accumulate a high concentration of $FeCl_2$ with resulting hydrolysis:

$$FeCl_2 + 2H_2O \rightarrow \underline{Fe(OH)_2}\downarrow + 2H^+ + 2Cl^- \qquad\qquad 2\text{-}8$$
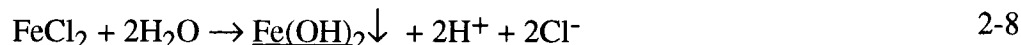
As the acidic conditions increase metal corrosion locally, even more of these cations tend to migrate into the crevice and the process accelerates with time. Poor construction practices can lead to crevice corrosion from such things as mud, sand, or cinders that can act as long lasting anodes. Threaded junctions, screwed joints and inverted seams are other potential sites for crevice corrosion.

2.2.4. Pitting corrosion

Pitting corrosion occurs when an anodic site remains static and a tubercle forms. It can occur when a portion of protective corrosion scale comes off leaving a bare metal spot that quickly becomes a localized permanent anodic site. As with crevices, circulation is very poor inside the tubercle resulting in a build-up of halides and sulfates. Uhlig (1948) measured pHs in the range of 3 to 4 in some pits. Pitting corrosion is typically found in ferrous materials.

2.2.5. Concentration cell corrosion

Concentration cell corrosion is believed to be the most common type of corrosion, but it is difficult to measure (AWWA 1990). It occurs when differences in the total or the type of mineralization exist. If the concentration of aqueous solution species is different between two parts of the metal a difference in electrode potential will exist and corrosion can occur.

2.2.6. Cracking corrosion

Cracking corrosion results in the formation of either inter granular or transgranular cracks which can lead to premature failure of the pipe. The amount of actual corrosion may be small but the results can be catastrophic.

2.2.7. Selective leaching

Soft, aggressive waters can selectively corrode away the zinc in brass leaving a porous mass of soft, brittle copper. Destanification in bronzes is another example of selective leaching.

2.2.8. Erosion corrosion

Erosion corrosion most often occurs at the entrance to pipes, sharp bends, near deposits, and where pipe volume changes suddenly. If water velocity is high enough to cause significant turbulence, severe localized corrosion can occur as a result of impingement attack and cavitation. Impingement attack occurs when gas bubbles strike the metal surface releasing enough energy to break-up film or corrosion scale. If the impacts keep occurring at the same location, pits can form. Cavitation is caused by vibration and the formation and collapse of vapour filled cavities at the metal surface where pressure changes frequently and abruptly.

2.2.9. Stress corrosion

Cold working of pipe during threading can lead to dissimilar stress of the metal which can result in localized corrosion. Stress corrosion occurs frequently at the threaded connections of galvanized steel pipe.

2.2.10. Microbiologically induced corrosion

Microbiologically induced corrosion is an area that deserves considerable more study. Nitrifying bacteria, for example, contribute to acidity by producing hydrogen ions in the conversion of ammonia to nitrites and nitrates:

$$NH_4^+ + 1\frac{1}{2}O_2 \rightarrow NO_2^- + 2H^+ + H_2O \qquad\qquad 2\text{-}9$$

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \qquad\qquad 2\text{-}10$$
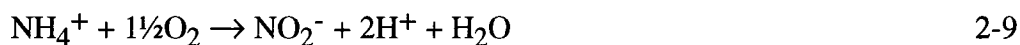
Microbiologically induced corrosion could be made worse if there is an excess of ammonia in a chloramination process and there are nitrifying bacteria present.

Another example of microbiologically induced corrosion may be caused by one of the iron bacteria, *Thiobacillus ferrooxidans*, which derives energy from oxidation of iron.

2.3 Factors Affecting Corrosivity

There is a myriad of factors that determine the corrosivity of a water and the efficacy of corrosion control strategies. The following is a list of some of the more important ones:

2.3.1. Alkalinity, buffering capacity, and buffer intensity

The higher the buffer capacity, the greater the resistance to change in pH; many water treatment chemicals such as hydroflurosilicic acid, alum, or chlorine tend to reduce pH which can contribute to corrosion (see 2.3.9. below). Alkalinity is also important in metal salt solubility considerations.

2.3.2. Ammonia

Ammonia has been shown to be corrosive to copper and copper alloys due to the formation of copper-ammonia complexes such as $Cu(NH_3)^{++}$.

2.3.3. Dissolved inorganic carbonate (DIC), total inorganic carbon (TIC)

DIC is the total concentration of all dissolved inorganic carbonate species including $H_2CO_3^{*3}$, HCO_3^-, $CO_3^=$, as well as salts, complexes and ion pairs including for example: $CaHCO_3^-$, $CaCO_3$, $PbCO_3$, $Pb(CO_3)_2^=$, $Pb_3(OH)_2(CO_3)_2$, $CuCO_3$, $Cu(CO_3)_2^=$,

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$^3H_2CO_3^*$ refers to the total concentration of dissolved carbon dioxide (CO_2) and carbonic acid (H_2CO_3).

$FeCO_3$ and many others. If total alkalinity, pH, temperature, and ionic strength are known, DIC can be calculated. DIC is an important factor in lead solubility. It is important to determine the DIC level and whether the addition of DIC will be necessary before pH adjustment is initiated, because of the interrelationship of total alkalinity and pH (Schock 1989).

The presence of $CO_3^=$ can lead to formation of protective scale of lead carbonate or basic lead carbonate [$Pb_3(OH)_2(CO_3)_2$, also known as hydrocerussite]. Patterson and O'Brien (1979) found that for minimum lead carbonate salt solubility there is a corresponding pH value at a given DIC concentration and a corresponding DIC value for a specific pH value . They observed that the highest lead corrosion rates occurred in the absence of carbonate and a slight addition of carbonate reduced the corrosion rate substantially. They also found that carbonate addition alone provides substantially better protection than pH adjustment alone. They concluded that the optimum level for minimum lead corrosion is in the pH 8 to 8.5 range and a minimum carbonate alkalinity of 20 mg/L as $CaCO_3$. Boffardi (1988) suggests that in high alkalinity waters ($\geq$ 100 mg/L as $CaCO_3$), lead solubility is insensitive to pH over a range of 6.5 to 8.

Schock and Gardels (1983) showed that copper and lead solubility actually increases with high levels of carbonate due to complex formation. They concluded that plumbosolvency can be substantially reduced by increasing the pH to 9 or more with TIC in the range of 10 to 80 mg/L as $CaCO_3$. Schock (1980, 1981) showed that in the 8 to 8.5 pH range, low concentrations (about 30 mg/L as $CaCO_3$) of TIC are more effective in reducing lead corrosion than higher TIC levels (100 to 200 mg/L).

In his investigation of the relationship between pH and TIC and the precipitation of a lead carbonate, hydroxycarbonate or hydroxide film, Schock (1985) showed the minimum lead solubility to occur at a pH of 9.8 with a DIC of 30 to 40 mg/L as $CaCO_3$.

2.3.4. Dissolved oxygen (DO)

Corrosivity of a water to ferrous piping is directly proportional to DO concentration, but above a certain minimum, its impact on copper and aluminum corrosivity is less significant. Stone et al. (1987) determined oxygen to be the rate-determining reactant in the corrosion of copper and zinc with the limitation being either diffusion through the corrosion film or the reduction reaction itself.

2.3.5. Halides

Halides aggravate crevice and pitting corrosion as discussed. They can also tend to promote pitting by increasing the porosity of passivation[4] film (Kirmeyer and Logsdon, 1983).

2.3.6. Hardness

Generally soft, low mineralized waters (hardness < 25 mg/L as $CaCO_3$, TDS < 50 mg/L) are the most corrosive to piping materials. Moderately hard, mineralized waters (hardness = 25 to 125 mg/L as $CaCO_3$, TDS = 50 to 300 mg/L) are considered non aggressive. Hard, mineralized waters (hardness > 125 mg/L as $CaCO_3$, TDS > 300 mg/L) usually form $CaCO_3$ scale on the pipe wall which inhibits corrosion, but pitting corrosion can be a problem under certain conditions. However, Lee et al., (1989) found no relationship between hardness or calcium levels and lead levels from plumbing materials.

2.3.7. Hydrogen sulfide

Hydrogen sulfide increases corrosivity especially in waters with high organic and sulfate content (AWWARF, 1989).

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[4]Passivation is attained as a result of the build-up of insoluble film composed of a metal-oxide or metal-inhibitor compound which reduces the reactivity of the metal.

2.3.8. Organic tannins

Organic tannins which occur frequently in surface waters appear to lay down a protective film on pipe walls which can inhibit corrosion to some extent (ibid.). However, they can also form complexes with some metals such as copper and aggravate corrosion.

2.3.9. pH

pH is a significant factor in corrosivity. In soft, low mineralized waters, decreasing pH below about 8 usually increases copper and galvanized steel corrosion but may actually lower black steel corrosion. Lead solubility decreases in a pH range of 8 to 9. Below a pH of 8 to 8.5, a difference of even a few tenths can yield a lead solubility difference of 3 to 5 times (Schock, 1989). Generally, optimum pH levels for minimization of corrosion are 8 for copper, 9 for lead, and 7.5 for steel and zinc. Stone et al. (1987) found copper corrosion rates to be highly pH dependent but zinc showed very little difference. In the soft, low mineralized waters of Boston, Karalekas et al. (1983) found that pH adjustment alone will reduce lead corrosion but not sufficiently to reduce lead to acceptable levels.

Considering a copper-hydrogen cell, hydrogen ions must be reduced for the copper to be oxidized. Based on standard oxidation potential, such a reaction cannot proceed spontaneously since .

Half cell	Cu^0	=	$Cu^+ + e^-$	$E_0 = -0.521$ V	2-11
Half cell	$H^+ + e^-$	=	$\frac{1}{2}H_2$	$E_0 = 0.000$ V	2-12
	$Cu^0 + H^+$	=	$Cu^+ + \frac{1}{2}H_2$	$E = -0.521$ V	2-13
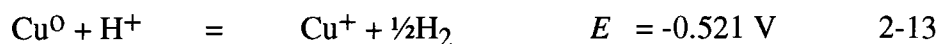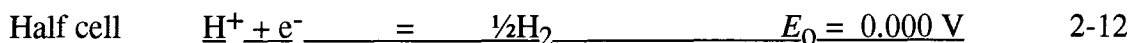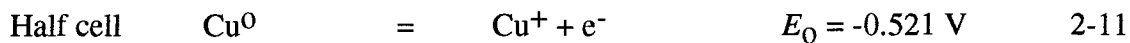
However, when oxygen is present, it will act as an oxidizing agent.

Half cell $\quad 2Cu^0 \qquad\qquad = \quad 2Cu^+ + 2e^- \quad E_0 = -0.521$ V $\qquad$ 2-14

Half cell $\quad \underline{2H^+ + \frac{1}{2}O_2 + 2e^-} \quad = \quad \underline{H_2O \qquad\qquad E_0 = +1.229\ V}$ $\qquad$ 2-15

$\qquad\qquad 2Cu^0 + 2H^+ + \frac{1}{2}O_2 \quad = \quad 2Cu^+ + H_2O \quad E = +0.708$ V $\qquad$ 2-16
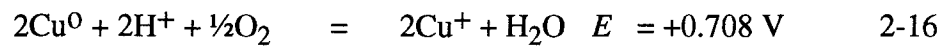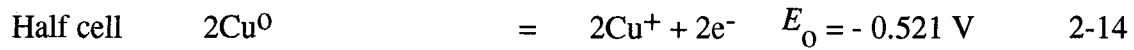
Thus it can be seen that in a pure water system, without oxygen presence, copper corrosion will not occur spontaneously.

Even though the hydrogen does not play a direct reduction role with copper, pH can influence copper corrosion in three ways (Reiber, 1989):

a. by altering the equilibrium potential of the oxygen reduction half cell; a decrease in pH shifts the reaction in the anodic direction and the potential of the copper-oxygen cell is raised increasing the corrosion driving force.

b. by changing the speciation of copper in solution; a change in pH alters the distribution of the dissolved copper species; a decreasing pH shifts the speciation from the hydroxocomplex form toward the hydrated (free) form; and

c. by affecting the stability and protective qualities of passivating films.

According to Reiber et al., (1987) and Reiber (1989) corrosion rates on copper surfaces with limited scale formation are extremely sensitive to pH, but aged surfaces with well formed scale are much less so. Reiber suggests that the solubilities of copper oxides [including suspected scale constituent cuprite (CuO_2)] increase with decreasing pH, making loss of scale at low pH values probable. At pHs less than 6, the corrosion rate increases rapidly such that, at pH 4, it is an order of magnitude higher than at pH 7. At higher pHs a greater buildup of oxide film layer occurs over time which increases the diffusional barrier and reduces the overall corrosion rate.

Hilburn (1983) proposed that copper corrosion rates may be limited by the transport of hydroxyl ions away from the cathodic site. The hydroxyl ions are generated by the oxygen half cell reduction:

$$O_2 + 2H_2O + 4e^- = 4OH^- \qquad E_O = 0.401 \text{ V} \qquad 2\text{-}17$$

The increase in hydroxyl ions at the cathode diminish the half cell reaction rate thus inhibiting the overall rate of corrosion. If the pH of the water is raised, the driving force for diffusional transport of the hydroxyl ions from the cathode is reduced.

Higher pH levels tend to reduce the effectiveness of free chlorine and increase rates of formation and final concentrations of trihalomethanes (THM) (Stevens, et al., 1976; Symons et al., 1981). In the pH ranges associated with drinking water, the only significant free chlorine species present are hypochlorous acid (HOCl) and hypochlorite ion (OCl⁻). Figure 2.2 is an approximation of the relative distribution of

Effect of pH on Distrubution of Free Chlorine Forms at 20 deg C
(After AWWA, 1990)
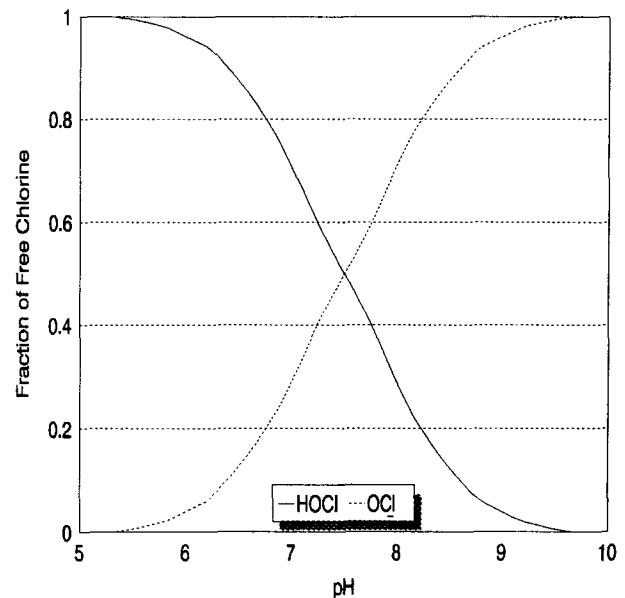
Figure 2-2

HOCl and OCl⁻ at pHs from 5 to 10. Since the disinfection effectiveness of HOCl is about 40 to 80 times that of OCl⁻ (Metcalf & Eddy, 1991) plans to change pH levels to reduce corrosion must take into account the effect it will have on disinfection and the amount of additional chlorine and contact time that may be required. The situation is further complicated by data (Berg, 1964) showing that viral destruction is enhanced sub-

stantially by the higher pH associated with lime softening, in spite of the reduced micro-biocidal effectiveness at the higher pH levels.

2.3.10. Chlorination

Chlorination usually increases corrosivity due to the formation of HOCl and pH reduction . Consider the strong HOCl corrosion cell with copper:

Half cell	$2Cu^0$	$=$	$2Cu^+ + 2e^-$	$E_0 = -0.521$ V	2-18
Half cell	$\underline{HOCl + H^+ + 2e^-}$	$=$	$\underline{Cl^- + H_2O}$	$\underline{E_0 = +1.49}$ V	2-19
	$2Cu^0 + HOCl + H^+$	$= 2Cu^+ + Cl^- + H_2O$		$E = +0.969$ V	2-20
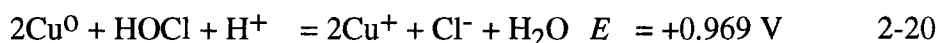
The OCl⁻ corrosion cell is also strong:

Half cell	$2Cu^0$	$= 2Cu^+ + 2e^-$	$E_0 = -0.521$ V	2-21
Half cell	$\underline{OCl^- + H_2O + 2e^-}$	$\underline{= Cl^- + 2OH^-}$	$\underline{E_0 = +0.90}$ V	2-22
	$2Cu^0 + OCl^- + H_2O$	$= 2Cu^+ + Cl^- + 2OH^-$	$E = +0.379$ V	2-23
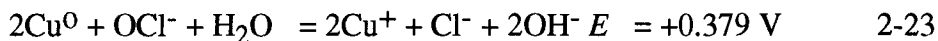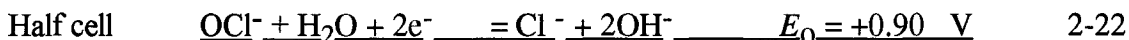
For each 1 mg/L of chlorine added, 0.7 to 1.4 mg/L of alkalinity as $CaCO_3$ will be neutralized depending on how the HOCl is ionized and how the chlorine is consumed by water constituents (Curry, 1978). Stone et al. (1987) found chlorine to be highly corrosive to copper with 1 mg/L of free residual chlorine giving roughly the same corrosion rate as 10 mg/L of dissolved oxygen, but the effect of chlorine on zinc corrosion was negligible. Note also that both corrosion cells result in the production of chlorides, which contribute to localized corrosion, as discussed earlier.

2.3.11. Silicates

Silicates often occur naturally in soft surface waters and in some ground waters due to leaching of siliceous material from soil and rock. They often act to inhibit corrosion by combining with corrosion by-products to form a protective scale (AWWARF, 1989).

2.3.12. Sulfates

Sulfates are comparable to halides in their effect on pitting corrosion, but they are not as serious as halides in their effect on crevice corrosion (ibid.).

2.3.13. Temperature

Generally, higher temperatures aggravate corrosion. Reaction rates for oxidation and reduction reactions tend to increase with increasing temperature, and the solubility of corrosion scale is also affected. The rate of product transport across the water/film boundary is temperature dependent as well. The solubility of $CaCO_3$ actually *decreases* with increasing temperature, so with hard waters, hot water lines often experience a significant drop in flow capacity due to scale buildup.

2.3.14. Velocity

Corrosivity can be exacerbated by both high and low flow velocity. High velocity can lead to erosion corrosion as discussed. Higher velocities also allow oxygen and other oxidizers to interact more easily with the pipe surface. If velocity is too low adequate corrosion scale may not form, or in the case of dead ends, the scale may partially dissolve or slough. Also, extremely low velocities make for poor circulation which encourages concentration cell corrosion.

2.3.15. Water Treatment Processes

a. <u>Turbidity removal</u> - The addition of alum [$Al_2(SO_4)_3 \cdot 14H_2O$] to raw water for turbidity removal typically results in the following chemical reaction where floc [$Al(OH)_3$] forms as a result of reaction with bicarbonate (HCO_3^-):

$$Al_2(SO_4)_3 \cdot 14H_2O + 6(HCO_3)^- \rightarrow 2\underline{Al(OH)_3}\downarrow + 3SO_4^= + 6CO_2 + 14H_2O$$
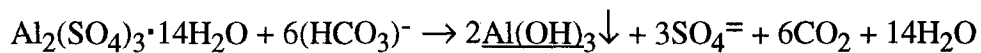
2-24

If there is not enough naturally occurring alkalinity to react with the alum dose, more will have to be added. Theoretically, each mg/L of alum will neutralize about 0.5 mg/L of alkalinity as $CaCO_3$ and produce 0.44 mg/L of CO_2 leaving a water that has a lower pH and less buffering capacity. For optimum coagulation, it is often necessary to keep the pH in the low 6 range during flocculation. Therefore, it may be necessary to add alkalinity after the turbidity removal process to maintain the original corrosivity characteristics of the raw water. But even if that is done, the dissolved sulfate will still be there to exacerbate pitting corrosion problems.

b. <u>Water softening</u> - Water softened by either ion exchange or lime-soda ash processes can leave a water more corrosive than before, due to alkalinity and calcium removal and consequently, lower buffering capacity.

2.3.16. Other parameters

The following may also influence corrosivity:

Total dissolved solids (TDS)	Iron
Ionic strength	Zinc
Conductivity	Copper
Polyphosphates	Sodium
Orthophosphates	Manganese
Nitrates	Magnesium
Natural color	Other trace metals
Total organic carbon (TOC)	

2.4. Chemical Approaches To Corrosion Control

No approach to corrosion control will be successful at eliminating it completely. At best, one can strive for a reduction in the rate to more manageable levels. That level of manageability will have to be weighed against the cost of implementing and operating corrosion control programs and any effects such programs have on the environment.

In terms of plant and equipment, it makes sense to use the most corrosion resistant materials available and to make use of corrosion resistant linings, coatings and paint where practical provided they are cost effective and they are harmless to human health. It also makes sense to discourage bad work habits in an effort to limit the corrosion that can be attributable to such. Even in the event that all reasonable efforts are being made to ensure that these more controllable factors are dealt with, corrosion can still be significant. The next step is to consider the use of chemical approaches.

Essentially chemical corrosion control programs can choose from two alternative approaches. Broadly speaking, they can be referred to as the *neutralization approach* and the *passivation approach*. The *neutralization* approach makes use of reactive chemi-

cals to overcome the effects of corrosive species in the water. For example, consider again the case of the copper corrosion reaction with HOCl:

$$2Cu + HOCl + H^+ \rightarrow 2Cu^+ + Cl^- + H_2O \qquad \text{2-25}$$
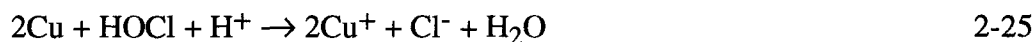
If the concentration of hydrogen ions is depressed via the addition of some form of alkaline chemical(s), the process will be less inclined to proceed and corrosion from this reaction will be less, provided nothing else of significance changes in the overall equilibrium.

Consider, once again, the oxidation of copper:

$$2Cu + 2H^+ + \tfrac{1}{2}O_2 \rightarrow 2Cu^+ + H_2O \qquad \text{2-26}$$

Oxygen removal would serve to reduce corrosion but that would be too costly to justify and it might result in a water that is less palatable. If the pH were suppressed, the reaction would also be slower.

The *neutralization* approach is based on stoichiometry and requires a great deal of theoretical knowledge of electrochemistry. If all the ingredients of a water are known and all of the significant contributors to corrosion are dealt with, all corrosion should, theoretically, be reduced by the use of *neutralization* measures. The problem is most waters are very dynamic, changing their chemical content continuously. While these changes may be minute in terms of percentage content in the water, they may be quite significant with respect to corrosion. Another problem is treatments for one corrosion problem may aggravate another e.g., raising pH to reduce copper corrosion may increase ferrous corrosion, as discussed.

The corrosion rate is governed by the slower of either the reaction kinetics at the metal surface or the transport of reactants or products through the solution and the cor-

rosion scale. Initially the rate is governed only by reaction kinetics and solution transport, but later, as corrosion scale develops (Figure 2.3) it becomes another possible rate limiting barrier. In most waters, the main reason that copper is so resistant to corrosion is due to the formation of a tough, adherent scale formed from naturally occurring copper corrosion products. Generally, the scale grows until it reaches a steady state thickness where the rate of growth is equal to the rate of destruction. The scale can be destroyed by dissolution or by spalling. In some cases, e.g., when a calcium carbonate scale is forming, the scale can continue to thicken indefinitely until flow becomes significantly impaired.
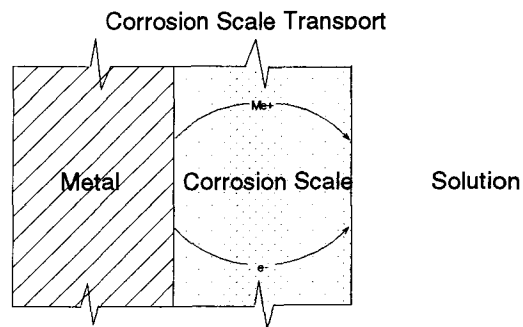
Figure 2.3

The *passivation* approach to chemical corrosion control involves physical interference with the operation of corrosion cells by deliberately causing a protective scale to be formed which tends to block the contact between the electrolyte and the anodes and cathodes. Such is the process that may occur naturally via the formation of $CaCO_3$ scale in some hard waters. While perfect insulation of the electrodes is not realistic, it is often possible to dramatically reduce the corrosion rate through the use of certain inhibitor chemicals whose sole function is to combine with the corrosion by-products and other water constituents to form a tough, adherent, protective scale. The scale is still slightly soluble, however, so inhibitor chemical feeds must continue indefinitely (normally at a lower rate after an initial passivation period) if the reduced corrosion rate is to be maintained. The initial passivation period is quite important. During this time, which may be several weeks, the inhibitor is fed at 2-3 times the normal rate in order to build a protective film quickly and minimize the opportunity for pitting corrosion to start before the entire metal surface is covered.

The *passivation* approach to chemical corrosion control may be easier than the *neutralization* approach because it is broader in scope, dealing with more corrosion problems at once. For example, if some form of copper-phosphate scale is formed as a result of a phosphate inhibitor feed it should afford some protection from both HOCl and oxygen attack. The better the knowledge of the solubility of the water's various ingredients and corrosion products in combination with each other and the inhibitors, the greater the chance of successful application of inhibitors.

Available corrosion control technology covers a broad spectrum. For industrial use, high concentrations of chromates, molybdates, tungstates, nitrates, phosphates, natural organics such as tannins, and synthetics such as mercaptans have been used successfully. However, treatment for potable water is essentially limited to pH and alkalinity adjustment, switching to chloramine from chlorine for disinfection, and the addition of phosphate and/or silicate inhibitors.

2.4.1. pH and alkalinity adjustment

pH and alkalinity adjustment may be the only method used to reduce corrosivity in some water systems. Systems that have high enough levels of hardness may only require a slight increase in calcium or alkalinity to bring the water to the point of $CaCO_3$ saturation to enable the formation of a passivation scale. pH, calcium, and to a limited extent alkalinity, levels can all be raised by the addition of slaked lime [$Ca(OH)_2$] for example.

In soft, low mineralized waters, it is not practical to attempt to reach $CaCO_3$ saturation. However, in some of these waters, merely raising the pH may be enough to reduce corrosivity to desired levels. In order to maintain stable pH conditions, usually it will also be necessary to raise the alkalinity as well, so that an adequate buffering intensity is available. Sometimes the only chemical required will be soda ash (Na_2CO_3). Other times it may be necessary to use a strong base like caustic soda (sodium hydroxide,

NaOH) or lime in combination with a buffering chemical like soda ash, sodium bicar-bonate (NaHCO$_3$), or CO$_2$.

In some waters it may also be necessary to adjust the carbonate species relative to the concentration of halides and/or sulfates if the latter two are at significant levels. An alkalinity to (Cl$^-$ + SO$_4^=$) ratio as CaCO$_3$ of at least 5:1 should be maintained to minimize the potential for pitting corrosion (Millette et al., 1980).

If pH adjustment is used it should be borne in mind that buffer capacity is mini-mal in the 8 to 8.5 range when the bicarbonate-carbonate system is the main buffer. Therefore, it will be much easier to maintain pH stability if the targeted pH is either below or above that range. Schock (1989) suggests that the upper limit should be 10.2, primarily based on a lack of field and laboratory data above that level. Pisigan and Singley (1987) found the corrosion rate for steel to be highest at pH 8 where the buffer capacity is near minimum. Stumm (1960) found corrosion rates higher at pH 8 to 8.5 and attributed this to the low buffer capacity in this pH range. Larson and Skold (1957, 1958) also found higher corrosion rates for cast iron and steel at pH 8.

For groundwaters with high CO$_2$ content (> 10 mg/L) air stripping to reduce the CO$_2$ may be a practical way to raise the pH without reducing the alkalinity.

2.4.2. Disinfection with chloramine

The usual way of chlorinating water for disinfection is with chlorine gas (Cl$_2$). Elemental chlorine combines with water to form hypochlorus acid, chloride ion, and hy-drogen ion as follows:

$$Cl_2 + H_2O \rightarrow HOCl + Cl^- + H^+ \qquad\qquad 2\text{-}27$$

The effects on corrosivity of the three products of the reaction have already been dis-cussed.

On the other hand, if HOCl and ammonia (NH_3) are combined to form monochloramine as follows:

$$HOCl + NH_3 \rightarrow NH_2Cl + H_2O \qquad \qquad \text{2-28}$$

and then chloramine is used for disinfection in the presence of copper for example:

Half cell $2Cu^0$ $\qquad = 2Cu^+ + 2e^-$ $\qquad \qquad E_0 = - 0.521$ V 2-29

Half cell $\underline{NH_2Cl + H_2O + 2e^-}$ $\quad \underline{= Cl^- + NH_3 + OH^-}$ $\qquad \qquad \underline{E_0 = + 0.75 \quad \text{V}}$ 2-30

$\qquad 2Cu^0 + NH_2Cl + H_2O = 2Cu^+ + Cl^- + NH_3 + OH^- \qquad E = + 0.229$ V 2-31
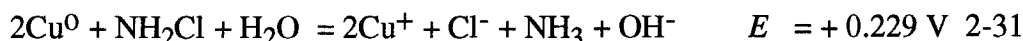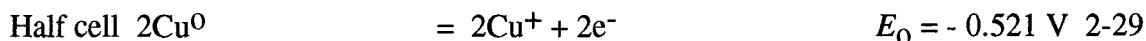
This corrosion cell is not nearly as strong as the HOCl and Cu cell or the OCl^- and Cu cell.

Being less reactive than either HOCl or OCl^-, chloramine is less effective as a disinfectant. However, free chlorine (i.e., the combination of Cl_2, HOCl and OCl^-) tends to dissipate much more quickly than chloramine.

In Portland, Ore. Treweek et al. (1985) confirmed experimentally with plain copper pipe that disinfection with free chlorine increased copper corrosion rates considerably over those for the same dose level of chloramine. But, surprisingly, in the case of lead soldered joints, both copper and lead levels were higher in chloraminated water than in chlorinated water. Treweek suggests that the chloraminated system may increase equilibrium solubility through complexation or by altering the precipitation kinetics of the passivating film on lead materials. Boffardi (1988) proposed that, if lead chloramines form, they may increase lead solubility by dissociating into lead amine complexes. On the other hand, in their study of 94 companies and districts of the American Water Works Service Company, which compared lead levels at the tap, Lee et al., (1989) found that

neither free chlorine levels nor total chlorine levels had any effect on the lead levels contributed from plumbing materials.

2.4.3. Phosphate and silicate inhibitors

Phosphate and silicate inhibitors are *passivation* approaches to corrosion control. They form a metal-inhibitor compound on the metal surface which builds to the point where some degree of protection is afforded. The scale is self limiting and does not build up beyond a certain level, so there is no significant reduction in flow capacity in the water line.

2.5. Phosphate Inhibitors

Phosphate inhibitors are available in several different types including phosphates and metaphosphates, linear and cyclic polyphosphates, glassy polyphosphates, orthophosphates, blends of ortho and polyphosphates, bimetallic polyphosphates, zinc polyphosphates, and zinc orthophosphates.

    a. <u>Sodium phosphates</u> - are made by combining soda ash or caustic soda with phosphoric acid (H_3PO_4) in various combinations to form such products as monobasic sodium phosphate (NaH_2PO_4), dibasic sodium phosphate (Na_2HPO_4), tribasic sodium phosphate (Na_3PO_4), sodium metaphosphate ($NaPO_3$) and sodium tripolyphosphate $Na_5P_3O_{10}$.

    b. <u>Glassy polyphosphates</u> - are sodium hexametaphosphates ($Na_{n+2}P_nO_{3n+1}$ where typically n = 10 to 16). In low dosages (2-4 mg/L) they have been used to combat red water problems. They complex with the iron in the water and mask the red color, but do not reduce corrosion. For corrosion control, dosages of up to 10 times higher were required. (AWWA 1990). They were first used as corrosion inhibitors around 1940 (Illig 1957).

c. Bimetallic polyphosphates - are usually a combination of 8-15 percent zinc with sodium polyphosphates. Their use as corrosion inhibitors began about 1950 (Kleber 1965). They often perform better than plain sodium polyphosphates in harder waters and can be effective at pH 8 or slightly higher (AWWARF 1989).

d. Blended ortho-polyphosphates - which have been available since about 1980 are composed of sodium and potassium phosphates in proportions from 10 to 30 percent ortho to polyphosphate. They have been successfully applied in moderately mineralized waters in a pH range of 7.2 to 7.8 for the protection of steel and copper (AWWARF 1989).

e. Zinc orthophosphates - are a blend of zinc sulfate ($ZnSO_4$), sodium dihydrogen phosphate (NaH_2PO_4), and sulfonic acid (H_3NO_3S) in proportions of 56:24:20. They initially came into use in the late 1960s (Murray 1970). They are most effective in the 6.5 - 7.5 pH range. They are available in liquid form thus eliminating the handling problems of dry, hygroscopic, low solubility properties normally associated with polyphosphate or bimetallic inhibitors.

Phosphates work best in water flowing at high velocities but are not effective in stagnant or near stagnant areas such as household service lines (Katsanis et al., 1985). In addition to forming a metal-inhibitor compound on the metal surface, phosphates may also combine with oxygen at the metal surface to form a crystalline lattice structure that anchors the precipitated salts (Nancollas, 1983).

Swayze (1983) reported that phosphates tend to soften previously formed scale which may cause temporary red water problems as the old scale washes out. However, by solubilizing old scale, phosphates can ultimately minimize red water problems and reduce head loss (Shull, 1980). Bimetallic polyphosphates were used successfully in Philadelphia for a number of years (Shull 1980). Reiber (1989) found that on copper, phosphate inhibitor protection develops quickly (at least on relatively fresh surfaces) but

requires at least periodic inhibitor application. Reiber suggests that a three to five fold decrease in corrosion rate is possible using concentrations in the range of 1 to 5 mg/L as P. Quantity of scale is minimal and inhibition is not degraded by the presence of chlorine.

The solubility of most metallic phosphates is pH dependent, so logically, one would expect pH to influence the performance of phosphate inhibitors. Hatch (1973) found that, with or without zinc, polyphosphate inhibitor performance decreased with increasing pH above about 7. Zinc polyphosphate either as a physical mix or bimetallic glass will reduce steel corrosion in a pH range 6 to 7.5 but pH should be maintained above 7 (Boffardi, 1988). When using zinc orthophosphate to control steel and lead corrosion Boffardi states, it is extremely important that a pH of 7.2 to 7.4 be maintained. According to Reiber (1989) the phosphate scales on copper appear more labile than the oxide scales formed in noninhibited waters. A low pH (< 6) can dissolve the phosphate scale within hours leading to corrosion rates comparable to those of a freshly polished copper surface.

Due to lead-carbonate complexation, lower DIC waters will have lower plumbosolvency, than those waters with higher DIC levels, as discussed. Orthophosphate addition, however, reduces lead solubility in high DIC situations more than water quality alterations short of *major* decarbonation or pH adjustment (Schock 1989). A number of sparingly soluble lead phosphate compounds can form, many of which are much less soluble than lead carbonates. The predominant compounds are hydroxypyromorphite [$Pb_5(PO_4)_3OH$] and possibly tertiary lead orthophosphate [$Pb_3(PO_4)_2$] (Boffardi, 1988; Schock, 1989). At very low DIC levels (<1 mg C/L), the optimum pH for orthophosphate film formation is about 8. The optimum pH gradually decreases as the orthophosphate level increases but it remains >7 for all but the highest DIC concentrations and orthophosphate dosages. Theoretically, a level of 0.01 mg/L of lead could be obtained for equilibrium lead solubility at a pH of about 7.6 and a DIC of about 5 to 10 mg C/L with

an orthophosphate dosage >4.5 mg/L PO_4. Practically speaking, adequate lead control can probably be obtained over a fairly wide range of orthophosphate, DIC, and pH conditions. The ability to use orthophosphate to control lead solubility at lower pH values, as opposed to pH and DIC adjustment, may prove to be advantageous in systems with THM formation problems.

Sodium dihydrogen orthophosphate at 2 mg/L was fed into the waters of the King's Park area of Scotland. Samples taken from dwellings showed lead levels of less than 25 percent of the levels prior to treatment (Richards and Moore, 1984). Ryder and Wagner (1985) found a combination of orthophosphates and polyphosphates to be effective in reducing copper corrosion, even though individually neither compound provided any protection. Studies with metaphosphates and pyrophosphates showed success in lead corrosion inhibition but they were not as effective as orthophosphate (Sheiham and Jackson, 1981). These studies also concluded that zinc orthophosphate works best if applied after pH adjustment.

Hatch (1973) found that the addition of zinc led to a reduction in the amount of phosphate that was required for the same level of protection. Zinc also reduced the time required before some degree of protection was afforded. Ryder and Wagner (1985) corroborate this finding. In the soft waters of New Jersey, Mullen and Ritter (1980, 1974) found zinc phosphate to be effective but bimetallic zinc phosphate at the same dose was not. They also found that zinc orthophosphate dosages of 0.2 to 0.5 mg/L as zinc provided 60 to 75 percent reduction in steel pipe corrosion. Bailey (1983) and Kelly (1978) reported similar results in Durham, N.C. and Portsmouth, Va, respectively. Kleber (1965) found sodium-zinc glassy phosphate containing 8-9 percent zinc to be three to five times as effective an inhibitor as straight sodium phosphate glass. According to Kleber, the zinc not only speeds up the formation of protective scale, but the scale is more complete and protective. Schock (1989) suggested that a combination of pH adjustment and zinc orthophosphate could provide better protection than pH adjustment

with orthophosphate added as a generic chemical (sodium or potassium orthophosphate, or orthophosphoric acid) but more controlled experimentation is needed to confirm this.

The study by Lee et al., (1989) (mentioned in paragraph 2.3.6) compared the effect of various pH levels and the addition of various phosphate treatments on lead levels at the tap, and found zinc orthophosphate to be the most beneficial. They found that sodium hexametaphosphate and zinc hexametaphosphate gave results similar to pH adjustment to ≥ 8.

There are other studies that show zinc and/or zinc phosphates to be ineffectual. Boffardi (1988) found that zinc orthophosphate provided no better protection of lead over orthophosphate alone, but it was more effective on carbon steel, and it had some efficacy on cast iron and copper and aided in the suppression of asbestos fibres from asbestos cement. Patterson and O'Brien (1979) found lead corrosion rates 25 and 60 percent higher in zinc orthophosphate treated water after one week and two weeks of treatment respectively. And in the soft, low mineralized waters of Boston, Karalekas et al. (1983) found no beneficial protection from zinc phosphate on copper, iron, or lead and they found no reduction in lead corrosion from zinc orthophosphate addition.

Studies by Schock and Wagner (1985) determined that polyphosphates may not only be ineffective in reducing lead corrosion, but they may actually increase lead levels by complexation and solubilization of protective films on the pipe. The complexation capacities of several polyphosphates show a potential for substantially increasing soluble lead levels in the absence of orthophosphates (AWWARF 1990). Holm and Schock (1991) showed theoretically that for solutions in equilibrium with hydrocerussite and having the same pH and alkalinity levels, a solution containing polyphosphates will have a greater dissolved lead concentration than a solution without polyphosphates. Schock (1989) states categorically that "to date experimental and field evidence does not support the use of polyphosphates in preference to almost any other treatment technique for the control of lead solubility".

A major concern about phosphates is that they may stimulate biological growth both within the distribution system and in the receiving waters. A chlorine or a chloramine residual may reduce the problem throughout the distribution system but will not help the receiving waters. However, studies by Rozenzweig (1987) on the effects of two phosphate corrosion control chemicals (one of them orthophosphate) on the growth of heterotrophic bacteria showed no significant influence.

Zinc may also be a concern because it is extremely toxic to fish so its effect on receiving waters may have to be considered. Also it may result in excessive zinc loading of wastewater treatment plants.

2.6. Silicate Inhibitors

Sodium silicates are manufactured as a dry chemical called water glass and as a liquid chemical solution. They are most commonly prepared by the fusion of silica sand and sodium or potassium carbonate at high temperatures in a furnace to produce a water soluble glass as follows:

$$Me_2CO_3 + nSiO_2 \rightarrow Me_2O \cdot nSiO_2 + CO_2 \uparrow \qquad \qquad 2\text{-}32$$
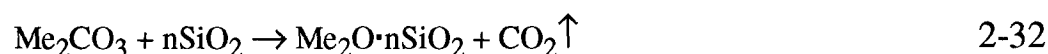
Table 2-1 shows the more common sodium silicate corrosion inhibitors (AWWARF 1989).

The type N and O silicates are normally used for corrosion control in waters in a pH range of 7 to 9 while the more alkaline type D and C silicates are recommended for more acidic waters.

Corrosion is inhibited by the formation of a thin metal silicate barrier on top of and interlatticed with a metal-hydroxide structure. Silicates are considered to be anodic inhibitors initially forming film on anodic areas. The deposition of film depends on the

Type	% Na$_2$O	% SiO$_2$	% Ratio	% Silicate Solids	Baume
N	8.9	28.7	1:3.22	37.6	41.0
O	9.2	29.8	1:3.22	39.0	42.2
D	14.5	29.0	1:2	43.5	50.0
C	18.0	36.0	1:2	54.0	59.1
Metso-granular	20.5	28.7	1:1	58.2	Solid

Table 2.1 - Common Silicate Inhibitors

presence of small amounts of corrosion products on the metal surface. The negatively charged silicate ions are attracted to the positive metallic ions formed at the anodes to form a protective film (Katsanis et al., 1985). With continuous feeding, the films extend to the cathodic areas, a very important phenomenon, because any reduction in anodic free surface without a corresponding reduction in the cathodic free surface would lead to an increase in current density at any unprotected anodic sites and accelerated localized corrosion. Microscopic and x-ray diffraction show that two distinct layers are formed with most of the silica in the surface layer adjacent to the water (ibid.). When the hydrous metal oxide or metal silicate has been covered with a silica layer, further growth is halted, so continued silicate feed does not cause a build-up of the films.

Silicates are often blended in engine antifreeze for their corrosion inhibitor capabilities and they are included in most cleaning and detergent formulations including home laundry and dishwashing products. Silicates contribute to the cleaning process plus inhibit corrosion to metal washing machine parts and other metals that are exposed to the cleaning solutions. Silicate bonded mineral insulation applied to stainless steel piping inhibits stress corrosion cracking that may occur in corrosive environments.

Silicates do not contribute to algal growth or eutrophication.

According to Katsanis et al., (1985) silicate treatment is most effective with soft waters of low pH and high oxygen content. They recommend an initial dose of 24 to 25 mg/L as SiO_2 for the first month or two followed by a maintenance dosage of 8 to 10 mg/L. In some cases, maintenance dosages may be as low as 4 to 5 mg/L. They also recommend that silicate treatment be started immediately following mechanical cleaning and flushing of distribution pipes.

The first documented successful use of silicates in drinking water was for the soft moorland waters in England for the control of lead corrosion from lead piping sometime before 1917 (Sussman, 1966). Stericker (1938) reported on successful use of silicates for corrosion control in domestic water supplies in Pennsylvania and New York. Courchene and Kirmeyer (1978) and Eastman (1983) report good results with silicates in the soft, low mineralized waters of Seattle and Baltimore, respectively. Schock and Buelow (1981) verified theoretically how silicates are effective in controlling corrosion of asbestos cement pipe.

Silicates have their detractors as well. Wagner (1985) claims that the beneficial effects often ascribed to silicates are really due to the fact that the silicates raise the pH of the water. Ryder and Wagner (1985), Wagner (1985), and Sontheimer (1985) found little or no benefit to copper, iron, lead, or zinc under the conditions in which silicates are normally applied. According to Boffardi (1988), silicates are known as cementing agents over corrosion products and consequently become effective only after a long period of exposure (8 to 9 months). This long term requirement is due to the slow formation of a kinetically inhibited metal-silicate film. Boffardi suggests that silicates can not match phosphates for protection of iron and steel. Schock (1985) found that a silicate level of at least 20 mg/L must be applied for several months to show any appreciable drop in lead levels. High levels of silica can have an adverse effect in hot water forming precipitates and tenacious non conducting deposits on heat transfer surfaces (Schock 1989). Due to the significantly higher dosage that are normally required, both for initial passivation and

long term maintenance, the application of silicates for corrosion control is usually more costly than phosphates.

Silicates can be combined with zinc to make bimetallic inhibitors, and sometimes they are combined with phosphates or zinc and phosphates in a attempt to combine inhibitor benefits. To date, the potential synergistic effect of combining two or more inhibitors has not been investigated to any significant extent.

2.7 Factors Affecting Inhibitor Selection

The following are some factors that should be considered in the corrosion inhibitor selection process:

 a. predominant type of corrosion that is occurring and the relevancy of inhibitor use;

 b. potential effects of temperature, velocity, and the concentration of corrosive agents in the water;

 c. expected chemical reaction with the corroding medium;

 d. potential effect on corrosion rate;

 e. expected effectiveness over time;

 f. minimum required concentration both for initial passivation and long term maintenance;

 g. expected reaction with existing surface films, scales and other corrosion products;

 h. efficacy on already corroded metal;

 i. potential effect on tanks at the water line;

 j. potential adverse effects on water quality particularly for industrial, health care and other special uses;

 k. potential effects on other water treatment processes;

l. capital and operating and environmental costs and cost/health/aesthetic bene-
    fits;

m. handling factors, toxicity etc.; and

n. environmental considerations; effect on wastewater treatment and receiving
    waters.

3. EXPERIMENTAL METHODS

3.1 Selection of Inhibitors and Plant Configuration

In addition to the literature search, extensive consultation was carried out with numerous chemical suppliers to assess the availability, physical form, method of delivery, applicability for use in GVWD type waters, recommended dosages, feed methods, and costs of various inhibitors. In addition, cost estimates were made for the continuous use of the inhibitors by GVWD based on the recommended maximum and minimum dosages and an average daily water consumption of 1,027,000 m^3 (1989 data). Capital costs and operation and maintenance considerations were only appraised on a qualitative basis. The following is the short list of chemical inhibitors from which the final selections were made:

a. Virchem 932 - a zinc orthophosphate from Technical Products Corp. (TPC), Portsmouth VA. It has a zinc content of 8.3 percent, and a zinc to phosphate ratio of 1:1. It is available in liquid form. The manufacturer's recommended dosage in GVWD water was 5 mg/L as product, with maximum/minimum dosages of 2.5 and 7.5 mg/L respectively. Thus, at maximum dosage, the phosphate and zinc levels would be 0.62 mg/L each. If actually used by the GVWD, the estimated annual chemical cost varies from a minimum of $608,000 to a maximum of $1,826,000.

b. Virchem 939 - another zinc orthophosphate from TPC. It also comes in liquid form with a zinc content of 8.3 percent, but the zinc to phosphate ratio is 1:3. Recommended dosage was 3 mg/L as product, with maximum/minimum dosages of 1.5 and 4.5 mg/L respectively. At maximum dosage, the phosphate level would be 1.12 mg/L and zinc

would be 0.37 mg/L. Actual use estimated annual chemical cost varies from a minimum of $438,000 to a maximum of $1,313,000.

c. TPC 223 - a silicate/orthophosphate blend from TPC. Recommended dosage was 5 mg/L as product, with maximum/minimum dosages of 2.5 and 7.5 mg/L respectively. Actual use estimated annual chemical cost varies from a minimum of $975,000 to a maximum of $2,925,000.

d. TG 10 - a zinc-sodium polyphosphate from Calgon Corp., Pittsburgh. Recommended dosages were a minimum 1 mg/L and a maximum 2.5 mg/L. It comes in dry form, and batching must be done every day as the solution becomes unstable after 24+ hours; therefore, much higher handling costs could be anticipated. Actual use estimated annual chemical cost varies from a minimum of $1,940,000 to a maximum of $4,850,000.

e. Type N Sodium Silicate - a blend of sodium oxide and silicate in a ratio of 1:3.22 sodium to silicate. It is available in liquid form at 28.7 percent silicate from National Silicates Limited. Recommended maximum/minimum dosages were 8 mg/L and 15 mg/L respectively as SiO_2. Estimated actual use annual chemical costs vary from a minimum of $2,405,000 to a maximum of $4,510,000.

In addition to annual chemical costs there were a few other things that were considered in making the final selection of the inhibitors that would be used in this study:

• Capital Costs - for Virchem 932, 939 and TPC 223 were expected to be approximately the same. To use Calgon's TG 10, the capital costs could be double or more because it comes in dry form. Due to the significantly higher feed rates, the capital costs associated with sodium silicate feeding could also be higher.

- <u>Past Success</u> - Past studies have demonstrated mixed results with all of these inhibitors. Essentially, each water tends to react in a unique way with different inhibitors. The only way to ascertain their effectiveness is through exhaustive testing with the water being studied. Of the five chemicals on the short list, zinc orthophosphate appeared to offer the most consistent results with waters similar to those of the GVWD. Although the manufacturer was interested in seeing TPC 223 tested, they had little confidence of success with that product in GVWD water.

- <u>Microbial Regrowth Potential</u> - With the exception of sodium silicate, all of the inhibitors could cause regrowth problems due to their phosphate content. The GVRD lab was asked to monitor bacterial growth during inhibitor testing so that an evaluation of the regrowth risk could be made. Since zinc is a bactericide, it could serve as an offset to a certain extent, but the potential effect of additional zinc to sewage treatment facilities and receiving waters must be assessed, as discussed.

- <u>Feed System Operation And Maintenance</u> - Costs should be about the same for Virchem 932, 939 and TPC 223. Due to Calgon's TG 10 being in dry form and the requirement for daily batching, operation and maintenance costs and problems would likely be significantly higher with its use. Because of the higher feed requirements, and caking and blockage problems frequently associated with their feed lines, it is possible that operation and maintenance costs would be higher for silicates as well.

Due to the limited number of loops available at the Seymour test facility, there was no way that all the inhibitor chemicals could be evaluated at one time. In fact, even a single chemical could not be fully evaluated in one study.

Initially, the following two configurations were considered:

a. **Three Inhibitors**

- Loop 1 - Control; raw water

- Loop 2 - Treated control; pH 8, alkalinity 20 mg/L

- Loop 3 - pH 8, alkalinity 20, Inhibitor #1 @ minimum dose

- Loop 4 - pH 8, alkalinity 20, Inhibitor #1 @ maximum dose

- Loop 5 - pH 8, alkalinity 20, Inhibitor #2 @ minimum dose

- Loop 6 - pH 8, alkalinity 20, Inhibitor #2 @ maximum dose

- Loop 7 - pH 8, alkalinity 20, Inhibitor #3 @ expected inhibiting dose

This setup could be used to test the three most favored inhibitors, but the results would not be conclusive and more testing would still be required.

b. **Single Inhibitor**

- Loop 1 - Control; raw water

- Loop 2 - Treated control; pH 8, alkalinity 20 mg/L

- Loop 3 - Raw water, inhibitor @ minimum dose

- Loop 4 - Raw water, inhibitor @ maximum dose

- Loop 5 - pH 8, alkalinity 20, inhibitor @ minimum dose

- Loop 6 - pH 8, alkalinity 20, Inhibitor @ maximum dose

- Loop 7 - pH 7, alkalinity 20, Inhibitor @ expected inhibiting dose

This setup could be used to test the single most favored inhibitor. Again more testing would likely be required, even with that one inhibitor.

If the objective of this study was to obtain as much information as possible about the effect of various inhibitors on GVWD waters, then the three inhibitor setup could be used in the following specific form:

- Loop 1 - Control; raw water

- Loop 2 - Treated control; pH 8, alkalinity 20 mg/L

- Loop 3 - pH 8, alkalinity 20, Virchem 939 @ 1.5 mg/L

- Loop 4 - pH 8, alkalinity 20, Virchem 939 @ 4.5 mg/L

- Loop 5 - pH 8, alkalinity 20, Sodium silicate @ 8 mg/L

- Loop 6 - pH 8, alkalinity 20, Sodium silicate @ 15 mg/L

- Loop 7 - pH 8, alkalinity 20, TPC 223 @ 5 mg/L

On the other hand, if the goal was to begin using an inhibitor as soon as possible, then probably the Virchem 939 should be tested using the single inhibitor setup. Virchem 939 appeared to be the logical choice for the following reasons:

- based on the literature search, zinc orthophosphates appeared to offer the best potential as inhibitors in GVWD type water;

- zinc orthophosphates appeared to be the most economical and Virchem 939 appeared to be the least expensive in all respects;

- with Virchem 939's higher phosphate content, it would represent a "worst case" in terms of zinc orthophosphate impact on bacterial regrowth;

- if the tests proved successful, it may be possible to initiate the use of this inhibitor in the distribution system, and carry on with testing of other inhibitors; then if another inhibitor is found to be more effective, it is likely that a switch could be made with very little disruption;

- other studies have shown zinc orthophosphates to be more effective at controlling corrosion than pH adjustment; there may be a better way to control corrosion than adjusting pH to 8 and alkalinity to 20 mg/L and then adding inhibitors.

In the end, a compromise was arrived at and the decision was made to set up the experiment to test Virchem 939, sodium silicate, and TPC 223 as follows:

- Loop 1 - Control; raw water;

- Loop 2 - Treated control; pH 8, alkalinity 20 mg/L;

- Loop 3 - pH 8, alkalinity 20, TPC 223 @ 5 mg/L;

- Loop 4 - pH 8, alkalinity 20, Sodium silicate @ 12 mg/L;

- Loop 5 - pH 8, alkalinity 20, Virchem 939 @ 1.5 mg/L;

- Loop 6 - pH 8, alkalinity 20, Virchem 939 @ 4.5 mg/L; and

- Loop 7 - pH 7.5, alkalinity 10-12, Virchem 939 @ 4.5 mg/L.

The plant configuration was set up as per Figure 3.1. Heavier emphasis was being placed on the Virchem 939 for the reasons discussed above. At the same time, there could be no way of determining whether or not sodium silicates or a silicate/phosphate blend are effective in GVWD waters without some form of actual testing. Thus, to preclude putting all faith in only one inhibitor which may not work, this compromise appeared to be the most acceptable.

In addition to the above treatments, the water to Loops 2 through 7 was to be disinfected with chloramines at 2.5 mg/L since, at the time, the plan was for GVWD to switch to chloramine for secondary disinfection within a few years and it was desired to get as close to a real simulation as possible. Slaked lime [$Ca(OH)_2$] and sodium bicarbonate ($NaHCO_3$) were to be used for pH and alkalinity adjustment respectively. The SiO_2 raised the pH of Loop 4 well above 9 so HCl was injected to bring it down to 8.

3.2 Pilot Plant Physical Description

The pilot plant (see schematic, Figure 3.1) is located at Seymour Dam at the base of Seymour Lake. The raw water source is Seymour Lake. Water pressure was reduced and regulated permitting constant pressure in the pilot plant. An electronic timer permitted automatic operation on a 24 hour basis, but manual operation was also possible. Chemical feed solutions were stored in plastic vats and were delivered by Masterflex L/S

Pressure
Regulator

Pressure
Guage

Gate Valve

2"

Rotameter

Corrosometer
Probe

Static
Mixer

Loop Over
Entrance

Copper Plumbing Coils

Vent

3/4"

A B

Static
Mixer

Check
Valve

Cast Iron
Pipe Inserts

1/2"

Strainer

Electric
Activated
Ball
Valve

Check
Valves

Globe
Valve

Water
Meter

C I L

3/4"

Pump Discharge

Check
Valve

Copper
Pipe Inserts

7

Static
Mixer

Loop 1 - Raw water Control
Loop 2 - Treated Control
        pH 8, Alk 20 mg/L
Loop 3 - TPC223 @ 5 mg/L
        pH 8, Alk 20 mg/L
Loop 4 - SiO2 @ 12 mg/L
        pH 8, Alk 20 mg/L
Loop 5 - Virchem 939 @ 1.5 mg/L
        pH 8, Alk 20 mg/L
Loop 6 - Virchem 939 @ 4.5 mg/L
        pH 8, Alk 20 mg/L
Loop 7 - V 939 @ 4.5 mg/L
        pH 7.5, Alk 10 mg/L

D M

E M

F N K

G O

H

J

6

5

4

3

2

1

3/4" For All Loops

Typical
Bypass
Line
for all
7 Loops

Typical
Faucet
Set-up
for all
7 Loops

W M

Lab Cock

Ball Valve

Typical Lead Solder
Coil for all 7 loops

Granulated
Activated
Charcoal

Floor Drain

Chemical Vat	NaOCl	NH4Cl	Ca(OH)2	NaHCO3	HCl	Virchem 939	SiO2	TPC 223
Pumps Fed	A	B	C,D,E,F,G,H	I,J	K	L,M	N	O
Feed Conc	4000 ppm	1334 ppm	1000 ppm	30,000 ppm	10,000 ppm	2500 ppm	2870 ppm	2000 ppm

Figure 3.1 - Seymour Pilot Plant Schematic

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peristaltic pump heads using Norprene tubing and driven by model L-07520-25 variable speed drives[5] to injection ports at appropriate doses for the desired treatments. Static, in-line mixers were located downstream of the injection ports to ensure rapid mixing.

3.2.1. Pipe Coupon Inserts

Each loop contained four pipe insert assemblies, as shown in Figure 3.2; these were modified versions of the Illinois State Water Survey Test Assembly (ASTM D2688-83, Method C). The first two assemblies of each loop held two - 4 inch lengths of 1 inch (inner) diameter cast iron pipe and the second two assemblies held two - 4 inch lengths of 1 inch diameter CDA122L copper pipe. The inserts were machined to fit the assemblies and to minimize flow distortions so as to reduce the chance of increased corrosion due to induced turbulence. The inserts were coated with epoxy on the outer surfaces and edges to limit corrosion to interior surfaces. They were wrapped in desiccant treated paper and sealed in a plastic container until ready for use. All coupons were in fresh machined condition with no visible evidence of corrosion at the time of insertion in the assemblies.[6]

3.2.2. Lead Soldered Copper Plumbing Coils

As a simulation of household plumbing systems, each loop had 84 feet (25.6 metres) of half inch (12.5 mm) soft copper tubing coils downstream of the coupon inserts. The coils were joined every 4 feet (1.22 metres) with 50/50 lead-tin solder which was typically used in premises plumbing until recently when the building code was changed disallowing its use. Flow through the coils was set such that the velocity was about 2.6 ft/sec (0.79 m/s) which is typical for household plumbing. Water could be isolated in the coils for any amount of time desired to simulate water standing in a household overnight

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[5]Purchased from Cole Parmer Instrument Company, Chicago.
[6]The inserts and assemblies were purchased from Metal Samples Co., Inc., Munford, AL.
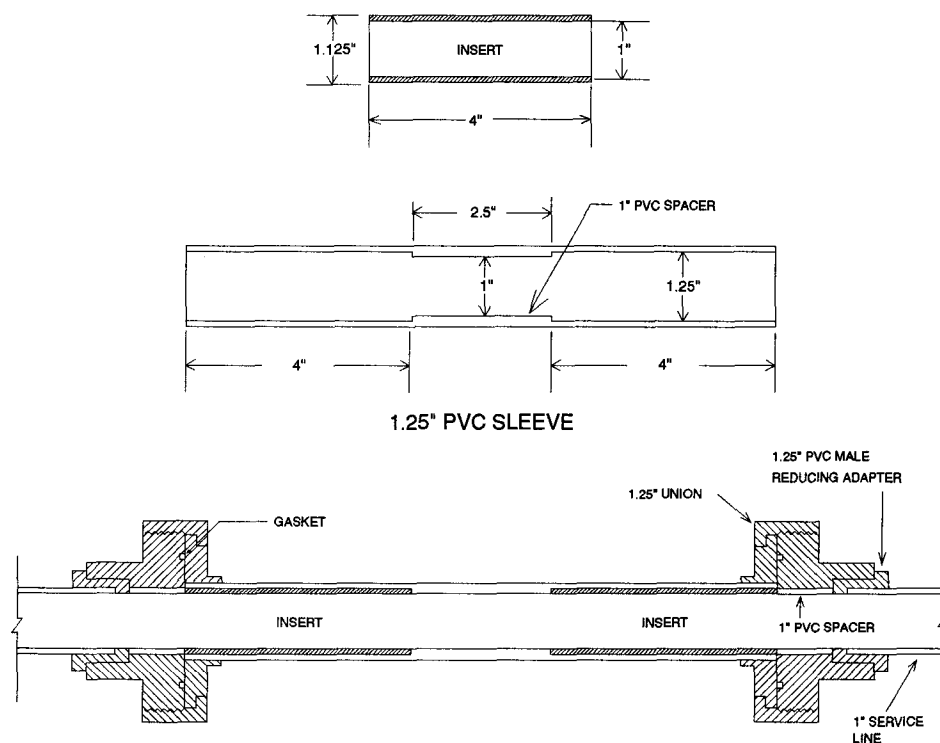
Figure 3.2
Pipe Coupon Inserts and Assembly

or longer. Metals content in samples taken from the standing water were used to give an indication of the relative corrosiveness of the treatments in each loop.

3.2.3. Lead/Tin Solder Coils

Plastic canisters holding coils of approximately 500 g of 50/50 lead/tin solder were installed immediately downstream of the plumbing coils . When water was flowing it circulated through the solder coils and the coils were submerged at all times. The canisters could be isolated to produce standing water samples in contact with the solder. Lead concentrations in the standing water samples were used to indicate the relative lead mobilization in each treatment water.

3.2.4. Brass Faucets

A two handled cast brass mixing faucet (manufactured by EMCO Canada Ltd.) was installed at the outlet of each loop. Again, water could be isolated in the faucets to give a standing sample for metals analysis.

3.2.5. Granular Activated Carbon (GAC) Filters

Due to the location of a fish hatchery a few hundred yards downstream of the dam, it was imperative that the chloramine be removed from the water prior to discharge from the pilot plant. All loops except the raw water loop discharged to vats containing GAC and periodically the water draining from the GAC filters was checked for total chlorine content. The design of the GAC filters permitted flow reversal for backwashing when required.

3.3 Modifications to the Existing Pilot Plant

The same pilot plant that EES used for their study (1990) was used for this study. A few modifications were made as follows:

- The existing 75 feet (22.9 metres) of three quarter inch (19 mm) copper plumbing coils which were soldered every 12 feet (3.66 metres) were replaced with new half inch (12.5 mm) pipe soldered every 4 feet (1.22 metres) since the intention was to simulate household plumbing (which normally consists of half inch pipe). Soldering every 4 feet (1.22 metres), may seem a bit extreme, but the lead levels from the plumbing coils in the EES study were so low that valid comparisons between the various treatments were difficult to make. It was hoped that the increased lead exposure would increase the absolute lead levels in the water and make the differences between the various treatment methods more obvious.

- So that the flow velocity through the plumbing coils would still be similar to what could be expected in household plumbing [2.6 ft/sec (0.79 m/s) as in the

EES study], bypass lines were installed upstream of the plumbing coils and the flow through the bypass lines was adjusted accordingly.

- In order to ensure that chloramine feed would be equal in Loops 2 to 6, the main water line to the pilot plant was modified so that NaOCl and NH_4OH were injected upstream of these loops. A check valve was installed upstream and a static mixer was installed downstream of the injection points. A branch line for Loop 1 (raw water control) was installed upstream of the check valve on the main.

- Similarly, the main was also modified downstream of the chloramine static mixer so that $NaHCO_3$ was injected upstream of Loops 2 through 6. Again a check valve and a static mixer were installed upstream and downstream of the injection point and a branch line for Loop 7 was installed upstream of the check valve.

- The faucets on all loops were replaced with new ones.

- Copper and mild steel resistance (Corrosometer) probes[7] were installed on each loop. These probes were used to measure corrosion on a weekly basis. The principle behind their use is that as the probe corrodes, the resistance increases and the increased resistance correlates to corrosion rate. Although linear polarization methods are generally accepted as being superior for ongoing electrical measurment of corrosion rates, the low conductivity of the water (11 to 15 μS/cm) precluded their use in this experiment. It would have been preferable to use cast iron probes as opposed to mild steel, but cast iron probes could not be obtained. In fact, due to attempts to obtain cast iron probes and finally abandoning the search, the probes that were used were not installed until May, six weeks after the experiment started.

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[7]Purchased from Rohrback Cosasco Systems, Santa Fe Springs, CA.

3.4 Operation Procedures

Water flow through the pilot plant was normally controlled by an electrically operated ball valve although it could also be controlled manually as stated. The valve was controlled by an electronic timer which allowed four on and off cycles daily. The following schedule was used:

0800 - 1000	Valve open, water flowing for 2 hours.
1000 - 1300	Valve closed, no flow for 3 hours.
1300 - 1400	Valve open, water flowing for 1 hour.
1400 - 1700	Valve closed, no flow for 3 hours.
1700 - 1900	Valve open, water flowing for 2 hours.
1900 - 2300	Valve closed, no flow for 4 hours.
2300 - 2400	Valve open, water flowing for 1 hour.
2400 - 0800	Valve closed, no flow for 8 hours.

Thus water flowed for a total of 6 hours each day. The intention was to simulate household use but the simulation was limited by the capability of the timer. Water flowing at 2.6 ft/sec (0.79 m/s) through the half inch (12.5 mm) plumbing coils represents a flow rate of 1.59 US gpm or 573 US gal in six hours (6 L/min or 2,166 L in six hours). For a family of 4 that would amount to 143 US gal (541 L) per person per day which is not unreasonable.

The total flow rate starting out through each loop was 15 L/min, which resulted in a velocity of about 1.5 ft/sec (0.46 m/s) through the pipe coupons. This was the same as that used in the EES study and midway between the velocities used in corrosion control studies done in Seattle and Portland (EES, 1990).

3.4.1. Daily Routine

The daily routine in the pilot plant consisted of the following:

- Flow in each loop was checked and globe valves adjusted as required.

- 1 L flowing water samples were taken from each loop.

- Temperature of each sample was measured immediately as it was drawn.

- Total chlorine of each sample was measured using a Wallace and Tiernan Amperometric Titrator following *Standard Methods*, 17th Edition (APHA et al., 1989), 4500-Cl D, "Amperometric Titration Method".

- 150 ml portions of each sample were brought to 25°C by immersion in a water bath.

- A Hanna Model 8733 conductivity meter was calibrated at 25°C and then conductivity was measured at 25°C. Calibration and measurement procedures were in accordance with the owner's manual.

- A Horiba Model D-13 pH meter was calibrated using 3 standards at 25°C and then the pH of each sample was measured at 25°C. Calibration and measurement procedures were in accordance with the owner's manual.

- Alkalinity of each sample was determined at 25°C in accordance with *Standard Methods*, 17th Edition (APHA et al., 1989), 2320 B "Titration Method", 5.b. "Potentiometric titration of low alkalinity".

3.4.2. Weekly Routine

In addition to the daily routine, the following procedures were carried out on a weekly basis:

- 500 ml samples were taken from each loop and brought to the UBC environmental lab for silica determination in accordance with *Standard Methods*, 17th Edition (APHA et al., 1989), 4500-Si F "Automated Method for Molybdate-Reactive Silica". This was used to monitor the silica levels in Loops 3 and 4 to ensure inhibitor dosages were in line. There was no means of measuring SiO_2 in the pilot plant.

- 300 ml samples were taken from each loop in glass BOD bottles that had previously been rinsed with hot 10 percent HCl. The samples were immediately acidified with 0.3 ml of concentrated HCl to give a 0.1 percent HCl matrix. They were taken to the UBC environmental lab where phosphorus was measured in accordance with *Standard Methods*, 17th Edition (APHA et al., 1989), 4500-P F "Automated Ascorbic Acid Reduction Method". This was used to monitor the phosphorus levels in Loops 3, 5, 6 and 7 since there was no means of measurement available in the pilot plant.

