June 20, 1994
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HDR

Mr. Patrick Chan
U.S. Environmental Protection Agency
75 Hawthorne Street
San Francisco, California 94105-3901

Subject: City of Fresno - Desktop Corrosion Control Evaluation

Dear Patrick:

Enclosed is one copy of the Desktop Corrosion Control Evaluation for the City of Fresno's Water Division. This copy is meant to be inserted directly into your City of Fresno Lead and Copper Compliance Monitoring binder. A new divider and table of contents are included so that the "Desktop Study" can be added at the end of the binder.

If you have any questions concerning this report and its conclusions, please call me at 916-939-4100.

Very truly yours,

Dave Murbach

For Perri Standish-Lee
Vice President

cc: Cindy Forbes, California Department of Health Services
Martin McIntyre, City of Fresno
Bill Dunn, City of Fresno
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Second Round Results	City of Fresno's Results of Second Round of Initial Monitoring for Lead and Copper Rule Compliance
Follow-Up Monitoring Results	To be completed
EPA/DHS Correspondence	City of Fresno's Correspondence with USEPA and CA DHS (Contains Log Sheet at Front of Section)
Desktop Study	City of Fresno's Desktop Corrosion Control Evaluation

Desktop Corrosion Control Evaluation

for

City of Fresno

Water Division

City of

FRESNO

Submitted by

HDR Engineering, Inc.
5175 Hillsdale Circle
El Dorado Hills, CA 95762

June 1994

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

The City of Fresno has fulfilled the initial USEPA Lead and Copper Rule (LCR) monitoring requirements, including two rounds of sampling and analysis for lead and copper at 130 customer tap water locations. The first round of samples was collected during April and May of 1993. The second round was collected during June and July of 1993. The 90th percentile levels for lead and copper were well below the LCR action limits during both rounds of sampling. During the second round of monitoring there were six sample locations with significant increases in tap water lead concentration compared to the first round. The consequence of these increased concentrations was to increase the 90th percentile lead level from 0.0025 mg/L for the first round to 0.008 mg/L for the second round. The City of Fresno contacted all these residents and found that sampling procedures were not followed. All six residences were sampled a third time with results comparable to the low lead concentrations observed during the first round of monitoring. The second round sampling results indicated that corrosion control had not been "optimized" by LCR standards. As a result, this Desktop Corrosion Control Evaluation for the affected areas of the system was initiated per LCR requirements. However, because of the errors in sampling, the recommendations of this Desktop Corrosion Evaluation will not be implemented unless follow-up monitoring shows that corrosion control within the system is not optimized.

The provisions of the LCR depend on the size of the system, with the City of Fresno regulated as a large-sized system. This classification is based upon the City's 97,000 service hookups which supply water to a population of approximately 400,000. This Desktop Corrosion Control Evaluation is required to be submitted to the Environmental Protection Agency and the California Department of Health Services by July 1, 1994.

The purpose of this evaluation is to identify feasible corrosion control strategies appropriate for the particular material types and water quality conditions present within the City of Fresno's water system. One of the first steps of the evaluation was to compile and analyze the water quality data for the existing water supplies that provide water to the LCR high corrosion risk residences identified during the Materials Survey. Currently, the City of Fresno's source

water is groundwater from approximately 200 wells throughout the service area. The eight wells monitored for the LCR contain pH levels in the range of 7.1 to 7.9 with moderate to high levels of alkalinity (79 to 180 mg/L as $CaCO_3$). Calculated Langelier indices for all waters indicate that the water is slightly undersaturated with respect to $CaCO_3$. These qualities are indicative of groundwater that may be slightly corrosive.

The corrosion control investigation reported herein focused on optimizing the lead corrosion within the City's water system. Seven corrosion control strategies were evaluated in the study. All are deemed capable of achieving reduction in lead corrosion rates: $CaCO_3$ deposition, carbonate passivation, orthophosphate addition, zinc orthophosphate addition, ortho-polyphosphate blend addition, silicate addition, and silicate-orthophosphate blend addition.

Each of the seven corrosion control strategies were evaluated based on the following criteria: overall corrosion control effectiveness; Safe Drinking Water Act regulatory constraints; minimization of potential re-equilibration and regrowth problems; functionality; and economics. Based on these criteria, the zinc orthophosphate addition strategy is ranked highest and is considered to be the most attractive corrosion control strategy for the City of Fresno's water system. This strategy was chosen because of its high ranking in the corrosion control effectiveness, functionality, and economics criteria. The addition of zinc orthophosphate achieves corrosion control by forming an insoluble scale on the pipe surface that changes the electrochemical nature of the metal surface. This method is also referred to as passivation. Orthophosphate corrosion inhibitor addition is also ranked high because of its operability and economics.

Implementation of any corrosion control strategy is not expected to significantly reduce the low 90th percentile lead concentrations (0.0025 and 0.008 mg/L). In general, unnecessary changes to a system's water quality are to be avoided. Any change to the chemical makeup of a distributed water, such as the implementation of corrosion control, forces the water to come to a new equilibrium with the new water chemistry. In this process of re-equilibration, substantial solubilization of scales and mineral deposits may take place, the consequences of which may be very serious for distributed water quality. Under a strict interpretation of the

LCR, the City of Fresno's water system is not optimized for corrosion control. Optimized corrosion control is defined in the LCR as having the 90th percentile lead level for tap water no greater than the source water lead level plus 0.005 mg/L. For the City of Fresno, the source water average lead level is 0.001 mg/L and the 90th percentile level for the second round (0.008 mg/L) defines the system as not optimized. However, if the resample