- Beginning on 8 May 92, a week after they were installed, Corrosometer readings were taken on each probe using a model CK-3 Corrosometer Instrument[8].

3.4.3. Batching of Chemicals

The following procedures were carried out for the batching of chemicals on a more-or-less weekly basis as required:

- Sodium Silicate - The concentrate contained 28.7 percent SiO_2 and was diluted 100:1 to give a vat concentration of 2870 mg/L. Normally 1 L of concentrate was added to the vat and then 99 L of water was added via a hose at fairly high pressure which allowed good mixing

- TPC 223 - The specific gravity of the concentrate was 1.35 and the vat concentration was 2000 mg/L as product, so the required dilution was 675:1. Normally enough new chemical was batched to bring the total in the 120L vat to 100 - 110 L. The required amount of concentrate was added to the vat and then the required water was added with good mixing.

- Virchem 939 - The specific gravity of the concentrate was 1.40 and the vat concentration was 2500 mg/L as product, so the required dilution was 560:1.

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[8]Purchased from Rohrback Cosasco, Santa Fe Springs, CA.

Normally enough new chemical was batched to bring the total in the 220 L vat to 180 - 190 L. The required amount of concentrate was added to the vat and then the required water was added with good mixing.

- Slaked Lime - Normally 400 L was mixed at a time in the 600 L mixing vat. Water was added to bring the level in the mixing vat up to 500 L. The vat concentration was 1000 mg/L and the powdered lime was about 95 percent pure, so the required weight of lime for 400 L of water was 400/0.95 = 421 g. The lime was weighed out and ground up in a blender so that it was a very fine powder to make it easier to dissolve. An electric mixer was used for dissolving the lime but, due to its low solubility the mixer was run for about two days for each batch. Following mixing, the remaining particulate matter in the mixing vat was allowed to settle for another day before the solution was transferred to the feed vat. Lime only had to be batched about once every three weeks.

- Sodium Bicarbonate - Normally 300 L was mixed at a time in the 400 L mixing vat. The vat concentration was 30,000 mg/L and the $NaHCO_3$ was reasonably pure so the required weight of bicarbonate was 9000 g for 300 L of water. After the bicarbonate and water were added to the vat, an electric mixer was run for several hours to dissolve the bicarbonate.

- Ammonia - The vat solution strength was 1,334 mg/L. Normally enough new chemical was batched to bring the total in the 220 L vat to 180 - 190 L. The strength of the ammonium hydroxide concentrate[9] was determined in accordance with *Standard Methods*, 17th Edition (APHA et al., 1989), 4500-NH_3 "Titrimetric Method". The required amount of concentrate and water were then added to the vat with good mixing. The strength of the new solution was then determined again using the titrimetric method. The strength

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[9]Reagent grade, percentage impurity was negligible for the purposes of this study.

of the vat solution was adjusted if required and remeasured; and this process was repeated until the required strength was reached.

- Sodium Hypochlorite - The vat solution strength was 4,000 mg/L. Normally enough new chemical was batched to bring the total in the 220 L vat to 180 - 190 L. The strength of the hypochlorite concentrate[9] was determined in accordance with *Standard Methods*, 17th Edition (APHA et al., 1989), 4500-Cl "Iodometric Method". The required amount of concentrate and water were then added to the vat with good mixing. The strength of the new solution was then determined again using the iodometric method. The strength of the vat solution was adjusted if required and remeasured; and this process was repeated until the required strength was reached.

- Hydrochloric Acid[9] - a 1 percent solution was batched as required.

3.4.4. Metals Sampling Routine

The routine outlined herein was undertaken weekly for the first 3 months, bi-weekly for the next 6 months and monthly for the last three months.

- Copper Plumbing Coils - The outlet valves on the plumbing coils were closed while the water was still flowing and then the valves on the bypass lines were closed to isolate water in the coils. At this time the plant was shut down for a 24 hour period by opening the main circuit switch which controlled the main electrically actuated ball valve and the chemical feed pumps. After the 24 hours the main circuit switch was closed and plant operations restarted. Prior to opening the outlet valves, 1 L and two - 500 ml samples were taken from the stopcock on each plumbing coil. Then the outlet valves and the valves on the bypass lines were opened. The 1 L samples were used for temperature, total chlorine, conductivity, pH, and alkalinity measurement as per the daily routine. The 500 ml samples were used for measurement of metals content.

- Lead/Tin Solder Coils - At the same time as water was isolated in the plumbing coils, it was also isolated in the canisters containing the lead/tin solder coils by closing the inlet and outlet valves to the canisters. After the 24 hour standing period, the canisters were removed and the water was divided between two containers. One container which held about 750 ml was used for temperature, total chlorine, conductivity, pH, and alkalinity measurement as per the daily routine. The other container which held about 250 ml was used for metals measurement. The canisters were then reattached and the inlet and outlet valves reopened.

- Brass Faucets - After the standing water samples had been taken from the plumbing and solder coils, the faucets were turned off and the valves leading to them were closed, isolating about 500 ml of water between the valves and the faucet outlets. Then the faucet bypass lines were opened so that plant operation could continue. 24 hours later 250 ml and 1 L samples were taken from each faucet. The 250 ml samples were for metals analysis and the 1L sample was for temperature, total chlorine, conductivity, pH, and alkalinity measurement as per the daily routine.

Samples for metals analysis were all subjected to the following procedures:

- All samples were acidified with concentrated nitric acid to a 2.5 percent matrix in the pilot plant.

- The samples were transported to the UBC environmental lab where they were analyzed for copper, zinc, and higher lead levels on a Thermo Jarrel Ash Video 22 Atomic Absorption Spectrophotometer in accordance with *Standard Methods*, 17th Edition(APHA et al., 1989), 3111 B "Direct Air-Acetylene Flame Method". The low level lead samples were measured on a Perkin-Elmer HGA-500 graphite furnace Atomic Absorption Spectrophotometer in

accordance with *Standard Methods*, 17th Edition (APHA et al., 1989), 3113 B "Electrothermal Atomic Absorption Spectrometric Method".

At the beginning of the experiment, the pilot plant was run for some time with raw water through all loops. Then, on a number of days, 24 hour standing raw water samples were taken from the plumbing coils, solder coils, and the faucets. These samples were acidified and the metals levels measured in order to provide a datum from which to compare metals content once the inhibitor treatment started. The detailed results of these measurements are presented in Appendices A through I.

In order to ensure that the chance of contamination was minimized, a strict sample bottle preparation routine was followed. The bottles were machine washed with soap and then given a deionized rinse. They were then filled with 10 percent nitric acid and allowed to stand for a minimum of 24 hours. Finally, they were thoroughly rinsed with deionized water, capped and labeled.

3.4.5. Cast Iron and Copper Coupons

The cast iron and copper coupon corrosion rates were measured over the course of 12 months. At 3 month intervals, one copper and one cast iron pipe insert was removed from each set of four copper and four cast iron inserts in each treatment loop and replaced with a new insert of the same type (except at 12 months when all coupons were removed and the experiment was terminated). Thus, the final set included of coupons exposed for 3, 6, 9, and 12 months, providing replicates of the 3, 6, and 9 exposures although for different times of the year. The initial installation date was 15 March 1991, with changes occurring on 17 June, 16 September, 18 Dec, and 16 March 1992.

As each coupon was removed, swabs of the interior biofilm were taken by GVRD laboratory staff for coliform measurement and heterotrophic plate count in the lab. The removed inserts were sent to Kennedy Jenks in San Francisco, where they were measured for weight loss and pitting corrosion in accordance with the procedures in ASTM D2688-

83, Method C. Kennedy Jenks were also employed for the same purpose in the EES (1990) study.

3.5. Quality Control

As a means of verifying the phosphorus, silica, and metals measurements done in the UBC lab, one sample from each weekly seven sample set taken for silica analysis and phosphorus analysis was sent to the GVRD lab for analysis for the same compounds. Also one sample from each of the plumbing coils, lead/tin solder coils, and faucet sets were submitted to the GVRD lab for metals analysis.

4. RESULTS AND DISCUSSION

4.1. Pipe Coupon Inserts

There are two main data sets associated with the coupon analyses: corrosion in terms of weight loss and pitting corrosion.

4.1.1. Copper Coupon Inserts

A summary of the results from the laboratory data sheets from Kennedy Jenks are included at Appendix A.

4.1.1.1. Copper Coupon Weight Loss Rates

The copper coupon weight loss rates are expressed in terms of equivalent rates of penetration in mm/yr as summarized in Table 4.1.

For the 3, 6, and 9 month exposure periods there were two sets of coupons. Essentially the only water quality difference between one set and another was one of temperature. This difference is apparently significant in all but the raw water loop and possibly Loop 5. With some exceptions, the data show, a fairly consistent pattern of lower corrosion rates under the colder water conditions which is in keeping with expectations. Figures 4.1 and 4.2 represent the data graphically. The 3, 6 and 9 month plots in Figure 4.1 are averages for two measurements. Some significant trends that are apparent from the data and graphs are:

- All treatments (Loops 2 through 6) resulted in a reduction in corrosion rate. The 12 month rate for Loop 2, the pH and alkalinity adjusted loop, showed a 35 percent improvement over that of the raw water. The 12 month rate for Loops 6 and 7, that received the zinc orthophosphate treatment at the higher dose, showed 77 percent improvement over that of the raw water, and 66 percent improvement over the rate for Loop 2.

Copper Coupon Corrosion Rates (mm/yr)*

Exposure Time	Loop Number						
	1	**2**	**3**	**4**	**5**	**6**	**7**
3 Months (a)	0.0134	0.0167	0.0161	0.0095	0.0075	0.0046	0.0075
3 Months (2) (b)	0.0161	0.0075	0.0108	0.0049	0.0106	0.0042	0.0084
6 Months (c)	0.0130	0.0105	0.0117	0.0073	0.0054	0.0036	0.0069
6 Months (2) (d)	0.0149	0.0087	0.0107	0.0060	0.0064	0.0022	0.0051
9 Months (e)	0.0127	0.0083	0.0091	0.0060	0.0059	0.0035	0.0037
9 Months (2) (f)	0.0134	0.0075	0.0073	0.0047	0.0052	0.0030	0.0028
12 months (g)	0.0111	0.0072	0.0075	0.0046	0.0045	0.0024	0.0025

Copper Coupon Average Corrosion Rates

Exposure Time	Loop Number						
	1	**2**	**3**	**4**	**5**	**6**	**7**
3 Months	0.0148	0.0121	0.0135	0.0072	0.0091	0.0044	0.0080
6 Months	0.0140	0.0096	0.0112	0.0066	0.0059	0.0029	0.0060
9 Months	0.0131	0.0079	0.0082	0.0054	0.0056	0.0033	0.0033
12 months	0.0111	0.0072	0.0075	0.0047	0.0045	0.0024	0.0025

(a) Exposed 15/03/91 to 17/06/91(warm)   (e) Exposed 15/03/91 to 18/12/91(warm)

(b) Exposed 18/12/91 to 16/03/92 (cold)   (f) Exposed 17/06/91 to 16/03/92 (cold)

(c) Exposed 15/03/91 to 16/09/91(warm)   (g) Exposed 15/03/91 to 16/03/92

(d) Exposed 16/09/91 to 16/03/92 (cold)

*Analysis in accordance with ASTM D 2688-83, Method C.

Table 4.1 - Copper Coupon Corrosion Rates

Figure 4.1 - Corrosion Rates of Copper Coupon Inserts

Based on Weight Loss Measurements

Legend:
- Loop 1 - Control
- Loop 2 - pH & Alk Only
- Loop 3 - TPC 223, 5 mg/L
- Loop 4 - Sodium Silicate, 12 mg/L
- Loop 5 - V 939, 1.5 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8
- Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Corrosion Rate, mm/yr

X-axis: Duration of Exposure, months
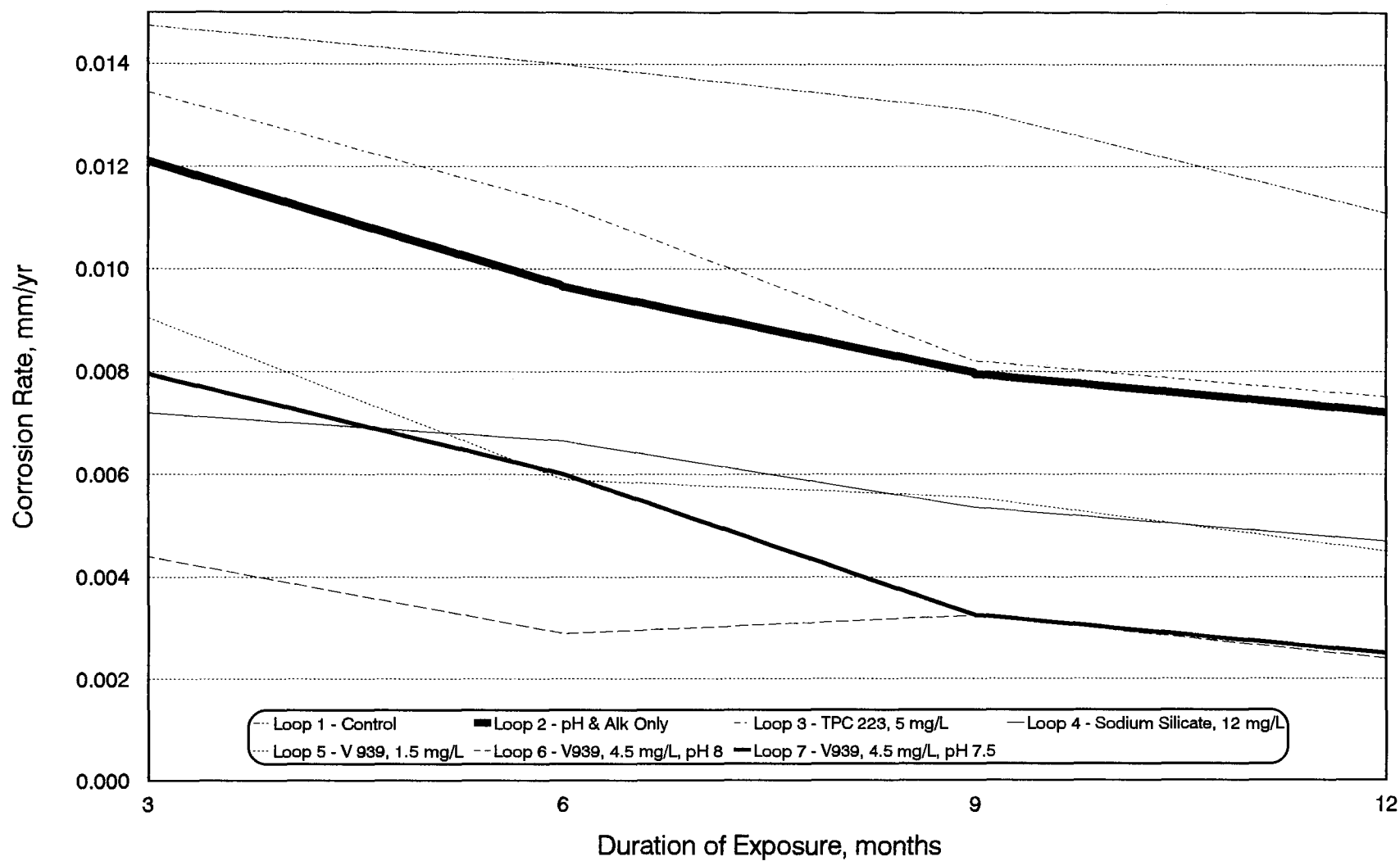
Figure 4.2 - Corrosion Rates of Copper Coupon Inserts
Based on Weight Loss Measurements
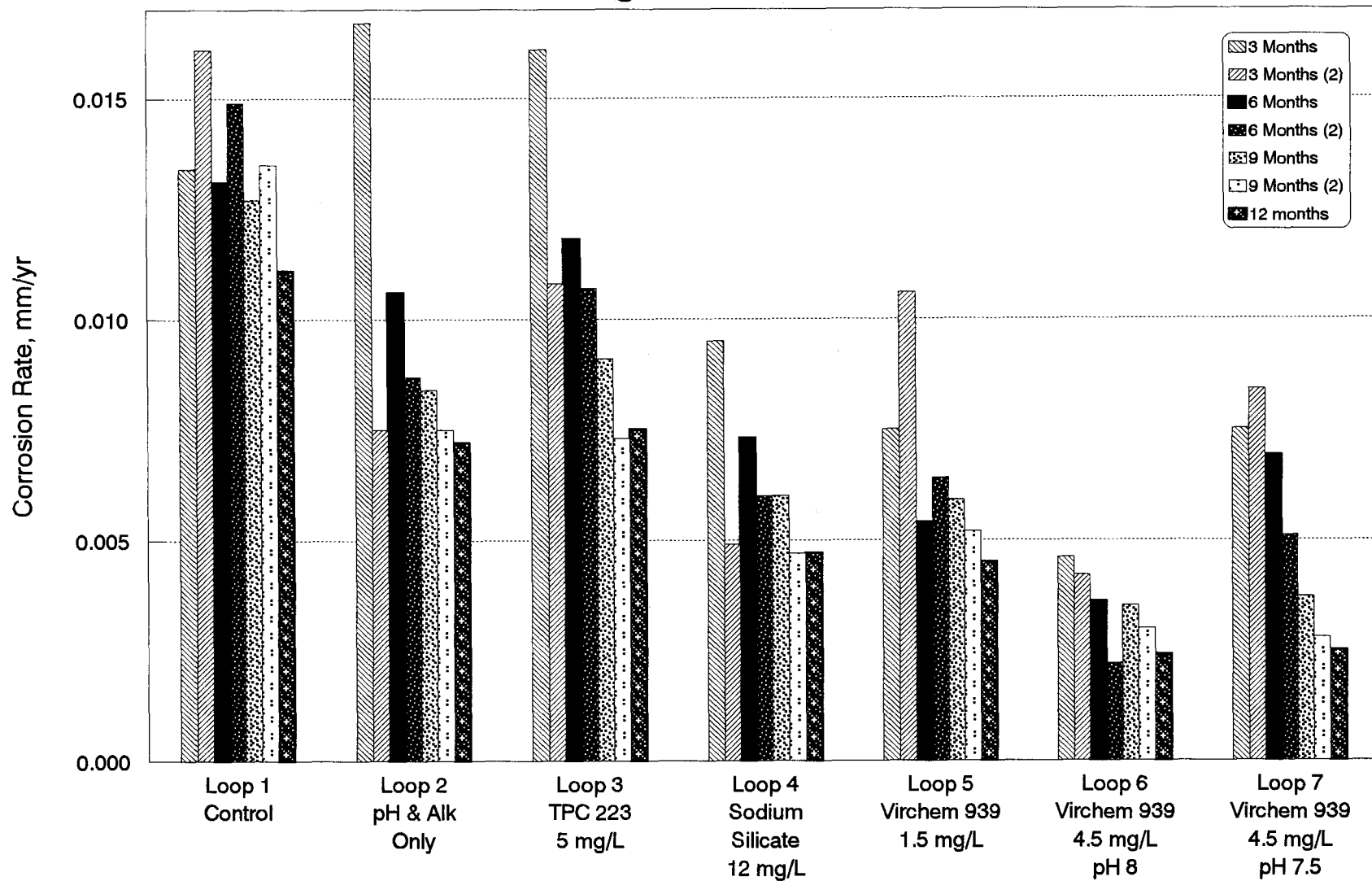
- In all loops, the corrosion rate decreased with time. These lower corrosion rates can be attributed, in part, to protective scale formation which will occur even in raw water. The difference between the raw water and the treated loops is a combination of less aggressive environment (higher pH and alkalinity) and an even better protective scale formed in Loops 4 through 7.

- The results for Loops 6 and 7 show that, when zinc orthophosphate is used as an inhibitor, good results may be obtained at a pH and alkalinity lower than 8 and 20 mg/L, respectively. This, in fact, corroborates numerous other studies that have been done with zinc orthophosphate. The supplier, TPC, recommends a pH range of 6.5 to 8.5 with the optimum at 7.5.

4.1.1.2. Copper Coupon Insert Pitting Analyses

The most important results from the pitting analyses (see the summary of the data sheets at Appendix A) are summarized in Table 4.2. The average and maximum pit depths are the actual observed data, while the nominal pitting rates were calculated by dividing the observed pit depths by the exposure time in years. These data are plotted in Figures 4.3 and 4.4.

Some significant trends which can be observed from the data and graphs are:

- All treatments (Loops 2 through 6) resulted in a reduction in pitting rate. The 12 month rate for Loop 2, the pH and alkalinity adjusted loop, showed a 40 percent improvement over that of the raw water. The 12 month rate for Loops 5, 6 and 7, which received the zinc orthophosphate treatment, showed 75 percent improvement over that of the raw water, and 58 percent improvement over the rate for Loop 2. It is interesting how close these figures are to those for the weight loss data.

Copper Coupon Pitting Analysis*

Pit Depths (mm)

Loop #	3 Months		6 Months		9 Months		12 Months	
	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	0.0088	0.0140	0.0047	0.0051	0.0038	0.0051	0.0152	0.0203
2	0.0053	0.0104	0.0032	0.0046	0.0036	0.0051	0.0089	0.0122
3	0.0050	0.0071	0.0034	0.0051	0.0036	0.0051	0.0079	0.0104
4	0.0037	0.0053	0.0038	0.0041	0.0038	0.0071	0.0064	0.0086
5	0.0039	0.0053	0.0029	0.0043	0.0034	0.0051	0.0043	0.0051
6	0.0038	0.0053	0.0025	0.0036	0.0034	0.0053	0.0041	0.0051
7	0.0036	0.0053	0.0030	0.0046	0.0032	0.0051	0.0038	0.0051

Nominal Pitting Rate (mm/yr)

Loop #	3 Months		6 Months		9 Months		12 Months	
	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	0.0351	0.0559	0.0094	0.0102	0.0051	0.0068	0.0152	0.0203
2	0.0213	0.0417	0.0064	0.0091	0.0047	0.0068	0.0089	0.0122
3	0.0198	0.0284	0.0069	0.0102	0.0047	0.0068	0.0079	0.0104
4	0.0147	0.0213	0.0076	0.0081	0.0051	0.0095	0.0064	0.0086
5	0.0157	0.0213	0.0058	0.0086	0.0046	0.0068	0.0043	0.0051
6	0.0152	0.0213	0.0051	0.0071	0.0046	0.0071	0.0041	0.0051
7	0.0142	0.0213	0.0061	0.0091	0.0042	0.0068	0.0038	0.0051

*Analysis in accordance with ASTM D 2688-83, Method C.

Table 4.2 - Copper Coupon Pitting Analysis

Figure 4.3 - Average Nominal Pittting Rates of Copper Coupon Inserts

Analysis in accordance with ASTM D 2688-83, Method C.

Legend:
- Loop 1 - Control
- Loop 2 - pH & Alk Only
- Loop 3 - TPC 223, 5 mg/L
- Loop 4 - Sodium Silicate, 12 mg/L
- Loop 5 - V939, 1.5 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8
- Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Pitting Rate, um/yr
X-axis: Time of Exposure, months
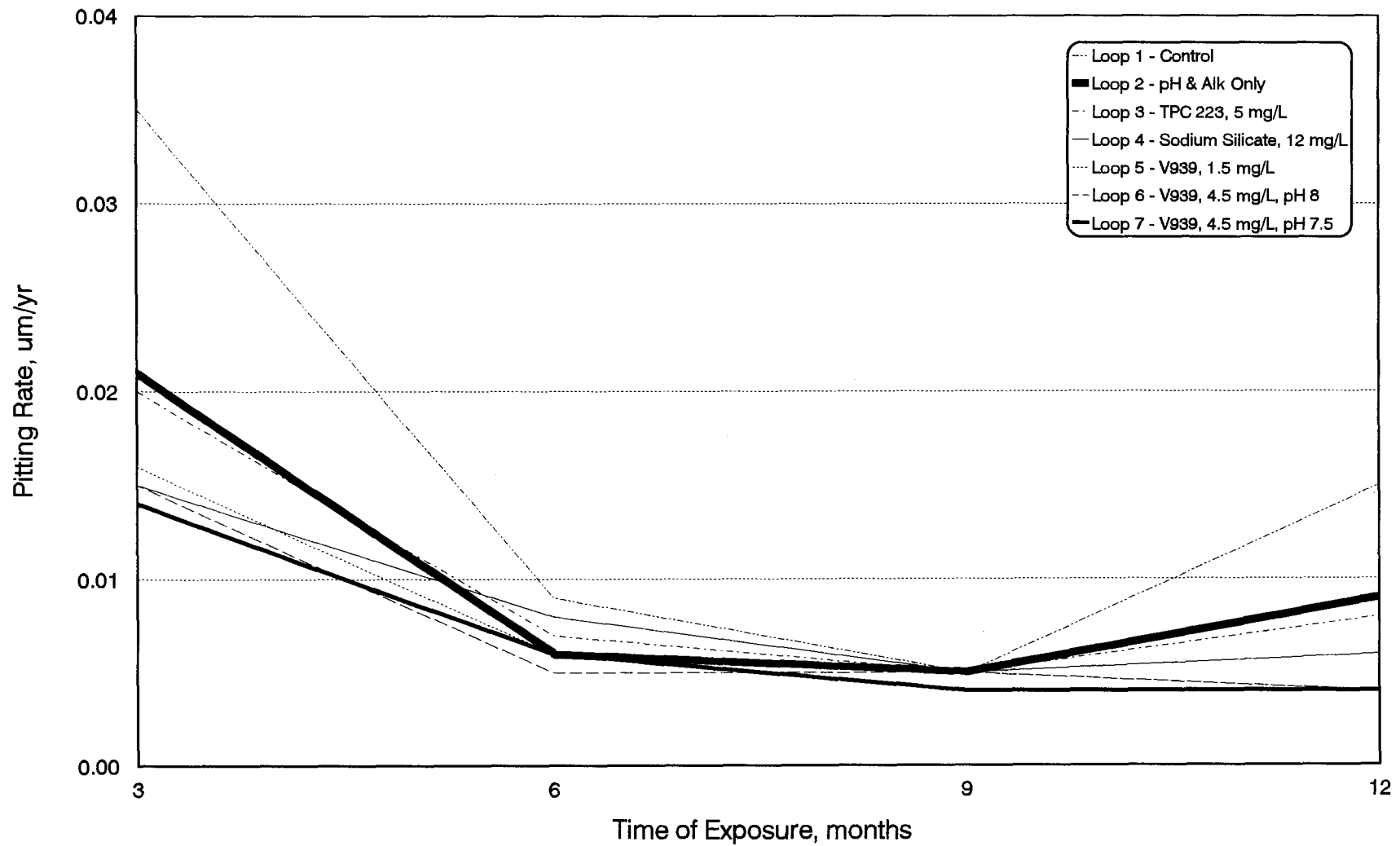
Figure 4.4 - Maximum Nominal Pittting Rates of Copper Coupon Inserts

Analysis in accordance with ASTM D 2688-83, Method C.
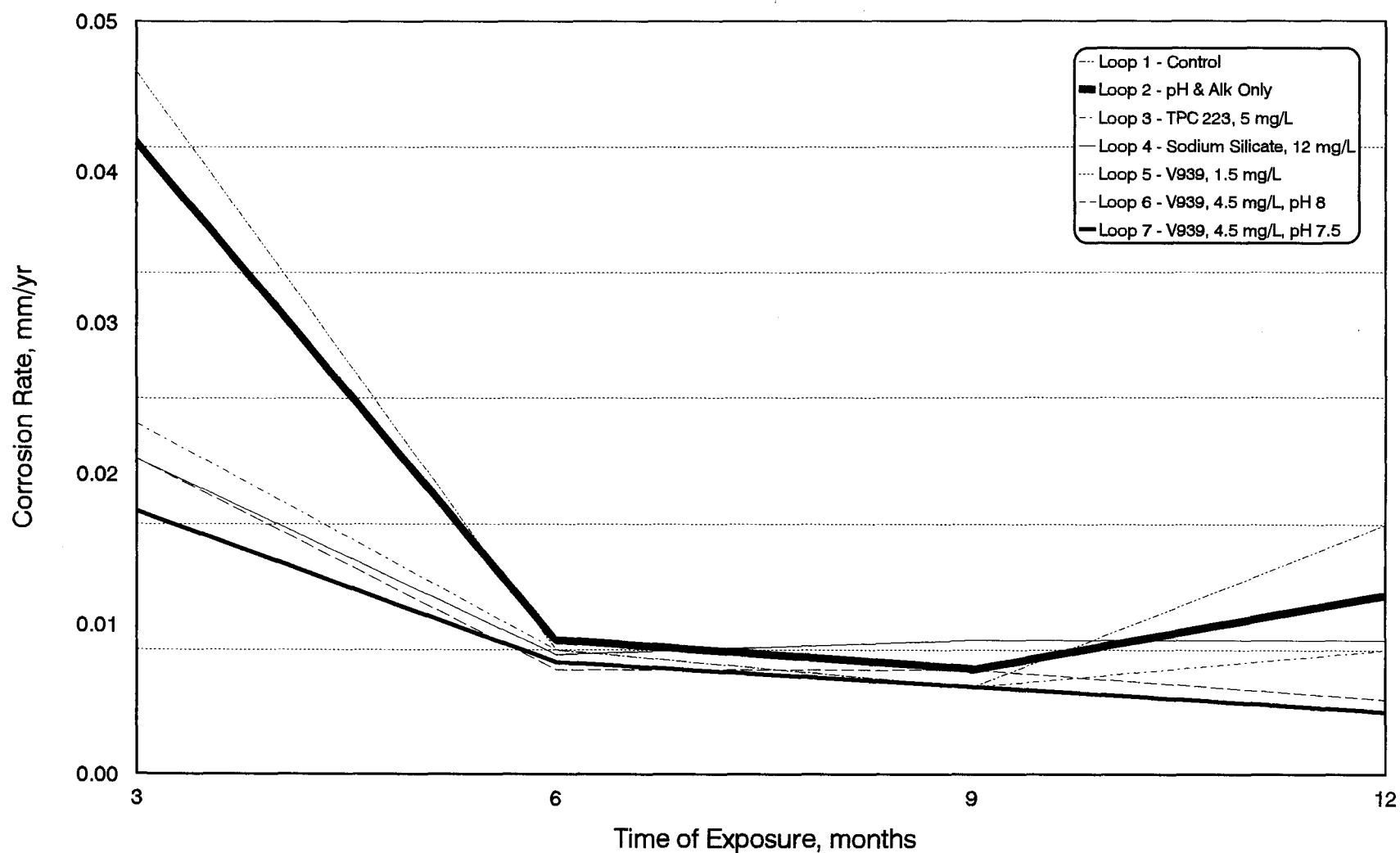
- Pitting rates appear to decrease with exposure time for all loops for the first 9 months. However, from 9 to 12 months the pitting rates in a few of the loops begin to increase again, particularly in the raw water loop. This may be an indication of some localized pitting taking place which is supported by the descriptions in the laboratory analysis sheets which most often described the pitting as "irregular".

- The results for Loops 5, 6 and 7 show that it may be possible to obtain good corrosion protection at a zinc orthophosphate dosage lower than 0.37 mg/L as P and Zn., and/or a pH and alkalinity lower than 8 and 20 mg/L, respectively.

Table 4.3 is presented as a summary comparing the relative copper corrosivity of the various treatments to that of raw water.

The relative corrosion rates in Table 4.3 could be used to estimate the expected service life of copper pipe under different water quality conditions. For example, the relative corrosivity of GVWD water at pH 8, alkalinity 20 mg/L, 2.5 mg/L of chloramine, and zinc orthophosphate at 0.37 mg/L as zinc and 0.37 mg/L as phosphorus, is 0.25 times that of raw water. Thus, the expected service life for copper exposed to this water could be approximately 1.00/0.25 = 4 times greater than that expected with raw water[10].

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[10]In Greater Vancouver currently, the life of domestic copper piping is typically 20-35 years with some failures as early as 3-10 years. Many commercial hot water recirculating systems systems require replacement after 12-15 years (AWWARF, 1989).

Copper Coupon Relative Corrosion Rates*								
Loop #	12 Month Thinning Rate (mm/yr)	Thinning Rate Relative to Raw Water	12 Month Pitting Rate mm/yr		Pitting Rate Relative to Raw Water		Average Penetration Rate (mm/yr)**	Average Penetration Relative to Raw Water
			Avg	Max	Avg	Max		
1	0.0111	1.00	0.0152	0.0203	1.00	1.00	0.0132	1.00
2	0.0072	0.65	0.0089	0.0122	0.58	0.60	0.0080	0.61
3	0.0075	0.68	0.0079	0.0104	0.52	0.51	0.0077	0.58
4	0.0047	0.42	0.0064	0.0086	0.42	0.43	0.0055	0.42
5	0.0045	0.41	0.0043	0.0051	0.28	0.25	0.0044	0.33
6	0.0024	0.22	0.0041	0.0051	0.27	0.25	0.0032	0.25
7	0.0025	0.23	0.0038	0.0051	0.25	0.25	0.0032	0.24
*Analysis in accordance with ASTM D 2688-83, Method C.								
**Average of the average pitting rate and the thinning rate.								

Table 4.3 - Copper Coupon Relative Corrosion Rates

4.1.2. Cast Iron Coupon Inserts

The results from the laboratory data sheets from Kennedy Jenks are summarized at Appendix B.

4.1.2.1. Cast Iron Coupon Weight Loss Rates

The cast iron coupon weight loss rates are expressed in terms of equivalent rates of penetration in mm/yr as summarized in Table 4.4.

As was the case with the copper coupons, for the 3, 6, and 9 month exposure periods, there were two sets of cast iron coupons with the only water quality difference

between sets being the temperature. The difference, this time, appears to be negligible, however, as there is no apparent trend differentiating the corrosion rates for the warmer and colder temperatures. Except for Loops 1 (raw water) and 6 (zinc orthophosphate, higher dosage), any differences are inconsistent.

Figures 4.5 and 4.6 represent the weight loss data graphically. The 3, 6, and 9 month plots in Figure 4.5 are averages for two measurements. These results are less conclusive than those for the copper coupons.

- Not all treatments show a reduction in 12 month corrosion rate. Loops 2 and 5 are slightly higher at 7 and 4 percent, respectively, than the raw water (negligible difference). The best 12 month rate was in Loop 4, the sodium silicate treated loop, which showed a 26 percent improvement over the raw water and a 30 percent improvement over that of Loop 2. The overall poor performance may very well be a consequence of attempting to maintain a pH in the low buffer capacity 8 to 8.5 range, offsetting any beneficial effect of the phosphate and silicate inhibitors. This could be an indication that, in terms of cast iron corrosion, pH is a more important factor than the addition of inhibitors.

- With a few exceptions, the corrosion rates decreased with time. Loops 3 and 7 showed slight increases from the 3 to the 6 month measurement levels, Loop 5 showed an increase from the 6 month to the 9 month levels, and Loop 2 increased from the 9 to the 12 month measurements, but these increases were negligible. Over all, corrosion rates decreased from the 3 to the 12 month measurements. The most dramatic improvement was in Loop 1, raw water, a decrease of 41 percent; this could be due to a combination of naturally occurring protective scale and possibly lower water temperature during the latter part of the experiment.

Cast Iron Coupon Corrosion Rates (mm/yr)							
Exposure Time	**Loop Number**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
3 Months (a)	0.314	0.185	0.196	0.206	0.211	0.242	0.194
3 Months (2) (b)	0.252	0.249	0.187	0.227	0.187	0.233	0.161
6 Months (c)	0.255	0.182	0.224	0.213	0.131	0.225	0.239
6 Months (2) (d)	0.183	0.219	0.197	0.205	0.214	0.190	0.171
9 Months (e)	0.224	0.180	0.165	0.156	0.208	0.170	0.168
9 Months (2) (f)	0.181	0.191	0.168	0.159	0.192	0.165	0.171
12 months (g)	0.181	0.193	0.167	0.135	0.189	0.150	0.159

Cast Iron Coupon Average Corrosion Rates							
Exposure Time	**Loop Number**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
3 Months	0.283	0.217	0.192	0.216	0.199	0.238	0.178
6 Months	0.219	0.201	0.210	0.209	0.173	0.208	0.205
9 Months	0.202	0.186	0.167	0.158	0.200	0.167	0.169
12 months	0.182	0.194	0.167	0.135	0.190	0.151	0.160

(a) Exposed 15/03/91 to 17/06/91(warm)   (e) Exposed 15/03/91 to 18/12/91(warm)

(b) Exposed 18/12/91 to 16/03/92 (cold)   (f) Exposed 17/06/91 to 16/03/92 (cold)

(c) Exposed 15/03/91 to 16/09/91(warm)   (g) Exposed 15/03/91 to 16/03/92

(d) Exposed 16/09/91 to 16/03/92 (cold)

*Analysis in accordance with ASTM D 2688-83, Method C.

Table 4.4 - Cast Iron Coupon Corrosion Rates

Figure 4.5 - Corrosion Rates of Cast Iron Coupon Inserts
Based on Weight Loss Measurements
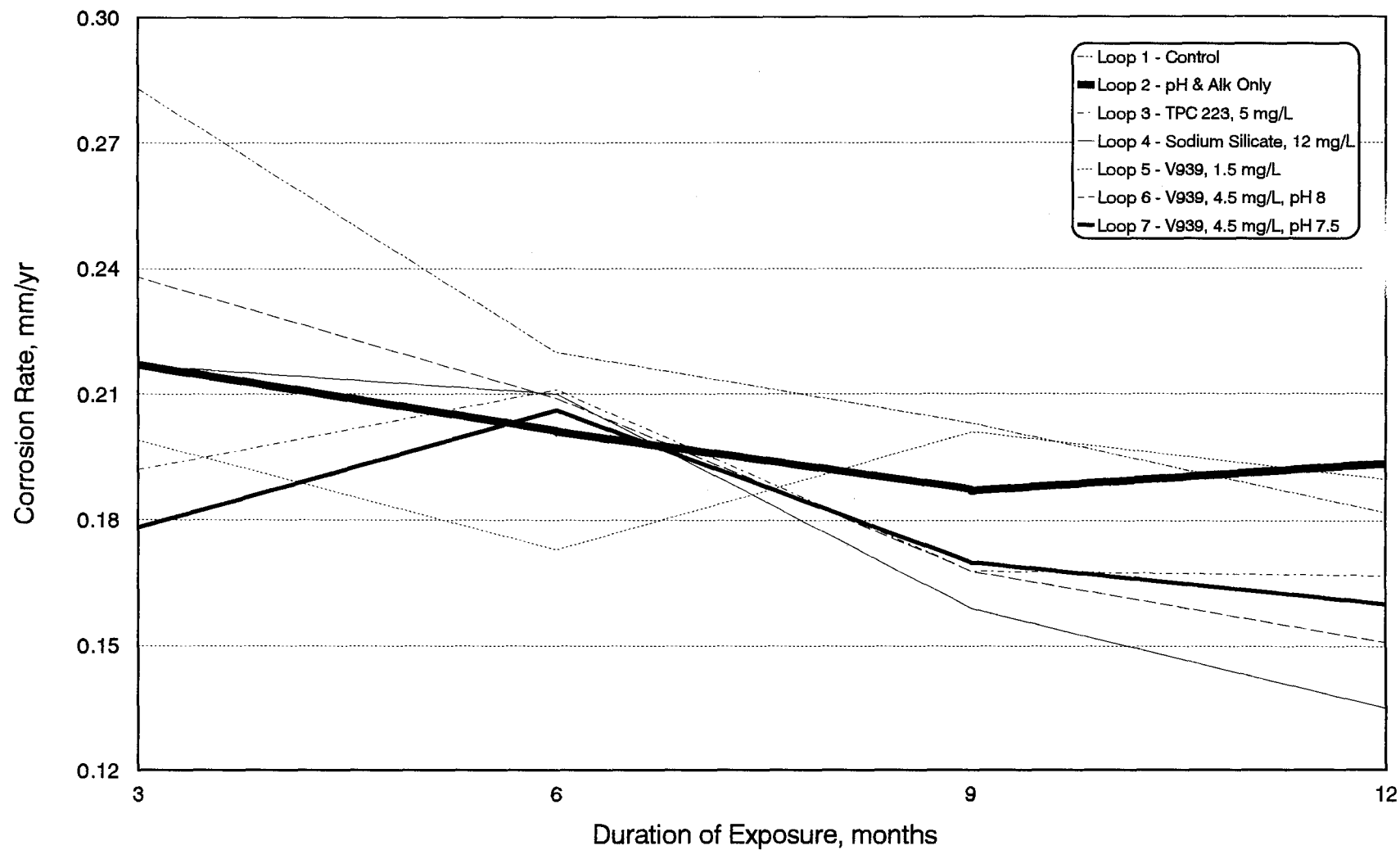
Figure 4.6 - Corrosion Rates of Cast Iron Coupon Inserts
Based on Weight Loss Measurements
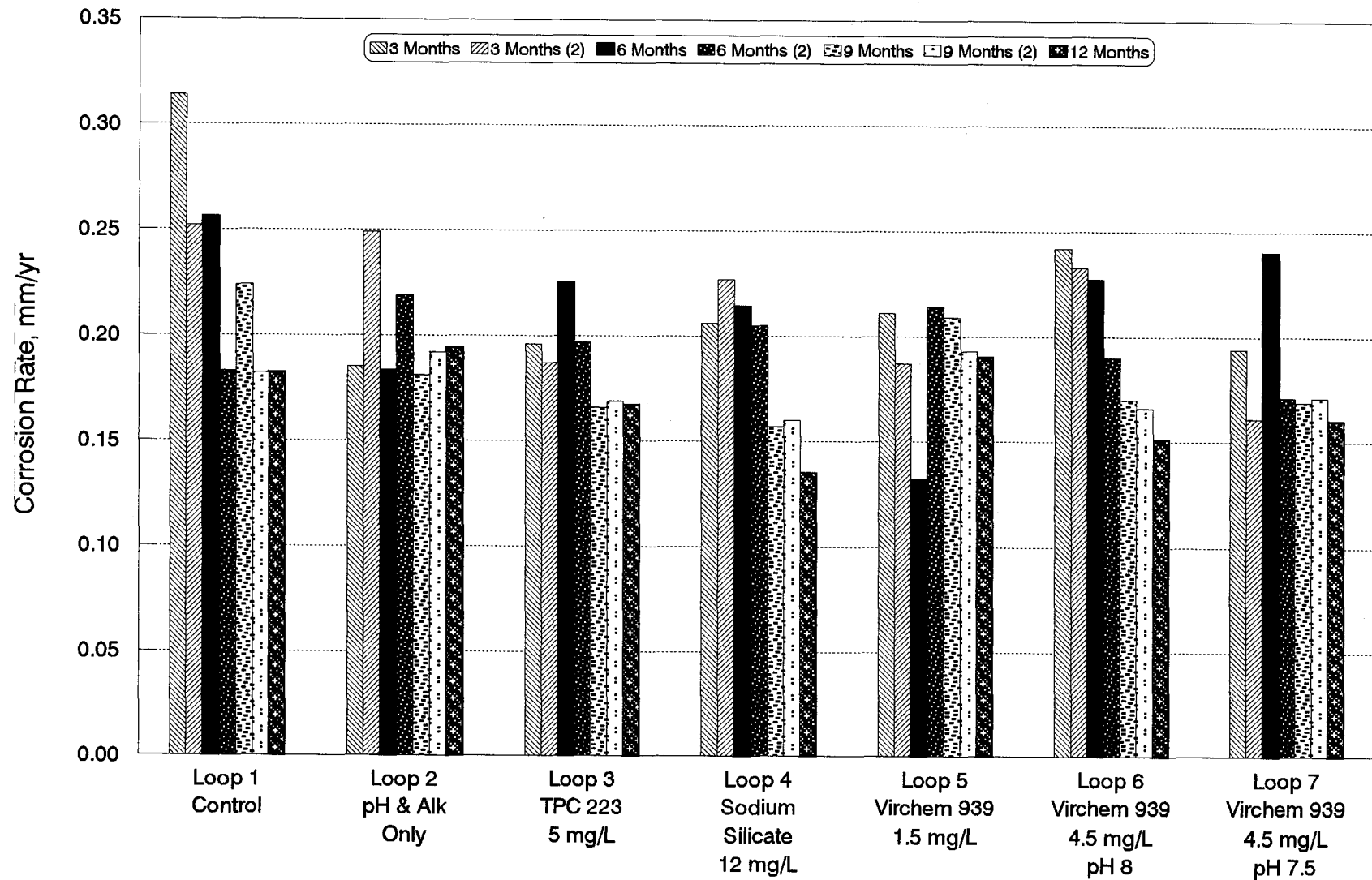
- As an overall observation, it seems obvious, particularly when viewing Figure 4.6 and given the margin of error expected in this type of experiment, that none of the treatments provided any significant degree of additional protection over that afforded by natural scale formation in the raw water.

- Given the results from the copper coupons, the cast iron coupon results appear to *mandate* further testing of these inhibitors at lower pHs.

4.1.2.2. Cast Iron Coupon Insert Pitting Analyses

The critical results (see Appendix B) pitting analyses are summarized in Table 4.5. Again, the average and maximum pit depths are the actual observed data, while the nominal pitting rates were calculated by dividing the observed pit depths by the exposure time in years. These data are plotted in Figures 4.7 and 4.8.

These results show the treatments to be even more questionable in terms of cast iron protection.

- With the exception of Loop 3, (the sodium silicate/zinc orthophosphate combination treated loop) the 12 month average nominal pitting rates in all loops are higher than that for the raw water. The rate for Loop 4 is 74 percent higher, and that for Loops 5, 6, and 7 (the loops which showed the lowest copper pitting rates) the rates are 55, 42, and 53 percent higher, respectively. Without exception, the 12 month maximum nominal pitting rates are higher than that for the raw water. Loop 6 is 76 percent higher. There are inconsistencies, however. For example, the 9 month average and maximum nominal pitting rates for all treatments are lower than the 9 month rates for the raw water. There is no apparent reason for these inconsistencies. Perhaps, this is an indication of the degree of difficulty that must be involved in providing data which has a low error level. The preparation of coupons after they are

removed from the water line is, by its very nature, *corrosive*. How much error does the preparation process introduce? Error level is also increased by virtue of the fact that, after they are prepared, the examination and measurement of the coupons, is a somewhat subjective process. When two parts of the same experiment conducted under overlapping conditions yield such different results, it means all the results must be viewed with a healthy degree of skepticism.

- Overall, the average and maximum nominal pitting rates decrease with time, but again there are exceptions as can be seen in the graphs.
- These results provide further evidence of the need for serious questioning and further testing before any of these treatments should be applied in the GVWD distribution network to control tron corrosion.

Cast Iron Coupon Pitting Analysis*								
Pit Depths (mm)								
Loop #	**3 Months**		**6 Months**		**9 Months**		**12 Months**	
	Avg	**Max**	**Avg**	**Max**	**Avg**	**Max**	**Avg**	**Max**
1	0.071	0.117	0.082	0.093	0.127	0.168	0.097	0.114
2	0.037	0.071	0.088	0.109	0.085	0.097	0.124	0.183
3	0.037	0.074	0.082	0.094	0.097	0.114	0.091	0.119
4	0.076	0.130	0.084	0.099	0.079	0.097	0.168	0.196
5	0.076	0.097	0.082	0.084	0.088	0.122	0.150	0.193
6	0.048	0.089	0.088	0.099	0.085	0.109	0.137	0.201
7	0.046	0.066	0.075	0.079	0.104	0.124	0.147	0.165

Nominal Pitting Rate (mm/yr)								
Loop #	**3 Months**		**6 Months**		**9 Months**		**12 Months**	
	Avg	**Max**	**Avg**	**Max**	**Avg**	**Max**	**Avg**	**Max**
1	0.284	0.467	0.164	0.186	0.169	0.224	0.097	0.114
2	0.147	0.284	0.177	0.218	0.113	0.129	0.124	0.183
3	0.149	0.295	0.165	0.187	0.129	0.152	0.091	0.119
4	0.305	0.518	0.167	0.198	0.105	0.129	0.168	0.196
5	0.305	0.386	0.164	0.168	0.117	0.163	0.150	0.193
6	0.193	0.356	0.175	0.198	0.113	0.146	0.137	0.201
7	0.183	0.264	0.150	0.157	0.139	0.166	0.147	0.165

*Analysis in accordance with ASTM D 2688-83, Method C.

Table 4.5 - Cast Iron Coupon Pitting Rates

Figure 4.7 - Average Nominal Pittting Rates of Cast Iron Coupon Inserts

Analysis in accordance with ASTM D 2688-83, Method C.

Legend:
- ···· Loop 1 - Control
- ▬ Loop 2 - pH & Alk Only
- ·· Loop 3 - TPC 223, 5 mg/L
- — Loop 4 - Sodium Silicate, 12 mg/L
- ···· Loop 5 - V939, 1.5 mg/L
- − − Loop 6 - V939, 4.5 mg/L, pH 8
- ▬ Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Pitting Rate, mm/yr (0.08, 0.16, 0.24, 0.32)

X-axis: Time of Exposure, months (3, 6, 9, 12)
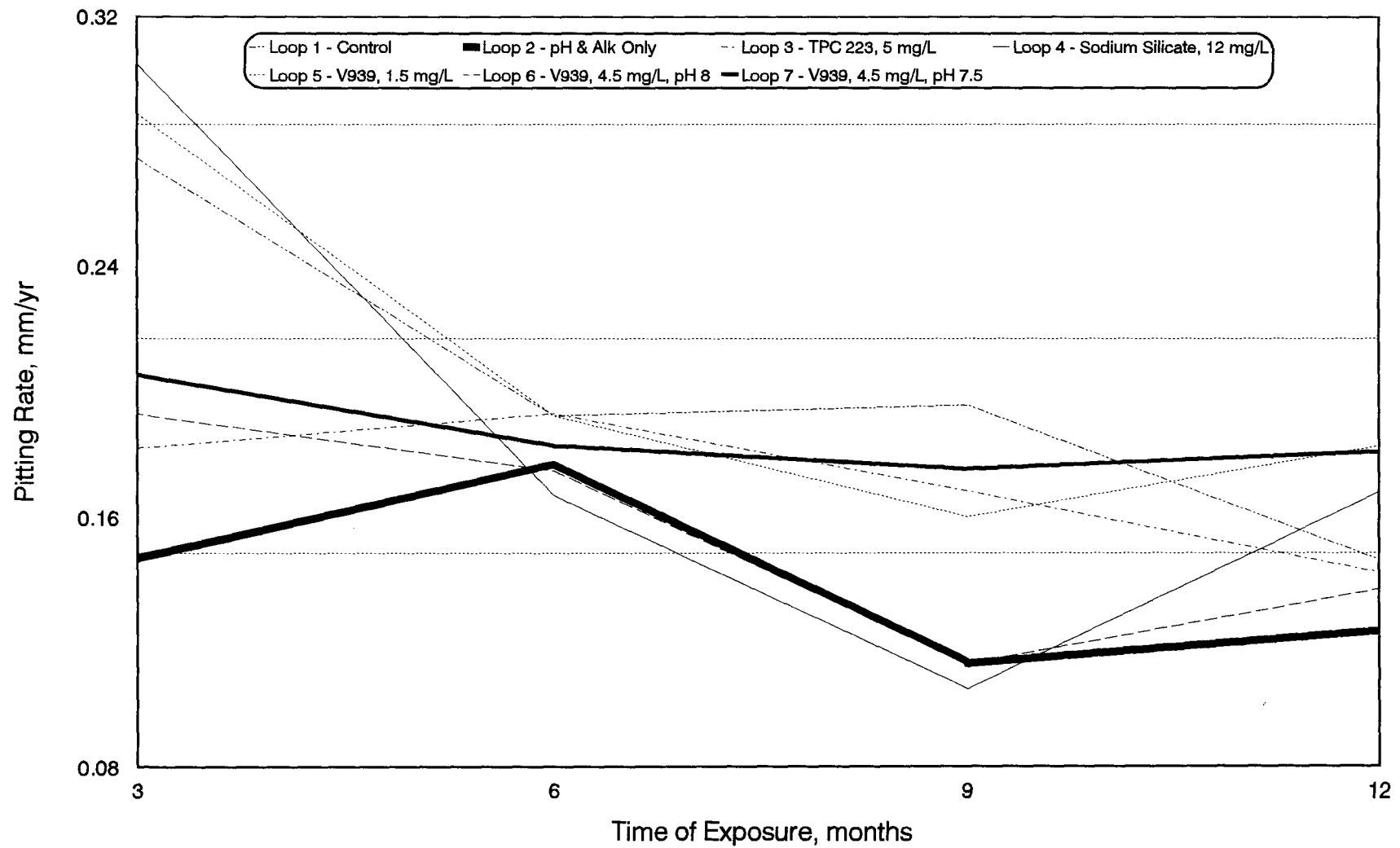
Figure 4.8 - Maximum Nominal Pittting Rates of Cast Iron Coupon Inserts

Analysis in accordance with ASTM D 2688-83, Method C.
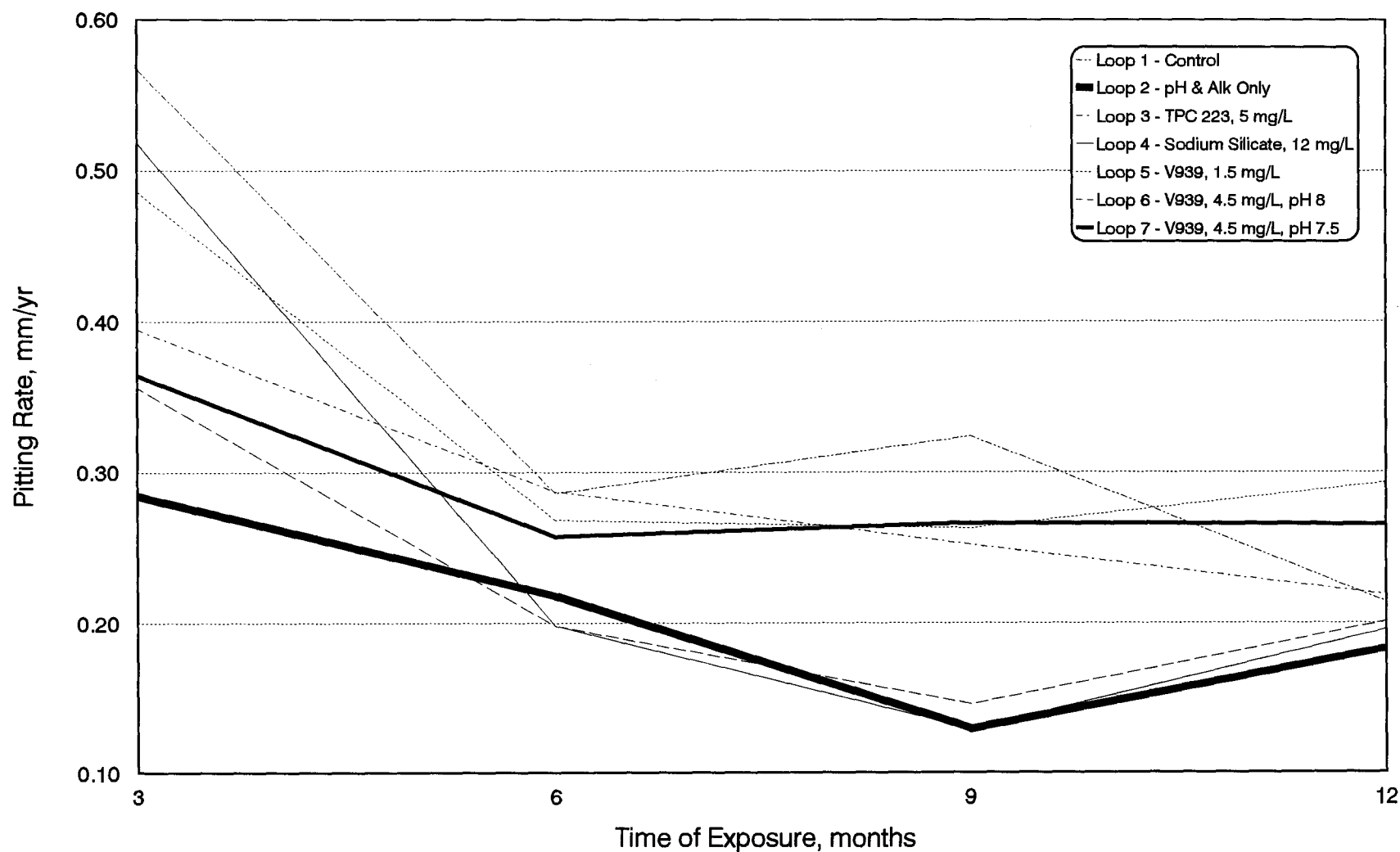
Table 4.6 is presented as a summary comparing the relative cast iron corrosivity with that of raw water.

		Cast Iron Coupon Relative Corrosion Rates*						
Loop #	12 Month Thinning Rate (mm/yr)	Thinning Rate Relative to Raw Water	12 Month Pitting Rate mm/yr		Pitting Rate Relative to Raw Water		Average Penetration Rate (mm/yr)**	Average Penetration Relative to Raw Water
			Avg	Max	Avg	Max		
1	0.182	1.00	0.097	0.114	1.00	1.00	0.139	1.00
2	0.194	1.07	0.124	0.183	1.29	1.60	0.159	1.14
3	0.167	0.92	0.091	0.119	0.95	1.04	0.129	0.93
4	0.135	0.74	0.168	0.196	1.74	1.71	0.151	1.09
5	0.190	1.04	0.150	0.193	1.55	1.69	0.170	1.22
6	0.151	0.83	0.137	0.201	1.42	1.76	0.144	1.03
7	0.160	0.88	0.147	0.165	1.53	1.44	0.154	1.10
*Analysis in accordance with ASTM D 2688-83, Method C.								
**Average of the average pitting rate and the thinning rate.								

Table 4.6 - Cast Iron Coupon Relative Corrosion Rates

If the relative corrosion rates in Table 4.6 were used to estimate the expected service life of cast iron under different water quality conditions, a less favorable comparison would result than that obtained for copper pipe. For example, the relative corrosivity of GVWD water at pH 8, alkalinity 20 mg/L, 2.5 mg/L chloramine, and zinc orthophosphate at 0.13 mg/L as zinc and 0.13 mg/L as phosphorus, is 1.22 times that of

raw water. Thus, the expected service life for cast iron exposed to this water could be only 1.00/1.22 = 82 percent of that expected from exposure to raw water. However, given the margin of error in this experiment, the difference shown in this case is probably statistically negligible.

4.1.2.3. Cast Iron Coupon Scaling Rates

There was extensive build-up of corrosion scale on all the cast iron coupons. The amount of scaled surface area increased steadily with exposure time until, after 12 months, all coupons were 100 percent covered with brown tubercules over black scale. The scale thickness also increased with time. Scaling information from the laboratory data sheets (Appendix B) is summarized in Table 4.7.

As can be seen, the treated loops all have thicker scales and higher scaling rates than the raw water. It is also interesting to note that the loops with the thickest scale were those with the highest relative corrosion rates shown in Table 4.6. These higher scaling rates also have implications in terms of reduction of flow capacity, as mentioned previously.

Cast Iron Coupon Relative Scale Build-up*						
Loop #	Scale Thickness (mm)				Scaling Rate (mm/yr)	Scaling Rate Relative to Raw Water
	3 Months	6 Months	9 Months	12 Months		
1	0.51	1.02	1.14	1.52	1.52	1.00
2	0.51	1.27	2.03	3.81	3.81	2.50
3	0.64	1.27	1.52	2.03	2.03	1.33
4	0.76	1.71	1.78	2.03	2.03	1.33
5	0.89	1.02	1.91	3.05	3.05	2.00
6	0.51	1.27	1.65	2.54	2.54	1.67
7	1.02	2.92	2.29	3.56	3.56	2.33

*Analysis in accordance with ASTM D 2688-83, Method C.

Table 4.7 - Cast Iron Coupon Relative Scale Build-up

4.2. Corrosometer Probes

4.2.1. Copper Corrosometer Probes

The copper Corrosometer probe data can be found in Appendix C. The formula, provided by the manufacturer, for converting the data to a corrosion rate is:

$$\text{`Corrosion Rate (mm/yr)} = \frac{\Delta \text{ Dial Reading} \times 0.00927 \times \text{Probe Span}}{\Delta \text{ Time (Days)}}$$

The *Probe Span* is a dimensionless constant provided by the manufacturer which takes into account the differences in probe types. For the copper Corrosometer probes, the probe span was 1. In order to try and provide some basis for comparison to the coupon results, 3, 6, 9, and 10 month corrosion rates were calculated. It was not possible to calculate 12 month corrosion rates due to the late installation of the probes. These corrosion rates are shown in Table 4.8, and they are plotted in Figures 4.9 and 4.10.

Copper Corrosometer Probe Corrosion Rates, mm/yr				
Loop #	3 Months	6 Months	9 Months	10 Months
1	0.0117	0.0090	0.0072	0.0067
2	0.0193	0.0147	0.0099	0.0091
3	0.0118	0.0080	0.0066	0.0062
4	0.0062	0.0052	0.0037	0.0035
5	0.0096	0.0097	0.0074	0.0070
6	0.0014	0.0021	0.0014	0.0014
7	0.0003	0.0025	0.0025	0.0023

Table 4.8 - Copper Corrosometer Probe Corrosion Rates

The following are some observations arising from the data and charts:

- The treatments in Loops 3, 4, 6, and 7 had corrosion rates lower than the raw water rate. Loops 2 and 5 had higher corrosion rates than the raw water. The lowest 10 month corrosion rate was in Loop 6, 66 percent lower than the raw water rate and 75 percent lower than the rate in Loop 2. The rate for Loop 1 was 26 percent lower than that for Loop 2.

Figure 4.9 - Corrosion Rates of Copper Corrosometer Probes

Legend:
- Loop 1 - Control
- Loop 2 - pH & Alk Only
- Loop 3 - TPC 223, 5 mg/L
- Loop 4 - Sodium Silicate, 12 mg/L
- Loop 5 - V 939, 1.5 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8
- Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Corrosion Rate, mm/yr

X-axis: Duration of Exposure, months
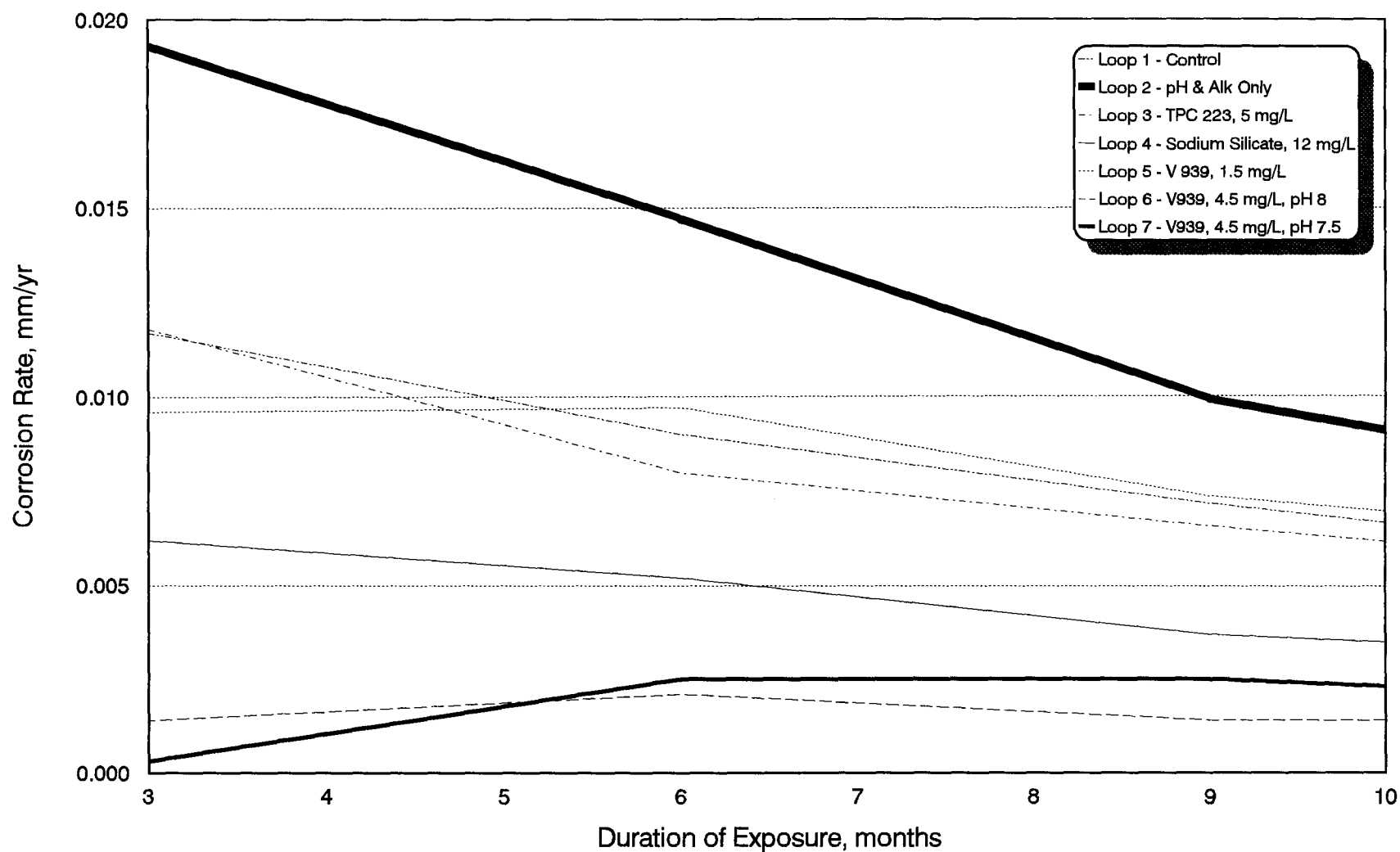
Figure 4.10 - Corrosion Rates of Copper Corrosometer Probes
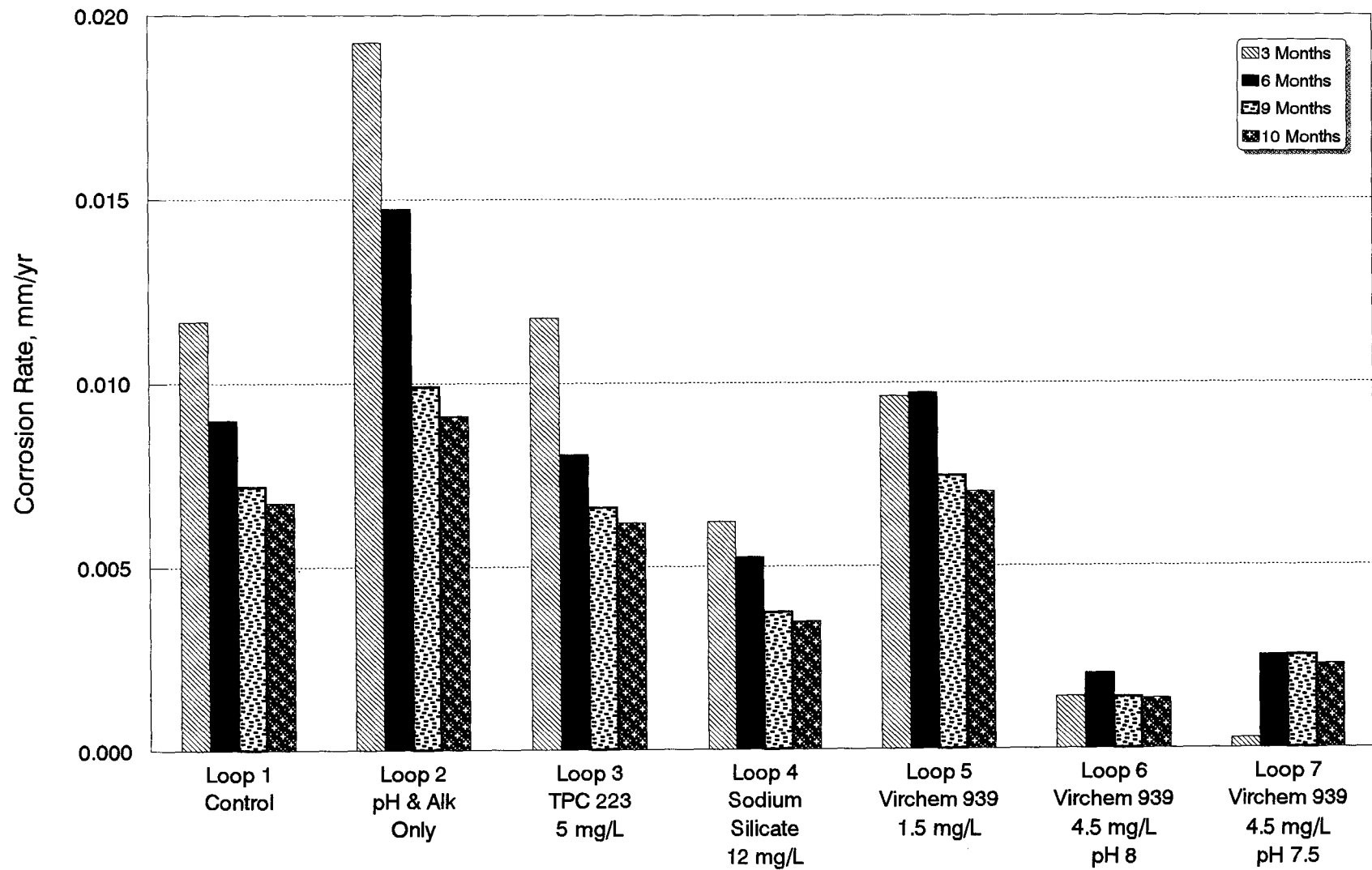
- Generally, corrosion rates in all loops decreased with time. The 3 month rate in Loop 7 appears out of line compared with all the others and should probably be ignored.

- As was the case with the copper coupon inserts, the lowest corrosion rates occurred in Loops 6 and 7, giving a further indication of the possible potential for zinc orthophosphate as a copper corrosion inhibitor.

Table 4-9 presents the corrosion rates of the copper Corrosometer probes relative to raw water.

Copper Corrosometer Probes Relative Corrosion Rates		
Loop #	10 Month Corrosion Rate mm/yr	Corrosion Rate Relative to Raw Water
1	0.0067	1.00
2	0.0091	1.35
3	0.0062	0.92
4	0.0035	0.52
5	0.0070	1.04
6	0.0014	0.20
7	0.0023	0.34

Table 4-9 - Copper Corrosometer Probe Relative Corrosion Rates

Plots of the Corrosometer *resistance readings* versus *time* are shown in Figure 4.11. The same plots are repeated in Figures 4.12 through 4.14, except that straight line slope approximations are superimposed. It is worthwhile studying the curves for a qualitative feel. The coincidental drop in dial readings, which occurred on 12/06/91 and 19/06/91 is best ignored. It is suspected that those readings were taken just after water flow had started. The water temperature would have dropped suddenly, causing an error in the resistance readings. The Corrosometer system does not require adjustment for temperature, provided the change is gradual or some time passes for the temperature to equalize throughout the probe. The check reading (Appendix C) measures the resistance of a sealed reference electrode. Due to the fact that the reference electrode is isolated such as it is, some time is required before the temperature of the two electrodes is close enough so as to minimize resistance differences due to temperature. In Loops 1 through 5, the corrosion rates started very high and stayed that way for 1 to 2 months and then slowed gradually until after about 6 to 7 months, the rates in all loops approached quite low levels. The corrosion rate in Loop 6 started very low and remained that way, declining slightly. The corrosion rate in Loop 7 started low until, after about 5 months, it increased for about 3 months and then leveled off. What is particularly interesting, is that during the last few months, the rates in all loops were several orders of magnitude lower than they were during the first few. Table 4.10 shows the, more or less, prevailing corrosion rates during the early, middle, and latter stages.

For the middle and later periods, instead of calculating the corrosion rate by dividing total change in dial reading by the total time since the start of the experiment, only the changes for the period in question were used; that should provide an approximation of the prevailing corrosion rate during that time. For example, the dial reading for Loop 5 in the later period went from 361 units to 383.5 over a period of 301 - 212 = 89 days (27/11/91 to 24/02/92). Therefore, the corrosion rate is calculated as per the formula:

$$\text{Corrosion Rate (mm/yr)} = \frac{22.5}{89} \times 0.00927 \times 1$$

$$= \underline{0.0023}$$

Copper Corrosometer Probe Prevailing Corrosion Rates, mm/yr			
Loop #	Early Months	Middle Months	Later Months
1	0.0146	0.0019	0.0033
2	0.0177	0.0131	0.0008
3	0.0307	0.0035	0.0008
4	0.0113	0.0038	0.0008
5	0.0126	0.0089	0.0023
6	0.0004	0.0004	0.0001
7	0.0007	0.0072	0.0006

Table 4.10 - Copper Corrosometer Probe Prevailing Corrosion Rates

These corrosion rates are plotted in Figures 4.15 and 4.16. From this perspective, the convergence to a low corrosion rate in all loops is more obvious. Again it appears that the treatment in Loop 6 offers the best protection, but the latter corrosion rates in Loops, 2, 3, 4, and 7 are so close to that in Loop 6, that over the long term, the differences may prove negligible.

In order to ensure correct operation of the Corrosometer system, the *Check Reading* mentioned above should remain constant (± 5 units). If the check reading changes significantly, it means that the seal on the check electrode has failed and any further readings are not valid. As can be seen in Appendix C all check readings stayed

Figure 4.11 - Copper Corrosometer Probes
Resistance Change Over Time

Legend:
- Loop 1 - Control
- Loop 2 - pH & Alk Only
- Loop 3 - TPC 223, 5 mg/L
- Loop 4 - Sodium Silicate, 12 mg/L
- Loop 5 - V 939, 1.5 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8
- Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Resistance, Dial units
X-axis: Days After Installation (29 Apr 91)
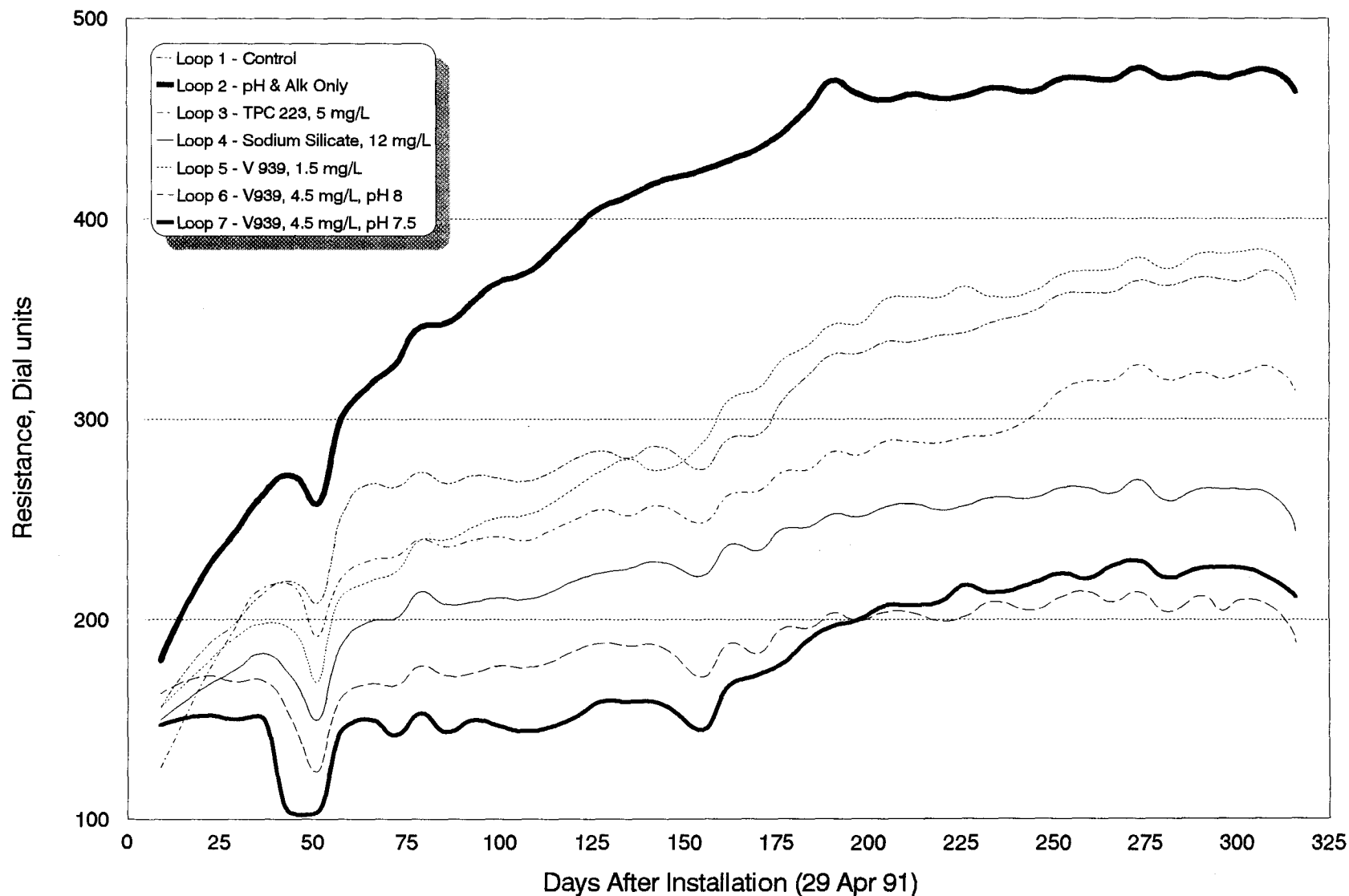
Figure 4.12 - Copper Corrosometer Probes
Resistance Change Over Time (Loops 1 and 4)

Legend:
- Loop 1 - Control
- Loop 4 - Sodium Silicate, 12 mg/L

Y-axis: Resistance, Dial units

X-axis: Days After Installation (29 Apr 91)
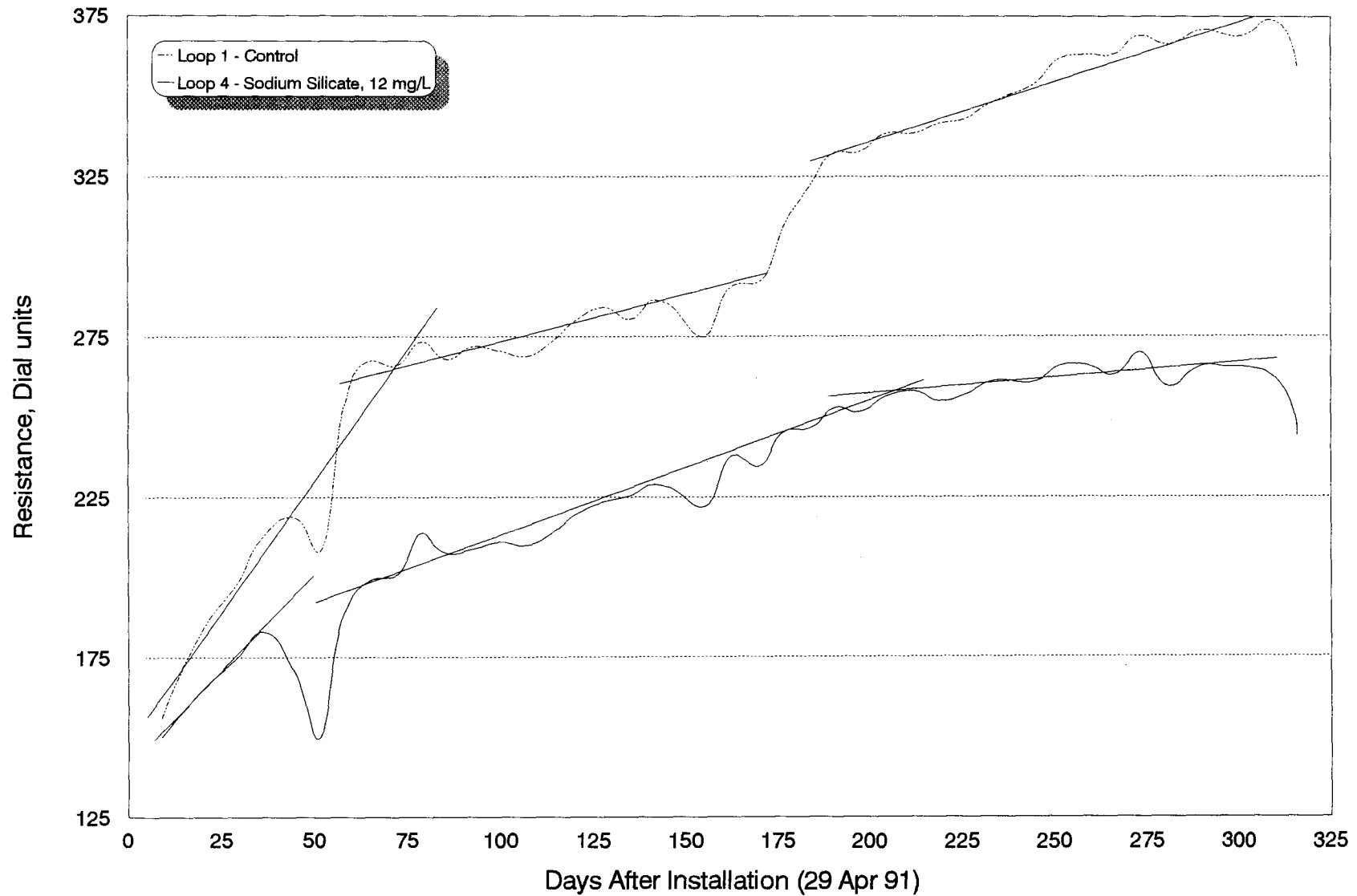
Figure 4.13 - Copper Corrosometer Probes
Resistance Change Over Time (Loops 2, 5, and 6)

Legend:
- Loop 2 - pH & Alk Only
- Loop 5 - V 939, 1.5 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8

Y-axis: Resistance, Dial units (100, 200, 300, 400, 500)

X-axis: Days After Installation (29 Apr 91) (0, 25, 50, 75, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325)
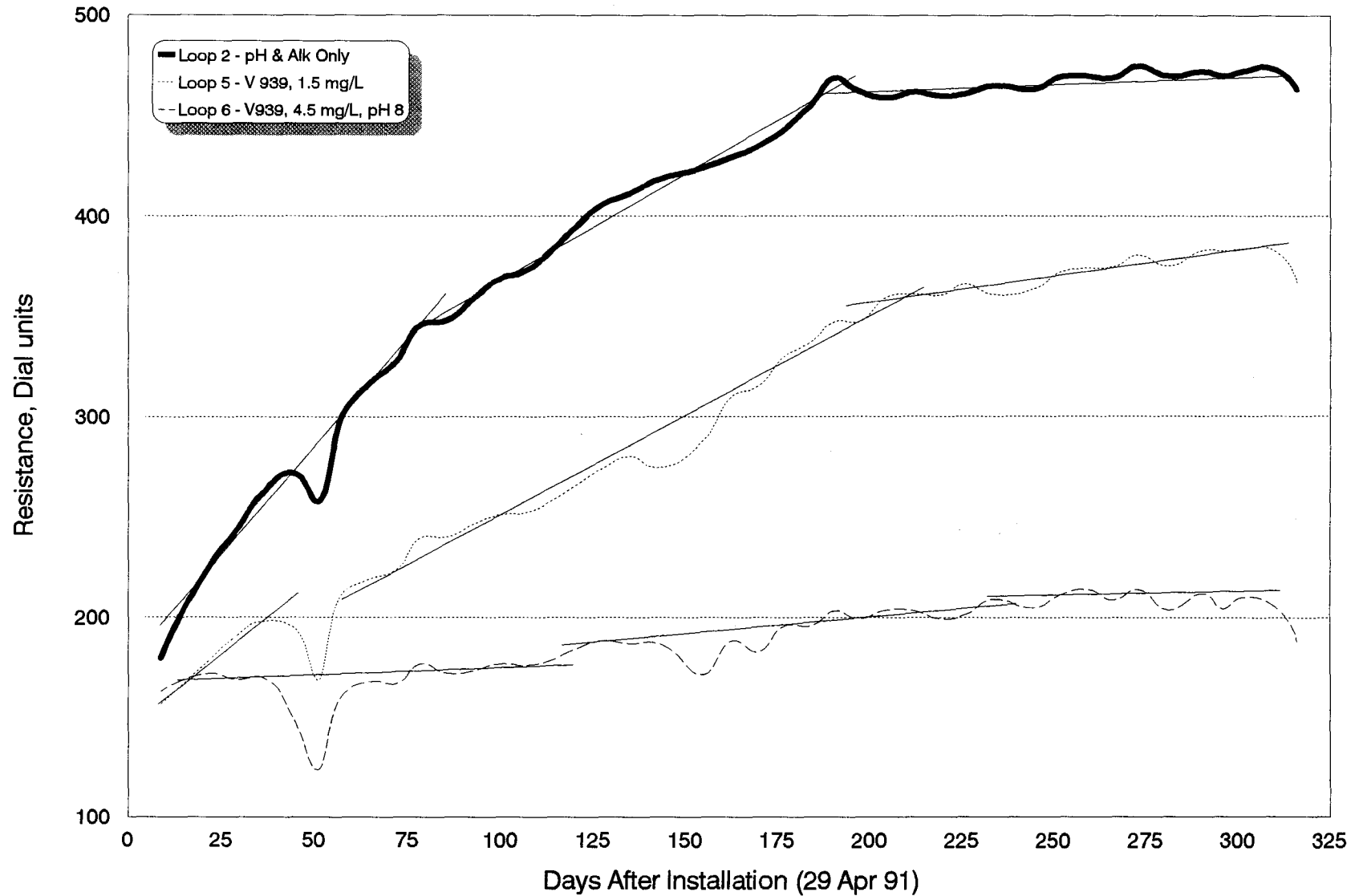
Figure 4.14 - Copper Corrosometer Probes
Resistance Change Over Time (Loops 3 and 7)

Legend:
- Loop 3 - TPC 223, 5 mg/L
- Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Resistance, Dial units

X-axis: Days After Installation (29 Apr 91)
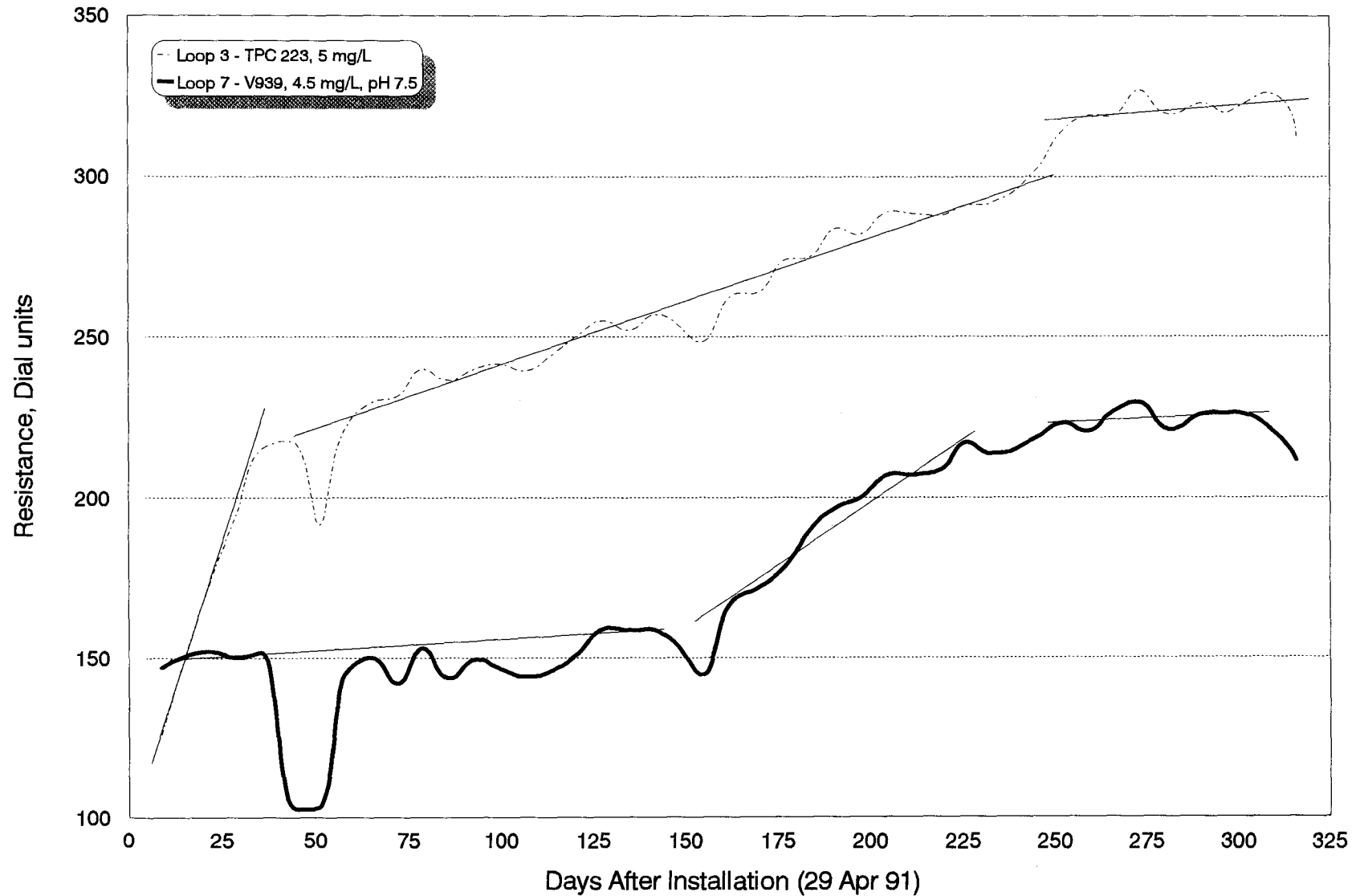
Figure 4.15 - Copper Corrosometer Probes
Prevailing Corrosion Rates

Loop 1 - Control
Loop 2 - pH & Alk Only
Loop 3 - TPC 223, 5 mg/L
Loop 4 - Sodium Silicate, 12 mg/L
Loop 5 - V 939, 1.5 mg/L
Loop 6 - V939, 4.5 mg/L, pH 8
Loop 7 - V939, 4.5 mg/L, pH 7.5

Corrosion Rate, mm/yr

0.03

0.02

0.01

0

0   50   100   150   200   250   300

Days After Installation (29 Apr 91)

92
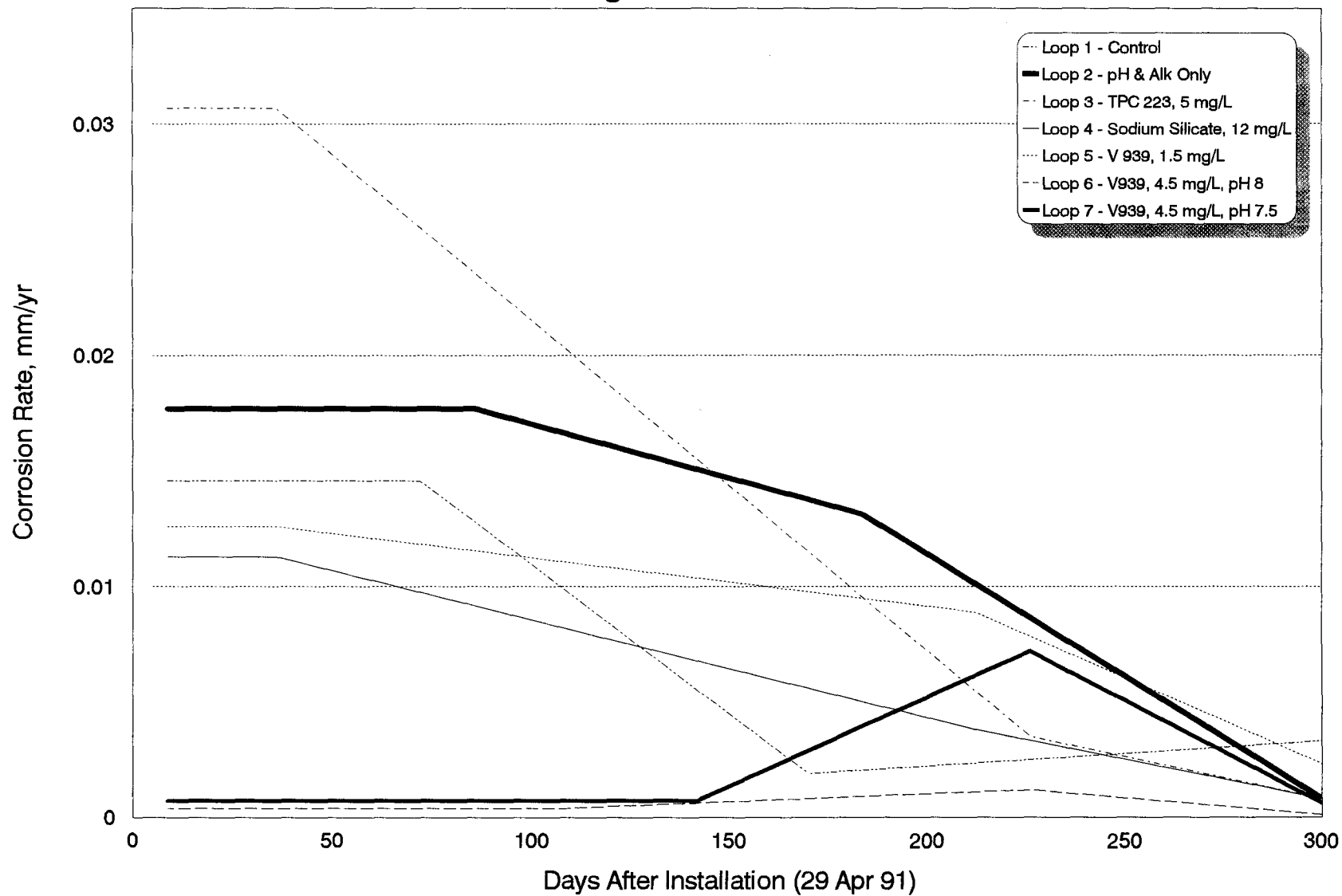
Figure 4.16 - Copper Corrosometer Probes
Prevailing Corrosion Rates
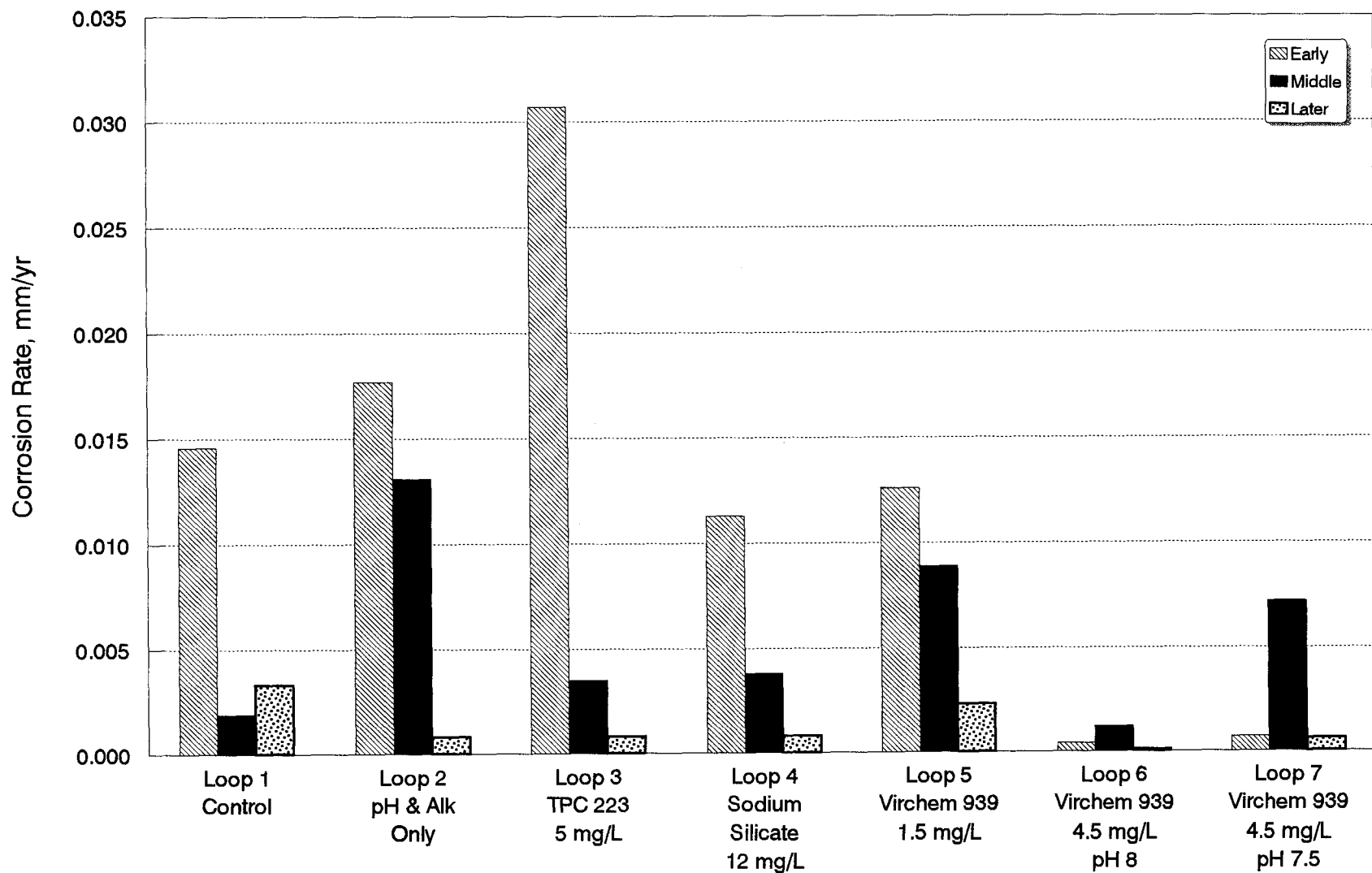
within the limits.

4.2.2. Mild Steel Corrosometer Probes

The mild steel Corrosometer probe data can be found in Appendix D. The same formula given above was used to convert the data to a corrosion rate. For the mild steel probes, the *Probe Span* was 10. Unfortunately, all of the probes corroded so quickly that they did not last through the duration of the experiment. The probe in Loop 3 only lasted 155 days. It is unlikely that any of the data is of much use. Even though the electrodes in Loops 4 and 7 lasted a little longer, the check readings on both of them changed enough to render their data suspect after about 18/09/91. Nevertheless, an attempt was made to calculate 3 and 6 month corrosion rates on all loops, and 9 month rates on Loops 4 and 7. These corrosion rates are shown in Table 4.11, and they are plotted in Figures 4.17 and 4.18.

Mild Steel Corrosometer Probe Corrosion Rates, mm/yr			
Loop #	3 Months	6 Months	9 Months
1	0.371	0.400	
2	0.400	0.414	
3	0.421	0.438	
4	0.316	0.308	0.312
5	0.409	0.420	
6	0.160	0.217	
7	0.216	0.265	0.287

Table 4.11 - Mild Steel Corrosometer Probe Corrosion Rates

Figure 4.17 - Mild Steel Corrosometer Probe Corrosion Rate

Legend:
- Loop 1 - Control
- Loop 2 - pH & Alk Only
- Loop 3 - TPC 223, 5 mg/L
- Loop 4 - Sodium Silicate, 12 mg/L
- Loop 5 - V 939, 1.5 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8
- Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Corrosion Rate, mm/yr

X-axis: Time of Exposure, months
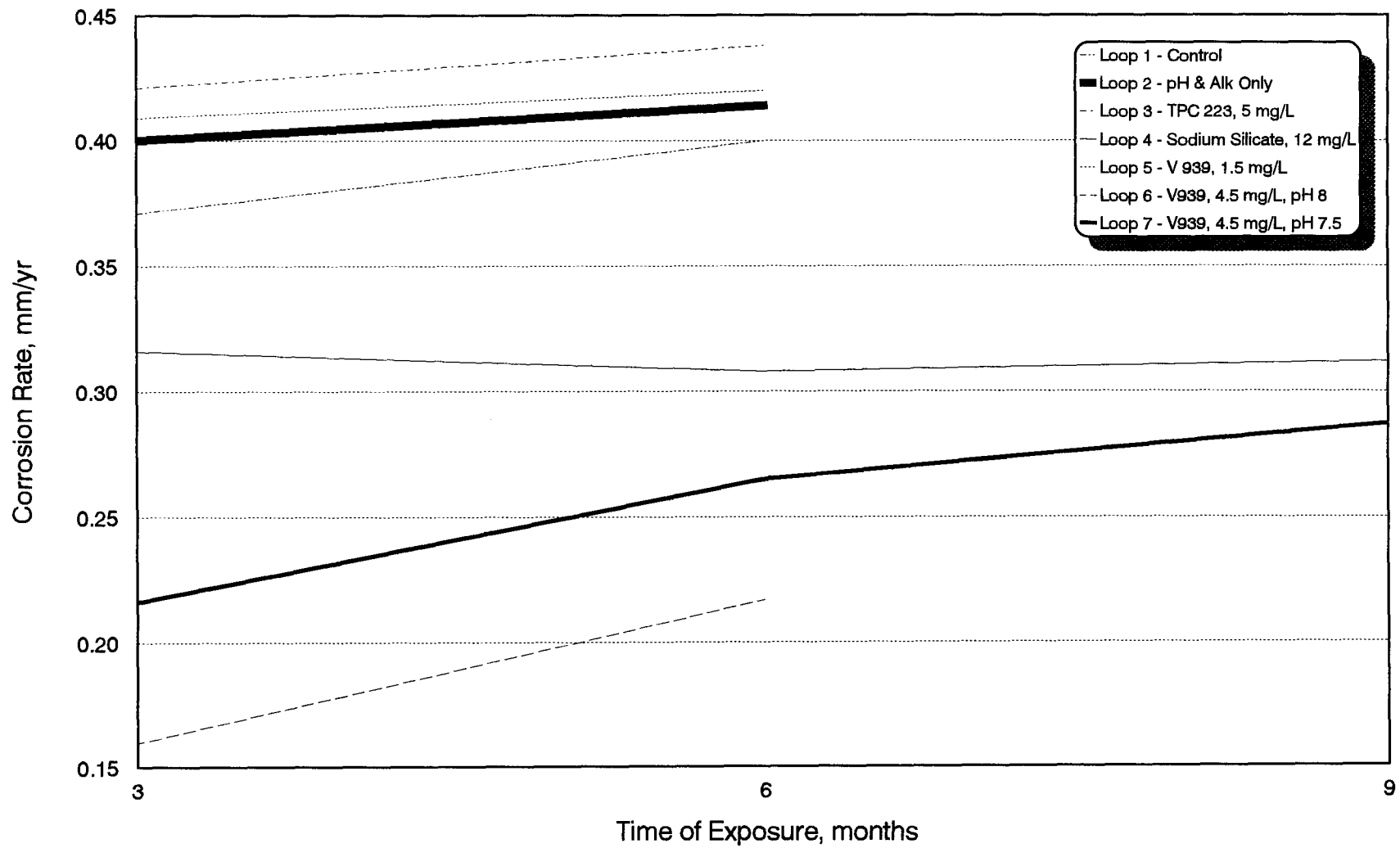
Figure 4.18 - Mild Steel Corrosometer Probe Corrosion Rate
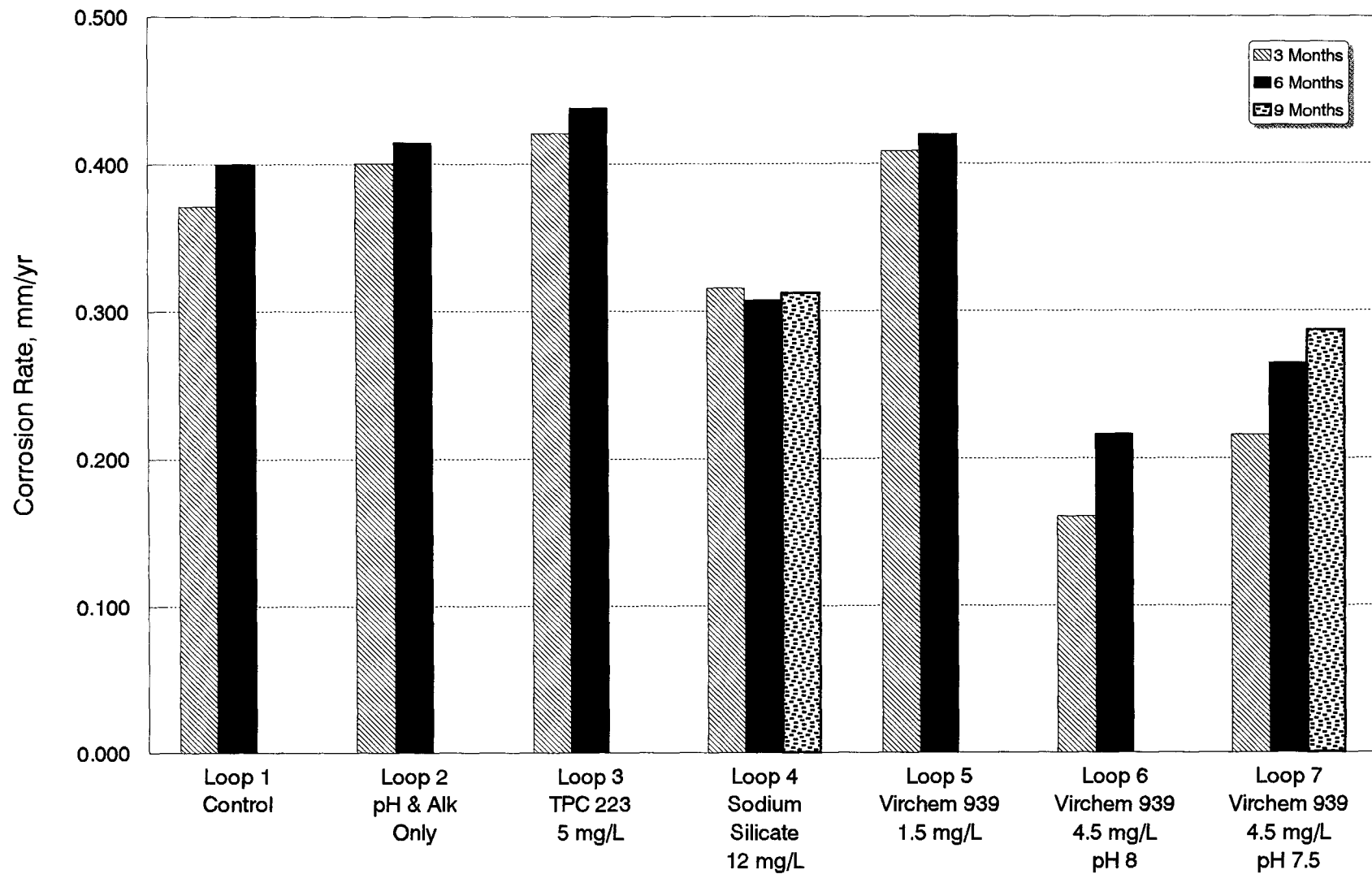
Despite the foregoing comments, the following observations are offered:

- The corrosion rates in Loops 1, 2, 3, and 5 are very similar, any differences being negligible. The lowest corrosion rates occurred in Loops 4, 6 and 7.

- It would appear that there may some beneficial protection afforded to mild steel from zinc orthophosphate and silicates.

Table 4-12 shows the mild steel Corrosometer probe relative corrosion rates

Mild Steel Corrosometer Probes Relative Corrosion Rates		
Loop #	10 Month Corrosion Rate mm/yr	Corrosion Rate Relative to Raw Water
1	0.40	1.00
2	0.41	1.04
3	0.44	1.09
4	0.31	0.77
5	0.42	1.05
6	0.22	0.54
7	0.26	0.66

Table 4-12 - Mild Steel Corrosometer Probe Relative Corrosion Rates

Plots of the Corrosometer *resistance readings* versus *time* are shown in Figure 4.19 and are repeated in Figures 4.20 through 4.23, so that straight line slope approximations could be superimposed upon the curves. In all except Loop 4, the corrosion rates started high and stayed that way for 1 to 4 months and then increased

gradually until the curves became non-linear. The non-linearity is an indication of pitting in the electrodes, which renders them useless from that point on. The useful life of the electrode in Loop 3 was less than 4 months. The corrosion rate in Loop 4 was essentially the same throughout the life of the electrode. Table 4.13 shows the approximate prevailing corrosion rates during the early and later stages.

Mild Steel Corrosometer Probe Prevailing Corrosion Rates, mm/yr		
Loop #	Early Months	Later Months
1	0.3582	0.4927
2	0.3179	0.4575
3	0.3510	0.5099
4	0.3158	0.3187
5	0.3413	0.4503
6	0.1585	0.2999
7	0.2210	0.4112

Table 4.13 - Mild Steel Corrosometer Probe
Prevailing Corrosion Rates

The same method used to calculate the prevailing corrosion rates for the copper probes was used for the mild steel probes. These corrosion rates are plotted in Figures 4.24 and 4.25. The uptrend in all loops, except 4, is obvious. It appears that the treatment in Loop 6 resulted in the lowest corrosion rate; however, it was still increasing

Figure 4.19 - Mild Steel Corrosometer Probes
Resistance Change Over Time

Loop 1 - Control
Loop 2 - pH & Alk Only
Loop 3 - TPC 223, 5 mg/L
Loop 4 - Sodium Silicate, 12 mg/L
Loop 5 - V 939, 1.5 mg/L
Loop 6 - V939, 4.5 mg/L, pH 8
Loop 7 - V939, 4.5 mg/L, pH 7.5

Resistance, Dial units

Days Since Installation (29 Apr 91)
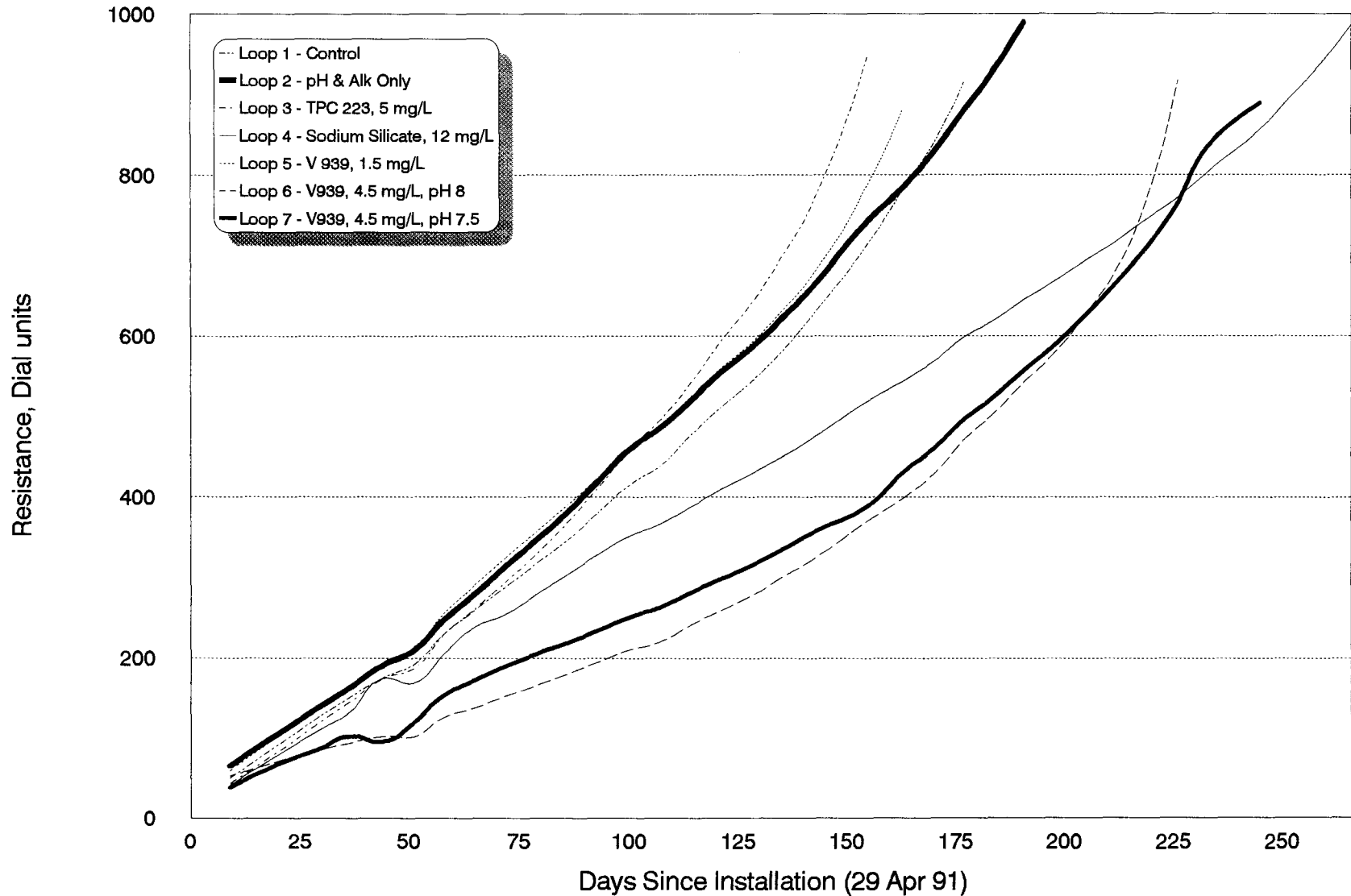
Figure 4.20 - Mild Steel Corrosometer Probes
Resistance Change Over Time (Loops 1 and 7)
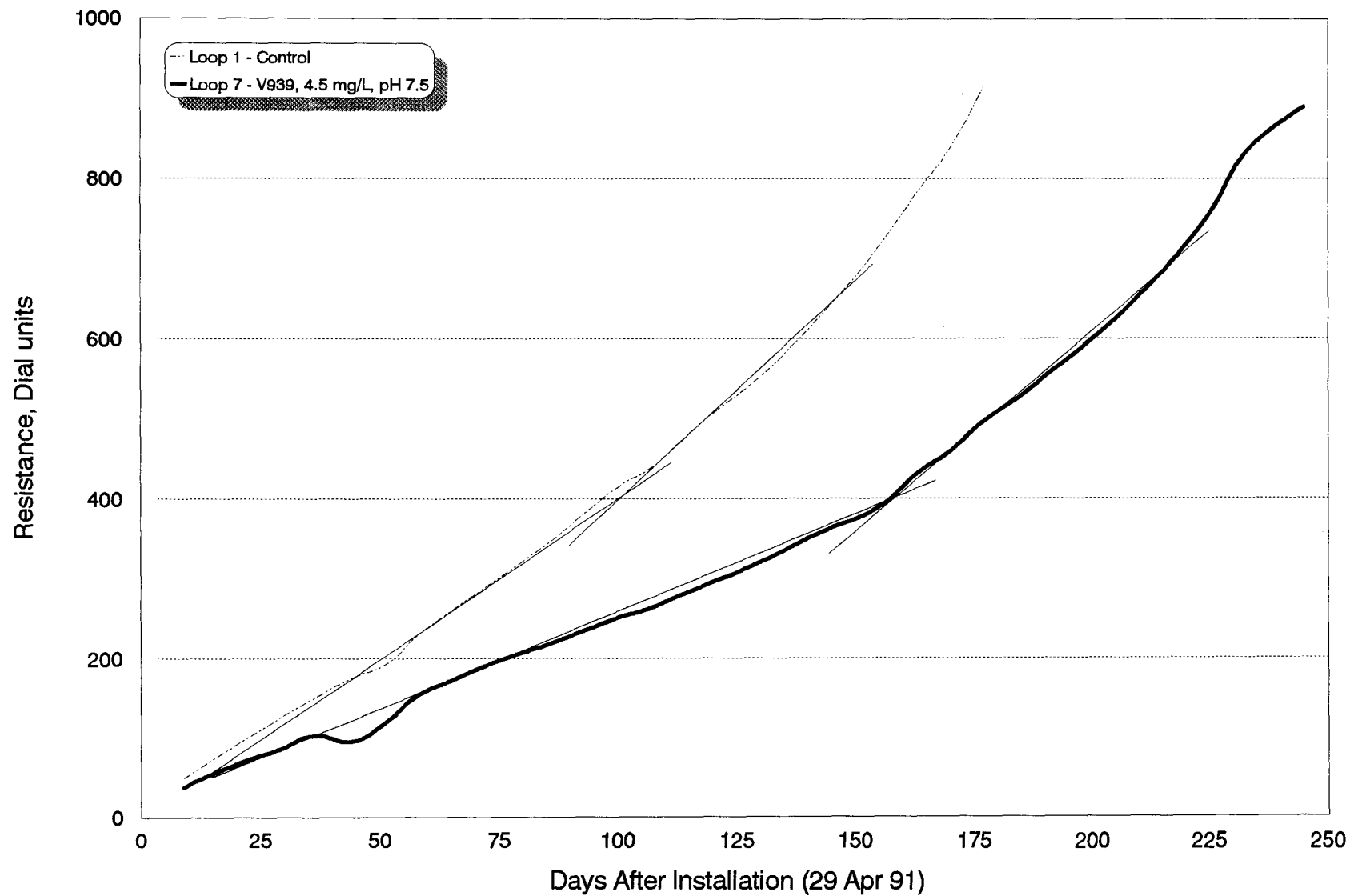
Figure 4.21 - Mild Steel Corrosometer Probes
Resistance Change Over Time (Loops 2, 4, and 6)

Legend:
- Loop 2 - pH & Alk Only
- Loop 4 - Sodium Silicate, 12 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8

Y-axis: Resistance, Dial units
X-axis: Days After Installation (29 Apr 91)
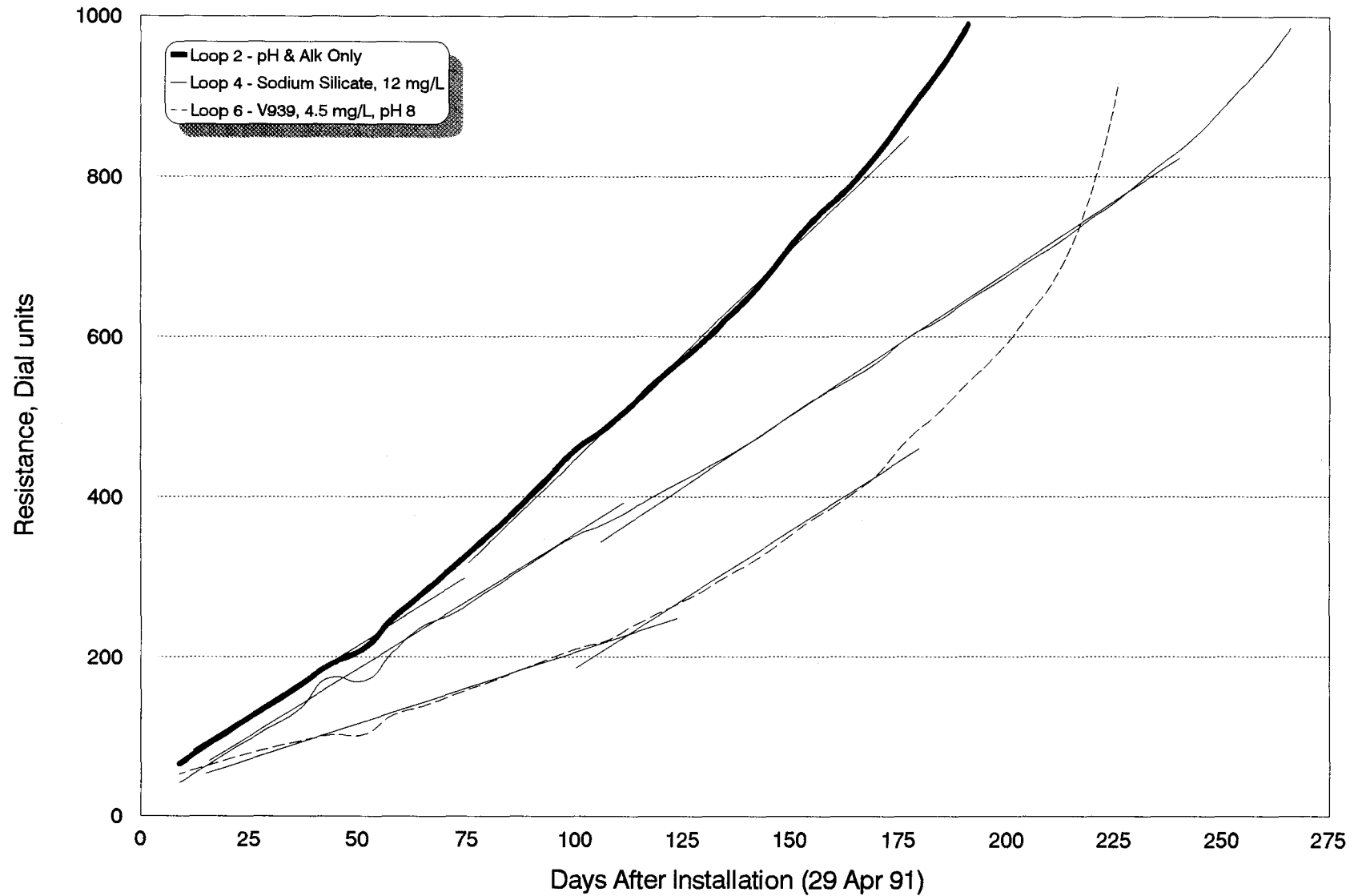
Figure 4.22 - Mild Steel Corrosometer Probes
Resistance Change Over Time (Loop 3, TPC 223, 5 mg/L)

Resistance, Dial units

Days After Installation (29 Apr 91)
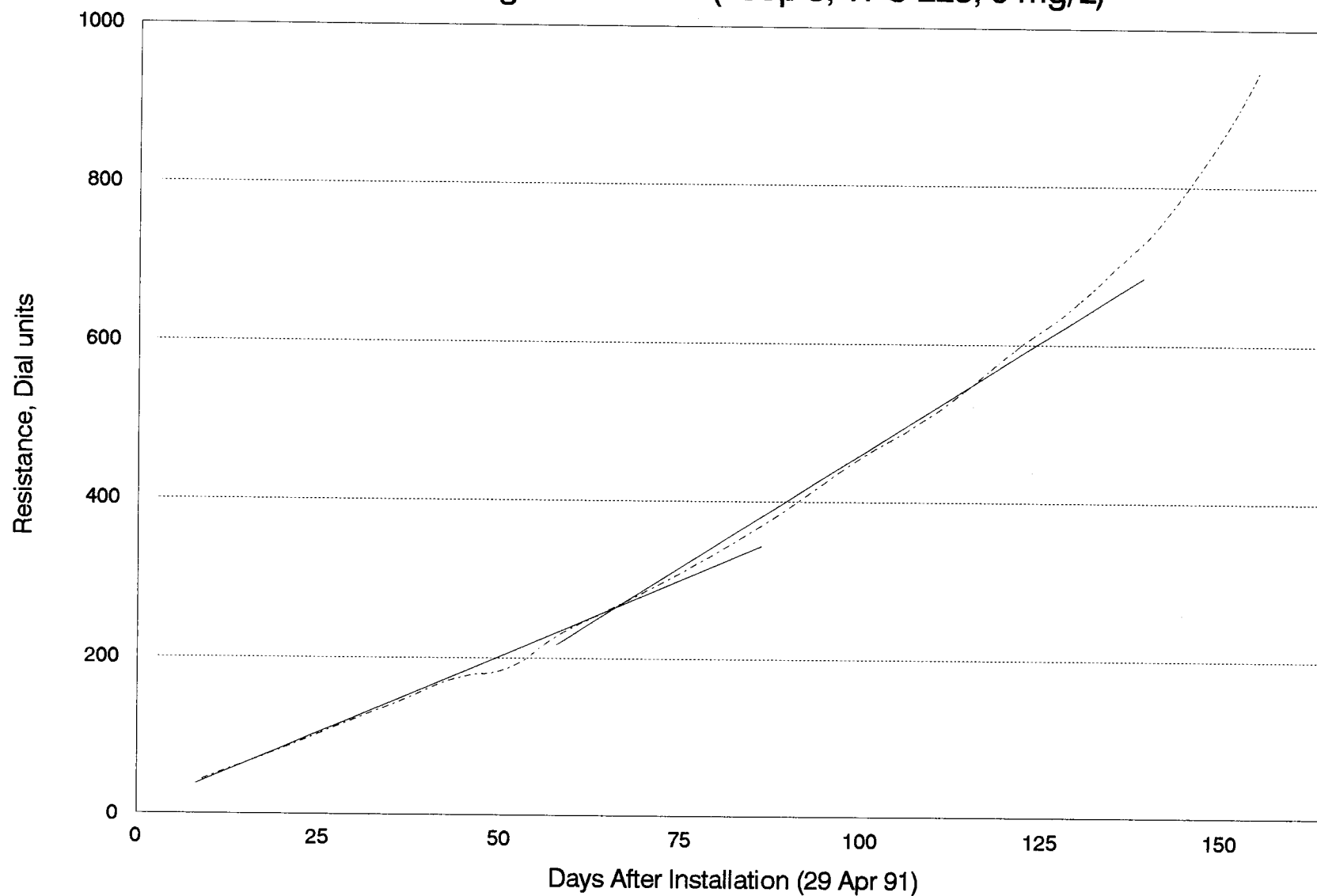
Figure 4.23 - Mild Steel Corrosometer Probes
Resistance Change Over Time (Loop 5, V939, 1.5 mg/L)
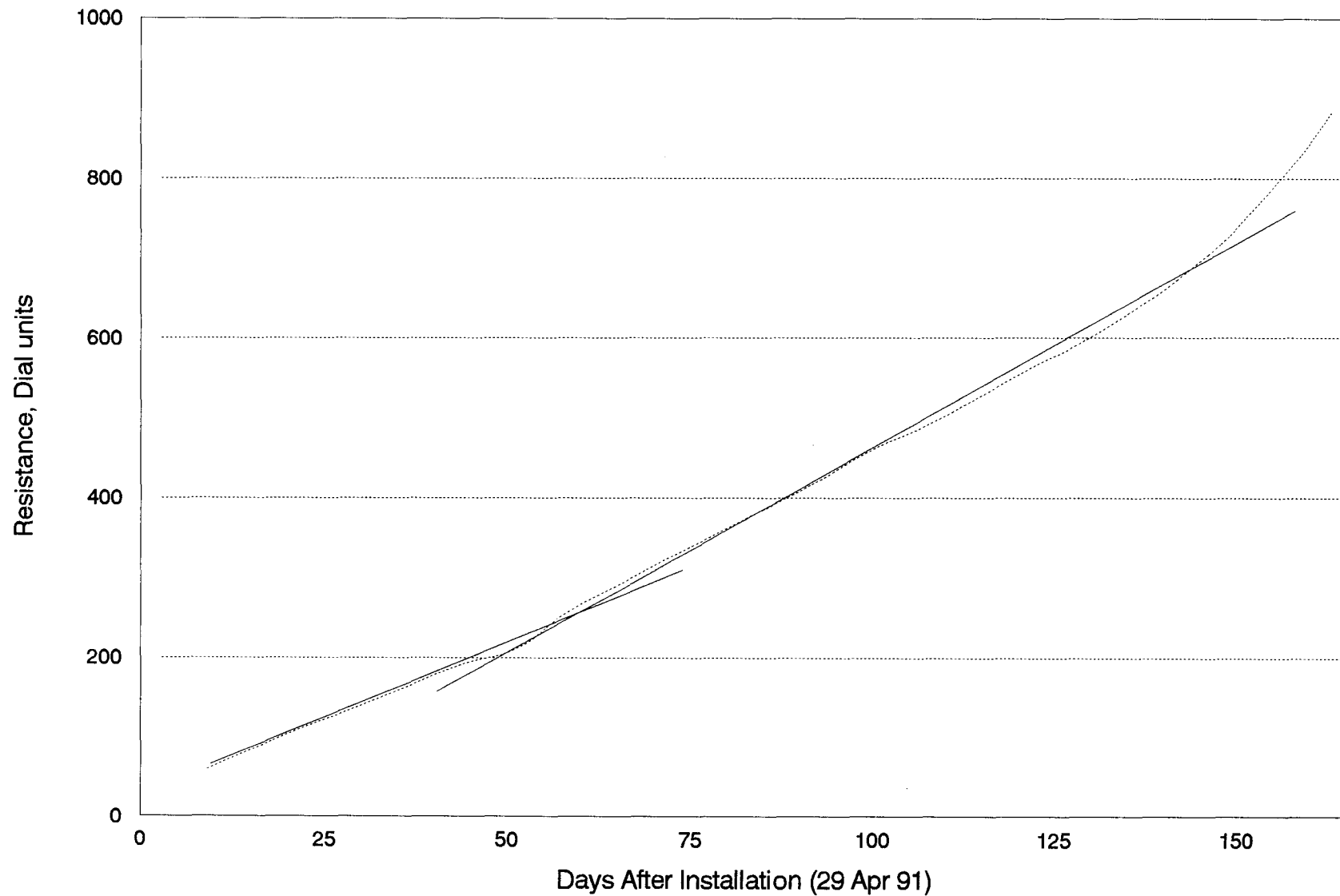
Figure 4.24 - Mild Steel Corrosometer Probes
Prevailing Corrosion Rates
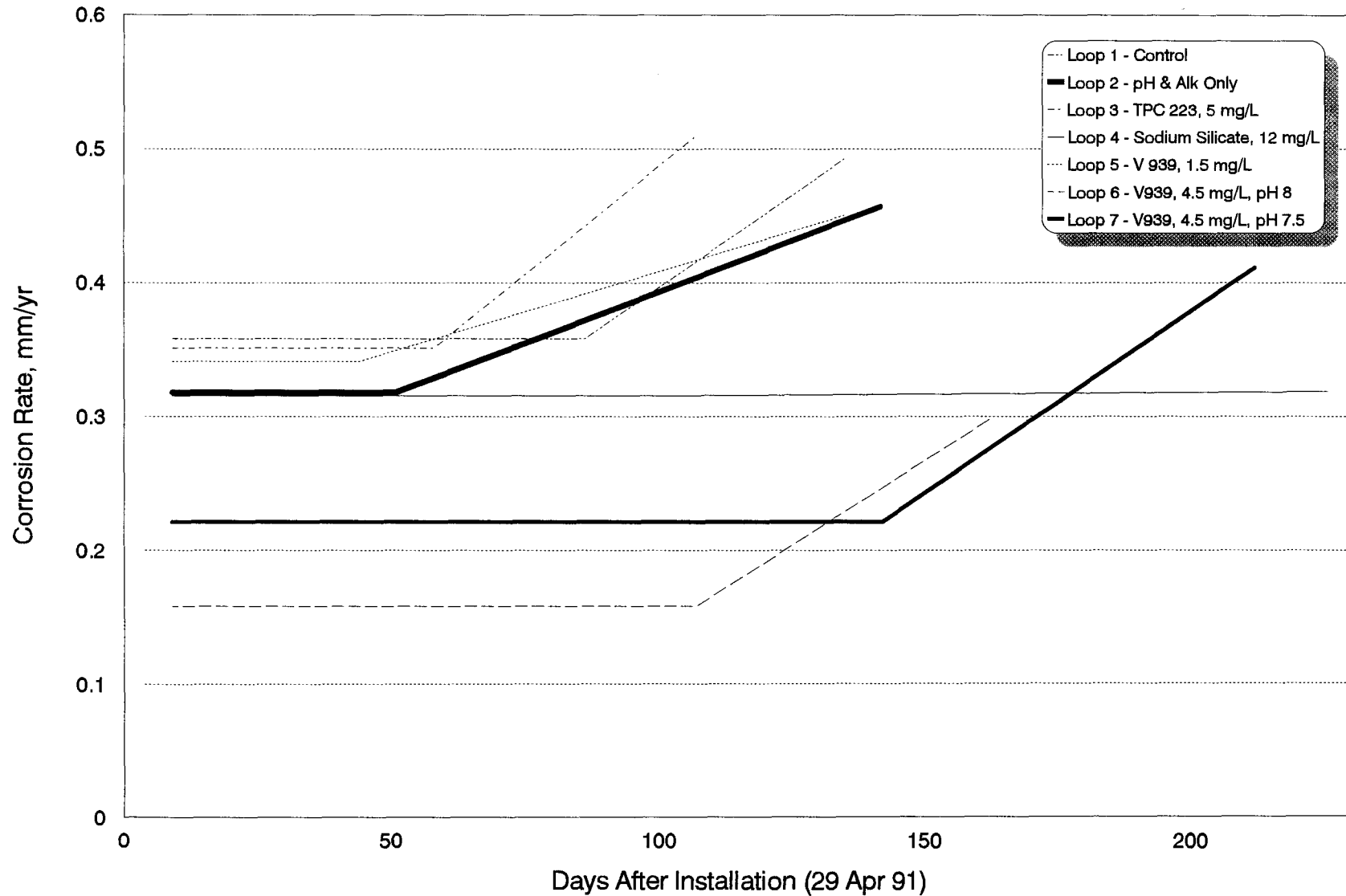
Figure 4.25 - Mild Steel Corrosometer Probes
Prevailing Corrosion Rates
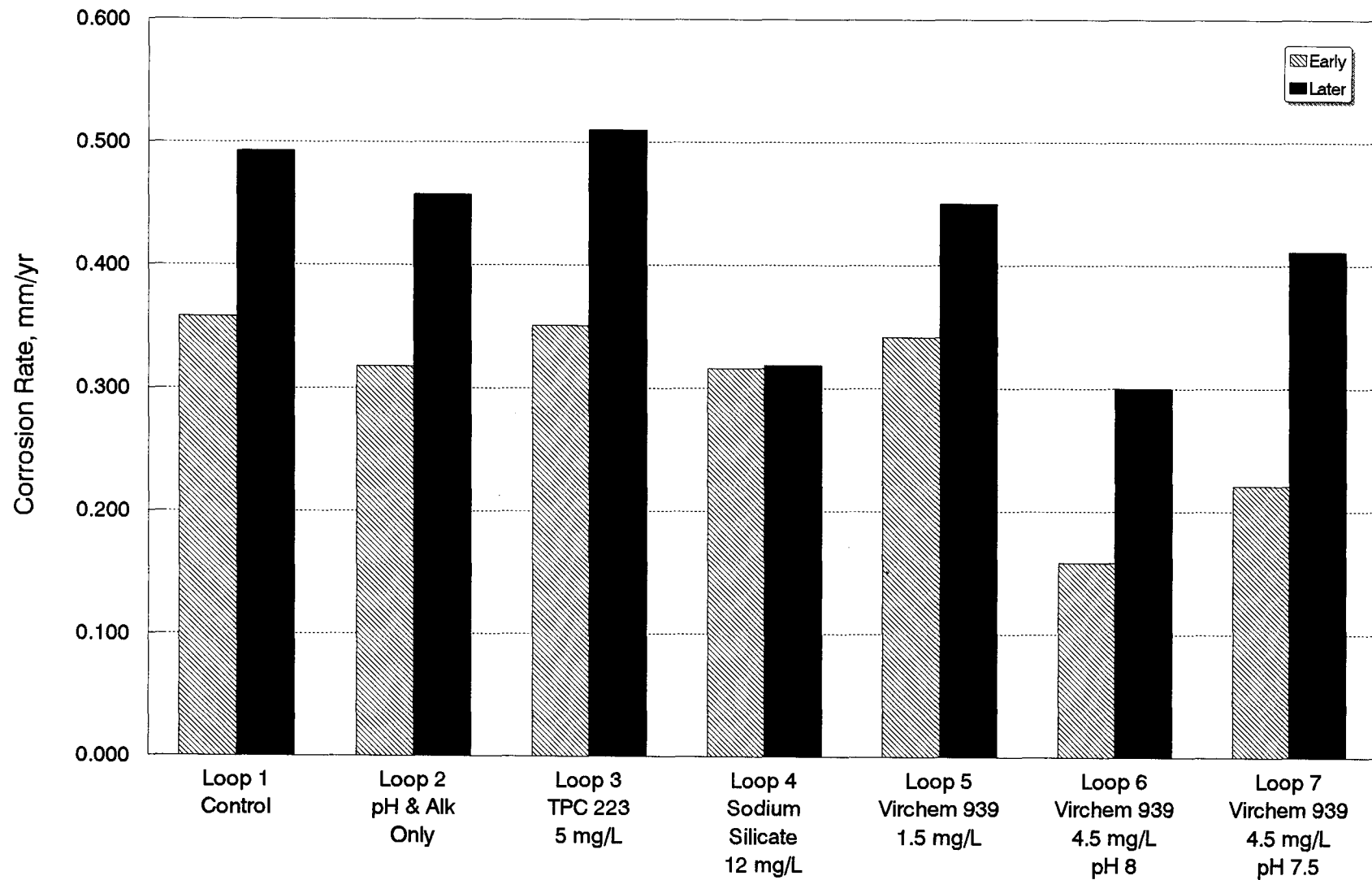
at the end of the electrode life. The stability of the corrosion rate in Loop 4 is also obviated in Figure 4.24. The clear flaw with these data are the short duration of the corrosion period. That reason alone should be sufficient to attach little credence to it.

4.3 . Comparison of Coupon and Corrosometer Relative Corrosion Rates

The coupon and the Corrosometer corrosion measurements are compared in Table 4-14. The relative corrosion rates measured for the copper Corrosometer probes in Loops 2, 3, and 5 were a lot higher than those determined for the copper coupons. The results for Corrosometer Loop 2 are definitely suspect since numerous previous studies have confirmed that raising the pH generally reduces copper corrosion rates. The Corrosometer relative corrosion rates for the mild steel probes were only for six months since most of the probes failed shortly after this period. Generally they showed lower relative corrosion rates in Loops 4, 6, and 7, compared to the copper probes. These results were not consistent with the cast iron coupon results, but there may no basis for expecting mild steel corrosion rates to be comparable to those of cast iron. Only a study comparing the two would tell. As previously stated, it was planned to use cast iron Corrosometer probes, but they could not be obtained in time for this project. The Corrosometer results generally confirm that both sodium silicate and zinc orthophosphate may offer some beneficial protection, and merit further study.

As a tool for measuring corrosion rates, the Corrosometer Instrument and probes, once installed, are convenient and simple to use. They also provide further insight into the corrosion process and instantaneous corrosion rates. Judging, particularly by the data generated by the mild steel Corrosometer probes, their use as stand-alone corrosion measurement devices should not be contemplated. Perhaps if thicker mild steel probes had been used, the results would have been more meaningful. Nevertheless, the

Corrosometer may prove useful if employed in addition to other means of corrosion monitoring.

	Comparison of Coupon and Corrosometer Corrosion Rates Relative to Water			
	Copper		Cast Iron	Mild Steel
Loop #	Coupon Relative Corrosion Rate	Corrosometer Relative Corrosion Rate	Coupon Relative Corrosion Rate	Corrosometer Relative Corrosion Rate
1	1.00	1.00	1.00	1.00
2	0.61	1.35	1.14	1.04
3	0.58	0.92	0.93	1.09
4	0.42	0.52	1.09	0.77
5	0.33	1.04	1.22	1.05
6	0.25	0.20	1.03	0.54
7	0.24	0.34	1.10	0.66

Table 4-14 - Comparison of Coupon and Corrosometer Corrosion Rates Relative to Water

4.4. Metal Concentrations in Standing Water Samples

At the beginning of the experiment, it was decided that the standing water samples would not be digested prior to metal measurement. This reasoning was based on the experience in the EES (1990) study. That study found no significant difference between metal levels in samples that were digested and those that were not. However, due to the high level of particulate matter in the samples taken in this experiment, the decision was

made in September to try filtering part of each sample for a few weeks and digest the unfiltered portions before metals measurement. The first filtration took place with the samples taken on 1 October (day 200 of the experiment). The metal levels measurements are presented in Appendices E through M. The differences between the unfiltered metal levels and the filtered are quite significant, indicating that most of the metal content in the water was undissolved. As a standard operating procedure, samples for metals measurement are acidified with concentrated nitric acid to a 2.5 percent matrix. Apparently, a significant portion of the metals contained in the particulate matter was dissolved by the acidification process so there was little difference between unfiltered samples that were digested and those that were not. In order to ensure that none of the metals would be missed, all samples were digested from 1 Oct onward. It did not appear to make a noticable difference. There were large swings in metal levels both before and after that date. It is certainly possible that some of the metal levels measured prior to October 1st were actually higher than reported.

4.4.1. Copper Concentrations in Standing Water Samples

The actual measured copper levels in the plumbing coils and the faucets, 24 hour standing water samples are presented in Appendices H and E. These data are represented graphically in Figures 4.26, and 4.28 and the data from those plumbing coil loops, which had the lowest levels, are shown in Figure 4.27. Some observations that can be made from the data and graphs are:

4.4.1.1. Copper Concentrations in Plumbing Coil Standing Water Samples

- Some extremely high copper levels were encountered, particularly from Loops 5, 6, and 7, the zinc orthophosphate loops.
- The highest copper concentrations occurred in the form of spikes, which were coincident in most and sometimes all of the loops.

- Generally speaking, the lowest copper levels were from Loop 2, the pH and alkalinity adjusted loop, followed by Loop 4, the sodium silicate loop. Overall, the levels in Loop 3, the zinc orthophosphate/sodium silicate loop, were higher than those in Loop 1, the raw water control loop.

- The copper levels in the raw water loop exceeded the EPA action level[11] of 1.3 mg/L often enough so that, if this represented actual consumer tap water, corrective action would be required if the GVWD were under EPA jurisdiction. Alternatively, it is possible that pH and alkalinity adjustment to 8 and 20 mg/L respectively, along with chloramine injection at 2.5 mg/L, would bring the water below the EPA action limits. The further addition of sodium silicate would do nothing to reduce copper mobility in pH and alkalinity adjusted water, but rather might make it slightly worse (practically, the difference between the average copper levels in Loops 2 and 4 is negligible).

4.4.1.2. Copper Concentrations in Faucet Standing Water Samples

- None of the loops had copper levels above the EPA action level; however, in a typical household, the metals from the faucets would be combined with the metals from the soldered copper plumbing, as well as the metals from the distribution system, so there is no room for complacency.

- The highest copper concentrations again occurred in the form of spikes, which were often coincident in a number of the loops; also some of the copper

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[11]The metal mobility portion of the experiment measured metal levels from the first draw of standing samples, therefore, since EPA action levels apply to first flush samples those standards were used as the basis for comparison. The Canadian Guidelines on Drinking Water Quality MAC for lead applies to well flushed samples.

Figure 4.26 - Copper Levels From Plumbing Coils
24 Hour Standing Samples (Average Values for Two Samples)
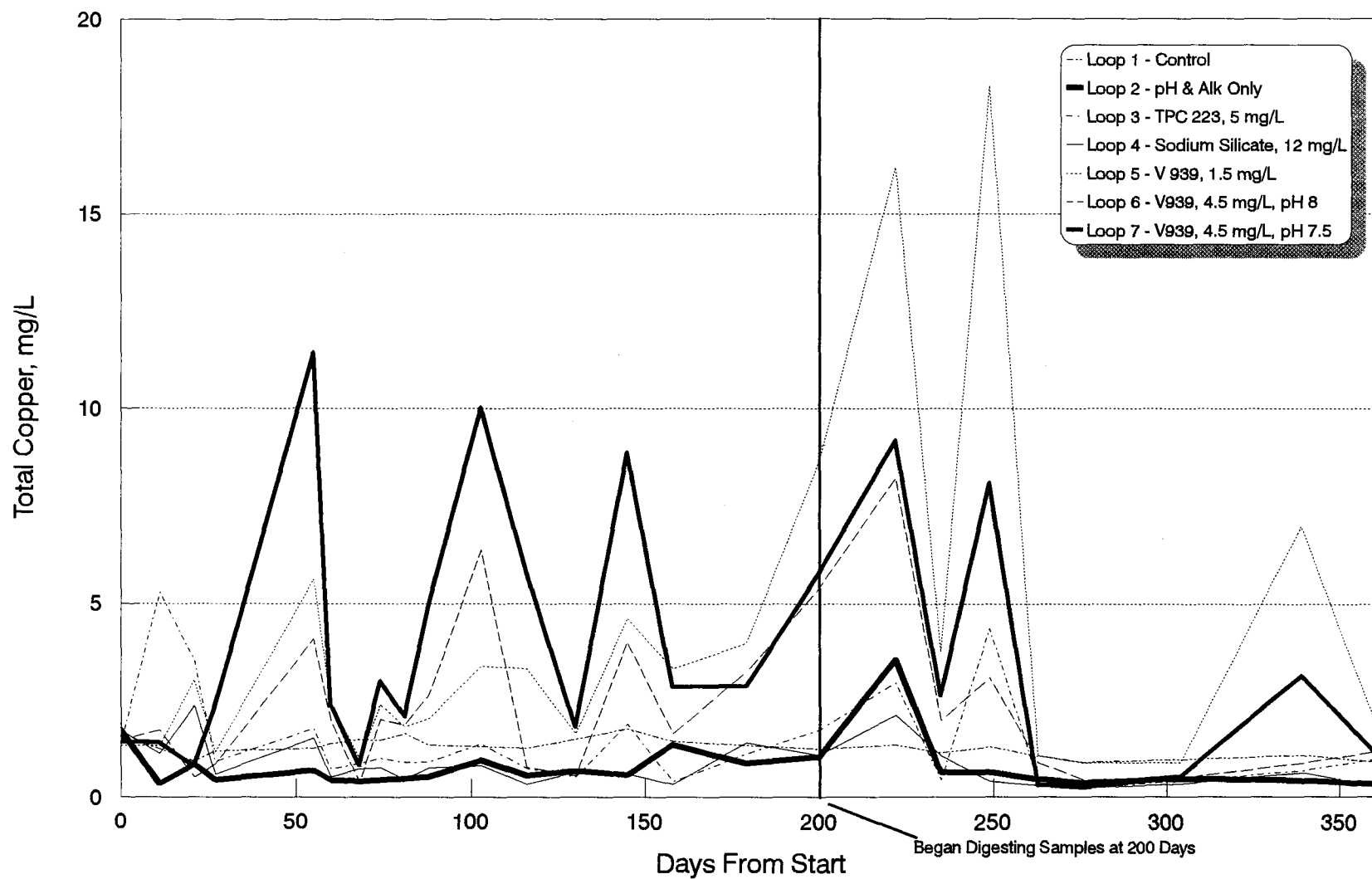
Figure 4.27 - Copper Levels From Plumbing Coils
24 Hour Standing Samples (Best Four Loops)
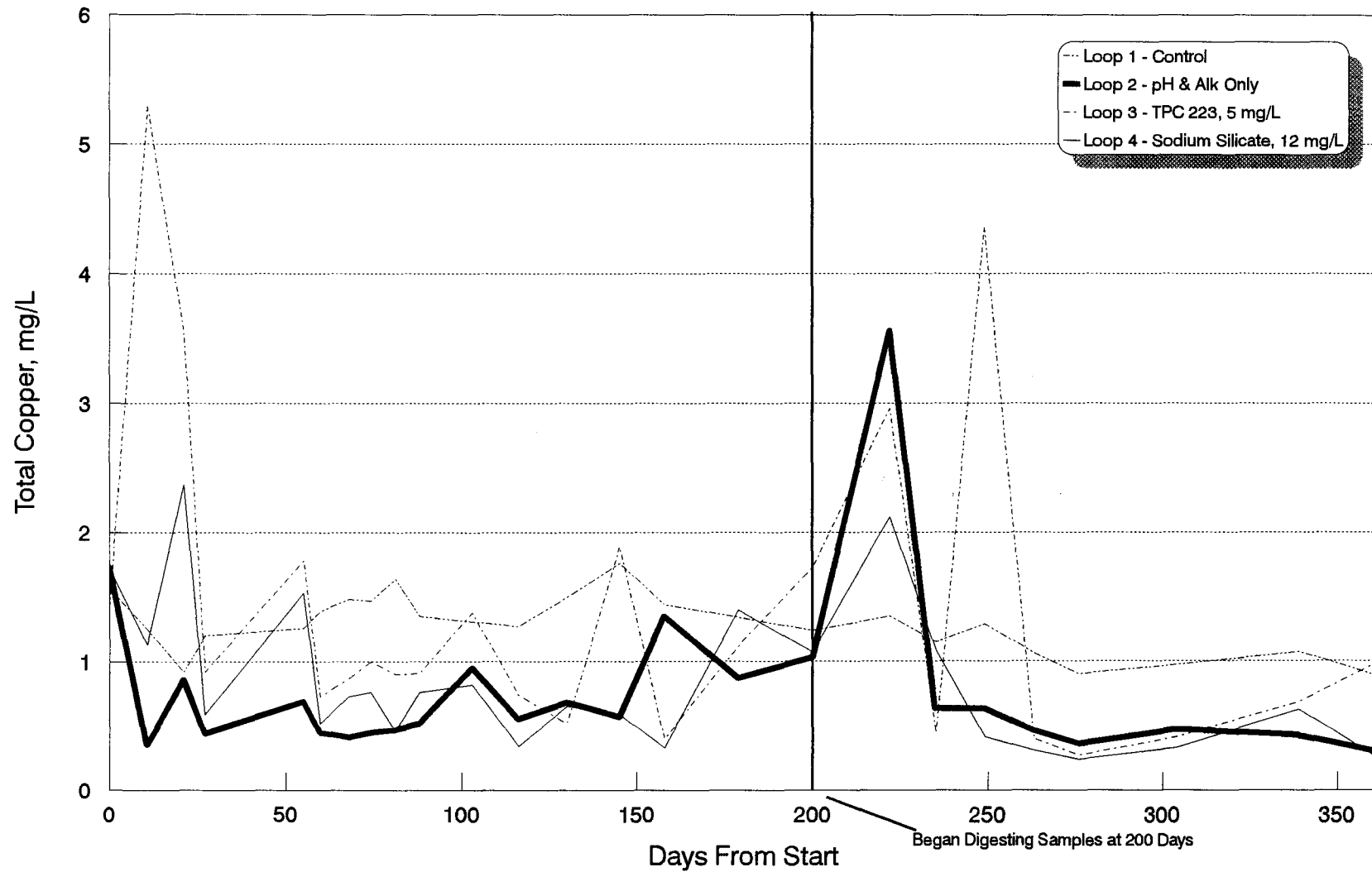
Figure 4.28 - Copper Levels From Faucets
24 Hour Standing Samples
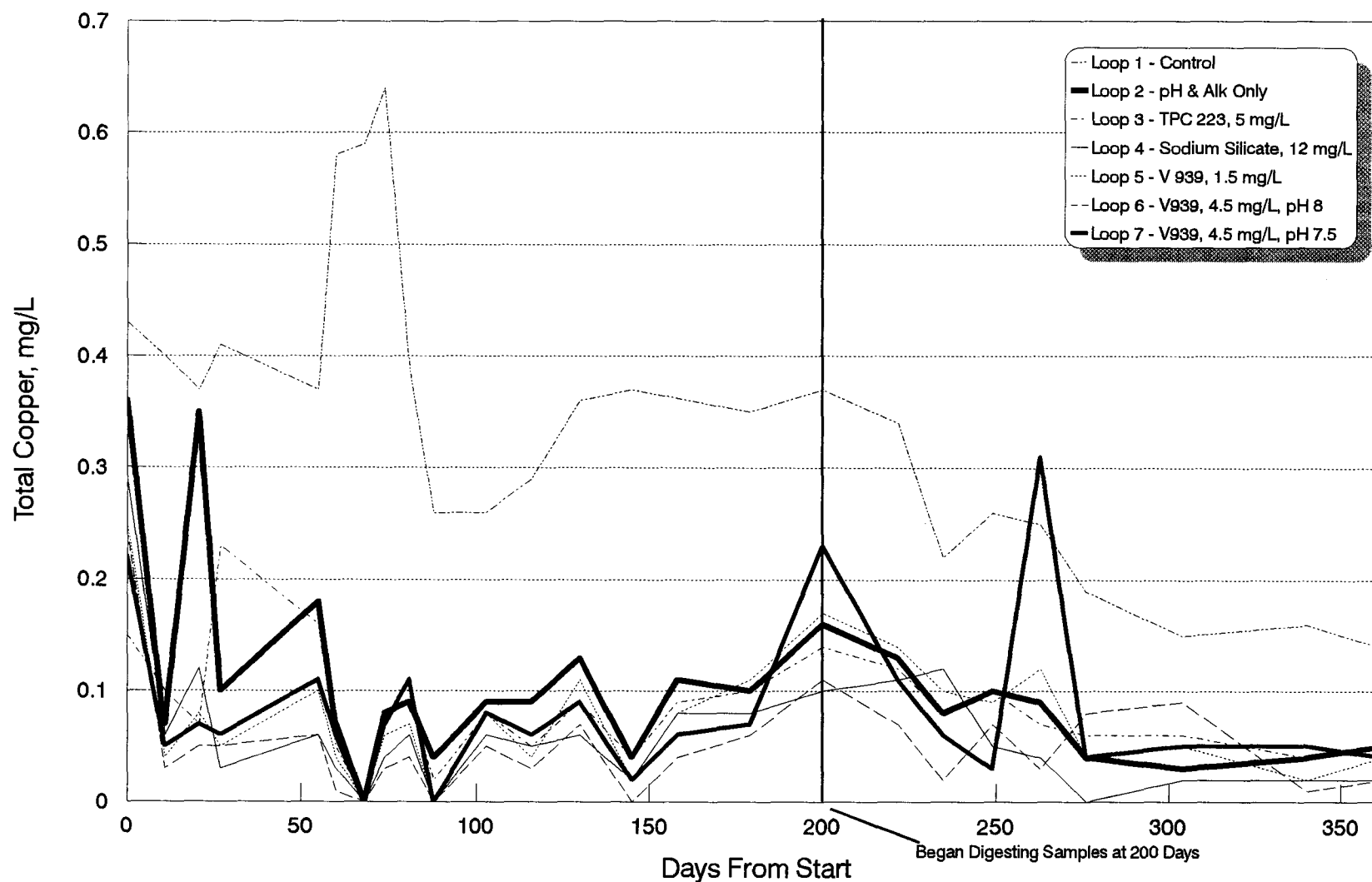
Legend:
- Loop 1 - Control
- Loop 2 - pH & Alk Only
- Loop 3 - TPC 223, 5 mg/L
- Loop 4 - Sodium Silicate, 12 mg/L
- Loop 5 - V 939, 1.5 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8
- Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Total Copper, mg/L

X-axis: Days From Start

Began Digesting Samples at 200 Days

spikes from the faucets also occurred coincidentally with the spikes from the plumbing and solder coils. It is interesting also that a number of the troughs in the faucet copper levels were coincident.

- The lowest copper levels were from Loop 6, but all of the treatments appeared to provide a significant degree of beneficial protection to the faucets over that from the raw water.

- There was a decreasing trend in copper levels with time in the raw water loop.

4.4.2. Lead Concentrations in Standing Water Samples

The actual measured lead levels in the 24 hour standing water samples are presented in Appendices F, I, and L. These data are represented graphically in Figures 4.29, 4.31, and 4.33. The data from those loops which had the lowest lead levels are shown in Figures 4.30, 4.32, and 4.34. Some observations that can be made from the data and graphs are:

4.4.2.1. Lead Concentrations in Plumbing Coil Standing Water Samples

- Some high lead levels were encountered, particularly from Loops 6 and 7, the higher dosage zinc orthophosphate loops. The high lead levels in loop 7, which had the lower pH and alkalinity (7.5 and 10 mg/L) may be indicative of the importance those two factors. It is possible that, if pH and alkalinity levels are too low, it will negate any potential benefit from zinc orthophosphate treatment.

- Again, the highest lead concentrations occurred in the form of spikes, which were coincident in several of the loops, but the trend of coincident spikes among loops was not as dramatic as occurred for the copper levels. The lead concentration spikes occurred at the same times as the copper concentration spikes.

Figure 4.29 - Lead Levels From Plumbing Coils
24 Hour Standing Samples (Average Values for Two Samples)
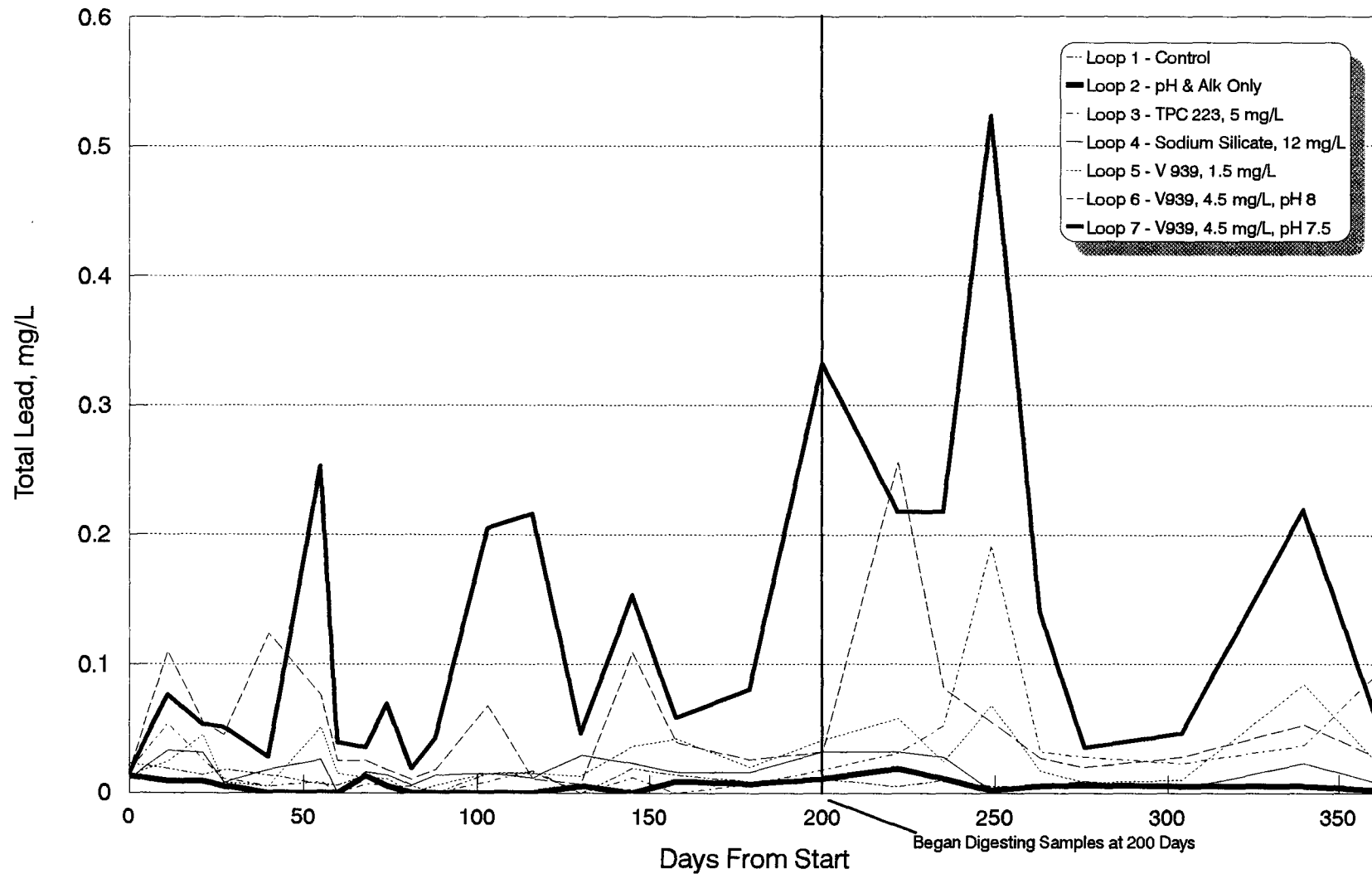
Figure 4.30 - Lead Levels From Plumbing Coils
24 Hour Standing Samples (Best Three Loops)

Legend:
- Loop 1 - Control
- Loop 2 - pH & Alk Only
- Loop 4 - Sodium Silicate, 12 mg/L

Y-axis: Total Lead, mg/L

X-axis: Days From Start

Began Digesting Samples at 200 Days
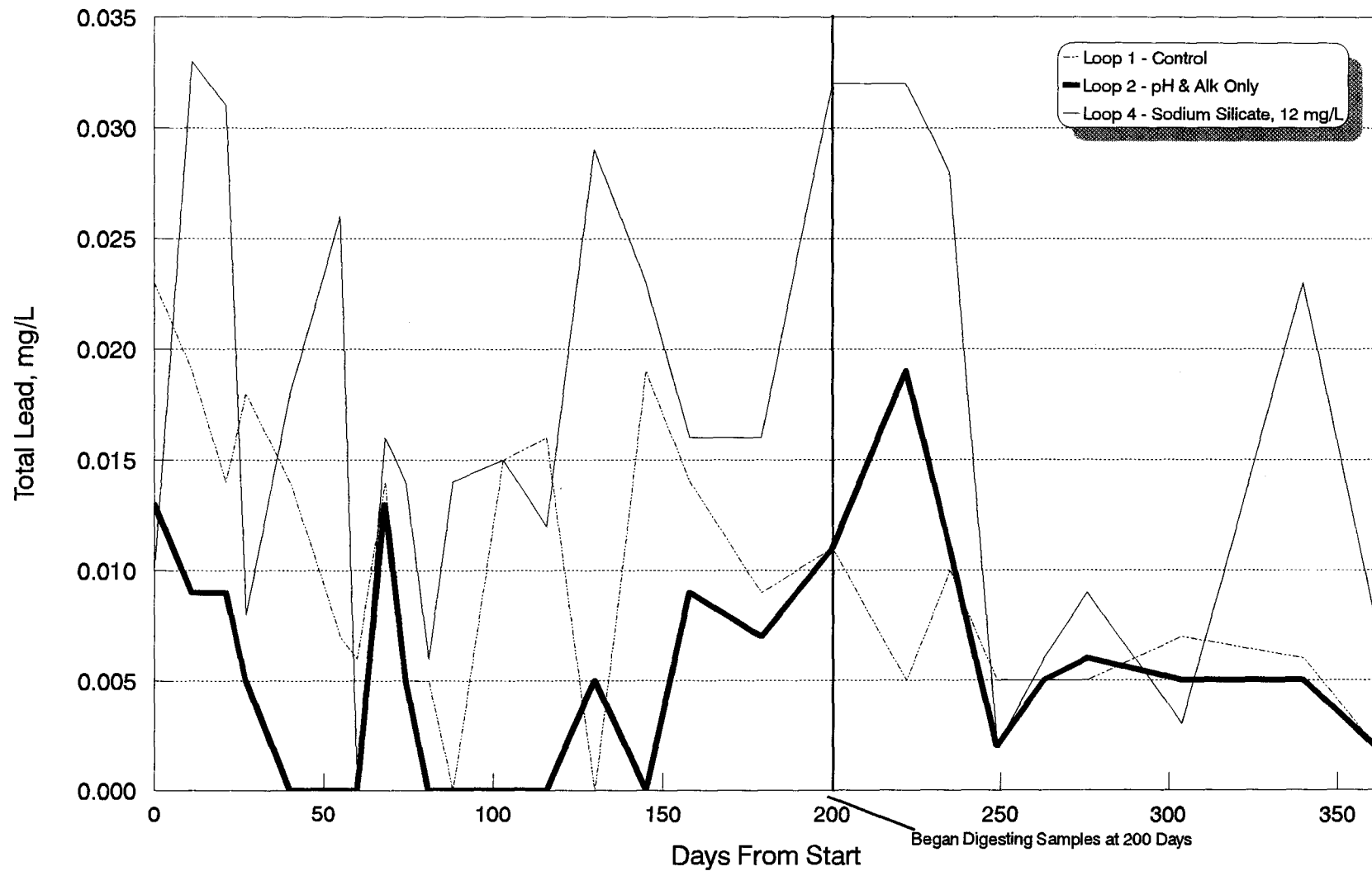
Figure 4.31 - Lead Levels From Solder Coils
24 Hour Standing Samples

Legend:
- Loop 1 - Control
- Loop 2 - pH & Alk Only
- Loop 3 - TPC 223, 5 mg/L
- Loop 4 - Sodium Silicate, 12 mg/L
- Loop 5 - V 939, 1.5 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8
- Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Total Lead, mg/L

X-axis: Days From Start

Began Digesting Samples at 200 Days
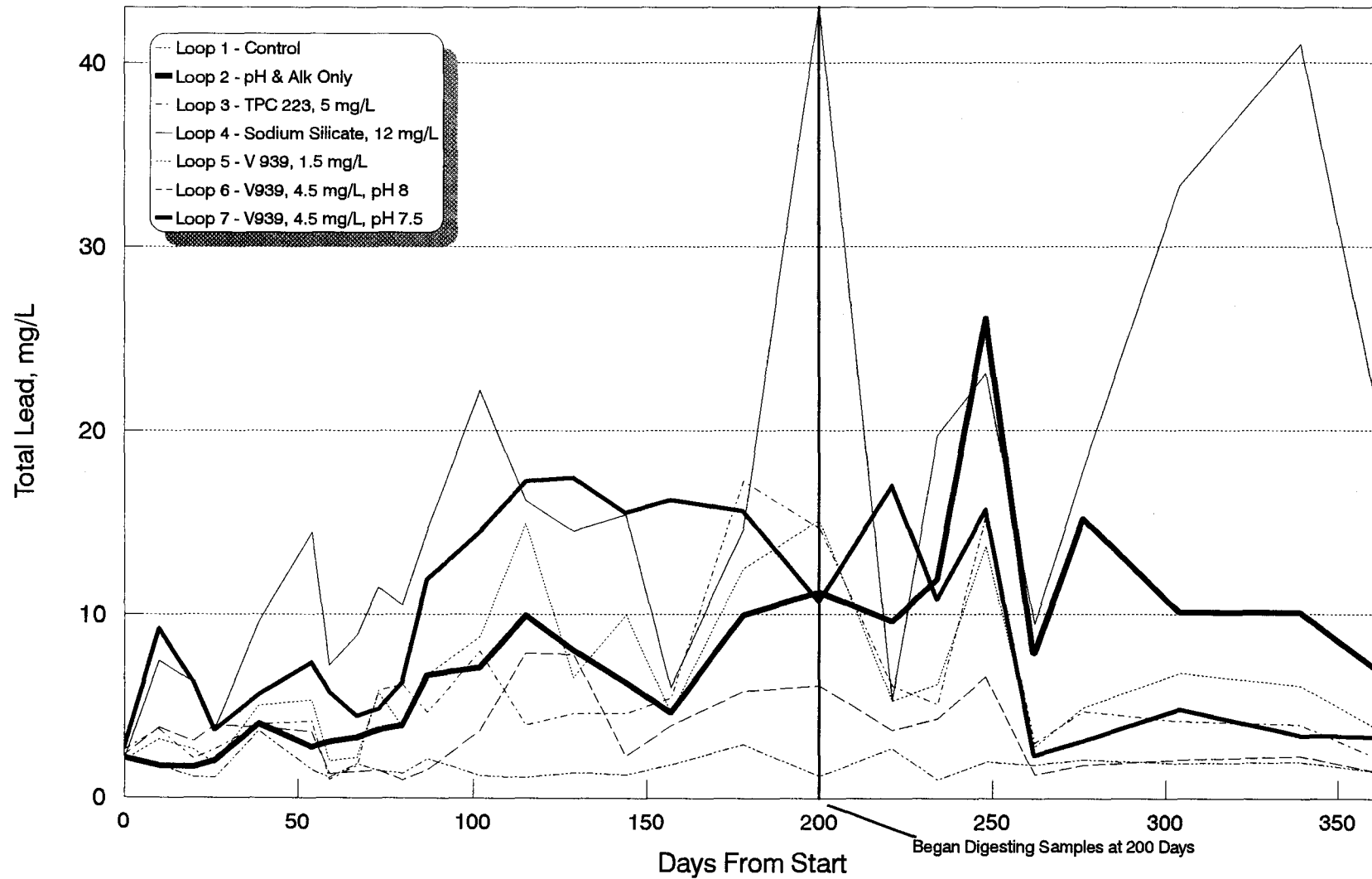
Figure 4.32 - Lead Levels From Solder Coils
24 Hour Standing Samples (Best Two Loops)

Began Digesting Samples at 200 Days

Days From Start
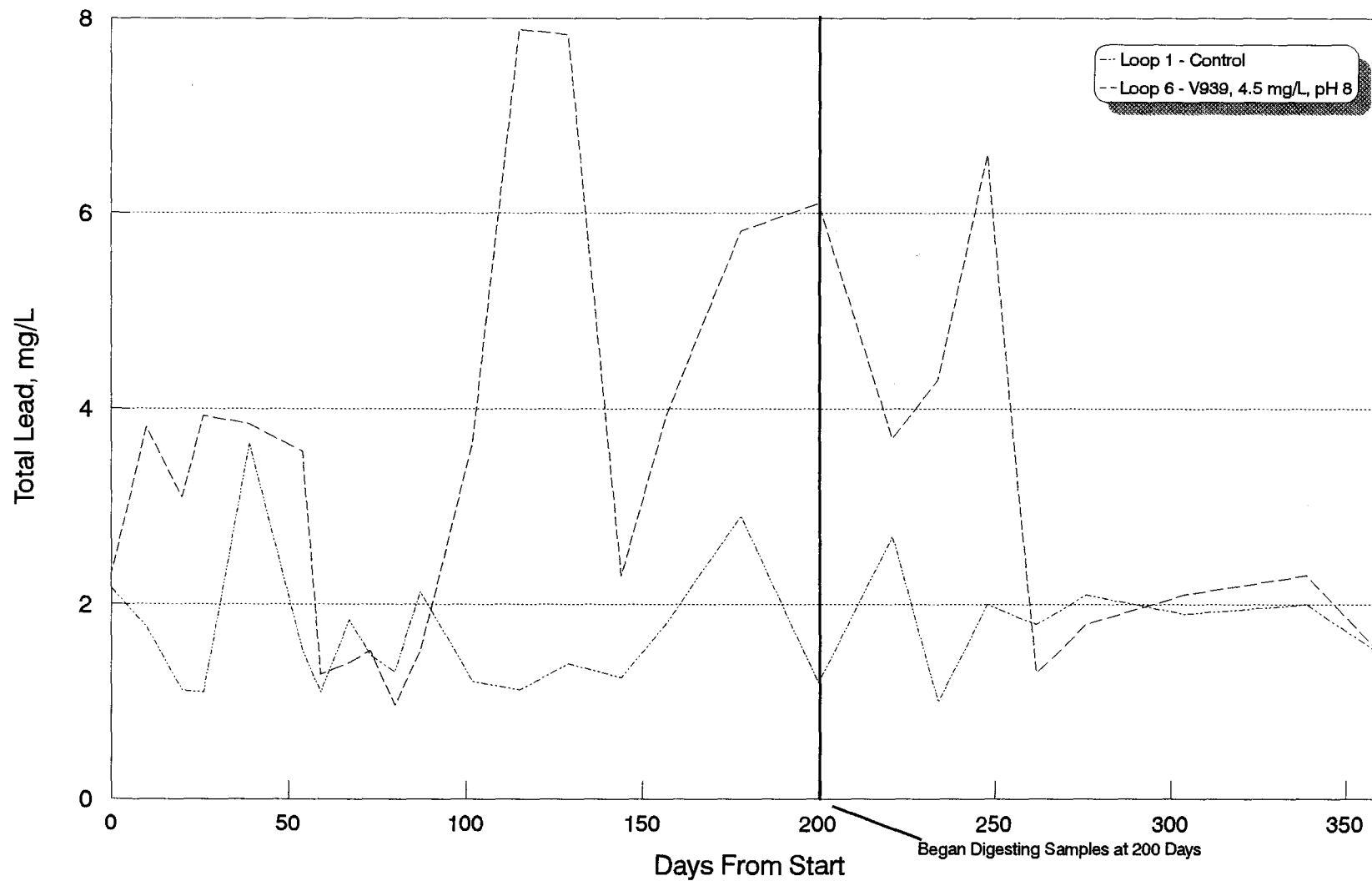
Figure 4.33 - Lead Levels From Faucets
24 Hour Standing Samples

Began Digesting Samples at 200 Days

Days From Start
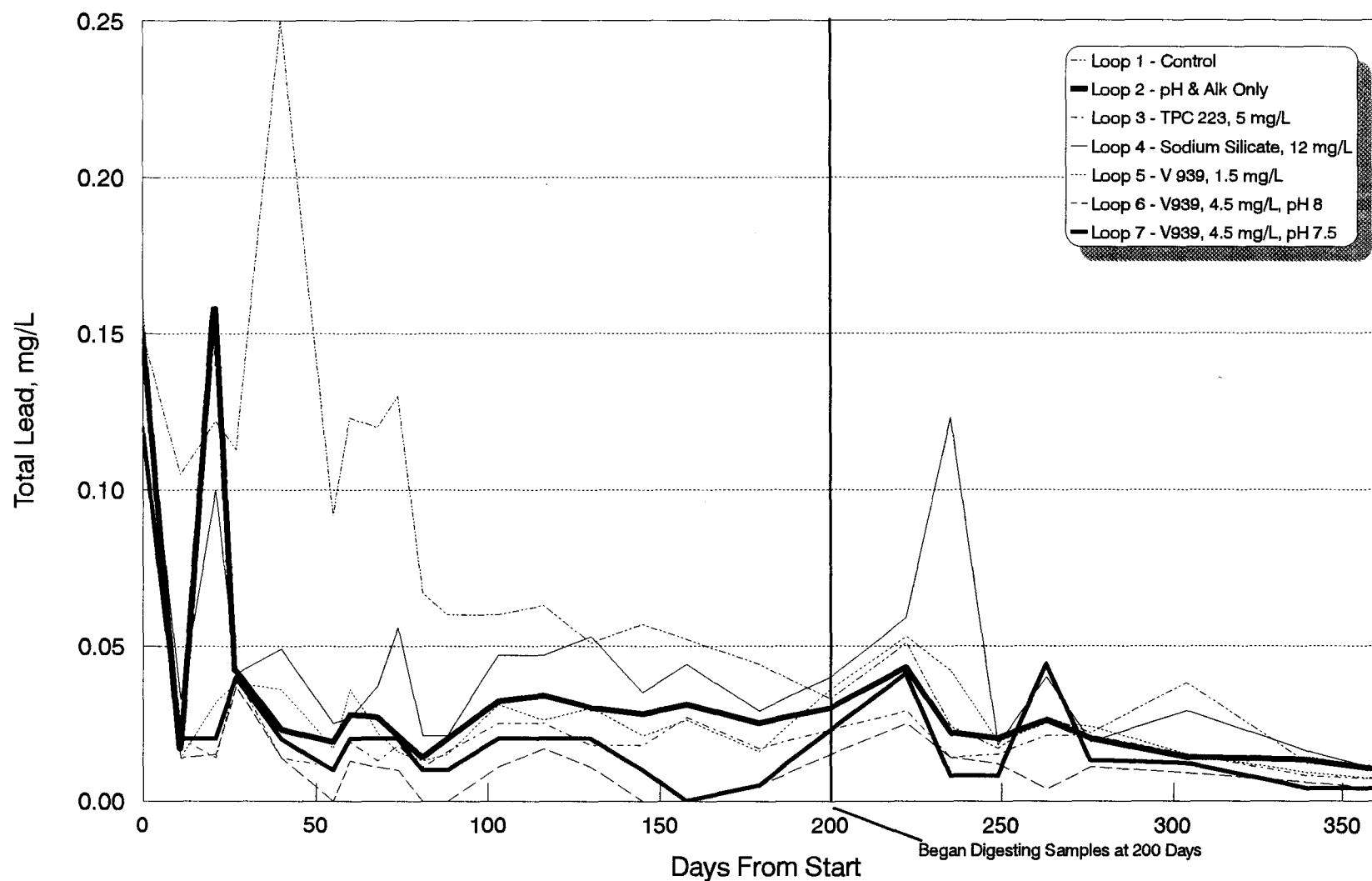
Figure 4.34 - Lead Levels From Faucets
24 Hour Standing Samples (Best Three Loops)

Legend:
- Loop 1 - Control
- Loop 3 - TPC 223, 5 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8
- Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Total Lead, mg/L

X-axis: Days From Start

Began Digesting Samples at 200 Days
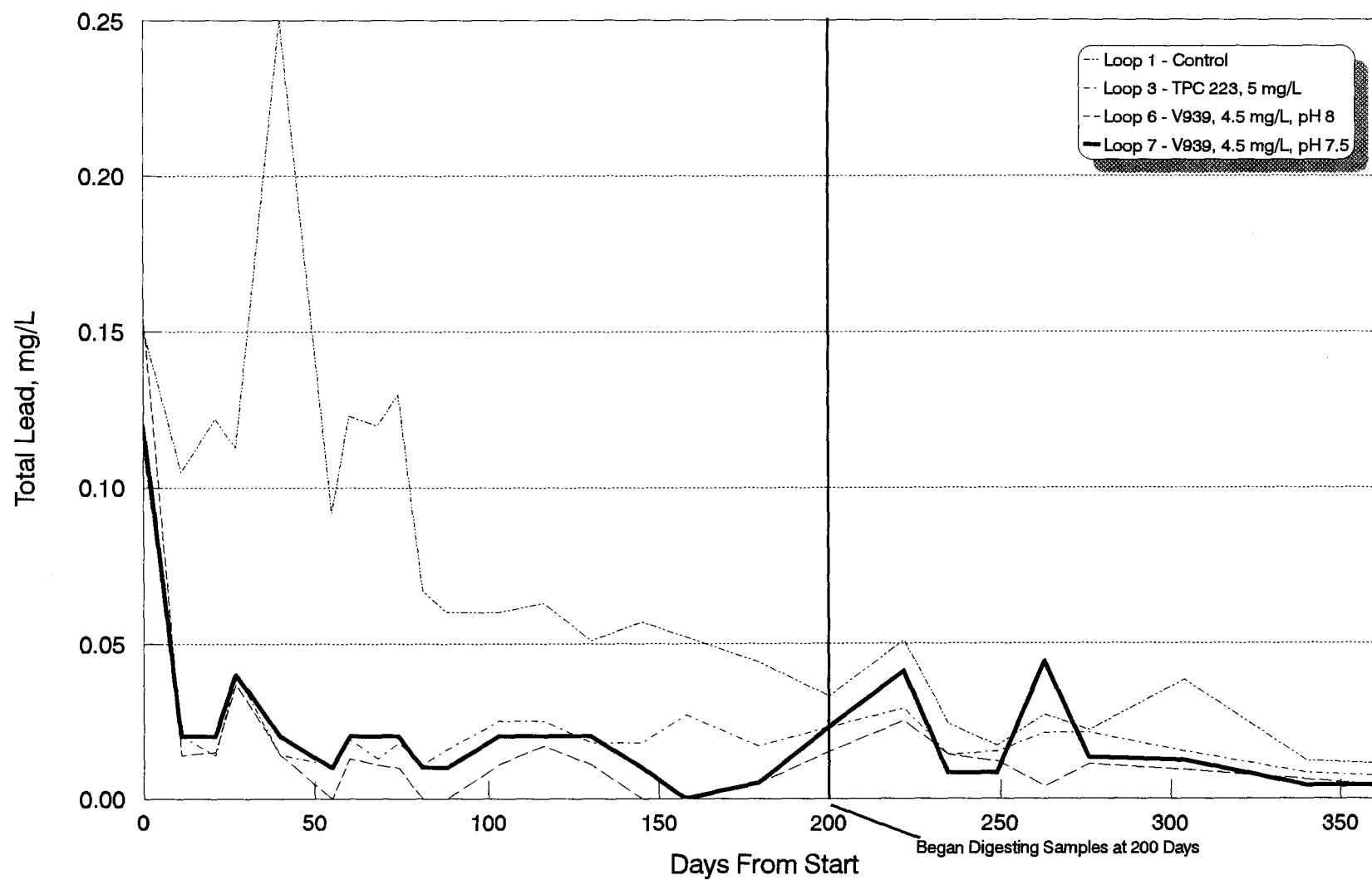
- Again the lowest lead levels were from Loop 2, the pH and alkalinity adjusted loop, followed by Loop 1, the raw water loop. Overall, the levels in Loop 4, the sodium silicate loop, were higher than those in Loop 1.

- The lead levels in the raw water loop rarely exceeded the EPA action level of 0.015 mg/L; therefore, if this represented actual consumer tap sampling, it is unlikely that any corrective action would be required if the GVWD were under EPA jurisdiction.[12] pH and alkalinity adjustment to 8 and 20 mg/L along with chloramine injection at 2.5 mg/L could cut lead levels by up to 44 percent. The further addition of sodium silicate would do nothing to reduce the lead mobility in pH and alkalinity adjusted water but rather might make it worse than the raw water alone.

4.4.2.2. Lead Concentrations in Lead/Tin Solder Coil Standing Water Samples

- High lead levels were encountered in all loops, with frequent extremely high levels occurring in all loops expect Loop 1 and possibly Loop 6, depending on what level one defines as "extreme" .

- Once more, the highest lead concentrations occurred in the form of spikes, which were often coincident in several of the loops. The trend of coincident spikes among loops was less pronounced than it was in the case with the metal measurements from the plumbing coils. However, many of the lead spikes from the solder coils occurred coincidentally with both the copper and lead spikes from the plumbing coils.

'owever, as discussed, Singh (1990) found lead levels often exceeded 0.015 mg/L in standing m Vancouver homes, once again confirming that lab results do not necessarily reflect s points out the need for in home sampling in conjunction with the implementation of atrol program.

- Almost without exception, the lowest lead levels were from Loop 1, the raw water loop. Average lead levels in Loop 1 were 50 percent lower than those for Loop 6, the next lowest loop which was, in turn, 38 percent lower than those of Loop 3, the third lowest loop.

- In sum, none of the treatments provided any lead mobility reduction in lead solder exposed in isolation. Indeed, all of the treatments that were tried, only aggravated the mobility rate. Since the exposure of lead/tin solder in such a manner in no way equates to a real plumbing situation, there is no point in relating this part of the experiment to EPA action limits. Hopefully, the experience in this study is not indicative of what would happen if these treatments were exposed to lead service pipe.

4.4.2.3. Lead Concentrations in Faucet Standing Water Samples

- Some fairly high lead levels were encountered in Loops 1, 2 and 4.

- The highest lead concentrations occurred in the form of spikes which were often coincident in a number of the loops; however, the spikes were not nearly as high as the other cases already discussed. Some of the lead spikes from the faucets also occurred coincidentally with the spikes from the plumbing and solder coils.

- The lowest lead levels were from Loops 3, 6, and 7. It is quite possible that treatment corresponding to that in Loop 6 would keep lead levels below the EPA action level but, whether the treatments in Loops 3 and 7 would, is questionable.

- Generally, all of the treatments appeared to provide some degree of lead mobility reduction in the faucets over that from the raw water.

- As with the faucet copper concentrations, there was a decreasing trend in lead levels with time in the raw water loop.

4.4.3. Zinc Concentrations in Standing Water Samples

The actual measured zinc levels in the 24 hour standing water samples from the plumbing coils and the solder coils is presented in Appendices J and M. These data are represented graphically in Figures 4.35 and 4.36. This information should have yielded an approximation of the zinc feed rates in Loops 3, 5, 6, and 7, but the very high zinc levels in Loops 5, 6 and 7 do not equate to the actual inhibitor feed rates of 0.13 mg/L in Loop 5, and 0.37 mg/L in Loops 6 and 7 (as zinc). As the graphs show, frequently, zinc was present in the standing water samples in large slugs. It is likely that the zinc was either inhibitor precipitating out before forming a protective scale, or the scale itself was sloughing. According to Schock (1989) "when orthophosphate is added via a formulation containing zinc rather than potassium or sodium salts or orthophosphoric acid, it is possible that basic zinc carbonate [hydrozincite, $Zn_5(CO_3)_2(OH)_6$] could precipitate resulting in turbid water, clogging of industrial or commercial filters, formation of corrosion concentration cells under deposits, or other problems". Such a situation would obviously reduce the inhibition potential for materials that would benefit from the presence of zinc in the water. There were many occasions when the samples taken from these loops were very turbid, while the raw water was clear. This may have been an indication of either inhibitor precipitation or sloughing of the scale, followed by disintegration.

The pattern with the zinc levels in the faucet samples, Figure 4.37, is far less erratic. Zinc levels in Loops 5, 6, and 7 are roughly in line with the actual feed rates. The most important observation from this chart is that the treatments of Loop 2, 3, and 4 will likely reduce zinc leaching from brass faucets to levels below that which would be the case with raw water. It also appears that the inhibitor problems which occurred in the plumbing coils and solder coils, were not repeated in the faucets.

Figure 4.38 is a chart of the data contained in Appendix K, the copper levels from the solder coils. Some very high copper levels were found in Loops 5, 6, and 7. Some

Figure 4.35 - Zinc Levels From Plumbing Coils
24 Hour Standing Samples (Average Values for Two Samples)

123
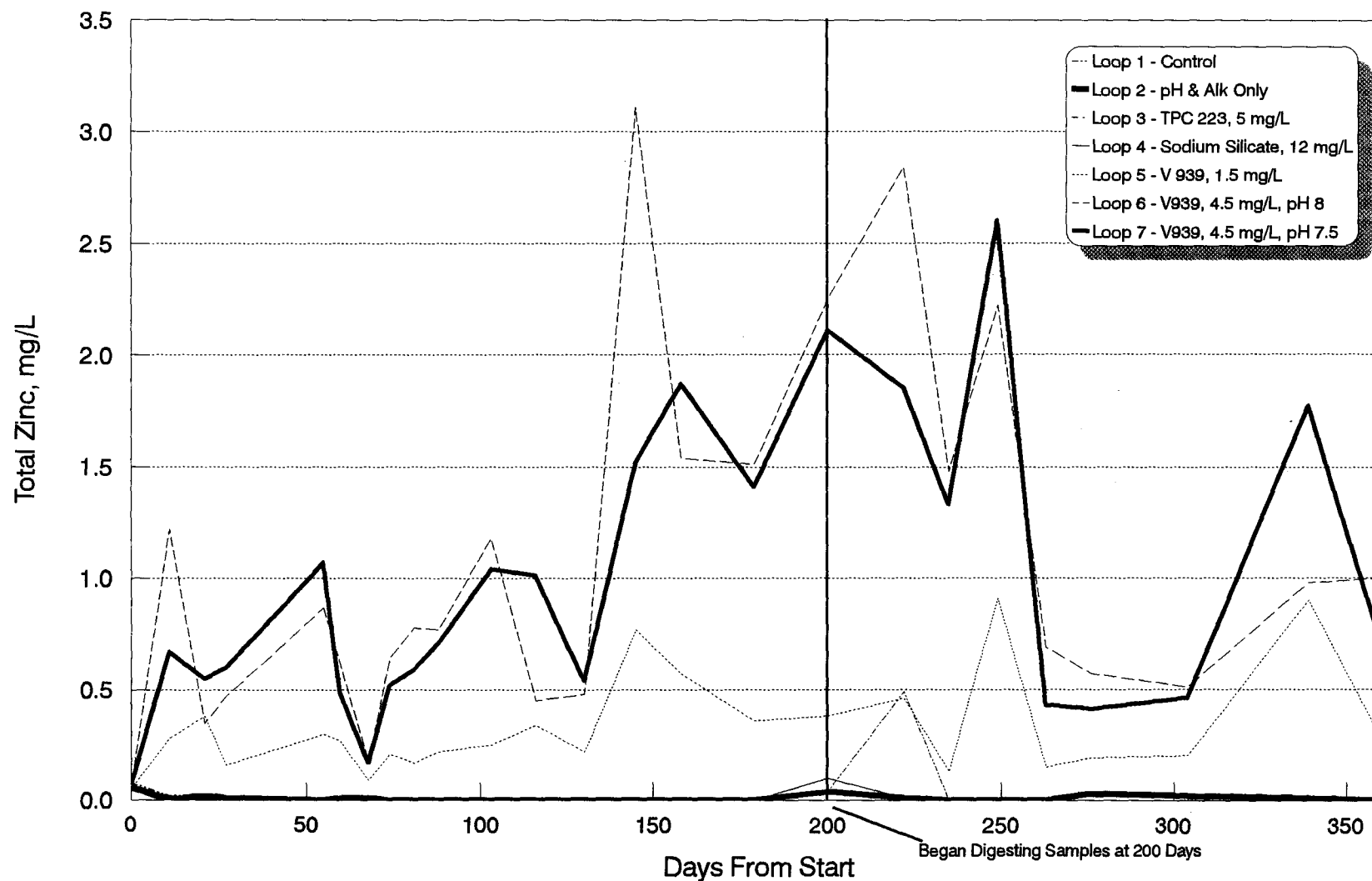
Figure 4.36 - Zinc Levels From Solder Coils
24 Hour Standing Samples

Legend:
- Loop 1 - Control
- Loop 2 - pH & Alk Only
- Loop 3 - TPC 223, 5 mg/L
- Loop 4 - Sodium Silicate, 12 mg/L
- Loop 5 - V 939, 1.5 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8
- Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Total Zinc, mg/L

X-axis: Days From Start

Began Digesting Samples at 200 Days
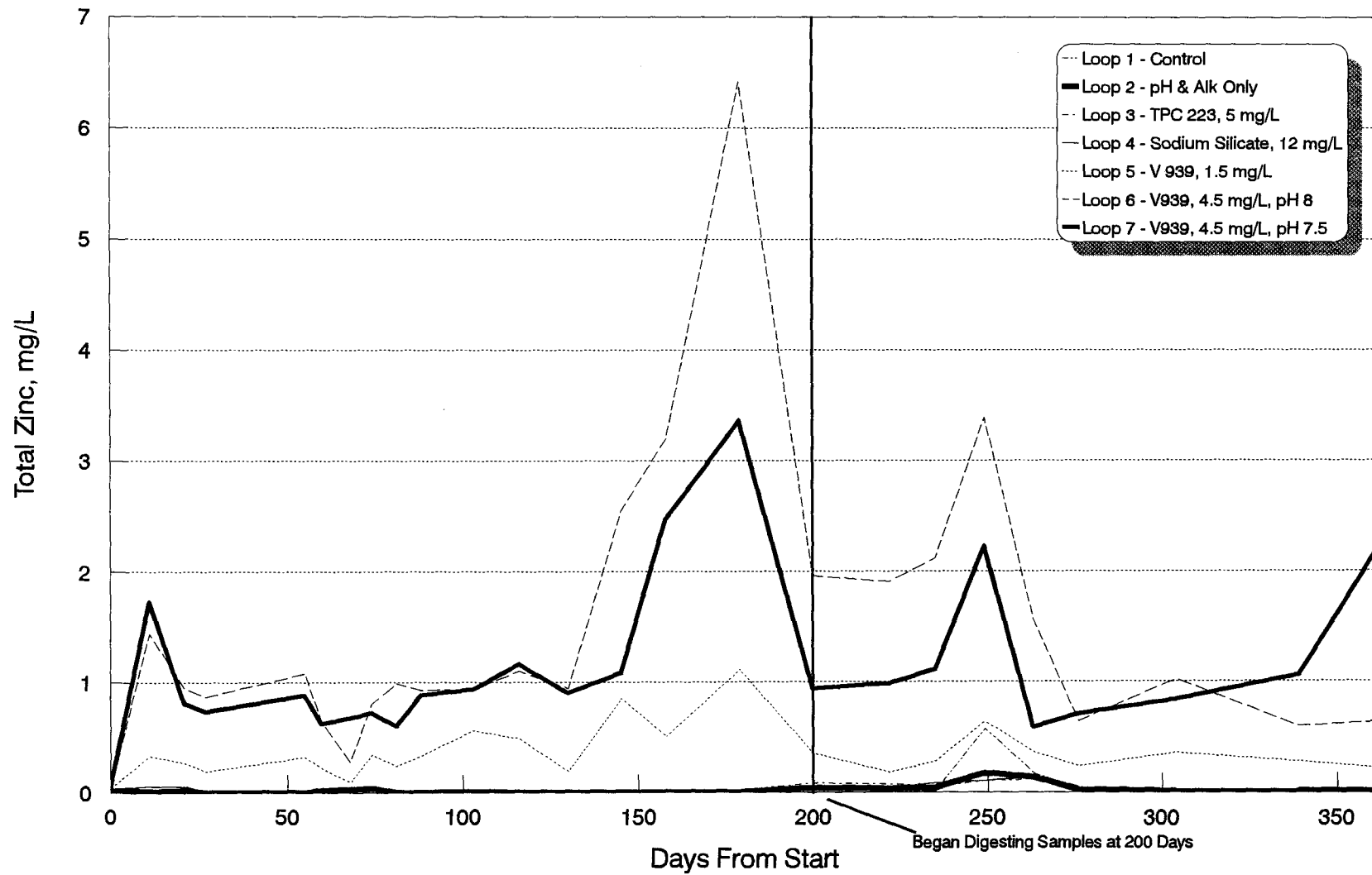
Figure 4.37 - Zinc Levels From Faucets
24 Hour Standing Samples

Legend:
- Loop 1 - Control
- Loop 2 - pH & Alk Only
- Loop 3 - TPC 223, 5 mg/L
- Loop 4 - Sodium Silicate, 12 mg/L
- Loop 5 - V 939, 1.5 mg/L
- Loop 6 - V939, 4.5 mg/L, pH 8
- Loop 7 - V939, 4.5 mg/L, pH 7.5

Y-axis: Total Zinc, mg/L

X-axis: Days From Start

Began Digesting Samples at 200 Days
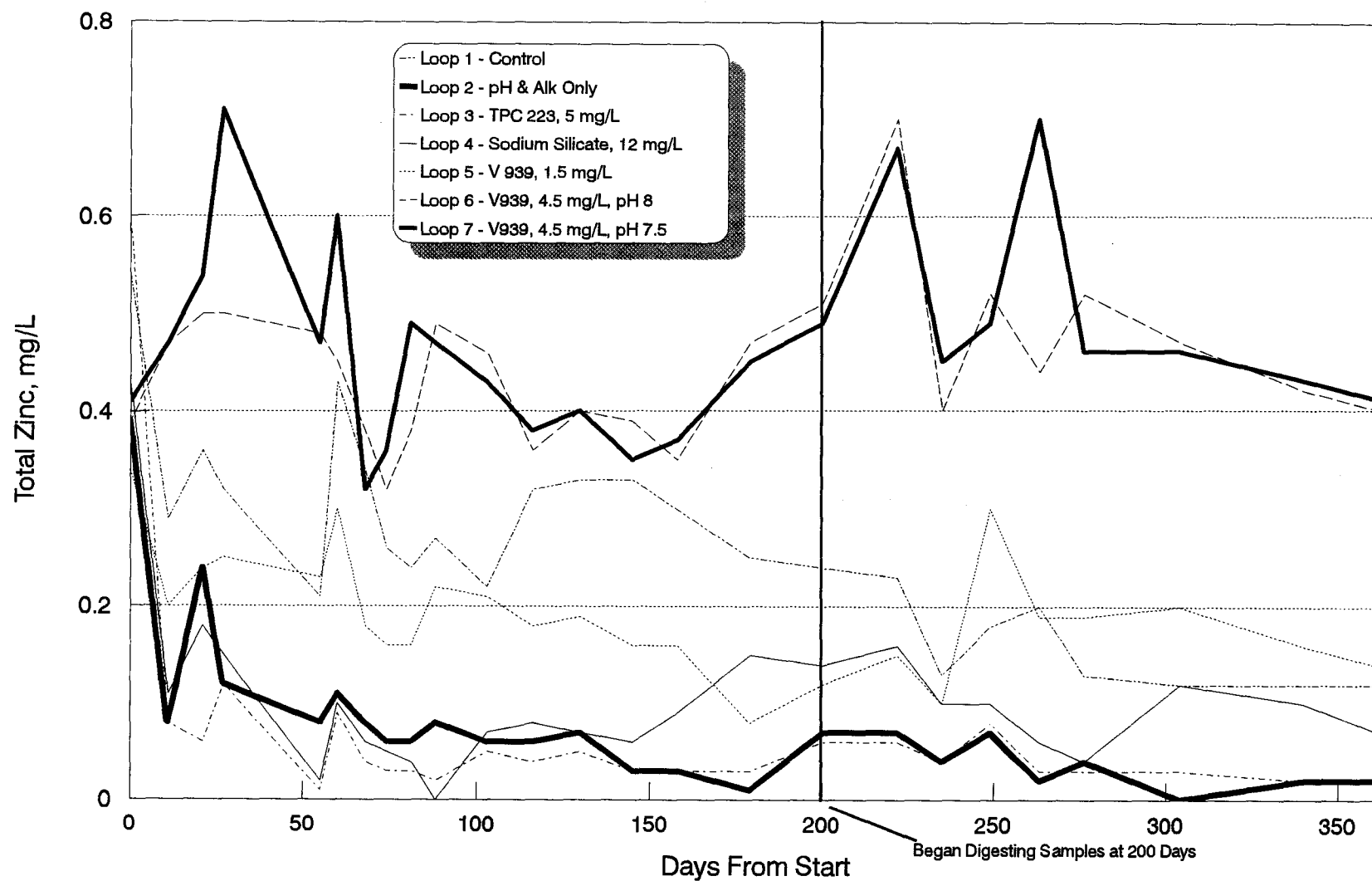
Figure 4.38 - Copper Levels From Solder Coils
24 Hour Standing Samples

Began Digesting Samples at 200 Days

Days From Start

Total Copper, mg/L

Loop 1 - Control
Loop 2 - pH & Alk Only
Loop 3 - TPC 223, 5 mg/L
Loop 4 - Sodium Silicate, 12 mg/L
Loop 5 - V 939, 1.5 mg/L
Loop 6 - V939, 4.5 mg/L, pH 8
Loop 7 - V939, 4.5 mg/L, pH 7.5
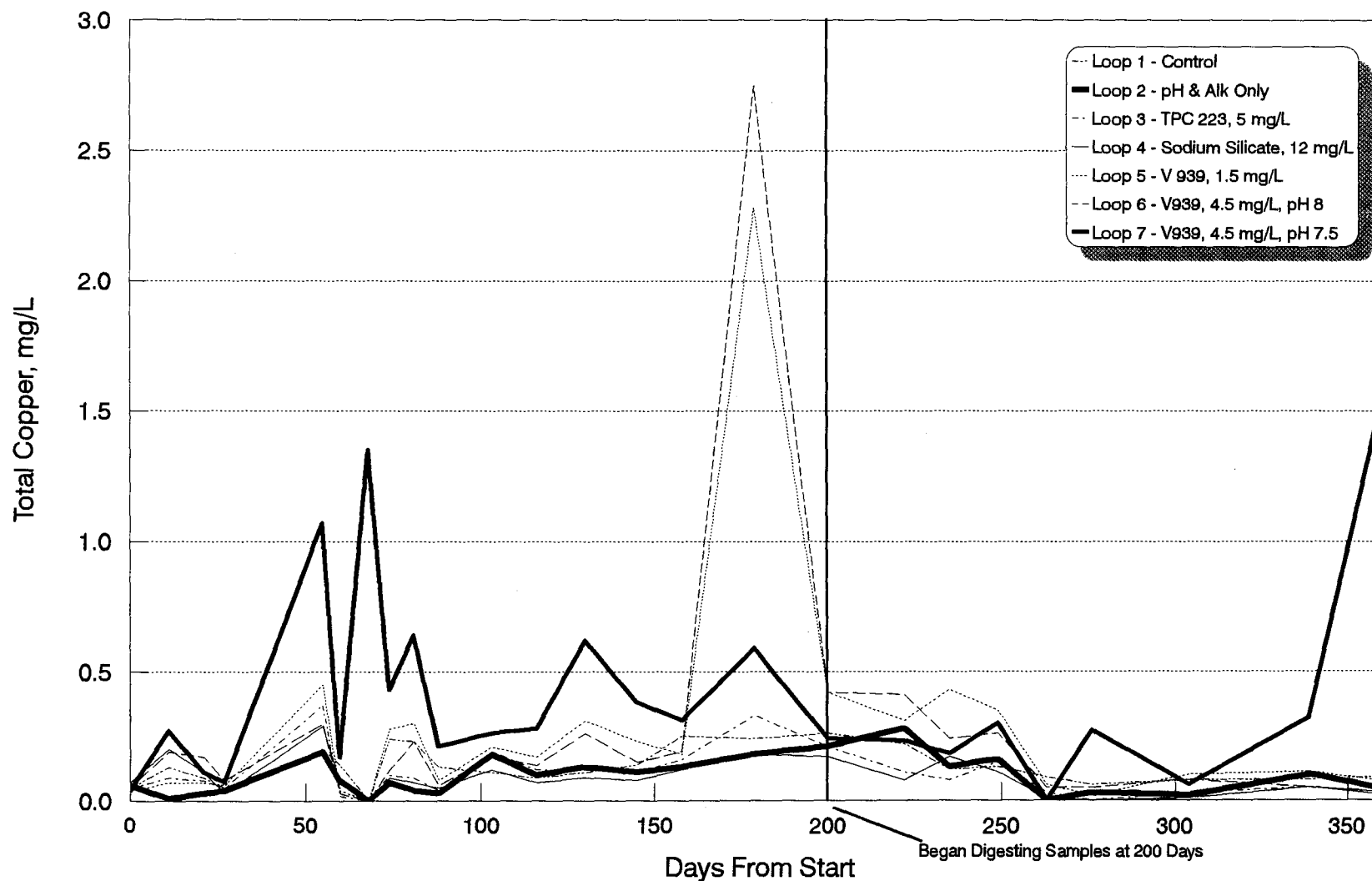
of the spikes happened at the same time as the zinc spikes from the solder coils (Figure 4.23). This appears to be evidence of scale sloughing. Consider again the copper levels from the plumbing coils (Figure 4.13). Almost all of the copper spikes from that chart coincide with the zinc spikes in Figure 4.35. Most of the lead peaks from the plumbing coils (Figure 4.29) also coincide with those same zinc peaks. Also, there appears to be a correlation between the zinc spikes from the solder coils and the lead spikes from the same source (Figures 4.36 and 4.31). This pattern is not as apparent in the faucet samples. The spikes in lead levels in Loop 4 samples generally do not coincide with the zinc spikes, which would be expected since no zinc was fed to Loop 4. It would appear that the spikes in Loop 4 were caused by scale sloughing. It seems there is evidence that the inhibitors broke down for some reason; it remains to be determined what could have caused it.

In the EES study (1990), both treated and untreated standing water samples were taken on several occasions. Some of the plots of metal concentrations in those samples show high upward spikes that are coincident in several or all loops. This may be further evidence of scale sloughing, but in the EES case, the scale was not composed of a metal-inhibitor combination. The whole matter of scale viability needs to be investigated thoroughly.

4.4.4. Relative Metal Mobility of Water Treatments

Table 4.12 rates the relative performance of the various treatments with regard to metal mobilization. Each treatment was given a numerical score based upon the metal levels from each sample. The highest score in each set was 6, corresponding to the highest overall metal level. The lowest score was 0.

		Relative Metal Mobility								
Loop #	**Plumbing Coils**			**Solder Coils**			**Faucets**			**Total Score**	**Score Relative to Raw Water**
	Cu	**Pb**	**Zn**	**Cu**	**Pb**	**Zn**	**Cu**	**Pb**	**Zn**		
1	2	1	0	3	0	0	6	6	3	21	1.00
2	0	0	0	1	4	0	5	4	0	14	0.67
3	3	4	0	2	2	0	3	2	1	17	0.81
4	1	2	0	0	6	0	1	5	2	17	0.81
5	6	3	4	4	3	4	2	3	4	33	1.57
6	4	5	6	5	1	6	0	0	5	32	1.52
7	5	6	5	6	5	5	4	1	6	43	2.05

Table 4.15 - Relative Metal Mobility

The lower the score relative to raw water, the better the treatment performed. As can be seen, in terms of metal mobility, the best treatment was in Loop 2, followed by Loops 3 and 4. However, even the treatment used in Loop 2 would probably result in lead concentrations that exceed EPA action levels due to the high lead release from the faucets. On the other hand, copper concentrations would likely be below EPA action levels. This was also the case in the EES study (1990) in the loop with a similar treatment. If treatment were in accordance with that in Loop 3, both copper and lead concentrations would probably exceed EPA action levels. Treatment in accordance with that done in Loop 4 would yield a water with copper concentrations below the action level but again lead would exceed the action level. In other words, none of the treatments would be produce a water that was below the EPA action levels for trace metals.

4.5. Water Quality Parameters

4.5.1. Temperature

Water temperatures measured over the course of the experiment can be found in Appendix N. The raw water temperature went from a low of 4°C at the beginning of the experiment to a high of about 16°C in August and then back down to 4°C by January. Some of the temperatures of the standing water samples were measured as well, as shown. Those temperatures reached as high as 21.5°C in the summer. It is quite possible that such high temperatures had some influence over the corrosivity of those waters. According to Smith (1989), "in almost all metallic corrosion, higher temperatures increase corrosion activity and colder temperatures reduce corrosion".

4.5.2. Conductivity

The conductivities measured over the duration of the experiment are tabulated in Appendix O. The main purpose of recording conductivities was to use them as a monitoring mechanism, the principle being that if some of them changed significantly from one day to the next, it would likely be an indication of some chemical feed problem. This proved to be quite useful on a couple of occasions. For example, on 06/04/91, the circuit breaker for the pumps feeding $NaHCO_3$, Virchem 939, and TPC 223 opened and the feed stopped. Although it was standard procedure to check all pumps everyday, on this day the problem was not discovered until the conductivities were measured. Since the conductivities were significantly different from where they should have been, an immediate investigation determined the cause of the problem and it was rectified.

4.5.3. pH

The measured pHs are tabulated in Appendix P. There are a few important points regarding the pH measurements which deserve mention.

- On first glance, the effort to maintain the targeted pHs appears quite successful, with the averages in all loops being within 0.05 of a unit. However, the standard deviations were fairly high. For example, in Loop 4, The pH low was 7.22 while the high was 9.37. This is an indication of the difficulty involved in maintaining a pH level in the 8 range.

- pH appears to change after a period of standing. This is indicative of chemical reactions involving hydrogen ions or hydroxyl ions taking place. Figure 4.39 is a plot of pH levels in Loop 1. There is a definite trend of higher pHs in the standing water samples from the plumbing coils, while in the solder coils and faucets standing samples the pHs are very close to that of the flowing water. A possible partial explanation for the higher pHs in the plumbing coil is as follows:

  Consider again the corrosion reaction of copper in the raw water:

  $$2Cu^0 + 2H^+ + \tfrac{1}{2}O_2 \rightarrow 2Cu^+ + H_2O \qquad\qquad 4\text{-}1$$
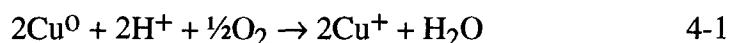
  As the copper corrodes, both molecular oxygen and hydrogen ions are used up. The system is closed, so it eventually reaches a state of equilibrium and the reaction stops. Since over time, there are fewer free hydrogen ions in the system, the pH will be higher.

  It appears that any reactions which occurred in the solder coil and the faucet standing water of Loop 1 were not of sufficient magnitude to cause a significant shift in pHs.

Figures 4.40 and 4.41 are plots of pHs in Loops 2 and 7. The trend in both plots is to lower pHs after standing. There is a myriad of reactions which could take place which would lead to a lower pH such as:

$$Cu^0 + OH^- \rightarrow \tfrac{1}{2}Cu_2O + \tfrac{1}{2}H_2O \text{ or} \qquad\qquad 4\text{-}2$$

$$PbO + Pb^{+4} + 2OH^- \rightarrow PbO_2 + H_2O + Pb^{+2}$$
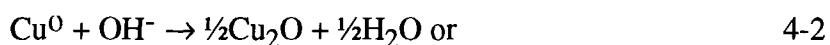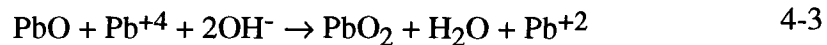
The opposite trend is apparent in Loop 4 as shown in Figure 4.42. Perhaps some of the negatively charged silicate ions tend to neutralize some of the positive hydrogen ions resulting in a higher pH.

4.5.4. Alkalinity

The measured alkalinities can be found in Appendix Q. As can be seen, the average alkalinities in Loops 2 to 7 were quite close to the targeted values, but the standard deviations were fairly high. As was the case with the pHs, the alkalinities of the Loop 1 standing water samples from the plumbing coils were consistently higher than the alkalinities of the flowing water. In fact, the standing water samples from the plumbing coils in all loops were slightly higher than the levels for the flowing waters. Except for Loop 4, the alkalinities of the standing water samples from both the solder coils and the faucets in all loops were lower than the flowing water levels. The alkalinities of the standing water samples in Loop 4 were consistently higher than the levels for the flowing water. It seems likely that some of the pH and alkalinity instability was due to the water's low buffer intensity in the pH 8 range, as discussed in Section 2.4.1 Thus, in spite of almost constant efforts to maintain stable pH and alkalinity levels, there were other factors that influence them and make control difficult.. These factors must be investigated and taken into account if pH and alkalinity adjustment are to be used successfully for corrosion control in water supply systems.

4.5.5. Combined Chlorine

The combined chlorine levels are tabulated in Appendix R. The average levels were right on target, and the standard deviations were quite low. The most obvious trend shows up in the plumbing coil standing samples. Over the course of 24 hours, practically all of the chloramine vanished. Since the system is sealed, it can only be assumed that

Figure 4.39 - pH Comparisons - Loop 1, Control
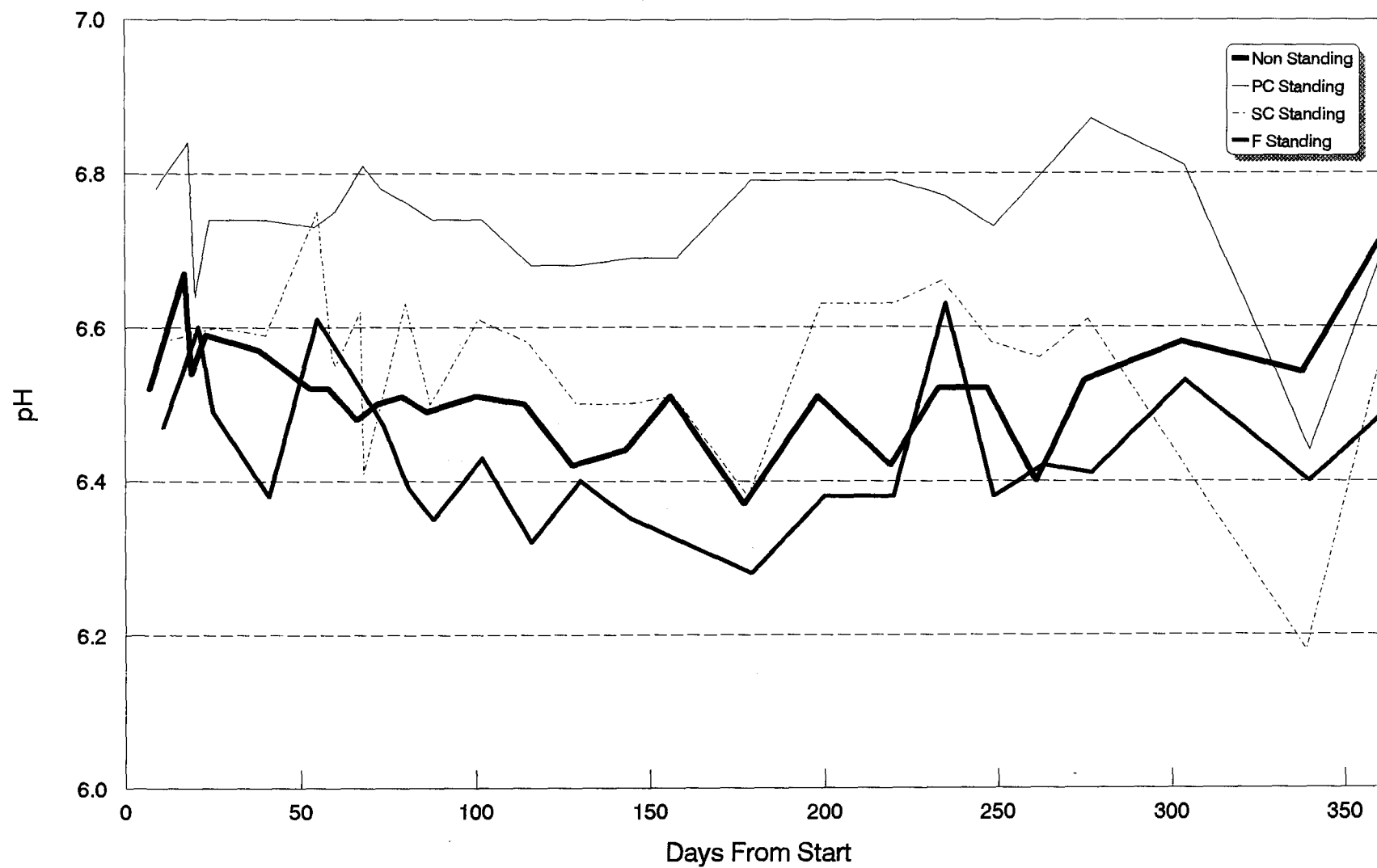
Figure 4.40 - pH Comparisons - Loop 2, pH & Alk Adjusted Only
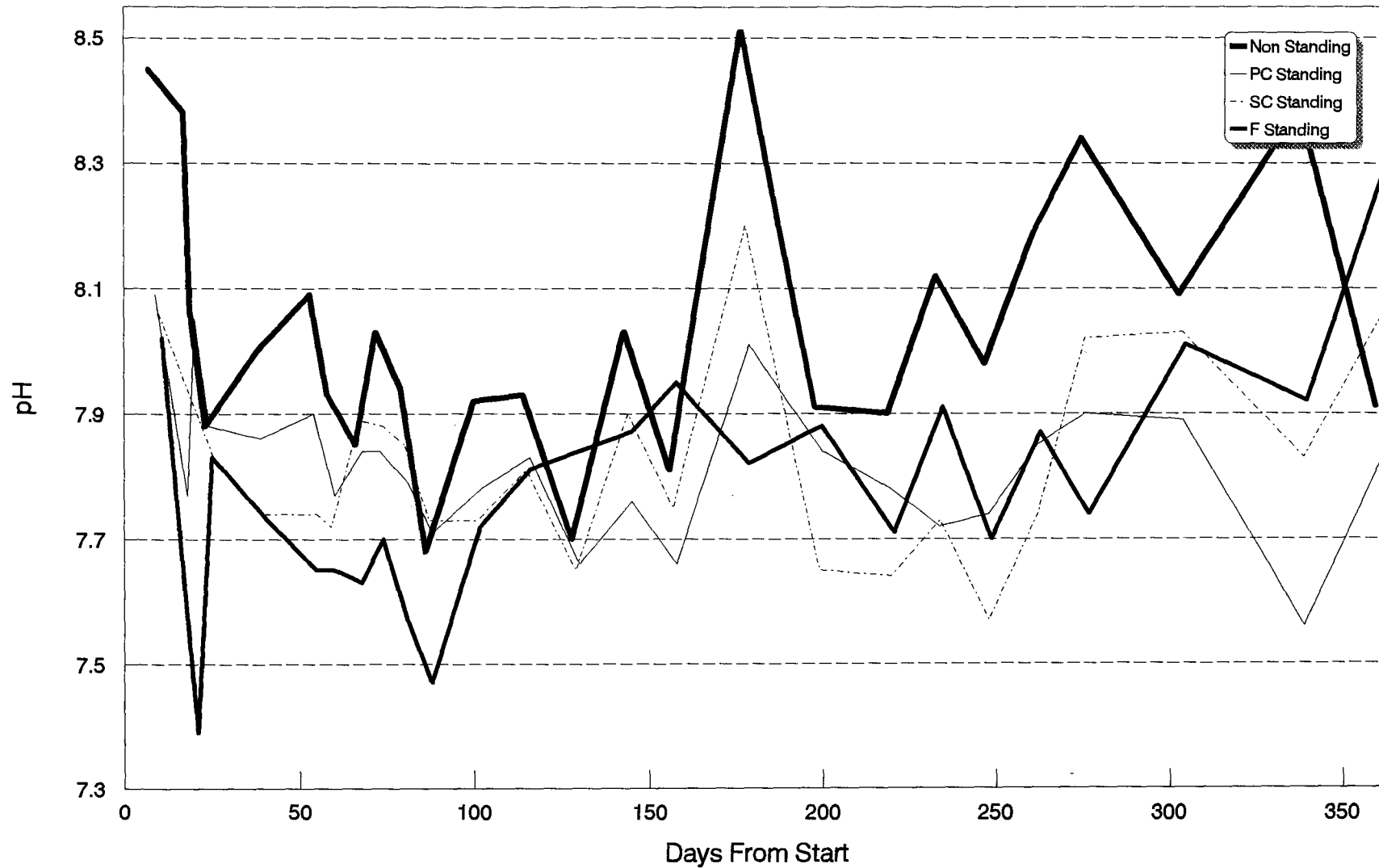
Figure 4.41 - pH Comparisons - Loop 7
Virchem 939, 4.5 mg/L, pH 7.5
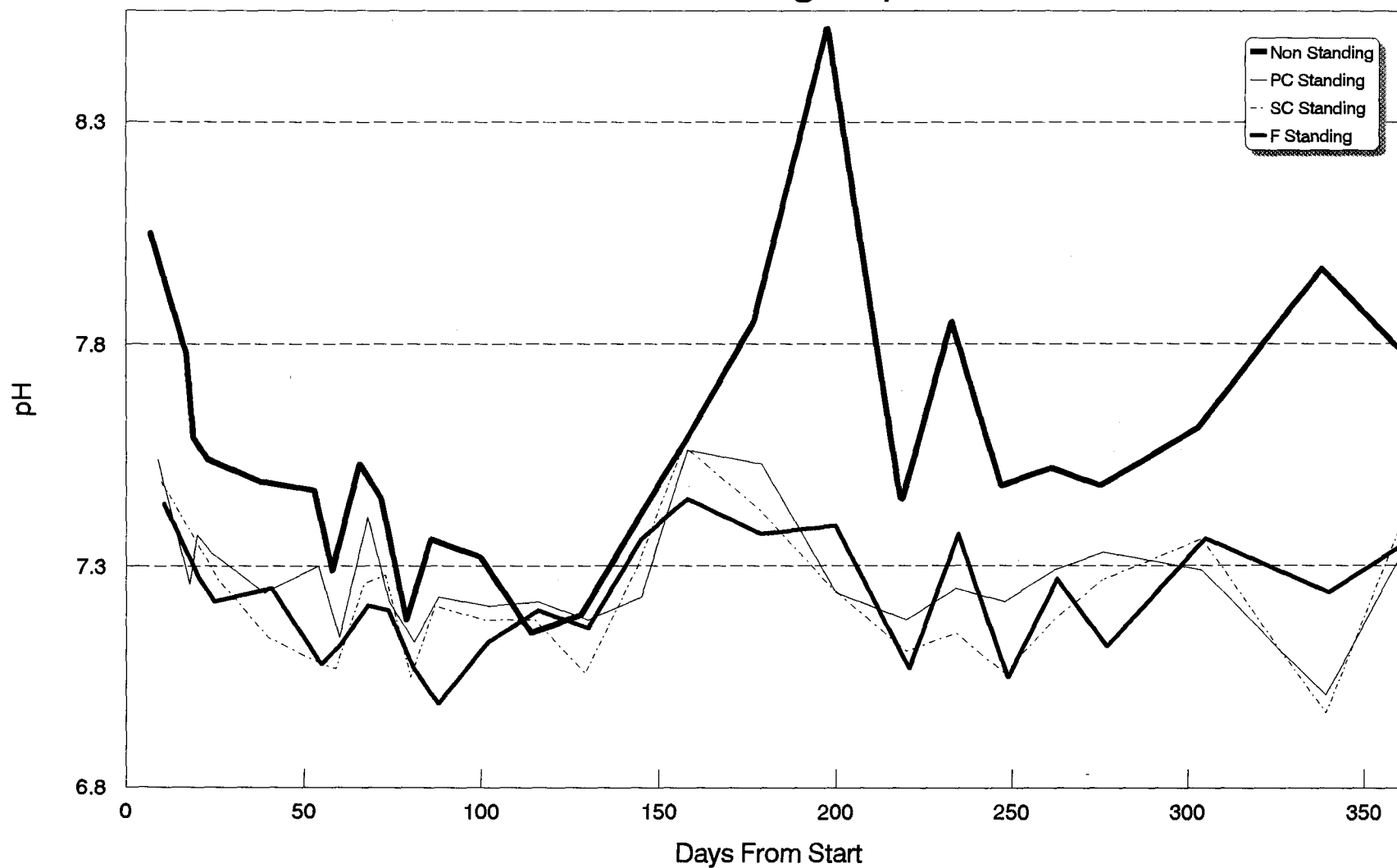
Figure 4.42 - pH Comparisons - Loop 4
Sodium Silicate, 12 mg/L
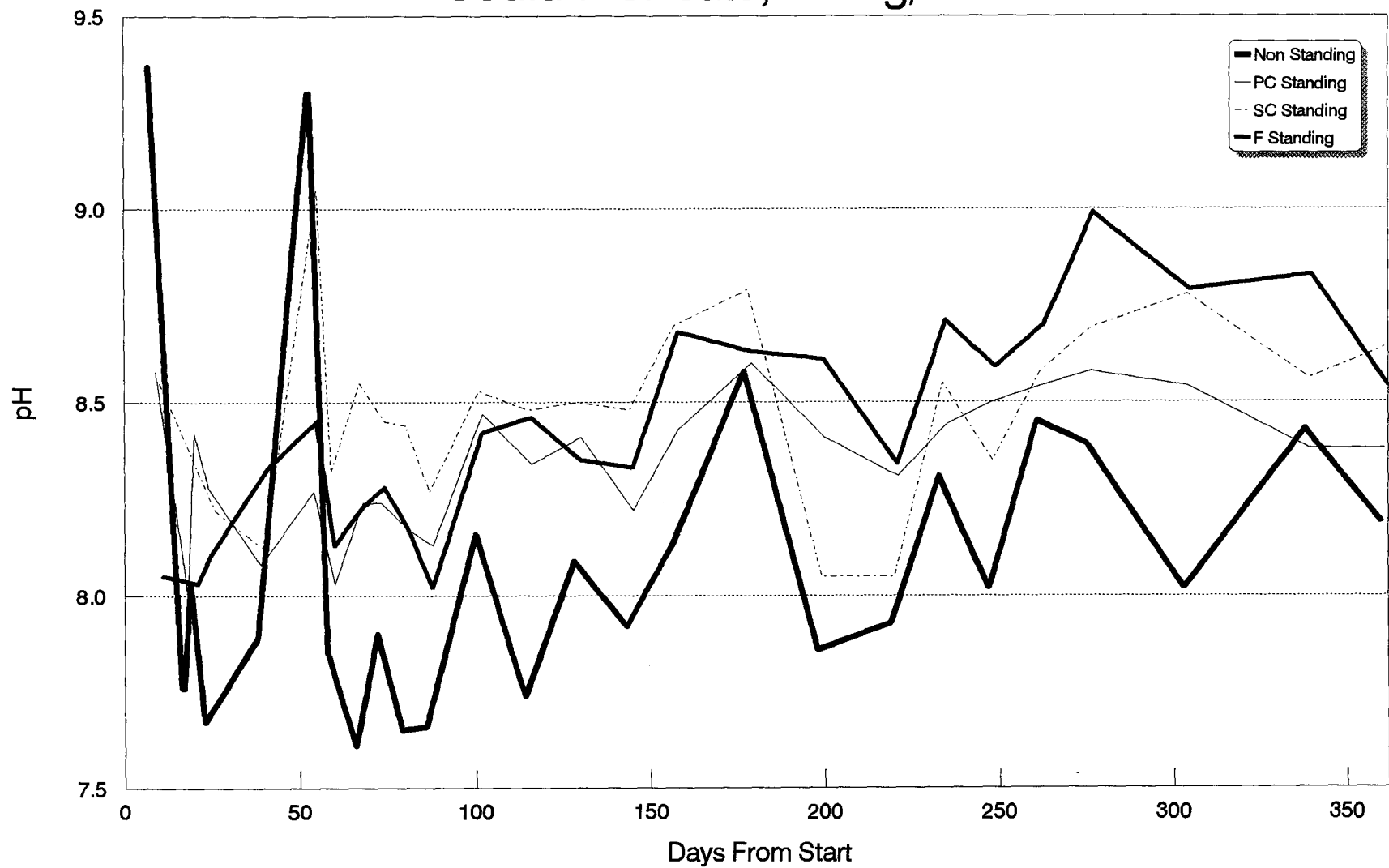
it reacted to form other compounds. As was discussed in para 2.4.2., the reaction of chloramine with copper is spontaneous, although not as strong as the reaction of free chlorine with copper. It is probably safe to assume that either disinfectant is more corrosive to copper than raw water alone. The chloramine levels were also lower in the solder coil standing samples, again leading to the impression that some of it combined chemically, probably forming some lead-amine complexes. The tendency for these reactions to occur does not appear to be as great as was the case in the plumbing coils. There was also a slight drop in chloramine levels in the faucet standing samples, but the difference is almost negligible. The reason the difference is so small may be partially attributable to the fact that the samples taken from the faucets for pH, alkalinity, conductivity, and combined chlorine measurements were larger than the volume of water actually isolated, so some fresh flowing water was also included. There was not enough water contained within the faucets to allow sufficient volume for all of the desired measurements to be made.

4.6. Possible Causes of Inhibitor Instability

A number of parameters were examined to see if there was some sort of pattern wherein one or a combination of water quality changes may have caused the instability of the inhibitor and/or the protective scale. There appears to be no relationship between the high metal spikes and changes to other parameters. Figures 4.43 through 4.50 show various combinations of plots of pH or alkalinity versus metal levels from some of the samples. It could be that inhibitor or scale instability occurs as a result of a significant drop in pH and/or alkalinity, but the instability does not appear until several weeks later on. Some of the plots tend to show such a pattern, but it is not consistent, as can be seen.

If the stability of the inhibitors/scales is pH and/or alkalinity dependent, then the results provide another reason for avoiding the pH 8.0 to 8.5 range. Not only are

attempts to maintain a pH in this range in water treatment extremely difficult, but they may also increase the risk of extremely high metal spikes in the water.

4.7. Bacterial Growth

The results of the bacteriological analyses done by the GVRD laboratory are presented in Appendix S. The following are some observations from these data:

4.7.1. Copper Coupons - Bacteriological Results

- All treatments had lower heterotrophic plate counts than the raw water.

- Loop 4 had the lowest heterotrophic plate count, being almost 2 orders of magnitude lower than the next lowest loop, Loop 5.

- There were no differences between loops in total coliform counts, all of them being below meaningful levels (counted as < 2 on the data sheets).

4.7.2. Cast Iron Coupons - Bacteriological Results

- All treatments had higher heterotrophic plate counts than the raw water.

- Loop 3 had the highest heterotrophic plate count, but all loops with phosphate feeds had higher counts by almost an order of magnitude.

- The only loop with a consistent total coliform count was the raw water loop. The others were all below meaningful levels (again counted as < 2 on the data sheets).

It appears, from this limited data, that there may be some cause for concern regarding the bacterial regrowth potential when phosphate inhibitors are used in the presence of ferrous pipe materials. It may be that the phosphates are particularly beneficial to iron bacteria, which could possibly lead to increased corrosion. To go any further was beyond the scope of this study, but these data point that these relationships need to be studied further, to determine the effects of phosphate inhibitors in

pH Versus Copper Levels from Plumbing Coils - Loop 2
(pH Measured Prior to Water Being Isolated in Coils)
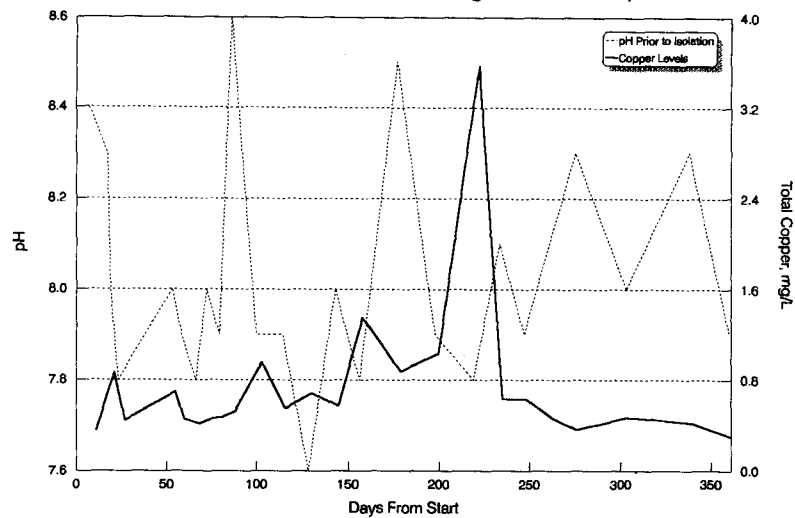
pH Versus Copper Levels from Plumbing Coils - Loop 2
(pH Measured from Standing Water Sample from Coils)
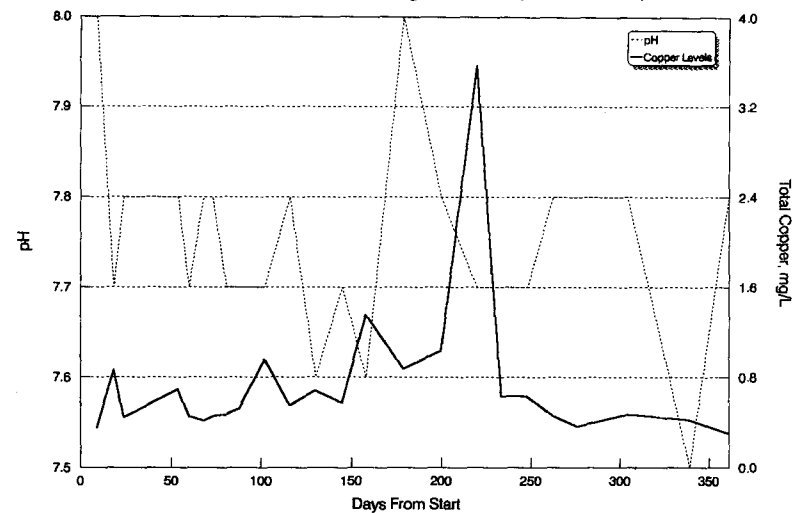
Alkalinity Versus Copper Levels from Plumbing Coils - Loop 2
(Alkalinity Measured Prior to Water Being Isolated in Coils)
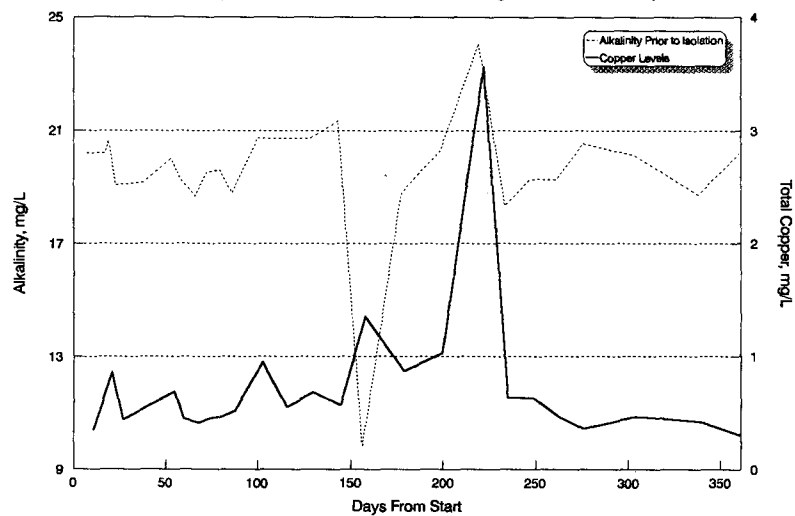
Alkalinity Versus Copper Levels from Plumbing Coils - Loop 2
(Alkalinity Measured from Standing Water Sample from Coils)
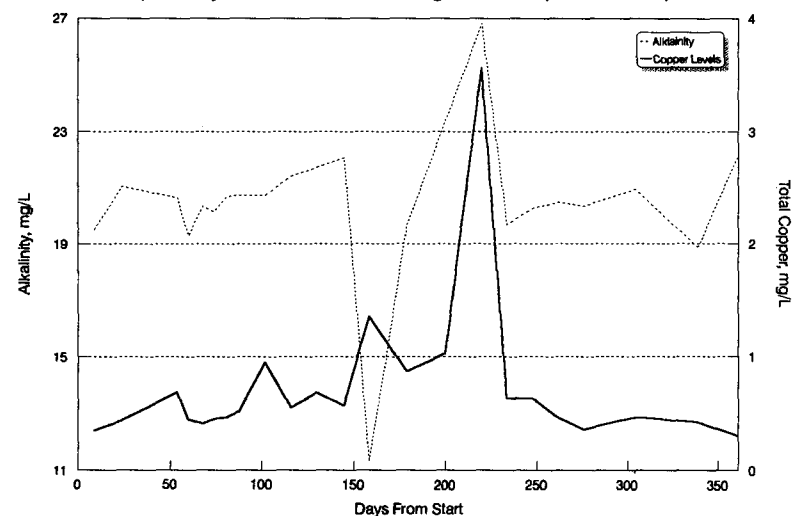
Figure 4.43

pH Versus Copper Levels from Plumbing Coils - Loop 4
(pH Measured Prior to Water Being Isolated in Coils)

pH Versus Copper Levels from Plumbing Coils - Loop 4
(pH Measured from Standing Water Sample from Coils)

Alkalinity Versus Copper Levels from Plumbing Coils - Loop 4
(Alkalinity Measured Prior to Water Being Isolated in Coils)

Alkalinity Versus Copper Levels from Plumbing Coils - Loop 4
(Alkalinity Measured from Standing Water Sample from Coils)

Figure 4.44

pH Versus Lead Levels from Solder Coils - Loop 4
(pH Measured Prior to Water Being Isolated in Coils)

pH Versus Lead Levels from Solder Coils - Loop 4
(pH Measured from Standing Water Sample from Coils)

Alkalinity Versus Lead Levels from Solder Coils - Loop 4
(Alkalinity Measured Prior to Water Being Isolated in Coils)

Alkalinity Versus Lead Levels from Solder Coils - Loop 4
(Alkalinity Measured from Standing Water Sample from Coils)
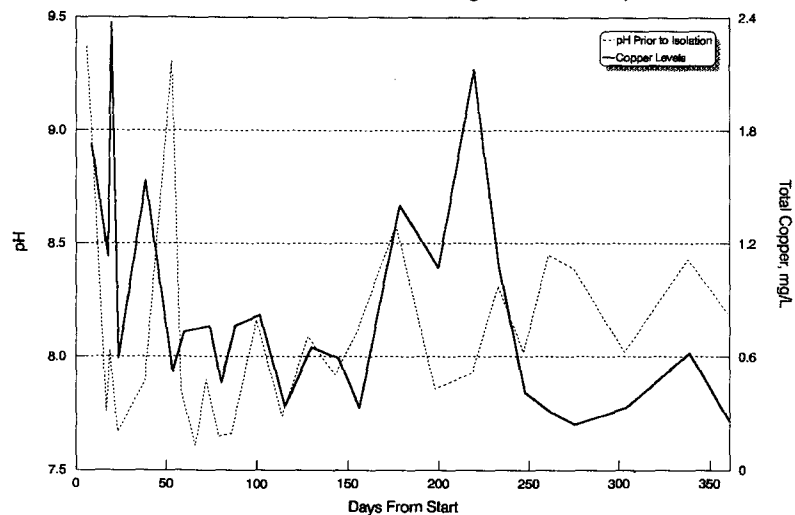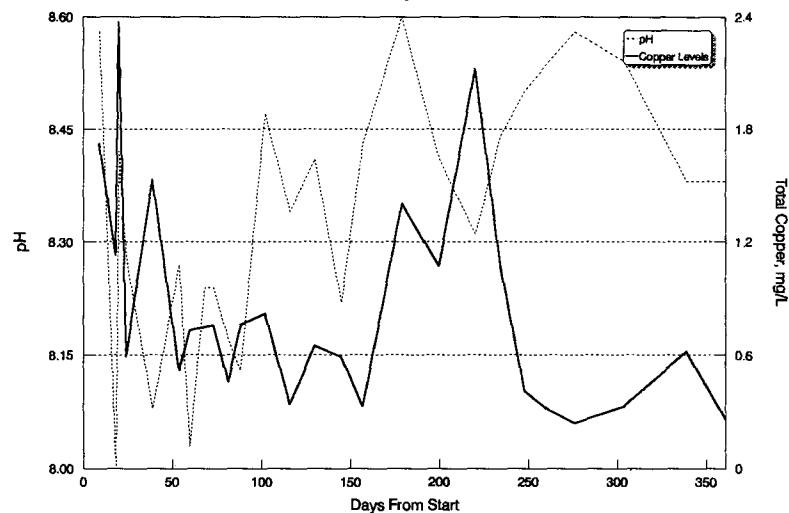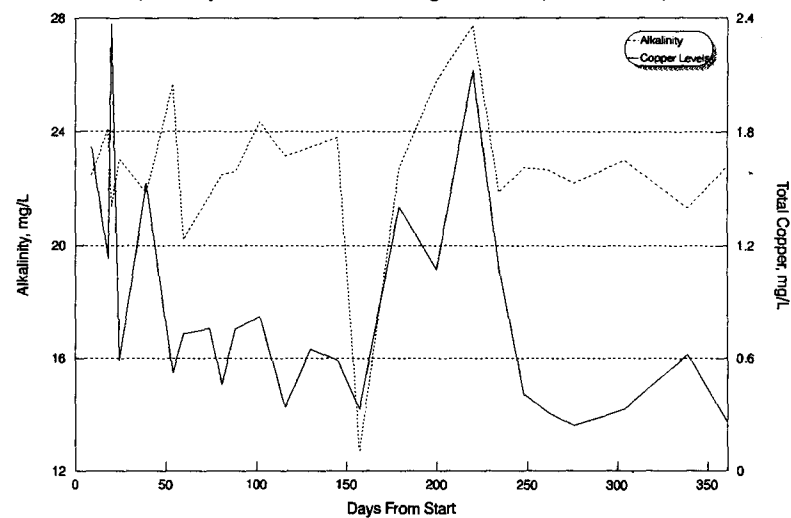
Figure 4.45

Figure 4.46

pH Versus Lead Levels from Plumbing Coils - Loop 6
(pH Measured Prior to Water Being Isolated in Coils)
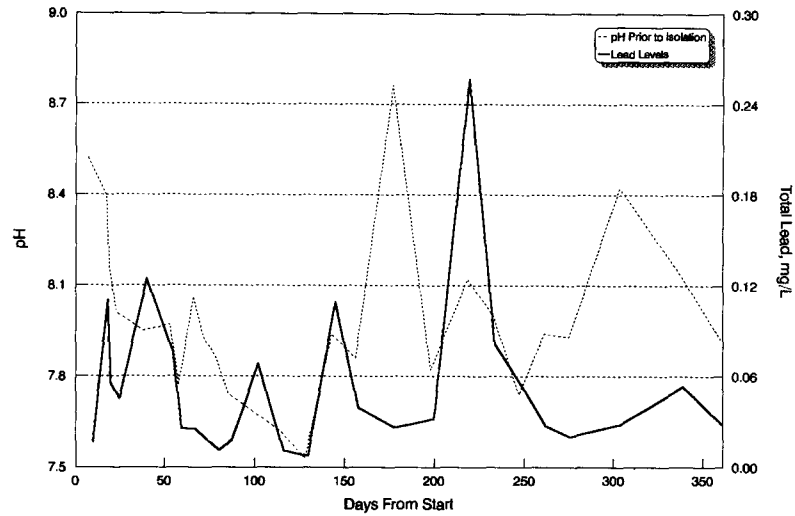
pH Versus Lead Levels from Plumbing Coils - Loop 6
(pH Measured from Standing Water Sample from Coils)
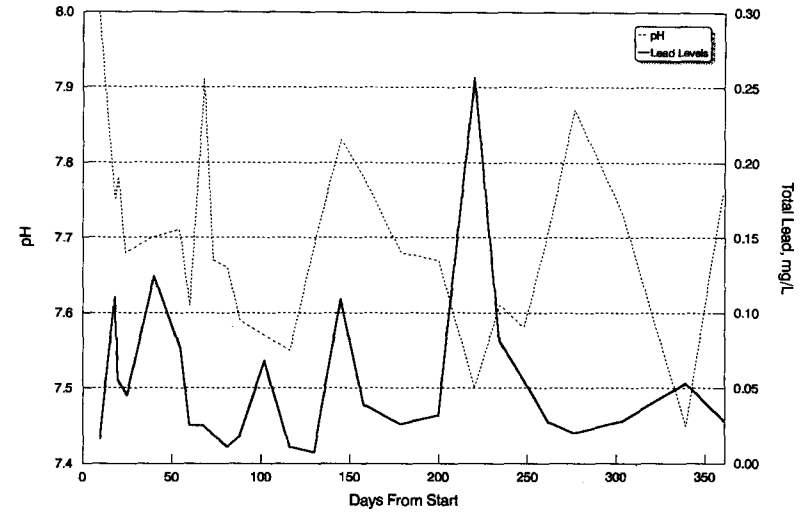
Alkalinity Versus Lead Levels from Plumbing Coils - Loop 6
(Alkalinity Measured Prior to Water Being Isolated in Coils)
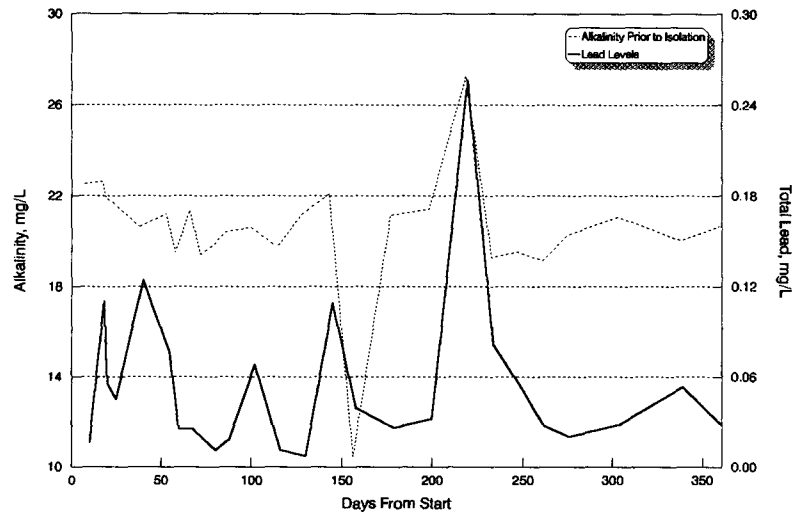
Alkalinity Versus Lead Levels from Plumbing Coils - Loop 6
(Alkalinity Measured from Standing Water Sample from Coils)
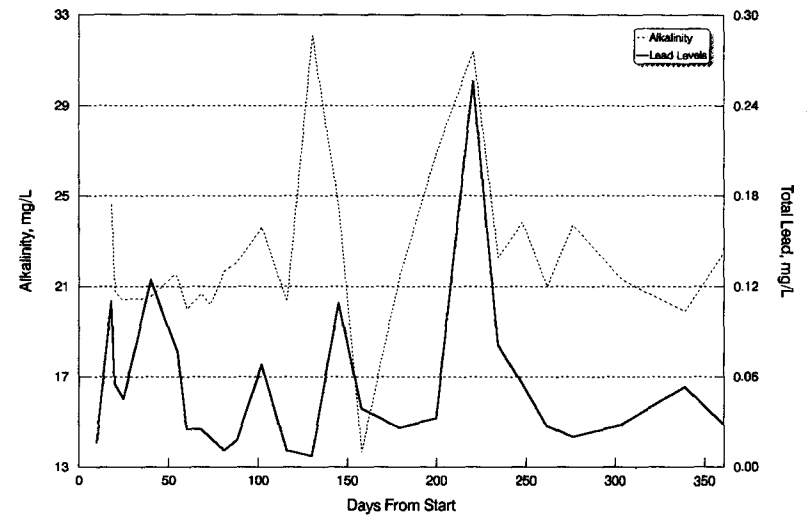
Figure 4.47
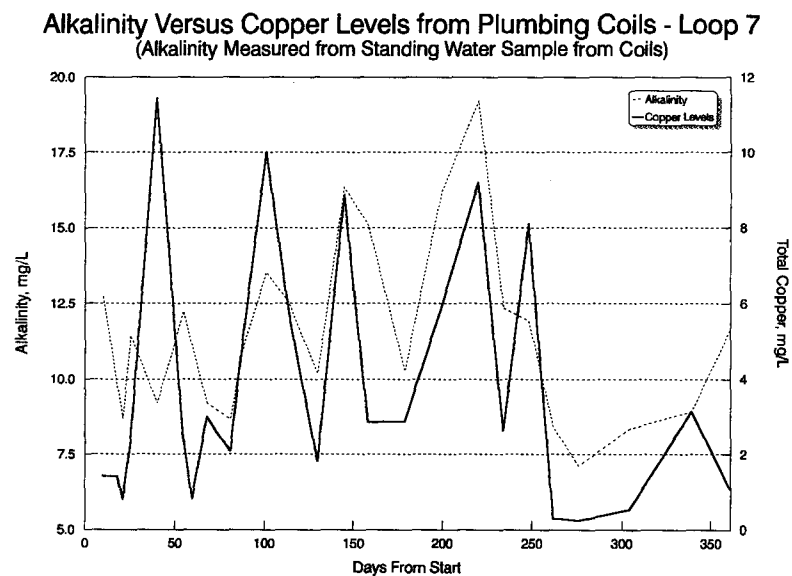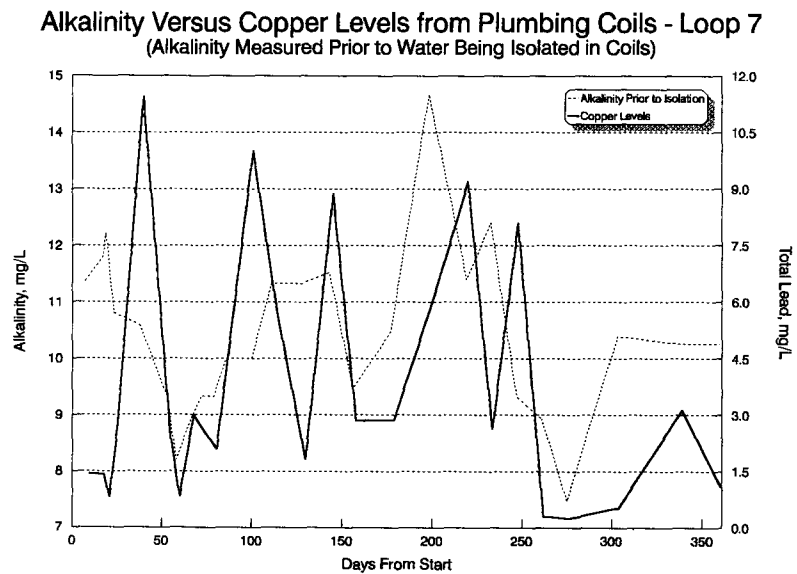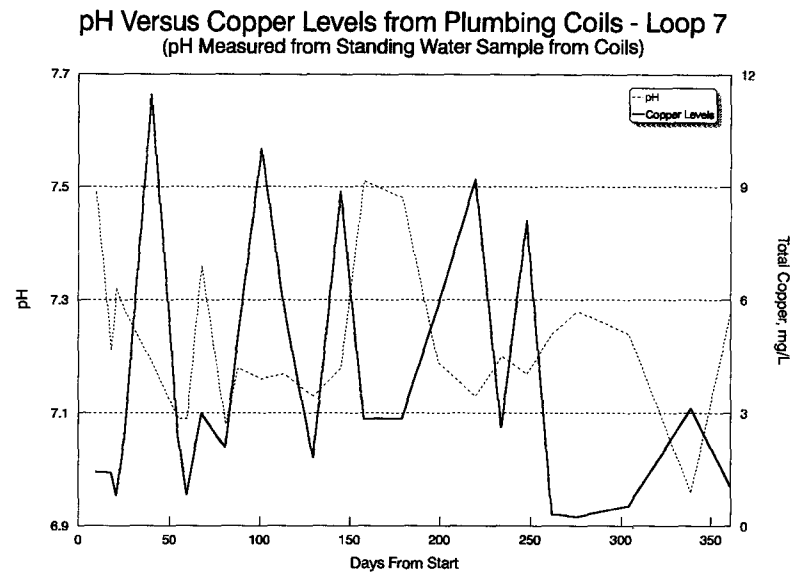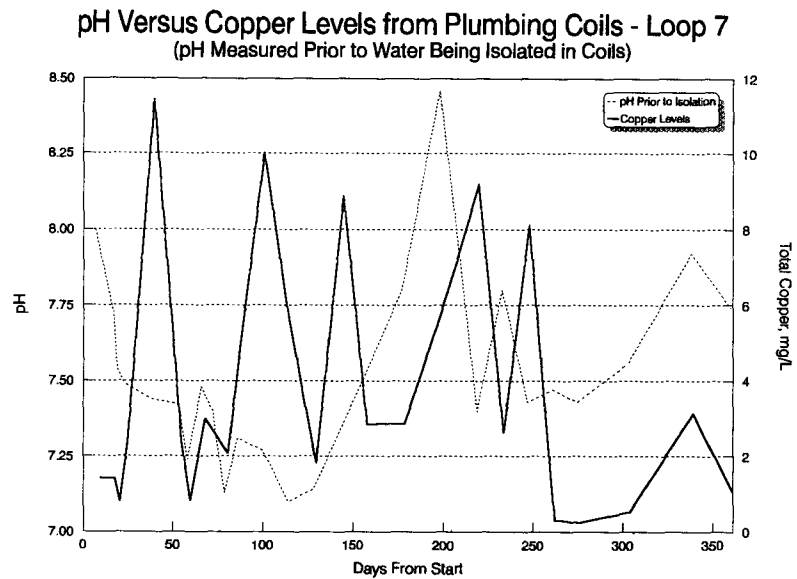
Figure 4.48

pH Versus Lead Levels from Plumbing Coils - Loop 7
(pH Measured Prior to Water Being Isolated in Coils)

pH Versus Lead Levels from Plumbing Coils - Loop 7
(pH Measured from Standing Water Sample from Coils)

Alkalinity Versus Lead Levels from Plumbing Coils - Loop 7
(Alkalinity Measured Prior to Water Being Isolated in Coils)

Alkalinity Versus Lead Levels from Plumbing Coils - Loop 7
(Alkalinity Measured from Standing Water Sample from Coils)

Figure 4.49

pH Versus Lead Levels from Solder Coils - Loop 7
(pH Measured Prior to Water Being Isolated in Coils)
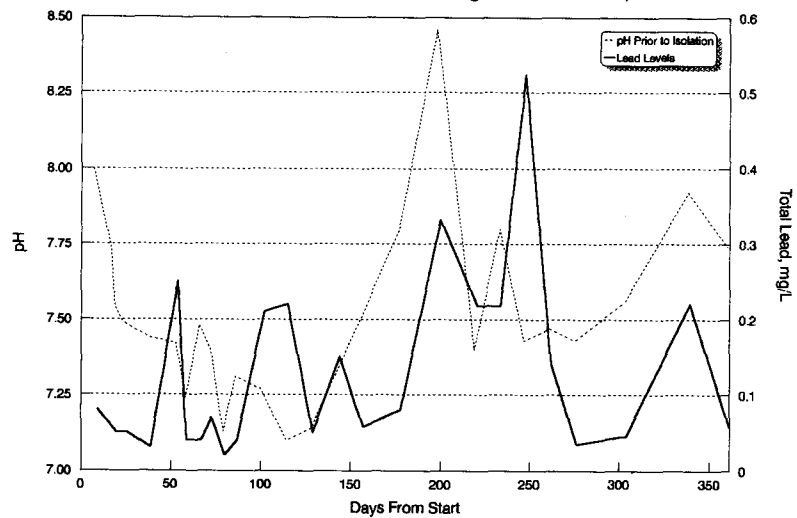
pH Versus Lead Levels from Solder Coils - Loop 7
(pH Measured from Standing Water Sample from Coils)
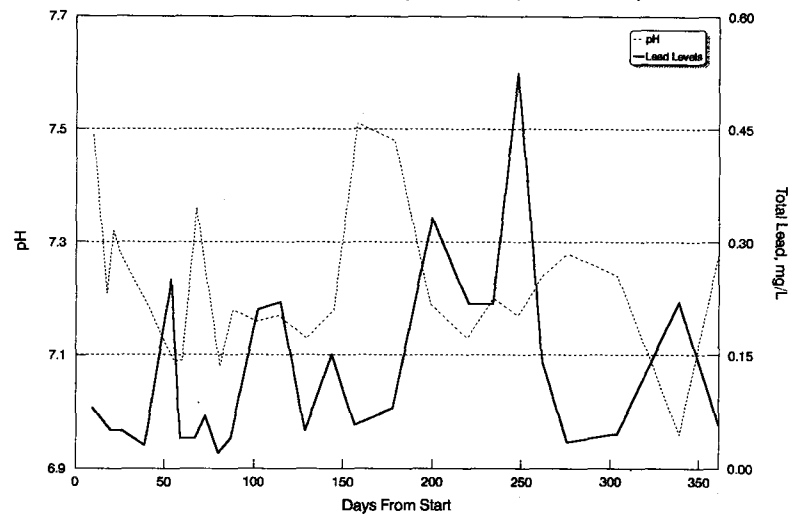
Alkalinity Versus Lead Levels from Solder Coils - Loop 7
(Alkalinity Measured Prior to Water Being Isolated in Coils)
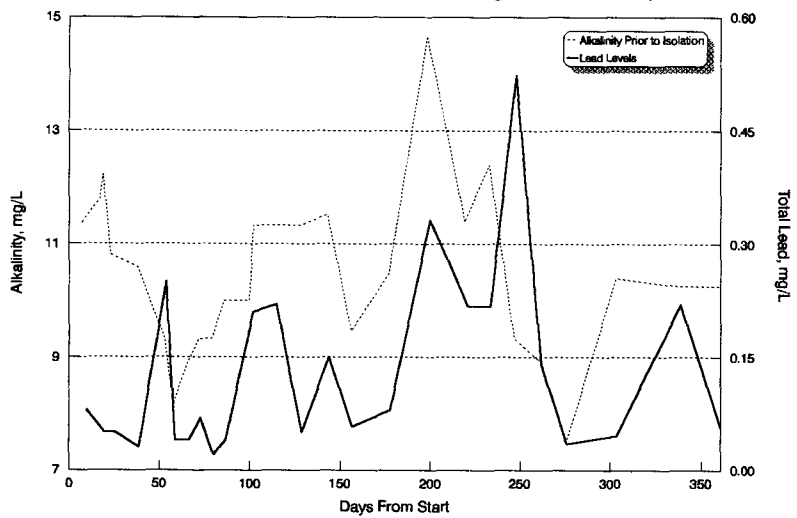
Alkalinity Versus Lead Levels from Solder Coils - Loop 7
(Alkalinity Measured from Standing Water Sample from Coils)
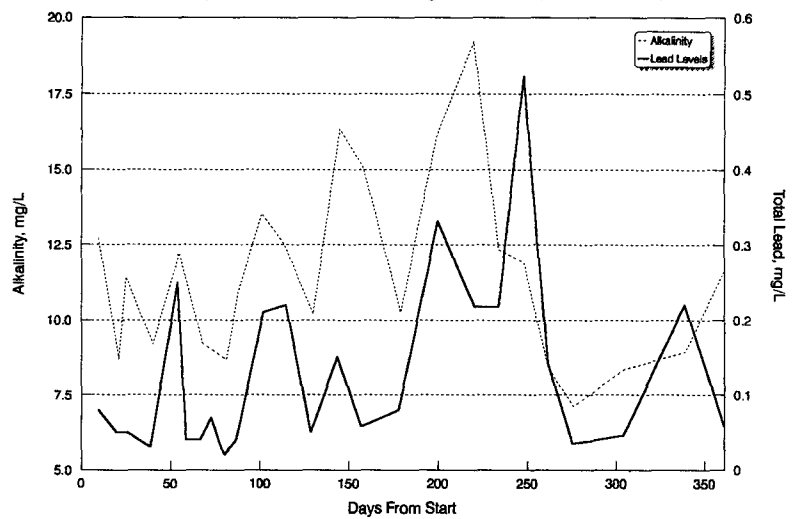
Figure 4.50

the actual distribution system, and their long term bacterial regrowth and possibly in-
duced bacterial corrosion effects. Bacterial growth in the presence of other pipe materi-
als also needs to be examined.

4.8. Quality Control

On a regular basis, selected samples were sent to the GVRD laboratory for analy-
sis for silica, phosphorus, copper, zinc and lead. The results of those analyses, along
with the UBC analyses for the same parameters, are presented in Appendix T. With
some exceptions, most of the results are quite comparable between the two labs. In some
cases, it is possible that, due to human error, some samples became mixed up and the
measurements recorded for one were, in fact, applicable to another.

The comparisons that are somewhat troubling are those for phosphorus in Loop 3.
Most of the GVRD laboratory measurements (measured as total phosphorus) were at
least an order of magnitude higher than those of the UBC laboratory. There is no appar-
ent reason for this fairly consistent difference. Since Loop 3 was one of the loops that
was fed zinc orthophosphate, this problem brings into question the actual levels of phos-
phate going into Loop 3. By comparison, almost all of the silica measurements for Loop
3 by the two labs are all within a 10 to 15 percent range of each other.

In spite of these few exceptions, overall, the quality assurance results are quite
satisfactory, with the two labs recording measurements that were consistently within a
reasonable margin of error (10 to 15 percent) of each other. It must be remembered that,
in this study, the absolute metal levels are not of as much concern as the relative levels
between loops since the goal was to determine the relative corrosiveness of the various
treatments. Furthermore, it makes little difference if, for example, lead is present at 10
mg/L or 15 mg/L The levels are unacceptably high in either case. Even if there were a
fairly high level of error in the UBC measurements (unlikely but possible), it can still be

safely concluded that the metal levels mandate a requirement for caution before inhibitors are used in the GVWD distribution system.

4.9. Power Failures, Breakdowns, and Other Problems

In spite of the best of efforts, with any experiment, things do go wrong. There was a number of incidents which may have had some influence on the outcome of this study. Fortunately, due to the long term nature of the study, it is unlikely that they had any serious effect on the overall results. Nevertheless, the incidents were recorded. Appendix W is a complete listing of them.

5. SUMMARY AND CONCLUSIONS

5.1 Major Findings

The purpose of this project was to study the inhibitor effects of zinc orthophosphate and sodium silicate treatments in GVWD water, as an adjunct to pH and alkalinity adjustment. Several vehicles were used in order to provide as many different measures of the effects of the inhibitors as possible, within the physical constraints of the existing pilot plant. There was no intention to examine the precise processes involved with these inhibitors or to attempt to learn exactly why the results turned out the way they did.

5.1.1. Copper Coupons

The results of the copper coupon experiments suggest that, with or without treatment, copper corrosion rates decrease with time, but all treatments reduce corrosion rates below those of the raw water. Zinc orthophosphate appears to offer the best copper corrosion reduction potential, but sodium silicate appears to be beneficial as well, and the benefits from pH and alkalinity adjustment alone are not insignificant.

5.1.2. Cast Iron Coupons

The cast iron coupon experiments again show a generally decreasing corrosion rate over time regardless of the treatment used. However, none of the treatments appear to provide any significant degree of protection over that obtained from the raw water. It could be argued that some of the treatments may cause corrosion to increase over levels obtained with raw water.

5.1.3. Copper Corrosometer Probes

The copper corrosometer probe experiment also showed a trend toward decreasing corrosion rates with time, but some of the treatments had corrosion rates that appeared to be higher than that of the raw water. Zinc orthophosphate at the higher dose

appeared to offer the best protection, but sodium silicate was effective as well. By examining corrosion rates over shorter periods of time, one can better observe how those rates change over time. Generally, the copper corrosometer probe data corroborate the copper coupon data.

5.1.4. Mild Steel Corrosometer Probes

The mild steel corrosometer probe experiment showed similar corrosion rates with all treatments, but treatment with zinc orthophosphate or sodium silicate may reduce corrosion rates somewhat. Unfortunately, the short life of the probes, evidence of pitting in the probes, and the fact that the check probes showed changing readings all render these data inadequate to assess the corrosion of mild steel.

5.1.5. Metal Mobility

The metal mobility experiments demonstrated that a high degree of caution is required before inhibitors are used in the actual distribution system. Generally, the inhibitor treatments resulted in the highest water-metal levels. The results do not necessarily contradict the results of the coupon experiments. Overall, corrosion rates do not necessarily relate to metal mobility during long standing periods. For the majority of time, the system ran on its regular schedule with water flowing 6 hours a day and the longest standing period being 8 hours each day; it is quite likely that corrosion rates were low during those times. It seems that during the 24 hour standing periods, the formerly protective scale (essentially a metal-inhibitor compound) became weakened and began to slough, either during that standing period, or sometime later. It is also likely that some of the zinc orthophosphate precipitated out before forming a scale, as demonstrated by the presence of zinc levels well in excess of the feed rates. These two phenomena could account for the high metal levels in particulate form.

The reason for the apparent scale weakening is not obvious. It could have something to do with changes in pH and/or alkalinity and the difficulty encountered with trying to maintain pH in the 8-8.5 range. It may also be dependent on the length of standing time. A representative from the zinc orthophosphate supplier, Technical Products Corp., also suggested that, due to the nature of the raw water, it is possible that the scale instability was because of low dosages of the chemical. He suggested that further experimentation be done at significantly higher dosages (up to 3-4 times the levels tried). A representative of National Silicates, the sodium silicate supplier, suggested that the 24 hour standing period is too long for the scale to remain stable. Overall, the lowest copper mobility appears to result from simple pH and alkalinity adjustment, but lead mobility may actually *increase* with treatment. As the literature corroborates, further experimentation is required to determine the optimum pH and alkalinity/DIC levels for minimization of lead mobility under standing conditions.

5.1.6. Bacterial Regrowth

The bacterial regrowth measurements showed no significant differences between treatments in the presence of copper, but the apparent effect of the phosphate inhibitors on regrowth in the presence of cast iron gives cause for concern. It may be that iron bacteria are able to benefit from the phosphate, which could lead to increased corrosion rates. The effects of phosphate inhibitors in the actual distribution system, where healthy bacterial colonies already exist, could not be demonstrated in this project. However, the limited work done here should give rise to significant concern. Bacterial regrowth should be examined fully in field trials before any consideration is given regarding phosphate inhibitor use in the total distribution system.

5.1.7. Chloramine

Due to the fact that a chloramine only loop was not tested, there is no way of corroborating the expectation that chloramine should reduce a water's corrosiveness over that of raw water.

5.2 Recommendations

Due to the high metal levels measured from the standing water samples in this study, the use of either zinc orthophosphate or sodium silicate by the GVWD in the distribution system is not recommended at this time. On the other hand, due to the promise they showed in terms of lowering overall corrosion rates, it is recommended that both zinc orthophosphate and sodium silicate be further studied as to the effect of the length of standing time and the effect of pH and alkalinity fluctuations and other factors on metal mobility. They should also be more closely examined in an effort to determine the optimum dosage that should be used for corrosion inhibition.

The use of the corrosometer system and other electrical/electronic methods, as a means to monitor corrosion in GVWD type waters, needs to be further studied. It is quite possible that one or more such methods, properly calibrated, could offer economical and less labour intensive alternatives to coupon studies.

The effect of phosphates on bacterial regrowth needs to be more closely examined, hopefully with actual field trials. The problem of bacterial induced corrosion also requires extensive investigation.

Perhaps the most profound lesson to be learned from this project lies in the contradictory conclusions that could be formed (perhaps mistakenly) when considering the results of either the coupons or the metal mobility experiments in isolation. Taken alone, the coupon experiments could lead to the conclusion that zinc orthophosphate, and perhaps even sodium silicate, administered in the proper manner and dosage, offers good potential as a corrosion inhibitor. Yet the metal mobility experiments clearly demon-

strate a cause for caution before inhibitor use is implemented. It seems ironic that consideration of the use of an inhibitor may have been, in part, prompted by health concerns.

The potential impact of zinc orthophosphate, or any other inhibitor containing zinc, on sewage treatment facilities and the receiving waters also needs to be studied before their use is contemplated in the GVWD. Zinc is a bactericide, and is toxic to fish. Presently, the zinc concentrations at the sewage treatment plants are at or near maximum acceptable levels (Greater Vancouver Regional District, 1989). If more zinc is added, it could impair sewage treatment operations. The Federal Department of Fisheries and Oceans would likely raise serious objections to any increase in zinc concentrations in sewage effluents. The current zinc concentration in GVWD sewage sludge is about 600 mg/kg. Sludge containing any more than 500 mg/kg is considered contaminated and requires remediation before it can be applied to anything but strict industrial use land (B.C. Ministry of Environment, 1989). Obviously, unless that maximum acceptable level is increased, additional zinc in the water cannot be tolerated.

It is, indeed, possible that some water systems are currently using inhibitors, based on limited coupon experiments which demonstrated potential economic benefit and *mistakenly assuming beneficial health effects*. The literature clearly demonstrates successful use of inhibitors in other studies and in actual distribution system use. At the very least, this study shows that any distribution system inhibitor application program must be accompanied by continuous monitoring until there is long term evidence that total metal levels at the tap are well below the accepted maximums. Obviously every system is unique, and a great deal more study is needed in all areas concerning inhibitor use.

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APPENDICES

Copper Coupons
Summary of Laboratory Data Sheets
As Prepared by
Kennedy/Jenks Consultants, San Francisco
Analysis in Accordance with ASTM D 2688-83, Method C.

Loop No.	Insert No.	Date Inserted	Date Removed	Total Days	Initial Wt, g	Removed Wt, g	Gain/Loss, g	Cleaned Wt, g	Scale & Corr Pro Wt, g	Coupon Weight Loss, g	Weight Loss Rate mm/yr	Pitting Depth, mm Avg	Pitting Depth, mm Max
Three Months													
1	CDA122L-01	15/03/91	17/06/91	94	92.8135	92.6542	-0.1593	92.5575	0.0967	0.2560	0.0134	0.0094	0.0140
2	CDA122L-02	15/03/91	17/06/91	94	92.8568	92.6680	-0.1888	92.5378	0.1302	0.3190	0.0167	0.0071	0.0104
3	CDA122L-03	15/03/91	17/06/91	94	92.7828	92.6442	-0.1386	92.4744	0.1698	0.3084	0.0161	0.0058	0.0071
4	CDA122L-04	15/03/91	17/06/91	94	92.8572	92.7613	-0.0959	92.6747	0.0866	0.1825	0.0095	0.0038	0.0053
5	CDA122L-05	15/03/91	17/06/91	94	92.8905	92.8036	-0.0869	92.7470	0.0566	0.1435	0.0075	0.0041	0.0053
6	CDA122L-06	15/03/91	17/06/91	94	92.9433	92.8891	-0.0542	92.8556	0.0335	0.0877	0.0046	0.0038	0.0053
7	CDA122L-21	15/03/91	17/06/91	94	92.7194	92.6115	-0.1079	92.5760	0.0355	0.1434	0.0075	0.0036	0.0053
1	CDA122L-43	18/12/91	16/03/92	89	92.9908	92.7872	-0.2036	92.6984	0.0888	0.2924	0.0161	0.0036	0.0041
2	CDA122L-44	19/12/91	17/03/92	89	92.9039	92.8349	-0.0690	92.7675	0.0674	0.1364	0.0075	0.0036	0.0041
3	CDA122L-45	20/12/91	18/03/92	89	92.7088	92.5992	-0.1096	92.5130	0.0862	0.1958	0.0108	0.0041	0.0046
4	CDA122L-46	21/12/91	19/03/92	89	92.8072	92.7676	-0.0396	92.7190	0.0486	0.0882	0.0049	0.0036	0.0041
5	CDA122L-47	22/12/91	20/03/92	89	92.8551	92.6990	-0.1561	92.6630	0.0360	0.1921	0.0106	0.0038	0.0041
6	CDA122L-49	23/12/91	21/03/92	89	92.9063	92.8851	-0.0212	92.8306	0.0545	0.0757	0.0042	0.0038	0.0041
7	CDA122L-48	24/12/91	22/03/92	89	92.8324	92.7099	-0.1225	92.6805	0.0294	0.1519	0.0084	0.0036	0.0041
Six Months													
1	CDA122L-08	15/03/91	16/09/91	185	92.8831	92.6435	-0.2396	92.3927	0.2508	0.4904	0.0130	0.0053	N/A*
2	CDA122L-09	15/03/91	16/09/91	185	92.9016	92.7252	-0.1764	92.5045	0.2207	0.3971	0.0105	0.0025	N/A*
3	CDA122L-10	15/03/91	16/09/91	185	92.8537	92.6803	-0.1734	92.4111	0.2692	0.4426	0.0117	0.0025	N/A*
4	CDA122L-12	15/03/91	16/09/91	185	92.8370	92.7094	-0.1276	92.5625	0.1469	0.2745	0.0073	0.0041	N/A*
5	CDA122L-11	15/03/91	16/09/91	185	92.8295	92.7385	-0.0910	92.6258	0.1127	0.2037	0.0054	0.0020	N/A*
6	CDA122L-13	15/03/91	16/09/91	185	92.8755	92.8030	-0.0725	92.7407	0.0623	0.1348	0.0036	0.0020	N/A*
7	CDA122L-23	15/03/91	16/09/91	185	92.9583	92.7632	-0.1951	92.6994	0.0638	0.2589	0.0069	0.0023	N/A*
1	CDA122L-39	16/09/91	16/03/92	182	92.6836	92.3981	-0.2855	92.1297	0.2684	0.5539	0.0149	0.0041	0.0051
2	CDA122L-40	16/09/91	16/03/92	182	92.8765	92.7462	-0.1303	92.5539	0.1923	0.3226	0.0087	0.0038	0.0046
3	CDA122L-41	16/09/91	16/03/92	182	92.8048	92.6362	-0.1686	92.4064	0.2298	0.3984	0.0107	0.0043	0.0051
4	CDA122L-36	16/09/91	16/03/92	182	92.7359	92.6195	-0.1164	92.5128	0.1067	0.2231	0.0060	0.0036	0.0038
5	DA122L--3	16/09/91	16/03/92	182	92.9664	92.8551	-0.1113	92.7310	0.1241	0.2354	0.0064	0.0038	0.0043
6	CDA122L-37	16/09/91	16/03/92	182	92.9955	92.4510	-0.5445	92.9124	-0.4614	0.0831	0.0022	0.0030	0.0036
7	CDA122L-42	16/09/91	16/03/92	182	92.8149	92.6850	-0.1299	92.6268	0.0582	0.1881	0.0051	0.0038	0.0046

* No values for maximum pitting depths provided by Kennedy/Jenks.

Copper Coupons
Summary of Laboratory Data Sheets
As Prepared by
Kennedy/Jenks Consultants, San Francisco
Analysis in Accordance with ASTM D 2688-83, Method C.

| | | Date | | | | | | | Scale & | Coupo | Weight | Pitting | |
Loop No.	Insert No.	In- serted	Re- moved	otal Days	Initial Wt, g	Removed Wt, g	Gain/ Loss, g	Cleaned Wt, g	Corr Pro Wt, g	Weight Loss, g	Loss Rate mm/yr	Depth, mm Avg	Max
						Nine Months							
1	CDA122L-15	15/03/91	18/12/91	278	92.9164	92.5628	-0.3536	92.1996	0.3632	0.7168	0.0127	0.0038	N/A*
2	DA122L-16	15/03/91	18/12/91	278	92.8928	92.7276	-0.1652	92.4201	0.3075	0.4727	0.0083	0.0033	N/A*
3	CDA122L-18	15/03/91	18/12/91	278	92.8527	92.6563	-0.1964	92.3376	0.3187	0.5151	0.0091	0.0033	N/A*
4	CDA122L-17	15/03/91	18/12/91	278	92.8987	92.8236	-0.0751	92.5577	0.2659	0.3410	0.0060	0.0023	N/A*
5	CDA122L-19	15/03/91	18/12/91	278	92.8053	92.6367	-0.1686	92.4739	0.1628	0.3314	0.0059	0.0028	N/A*
6	CDA122L-07	15/03/91	18/12/91	278	93.0408	92.9290	-0.1118	92.8407	0.0883	0.2001	0.0035	0.0023	N/A*
7	CDA122L-14	15/03/91	18/12/91	278	92.9803	92.8701	-0.1102	92.7710	0.0991	0.2093	0.0037	0.0023	N/A*
1	CDA122L-31	17/06/91	16/03/92	273	92.9076	92.5351	-0.3725	92.1618	0.3733	0.7458	0.0134	0.0038	0.0051
2	CDA122L-30	17/06/91	16/03/92	273	92.9082	92.7158	-0.1924	92.4903	0.2255	0.4179	0.0075	0.0038	0.0051
3	CDA122L-33	17/06/91	16/03/92	273	92.8300	92.6713	-0.1587	92.4229	0.2484	0.4071	0.0073	0.0038	0.0051
4	CDA122L-32	17/06/91	16/03/92	273	92.8903	92.8307	-0.0596	92.6276	0.2031	0.2627	0.0047	0.0053	0.0071
5	CDA122L-34	17/06/91	16/03/92	273	92.8521	92.7353	-0.1168	92.5649	0.1704	0.2872	0.0052	0.0041	0.0051
6	CDA122L-29	17/06/91	16/03/92	273	92.8949	92.8030	-0.0919	92.7276	0.0754	0.1673	0.0030	0.0046	0.0053
7	CDA122L-35	17/06/91	16/03/92	273	92.7999	92.7380	-0.0619	92.6460	0.0920	0.1539	0.0028	0.0041	0.0051
						Twelve Months							
1	CDA122L-22	15/03/91	16/03/92	367	92.8276	92.4328	-0.3948	92.0004	0.4324	0.8272	0.0111	0.0152	0.0203
2	CDA122L-24	15/03/91	16/03/92	367	92.9164	92.7461	-0.1703	92.3788	0.3673	0.5376	0.0072	0.0089	0.0122
3	CDA122L-25	15/03/91	16/03/92	367	92.8755	92.7175	-0.1580	92.3174	0.4001	0.5581	0.0075	0.0079	0.0104
4	CDA122L-27	15/03/91	16/03/92	367	92.8480	92.7600	-0.0880	92.5010	0.2590	0.3470	0.0046	0.0064	0.0086
5	CDA122L-28	15/03/91	16/03/92	367	92.7092	92.5843	-0.1249	92.3760	0.2083	0.3332	0.0045	0.0043	0.0051
6	CDA122L-26	15/03/91	16/03/92	367	92.8444	92.7542	-0.0902	92.6687	0.0855	0.1757	0.0024	0.0041	0.0051
7	CDA122L-20	15/03/91	16/03/92	367	92.9216	92.8507	-0.0709	92.7378	0.1129	0.1838	0.0025	0.0038	0.0051

* No values for maximum pitting depths provided by Kennedy/Jenks.

Cast Iron Coupons
Summary of Laboratory Data Sheets
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Analysis in Accordance with ASTM D 2688-83, Method C.

Loop No.	Insert No.	Date In-serted	Date Re-moved	Total Days	Initial Wt, g	Removed Wt, g	Gain/ Loss, g	Cleaned Wt, g	Scale & Corr Pro Wt, g	Coupon Weight Loss, g	Weight Loss Rate mm/yr	Pitting Depth, mm Avg	Pitting Depth, mm Max
Three Months													
1	CI-01	15/03/91	17/06/91	94	237.50	238.70	1.20	232.53	6.17	4.97	0.314	0.079	0.117
2	CL-02	15/03/91	17/06/91	94	232.30	230.23	-2.07	229.37	0.86	2.93	0.185	0.020	0.030
3	CI-05	15/03/91	17/06/91	94	233.40	231.34	-2.06	230.29	1.05	3.11	0.196	0.019	0.030
4	CI-03	15/03/91	17/06/91	94	231.80	232.45	0.65	228.54	3.91	3.26	0.206	0.046	0.069
5	CI-04	15/03/91	17/06/91	94	232.00	230.74	-1.26	228.66	2.08	3.34	0.211	0.074	0.091
6	CI-06	15/03/91	17/06/91	94	234.60	234.15	-0.45	230.76	3.39	3.84	0.242	0.033	0.048
7	CI-07	15/03/91	17/06/91	94	232.30	230.57	-1.73	229.23	1.34	3.07	0.194	0.033	0.048
1	CI-43	18/12/91	16/03/92	89	233.80	234.42	0.62	230.02	4.40	3.78	0.252	0.064	0.094
2	CI-44	19/12/91	17/03/92	89	235.30	234.57	-0.73	231.57	3.00	3.73	0.249	0.053	0.071
3	CI-45	20/12/91	18/03/92	89	234.80	232.80	-2.00	232.00	0.80	2.80	0.187	0.056	0.074
4	CI-46	21/12/91	19/03/92	89	232.70	233.17	0.47	229.30	3.87	3.40	0.227	0.107	0.130
5	CI-47	22/12/91	20/03/92	89	231.00	231.42	0.42	228.19	3.23	2.81	0.187	0.079	0.097
6	CI-48	23/12/91	21/03/92	89	232.40	232.03	-0.37	228.91	3.12	3.49	0.233	0.064	0.089
7	CI-49	24/12/91	22/03/92	89	234.40	233.37	-1.03	231.99	1.38	2.41	0.161	0.058	0.066
Six Months													
1	CI-08	15/03/91	16/09/91	185	234.00	236.12	2.12	226.06	10.06	7.94	0.255	0.093	*N/A
2	CI-09	15/03/91	16/09/91	185	230.60	229.40	-1.20	224.92	4.48	5.68	0.182	0.093	*N/A
3	CI-10	15/03/91	16/09/91	185	231.90	229.40	-2.50	224.92	4.48	6.98	0.224	0.094	*N/A
4	CI-11	15/03/91	16/09/91	185	231.80	234.61	2.81	225.17	9.44	6.63	0.213	0.088	*N/A
5	CI-12	15/03/91	16/09/91	185	231.50	232.82	1.32	227.40	5.42	4.10	0.131	0.080	*N/A
6	CI-25	15/03/91	16/09/91	185	233.70	235.58	1.88	226.67	8.91	7.03	0.225	0.096	*N/A
7	CI-13	15/03/91	16/09/91	185	232.00	229.34	-2.66	224.56	4.78	7.44	0.239	0.091	*N/A
1	CI-36	16/09/91	16/03/92	182	235.20	237.10	1.90	229.59	7.51	5.61	0.183	0.071	0.079
2	CI-37	16/09/91	16/03/92	182	234.60	236.28	1.68	227.87	8.41	6.73	0.219	0.084	0.109
3	CI-39	16/09/91	16/03/92	182	232.50	233.34	0.84	226.46	6.88	6.04	0.197	0.071	0.086
4	CI-40	16/09/91	16/03/92	182	232.70	235.94	3.24	226.41	9.53	6.29	0.205	0.079	0.099
5	CI-38	16/09/91	16/03/92	182	232.80	234.48	1.68	226.24	8.24	6.56	0.214	0.071	0.084
6	CI-41	16/09/91	16/03/92	182	234.40	235.97	1.57	228.56	7.41	5.84	0.190	0.079	0.099
7	CI-42	16/09/91	16/03/92	182	234.10	236.24	2.14	228.84	7.40	5.26	0.171	0.058	0.079

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Cast Iron Coupons
Summary of Laboratory Data Sheets
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Analysis in Accordance with ASTM D 2688-83, Method C.

Loop No.	Insert No.	Date In-serted	Date Re-moved	Total Days	Initial Wt, g	Removed Wt, g	Gain/ Loss, g	Cleaned Wt, g	Scale & Corr Pro Wt, g	Coupo Weight Loss, g	Weight Loss Rate mm/yr	Pitting Depth, mm Avg	Pitting Depth, mm Max
Nine Months													
1	CI-15	15/03/91	18/12/91	278	233.30	237.83	4.53	222.82	15.01	10.48	0.224	0.150	*N/A
2	CI-16	15/03/91	18/12/91	278	231.90	235.01	3.11	223.45	11.56	8.45	0.180	0.089	*N/A
3	CI-17	15/03/91	18/12/91	278	234.10	238.40	4.30	226.37	12.03	7.73	0.165	0.114	*N/A
4	CI-18	15/03/91	18/12/91	278	234.00	238.23	4.23	226.67	11.56	7.33	0.156	0.097	*N/A
5	CI-19	15/03/91	18/12/91	278	235.10	240.14	5.04	225.34	14.80	9.76	0.208	0.122	*N/A
6	CI-20	15/03/91	18/12/91	278	232.80	237.41	4.61	224.85	12.56	7.95	0.170	0.094	*N/A
7	CI-14	15/03/91	18/12/91	278	234.10	239.30	5.20	226.22	13.08	7.88	0.168	0.124	*N/A
1	CI-29	17/06/91	16/03/92	273	234.60	237.58	2.98	226.27	11.31	8.33	0.181	0.104	0.168
2	CI-30	17/06/91	16/03/92	273	232.70	236.34	3.64	223.90	12.44	8.80	0.191	0.081	0.097
3	CI-32	17/06/91	16/03/92	273	232.70	236.59	3.89	224.96	11.63	7.74	0.168	0.079	0.104
4	CI-31	17/06/91	16/03/92	273	235.50	239.54	4.04	228.16	11.38	7.34	0.159	0.061	0.079
5	CI-33	17/06/91	16/03/92	273	232.90	236.56	3.66	224.04	12.52	8.86	0.192	0.053	0.074
6	CI-34	17/06/91	16/03/92	273	232.10	235.73	3.63	224.51	11.22	7.59	0.165	0.076	0.109
7	CI-35	17/06/91	16/03/92	273	232.50	236.57	4.07	224.65	11.92	7.85	0.171	0.084	0.104
Twelve Months													
1	CI-22	15/03/91	16/03/92	367	234.00	240.84	6.84	222.80	18.04	11.20	0.181	0.097	0.114
2	CI-23	15/03/91	16/03/92	367	232.60	239.09	6.49	220.67	18.42	11.93	0.193	0.124	0.183
3	CI-24	15/03/91	16/03/92	367	233.10	239.56	6.46	222.77	16.79	10.33	0.167	0.091	0.119
4	CI-27	15/03/91	16/03/92	367	234.80	240.65	5.85	226.45	14.20	8.35	0.135	0.168	0.196
5	CI-26	15/03/91	16/03/92	367	232.60	240.67	8.07	220.89	19.78	11.71	0.189	0.150	0.193
6	CI-28	15/03/91	16/03/92	367	232.60	239.48	6.88	223.30	16.18	9.30	0.150	0.137	0.201
7	CI-21	15/03/91	16/03/92	367	235.60	243.25	7.65	225.75	17.50	9.85	0.159	0.147	0.165

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Cast Iron Coupons
Summary of Laboratory Data Sheets
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Analysis in Accordance with ASTM D 2688-83, Method C.

Three Months					
		Date			**Scale**
Loop No.	**Insert No.**	**In-serted**	**Re-moved**	**Total Days**	**Thickness, mm**
1	CI-01	15/03/91	17/06/91	94	0.51
2	CL-02	15/03/91	17/06/91	94	0.76
3	CI-05	15/03/91	17/06/91	94	1.02
4	CI-03	15/03/91	17/06/91	94	0.76
5	CI-04	15/03/91	17/06/91	94	1.27
6	CI-06	15/03/91	17/06/91	94	0.51
7	CI-07	15/03/91	17/06/91	94	1.02
1	CI-43	18/12/91	16/03/92	89	0.51
2	CI-44	19/12/91	17/03/92	89	0.25
3	CI-45	20/12/91	18/03/92	89	0.25
4	CI-46	21/12/91	19/03/92	89	0.76
5	CI-47	22/12/91	20/03/92	89	0.51
6	CI-48	23/12/91	21/03/92	89	0.51
7	CI-49	24/12/91	22/03/92	89	1.02
Six Months					
1	CI-08	15/03/91	16/09/91	185	0.76
2	CI-09	15/03/91	16/09/91	185	1.27
3	CI-10	15/03/91	16/09/91	185	1.27
4	CI-11	15/03/91	16/09/91	185	1.52
5	CI-12	15/03/91	16/09/91	185	1.02
6	CI-25	15/03/91	16/09/91	185	1.02
7	CI-13	15/03/91	16/09/91	185	0.76
1	CI-36	16/09/91	16/03/92	182	1.27
2	CI-37	16/09/91	16/03/92	182	1.27
3	CI-39	16/09/91	16/03/92	182	1.27
4	CI-40	16/09/91	16/03/92	182	1.91
5	CI-38	16/09/91	16/03/92	182	1.02
6	CI-41	16/09/91	16/03/92	182	1.52
7	CI-42	16/09/91	16/03/92	182	5.08

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Summary of Laboratory Data Sheets
As Prepared by
Kennedy/Jenks Consultants, San Francisco
Analysis in Accordance with ASTM D 2688-83, Method C.

Nine Months					
Loop No.	Insert No.	Date		Total Days	Scale Thickness, mm
		In- serted	Re- moved		
1	CI-15	15/03/91	18/12/91	278	1.27
2	CI-16	15/03/91	18/12/91	278	2.03
3	CI-17	15/03/91	18/12/91	278	1.52
4	CI-18	15/03/91	18/12/91	278	2.03
5	CI-19	15/03/91	18/12/91	278	1.52
6	CI-20	15/03/91	18/12/91	278	1.27
7	CI-14	15/03/91	18/12/91	278	2.03
1	CI-29	17/06/91	16/03/92	273	1.02
2	CI-30	17/06/91	16/03/92	273	2.03
3	CI-32	17/06/91	16/03/92	273	1.52
4	CI-31	17/06/91	16/03/92	273	1.52
5	CI-33	17/06/91	16/03/92	273	2.29
6	CI-34	17/06/91	16/03/92	273	2.03
7	CI-35	17/06/91	16/03/92	273	2.54
Twelve Months					
1	CI-22	15/03/91	16/03/92	367	1.52
2	CI-23	15/03/91	16/03/92	367	3.81
3	CI-24	15/03/91	16/03/92	367	2.03
4	CI-27	15/03/91	16/03/92	367	2.03
5	CI-26	15/03/91	16/03/92	367	3.05
6	CI-28	15/03/91	16/03/92	367	2.54
7	CI-21	15/03/91	16/03/92	367	3.56

Copper Corrosometer Probe Data (Installed 29 Apr 91)

Date	Days Since Installed	Loop 1		Loop 2		Loop 3		Loop 4	
		Check Reading	Dial Reading	Check Reading	Dial Reading	Check Reading	Dial Reading	Check Reading	Dial Reading
08/05/91	9	798.5	156.0	808.0	179.5	800.0	126.0	798.0	150.0
21/05/91	22	799.5	187.5	809.0	226.0	801.5	174.0	799.0	167.5
28/05/91	29	798.0	197.5	808.5	242.5	800.5	195.0	798.5	174.5
04/06/91	36	799.5	212.5	808.0	261.0	800.5	215.5	798.0	183.0
12/06/91	44	796.5	219.0	805.5	272.0	797.5	217.5	794.5	172.0
19/06/91	51	797.0	208.0	807.0	257.5	799.0	191.5	796.0	149.5
26/06/91	58	798.0	253.0	808.5	301.5	799.0	221.5	797.0	188.5
03/07/91	65	798.5	267.5	806.5	316.5	799.5	229.5	796.5	199.0
10/07/91	72	796.0	266.0	805.0	327.0	798.5	231.5	795.5	200.5
17/07/91	79	798.0	273.5	808.0	346.0	799.5	240.0	797.5	214.0
24/07/91	86	797.5	268.0	806.5	348.0	799.0	236.5	796.0	207.5
31/07/91	93	798.0	272.0	808.0	359.0	799.0	240.0	797.0	209.0
07/08/91	100	797.0	270.5	807.0	368.5	799.5	241.5	796.0	211.0
14/08/91	107	797.5	269.0	806.5	372.5	798.5	239.5	796.0	210.0
21/08/91	114	797.0	273.5	806.0	382.5	797.5	244.5	796.0	214.0
28/08/91	121	798.0	280.5	808.0	395.5	800.0	250.5	798.0	220.0
04/09/91	128	799.0	284.0	809.5	406.0	801.5	255.0	799.0	223.5
11/09/91	135	798.5	280.5	808.0	411.0	801.0	252.0	797.5	225.5
18/09/91	142	799.0	286.5	808.0	417.5	799.5	257.0	797.5	229.0
01/10/91	155	798.0	275.0	807.0	424.0	799.0	248.5	797.0	222.0
09/10/91	163	798.5	291.0	808.5	429.5	799.5	263.0	797.5	238.0
16/10/91	170	798.5	292.0	808.0	434.5	800.0	264.0	799.0	234.5
23/10/91	177	800.0	310.0			802.0	274.0	799.0	245.5
30/10/91	184	801.0	322.0	810.5	455.0	802.0	275.0	800.0	246.5
06/11/91	191	801.0	332.5	812.0	469.0	803.0	284.0	801.5	253.0
12/11/91	197	803.0	332.5	811.5	462.5	804.0	282.0	801.5	251.5
20/11/91	205	802.5	338.5	813.0	459.0	804.0	289.0	802.5	256.5
27/11/91	212	803.5	338.5	812.5	462.0	804.0	288.5	801.5	258.0
04/12/91	219	802.5	341.5	813.0	460.0	804.0	288.0	801.5	255.0
11/12/91	226	803.5	343.0	813.0	461.0	804.0	291.0	801.5	257.0
18/12/91	233	804.0	348.0	812.5	465.0	805.0	292.0	802.0	261.0
30/12/91	245	803.5	354.0	813.0	463.5	805.0	302.0	802.0	261.0
06/01/92	252	804.0	362.0	813.0	469.5	805.5	314.0	803.0	266.0
13/01/92	259	804.0	363.0	813.0	470.0	805.0	319.0	803.5	266.0
20/01/92	266	803.5	363.0	813.0	469.0	804.0	319.0	803.0	263.0
27/01/92	273	804.0	369.0	813.0	475.0	805.5	327.0	803.5	270.0
04/02/92	281	803.5	366.5	812.0	470.0	804.5	319.5	802.0	259.5
14/02/92	291	804.0	371.0	813.0	472.0	805.5	323.0	802.5	266.0
19/02/92	296	804.0	369.5	812.5	470.0	805.5	320.0	802.5	265.5
24/02/92	301	803.5	369.0	813.0	472.0	805.0	322.5	802.0	265.5
03/03/92	309	804.0	374.0	812.0	474.0	804.0	326.0	801.0	263.0
10/03/92	316	802.0	359.0	809.5	463.0	802.0	312.5	800.0	244.0

Copper Corrosometer Probe Data (Installed 29 Apr 91)

Date	Days Since Installed	Loop 5		Loop 6		Loop 7	
		Check Reading	Dial Reading	Check Reading	Dial Reading	Check Reading	Dial Reading
08/05/91	9	802.0	156.5	795.5	163.0	802.0	147.0
21/05/91	22	803.0	179.0	796.0	172.0	803.5	152.0
28/05/91	29	802.0	190.5	796.0	169.0	802.0	150.0
04/06/91	36	802.5	198.0	795.5	170.0	803.0	151.5
12/06/91	44	799.0	195.5	792.5	151.0	800.0	103.0
19/06/91	51	800.5	168.5	793.5	123.5	800.5	103.0
26/06/91	58	800.5	212.5	794.0	162.0	801.5	145.0
03/07/91	65	800.0	219.0	794.0	168.0	801.5	150.0
10/07/91	72	798.5	223.5	792.5	167.0	800.0	142.0
17/07/91	79	800.0	240.0	795.0	177.0	802.0	153.0
24/07/91	86	799.0	240.0	793.0	172.0	800.5	143.5
31/07/91	93	798.0	246.5	793.5	173.5	801.0	149.5
07/08/91	100	798.5	251.0	793.0	177.0	801.5	146.5
14/08/91	107	798.5	252.0	793.0	176.0	801.5	144.0
21/08/91	114	797.0	258.0	793.0	179.0	801.5	146.0
28/08/91	121	800.0	266.5	794.5	185.0	803.0	151.5
04/09/91	128	799.0	274.5	795.5	188.5	803.0	159.0
11/09/91	135	800.0	280.0	794.5	187.0	802.5	158.5
18/09/91	142	798.5	274.5	795.0	187.5	802.0	158.5
01/10/91	155	797.0	288.0	794.0	171.5	801.5	144.5
09/10/91	163	797.0	310.5	795.0	188.5	802.5	168.0
16/10/91	170	797.5	315.0	795.0	183.0	802.5	172.0
23/10/91	177	799.0	330.0	795.5	196.0	804.0	178.5
30/10/91	184	799.5	337.0	797.5	196.0	805.0	190.0
06/11/91	191	800.5	347.5	798.5	203.5	806.5	197.0
12/11/91	197	801.5	347.0	798.5	199.5	806.0	199.5
20/11/91	205	802.0	360.0	799.0	204.0	807	207.0
27/11/91	212	802.0	361.0	799.5	203.5	807.0	207.0
04/12/91	219	802.5	360.5	799.0	199.5	805.5	208.5
11/12/91	226	801.5	366.0	800.0	201.5	807.0	217.0
18/12/91	233	802.0	361.0	799.5	209.0	807.5	213.5
30/12/91	245	803.0	364.0	800.0	205.0	808.0	218.5
06/01/92	252	803.5	372.0	800.0	211.5	807.5	223.0
13/01/92	259	804.0	374.0	801.0	214.0	808.0	220.5
20/01/92	266	803.5	374.5	800.0	209.0	808.0	226.5
27/01/92	273	804.5	380.5	801.0	214.0	808.0	229.5
04/02/92	281	802.0	375.0	800.0	204.0	806.0	221.0
14/02/92	291	804.5	383.0	800.0	212.0	807.5	226.0
19/02/92	296	803.5	382.5	799.5	204.5	807.5	226.0
24/02/92	301	803.0	383.5	800.0	210.0	808.0	226.0
03/03/92	309	802.0	383.5	799.0	207.0	806.5	221.0
10/03/92	316	800.0	366.0	797.0	188.0	804.0	211.5

Copper Corrosometer Probe Data (Installed 29 Apr 91)

Corrosion Rates, mm/yr							
	Initial	Middle	Latter	3 Months	6 Months	9 Months	10 Months
Loop 1	0.0146	0.0019	0.0033	0.0117	0.0090	0.0072	0.0067
Loop 2	0.0177	0.0131	0.0008	0.0193	0.0147	0.0099	0.0091
Loop 3	0.0307	0.0035	0.0008	0.0118	0.0080	0.0066	0.0062
Loop 4	0.0113	0.0038	0.0008	0.0062	0.0052	0.0037	0.0035
Loop 5	0.0126	0.0089	0.0023	0.0096	0.0097	0.0074	0.0070
Loop 6	0.0004	0.0004	0.0001	0.0014	0.0021	0.0014	0.0014
Loop 7	0.0007	0.0072	0.0006	0.0003	0.0025	0.0025	0.0023

Mild Steel Corrosometer Probe Data (Installed 29 Apr 91)

Date	Days Since Installed	Loop 1 Check Reading	Loop 1 Dial Reading	Loop 2 Check Reading	Loop 2 Dial Reading	Loop 3 Check Reading	Loop 3 Dial Reading	Loop 4 Check Reading	Loop 4 Dial Reading
08/05/91	9	814.0	50.0	815.0	65.0	797.0	44.0	800.0	41.5
21/05/91	22	814.0	99.5	815.0	113.0	797.0	91.0	801.0	86.5
28/05/91	29	814.0	125.5	815.0	137.0	797.0	118.0	800.5	109.0
04/06/91	36	814.0	150.0	815.0	161.5	797.0	144.0	800.5	131.5
12/06/91	44	812.0	175.5	813.0	191.0	795.0	174.0	795.0	174.5
19/06/91	51	812.0	192.0	813.0	209.0	795.0	187.0	799.0	169.0
26/06/91	58	814.0	230.0	814.0	247.5	796.5	229.5	800.0	205.5
03/07/91	65	813.5	260.0	814.5	279.5	796.5	261.5	800.5	238.5
10/07/91	72	813.0	288.5	813.5	313.5	796.0	294.5	799.5	254.5
17/07/91	79	813.5	318.0	814.5	347.0	796.5	330.0	800.0	279.5
24/07/91	86	813.5	347.5	814.0	381.5	796.5	369.0	800.5	304.0
31/07/91	93	813.5	380.5	814.0	419.5	796.5	412.0	800.5	329.0
07/08/91	100	813.5	414.5	814.5	458.0	796.5	457.0	800.0	351.5
14/08/91	107	813.5	438.0	814.5	485.0	796.0	495.0	799.5	366.5
21/08/91	114	812.5	475.5	814.0	518.0	796.5	540.0	798.0	387.0
28/08/91	121	814.0	511.0	815.0	554.0	796.5	592.5	798.5	409.0
04/09/91	128	814.5	542.5	815.0	584.5	797.0	639.5	798.5	428.5
11/09/91	135	814.0	580.0	815.0	620.5	796.5	697.0	797.5	449.0
18/09/91	142	813.5	624.0	814.5	659.5	796.5	762.0	795.0	472.0
01/10/91	155	814.5	715.0	815.5	743.0	795.5	950.5	792.5	519.5
09/10/91	163	814.5	782.5	815.5	784.5			791.0	544.0
16/10/91	170	814.0	839.0	815.5	828.0			788.0	568.0
23/10/91	177	815.5	915.5	815.5	879.5			786.5	598.5
30/10/91	184			815.5	930.5			783.5	619.5
06/11/91	191			816.5	990.0			780.0	645.5
12/11/91	197							779.0	665.5
20/11/91	205							776.5	694.0
27/11/91	212							771.0	717.5
04/12/91	219							767.5	745.5
11/12/91	226							764.5	772.0
18/12/91	233							756.5	803.5
30/12/91	245							741.0	857.0
06/01/92	252							730.5	897.0
13/01/92	259							715.5	938.0
20/01/92	266							701.0	986.5

Mild Steel Corrosometer Probe Data (Installed 29 Apr 91)

Date	Days Since Installed	Loop 5		Loop 6		Loop 7	
		Check Reading	Dial Reading	Check Reading	Dial Reading	Check Reading	Dial Reading
08/05/91	9	797.5	59.5	806.0	52.5	792.5	38.0
21/05/91	22	797.5	111.0	807.0	74.5	792.5	71.5
28/05/91	29	797.5	136.0	806.5	84.5	792.5	85.0
04/06/91	36	797.5	162.5	807.0	93.5	792.5	102.0
12/06/91	44	796.0	192.0	804.0	102.0	791.0	95.0
19/06/91	51	795.0	210.0	804.0	102.0	790.0	119.0
26/06/91	58	797.0	256.0	806.5	126.5	792.0	153.5
03/07/91	65	797.0	291.0	806.5	138.5	792.0	172.0
10/07/91	72	796.0	325.0	805.5	152.5	791.5	189.5
17/07/91	79	797.5	357.5	806.5	166.0	792.5	205.0
24/07/91	86	797.0	390.5	806.5	180.5	792.5	218.5
31/07/91	93	797.0	424.0	806.0	195.5	792.5	234.0
07/08/91	100	796.0	460.5	806.0	210.0	792.0	250.0
14/08/91	107	796.5	489.0	806.5	220.0	792.0	262.5
21/08/91	114	797.0	523.0	805.5	240.5	791.0	280.5
28/08/91	121	797.0	559.0	806.5	259.0	792.0	297.5
04/09/91	128	797.0	591.0	806.5	277.5	792.0	314.5
11/09/91	135	797.0	630.0	807.0	300.0	791.5	334.5
18/09/91	142	797.5	674.0	806.5	322.0	790.5	355.0
01/10/91	155	796.5	789.0	807.0	371.0	786.5	389.0
09/10/91	163	796.5	882.5	806.5	399.0	786.0	430.5
16/10/91	170			806.5	428.5	782.0	459.5
23/10/91	177			807.5	471.0	779.5	496.0
30/10/91	184			807.5	504.5	775.0	524.5
06/11/91	191			807.5	543.0	773.5	557.5
12/11/91	197			808.0	574.5	770.0	584.5
20/11/91	205			808.0	627.0	767.5	625.5
27/11/91	212			808.5	681.5	764.5	665.5
04/12/91	219			808.0	771.0	763.5	710.0
11/12/91	226			808.5	918.0	763.0	765.0
18/12/91	233					762.0	835.0
30/12/91	245					761.5	889.5
06/01/92	252						
13/01/92	259						
20/01/92	266						

Mild Steel Corrosometer Probe Data (Installed 29 Apr 91)

Corrosion Rates, mmpy					
Loop #	Initial	Later	3 Months	6 Months	9 Months
1	0.3582	0.4927	0.3713	0.4001	
2	0.3179	0.4575	0.4004	0.4144	
3	0.3510	0.5099	0.4208	0.4379	
4	0.3158	0.3187	0.3158	0.3077	0.3121
5	0.3413	0.4503	0.4085	0.4198	
6	0.1585	0.2999	0.1605	0.2165	
7	0.2210	0.4112	0.2160	0.2646	0.2866

Faucet Copper Levels, mg/L

Copper levels for raw running water samples were measured on 14/02/91, 18/02/91, 20/02/91, and 28/02/91. Levels in all cases were 0.04 mg/L or less.

Copper levels below were measured after a 24 hour standing period.

Faucets - Pre-treatment								
Date		Loop Number						
		1	2	3	4	5	6	7
18/02/91		0.49	0.43	0.13	0.33	0.23	0.25	0.28
20/02/91		0.40	0.27	0.27	0.27	0.31	0.25	0.21
27/02/91		0.40	0.37	0.06	0.28	0.22	0.23	0.18
Averages		**0.43**	**0.36**	**0.15**	**0.29**	**0.25**	**0.24**	**0.22**

Faucets - Treated								
Date	Days From Start	Loop Number						
		1	2	3	4	5	6	7
27/03/91	11	0.40	0.07	0.10	0.06	0.04	0.03	0.05
05/04/91	20	0.37	0.35	0.07	0.12	0.08	0.05	0.07
10/04/91	25	0.41	0.10	0.23	0.03	0.05	0.05	0.06
10/05/91	55	0.37	0.18	0.16	0.06	0.10	0.06	0.11
15/05/91	60	0.58	0.07	0.05	0.03	0.04	0.01	0.06
23/05/91	68	0.59	0.00	0.00	0.00	0.00	0.00	0.00
29/05/91	74	0.64	0.08	0.08	0.04	0.06	0.03	0.07
05/06/91	81	0.39	0.09	0.09	0.06	0.07	0.04	0.11
12/06/91	88	0.26	0.04	0.02	0.00	0.00	0.00	0.00
25/06/91	101	0.26	0.09	0.08	0.06	0.08	0.05	0.08
10/07/91	116	0.29	0.09	0.05	0.05	0.04	0.03	0.06
24/07/91	130	0.36	0.13	0.09	0.06	0.11	0.07	0.09
10/08/91	147	0.37	0.04	0.04	0.02	0.02	0.00	0.02
20/08/91	157		0.11	0.09	0.08	0.08	0.04	0.06
10/09/91	178	0.35	0.10	0.10	0.08	0.11	0.06	0.07
01/10/91*	200	0.37	0.16	0.14	0.10	0.17	0.11	0.23
22/10/91	220	0.34	0.13	0.12	0.11	0.14	0.07	0.11
05/11/91	234	0.22	0.08	0.08	0.12	0.10	0.02	0.06
20/11/91	249	0.26	0.10	0.10	0.05	0.09	0.07	0.03
04/12/91	263	0.25	0.09	0.07	0.04	0.12	0.03	0.31
18/12/91	277	0.19	0.04	0.06	0.00	0.04	0.08	0.04
15/01/92	305	0.15	0.03	0.06	0.02	0.05	0.09	0.05
19/02/92	340	0.16	0.04	0.04	0.02	0.02	0.01	0.05
12/03/92	362	0.14	0.05	0.05	0.02	0.04	0.02	0.04
Averages		**0.34**	**0.09**	**0.08**	**0.05**	**0.07**	**0.04**	**0.08**

*Beginning 01/10/91, samples were digested prior to metals analysis.

Faucets - Filtered Samples (not digested)								
Date		Loop Number						
		1	2	3	4	5	6	7
01/10/91	199	0.12	0.06	0.07	0.05	0.06	0.04	0.04
22/10/91	220	0.05	0.04	0.03	0.01	0.06	0.03	0.03
05/11/91	234	0.03	0.02	0.03	0.02	0.03	0.01	0.01
20/11/91	249	0.08	0.06	0.04	0.05	0.05	0.06	0.07

Faucet Lead Levels, mg/L

Lead levels for raw water, running samples were measured on 18/02/91, 20/02/91, and 28/02/91. Levels in all loops were 0.001 mg/L or less in all cases.

Lead levels were measured after a 24 hour standing period.

Faucets - Pre-treatment

Date	Loop Number						
	1	2	3	4	5	6	7
18/02/91	0.180	0.180	0.100	0.150	0.120	0.160	0.150
20/02/91	0.140	0.140	0.210	0.160	0.170	0.160	0.100
28/02/91	0.140	0.140	0.100	0.120	0.170	0.150	0.110
04/03/91	0.140	0.140	0.070	0.140	0.170	0.150	0.120
Averages	**0.150**	**0.150**	**0.120**	**0.143**	**0.158**	**0.155**	**0.120**

Faucets - Treated

Date	Days From Start	Loop Number						
		1	2	3	4	5	6	7
26/03/91	10	0.105	0.017	0.020	0.033	0.014	0.014	0.018
05/04/91	20	0.122	0.158	0.014	0.100	0.032	0.015	0.016
11/04/91	26	0.113	0.042	0.040	0.041	0.038	0.037	0.038
24/04/91	39	0.250	0.023	0.014	0.049	0.036	0.014	0.017
09/05/91	54	0.092	0.019	0.011	0.025	0.017	0.000	0.014
14/05/91	59	0.123	0.028	0.019	0.027	0.036	0.013	0.021
22/05/91	67	0.120	0.027	0.013	0.037	0.022	0.011	0.015
28/05/91	73	0.130	0.021	0.018	0.056	0.016	0.010	0.017
04/06/91	80	0.067	0.014	0.011	0.021	0.013	0.000	0.010
11/06/91	87	0.060	0.020	0.016	0.021	0.015	0.000	0.011
26/06/91	102	0.060	0.032	0.025	0.047	0.031	0.011	0.017
09/07/91	115	0.063	0.034	0.025	0.047	0.026	0.017	0.020
23/07/91	129	0.051	0.030	0.018	0.053	0.030	0.011	0.019
07/08/91	144	0.057	0.028	0.018	0.035	0.021	0.010	0.010
20/08/91	157		0.031	0.027	0.044	0.026	0.000	0.000
10/09/91	178	0.044	0.025	0.017	0.029	0.016	0.005	0.005
01/10/91*	200	0.033	0.030	0.023	0.040	0.036	0.015	0.023
23/10/91	221	0.051	0.043	0.029	0.059	0.053	0.025	0.041
05/11/91	234	0.024	0.022	0.014	0.123	0.042	0.014	0.008
19/11/91	248	0.017	0.020	0.015	0.018	0.019	0.012	0.008
03/12/91	262	0.027	0.026	0.021	0.040	0.025	0.004	0.044
17/12/92	642	0.022	0.020	0.021	0.019	0.024	0.011	0.013
14/01/92	304	0.038	0.014	0.015	0.029	0.015	0.009	0.012
18/02/92	339	0.012	0.013	0.008	0.016	0.009	0.006	0.004
12/03/92	362	0.011	0.010	0.007	0.010	0.007	0.004	0.004
Averages		**0.0705**	**0.0299**	**0.0184**	**0.0408**	**0.0248**	**0.0103**	**0.0162**

* Beginning 01/10/91, samples were digested prior to metals analysis.

Faucets - Filtered Samples (not digested)

Date	Loop Number						
	1	2	3	4	5	6	7
01/10/91	0.01	0.017	0.013	0.027	0.018	0.008	0.009
23/10/91	0.011	0.014	0.014	0.024	0.015	0.008	0.011
05/11/91	0.012	0.013	0.014	0.014	0.013	0.007	0.009
19/11/91	0.003	0.007	0.006	0.008	0.006	0.004	0.004

Faucet Zinc Levels, mg/L

Zinc levels for raw running water samples were measured on 14/02/91, 18/02/91, 20/02/91, and 28/02/91. Levels in all cases were 0.03 mg/L or less. Zinc levels below were measured after a 24 hour standing period.

Faucets - Pre-treatment							
	Loop Number						
Date	1	2	3	4	5	6	7
18/02/91	0.46	0.40	0.35	0.40	0.20	0.34	0.35
20/02/91	0.45	0.31	1.10	0.44	0.41	0.39	0.51
27/02/91	0.72	0.45	0.34	0.44	0.40	0.44	0.37
Averages	**0.54**	**0.39**	**0.60**	**0.43**	**0.34**	**0.39**	**0.41**

Faucets - Pre-treatment								
	Days From	Loop Number						
Date	Start	1	2	3	4	5	6	7
27/03/91	11	0.29	0.08	0.08	0.11	0.20	0.47	0.47
05/04/91	20	0.36	0.24	0.06	0.18	0.24	0.50	0.54
10/04/91	25	0.32	0.12	0.12	0.15	0.25	0.50	0.71
10/05/91	55	0.21	0.08	0.01	0.02	0.23	0.48	0.47
15/05/91	60	0.43	0.11	0.09	0.10	0.30	0.45	0.60
23/05/91	68	0.34	0.08	0.04	0.06	0.18	0.38	0.32
29/05/91	74	0.26	0.06	0.03	0.05	0.16	0.32	0.36
05/06/91	81	0.24	0.06	0.03	0.04	0.16	0.38	0.49
12/06/91	88	0.27	0.08	0.02	0.00	0.22	0.49	0.47
25/06/91	101	0.22	0.06	0.05	0.07	0.21	0.46	0.43
10/07/91	116	0.32	0.06	0.04	0.08	0.18	0.36	0.38
24/07/91	130	0.33	0.07	0.05	0.07	0.19	0.40	0.40
10/08/91	147	0.33	0.03	0.03	0.06	0.16	0.39	0.35
20/08/91	157		0.03	0.03	0.09	0.16	0.35	0.37
10/09/91	178	0.25	0.01	0.03	0.15	0.08	0.47	0.45
01/10/91*	200	0.24	0.07	0.06	0.14	0.12	0.51	0.49
22/10/91	220	0.23	0.07	0.06	0.16	0.15	0.70	0.67
05/11/91	234	0.13	0.04	0.04	0.10	0.10	0.40	0.45
20/11/91	249	0.18	0.07	0.08	0.10	0.30	0.52	0.49
04/12/91	263	0.20	0.02	0.03	0.06	0.19	0.44	0.70
18/12/91	277	0.13	0.04	0.03	0.04	0.19	0.52	0.46
15/01/92	305	0.12	0.00	0.03	0.12	0.20	0.47	0.46
19/02/92	340	0.12	0.02	0.02	0.10	0.16	0.42	0.43
12/03/92	362	0.12	0.02	0.02	0.07	0.14	0.40	0.41
Averages		**0.25**	**0.06**	**0.05**	**0.09**	**0.19**	**0.45**	**0.47**

*Beginning 01/10/91, samples were digested prior to metals analysis.

Faucets - Pre-treatment								
		Loop Number						
Date		1	2	3	4	5	6	7
01/10/91	199	0.14	0.01	0.01	0.01	0.04	0.29	0.25
22/10/91	220	0.10	0.03	0.03	0.02	0.04	0.28	0.24
05/11/91	234	0.05	0.00	0.01	0.00	0.02	0.15	0.13
20/11/91	249	0.11	0.04	0.03	0.05	0.11	0.23	0.29

Plumbing Coil Copper Levels, mg/L

Copper levels for raw running water samples were measured on 14/02/91, 18/02/91, 20/02/91, and 28/02/91. Levels in all cases were 0.04 mg/L or less.
Copper levels below were measured after a 24 hour standing period.

Plumbing Coils - Pre-treatment - Average Levels for Two Samples								
		Loop Number						
Date		1	2	3	4	5	6	7
18/02/91		1.32	1.57	1.02	1.65	1.36	1.39	1.34
27/02/91		1.82	1.88	1.81	1.78	1.32	1.54	1.52
Averages		**1.57**	**1.73**	**1.42**	**1.72**	**1.34**	**1.47**	**1.43**

Plumbing Coils - Average Levels for Two Samples								
	Days From	Loop Number						
Date	Start	1	2	3	4	5	6	7
27/03/91	11	1.25	0.35	5.29	1.13	1.33	1.73	1.41
05/04/91	20	0.92	0.86	3.55	2.37	3.04	0.51	0.80
10/04/91	25	1.20	0.44	0.92	0.59	1.17	0.85	2.36
10/05/91	55	1.26	0.69	1.78	1.53	5.63	4.09	11.43
15/05/91	60	1.39	0.45	0.73	0.52	2.43	1.98	2.40
23/05/91	68	1.48	0.41	0.87	0.73	1.01	0.38	0.82
29/05/91	74	1.47	0.45	1.00	0.76	2.39	2.01	2.99
05/06/91	81	1.64	0.47	0.90	0.46	1.82	1.87	2.08
12/06/91	88	1.35	0.52	0.91	0.76	2.04	2.64	4.98
25/06/91	101	1.31	0.95	1.38	0.82	3.39	6.38	10.01
10/07/91	116	1.27	0.55	0.74	0.34	3.33	0.77	5.80
24/07/91	130	1.50	0.68	0.52	0.65	1.64	0.56	1.82
10/08/91	147	1.76	0.57	1.89	0.59	4.63	4.01	8.86
20/08/91	157	1.44	1.35	0.40	0.33	3.33	1.64	2.84
10/09/91	178	1.34	0.87	1.12	1.40	3.98	3.24	2.87
01/10/91*	200	1.24	1.03	1.73	1.07	8.67	5.41	5.81
22/10/91	220	1.35	3.56	2.96	2.12	16.19	8.22	9.18
05/11/91	234	1.15	0.63	0.45	1.08	3.76	1.98	2.62
19/11/91	248	1.29	0.63	4.36	0.41	18.27	3.09	8.10
03/12/91	262	1.06	0.46	0.40	0.31	1.06	0.90	0.31
17/12/91	276	0.90	0.36	0.27	0.24	0.88	0.45	0.24
14/01/92	304	0.97	0.47	0.41	0.33	0.88	0.48	0.53
18/02/92	339	1.07	0.42	0.68	0.62	7.00	0.87	3.13
11/03/92	361	0.89	0.30	0.98	0.26	1.77	1.17	1.07
Averages		**1.27**	**0.73**	**1.42**	**0.81**	**4.15**	**2.30**	**3.85**

*Beginning 01/10/91, samples were digested prior to metals analysis.

Plumbing Coils - Average Levels for Two Samples Filtered Samples (Not Digested)								
		Loop Number						
Date		1	2	3	4	5	6	7
01/10/91	199	0.56	0.29	0.25	0.24	0.31	0.36	0.31
22/10/91	220	0.17	0.30	0.22	0.23	0.25	0.17	0.19
05/11/91	234	0.17	0.10	0.11	0.11	0.10	0.05	0.06
19/11/91	248	0.30	0.16	0.18	0.15	0.19	0.14	0.15

Plumbing Coil Lead Levels, mg/L

Lead levels for raw water, running samples were measured on 18/02/91, 20/02/91, and 28/02/91. Levels in all loops were 0.001 mg/L or less in all cases.

Lead levels were measured after a 24 hour standing period.

Plumbing Coils - Pre-treatment - Average Levels for Two Samples								
Date		Loop Number						
		1	2	3	4	5	6	7
20/02/91		0.025	0.011	0.015	0.010	0.015	0.015	0.016
28/02/91		0.025	0.015	0.017	0.011	0.013	0.018	0.015
04/03/91		0.021	0.013	0.016	0.011	0.011	0.015	0.013
Averages		0.023	0.013	0.016	0.010	0.013	0.016	0.014

Plumbing Coils - Average Levels for Two Samples								
Date	Days From Start	Loop Number						
		1	2	3	4	5	6	7
26/03/91	10	0.019	0.009	0.054	0.033	0.024	0.110	0.076
05/04/91	20	0.014	0.009	0.026	0.031	0.045	0.055	0.053
11/04/91	26	0.018	0.005	0.011	0.008	0.008	0.045	0.051
24/04/91	39	0.014	0.000	0.005	0.018	0.005	0.124	0.028
09/05/91	54	0.007	0.000	0.009	0.026	0.051	0.076	0.253
14/05/91	59	0.006	0.000	0.000	0.000	0.015	0.025	0.039
22/05/91	67	0.014	0.013	0.007	0.016	0.012	0.025	0.035
28/05/91	73	0.005	0.005	0.006	0.014	0.011	0.018	0.069
04/06/91	80	0.005	0.000	0.000	0.006	0.000	0.011	0.019
11/06/91	87	0.000	0.000	0.000	0.014	0.006	0.018	0.043
26/06/91	102	0.015	0.000	0.009	0.015	0.015	0.068	0.205
09/07/91	115	0.016	0.000	0.017	0.012	0.015	0.011	0.216
23/07/91	129	0.000	0.005	0.000	0.029	0.013	0.007	0.046
07/08/91	144	0.019	0.000	0.012	0.023	0.036	0.109	0.153
20/08/91	157	0.014	0.009	0.000	0.016	0.042	0.039	0.058
10/09/91	178	0.009	0.007	0.007	0.016	0.020	0.026	0.080
01/10/91*	200	0.011	0.011	0.018	0.032	0.041	0.032	0.332
23/10/91	221	0.005	0.019	0.031	0.032	0.058	0.256	0.218
05/11/91	234	0.010	0.011	0.052	0.028	0.024	0.081	0.218
19/11/91	248	0.005	0.002	0.192	0.002	0.068	0.055	0.523
03/12/91	262	0.005	0.005	0.032	0.006	0.017	0.027	0.141
17/12/91	276	0.005	0.006	0.028	0.009	0.008	0.020	0.035
14/01/92	304	0.007	0.005	0.023	0.003	0.010	0.028	0.046
18/02/92	339	0.006	0.005	0.037	0.023	0.084	0.053	0.220
12/03/92	362	0.002	0.002	0.092	0.008	0.024	0.028	0.058
Averages		0.009	0.005	0.027	0.017	0.026	0.054	0.128

*Beginning 01/10/91, samples were digested prior to metals analysis.

Plumbing Coils - Average Levels for Two Samples Filtered Samples (Not Digested)								
Date	Days From Start	Loop Number						
		1	2	3	4	5	6	7
01/10/91	199	0.010	0.015	0.007	0.016	0.004	0.012	0.024
23/10/91	221	0.001	0.007	0.009	0.016	0.006	0.004	0.008
05/11/91	234	0.004	0.007	0.023	0.008	0.004	0.003	0.005
19/11/91	248	0.006	0.002	0.005	0.003	0.005	0.003	0.005

Plumbing Coil Zinc Levels, mg/L

Zinc levels for raw running water samples were measured on 14/02/91, 18/02/81, 20/02/91, and 28/02/91. Levels in all cases were 0.03 mg/L or less.
Zinc levels below were measured after a 24 hour standing period.

Plumbing Coils - Pre-treatment - Average Levels for Two Samples								
Date		**1**	**2**	**3**	**4**	**5**	**6**	**7**
				Loop Number				
18/02/91		0.06	0.02	0.05	0.02	0.02	0.02	0.03
27/02/91		0.10	0.09	0.09	0.08	0.08	0.09	0.09
Averages		**0.08**	**0.06**	**0.07**	**0.05**	**0.05**	**0.06**	**0.06**

Plumbing Coils - Average Levels for Two Samples								
Date	**Days From Start**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
27/03/91	11	0.02	0.00	0.00	0.02	0.28	1.22	0.67
05/04/91	20	0.03	0.02	0.01	0.00	0.38	0.35	0.55
10/04/91	25	0.00	0.01	0.01	0.01	0.16	0.47	0.60
10/05/91	55	0.00	0.00	0.00	0.00	0.30	0.87	1.07
15/05/91	60	0.01	0.01	0.01	0.01	0.27	0.62	0.49
23/05/91	68	0.01	0.01	0.01	0.01	0.09	0.18	0.17
29/05/91	74	0.00	0.00	0.00	0.00	0.21	0.64	0.52
05/06/91	81	0.01	0.00	0.00	0.00	0.17	0.78	0.59
12/06/91	88	0.00	0.00	0.00	0.00	0.22	0.77	0.71
25/06/91	101	0.00	0.00	0.00	0.00	0.25	1.18	1.04
10/07/91	116	0.00	0.00	0.00	0.00	0.34	0.45	1.01
24/07/91	130	0.00	0.00	0.00	0.00	0.22	0.48	0.54
10/08/91	147	0.00	0.00	0.00	0.00	0.77	3.11	1.52
20/08/91	157	0.00	0.00	0.00	0.00	0.57	1.54	1.87
10/09/91	178	0.00	0.00	0.00	0.00	0.36	1.51	1.41
01/10/91*	200	0.04	0.04	0.04	0.10	0.38	2.25	2.11
22/10/91	220	0.49	0.01	0.01	0.01	0.46	2.84	1.85
05/11/91	234	0.00	0.00	0.00	0.00	0.13	1.48	1.33
19/11/91	248	0.00	0.00	0.01	0.00	0.91	2.22	2.60
03/12/91	262	0.00	0.00	0.00	0.00	0.15	0.69	0.43
17/12/91	276	0.03	0.03	0.03	0.03	0.19	0.57	0.41
14/01/92	304	0.02	0.02	0.02	0.02	0.20	0.51	0.46
18/02/92	339	0.01	0.01	0.01	0.00	0.90	0.98	1.77
11/03/92	361	0.00	0.00	0.00	0.00	0.25	1.00	0.67
Averages		**0.03**	**0.01**	**0.01**	**0.00**	**0.57**	**0.99**	**1.22**

*Beginning 01/10/91, samples were digested prior to metals analysis.

Plumbing Coils - Average Levels for Two Samples Filtered Samples (Not Digested)								
Date	**Days From Start**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
01/10/91	199	0.00	0.00	0.00	0.00	0.03	0.27	0.41
22/10/91	220	0.05	0.04	0.05	0.05	0.08	0.33	0.35
05/11/91	234	0.00	0.00	0.00	0.00	0.02	0.20	0.23
19/11/91	248	0.03	0.03	0.03	0.02	0.10	0.24	0.35

Solder Coil Copper Levels, mg/L

Copper levels for raw running water samples were measured on 14/02/91, 18/02/91, 20/20/91, and 28/02/91. Levels in all cases were 0.04 mg/L or less. Copper levels below were measured after a 24 hour standing period.

Solder Coils - Pre-treatment								
Date		**Loop Number**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
18/02/91		0.07	0.06	0.13	0.12	0.07	0.06	0.07
20/02/91		0.03	0.01	0.00	0.03	0.00	0.00	0.00
28/02/91		0.06	0.10	0.03	0.06	0.05	0.08	0.05
Averages		**0.05**	**0.06**	**0.05**	**0.07**	**0.04**	**0.05**	**0.04**

Solder Coils - Pre-treatment								
Date	**Days From Start**	**Loop Number**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
27/03/91	11	0.13	0.01	0.09	0.20	0.07	0.19	0.27
05/04/91	20	0.09	0.03	0.08	0.11	0.07	0.17	0.11
10/04/91	25	0.05	0.04	0.05	0.03	0.06	0.08	0.07
10/05/91	55	0.20	0.19	0.37	0.29	0.45	0.30	1.07
15/05/91	60	0.14	0.08	0.02	0.07	0.04	0.03	0.17
23/05/91	68	0.00	0.00	0.00	0.00	0.00	0.00	1.35
29/05/91	74	0.24	0.07	0.10	0.09	0.28	0.12	0.43
05/06/91	81	0.23	0.04	0.09	0.07	0.30	0.23	0.64
12/06/91	88	0.13	0.03	0.04	0.05	0.08	0.06	0.21
25/06/91	101	0.11	0.18	0.19	0.12	0.21	0.17	0.26
10/07/91	116	0.09	0.10	0.12	0.07	0.17	0.14	0.28
24/07/91	130	0.11	0.13	0.12	0.09	0.31	0.26	0.62
10/08/91	147	0.14	0.11	0.11	0.08	0.23	0.15	0.38
20/08/91	157	0.25	0.13	0.16	0.12	0.18	0.19	0.31
10/09/91	178	0.24	0.18	0.33	0.18	2.28	2.75	0.59
01/10/91*	200	0.26	0.21	0.21	0.17	0.42	0.42	0.24
22/10/91	220	0.22	0.28	0.11	0.08	0.31	0.41	0.23
05/11/91	234	0.12	0.13	0.08	0.17	0.43	0.24	0.18
19/11/91	248	0.13	0.16	0.15	0.11	0.35	0.26	0.30
03/12/91	262	0.09	0.00	0.03	0.01	0.06	0.05	0.00
17/12/91	276	0.06	0.03	0.00	0.00	0.02	0.05	0.27
14/01/92	304	0.08	0.02	0.03	0.01	0.10	0.08	0.06
18/02/92	339	0.08	0.10	0.05	0.05	0.11	0.05	0.32
11/03/92	361	0.09	0.04	0.02	0.03	0.07	0.02	1.59
Averages		**0.14**	**0.10**	**0.11**	**0.09**	**0.28**	**0.27**	**0.41**

*Beginning 01/10/91, samples were digested prior to metals analysis.

Solder Coils - Pre-treatment								
Date	**Days From Start**	**Loop Number**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
01/10/91	199	0.04	0.02	0.02	0.04	0.05	0.04	0.01
22/10/91	220	0.01	0.03	0.02	0.00	0.00	0.01	0.01
05/11/91	234	0.03	0.02	0.02	0.02	0.01	0.01	0.02
19/11/91	248	0.06	0.07	0.05	0.07	0.08	0.04	0.04

Solder Coil Lead Levels, mg/L

Lead levels for raw water, running samples were measured on 18/02/91, 20/02/91, and 28/02/91. Levels in all loops were 0.001 mg/L or less in all cases. Lead levels were measured after a 24 hour standing period.

Solder Coils - Pre-treatment								
		Loop Number						
Date		1	2	3	4	5	6	7
18/02/91		2.070	2.070	2.950	2.490	2.620	2.530	2.540
20/02/91		2.630	2.270	2.590	2.290	2.200	2.460	2.500
28/02/91		2.080	2.080	2.350	1.880	1.620	2.260	2.790
04/03/91		1.850	2.250	2.470	1.640	1.620	2.000	2.800
Averages		**2.158**	**2.168**	**2.590**	**2.075**	**2.015**	**2.313**	**2.658**

Solder Coils - Treated								
	Days From	Loop Number						
Date	Start	1	2	3	4	5	6	7
26/03/91	10	1.770	1.730	3.715	7.500	3.180	3.815	9.23
05/04/91	20	1.115	1.680	2.125	6.290	2.630	3.095	6.29
11/04/91	26	1.100	2.010	2.635	3.727	1.855	3.930	3.66
24/04/91	39	3.650	4.010	3.990	9.620	5.020	3.850	5.64
09/05/91	54	1.530	2.740	4.170	14.480	5.320	3.570	7.37
14/05/91	59	1.100	3.040	0.960	7.240	1.990	1.280	5.75
22/05/91	67	1.840	3.270	1.750	8.890	2.200	1.400	4.42
28/05/91	73	1.480	3.710	5.870	11.480	5.765	1.530	4.82
04/06/91	80	1.310	3.920	6.160	10.500	3.850	0.960	6.31
11/06/91	87	2.130	6.690	4.640	14.600	6.720	1.520	11.90
26/06/91	102	1.210	7.120	8.020	22.200	8.790	3.660	14.50
09/07/91	115	1.120	9.960	3.950	16.200	14.920	7.890	17.22
23/07/91	129	1.390	8.060	4.600	14.540	6.570	7.830	17.44
07/08/91	144	1.250	6.280	4.600	15.440	9.990	2.290	15.520
20/08/91	157	1.810	4.620	5.440	6.020	4.630	3.940	16.200
10/09/91	178	2.910	9.940	17.250	14.650	12.480	5.820	15.590
01/10/91*	200	1.200	11.200	14.700	43.000	15.100	6.100	10.700
23/10/91	221	2.700	9.600	6.100	5.300	5.300	3.700	17.000
05/11/91	234	1.000	11.900	5.100	19.700	6.200	4.300	10.800
19/11/91	248	2.000	26.100	15.300	23.100	13.700	6.600	15.700
03/12/91	262	1.800	7.900	3.000	9.500	2.800	1.300	2.300
17/12/91	276	2.100	15.200	4.700	17.900	4.900	1.800	3.100
14/01/92	304	1.900	10.100	4.200	33.300	6.800	2.100	4.800
18/02/92	339	2.000	10.100	4.000	41.000	6.100	2.300	3.400
11/03/92	361	1.470	7.020	2.240	21.300	3.840	1.460	3.310
Averages		**1.715**	**7.516**	**5.569**	**15.899**	**6.426**	**3.442**	**9.319**

* Beginning 01/10/91, samples were digested prior to metals analysis.

Solder Coils - Filtered Samples (Not Digested)								
	Days From	Loop Number						
Date	Start	1	2	3	4	5	6	7
01/10/91	199	0.100	0.200	0.300	0.600	0.100	0.200	0.300
23/10/91	221	0.200	0.300	0.300	0.400	0.100	0.200	0.300
05/11/91	234	0.100	0.200	0.300	0.500	0.100	0.100	0.200
19/11/91	248	0.150	0.280	0.250	0.280	0.130	0.090	0.190

Solder Coil Zinc Levels, mg/L

Zinc levels for raw running water samples were measured on 14/02/91, 18/02/91, 20/02/91, and 28/02/91. Levels in all cases were 0.03 mg/L or less.
Zinc levels below were measured after a 24 hour standing period.

Solder Coils - Pre-treatment								
Date		**1**	**2**	**3**	**4**	**5**	**6**	**7**
18/02/91		0.00	0.01	0.01	0.02	0.01	0.01	0.01
20/02/91		0.01	0.02	0.02	0.02	0.02	0.03	0.03
28/02/91		0.03	0.04	0.06	0.07	0.08	0.08	0.08
Averages		**0.01**	**0.02**	**0.03**	**0.04**	**0.04**	**0.04**	**0.04**

(Loop Number spans columns 1–7)

Solder Coils - Treated								
Date	Days From Start	**1**	**2**	**3**	**4**	**5**	**6**	**7**
27/03/91	11	0.03	0.01	0.00	0.06	0.33	1.44	1.73
05/04/91	20	0.00	0.02	0.05	0.06	0.27	0.94	0.80
10/04/91	25	0.00	0.00	0.00	0.01	0.19	0.87	0.73
10/05/91	55	0.00	0.00	0.00	0.00	0.32	1.08	0.88
15/05/91	60	0.00	0.02	0.01	0.02	0.22	0.64	0.62
23/05/91	68	0.01	0.03	0.00	0.01	0.09	0.28	0.67
29/05/91	74	0.03	0.04	0.04	0.04	0.34	0.80	0.72
05/06/91	81	0.00	0.00	0.00	0.00	0.24	0.99	0.60
12/06/91	88	0.00	0.00	0.00	0.00	0.33	0.93	0.88
25/06/91	101	0.00	0.01	0.02	0.02	0.56	0.93	0.93
10/07/91	116	0.00	0.00	0.00	0.00	0.49	1.10	1.16
24/07/91	130	0.00	0.00	0.00	0.00	0.19	0.94	0.90
10/08/91	147	0.00	0.00	0.00	0.00	0.85	2.55	1.08
20/08/91	157	0.00	0.00	0.00	0.00	0.51	3.20	2.48
10/09/91	178	0.00	0.00	0.02	0.01	1.11	6.42	3.36
01/10/91*	200	0.06	0.04	0.08	0.05	0.35	1.96	0.93
22/10/91	220	0.00	0.03	0.07	0.04	0.18	1.91	0.98
05/11/91	234	0.01	0.04	0.05	0.08	0.28	2.12	1.11
19/11/91	248	0.57	0.17	0.10	0.10	0.64	3.39	2.23
03/12/91	262	0.17	0.13	0.11	0.13	0.36	1.57	0.58
17/12/91	276	0.03	0.02	0.03	0.04	0.23	0.64	0.70
14/01/92	304	0.01	0.00	0.00	0.01	0.35	1.02	0.83
18/02/92	339	0.00	0.01	0.00	0.01	0.27	0.59	1.05
11/03/92	361	0.01	0.01	0.02	0.01	0.21	0.63	2.16
Averages		**0.04**	**0.02**	**0.03**	**0.03**	**0.37**	**1.54**	**1.17**

*Beginning 01/10/91, samples were digested prior to metals analysis.

Solder Coils - Filtered Samples (Not Digested)								
Date	Days From Start	**1**	**2**	**3**	**4**	**5**	**6**	**7**
01/10/91	199	0.01	0.00	0.00	0.00	0.03	0.39	0.19
22/10/91	220	0.01	0.01	0.02	0.02	0.02	0.22	0.16
05/11/91	234	0.00	0.00	0.00	0.00	0.02	0.22	0.22
19/11/91	248	0.38	0.06	0.05	0.04	0.11	0.23	0.27

Temperature Measurements, Degrees C

| | Days From | Treated Samples | | | | | | | |
| | | Loop Number | | | | | | | |
Date	Start	1	2	3	4	5	6	7	Comment
16/03/91	0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
17/03/91	1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
19/03/91	3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
20/03/91	4	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
21/03/91	5	5.0	5.0	6.0	6.0	6.0	6.0	6.0	
22/03/91	6	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
23/03/91	7	4.0	4.0	4.0	4.0	4.0	4.0	4.5	
28/03/91	12	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
02/04/91	17	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
04/04/91	19	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
08/04/91	23	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
13/04/91	28	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
18/04/91	33	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
23/04/91	38	7.0	7.0	8.0	8.0	8.0	8.0	8.0	
27/04/91	42	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
29/04/91	44	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
06/05/91	51	8.0	8.0	8.0	8.0	9.0	9.0	8.0	
08/05/91	53	8.0	8.0	8.0	8.0	8.0	8.0	8.0	
13/05/91	58	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
17/05/91	62	8.0	8.0	8.0	8.0	8.0	8.0	8.0	
21/05/91	66	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
25/05/91	70	8.0	8.0	8.0	8.0	8.0	8.0	8.0	
27/05/91	72	8.0	8.0	8.0	8.0	8.0	8.0	8.0	
31/05/91	76	8.0	8.0	8.0	8.0	8.0	8.0	8.0	
03/06/91	79	8.0	8.0	8.0	8.0	8.0	8.0	8.0	
06/06/91	82	8.5	8.5	8.5	8.5	8.5	8.5	8.5	
08/06/91	84	8.5	8.5	8.5	8.5	8.5	8.5	8.5	
10/06/91	86	9.0	9.0	9.0	9.0	9.0	9.0	9.0	
14/06/91	90	9.0	9.0	9.0	9.0	9.0	9.0	9.0	
18/06/91	94	9.0	9.0	9.0	9.0	9.0	9.0	9.0	
19/06/91	95	9.0	9.0	9.0	9.0	9.5	9.5	9.0	
21/06/91	97	9.5	9.5	9.5	9.5	9.5	9.5	9.5	
24/06/91	100	9.5	9.5	9.0	9.0	9.0	9.5	9.0	
27/06/91	103	9.0	9.0	9.0	9.5	9.0	9.0	9.0	
02/07/91	108	10.0	10.0	10.0	10.0	10.0	10.0	10.0	
03/07/91	109	10.0	10.0	10.0	10.0	10.0	9.5	9.5	
05/07/91	111	10.0	10.0	10.0	10.0	10.0	10.0	10.0	
08/07/91	114	10.0	10.0	10.0	10.0	10.0	10.0	10.0	
12/07/91	118	11.0	11.0	11.0	11.0	11.0	11.0	11.0	
15/07/91	121	11.0	11.0	11.0	11.0	11.5	11.0	11.0	
17/07/91	123	12.0	11.5	11.5	12.0	11.5	11.5	12.0	
19/07/91	125	11.5	12.0	12.0	12.0	12.0	12.0	12.0	

Temperature Measurements, Degrees C

Date	Days From Start	Loop Number							Comment
		1	2	3	4	5	6	7	
22/07/91	128	12.0	12.0	12.0	12.0	12.0	12.0	12.0	
26/07/91	132	13.0	13.0	13.0	13.0	13.0	13.0	13.0	
29/07/91	135	14.0	14.0	14.0	14.0	14.0	14.0	14.0	
31/07/91	137	15.0	15.0	15.0	15.0	15.0	15.0	15.0	
02/08/91	139	15.5	15.5	15.5	15.5	15.5	15.5	15.5	
06/08/91	143	15.5	16.0	15.5	16.0	16.0	15.5	15.0	
12/08/91	149	14.5	15.0	15.0	15.0	15.0	15.0	15.0	
14/08/91	151	14.5	14.5	14.5	14.5	14.5	14.5	14.5	
15/08/91	152	15.0	15.0	15.0	15.0	15.0	15.0	15.0	
19/08/91	156	14.5	15.0	15.0	15.0	15.0	15.0	15.0	
23/08/91	160	15.0	15.0	15.0	15.0	15.0	15.0	15.0	
26/08/91	163	15.0	15.0	15.0	15.0	15.0	15.0	15.0	
28/08/91	165	15.0	15.0	15.0	15.0	15.0	15.0	15.0	
03/09/91	171	12.0	12.0	12.0	12.5	12.5	12.0	12.0	
04/09/91	172	13.0	13.0	13.0	13.0	13.0	13.0	13.0	
06/09/91	174	13.0	13.0	13.0	13.0	13.0	13.0	13.0	
09/09/91	177	13.5	14.0	14.0	14.0	14.0	14.0	14.0	
13/09/91	181	13.0	13.0	13.0	13.0	13.0	13.0	13.0	
18/09/91	186	15.0	15.0	15.0	15.0	15.0	15.0	15.0	
20/09/91	188	14.0	14.0	14.0	14.0	14.0	14.5	14.5	
27/09/91	195	14.0	15.0	15.0	15.0	14.5	15.0	14.5	
30/09/91	198	15.0	15.0	15.0	15.0	15.0	15.0	15.0	
01/10/91	199	21.5	21.5	21.5	21.5	21.5	21.5	21.5	Solder Coils - 24 hr standing
02/10/91	200	21.0	21.0	21.0	21.0	21.0	21.0	21.0	Plumbing Coils - 24 hr standing
04/10/91	202	14.5	14.5	14.5	14.5	14.5	14.5	14.5	
07/10/91	205	14.0	14.0	14.0	14.0	14.0	14.0	14.0	
09/10/91	207	14.0	14.0	14.0	14.0	13.5	13.5	13.5	
11/10/91	209	14.0	14.0	14.0	14.0	14.0	14.0	14.0	
15/10/91	213	13.0	13.0	13.0	13.0	13.0	13.0	13.0	
16/10/91	214	12.5	12.5	12.5	12.5	12.0	12.5	12.5	
21/10/91	219	11.0	11.5	11.5	11.5	11.5	11.5	11.0	
22/10/91	220	21.0	21.0	21.0	21.0	21.0	21.0	21.0	Solder Coils - 24 hr standing
22/10/91	220	21.5	21.5	21.5	21.5	21.5	21.5	21.5	Plumbing Coils - 24 hr standing
23/10/91	221	15.5	15.5	15.5	15.5	15.5	15.5	15.5	Faucets - 24 hr standing
25/10/91	223	10.0	10.0	10.0	11.5	10.0	10.0	10.0	
28/10/91	226	8.5	8.5	8.5	8.5	8.5	8.5	8.5	
30/10/91	228	7.5	7.5	7.5	7.5	7.5	7.5	7.5	
01/11/91	230	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
04/11/91	233	6.5	6.5	6.5	6.5	6.5	6.5	6.5	
05/11/91	234	16.5	16.5	16.5	16.5	16.5	16.5	16.5	Solder Coils - 24 hr standing
08/11/91	237	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
12/11/91	241	7.0	7.0	7.0	7.0	7.0	7.0	7.0	

Temperature Measurements, Degrees C

	Days From Start	Loop Number							
Date		1	2	3	4	5	6	7	Comment
15/11/91	244	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
18/11/91	247	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
22/11/91	251	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
25/11/91	254	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
27/11/91	256	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
29/11/91	258	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
02/12/91	261	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
06/12/91	265	5.5	6.0	6.0	6.0	6.0	5.5	6.0	
09/12/91	268	5.5	5.5	5.5	5.5	5.5	5.5	5.5	
11/12/91	270	5.0	5.0	5.0	5.0	5.5	5.0	5.0	
13/12/91	272	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
16/12/91	275	4.5	4.5	4.5	4.5	4.5	4.5	4.5	
17/12/91	276	15.5	15.5	15.5	15.0	14.0	13.5	12.5	Solder Coils - 24 hr standing
22/12/91	281	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
30/12/91	289	4.5	4.5	4.5	4.5	4.5	4.5	4.5	
06/01/92	296	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
13/01/92	303	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
14/01/92	304	12.0	12.0	12.0	12.0	12.0	12.0	12.0	Solder Coils - 24 hr standing
14/01/92	304	11.0	11.0	11.0	11.0	11.0	11.0	11.0	Plumbing Coils - 24 hr standing
15/01/92	305	8.0	8.0	8.0	8.0	8.0	8.0	8.0	Faucets - 24 hr standing
20/01/92	310	4.0	4.0	3.5	4.0	4.0	4.0	4.0	
27/01/92	317	4.0	4.0	4.0	4.0	4.0	4.0	4.0	
04/02/92	325	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
17/02/92	338	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
18/02/92	339	16.0	16.0	16.0	16.0	16.0	16.0	16.0	Solder Coils - 24 hr standing
18/02/92	339	16.0	16.0	16.0	16.0	16.0	16.0	16.0	Plumbing Coils - 24 hr standing
24/02/92	345	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
03/03/92	353	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
10/03/92	360	6.0	6.0	6.0	6.0	6.0	6.0	6.0	
11/03/92	361	17.0	17.0	17.0	17.0	17.0	17.0	17.0	Solder Coils - 24 hr standing
11/03/92	361	18.0	18.0	18.0	18.0	18.0	18.0	18.0	Plumbing Coils - 24 hr standing
12/03/92	362	15.0	15.0	15.0	15.0	15.0	15.0	15.0	Faucets - 24 hr standing

Conductivity Measurements, u S/cm

Pre-Treatment									
		Loop Number							
Date		1	2	3	4	5	6	7	Comment
12/02/91		13.7	14.7	13.6	13.4	13.2	13.3	12.6	Plumbing Coils - 8 hr standing
13/02/91		10.4	10.8	10.7	10.8	10.5	10.8	11.1	
13/02/91		15.5	13.7	13.7	14.7	13.2	14.5	14.5	Plumbing Coils - 8 hr standing
18/02/91		11.9	12.4	11.8	11.8	12.1	11.9	11.8	Faucets - 8 hr standing
18/02/91		11.8	11.9	11.5	11.8	11.6	12.1	11.6	Solder Coils - 8 hr standing
27/02/91		14.3	14.1	14.0	13.9	13.6	13.4	13.1	Plumbing Coils - 24 hr standing
27/02/91		11.6	11.2	11.1	11.8	11.1	11.4	11.1	Faucets - 24 hr standing
02/03/91		14.0	14.1	13.6	13.8	13.9	13.7	13.9	Plumbing Coils - 24 hr standing
02/03/91		12.4	12.2	12.3	11.7	11.7	11.9	11.9	Solder Coils - 24 hr standing

Treated Samples									
	Days From Start	Loop Number							
Date		1	2	3	4	5	6	7	Comment
16/03/91	0	12.1	56.3	57.0	74.0	59.3	65.5	55.2	
17/03/91	1	12.2	54.0	55.8	74.7	61.2	69.0	53.4	
19/03/91	3	12.4	54.5	56.6	72.7	57.2	61.2	44.1	
20/03/91	4	12.0	52.5	52.0	70.6	57.1	59.6	42.0	
22/03/91	6	12.8	57.0	55.9	75.5	59.7	62.4	42.5	
23/03/91	7	12.5	57.8	56.7	71.5	60.8	63.0	43.6	
25/03/91	9	15.6	57.6	60.6	79.2	64.7	65.0	42.6	Plumbing Coils - 24 hr standing
26/03/91	10	13.2	57.0	58.4	74.2	58.6	60.8	40.5	Solder Coils - 24 hr standing
27/03/91	11	13.1	56.8	57.3	77.0	59.7	61.5	40.8	Faucets - 24 hr standing
28/03/91	12	13.3	50.4	50.4	72.7	55.1	55.3	37.9	
02/04/91	17	13.7	50.5	51.8	72.8	53.6	55.2	36.7	
03/04/91	18	16.4	56.2	58.0	74.4	56.5	64.4	38.1	Plumbing Coils - 24 hr standing
04/04/91	19	13.1	49.6	49.8	66.2	53.7	55.0	36.2	
05/04/91	20	14.4	49.7	50.7	64.8	50.4	52.5	32.3	Plumbing Coils - 24 hr standing
06/04/91	21	13.8	27.5	22.9	46.8	34.3	34.2	25.9	Faucets - 24 hr standing
08/04/91	23	13.4	46.0	45.7	62.9	49.3	52.3	34.4	
09/04/91	24	16.0	52.0	49.8	66.6	51.3	48.6	31.5	Plumbing Coils - 24 hr standing
10/04/91	25	13.8	51.6	50.8	67.3	49.5	51.5	30.8	Faucets - 24 hr standing
11/04/91	26	13.8	46.8	47.2	62.5	47.8	49.7	30.4	Solder Coils - 24 hr standing
13/04/91	28	13.7	45.5	47.3	64.4	48.5	50.6	33.7	
18/04/91	33	13.5	43.3	43.4	57.1	47.1	49.1	31.5	
23/04/91	38	13.3	45.2	45.5	60.3	45.9	48.5	32.2	
24/04/91	39	16.7	50.6	50.8	61.4	51.8	51.9	32.7	Plumbing Coils - 24 hr standing
25/04/91	40	13.9	46.2	46.9	58.5	47.1	48.2	30.0	Solder Coils - 24 hr standing
26/04/91	41	15.5	48.8	49.4	63.4	49.0	51.5	31.4	Faucets - 24 hr standing
27/04/91	42	13.3	44.5	48.0	62.6	49.2	51.8	32.2	
29/04/91	44	13.1	45.4	45.4	56.5	45.7	47.8	30.4	
06/05/91	51	13.2	45.4	52.5	54.7	45.2	49.6	30.4	

Conductivity Measurements, u S/cm

Pre-Treatment									
		Loop Number							
Date		1	2	3	4	5	6	7	Comment
08/05/91	53	12.8	44.8	43.9	57.2	47.6	49.9	31.1	
09/05/91	54	15.7	50.5	49.6	59.8	55.0	50.0	28.6	Plumbing Coils - 24 hr standing
10/05/91	55	13.1	45.8	46.3	57.0	47.6	45.7	27.5	Solder Coils - 24 hr standing
10/05/91	55	12.3	44.7	44.0	56.8	45.3	47.2	26.4	Faucets - 24 hr standing
13/05/91	58	12.1	42.7	42.7	55.9	43.5	45.4	26.8	
14/05/91	59	13.6	48.3	47.4	60.6	47.7	48.8	28.7	Solder Coils - 24 hr standing
15/05/91	60	16.0	51.6	53.3	65.1	51.2	53.4	33.0	Plumbing Coils - 24 hr standing
15/05/91	60	13.4	47.1	47.7	61.2	47.9	50.2	28.2	Faucets - 24 hr standing
17/05/91	62	13.3	51.1	53.8	65.7	53.2	56.1	35.6	
21/05/91	66	12.9	46.0	45.0	61.0	48.6	53.0	31.8	
22/05/91	67	13.8	52.0	51.1	65.0	52.1	55.1	32.2	Solder Coils - 24 hr standing
23/05/91	68	16.5	55.2	54.2	67.8	55.7	58.1	35.6	Plumbing Coils - 24 hr standing
23/05/91	68	13.9	47.6	47.8	61.6	49.0	51.6	29.3	Faucets - 24 hr standing
25/05/91	70	12.9	48.4	47.1	65.6	52.3	55.8	34.6	
27/05/91	72	12.9	48.8	46.8	61.5	50.1	51.1	32.4	
28/05/91	73	16.6	54.1	54.4	66.5	55.5	50.6	32.3	Plumbing Coils - 24 hr standing
29/05/91	74	13.3	49.8	57.7	63.3	49.1	50.6	30.3	Solder Coils - 24 hr standing
29/05/91	74	13.1	48.6	49.1	64.1	51.5	53.2	29.9	Faucets - 24 hr standing
31/05/91	76	12.9	46.7	46.6	61.2	50.3	53.0	32.8	
03/06/91	79	13.6	48.6	47.3	62.9	50.4	52.9	33.9	
04/06/91	80	15.9	51.9	51.4	64.1	51.8	53.2	29.5	Solder Coils - 24 hr standing
05/06/91	81	17.3	53.7	55.5	66.8	52.1	54.5	32.3	Plumbing Coils - 24 hr standing
05/06/91	81	13.5	47.5	46.2	60.0	46.5	49.7	28.1	Faucets - 24 hr standing
06/06/91	82	13.5	48.5	47.7	65.3	53.9	55.8	32.6	
08/06/91	84	13.6	50.2	49.7	65.9	52.4	55.3	33.4	
10/06/91	86	13.1	46.6	46.8	62.8	50.7	50.2	32.0	
11/06/91	87	13.8	49.3	49.2	60.8	49.5	51.4	30.4	Solder Coils - 24 hr standing
12/06/91	88	16.5	52.5	54.0	64.7	53.4	53.7	33.5	Plumbing Coils - 24 hr standing
12/06/91	88	13.2	46.1	46.0	58.7	47.2	47.9	27.7	Faucets - 24 hr standing
14/06/91	90	13.1	48.7	47.3	62.7	50.8	52.8	30.9	
18/06/91	94	13.2	51.0	48.0	62.7	55.3	55.4	34.3	
19/06/91	95	13.2	51.7	49.5	63.6	54.0	55.4	35.8	
21/06/91	97	13.2	49.8	49.2	64.7	53.4	55.0	42.4	
24/06/91	100	13.0	48.7	48.8	62.3	50.8	51.7	33.0	
25/06/91	101	14.6	50.2	50.8	61.7	50.4	50.9	31.3	Solder Coils - 24 hr standing
26/06/91	102	17.3	54.7	55.6	64.3	54.3	55.1	35.2	Plumbing Coils - 24 hr standing
26/06/91	102	13.1	49.9	48.9	61.8	49.3	50.8	30.1	Faucets - 24 hr standing
27/06/91	103	13.2	50.7	50.1	65.7	52.5	54.8	33.7	
02/07/91	108	13.0	49.8	46.8	60.6	48.6	52.5	32.9	
03/07/91	109	13.0	47.4	48.1	60.1	50.6	51.8	33.6	
05/07/91	111	13.0	48.8	51.8	62.4	50.0	51.4	36.0	
08/07/91	114	12.9	50.1	50.9	63.7	50.3	51.1	29.8	
09/07/91	115	13.8	50.2	51.2	90.9	50.4	50.8	31.2	Solder Coils - 24 hr standing

Conductivity Measurements, u S/cm

Date		Loop Number							Comment
		1	2	3	4	5	6	7	
10/07/91	116	17.0	55.1	56.4	64.8	50.1	55.2	35.6	Plumbing Coils - 24 hr standing
10/07/91	116	13.0	49.0	47.8	58.2	48.5	50.4	30.6	Faucets - 24 hr standing
12/07/91	118	13.3	48.8	48.7	62.2	50.5	54.3	34.4	
15/07/91	121	12.9	49.4	49.4	62.0	50.7	52.2	35.5	
17/07/91	123	13.0	49.6	49.5	61.7	51.5	53.4	34.6	
19/07/91	125	12.8	51.6	52.8	63.7	53.3	55.7	36.0	
22/07/91	128	12.9	48.6	48.5	59.1	46.9	51.7	34.0	
23/07/91	129	13.7	50.1	49.9	59.7	54.0	60.8	32.1	Solder Coils - 24 hr standing
24/07/91	130	17.1	54.0	58.2	61.0	62.3	80.8	39.5	Plumbing Coils - 24 hr standing
24/07/91	130	13.5	49.5	49.2	59.7	51.8	52.4	31.9	Faucets - 24 hr standing
26/07/91	132	13.1	50.2	51.8	62.5	53.2	53.8	33.5	
29/07/91	135	13.2	48.2	49.3	60.2	51.4	51.3	35.5	
31/07/91	137	13.3	48.1	48.8	59.6	51.3	52.2	31.9	
02/08/91	139	13.2	48.1	47.4	57.7	50.8	52.5	32.7	
06/08/91	143	13.4	50.2	49.9	61.1	52.9	53.9	35.9	
07/08/91	144	13.8	51.3	50.8	58.9	51.9	54.5	32.8	Solder Coils - 24 hr standing
08/08/91	145	17.5	55.0	56.8	63.7	57.0	58.7	37.7	Plumbing Coils - 24 hr standing
08/08/91	145	14.0	50.1	49.0	58.4	51.7	54.9	33.6	Faucets - 24 hr standing
12/08/91	149	14.9	49.4	50.0	58.2	53.2	55.5	35.1	
14/08/91	151	17.7	50.3	50.3	60.9	55.5	55.2	34.8	
15/08/91	152	14.4	50.5	50.8	60.5	54.3	56.5	35.4	
19/08/91	156	14.7	30.5	30.7	40.3	31.8	33.6	32.7	
20/08/91	157	14.9	32.5	32.1	39.7	32.5	34.5	33.1	Solder Coils - 24 hr standing
21/08/91	158	17.7	35.5	35.6	43.4	37.1	40.0	38.2	Plumbing Coils - 24 hr standing
21/08/91	158		48.5	47.4	54.2	47.7	50.9	34.8	Faucets - 24 hr standing
23/08/91	160	13.9	50.4	47.8	62.4	51.3	53.0	32.7	
26/08/91	163	14.0	48.1	47.8	61.1	50.8	52.6	33.3	
28/08/91	165	13.5	45.2	47.3	56.4	49.5	51.2	32.7	
03/09/91	171	9.4	40.7	40.8	52.6	41.6	39.1	26.0	
04/09/91	172	9.6	40.6	42.4	51.5	41.6	40.6	28.6	
06/09/91	174	9.4	41.2	41.9	50.2	43.5	47.3	29.0	
09/09/91	177	10.1	41.9	42.4	52.2	42.2	47.8	30.6	
10/09/91	178	12.7	53.2	53.3	62.6	53.1	54.4	35.2	Solder Coils - 24 hr standing
11/09/91	179	15.1	57.4	59.7	66.6	57.3	58.6	39.9	Plumbing Coils - 24 hr standing
11/09/91	179	13.4	52.1	52.3	64.6	52.6	54.6	34.1	Faucets - 24 hr standing
13/09/91	181	13.3	51.7	52.1	66.1	53.3	56.7	40.8	
16/09/91	184	13.3	56.5	56.2	69.4	56.8	59.4	35.7	
18/09/91	186	13.4	55.2	56.4	67.5	57.5	64.6	45.3	
20/09/91	188	14.0	53.2	54.2	66.9	55.0	58.5	41.1	
27/09/91	195	14.4	54.9	56.6	70.1	70.0	60.0	35.4	
30/09/91	198	15.3	54.5	53.7	68.4	55.5	59.8	46.5	
01/10/91	199	15.4	56.0	56.9	67.2	56.1	57.0	36.8	Solder Coils - 24 hr standing
02/10/91	200	26.2	64.0	65.3	74.0	65.2	65.4	40.7	Plumbing Coils - 24 hr standing

Conductivity Measurements, u S/cm

Pre-Treatment									
		Loop Number							
Date		1	2	3	4	5	6	7	Comment
02/10/91	200	14.9	55.0	56.7	67.4	57.2	59.7	36.9	Faucets - 24 hr standing
04/10/91	202	15.4	56.9	59.7	71.3	59.9	64.3	44.2	
07/10/91	205	15.7	57.5	56.9	70.5	58.2	63.5	40.0	
09/10/91	207	15.7	55.7	56.3	68.8	55.7	61.2	48.1	
11/10/91	209	15.7	55.2	55.8	68.2	58.5	62.3	42.8	
15/10/91	213	15.5	57.2	57.0	70.1	59.2	62.6	45.6	
16/10/91	214	16.3	58.0	59.2	70.8	61.7	63.1	43.5	
21/10/91	219	17.3	59.8	60.6	75.0	65.6	72.3	44.2	
22/10/91	220	15.9	66.1	62.5	71.4	62.7	63.5	40.1	Solder Coils - 24 hr standing
22/10/91	220	19.6	68.8	68.5	77.4	67.3	67.6	44.3	Plumbing Coils - 24 hr standing
23/10/91	221	15.4	54.6	55.8	66.7	59.4	60.7	35.3	Faucets - 24 hr standing
25/10/91	223	15.0	51.1	51.3	62.6	50.3	52.7	40.3	
28/10/91	226	14.8	52.5	53.4	63.6	55.7	55.6	46.3	
30/10/91	228	14.8	50.5	51.7	62.9	52.8	55.8	40.5	
01/11/91	230	14.8	49.8	50.5	61.5	51.7	54.2	38.3	
04/11/91	233	14.8	48.7	50.5	61.9	52.7	53.6	42.0	
05/11/91	234	15.0	49.7	50.9	58.7	51.2	52.2	36.0	Solder Coils - 24 hr standing
05/11/91	234	16.8	54.4	55.5	62.0	55.1	56.5	39.7	Plumbing Coils - 24 hr standing
06/11/91	235	15.7	47.7	49.5	58.7	48.6	51.4	35.0	Faucets - 24 hr standing
08/11/91	237	15.3	50.8	50.9	62.9	53.0	55.4	42.1	
12/11/91	241	14.5	47.7	49.1	59.2	50.0	52.7	36.8	
15/11/91	244	14.4	50.1	50.0	62.3	50.6	52.8	36.6	
18/11/91	247	13.7	48.6	49.2	60.6	50.7	52.3	35.3	
19/11/91	248	14.1	50.3	50.4	58.6	50.5	52.9	33.3	Solder Coils - 24 hr standing
19/11/91	248	15.4	53.4	55.5	62.7	54.6	56.6	36.1	Plumbing Coils - 24 hr standing
20/11/91	249	13.1	47.3	48.0	56.8	48.0	50.1	30.0	Faucets - 24 hr standing
22/11/91	251	12.4	46.9	47.9	59.0	49.6	51.5	34.5	
25/11/91	254	12.2	46.9	47.6	58.6	49.3	51.6	33.4	
27/11/91	256	11.8	46.9	46.7	58.1	50.4	53.3	33.7	
29/11/91	258	16.0	59.2	58.8	69.8	59.7	61.4	45.1	
02/12/91	261	13.6	53.9	55.0	67.2	55.7	57.1	38.6	
03/12/91	262	14.1	54.9	56.2	65.2	55.6	59.2	35.7	Solder Coils - 24 hr standing
03/12/91	262	16.4	60.4	62.4	70.1	60.8	62.4	40.4	Plumbing Coils - 24 hr standing
04/12/91	263	13.8	51.6	52.2	61.8	52.4	54.4	35.0	Faucets - 24 hr standing
06/12/91	265	14.3	56.1	57.6	69.5	57.8	60.4	38.7	
09/12/91	268	13.6	53.9	54.8	67.9	56.8	58.1	39.9	
11/12/91	270	14.0	53.6	53.8	66.3	56.4	58.1	40.0	
13/12/91	272	13.1	52.8	53.0	65.6	55.3	56.7	38.1	
16/12/91	275	14.0	53.2	52.0	65.2	55.2	57.7	34.3	
17/12/91	276	13.9	54.9	54.6	64.0	55.1	61.6	34.5	Solder Coils - 24 hr standing
17/12/91	276	16.1	59.6	60.3	69.2	60.2	67.4	38.3	Plumbing Coils - 24 hr standing
18/12/91	277	13.3	49.0	54.0	61.3	49.9	51.9	32.4	Faucets - 24 hr standing
22/12/91	281	13.3	51.2	53.2	63.3	53.7	57.1	41.7	

Conductivity Measurements, u S/cm

Pre-Treatment									
		Loop Number							
Date		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Comment**
30/12/91	289	13.7	50.3	52.4	62.9	50.2	56.8	37.7	
06/01/92	296	14.1	52.9	53.1	65.5	54.1	55.4	37.8	
13/01/92	303	14.9	54.0	53.4	66.7	56.3	58.4	39.0	
14/01/92	**304**	**13.7**	**54.1**	**54.7**	**63.8**	**54.9**	**58.9**	**39.8**	Solder Coils - 24 hr standing
14/01/92	**304**	**15.7**	**59.0**	**61.0**	**68.6**	**59.5**	**61.4**	**39.4**	Plumbing Coils - 24 hr standing
15/01/92	**305**	**13.3**	**54.1**	**54.8**	**65.4**	**54.9**	**57.5**	**35.6**	Faucets - 24 hr standing
20/01/92	310	14.3	57.4	58.3	70.6	59.9	62.2	43.1	
27/01/92	317	13.6	55.6	56.5	69.4	59.7	59.4	42.4	
04/02/92	325	11.7	49.9	52.5	63.7	51.9	52.5	34.9	
17/02/92	338	11.4	52.8	53.3	65.8	53.5	57.1	39.5	
18/02/92	**339**	**11.1**	**54.4**	**53.8**	**63.9**	**53.8**	**55.1**	**32.7**	Solder Coils - 24 hr standing
18/02/92	**339**	**13.1**	**58.0**	**60.0**	**69.0**	**59.0**	**60.2**	**37.7**	Plumbing Coils - 24 hr standing
19/02/92	**340**	**11.3**	**51.2**	**51.6**	**65.1**	**51.7**	**53.9**	**33.0**	Faucets - 24 hr standing
24/02/92	345	11.7	51.9	52.8	66.2	52.0	57.0	40.1	
03/03/92	353	13.0	52.7	53.8	65.7	55.0	56.1	35.7	
10/03/92	360	17.3	55.4	55.5	68.0	59.1	60.9	45.4	
11/03/92	**361**	**12.9**	**55.4**	**57.9**	**69.6**	**57.3**	**59.7**	**39.3**	Solder Coils - 24 hr standing
11/03/92	**361**	**15.7**	**61.1**	**64.6**	**73.7**	**62.8**	**63.5**	**43.1**	Plumbing Coils - 24 hr standing
12/03/92	**362**	**13.0**	**57.1**	**48.2**	**70.7**	**61.0**	**44.0**	**38.6**	Faucets - 24 hr standing

Average Conductivities, uS/cm

	Loop Number						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Non Standing	13.5	50.5	50.9	63.9	53.0	55.3	37.0
Std Deviation	1.4	4.2	4.3	5.3	4.9	5.2	5.4
P Coil - 24 Hr	16.7	55.9	57.2	67.4	56.9	58.9	36.8
Std Deviation	2.3	4.5	4.9	5.1	4.9	7.2	4.1
S Coil - 24 Hr	13.9	52.1	52.6	64.4	52.5	54.6	33.5
Std Deviation	1.0	4.4	4.2	7.2	3.9	4.9	3.8
Faucet - 24 Hr	13.0	50.2	50.2	62.5	51.3	52.6	32.5
Std Deviation	2.9	3.3	3.5	5.0	4.3	4.1	3.6

* On 06/04/91, and 19-21/08/91 the circuit breaker feeding NaHCO3, V939, and TPC 223 was thrown which accounts for the low conductivities in some loops on those dates.

pH Measurements

Pre-treatment									
		Loop Number							
Date		1	2	3	4	5	6	7	Comment
12/02/91		6.47	6.57	6.50	6.46	6.50	6.48	6.45	Plumbing Coils - 8 hr standing
13/02/91		6.22	6.32	6.23	6.27	6.25	6.25	6.35	
13/02/91		6.33	6.34	6.28	6.33	6.40	6.50	6.50	Plumbing Coils - 8 hr standing
18/02/91		6.06	6.20	6.19	6.12	6.08	6.07	6.07	Faucets - 8 hr standing
18/02/91		6.16	6.19	6.07	6.10	6.07	6.08	6.05	Solder Coils - 8 hr standing
27/02/91		6.38	6.50	6.44	6.40	6.37	6.27	6.23	Plumbing Coils - 24 hr standing
27/02/91		6.02	6.03	6.03	5.95	6.02	5.99	6.00	Faucets - 24 hr standing
02/03/91		6.68	6.69	6.77	6.81	6.71	6.82	6.74	Plumbing Coils - 24 hr standing
02/03/91		6.49	6.53	6.50	6.46	6.48	6.45	6.41	Solder Coils - 24 hr standing

pH Measurements - Treated Samples

Treated Samples									
	Days From	Loop Number							
Date	Start	1	2	3	4	5	6	7	Comment
16/03/91	0	6.43	7.89	7.96	7.72	7.96	8.22	7.74	
17/03/91	1	6.45	7.93	7.80	8.13	7.74	7.89	7.58	
19/03/91	3	6.53	8.04	8.07	7.96	8.08	8.51	8.16	
20/03/91	4	6.39	8.06	7.92	7.98	8.06	8.24	7.58	
21/03/91	5	6.46	8.00	7.97	7.93	8.08	8.09	7.58	
22/03/91	6	6.54	7.95	7.89	8.03	7.96	8.00	7.51	
23/03/91	7	6.52	8.40	8.02	9.37	8.45	8.52	8.00	
25/03/91	9	6.78	8.04	8.11	8.58	8.10	8.01	7.49	Plumbing Coils - 24 hr standing
26/03/91	10	6.58	8.01	8.01	8.55	8.06	7.95	7.44	Solder Coils - 24 hr standing
27/03/91	11	6.47	7.97	8.05	8.05	7.96	7.95	7.39	Faucets - 24 hr standing
28/03/91	12	6.54	7.95	8.05	7.45	8.30	8.30	7.55	
02/04/91	17	6.67	8.33	8.40	7.76	8.36	8.40	7.73	
03/04/91	18	6.84	7.72	7.77	8.00	7.94	7.75	7.21	Plumbing Coils - 24 hr standing
04/04/91	19	6.54	8.01	8.15	8.03	8.47	8.16	7.54	
05/04/91	20	6.64	8.00	7.95	8.42	7.90	7.78	7.32	Plumbing Coils - 24 hr standing
06/04/91	21	6.60	7.34	7.17	8.03	7.43	7.50	7.22	Faucets - 24 hr standing
08/04/91	23	6.59	7.83	7.92	7.67	7.90	8.01	7.49	
09/04/91	24	6.74	7.83	7.88	8.28	7.78	7.68	7.28	Plumbing Coils - 24 hr standing
10/04/91	25	6.49	7.78	7.81	8.11	7.59	7.59	7.17	Faucets - 24 hr standing
11/04/91	26	6.60	7.77	7.77	8.22	7.65	7.61	7.22	Solder Coils - 24 hr standing
13/04/91	28	6.56	7.83	7.93	7.62	8.05	8.00	7.52	
18/04/91	33	6.51	7.77	7.80	7.76	8.08	8.11	7.49	
23/04/91	38	6.57	7.95	7.85	7.89	7.78	7.95	7.44	
24/04/91	39	6.74	7.81	7.80	8.08	7.77	7.70	7.19	Plumbing Coils - 24 hr standing
25/04/91	40	6.59	7.69	7.60	8.12	7.58	7.55	7.09	Solder Coils - 24 hr standing
26/04/91	41	6.38	7.68	7.79	8.33	7.65	7.65	7.20	Faucets - 24 hr standing
27/04/91	42	6.52	7.72	7.88	7.84	7.90	7.92	7.43	

pH Measurements - Treated Samples

Date	Days From Start	Loop Number							Comment
		1	**2**	**3**	**4**	**5**	**6**	**7**	
29/04/91	44	6.58	8.10	7.86	7.99	7.80	7.80	7.38	
06/05/91	51	6.65	8.33	8.96	9.23	7.97	8.43	7.87	
08/05/91	53	6.52	8.04	7.82	9.30	8.11	7.97	7.42	
09/05/91	**54**	**6.73**	**7.85**	**7.62**	**8.27**	**7.81**	**7.71**	**7.25**	**Plumbing Coils - 24 hr standing**
10/05/91	**55**	**6.75**	**7.69**	**7.69**	**9.05**	**7.62**	**7.55**	**7.03**	**Solder Coils - 24 hr standing**
10/05/91	**55**	**6.61**	**7.60**	**7.55**	**8.45**	**7.56**	**7.55**	**7.03**	**Faucets - 24 hr standing**
13/05/91	58	6.52	7.88	7.76	7.85	7.75	7.77	7.24	
14/05/91	**59**	**6.56**	**7.67**	**7.66**	**8.32**	**7.58**	**7.51**	**7.02**	**Solder Coils - 24 hr standing**
15/05/91	**60**	**6.75**	**7.72**	**7.61**	**8.03**	**7.55**	**7.61**	**7.09**	**Plumbing Coils - 24 hr standing**
15/05/91	**60**	**6.55**	**7.60**	**7.54**	**8.13**	**7.54**	**7.58**	**7.07**	**Faucets - 24 hr standing**
17/05/91	62	6.54	8.18	8.43	8.14	8.22	8.25	7.57	
21/05/91	66	6.48	7.80	7.60	7.61	7.85	8.06	7.48	
22/05/91	**67**	**6.62**	**7.84**	**7.73**	**8.55**	**7.71**	**7.76**	**7.21**	**Solder Coils - 24 hr standing**
23/05/91	**68**	**6.81**	**7.79**	**7.62**	**8.24**	**7.76**	**7.91**	**7.36**	**Plumbing Coils - 24 hr standing**
23/05/91	**68**	**6.41**	**7.58**	**7.50**	**8.23**	**7.55**	**7.64**	**7.16**	**Faucets - 24 hr standing**
25/05/91	70	6.56	7.90	7.70	7.91	8.08	8.12	7.53	
27/05/91	72	6.50	7.98	7.70	7.90	7.99	7.93	7.40	
28/05/91	**73**	**6.78**	**7.79**	**7.68**	**8.24**	**7.73**	**7.67**	**7.23**	**Plumbing Coils - 24 hr standing**
29/05/91	**74**	**6.52**	**7.83**	**6.64**	**8.45**	**7.64**	**7.63**	**7.17**	**Solder Coils - 24 hr standing**
29/05/91	**74**	**6.47**	**7.65**	**7.65**	**8.28**	**7.67**	**7.68**	**7.15**	**Faucets - 24 hr standing**
31/05/91	76	6.50	8.05	7.76	7.99	8.09	8.21	7.40	
03/06/91	79	6.51	7.89	7.64	7.65	7.93	7.86	7.13	
04/06/91	**80**	**6.63**	**7.80**	**7.62**	**8.44**	**7.66**	**7.63**	**7.00**	**Solder Coils - 24 hr standing**
05/06/91	**81**	**6.76**	**7.74**	**7.62**	**8.17**	**7.66**	**7.66**	**7.08**	**Plumbing Coils - 24 hr standing**
05/06/91	**81**	**6.39**	**7.52**	**7.46**	**8.17**	**7.51**	**7.57**	**7.02**	**Faucets - 24 hr standing**
06/06/91	82	6.52	7.79	7.61	7.92	8.04	7.96	7.35	
08/06/91	84	6.49	7.87	7.68	7.63	8.04	7.97	7.32	
10/06/91	86	6.49	7.63	7.52	7.66	7.82	7.74	7.31	
11/06/91	**87**	**6.50**	**7.68**	**7.53**	**8.27**	**7.54**	**7.51**	**7.16**	**Solder Coils - 24 hr standing**
12/06/91	**88**	**6.74**	**7.66**	**7.58**	**8.13**	**7.61**	**7.59**	**7.18**	**Plumbing Coils - 24 hr standing**
12/06/91	**88**	**6.35**	**7.42**	**7.34**	**8.02**	**7.35**	**7.41**	**6.94**	**Faucets - 24 hr standing**
14/06/91	90	6.46	7.88	7.60	7.88	7.84	7.85	7.22	
18/06/91	94	6.45	8.28	7.63	7.79	8.62	8.39	7.47	
19/06/91	95	6.50	8.05	7.69	8.34	8.21	7.90	7.44	
21/06/91	97	6.46	7.71	7.57	7.98	7.82	7.71	7.67	
24/06/91	100	6.51	7.87	7.71	8.16	7.79	7.68	7.27	
25/06/91	**101**	**6.61**	**7.68**	**7.65**	**8.53**	**7.53**	**7.50**	**7.13**	**Solder Coils - 24 hr standing**
26/06/91	**102**	**6.74**	**7.73**	**7.62**	**8.47**	**7.62**	**7.57**	**7.16**	**Plumbing Coils - 24 hr standing**
26/06/91	**102**	**6.43**	**7.67**	**7.55**	**8.42**	**7.52**	**7.47**	**7.08**	**Faucets - 24 hr standing**
27/06/91	103	6.54	7.86	7.70	7.94	7.80	7.75	7.35	
02/07/91	108	6.50	7.75	7.53	8.01	7.66	7.66	7.25	
03/07/91	109	6.52	7.59	7.61	7.90	7.59	7.55	7.26	
05/07/91	111	6.50	7.97	7.96	7.95	7.82	7.72	7.51	

pH Measurements - Treated Samples

Date	Days From Start	Loop Number							Comment
		1	**2**	**3**	**4**	**5**	**6**	**7**	
08/07/91	114	6.52	7.88	7.84	7.74	7.68	7.62	7.10	
09/07/91	115	6.58	7.76	7.69	8.48	7.56	7.46	7.13	Solder Coils - 24 hr standing
10/07/91	116	6.68	7.78	7.64	8.34	7.63	7.55	7.17	Plumbing Coils - 24 hr standing
10/07/91	116	6.32	7.76	7.58	8.46	7.62	7.56	7.15	Faucets - 24 hr standing
12/07/91	118	6.44	7.90	7.98	7.86	7.85	7.97	7.42	
15/07/91	121	6.49	8.03	7.92	8.11	7.84	7.71	7.44	
17/07/91	123	6.46	7.94	7.85	8.07	7.80	7.77	7.38	
19/07/91	125	6.43	8.06	8.16	8.22	8.07	8.03	7.45	
22/07/91	128	6.42	7.65	7.70	8.09	7.33	7.53	7.14	
23/07/91	129	6.50	7.60	7.51	8.50	7.49	7.57	7.01	Solder Coils - 24 hr standing
24/07/91	130	6.68	7.61	7.53	8.41	7.50	7.69	7.13	Plumbing Coils - 24 hr standing
24/07/91	130	6.40	7.59	7.52	8.35	7.71	7.63	7.11	Faucets - 24 hr standing
26/07/91	132	6.70	7.96	7.85	8.05	7.85	7.71	7.23	
29/07/91	135	6.52	8.01	8.03	8.23	8.06	7.73	7.35	
31/07/91	137	6.52	8.00	7.96	8.27	8.32	7.95	7.35	
02/08/91	139	6.54	7.83	7.84	7.88	8.18	8.02	7.33	
06/08/91	143	6.44	7.98	7.93	7.92	8.22	7.94	7.34	
07/08/91	144	6.50	7.85	7.71	8.48	7.83	7.87	7.25	Solder Coils - 24 hr standing
08/08/91	145	6.69	7.71	7.56	8.22	7.75	7.83	7.18	Plumbing Coils - 24 hr standing
08/08/91	145	6.35	7.82	7.58	8.33	7.89	8.20	7.31	Faucets - 24 hr standing
12/08/91	149	6.48	8.05	8.03	7.67	8.45	8.47	7.58	
14/08/91	151	6.48	7.99	7.84	7.63	8.55	8.14	7.52	
15/08/91	152	6.49	8.20	8.11	8.26	8.39	8.35	7.81	
19/08/91	156	6.51	7.76	7.84	8.13	7.63	7.86	7.51	
20/08/91	157	6.51	7.70	7.49	8.70	7.51	7.79	7.52	Solder Coils - 24 hr standing
21/08/91	158	6.69	7.61	7.32	8.43	7.54	7.78	7.51	Plumbing Coils - 24 hr standing
21/08/91	158		7.90	7.76	8.68	7.69	8.01	7.40	Faucets - 24 hr standing
23/08/91	160	6.48	8.34	8.02	8.63	7.99	8.27	7.52	
26/08/91	163	6.46	8.04	8.14	8.47	8.03	7.94	7.49	
28/08/91	165	6.52	7.70	7.82	8.16	7.87	8.01	7.42	
03/09/91	171	6.26	7.96	7.89	7.56	8.04	7.46	8.00	
04/09/91	172	6.34	8.03	8.18	8.05	7.89	7.31	7.39	
06/09/91	174	6.27	7.88	8.31	7.75	8.41	8.66	7.58	
09/09/91	177	6.37	8.46	8.44	8.58	8.16	8.76	7.80	
10/09/91	178	6.38	8.15	7.85	8.79	7.74	7.64	7.38	Solder Coils - 24 hr standing
11/09/91	179	6.79	7.96	7.81	8.60	7.83	7.68	7.48	Plumbing Coils - 24 hr standing
11/09/91	179	6.28	7.77	7.67	8.63	7.71	7.53	7.32	Faucets - 24 hr standing
13/09/91	181	6.29	7.81	7.85	7.78	7.85	7.76	7.47	
16/09/91	184	6.40	8.42	8.08	8.25	8.19	7.88	7.66	
18/09/91	186	6.55	8.56	8.59	8.36	8.32	7.64	7.29	
20/09/91	188	6.46	8.25	8.32	8.45	8.12	7.97	7.94	
27/09/91	195	6.46	7.87	8.40	7.80	7.67	8.05	7.03	
30/09/91	198	6.51	7.86	7.73	7.86	7.71	7.82	8.46	

pH Measurements - Treated Samples

Date	Days From Start	Loop Number							Comment
		1	2	3	4	5	6	7	
01/10/91	199	6.63	7.60	7.49	8.05	7.54	7.53	7.20	Solder Coils - 24 hr standing
02/10/91	200	6.90	7.79	7.72	8.41	7.81	7.67	7.19	Plumbing Coils - 24 hr standing
02/10/91	200	6.37	7.83	7.85	8.61	7.99	7.68	7.34	Faucets - 24 hr standing
04/10/91	202	6.47	8.10	8.54	8.05	8.41	8.26	7.88	
07/10/91	205	6.51	8.00	7.93	7.97	8.13	8.22	7.50	
09/10/91	207	6.53	8.09	8.10	7.76	7.92	8.29	8.11	
11/10/91	209	6.52	7.85	7.85	7.79	8.42	8.41	7.87	
15/10/91	213	6.55	8.05	7.98	7.77	8.25	8.25	7.73	
16/10/91	214	6.30	7.20	7.26	7.22	7.48	7.34	7.14	
21/10/91	219	6.42	7.85	7.89	7.93	8.22	8.12	7.40	
22/10/91	220	6.63	7.59	7.46	8.05	7.44	7.42	7.06	Solder Coils - 24 hr standing
22/10/91	220	6.79	7.73	7.55	8.31	7.61	7.50	7.13	Plumbing Coils - 24 hr standing
23/10/91	221	6.38	7.66	7.55	8.34	7.63	7.45	7.02	Faucets - 24 hr standing
25/10/91	223	6.44	7.79	7.85	7.64	7.52	7.54	7.32	
28/10/91	226	6.49	8.29	8.36	7.96	8.68	7.81	7.77	
30/10/91	228	6.47	8.07	8.23	7.84	8.37	8.12	7.79	
01/11/91	230	6.48	7.90	8.12	7.94	8.30	7.97	7.47	
04/11/91	233	6.52	8.07	8.28	8.31	8.63	8.00	7.80	
05/11/91	234	6.66	7.68	7.61	8.55	7.54	7.48	7.10	Solder Coils - 24 hr standing
05/11/91	234	6.77	7.67	7.60	8.44	7.56	7.61	7.20	Plumbing Coils - 24 hr standing
06/11/91	235	6.63	7.86	7.80	8.71	7.68	7.68	7.32	Faucets - 24 hr standing
08/11/91	237	6.63	7.98	8.01	8.15	8.14	7.89	7.54	
12/11/91	241	6.55	7.91	8.01	8.24	7.78	7.75	7.32	
15/11/91	244	6.51	7.92	7.89	7.90	7.73	7.73	7.39	
18/11/91	247	6.52	7.93	7.96	8.02	7.86	7.74	7.43	
19/11/91	248	6.58	7.52	7.56	8.35	7.45	7.48	7.01	Solder Coils - 24 hr standing
19/11/91	248	6.73	7.69	7.60	8.50	7.50	7.58	7.17	Plumbing Coils - 24 hr standing
20/11/91	249	6.38	7.65	7.61	8.59	7.44	7.54	7.00	Faucets - 24 hr standing
22/11/91	251	6.35	7.92	7.91	8.15	7.96	7.81	7.43	
25/11/91	254	6.40	8.01	8.00	8.27	8.13	7.97	7.50	
27/11/91	256	6.42	8.10	7.94	8.19	8.01	8.23	7.52	
29/11/91	258	6.62	8.34	8.25	8.24	8.13	8.13	7.72	
02/12/91	261	6.40	8.14	8.06	8.45	7.95	7.94	7.47	
03/12/91	262	6.56	7.69	7.68	8.58	7.55	7.52	7.13	Solder Coils - 24 hr standing
03/12/91	262	6.80	7.80	7.71	8.54	7.62	7.71	7.24	Plumbing Coils - 24 hr standing
04/12/91	263	6.42	7.82	7.74	8.70	7.61	7.65	7.22	Faucets - 24 hr standing
06/12/91	265	6.56	8.18	8.14	8.26	8.06	7.89	7.48	
09/12/91	268	6.47	8.16	7.99	8.23	7.99	7.83	7.47	
11/12/91	270	6.42	7.96	7.85	8.15	7.94	7.85	7.46	
13/12/91	272	6.50	8.13	7.99	8.11	8.08	7.85	7.50	
16/12/91	275	6.53	8.29	7.90	8.39	8.07	7.93	7.43	
17/12/91	276	6.61	7.97	7.85	8.69	7.74	7.80	7.22	Solder Coils - 24 hr standing
17/12/91	276	6.87	7.85	7.74	8.58	7.73	7.87	7.28	Plumbing Coils - 24 hr standing

pH Measurements - Treated Samples

	Days From Start	Loop Number							Comment
Date		1	2	3	4	5	6	7	
18/12/91	277	6.41	7.69	7.70	8.99	7.53	7.64	7.07	Faucets - 24 hr standing
22/12/91	281	6.47	8.17	8.55	8.26	7.79	7.49	7.12	
30/12/91	289	6.48	7.93	8.12	7.75	7.57	8.15	7.49	
06/01/92	296	6.47	8.01	7.96	7.83	8.08	7.82	7.46	
13/01/92	303	6.58	8.04	7.90	8.02	8.07	8.42	7.56	
14/01/92	304		7.98	7.92	8.78	7.71	7.74	7.31	Solder Coils - 24 hr standing
14/01/92	304	6.81	7.84	7.78	8.54	7.70	7.73	7.24	Plumbing Coils - 24 hr standing
15/01/92	305	6.53	7.96	7.84	8.79	7.73	7.78	7.31	Faucets - 24 hr standing
20/01/92	310	6.46	8.15	7.98	8.13	8.07	8.07	7.57	
27/01/92	317	6.55	8.38	8.25	8.48	8.53	8.16	7.82	
04/02/92	325	6.35	8.05	7.97	8.60	8.04	7.74	7.43	
17/02/92	338	6.54	8.34	8.11	8.43	7.77	8.13	7.92	
18/02/92	339	6.18	7.78	7.70	8.56	7.37	7.44	6.92	Solder Coils - 24 hr standing
18/02/92	339	6.44	7.51	7.51	8.38	7.40	7.45	6.96	Plumbing Coils - 24 hr standing
19/02/92	340	6.40	7.87	7.83	8.83	7.63	7.69	7.19	Faucets - 24 hr standing
24/02/92	345	6.49	8.30	8.24	8.40	7.71	8.25	7.78	
03/03/92	353	6.53	7.76	7.81	8.18	8.01	7.83	7.33	
10/03/92	360	6.71	7.86	7.84	8.19	8.25	7.92	7.74	
11/03/92	361	6.57	8.00	8.00	8.64	7.75	7.75	7.35	Solder Coils - 24 hr standing
11/03/92	361	6.71	7.77	7.68	8.38	7.68	7.76	7.28	Plumbing Coils - 24 hr standing
12/03/92	362	6.49	8.23	7.67	8.54	7.77	7.47	7.30	Faucets - 24 hr standing

Average pH Levels

	Loop Number						
	1	2	3	4	5	6	7
Non Standing	6.49	8.00	7.96	8.05	8.02	7.98	7.52
Std Deviation	0.08	0.21	0.26	0.34	0.27	0.28	0.24
Maximun	6.71	8.56	8.96	9.37	8.68	8.76	8.46
Minimum	6.26	7.20	7.26	7.22	7.33	7.31	7.03
P Coil - 24 Hr St	6.75	7.77	7.68	8.35	7.70	7.69	7.23
Std Deviation	0.09	0.12	0.16	0.17	0.15	0.13	0.13
Maximun	6.90	8.04	8.11	8.60	8.10	8.01	7.51
Minimum	6.44	7.51	7.32	8.00	7.40	7.45	6.96
S Coil - 24 Hr St	6.56	7.77	7.64	8.49	7.62	7.61	7.17
Std Deviation	0.11	0.16	0.26	0.24	0.15	0.15	0.15
Maximun	6.75	8.15	8.01	9.05	8.06	7.95	7.52
Minimum	6.18	7.52	6.64	8.05	7.37	7.42	6.92
Faucet - 24 Hr St	6.44	7.73	7.64	8.43	7.64	7.64	7.18
Std Deviation	0.09	0.19	0.19	0.27	0.16	0.17	0.13
Maximun	6.63	8.23	8.05	8.99	7.99	8.20	7.40
Minimum	6.28	7.34	7.17	8.02	7.35	7.41	6.94

Alkalinity Measurements, mg/L

Pre-treatment								
		Loop Number						
Date		1	2	3	4	5	6	7	Comment
12/02/91		7.25	7.00	4.96	4.88	4.96	5.08	4.80	Plumbing Coils - 8 hr standing
13/02/91		2.86	2.41	2.59	2.52	2.69	3.09	2.25	
13/02/91		6.91	4.72	4.27	5.10	4.05	5.06	5.13	Plumbing Coils - 8 hr standing
18/02/91		2.80	2.81	1.80	2.47	2.42	2.60	2.41	Faucets - 8 hr standing
18/02/91		3.78	3.77	3.60	3.37	3.28	3.56	3.22	Solder Coils - 8 hr standing
27/02/91		5.85	5.97	5.49	5.68	5.53	5.59	4.92	Plumbing Coils - 24 hr standing
27/02/91		3.41	2.62	2.52	2.82	2.69	2.78	2.59	Faucets - 24 hr standing
02/03/91		4.96	5.44	4.85	5.62	5.25	5.14	5.38	Plumbing Coils - 24 hr standing
02/03/91		3.75	3.97	3.92	3.48	3.47	3.67	3.51	Solder Coils - 24 hr standing

Alkalinity Measurements, mg/L - Treated Samples

Treated Samples									
	Days From Start	Loop Number							
Date		1	2	3	4	5	6	7	Comment
16/03/91	0	3.02	18.44	18.73	17.60	20.42	20.99	14.06	
17/03/91	1	3.08	18.16	17.87	18.09	18.80	20.91	11.80	
19/03/91	3	3.33	18.66	18.66		19.72	20.71	12.01	
20/03/91	4	3.21	18.66	18.51	18.44	19.43		10.03	
21/03/91	5	3.07	18.02	18.23	17.95	18.51	19.57	10.10	
22/03/91	6	3.38	20.21	19.43	20.28	20.49	21.20		
23/03/91	7	3.48	20.21	19.86		18.66	22.54	11.37	
25/03/91	9	6.24	19.50	23.32	22.47	22.05		12.72	Plumbing Coils - 24 hr standing
26/03/91	10	4.19	20.63	20.56	22.33	20.63	21.62	9.04	Solder Coils - 24 hr standing
27/03/91	11	3.99	20.00	21.05	20.84	20.70	21.69	8.90	Faucets - 24 hr standing
28/03/91	12	3.61	20.53		18.51	22.54	21.62	11.24	
02/04/91	17	3.82	20.21	21.76	19.72	21.84	22.61	11.80	
03/04/91	18	6.45	21.05	22.47	24.09	21.27	24.59		Plumbing Coils - 24 hr standing
04/04/91	19	3.82	20.63	22.33	20.84		21.91	12.22	
05/04/91	20	4.50	20.63		21.34	20.42	20.78	8.69	Plumbing Coils - 24 hr standing
06/04/91	21	4.20	9.89		14.06	13.07		7.21	Faucets - 24 hr standing*
08/04/91	23	3.67	19.08	18.93	18.58	20.49	21.69	10.81	
09/04/91	24	6.16	21.05	19.57	23.03	21.34	20.42	11.45	Plumbing Coils - 24 hr standing
10/04/91	25	4.16	25.44	20.63	23.39	20.70	20.70	8.12	Faucets - 24 hr standing
11/04/91	26	4.30	19.22	19.29	20.63	19.01		7.91	Solder Coils - 24 hr standing
13/04/91	28	3.43	19.29	20.56		19.93	20.42	10.60	
18/04/91	33	3.52	18.51	18.59	17.95	19.65	20.92	10.74	
23/04/91	38	3.63	19.15	18.80	19.43	18.59	20.63	10.60	
24/04/91	39	7.45	19.36	20.14	21.84	20.42	20.49	9.20	Plumbing Coils - 24 hr standing
25/04/91	40	4.35	18.94	18.37	20.49	18.66	19.01	13.14	Solder Coils - 24 hr standing
26/04/91	41	4.05		20.42	22.68	20.00		7.77	Faucets - 24 hr standing
27/04/91	42	3.76	18.94		20.21	20.56	20.92	9.89	
29/04/91	44	3.60	19.65	18.80	18.44	18.94	19.93	7.60	

Alkalinity Measurements, mg/L - Treated Samples

Date	Days From Start	Loop Number							Comment
		1	**2**	**3**	**4**	**5**	**6**	**7**	
06/05/91	51	4.00	20.49	23.46	25.93	19.57	21.90	9.82	
08/05/91	53	3.55	20.01	19.01	26.57	20.78	21.20	9.33	
09/05/91	**54**	**6.86**	**20.63**	**19.36**	**25.65**	**23.11**	**21.55**	**12.23**	**Plumbing Coils - 24 hr standing**
10/05/91	**55**	**5.16**	**20.85**	**20.21**	**27.98**	**20.00**	**19.22**	**8.33**	**Solder Coils - 24 hr standing**
10/05/91	**55**		**19.01**	**19.29**	**23.25**	**17.73**	**18.33**		**Faucets - 24 hr standing**
13/05/91	58	3.61	19.29	18.80	18.37	18.59	19.50	8.20	
14/05/91	**59**	**4.30**	**18.73**	**17.95**	**21.55**	**18.51**	**18.30**	**7.28**	**Solder Coils - 24 hr standing**
15/05/91	**60**	**6.78**	**19.29**	**18.80**	**20.21**	**19.08**	**20.00**		**Plumbing Coils - 24 hr standing**
15/05/91	**60**	**3.98**	**19.15**	**18.51**	**21.48**	**19.08**	**18.94**	**7.28**	**Faucets - 24 hr standing**
17/05/91	62	3.51	19.60	21.20	19.73	20.13	21.06	10.07	
21/05/91	66	3.42	18.67	17.33	17.60	19.13	21.33	8.93	
22/05/91	**67**	**4.54**	**20.00**	**18.73**	**21.60**	**19.07**	**19.33**	**8.40**	**Solder Coils - 24 hr standing**
23/05/91	**68**	**7.00**	**20.33**	**19.67**	**21.53**	**20.00**	**20.67**	**9.20**	**Plumbing Coils - 24 hr standing**
23/05/91	**68**	**4.40**	**19.13**		**20.33**	**18.40**	**19.33**	**7.60**	**Faucets - 24 hr standing**
25/05/91	70	3.63	19.87	19.07	20.07	21.40	22.73	10.20	
27/05/91	72	3.56	19.53	18.93	19.53	19.87	19.40	9.33	
28/05/91	**73**	**7.10**	**20.53**	**20.67**	**22.20**	**22.53**	**20.20**	**10.60**	**Plumbing Coils - 24 hr standing**
29/05/91	**74**	**4.31**	**20.13**	**11.20**	**21.73**	**18.60**	**19.27**	**7.93**	**Solder Coils - 24 hr standing**
29/05/91	**74**	**3.93**	**19.20**	**19.80**	**22.07**	**19.73**	**20.33**	**7.87**	**Faucets - 24 hr standing**
31/05/91	76	3.67	19.07	19.07	19.47	20.13	20.67	9.80	
03/06/91	79	3.87	19.60	18.67	18.73	19.67	19.80	9.33	
04/06/91	**80**	**5.68**	**19.80**	**19.80**	**22.00**	**19.33**	**20.13**	**8.07**	**Solder Coils - 24 hr standing**
05/06/91	**81**	**7.72**	**20.67**	**21.00**	**22.47**	**19.73**	**21.67**	**8.67**	**Plumbing Coils - 24 hr standing**
05/06/91	**81**	**3.98**	**18.87**	**18.47**	**20.80**	**19.00**	**20.00**	**7.47**	**Faucets - 24 hr standing**
06/06/91	82	4.01	20.13	18.67	20.53	21.60	22.27	10.20	
08/06/91	84	3.78	19.87	19.47	19.67	20.73	21.13	9.13	
10/06/91	86	3.78	18.80	18.67	19.00	20.87	20.40	10.00	
11/06/91	**87**	**4.32**	**19.47**	**19.53**	**21.33**	**19.13**	**19.67**	**13.27**	**Solder Coils - 24 hr standing**
12/06/91	**88**	**8.11**	**20.73**	**20.67**	**22.60**	**20.87**	**22.07**	**11.00**	**Plumbing Coils - 24 hr standing**
12/06/91	**88**	**3.96**	**17.93**	**18.47**	**20.67**	**18.67**	**18.73**	**7.00**	**Faucets - 24 hr standing**
14/06/91	90	3.82	20.53	19.00	19.00	20.60	21.07	9.07	
18/06/91	94	3.77	21.07	18.80	19.87	22.13	22.00	10.40	
19/06/91	95	3.87	21.06	19.20	21.53	21.60	21.33	10.53	
21/06/91	97	3.88	20.07	19.80	21.47	21.07	21.53	14.40	
24/06/91	100	4.01	20.73	19.67	21.20	20.80	20.60	10.00	
25/06/91	**101**	**4.92**	**20.47**	**19.60**	**22.80**	**19.93**	**19.47**	**8.53**	**Solder Coils - 24 hr standing**
26/06/91	**102**	**7.73**	**20.73**	**21.07**	**24.33**	**21.00**	**23.60**	**13.53**	**Plumbing Coils - 24 hr standing**
26/06/91	**102**	**4.02**	**20.20**	**19.33**	**22.13**	**19.00**	**19.47**	**7.93**	**Faucets - 24 hr standing**
27/06/91	103	4.00	20.80	20.00	21.40	20.87	22.13	9.60	
02/07/91	108	3.93	19.47	18.93	20.67	19.20	20.33	9.80	
03/07/91	109	4.08	19.06	19.33	21.40	20.00	20.13	10.07	
05/07/91	111	4.03	20.40	21.47	20.00	20.53	20.13	11.33	
08/07/91	114	3.88	20.73	20.80	20.33	20.06	19.73		

Alkalinity Measurements, mg/L - Treated Samples

Date	Days From Start	Loop Number							Comment
		1	**2**	**3**	**4**	**5**	**6**	**7**	
09/07/91	**115**	**4.71**	**20.60**	**20.60**	**22.80**	**19.67**	**20.00**	**8.60**	Solder Coils - 24 hr standing
10/07/91	**116**	**7.53**	**21.40**	**21.67**	**23.13**	**22.53**	**20.33**	**12.53**	Plumbing Coils - 24 hr standing
10/07/91	**116**	**4.20**	**21.00**	**19.67**	**22.47**	**20.20**	**19.93**	**8.67**	Faucets - 24 hr standing
12/07/91	118	4.04	20.47	20.47	20.47	20.73	21.87	11.00	
15/07/91	121	4.12	20.60	20.53	21.07	20.20	20.73	11.13	
17/07/91	123	4.10	21.07	21.00	21.87	21.07	21.73	10.93	
19/07/91	125	4.07	22.20	23.13	22.60	22.80	22.80	11.20	
22/07/91	128	4.11	20.73	21.00	21.93	19.00	21.20	11.33	
23/07/91	**129**	**4.71**	**20.53**	**20.73**	**23.33**	**22.00**	**24.40**	**8.40**	Solder Coils - 24 hr standing
24/07/91	**130**	**8.25**	**21.73**	**23.60**		**24.67**	**32.07**	**10.20**	Plumbing Coils - 24 hr standing
24/07/91	**130**	**4.54**	**21.07**	**20.60**	**23.87**	**21.60**	**22.20**	**9.40**	Faucets - 24 hr standing
26/07/91	132	4.71	22.13	22.06	22.27	22.67	22.47	10.60	
29/07/91	135	4.46	20.67	20.27	20.67	21.00	20.13	11.33	
31/07/91	137	4.35	20.33	20.47	20.87	21.20	21.13	9.06	
02/08/91	139	4.96	20.27	19.67	20.07	21.47	21.87	10.00	
06/08/91	143	4.75	21.33	20.67	20.93	22.00	22.07	11.53	
07/08/91	**144**	**5.10**	**21.46**	**20.47**	**23.20**	**21.73**	**22.87**	**9.87**	Solder Coils - 24 hr standing
08/08/91	**145**	**11.80**	**22.07**	**23.60**	**23.80**	**24.67**	**24.47**	**16.33**	Plumbing Coils - 24 hr standing
08/08/91	**145**	**4.70**	**21.73**	**20.87**	**22.80**	**21.87**	**23.46**	**10.60**	Faucets - 24 hr standing
12/08/91	149	4.82	21.47	21.33	19.60	22.60	23.40	11.73	
14/08/91	151	4.66	21.40	21.00	19.47	23.20	22.93	10.33	
15/08/91	152	4.60	21.40	21.73	21.40	22.67	24.13	11.00	
19/08/91	156	4.75	9.80	10.00	9.60	9.93	10.47	9.47	*
20/08/91	**157**	**5.38**	**10.00**	**10.13**	**12.60**	**10.67**	**12.33**	**11.20**	Solder Coils - 24 hr standing*
21/08/91	**158**	**8.33**	**11.33**	**10.93**	**12.67**	**12.47**	**13.67**	**15.07**	Plumbing Coils - 24 hr standing*
21/08/91	**158**		**21.60**	**23.20**	**23.07**	**20.53**	**21.60**	**11.50**	Faucets - 24 hr standing
23/08/91	160	4.56	22.87	20.73	24.53	21.93	23.07	10.00	
26/08/91	163	4.63	21.73	21.40	22.73	22.40	22.13	10.40	
28/08/91	165	4.70	21.13	21.87	22.40	22.53	22.73	10.60	
03/09/91	171	2.40	18.80	18.20	17.40	18.47	16.80	9.00	
04/09/91	172	2.51	18.67	19.20	18.60	18.20	15.93	8.87	
06/09/91	174	2.58	18.67	19.40	17.33	20.00	21.13	9.53	
09/09/91	177	2.68	18.80	19.07	19.80	18.13	21.13	10.47	
10/09/91	**178**	**3.13**	**19.00**	**18.80**	**21.53**	**19.20**	**19.33**	**9.47**	Solder Coils - 24 hr standing
11/09/91	**179**	**5.60**	**19.67**	**20.13**	**22.73**	**20.53**	**21.40**	**10.27**	Plumbing Coils - 24 hr standing
11/09/91	**179**	**3.23**	**19.00**	**19.33**	**21.33**	**19.07**	**18.73**	**7.86**	Faucets - 24 hr standing
13/09/91	181	3.21	16.47	16.33	16.53	16.93	17.26	9.87	
16/09/91	184	3.24	19.13	18.87	19.13	18.47	18.87	7.60	
18/09/91	186	3.31	21.20	21.40	20.27	21.27	21.27	10.67	
20/09/91	188	3.65	21.27	21.40	21.47	20.47	20.80	11.87	
27/09/91	195	3.78	20.67	21.87	20.00	18.93	21.93	8.07	
30/09/91	198	3.93	20.27	19.47	19.73	19.67	21.40	14.67	
01/10/91	**199**	**4.43**	**21.87**	**21.07**	**24.13**	**21.13**	**22.00**	**9.87**	Solder Coils - 24 hr standing

Alkalinity Measurements, mg/L - Treated Samples

Date	Days From Start	Loop Number							Comment
		1	2	3	4	5	6	7	
02/10/91	200	8.97	23.40	23.93	25.80	27.53	26.93	16.07	Plumbing Coils - 24 hr standing
02/10/91	200	4.31	21.06	21.33	23.53	22.07	21.53	9.60	Faucets - 24 hr standing
04/10/91	202	4.15	21.20	22.07	21.00	22.20	23.00	12.73	
07/10/91	205	4.35	21.53	20.73	21.07	22.07	23.00	10.27	
09/10/91	207	4.47	21.53	21.53	20.27	20.80	23.00	19.00	
11/10/91	209	4.37	21.27	21.00	20.53	22.73	23.67	12.40	
15/10/91	213	4.57	22.13	22.13	20.73	23.20	23.60	13.73	
16/10/91	214	4.54	21.80	21.87	21.73	24.20	23.80	13.13	
21/10/91	219	4.14	24.07	24.00	24.33	25.53	27.27	11.40	
22/10/91	220	4.83	25.27	23.40	27.40	23.20	24.00	10.87	Solder Coils - 24 hr standing
22/10/91	220	8.69	26.80	26.33	27.73	32.60	31.40	19.20	Plumbing Coils - 24 hr standing
23/10/91	221	4.45	20.47	20.40	23.33	21.80	21.00	7.73	Faucets - 24 hr standing
25/10/91	223	4.19	19.00	19.20	18.20	18.33	18.73	11.20	
28/10/91	226	4.02	19.87	20.07	18.80	21.67	19.87	14.47	
30/10/91	228	4.03	19.07	19.20	18.00	20.13	20.60	11.60	
01/11/91	230	3.83	18.20	19.27	18.87	19.40	19.53	10.33	
04/11/91	233	4.15	18.33	19.20	19.47	20.00	19.27	12.40	
05/11/91	234	4.66	19.20	18.80	22.87	19.53	20.47	9.93	Solder Coils - 24 hr standing
05/11/91	234	7.12	19.67	19.93	21.87	20.80	22.27	12.33	Plumbing Coils - 24 hr standing
06/11/91	235	5.08	18.07	18.33	21.53	17.93	18.47	8.73	Faucets - 24 hr standing
08/11/91	237	4.39	19.27	19.27	19.67	19.60	20.47	12.07	
12/11/91	241	3.89	18.53	19.06	19.47	18.73	19.67	9.27	
15/11/91	244	3.60	19.93	19.73	20.13	19.67	19.80	9.80	
18/11/91	247	3.04	19.27	19.27	19.53	19.73	19.53	9.33	
19/11/91	248	3.69	21.13	20.07	23.47	19.73	20.87	9.13	Solder Coils - 24 hr standing
19/11/91	248	6.17	20.27	22.87	22.73	29.60	23.80	11.93	Plumbing Coils - 24 hr standing
20/11/91	249	3.29	18.33	18.40	21.53	17.87	18.53	4.80	Faucets - 24 hr standing
22/11/91	251	2.78	18.87	18.93	19.47	19.07	19.53	8.93	
25/11/91	254	2.77	18.67	18.53	19.33	19.27	19.53	8.53	
27/11/91	256	2.84	18.53	18.53	18.80	19.47	21.13	8.33	
29/11/91	258	4.05	21.80	21.27	20.93	20.33	21.06	12.27	
02/12/91	261	2.83	19.27	19.33	20.20	19.27	19.13	8.93	
03/12/91	262	3.74	19.27	18.80	22.33	18.53	19.53	7.73	Solder Coils - 24 hr standing
03/12/91	262	5.87	20.47	20.13	22.67	20.07	21.00	8.40	Plumbing Coils - 24 hr standing
04/12/91	263	3.18	18.40	18.13	20.80	17.93	18.53	7.67	Faucets - 24 hr standing
06/12/91	265	3.46	20.53	20.87	21.20	20.80	21.27	9.33	
09/12/91	268	3.14	20.13	19.93	20.33	20.33	20.27	10.07	
11/12/91	270	2.86	19.07	19.53	20.13	20.27	20.73	10.13	
13/12/91	272	3.00	19.40	19.40	19.40	19.93			
16/12/91	275	3.56	20.53	18.87	20.47	19.73	20.27	7.47	
17/12/91	276	4.46	18.93	18.73		18.67	20.73	6.27	Solder Coils - 24 hr standing
17/12/91	276	5.68	20.33	20.00	22.20	19.93	23.67	7.13	Plumbing Coils - 24 hr standing
18/12/91	277	3.12	16.87	18.80	23.47	16.93	17.87	6.20	Faucets - 24 hr standing

Alkalinity Measurements, mg/L - Treated Samples

Date	Days From Start	Loop Number 1	2	3	4	5	6	7	Comment
22/12/91	281	2.98	18.67	19.87	18.67	17.93	18.00	8.60	
30/12/91	289	3.09	18.87	19.20	17.93	17.67	20.60	9.80	
06/01/92	296	3.13	19.47	19.07	18.67	20.00	19.33	9.87	
13/01/92	303	3.88	20.13	19.33	20.07	20.53	21.07	10.40	
14/01/92	304	3.94	18.93	19.67	22.53	19.60	20.27	8.27	Solder Coils - 24 hr standing
14/01/92	304	5.67	20.93	21.87	23.00	20.87	21.27	8.33	Plumbing Coils - 24 hr standing
15/01/92	305	3.44	20.00	20.27	23.67	20.27	20.33	7.60	Faucets - 24 hr standing
20/01/92	310	3.16	19.87	19.80	19.87	20.40	20.67	10.53	
27/01/92	317	3.01	19.73	19.53	20.40	20.40	19.67	10.00	
04/02/92	325	2.31	17.80	18.87	20.07	18.33	17.67	7.33	
17/02/92	338	2.80	18.73	18.53	19.47	18.80	20.00	10.27	
18/02/92	339	2.57	18.13	17.40	21.07	17.67	18.20	6.40	Solder Coils - 24 hr standing
18/02/92	339	4.32	18.87	19.07	21.33	21.73	19.87	8.93	Plumbing Coils - 24 hr standing
19/02/92	340	2.69	17.60	17.87	22.20	17.60	18.00	6.73	Faucets - 24 hr standing
24/02/92	345	2.80	17.87	19.13	19.33	17.93	20.00	10.80	
03/03/92	353	3.23	18.33	18.73	18.93	19.00	18.87	7.93	
10/03/92	360	3.93	20.20	19.73	20.40	20.80	20.67	10.27	
11/03/92	361	3.73	20.07	19.53	22.80	20.33	20.60	11.47	Solder Coils - 24 hr standing
11/03/92	361	5.56	22.13	22.20	22.80	21.73	22.47	11.67	Plumbing Coils - 24 hr standing
12/03/92	362	2.74	20.87	16.07	22.06	19.33	15.47	9.87	Faucets - 24 hr standing

Average Alkalinities, mg/L

	Loop Number 1	2	3	4	5	6	7
Non Standing	3.71	19.82	19.77	19.97	20.25	20.81	10.49
Std Deviation	0.61	1.61	1.67	1.97	2.53	1.93	1.73
Maximum	4.96	24.07	24.00	26.57	25.53	27.27	19.00
Minimum	2.31	9.80	10.00	9.60	9.93	10.47	7.33
P Coil - 24 Hr St	6.99	20.52	20.92	22.57	21.98	22.43	11.49
Std Deviation	1.56	2.44	2.78	2.61	3.72	3.68	2.95
Maximum	11.80	26.80	26.33	27.73	32.60	32.07	19.20
Minimum	4.32	11.33	10.93	12.67	12.47	13.67	7.13
S Coil - 24 Hr St	4.38	19.69	18.89	22.28	19.36	20.07	9.14
Std Deviation	0.69	2.52	2.81	2.79	2.24	2.34	1.82
Maximum	5.68	25.27	23.40	27.98	23.20	24.40	13.27
Minimum	2.57	10.00	10.13	12.60	10.67	12.33	6.27
Faucet - 24 Hr St	3.90	18.96	18.72	22.22	19.50	18.88	7.79
Std Deviation	0.62	4.41	4.24	1.09	1.49	4.37	2.18
Maximum	5.08	25.44	23.20	23.87	22.07	23.46	11.50
Minimum	2.69	9.89	16.07	14.06	13.07	15.47	4.80

* On 06/04/91 and 19-21/08/91 the circuit breaker feeding NaHCO3, V939, and TPC 223 was thrown which accounts for the low alkalinities in some loops on those dates.

Chloramine Measurements, mg/L

Date	Days From Start	Loop Number							Comment
		1	2	3	4	5	6	7	
16/03/91	0	0.0	2.5	2.5	2.4	2.4	2.4	2.4	
17/03/91	1	0.0	2.4	2.4	2.5	2.4	2.4	2.4	
19/03/91	3	0.0	2.5	2.5	2.4	2.4	2.5	2.4	
20/03/91	4	0.0	2.5	2.4	2.4	2.5	2.5	2.4	
21/03/91	5	0.0	2.5	2.4	2.5	2.5	2.5	2.5	
22/03/91	6	0.0	2.5	2.4	2.5	2.5	2.5	2.4	
23/03/91	7	0.0	2.5	2.5	2.3	2.4	2.4	2.4	
25/03/91	9	0.0	0.0	0.0	0.0	<0.1	<0.1	<0.1	Plumbing Coils - 24 hr standing
26/03/91	10	0.0	1.3	1.3	1.8	1.8	2.0	2.0	Solder Coils - 24 hr standing
27/03/91	11	0.0	2.4	2.4	2.3	2.4	2.2	2.3	Faucets - 24 hr standing
28/03/91	12	0.0	2.5	2.5	2.5	2.6	2.4	2.3	
02/04/91	17	0.0	2.5	2.5	2.4	2.5	2.5	2.4	
03/04/91	18	0.0	0.2	0.3	0.1	0.3	0.0	0.2	Plumbing Coils - 24 hr standing
04/04/91	19	0.0	2.5	2.5	2.6	2.6	2.6	2.5	
05/04/91	20	0.0	1.7	1.7	1.8	1.7	1.9	1.9	Plumbing Coils - 24 hr standing*
06/04/91	21	0.0	2.2	2.2	2.1	2.1	2.0	2.1	Faucets - 24 hr standing
08/04/91	23	0.0	2.5	2.4	2.4	2.4	2.4	2.4	
09/04/91	24	0.0	0.2	0.3	0.1	0.2	<0.1	0.2	Plumbing Coils - 24 hr standing
10/04/91	25	0.0	1.2	1.1	1.2	1.8	1.8	1.8	Faucets - 24 hr standing
11/04/91	26	0.0	1.6	1.8	1.9	1.8	1.8	1.9	Solder Coils - 24 hr standing
13/04/91	28	0.0	2.5	2.5	2.5	2.5	2.5	2.5	
18/04/91	33	0.0	2.3	2.3	2.4	2.4	2.4	2.4	
23/04/91	38	0.0	2.5	2.6	2.6	2.6	2.6	2.6	
24/04/91	39	0.0	0.2	0.3	0.1	0.3	0.1	0.2	Plumbing Coils - 24 hr standing
25/04/91	40	0.0	1.5	1.3	1.7	1.3	1.6		Solder Coils - 24 hr standing
26/04/91	41	0.0	2.1	2.5	2.0	2.4	2.3	1.8	Faucets - 24 hr standing
27/04/91	42	0.0	2.6	2.8	2.7	2.8	2.7	2.7	
29/04/91	44	0.0	2.6	2.6	2.5	2.5	2.5	2.4	
06/05/91	51	0.0	2.2	2.2	2.2	2.2	2.2	2.2	
08/05/91	53	0.0	2.4	2.5	2.5	2.5	2.4	2.5	
09/05/91	54	0.0	0.1	0.2	0.0	0.2	0.0	0.0	Plumbing Coils - 24 hr standing
10/05/91	55	0.0	1.2	1.1	1.0	1.2	1.3	1.2	Solder Coils - 24 hr standing
10/05/91	55	0.0	2.3	2.3	2.3	2.3	2.3	2.2	Faucets - 24 hr standing
13/05/91	58	0.0	2.4	2.4	2.3	2.3	2.4	2.3	
14/05/91	59	0.0	1.2	1.2	1.3	1.5	1.6	1.5	Solder Coils - 24 hr standing
15/05/91	60	0.0	0.0	0.1	0.0	0.1	0.0	0.1	Plumbing Coils - 24 hr standing
15/05/91	60	0.0	2.2	2.2	2.2	2.3	2.3	2.2	Faucets - 24 hr standing
17/05/91	62	0.0	2.4	2.4	2.4	2.4	2.4	2.4	
21/05/91	66	0.0	2.3	2.3	2.3	2.3	2.4	2.3	
22/05/91	67	0.0	1.4	1.4	1.4	1.4	1.5	1.4	Solder Coils - 24 hr standing
23/05/91	68	0.0	0.0	0.1	0.0	0.1	0.0	0.2	Plumbing Coils - 24 hr standing
23/05/91	68	0.0	2.2	2.2	2.2	2.2	2.2	2.2	Faucets - 24 hr standing

Chloramine Measurements, mg/L

Date	Days From Start	Loop Number							Comment
		1	2	3	4	5	6	7	
25/05/91	70	0.0	2.4	2.3	2.5	2.4	2.4	2.4	
27/05/91	72	0.0	2.3	2.4	2.4	2.4	2.3	2.3	
28/05/91	73	0.0	0.1	0.1	0.0	0.1	0.1	0.1	Plumbing Coils - 24 hr standing
29/05/91	74	0.0	1.3	1.2	1.4	1.2	1.6	1.4	Solder Coils - 24 hr standing
29/05/91	74	0.0	2.4	2.5	2.4	2.5	2.4	2.3	Faucets - 24 hr standing
31/05/91	76	0.0	2.3	2.3	2.3	2.3	2.3	2.3	
03/06/91	79	0.0	2.4	2.3	2.3	2.3	2.2	2.2	
04/06/91	80	0.0	1.2	1.1	1.4	1.2	1.6	1.3	Solder Coils - 24 hr standing
05/06/91	81	0.0	<0.1	0.0	<0.1	0.1	0.1	0.1	Plumbing Coils - 24 hr standing
05/06/91	81	0.0	2.2	2.0	2.2	2.1	2.2	2.2	Faucets - 24 hr standing
06/06/91	82	0.0	2.3	2.3	2.3	2.4	2.4	2.4	
08/06/91	84	0.0	2.3	2.4	2.3	2.3	2.3	2.4	
10/06/91	86	0.0	2.3	2.3	2.3	2.3	2.3	2.4	
11/06/91	87	0.0	1.1	1.1	1.4	1.4	1.6	1.5	Solder Coils - 24 hr standing
12/06/91	88	0.0	0.0	0.1	0.0	0.1	0.1	<0.1	Plumbing Coils - 24 hr standing
12/06/91	88	0.0	2.0	2.1	2.1	2.1	2.1	2.0	Faucets - 24 hr standing
14/06/91	90	0.0	2.3	2.3	2.3	2.2	2.3	2.2	
18/06/91	94	0.0	2.3	2.3	2.3	2.3	2.3	2.3	
19/06/91	95	0.0	2.7	2.6	2.6	2.6	2.7	2.6	
21/06/91	97	0.0	2.5	2.5	2.5	2.5	2.6	2.7	
24/06/91	100	0.0	2.4	2.5	2.4	2.4	2.4	2.4	
25/06/91	101	0.0	1.3	1.1	1.5	1.4	1.6	1.6	Solder Coils - 24 hr standing
26/06/91	102	0.0	<0.1	0.1	0.0	0.1	0.0	0.0	Plumbing Coils - 24 hr standing
26/06/91	102	0.0	2.3	2.4	2.3	2.3	2.3	2.3	Faucets - 24 hr standing
27/06/91	103	0.0	2.5	2.5	2.5	2.5	2.4	2.5	
02/07/91	108	0.0	2.4	2.5	2.4	2.4	2.4	2.3	
03/07/91	109	0.0	2.4	2.3	2.4	2.4	2.4	2.4	
05/07/91	111	0.0	2.5	2.6	2.5	2.5	2.5	2.5	
08/07/91	114	0.0	2.5	2.5	2.3	2.3	2.4	2.4	
09/07/91	115	0.0	1.3	1.3	1.6	1.4	1.8	1.7	Solder Coils - 24 hr standing
10/07/91	116	0.0	<0.1	<0.1	0.0	0.1	0.1	0.0	Plumbing Coils - 24 hr standing
10/07/91	116	0.0	2.2	2.3	2.3	2.3	2.3	2.3	Faucets - 24 hr standing
12/07/91	118	0.0	2.5	2.4	2.5	2.5	2.5	2.5	
15/07/91	121	0.0	2.4	2.5	2.5	2.6	2.6	2.6	
17/07/91	123	0.0	2.6	2.5	2.5	2.6	2.6	2.5	
19/07/91	125	0.0	2.6	2.6	2.6	2.6	2.6	2.6	
22/07/91	128	0.0	2.6	2.5	2.4	2.5	2.5	2.4	
23/07/91	129	0.0	1.1	1.1	1.7	1.4	2.2	1.6	Solder Coils - 24 hr standing
24/07/91	130	0.0	<0.1	0.1	<0.1	0.1	0.1	0.1	Plumbing Coils - 24 hr standing
24/07/91	130	0.0	2.4	2.3	2.3	2.3	2.3	2.3	Faucets - 24 hr standing
26/07/91	132	0.0	2.6	2.6	2.5	2.5	2.5	2.6	
29/07/91	135	0.0	2.6	2.6	2.6	2.6	2.5	2.6	

Chloramine Measurements, mg/L

Date	Days From Start	Loop Number							Comment
		1	2	3	4	5	6	7	
31/07/91	137	0.0	2.6	2.6	2.6	2.5	2.5	2.5	
02/08/91	139	0.0	2.5	2.5	2.5	2.5	2.5	2.5	
06/08/91	143	0.0	2.7	2.6	2.6	2.7	2.5	2.6	
07/08/91	**144**	**0.0**	**1.3**	**1.3**	**1.8**	**1.7**	**2.0**	**1.8**	**Solder Coils - 24 hr standing**
08/08/91	**145**	**0.0**	**0.1**	**0.1**	**0.0**	**0.1**	**0.0**	**0.0**	**Plumbing Coils - 24 hr standing**
08/08/91	**145**	**0.0**	**2.5**	**2.5**	**2.6**	**2.5**	**2.5**	**2.4**	**Faucets - 24 hr standing**
12/08/91	149	0.0	2.4	2.4	2.4	2.3	2.3	2.3	
14/08/91	151	0.0	2.6	2.5	2.5	2.7	2.6	2.6	
15/08/91	152	0.0	2.7	2.6	2.6	2.6	2.5	2.6	
19/08/91	156	0.0	2.6	2.8	2.7	2.7	2.7	2.6	
20/08/91	**157**	**0.0**	**1.4**	**1.4**	**1.9**	**1.7**	**2.1**	**1.9**	**Solder Coils - 24 hr standing**
21/08/91	**158**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.1**	**0.0**	**Plumbing Coils - 24 hr standing**
21/08/91	**158**	**0.0**	**2.5**	**2.5**	**2.5**	**2.5**	**2.4**	**2.4**	**Faucets - 24 hr standing**
23/08/91	160	0.0	2.7	2.7	2.7	2.7	2.8	2.8	
26/08/91	163	0.0	2.8	2.8	2.8	2.8	2.9	2.9	
28/08/91	165	0.0	2.7	2.7	2.7	2.7	2.8	2.8	
03/09/91	171	0.0	2.6	2.6	2.7	2.6	2.6	2.6	
04/09/91	172	0.0	2.6	2.6	2.5	2.5	2.5	2.5	
06/09/91	174	0.0	2.6	2.6	2.5	2.6	2.5	2.4	
09/09/91	177	0.0	2.5	2.6	2.6	2.6	2.6	2.6	
10/09/91	**178**	**0.0**	**1.6**	**1.5**	**1.7**	**1.8**	**1.8**	**1.8**	**Solder Coils - 24 hr standing**
11/09/91	**179**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**Plumbing Coils - 24 hr standing**
11/09/91	**179**	**0.0**	**2.6**	**2.5**	**2.5**	**2.5**	**2.6**	**2.4**	**Faucets - 24 hr standing**
13/09/91	181	0.0	2.6	2.6	2.6	2.6	2.6	2.6	
16/09/91	184	0.0	2.5	2.5	2.4	2.4	2.4	2.5	
18/09/91	186	0.0	2.6	2.6	2.5	2.6	2.6	2.5	
20/09/91	188	0.0	2.6	2.5	2.5	2.6	2.5	2.5	
27/09/91	195	0.0	2.7	2.6	2.7	2.7	2.6	2.6	
30/09/91	198	0.0	2.6	2.6	2.6	2.6	2.6	2.5	
01/10/91	**199**	**0.0**	**1.2**	**1.1**	**1.8**	**1.4**	**1.9**	**1.8**	**Solder Coils - 24 hr standing**
02/10/91	**200**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**Plumbing Coils - 24 hr standing**
02/10/91	**200**	**0.0**	**2.5**	**2.5**	**2.5**	**2.4**	**2.5**	**2.3**	**Faucets - 24 hr standing**
04/10/91	202	0.0	2.7	2.7	2.7	2.7	2.7	2.7	
07/10/91	205	0.0	2.5	2.5	2.5	2.5	2.5	2.5	
09/10/91	207	0.0	2.5	2.5	2.5	2.5	2.5	2.5	
11/10/91	209	0.0	2.5	2.5	2.4	2.4	2.3	2.4	
15/10/91	213	0.0	2.6	2.6	2.6	2.6	2.6	2.5	
16/10/91	214	0.0	2.6	2.6	2.6	2.5	2.6	2.6	
21/10/91	219	0.0	2.8	2.8	2.9	2.9	3.1	3.1	
22/10/91	**220**	**0.0**	**1.3**	**1.3**	**2.0**	**1.3**	**1.9**	**1.7**	**Solder Coils - 24 hr standing**
22/10/91	**220**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**Plumbing Coils - 24 hr standing**
23/10/91	**221**	**0.0**	**2.4**	**2.8**	**2.7**	**3.1**	**3.0**	**2.6**	**Faucets - 24 hr standing**

Chloramine Measurements, mg/L

		Treated Samples							
	Days From	**Loop Number**							
Date	**Start**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Comment**
25/10/91	223	0.0	2.6	2.5	2.5	2.6	2.5	2.5	
28/10/91	226	0.0	2.6	2.6	2.6	2.6	2.7	2.6	
30/10/91	228	0.0	2.6	2.6	2.6	2.6	2.6	2.6	
01/11/91	230	0.0	2.6	2.5	2.5	2.5	2.5	2.5	
04/11/91	233	0.0	2.6	2.6	2.7	2.5	2.6	2.5	
05/11/91	**234**	**0.0**	**1.6**	**1.4**	**2.1**	**1.7**	**2.0**	**1.9**	**Solder Coils - 24 hr standing**
05/11/91	**234**	**0.0**	**<0.1**	**0.1**	**<0.1**	**0.1**	**0.1**	**<0.1**	**Plumbing Coils - 24 hr standing**
06/11/91	**235**	**0.0**	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**	**Faucets - 24 hr standing**
08/11/91	237	0.0	2.7	2.7	2.6	2.6	2.7	2.7	
12/11/91	241	0.0	2.6	2.6	2.6	2.6	2.6	2.6	
15/11/91	244	0.0	2.5	2.5	2.6	2.4	2.5	2.4	
18/11/91	247	0.0	2.5	2.5	2.5	2.5	2.5	2.5	
19/11/91	**248**	**0.0**	**1.5**	**1.4**	**1.9**	**1.5**	**1.8**	**1.7**	**Solder Coils - 24 hr standing**
19/11/91	**248**	**0.0**	**0.0**	**0.1**	**0.1**	**0.0**	**<0.1**	**0.0**	**Plumbing Coils - 24 hr standing**
20/11/91	**249**	**0.0**	**2.5**	**2.5**	**2.5**	**2.4**	**2.5**	**2.4**	**Faucets - 24 hr standing**
22/11/91	251	0.0	2.4	2.5	2.5	2.5	2.5	2.5	
25/11/91	254	0.0	2.6	2.6	2.6	2.5	2.6	2.6	
27/11/91	256	0.0	2.6	2.5	2.5	2.6	2.6	2.6	
29/11/91	258	0.0	2.5	2.5	2.5	2.5	2.6	2.5	
02/12/91	261	0.0	2.5	2.5	2.5	2.5	2.5	2.5	
03/12/91	**262**	**0.0**	**1.5**	**1.6**	**1.9**	**1.6**	**1.3**	**1.8**	**Solder Coils - 24 hr standing**
03/12/91	**262**	**0.0**	**0.0**	**0.1**	**<0.1**	**<0.1**	**0.0**	**0.1**	**Plumbing Coils - 24 hr standing**
04/12/91	**263**	**0.0**	**2.2**	**2.3**	**2.3**	**2.3**	**2.3**	**2.1**	**Faucets - 24 hr standing**
06/12/91	265	0.0	2.6	2.6	2.6	2.5	2.6	2.6	
09/12/91	268	0.0	2.6	2.6	2.6	2.6	2.5	2.6	
11/12/91	270	0.0	2.5	2.6	2.5	2.6	2.5	2.5	
13/12/91	272	0.0	2.5	2.5	2.5	2.5	2.5	2.5	
16/12/91	275	0.0	2.6	2.6	2.5	2.6	2.6	2.6	
17/12/91	**276**	**0.0**	**1.7**	**1.7**	**2.1**	**1.7**	**0.4**	**1.8**	**Solder Coils - 24 hr standing**
17/12/91	**276**	**0.0**	**0.0**	**0.1**	**0.1**	**<0.1**	**0.0**	**0.0**	**Plumbing Coils - 24 hr standing**
18/12/91	**277**	**0.0**	**2.3**	**0.7**	**2.5**	**2.3**	**2.3**	**2.2**	**Faucets - 24 hr standing**
22/12/91	281	0.0	2.5	2.4	2.4	2.5	2.4	2.4	
30/12/91	289	0.0	2.4	2.4	2.4	2.4	2.4	2.4	
06/01/92	296	0.0	2.5	2.5	2.5	2.5	2.4	2.4	
13/01/92	303	0.0	2.5	2.5	2.4	2.5	2.5	2.5	
14/01/92	**304**	**0.0**	**1.7**	**1.7**	**2.0**	**1.8**	**1.0**		**Solder Coils - 24 hr standing**
14/01/92	**304**	**0.0**	**0.0**	**0.1**	**0.1**	**<0.1**	**0.0**	**0.1**	**Plumbing Coils - 24 hr standing**
15/01/92	**305**	**0.0**	**2.6**	**2.5**	**2.6**	**2.6**	**2.6**	**2.6**	**Faucets - 24 hr standing**
20/01/92	310	0.0	2.5	2.5	2.5	2.5	2.5	2.5	
27/01/92	317	0.0	2.5	2.6	2.5	2.5	2.5	2.5	
04/02/92	325	0.0	2.4	2.5	2.5	2.4	2.5	2.5	
17/02/92	338	0.0	2.5	2.5	2.4	2.5	2.5	2.4	

Chloramine Measurements, mg/L

	Days From Start	Loop Number							
Date		1	2	3	4	5	6	7	Comment
18/02/92	339	0.0	1.1	1.7	2.0	1.7	2.1	2.0	Solder Coils - 24 hr standing
18/02/92	339	0.0	0.0	0.1	0.1	0.0	0.1	0.1	Plumbing Coils - 24 hr standing
19/02/92	340	0.0	2.4	2.3	2.4	2.3	2.3	2.3	Faucets - 24 hr standing
24/02/92	345	0.0	2.5	2.5	2.4	2.5	2.5	2.4	
03/03/92	353	0.0	2.5	2.4	2.5	2.4	2.4	2.4	
10/03/92	360	0.0	2.6	2.5	2.5	2.5	2.4	2.4	
11/03/92	361	0.0	1.6	1.6	2.0	1.7	2.1	1.8	Solder Coils - 24 hr standing
11/03/92	361	0.0	<0.1	0.1	0.1	0.1	0.1	0.1	Plumbing Coils - 24 hr standing
12/03/92	362	0.0	2.1	1.4	1.4	1.9	1.3	1.4	Faucets - 24 hr standing

* Levels for Plumbing Coils for 05/04/91 not included in averages because they
are so much higher than all the other measured levels for the Plumbing Coils.

Average Chloramine Levels, mg/L

	Loop Number						
	1	2	3	4	5	6	7
Non Standing	0.0	2.5	2.5	2.5	2.5	2.5	2.5
Std Deviation	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Maximum	0.0	2.8	2.8	2.9	2.9	3.1	3.1
Minimum	0.0	2.2	2.2	2.2	2.2	2.2	2.2
P Coil - 24 Hr St	0.0	0.1	0.1	0.0	0.1	0.1	0.1
Std Deviation	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Maximum	0.2	0.3	0.1	0.3	0.1	0.2	0.0
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S Coil - 24 Hr St	0.0	1.4	1.4	1.7	1.5	1.7	1.7
Std Deviation	0.0	0.2	0.2	0.3	0.2	0.4	0.2
Maximum	0.0	1.7	1.8	2.1	1.8	2.2	2.0
Minimum	0.0	1.1	1.1	1.0	1.2	0.4	0.0
Faucet - 24 Hr St	0.0	2.3	2.2	2.3	2.3	2.3	2.2
Std Deviation	0.0	0.3	0.5	0.3	0.2	0.3	0.3
Maximum	0.0	2.6	2.8	2.7	3.1	3.0	2.6
Minimum	0.0	1.2	0.7	1.2	1.8	1.3	1.4

Copper Coupons - Bacteriological Results

Heterotrophic Plate Count, CFU/in2							
Exposure Time	**Loop Number**						
	1	2	3	4	5	6	7
3 Months (a)	1.8E+06	8.5E+01	1.5E+05	1.0E+03	1.7E+02	7.1E+02	3.6E+05
3 Months (2) (b)	2.1E+05	7.8E+03	3.0E+05	6.4E+02	1.0E+04	8.4E+02	3.0E+06
6 Months (c)	1.2E+06	1.2E+06	2.2E+04	2.4E+03	1.2E+04	2.6E+02	2.4E+03
6 Months (2) (d)	5.6E+04	8.5E+03	1.3E+05	1.2E+04	6.2E+04	4.5E+05	7.2E+03
9 Months (e)	1.2E+06	9.5E+01	4.3E+02	1.4E+03	8.0E+01	8.6E+05	1.1E+05
9 Months (2) (f)	2.7E+05	5.7E+04	1.2E+06	2.1E+03	1.2E+05	3.3E+03	1.4E+05
12 months (g)	4.6E+05	2.4E+03	1.8E+05	4.9E+03	6.2E+05	1.2E+06	6.0E+05
Averages	7.4E+05	1.8E+05	2.8E+05	3.5E+03	1.2E+05	3.6E+05	6.0E+05
Plate Count Relative to Raw Water	1.00	0.25	0.38	0.005	0.16	0.48	0.81

Total Coliform Bacteria, MPN/100 ml							
Exposure Time	**Loop Number**						
	1	2	3	4	5	6	7
3 Months (a)	<2	<2	<2	<2	<2	<2	<2
3 Months (2) (b)	<2	<2	<2	<2	<2	<2	<2
6 Months (c)	<2	<2	<2	<2	<2	<2	<2
6 Months (2) (d)	<2	<2	<2	<2	<2	<2	<2
9 Months (e)	<2	<2	<2	<2	<2	<2	<2
9 Months (2) (f)	<2	<2	<2	<2	<2	<2	<2
12 months (g)	<2	<2	<2	<2	<2	<2	<2
Averages	<2	<2	<2	<2	<2	<2	<2
Total Coliforms Relative to Raw Water	1	1	1	1	1	1	1

(a) Exposed 15/03/91 to 17/06/91(warmer)
(b) Exposed 18/12/91 to 16/03/92 (colder)
(c) Exposed 15/03/91 to 16/09/91(warmer)
(d) Exposed 16/09/91 to 16/03/92 (colder)

(e) Exposed 15/03/91 to 18/12/91(warmer)
(f) Exposed 17/06/91 to 16/03/92 (colder)
(g) Exposed 15/03/91 to 16/03/92

Cast Iron Coupons - Bacteriological Results

Heterotrophic Plate Count, CFU/in2							
Exposure Time	Loop Number						
	1	2	3	4	5	6	7
3 Months (a)	5.5E+07	7.7E+07	1.9E+08	7.2E+07	1.7E+08	3.8E+06	4.6E+08
3 Months (2) (b)	1.9E+07	1.1E+08	7.6E+08	5.4E+07	3.5E+08	4.0E+08	3.2E+08
6 Months (c)	4.0E+07	3.8E+07	2.9E+07	1.7E+07	8.3E+07	6.8E+07	3.5E+07
6 Months (2) (d)	4.3E+06	1.8E+07	5.7E+08	8.7E+06	2.9E+08	2.2E+08	2.5E+08
9 Months (e)	1.5E+07	3.0E+07	5.3E+07	4.9E+06	5.1E+07	8.8E+07	1.3E+08
9 Months (2) (f)	7.0E+06	9.4E+06	4.3E+08	8.8E+06	4.9E+08	1.1E+08	2.4E+08
12 months (g)	4.0E+06	1.1E+08	3.0E+08	9.9E+06	1.9E+08	6.7E+07	1.1E+07
Averages	2.1E+07	5.6E+07	3.3E+08	2.5E+07	2.3E+08	1.4E+08	2.1E+08
Plate Count Relative to Raw Water	1.00	2.72	16.16	1.21	11.25	6.63	10.02

Total Coliform Bacteria, MPN/100 ml							
Exposure Time	Loop Number						
	1	2	3	4	5	6	7
3 Months (a)	9	<2	<2	<2	<2	<2	<2
3 Months (2) (b)	22	<2	<2	<2	<2	<2	<2
6 Months (c)	34	<2	<2	<2	4	<2	<2
6 Months (2) (d)	23	<2	<2	<2	<2	<2	<2
9 Months (e)	13	<2	<2	<2	<2	<2	<2
9 Months (2) (f)	30	<2	<2	<2	<2	<2	<2
12 months (g)	30	<2	<2	<2	<2	<2	<2
Averages	23	<2	<2	<2	<2	<2	<2
Total Coliforms Relative to Raw Water	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

(a) Exposed 15/03/91 to 17/06/91(warmer)
(b) Exposed 18/12/91 to 16/03/92 (colder)
(c) Exposed 15/03/91 to 16/09/91(warmer)
(d) Exposed 16/09/91 to 16/03/92 (colder)

(e) Exposed 15/03/91 to 18/12/91(warmer)
(f) Exposed 17/06/91 to 16/03/92 (colder)
(g) Exposed 15/03/91 to 16/03/92

Quality Control Samples

The following samples were measured by the GVWD laboratory as a check on analyses done at the UBC laboratory.

Total Phosphorus				Silica as SiO2				
Sample Date	Loop	GVWD Measure	UBC Measure	UBC Relative to GVWD	Sample Date	Loop	GVWD Measure	UBC Measure	UBC Relative to GVWD
09/04/91	3	0.16	0.019	0.12	09/04/91	4	18	17.659	0.98
18/04/91	5	0.13	0.154	1.18	18/04/91	2	3.2	3.386	1.06
23/04/91	7	0.32	0.39	1.22	23/04/91	3	4	4.44	1.11
29/04/91	6	0.34	0.385	1.13	29/04/91	1	3.20	3.118	0.97
08/05/91	1	<0.005	0.007	1.40	08/05/91	3	3.7	3.829	1.03
15/05/91	7	0.35	0.408	1.17	15/05/91	4	16	15.025	0.94
23/05/91	2	<0.005	0.005	1.00	23/05/91	7	2.9	2.636	0.91
28/05/91	4	<0.005	0.006	1.20	28/05/91	5	2.9	2.767	0.95
04/06/91	5	0.101	0.135	1.34	04/06/91	3	3.7	3.556	0.96
11/06/91	6	0.301	0.398	1.32	11/06/91	4	16	15.759	0.98
19/06/91	3	0.2	0.019	0.10	19/06/91	2	2.9	2.91	1.00
26/06/91	1	<0.005	0.005	1.00	26/06/91	3	3.7	3.686	1.00
03/07/91	2	<0.005	0.007	1.40	03/07/91	5	2.8	2.868	1.02
10/07/91	7	0.3	0.337	1.12	10/07/91	4	17	16.598	0.98
17/07/91	5	0.13	0.142	1.09	17/07/91	3	3.6	3.766	1.05
24/07/91	6	0.32	0.384	1.20	24/07/91	4	15	13.833	0.92
31/07/91	7	0.3	0.33	1.10	31/07/91	3	3.8	3.779	0.99
08/08/91	3	0.15	0.022	0.15	08/08/91	1	3	3.271	1.09
14/08/91	4	<0.005	0.01	2.00	14/08/91	7	3.1	3.564	1.15
21/08/91	2	0.007	0.008	1.14	21/08/91	6	3.1	3.34	1.08
28/08/91	5	0.16	0.216	1.35	28/08/91	4	20	17.861	0.89
04/09/91	6	0.42	0.476	1.13	04/09/91	3	4.1	4.183	1.02
11/09/91	7	0.317	0.386	1.22	11/09/91	4	15	13.908	0.93
18/09/91	3	<0.005	0.039	7.80	18/09/91	2	3.5	3.437	0.98
02/10/91	1	<0.005	0.009	1.80	02/10/91	5	3.6	3.481	0.97
09/10/91	7	0.402	0.52	1.29	09/10/91	4	16	14.583	0.91
16/10/91	6	0.404	0.478	1.18	16/10/91	2	3.9	3.904	1.00
23/10/91	5	0.053	0.055	1.04	23/10/91	3	4.6	4.858	1.06
30/10/91	3	0.177	0.036	0.20	30/10/91	7	3.8	4.064	1.07
06/11/91	7	0.308	0.368	1.19	06/11/91	4	16	14.773	0.92
15/11/91	4	<0.005	0.004	0.80	15/11/91	6	3.6	3.706	1.03
20/11/91	5	0.083	0.123	1.48	20/11/91	4	14	13.821	0.99
27/11/91	2	0.007	0.008	1.14	27/11/91	1	3.1	3.618	1.17
04/12/91	3	0.183	0.025	0.14	04/12/91	3	4.3	4.558	1.06
11/12/91	7	0.35	0.368	1.05	11/12/91	7	2.8	3.979	1.42
18/12/91	6	1.2	1.265	1.05	18/12/91	6	2.9	3.798	1.31
30/12/91	5	0.12	0.063	0.53	30/12/91	5	3.4	3.783	1.11
06/01/92	4	<0.005	0.002	0.40	06/01/92	4	12	13.839	1.15
13/01/92	3	0.23	0.03	0.13	13/01/92	3	4.5	4.496	1.00
20/01/92	2	<0.005	0.008	1.60	20/01/92	2	3.3	3.716	1.13
27/01/92	1	<0.005	0.007	1.40	27/01/92	1	3.4	3.889	1.14
04/02/92	7	0.23	0.337	1.47	04/02/92	7	2.1	2.483	1.18
19/02/92	1	0.006	0.01	1.67	19/02/92	1	1.9	3.027	1.59
24/02/92	2	<0.005	0.009	1.80	24/02/92	2	2.9	3.483	1.20
03/03/92	3	0.22	0.016	0.07	03/03/92	3	3.6	5.15	1.43
10/03/92	3	0.19	0.092	0.48	10/03/92	3	3.5	5.238	1.50

Quality Control Samples - Faucets

The following faucet samples were measured by the GVWD laboratory as a check on analyses done at the UBC laboratory.

Sample Date	Loop	Total Copper, mg/L			Total Zinc, mg/L			Total Lead, mg/L		
		GVWD Meas.	UBC Meas.	UBC Relative to GVWD	GVWD Meas.	UBC Meas.	UBC Relative to GVWD	GVWD Meas.	UBC Meas.	UBC Relative to GVWD
27/03/91	7	0.11	0.05	0.45	0.47	0.47	1.00	0.027	0.020	0.74
06/04/91	2	0.38	0.35	0.92	0.23	0.24	1.04	0.190	0.158	0.83
10/04/91	5	0.09	0.05	0.56	0.22	0.25	1.14	0.030	0.036	1.20
26/04/91	1	0.62			0.28			0.260	0.250	0.96
10/05/91	3	0.08	0.16	2.00	0.07	0.01	0.14	0.017	0.011	0.65
15/05/91	6	0.05	0.01	0.20	0.41	0.45	1.10	0.014	0.013	0.93
23/05/91	4	0.05	0.00	0.00	0.06	0.06	1.00	0.032	0.037	1.16
29/05/91	1	0.69	0.64	0.93	0.30	0.26	0.87	0.093	0.130	1.40
26/06/91	3	0.10	0.08	0.80	0.08	0.05	0.63	0.023	0.025	1.09
09/07/91	4	0.07	0.05	0.71	0.11	0.08	0.73	0.034	0.047	1.38
24/07/91	5	0.11	0.11	1.00	0.21	0.19	0.90	0.027	0.030	1.11
08/08/91	6	0.03	<0.01	0.33	0.41	0.39	0.95	0.008	<0.010	1.25
01/10/91*	1	0.41	0.37	0.90	0.27	0.24	0.89	0.033	0.033	1.00
01/10/91**	7	0.06	0.04	0.67	0.28	0.25	0.89	0.009	0.009	1.00
23/10/91*	2	0.17	0.13	0.76	0.08	0.07	0.88	0.035	0.043	1.23
23/10/91**	4	0.04	0.01	0.25	0.02	0.02	1.00	0.020	0.024	1.20
06/11/91*	2	0.14	0.08	0.57	0.07	0.04	0.57	0.025	0.022	0.88
06/11/91**	1	0.05	0.03	0.60	0.07	0.05	0.71	0.006	0.012	2.00
20/11/91*	7	0.08	0.03	0.38	0.49	0.49	1.00	0.009	0.008	0.89
20/11/91**	5	0.04	0.05	1.25	0.08	0.11	1.38	0.005	0.006	1.20
04/12/91	5	0.12	0.12	1.00	0.22	0.19	0.86	0.021	0.025	1.19
18/12/91	6	0.13	0.08	0.62	0.51	0.52	1.02	0.008	0.011	1.38
15/01/92	4	0.07	0.02	0.29	0.14	0.12	0.86	0.025	0.029	1.16
19/02/92	5	0.07	0.02	0.29	0.17	0.16	0.94	0.010	0.009	0.90
12/03/92	5	0.08	0.04	0.50	0.18	0.14	0.78	0.009	0.007	0.78

* Filtered samples
** Digested samples. All samples after 20/11/91 were digested.

Quality Control Samples - Plumbing Coils

The following samples were measured by the GVWD laboratory as a check on analyses done at the UBC laboratory.

Sample Date	Loop	Total Copper, mg/L			Total Zinc, mg/L			Total Lead, mg/L		
		GVWD Meas.	UBC Meas.	UBC Relative to GVWD	GVWD Meas.	UBC Meas.	UBC Relative to GVWD	GVWD Meas.	UBC Meas.	UBC Relative to GVWD
25/03/91	5-2	2.08	1.96	0.94	0.38	0.44	1.16	0.026	0.026	1.00
03/04/91	1-1	0.90	0.87	0.97	0.04	0.02	0.50	0.020	0.022	1.10
09/04/91	3-2	1.17	1.11	0.95	0.02	0.01	0.50	0.011	0.012	1.09
24/04/91	4-1	2.68			0.02			0.016	0.012	0.75
09/05/91	2-2	0.91	0.87	0.96	0.01	<0.01	1.00	0.018	<0.01	0.56
14/05/91	6-1	1.97	1.95	0.99	0.60	0.61	1.02	0.045	0.049	1.09
22/05/91	7-2	0.81	0.78	0.96	0.17	0.18	1.06	0.035	0.052	1.49
28/05/91	3-1	1.01	0.99	0.98	0.01	<0.01	1.00	0.004	<0.01	2.50
04/06/91	4-2	0.46	0.44	0.96	<0.01	<0.01	1.00	0.017	0.012	0.71
11/06/91	5-1	1.95	2.03	1.04	0.22	0.18	0.82	0.008	<0.01	1.25
25/06/91	7-1	10.00	10.26	1.03	1.06	1.03	0.97	0.140	0.180	1.29
09/07/91	4-2	0.38	0.32	0.84	0.01	<0.01	1.00	0.023	0.023	1.00
23/07/91	6-2	0.64	0.62	0.97	0.54	0.50	0.93	0.003	<0.01	3.33
07/08/91	1-2	1.97	1.92	0.97	0.01	<0.01	1.00	0.023	0.021	0.91
20/08/91	5-1	3.30	3.13	0.95	0.56	0.52	0.93	0.029	0.028	0.97
10/09/91	3-2	1.10	1.05	0.95	<0.01	<0.01	1.00	0.008	0.005	0.63
01/10/91*	4-2	0.24	0.24	1.00	<0.01	<0.01	1.00	0.019	0.021	1.11
01/10/91**	1-1	1.18	1.18	1.00	0.06	0.05	0.83	0.009	0.014	1.56
22/10/91*	1-1	0.16	0.16	1.00	<0.01	0.04	4.00	0.003	0.001	0.33
22/10/91**	5-2	15.60	15.50	0.99	0.55	0.44	0.80	0.049	0.027	0.55
05/11/91*	6-2	0.08	0.06	0.75	0.21	0.20	0.95	0.001	0.003	3.00
05/11/91**	3-1	0.50	0.46	0.92	0.02	0.00	0.00	0.004	0.037	9.25
19/11/91*	7-1	0.12	0.14	1.17	0.30	0.30	1.00	0.008	0.008	1.00
19/11/91**	5-2	17.30	18.16	1.05	1.00	0.97	0.97	0.047	0.049	1.04
03/12/91	7-2	0.38	0.33	0.87	0.46	0.43	0.93	0.940	0.081	0.09
17/12/91	2-2	0.43	0.36	0.84	0.02	0.03	1.50	0.003	0.003	1.00
14/01/92	4-2	0.24	0.33	1.38	0.02	0.01	0.50	0.004	0.002	0.50
18/02/92	5-1	7.94	7.98	1.01	0.89	0.90	1.01	0.160	0.135	0.84
11/03/92	5-1	1.51	1.44	0.95	0.23	0.25	1.09	0.038	0.026	0.68

* Filtered samples
** Digested samples. All samples after 20/11/91 were digested.

Quality Control Samples - Solder Coils

The following samples were measured by the GVWD laboratory as a check on analyses done at the UBC laboratory.

Sample Date	Loop	Total Copper, mg/L			Total Zinc, mg/L			Total Lead, mg/L		
		GVWD Meas.	UBC Meas.	UBC Relative to GVWD	GVWD Meas.	UBC Meas.	UBC Relative to GVWD	GVWD Meas.	UBC Meas.	UBC Relative to GVWD
26/03/91	3	0.16	0.09	0.56	0.04	<0.01	0.25	3.50	3.72	1.06
05/04/91	6	0.21	0.17	0.81	0.90	0.94	1.04	3.01	3.10	1.03
11/04/91	4	0.06	0.03	0.50	0.03	0.01	0.33	3.65	3.73	1.02
24/04/91	5	0.53			0.54			5.07	5.02	0.99
09/05/91	1	0.14	0.20	1.43	0.01	<0.01	1.00	1.47	1.53	1.04
14/05/91	7	0.21	0.17	0.81	0.58	0.62	1.07	5.49	5.75	1.05
22/05/91	2	0.05	<0.01	0.20	0.04	0.03	0.75	3.11	3.27	1.05
28/05/91	6	0.13	0.12	0.92	0.84	0.80	0.95	1.90	1.53	0.81
04/06/91	3	0.13	0.09	0.69	0.02	<0.01	0.50	6.19	6.16	1.00
11/06/91	4	0.08	0.05	0.63	0.03	<0.01	0.33	15.60	14.60	0.94
25/06/91	4	0.14	0.12	0.86	0.03	0.02	0.67	21.90	22.20	1.01
09/07/91	5	0.19	0.17	0.89	0.52	0.49	0.94	12.60	14.92	1.18
23/07/91	7	0.62	0.62	1.00	0.94	0.90	0.96	14.90	17.44	1.17
07/08/91	4	0.13	0.08	0.62	0.02	<0.01	0.50	15.20	15.44	1.02
10/09/91	1	0.28	0.24	0.86	<0.01	<0.01	1.00	3.57	2.91	0.82
01/10/91*	3	0.03	0.02	0.67	0.01	<0.01	1.00	0.44	0.30	0.68
01/10/91**	1	0.30	0.26	0.87	0.06	0.06	1.00	1.46	1.20	0.82
22/10/91*	6	0.03	0.01	0.33	0.25	0.22	0.88	0.05	0.20	4.44
22/10/91**	3	0.14	0.11	0.79	0.10	0.07	0.70	7.10	6.10	0.86
05/11/91*	4	0.03	0.02	0.67	<0.01	<0.01	1.00	0.27	0.50	1.85
05/11/91**	5	0.46	0.43	0.93	0.34	0.28	0.82	6.58	4.30	0.65
19/11/91*	4	<0.02	0.07	3.50	0.01	0.04	4.00	0.34	0.28	0.82
19/11/91**	3	0.19	0.15	0.79	0.10	0.10	1.00	14.60	15.30	1.05
03/12/91	6	0.07	0.05	0.71	1.56	1.57	1.01	1.35	1.30	0.96
17/12/91	2	0.11	0.03	0.27	0.03	0.02	0.67	15.60	15.20	0.97
14/01/92	7	0.08	0.06	0.75	0.84	0.83	0.99	4.79	4.80	1.00
18/02/92	5	0.17	0.11	0.65	0.31	0.27	0.87	6.21	6.10	0.98
11/03/92	3	0.65	0.02	0.03	0.03	0.02	0.67	2.89	2.24	0.78

* Filtered samples
** Digested samples. All samples after 20/11/91 were digested.

PHOSPHORUS CONTENT, mg/L (Average of Two Samples)

Date			Loop Number					Avg Loops 1,2 & 4	Loop 3 Dose mg/L	Loop 5 Dose mg/L	Loop 6 Dose mg/L	Loop 7 Dose mg/L
	1	2	3	4	5	6	7					
15/02/91*	0.011	0.012	0.009	0.010	0.007	0.002	0.004	0.008	0.000	0.000	0.000	0.000
18/03/91**	0.003	0.006	0.075	0.004	0.480	1.313	1.313	0.027	0.048	0.452	1.285	1.286
28/03/91	0.017	0.011	0.027	0.002	0.137	0.301	0.370	0.015	0.012	0.122	0.286	0.355
02/04/91	0.004	0.008	0.010	0.004	0.138	0.357	0.377	0.006	0.004	0.132	0.351	0.371
10/04/91	0.011	0.011	0.019	0.010	0.141	0.354	0.344	0.013	0.006	0.128	0.340	0.330
18/04/91	0.006	0.005	0.017	0.014	0.154	0.394	0.420	0.012	0.005	0.141	0.381	0.407
23/04/91	0.018	0.093	0.024	0.007	0.131	0.384	0.390	0.016	0.008	0.115	0.368	0.374
29/04/91	0.007	0.016	0.039	0.012	0.156	0.385	0.389	0.019	0.020	0.136	0.365	0.369
08/05/91	0.007	0.013	0.019	0.006	0.147	0.385	0.370	0.010	0.008	0.136	0.374	0.359
15/05/91	0.002	0.003	0.035	0.008	0.172	0.411	0.408	0.015	0.020	0.157	0.396	0.393
23/05/91	0.005	0.005	0.025	0.005	0.128	0.355	0.348	0.012	0.014	0.116	0.344	0.336
28/05/91	0.010	0.010	0.034	0.006	0.171	0.351	0.380	0.016	0.018	0.154	0.334	0.363
04/06/91	0.012	0.010	0.037	0.009	0.135	0.373	0.346	0.019	0.018	0.116	0.354	0.327
11/06/91	0.005	0.010	0.040	0.009	0.150	0.398	0.379	0.018	0.022	0.132	0.380	0.361
19/06/91	0.002	0.006	0.019	0.010	0.161	0.377	0.365	0.010	0.009	0.150	0.367	0.354
26/06/91	0.005	0.003	0.026	0.001	0.107	0.326	0.305	0.011	0.015	0.096	0.315	0.294
03/07/91	0.003	0.007	0.024	0.005	0.107	0.327	0.288	0.011	0.014	0.097	0.316	0.278
10/07/91	0.006	0.008	0.024	0.004	0.131	0.401	0.337	0.011	0.013	0.120	0.389	0.325
17/07/91	0.006	0.006	0.013	0.003	0.142	0.358	0.311	0.007	0.006	0.135	0.351	0.304
24/07/91	0.006	0.005	0.016	0.005	0.158	0.384	0.352	0.009	0.007	0.149	0.375	0.343
31/07/91	0.003	0.000	0.014	0.002	0.147	0.414	0.330	0.006	0.008	0.141	0.408	0.324
08/08/91	0.004	0.007	0.022	0.003	0.171	0.419	0.368	0.010	0.012	0.162	0.409	0.359
14/08/91	0.022	0.008	0.031	0.010	0.172	0.423	0.365	0.021	0.010	0.151	0.402	0.344
21/08/91	0.004	0.008	0.035	0.006	0.164	0.372	0.365	0.015	0.020	0.149	0.357	0.350
28/08/91	0.007	0.008	0.036	0.006	0.216	0.375	0.359	0.016	0.020	0.200	0.359	0.343
04/09/91	0.025	0.015	0.038	0.043	0.077	0.476	0.428	0.035	0.003	0.041	0.440	0.392
11/09/91	0.009	0.008	0.024	0.006	0.051	0.441	0.386	0.013	0.011	0.038	0.428	0.373
18/09/91**	0.009	0.012	0.039	0.011	0.126	1.313	1.189	0.020	0.019	0.106	1.293	1.170
02/10/91	0.009	0.009	0.024	0.005	0.031	0.449	0.395	0.013	0.012	0.019	0.437	0.383
09/10/91	0.008	0.012	0.032	0.008	0.038	0.449	0.520	0.016	0.016	0.022	0.433	0.504
16/10/91	0.004	0.006	0.033	0.004	0.029	0.478	0.401	0.014	0.020	0.016	0.464	0.387
23/10/91	0.002	0.002	0.025	0.004	0.055	0.508	0.383	0.010	0.015	0.045	0.498	0.373
30/10/91	0.009	0.009	0.036	0.003	0.029	0.392	0.381	0.016	0.020	0.013	0.376	0.365
06/11/91	0.007	0.009	0.032	0.004	0.038	0.380	0.368	0.014	0.018	0.023	0.366	0.354
15/11/91	0.006	0.008	0.035	0.004	0.136	0.387	0.375	0.015	0.020	0.121	0.372	0.360
20/11/91	0.003	0.006	0.028	0.005	0.123	0.398	0.391	0.012	0.016	0.111	0.386	0.380
27/11/91	0.010	0.008	0.030	0.005	0.129	0.384	0.373	0.015	0.015	0.114	0.369	0.358
04/12/91	0.005	0.005	0.025	0.004	0.136	0.410	0.359	0.011	0.014	0.125	0.399	0.348
11/12/91	0.010	0.010	0.026	0.006	0.118	0.364	0.368	0.014	0.012	0.104	0.350	0.354
18/12/91**	0.008	0.007	0.055	0.002	0.367	1.265	1.182	0.022	0.034	0.345	1.243	1.161
30/12/91	0.009	0.006	0.021	0.006	0.063	0.349	0.320	0.012	0.009	0.051	0.337	0.308
06/01/92	0.006	0.007	0.038	0.002	0.109	0.393	0.342	0.015	0.023	0.093	0.377	0.327
13/01/92	0.007	0.007	0.030	0.003	0.106	0.379	0.335	0.013	0.017	0.093	0.366	0.322
20/01/92	0.008	0.008	0.045	0.004	0.110	0.378	0.332	0.019	0.026	0.091	0.359	0.313
27/01/92	0.007	0.008	0.035	0.005	0.112	0.343	0.338	0.016	0.020	0.097	0.327	0.322
04/02/92	0.009	0.009	0.038	0.004	0.116	0.370	0.337	0.017	0.021	0.099	0.353	0.320
19/02/92	0.010	0.008	0.032	0.009	0.137	0.409	0.355	0.017	0.015	0.120	0.392	0.338
24/02/92	0.005	0.009	0.048	0.005	0.111	0.381	0.343	0.019	0.029	0.092	0.362	0.324
03/03/92	0.001	0.002	0.016	0.000	0.097	0.318	0.303	0.005	0.010	0.092	0.313	0.297
10/03/92	0.018	0.016	0.092	0.011	0.140	0.368	0.363	0.040	0.052	0.099	0.327	0.323
Overall Averages, mg/L								**0.015**	**0.015**	**0.105**	**0.373**	**0.350**

* Pre-treatment levels. Average is for all loops.

** Indicates that inhibitor dosage in Loops 3, 5, 6 and 7 were tripled for initial passivation as recommended by the manufacturer. These dosage levels were not included in the averages.

SILICA CONTENT, mg/L (Average of Two Samples)

Date	Loop Number							Avg Loops 1,2&5-7	Loop 3 Dose mg/L	Loop 4 Dose mg/L
	1	2	3	4	5	6	7			
15/02/91*	2.455	2.517	2.533	2.478	2.529	2.493	2.560	2.509	0.000	0.000
18/03/91**	3.156	3.055	3.903	17.786	3.070	3.188	3.148	3.123	0.780	14.663
28/03/91	3.320	3.271	4.314	19.898	3.354	3.361	3.406	3.342	0.971	16.556
02/04/91	3.543	3.414	4.275	17.123	3.436	3.512	3.378	3.456	0.818	13.666
10/04/91	3.402	3.322	4.177	17.659	3.343	3.400	3.499	3.393	0.784	14.265
18/04/91	3.298	3.386	4.532	15.824	3.537	3.516	3.451	3.437	1.095	12.386
23/04/91	3.395	3.587	4.440	15.343	3.619	3.715	3.600	3.583	0.856	11.759
29/04/91	3.118	3.145	3.906	14.564	3.117	3.300	3.251	3.186	0.720	11.378
08/05/91	3.154	3.118	3.829	15.566	3.010	3.072	3.027	3.076	0.753	12.490
15/05/91	2.854	2.858	3.615	15.025	2.832	2.847	2.890	2.856	0.759	12.169
23/05/91	2.652	2.610	3.367	13.369	2.589	2.649	2.636	2.627	0.740	10.741
28/05/91	2.851	2.845	3.649	15.075	2.767	2.931	2.824	2.843	0.806	12.231
04/06/91	2.869	2.761	3.556	14.470	2.732	2.974	2.847	2.836	0.719	11.633
11/06/91	2.959	2.942	3.858	15.759	2.910	3.010	2.999	2.964	0.894	12.795
19/06/91	2.929	2.910	3.678	13.783	2.836	2.922	2.911	2.902	0.776	10.881
26/06/91	2.960	2.924	3.686	15.569	2.833	3.005	2.987	2.941	0.744	12.627
03/07/91	2.929	2.892	3.723	14.274	2.868	2.993	2.952	2.926	0.797	11.348
10/07/91	2.924	2.897	3.789	16.598	2.945	3.065	2.974	2.961	0.828	13.637
17/07/91	3.082	2.918	3.766	14.477	2.877	3.065	3.064	3.001	0.765	11.476
24/07/91	3.016	3.015	3.704	13.833	2.965	3.052	3.047	3.019	0.685	10.814
31/07/91	3.052	3.111	3.997	15.015	2.962	3.176	3.180	3.096	0.901	11.919
08/08/91	3.271	3.279	4.191	14.956	3.257	3.338	3.290	3.287	0.904	11.669
14/08/91	3.397	3.368	4.307	13.835	3.390	3.573	3.564	3.458	0.849	10.377
21/08/91	3.273	3.260	4.209	15.838	3.265	3.340	3.341	3.296	0.913	12.543
28/08/91	3.624	3.565	4.272	17.861	3.546	3.747	3.741	3.644	0.627	14.216
04/09/91	3.327	3.286	4.183	14.468	3.228	3.363	3.331	3.307	0.876	11.161
11/09/91	3.369	3.323	4.193	13.908	3.271	3.403	3.358	3.345	0.848	10.563
18/09/91**	3.475	3.437	4.819	14.100	3.459	3.731	3.670	3.554	1.264	10.545
02/10/91	3.616	3.511	4.334	14.945	3.481	3.633	3.615	3.571	0.763	11.374
09/10/91	3.916	3.907	4.672	14.583	3.821	3.966	3.985	3.919	0.753	10.664
16/10/91	3.959	3.904	4.822	15.440	3.936	4.128	4.154	4.016	0.805	11.423
23/10/91	3.998	4.025	4.858	16.062	4.000	4.065	4.083	4.034	0.824	12.027
30/10/91	4.009	3.921	4.857	15.246	3.926	4.157	4.064	4.015	0.842	11.231
06/11/91	3.865	3.777	4.774	14.773	3.737	3.871	3.843	3.818	0.955	10.954
15/11/91	3.760	3.623	4.550	13.383	3.623	3.706	3.671	3.676	0.874	9.706
20/11/91	3.462	3.391	4.370	13.821	3.169	3.441	3.467	3.386	0.984	10.435
27/11/91	3.618	3.542	4.639	13.731	3.601	3.783	3.756	3.660	0.979	10.071
04/12/91	3.655	3.525	4.558	14.024	3.454	3.778	3.695	3.621	0.937	10.403
11/12/91	3.772	3.710	4.830	15.470	3.619	3.926	3.979	3.801	1.029	11.669
18/12/91**	3.572	3.498	5.452	16.011	3.533	3.798	3.755	3.631	1.821	12.380
30/12/91	3.816	3.713	4.513	13.877	3.783	3.800	3.636	3.749	0.764	10.128
06/01/91	3.650	3.625	4.533	13.839	3.559	3.635	3.797	3.653	0.880	10.186
13/01/92	3.678	3.605	4.496	14.127	3.534	3.723	3.687	3.645	0.851	10.482
20/01/92	3.680	3.716	4.681	15.010	3.721	3.859	3.853	3.766	0.915	11.244
27/01/92	3.889	3.767	4.753	14.836	3.768	3.896	3.893	3.842	0.911	10.994
04/02/92	2.410	2.446	3.346	13.177	2.367	2.557	2.483	2.452	0.894	10.725
19/02/92	3.027	3.201	3.876	13.893	3.060	3.399	3.365	3.210	0.666	10.682
24/02/92	3.522	3.483	4.501	14.405	3.401	3.493	3.473	3.474	1.026	10.931
03/03/92	4.349	4.266	5.150	17.079	4.203	4.438	4.402	4.331	0.819	12.748
10/03/92	4.044	4.329	5.238	18.119	4.237	4.418	4.395	4.284	0.954	13.835
							Overall Averages, mg/L	3.390	0.845	11.731

* Pre-treatment levels. Average is for all loops.

** Indicates that inhibitor dosage in Loop 3 was tripled for initial passivation as recommended by the manufacturer. These dosage levels were not included in the averages.

Incidents Which May Have Impacted The Outcome Of The Experiment

The following are copies of comments from the experiment notes.

DATE	ITEM
28/03/91	Discovered that the Pump feeding TPC 223 in Loop 3 was set too low by about 20 percent. Pump was reset to the correct setting.
06/04/91	Circuit breaker for the outlet for the pumps that feed $NaHCO_3$, Virchem 939 and TPC 223 was open. For how long is not known; could be as long as 2 days.
30/04/91	Plant shut down at 10:00 to install Corrosometer probes. Allowed 24 hours for PVC soldered welds to set. Plant restarted at 10:15 on 01/05/91.
06/05/91	Plant ran continuously from startup (by others) on 01/05/91 til about 10:00 on 03/05/91 when it shut down automatically probably because of GAC filter headloss. The timer was not set, so flow was continuous. It then sat idle until today because I was away for the week and there was no one to check on the plant in my absence. All chemicals except HCl ran out. Chemicals were rebatched and the plant was restarted at 11:05 today.
	After rebatching chemicals it was noticed that the pH in Loops 3 and 4 were quite high (8.96 and 9.23 respectively). This could have been due to poor mixing and a higher concentration of inhibitor (both of which are basic) being on the bottom near the pump intake. Care will be taken to ensure proper mixing in future.
	While backwashing the GAC filters, one of the perforated pipes on the smaller filter gave way which resulted in a loss of about $2/3$ of the GAC being lost from that filter. System was shut down and the GAC replaced on 07/05/91. System was back on at 17:00 on 07/05/91.
10/05/91	High pH and alkalinity in Loop4 was due to the HCl feed being blocked. Line was replaced and feed then seemed OK.
13/05/91	Lines to faucets for Loops 1 and 3 were leaking. Repaired.
21/05/91	Circuit breaker for the outlet for the pumps that feed $NaHCO_3$, Virchem 939 and TPC 223 was open again, since about P.M. 19/05/91. Reset at 12:00 today.

04/06/91   Faucet on Loop 1 was almost totally clogged, and had been so for
                            several weeks. Faucet screen was cleaned out and now runs freely.

05/06/91   Feed pump for $Ca(OH)_2$ to Loop 7 was off, for how long is
                            unknown. The electrical plug was loose. Rectified.

06/06/91   Feed pump for $Ca(OH)_2$ to Loop 5 was off, for how long is
                            unknown. Rectified.

08/06/91   Feed pump for $Ca(OH)_2$ to Loop 2 was off, for how long is
                            unknown. Rectified.

11/06/91   Power for $CA(OH)_2$ feeds to Loops 2, 5, and 3 is out and have not
                            been able to rectify. System shut down until A.M. 12/06/91. There
                            was a blown fuse in the control panel.

17/06/91   System shut down for removal and replacement of pipe coupons
                            (three month or 94 days). New City of Vancouver test loops
                            installed. System kept down for 24 hours so PVC solder welds
                            could set. System back up A.M. 18/06/91.

12/08/91   Discovered that the system had been shut down since 08/08/91.
                            Power was never turned back on after having been shut off.

19/08/91   Circuit breaker for the outlet for the pumps that feed $NaHCO_3$,
                            Virchem 939 and TPC 223 was open again. Reset at 10:15 today.

21/08/91   Hose to the faucet for Loop 1 had popped off. Unable to obtain an
                            isolated faucet sample for Loop 1 this time.

26/08/91   HCl feed hose to Loop 4 was crimped. Rectified.

29/08/91   System was shut down at about midnight due to flooding (extreme
                            heavy rain). The flooding kept me from going into the plant for
                            two days and caused numerous minor problems which had to be
                            rectified, and some of the chemicals had to be rebatched. System
                            was back up and running at 15:00 on 01/09/91.

03/09/91   Circuit breaker for the outlet for the pumps that feed $NaHCO_3$,
                            Virchem 939 and TPC 223 was open again. Reset at 10:10 today.

                            Flow in Loops 1 and 4 was quite low (Loop 1 - 2.9 USGPM and
                            Loop 4 - 3.7 USGPM). Problem was due to the bypass valves for
                            those loops only being partially open. Rectified.

Have noticed that flow backs off in some loops overnight for no apparent reason. The only way to deal with this is to be sure and chech the flow the first thing each day.

04/09/91

Pump feeding Virchem 939 to Loops 6 and 7 is not working even though the power light comes on. Problem may have occurred during the flood but not discovered until today. Pump was changed and sent in for repair.

Feed pump for $Ca(OH)_2$ was off, for how long is unknown. Power indicator light was on but the "INT/EXT" switch on the back was set to "EXT". Rectified.

07/09/91

Water was shut off at 10:45 for about 6 hours due to a leak in the generating room. Feed pumps were still on, though, so they ran by themselves from 14:00 to 15:00. System was back to normalwhen the timer came on again at 19:00.

10/09/91

Used new KCl solution to calibrate the Conductivity meter. The meter required about a 20 percent upward adjustment, so the more recent readings may be somewhat suspect.

16/09/91

System shut down at 08:20 for removal and replacement of pipe coupons (6 months, or 184 days) and replacement. Virchem 939 and TPC 223 dosage rates tripled and doubled respectively for the next two days for initial passivation.

18/09/91

Rebatched Virchem 939 and TPC 223 vats to give normal feed again.

27/09/91

After one week absence, discovered that flow in Loop 1 was low at about 60 percent of the required level. No explanation for this. Valve was readjusted.

30/09/91

Pump feeding $Ca(OH)_2$ to Loop 7 was not working even though the power light was on. How long is unknown. Pump replaced.

01/10/91

Change in metals sampling protocol. For the Solder Coils samples, the water in the cannisters was shaken up as much as possible to mix the sediment and suspend it and all of it was poured into a two L container. The container was then shaken vigorously and one L was poured into a container for pH, alkalinity, etc., analysis. The remainder was poured into a 250 ml container. The sample in the 250 ml container was divided in half, with half being filtered through a no. 42 Whatman filter. Finally, the two 125 ml samples were acidified and transported to UBC for

metals analysis. The solder canisters were cleaned out before replacing them on the system to minimize metals being carried from one sample period to the next. The Plumbing Coil and Faucet samples were gathered the same way, but a portion of each was filtered through no. 42 Whatman filters and then both the filtered and the unfiltered samples were acidified. Prior to metals measurement, the unfiltered samples were digested.

09/10/91   Main water valve was closed since 08/10/91, so the system ran for almost 24 hours with no water, only chemicals flowing. Rectified.

15/10/91   Water flow in Loop 1 was very low again. No apparent reason. Rectified.

21/10/91   The water flow in all loops needed considerable adjustment. This seems to be an ongoing problem that seems to be getting worse.

23/10/91   Again water flow needed considerable adjustment in all loops.

25/10/91   Water flow needed adjustment, particularly Loop 1.

05/11/91   Water flow has not required nearly as much adjustment lately, seems back to normal. Noticed that it was impossible to remove all the sediment from the solder coil cannisters. Some of it always stays behind meaning that the metals determinations have a negative error.

12/11/91   Ca(OH)$_2$ feed line to Loop 5 was leaking. Repaired.

20/11/91   Heavy rainfall for the last few days likely responsible for the lower conductivity, pH, and alkalinity levels.

26/11/91   System was not working at 09:35 due to auto shutoff. Probable cause was the float valve being bumped yesterday afternoon while SCBV pers were washing anthricite in the large GAC filter.
29/11/91   Used new KCl solution for Conductivity which could account for the higher conductivity measurements today.

02/12/91   Change in metals sampling protocol. The Solder Coil canisters were flushed out to remove any sediment (significant amounts of sediment were flushed from the canisters for Loops 5, 6, and 7) before they were isolated for the 24 our standing period. This should help ensure that the metals measured are from the 24 hour standing period only.

16/12/91	Power plug for the pumps feeding TPC 223 to Loop 3 and NaHCO3 to Loop 7 was out. Rectified.

Had planned to replace the third set of pipe coupons, but due to a breakdown in communications with GVRD lab staff the task was postponed to Wed. The lines had all been loosened and drained, and had to be resealed and water flow restarted. Initial flow after reconnection was very dirty, likely due to sloughing off of some of the biofilm.

18/12/91	System shut down for removal and replacement of the third set of pipe coupons (nine months or 277 days). Virchem 939 and TPC 223 dosage rates tripled and doubled respectively for the next four days for initial passivation.

HCl feed line to Loop 4 was crimped. Rectified.

22/12/91	Rebatched Virchem 939 and TPC 223 vats to give normal feed again.
04/02/92	HCl feed line to Loop 4 was crimped. Rectified.
06/02/91	System had been shut down since 04/02. Neglected to turn it back on that day. Back on at 08:15 today.
16/03/92	System shut down for removal of all the remaining pipe coupons (12 month, duplicates of 3, 6, and 9 month; 366 days). Cu coupon no. 37 was damaged on removal because it was stuck in its container. Cu coupon no. 20 was also damaged because it fell on the floor. Some epoxy scraped off both of these.

Experiment terminated today. Plant allowed to run for a few days to use up the remainder of the chemicals in the vats.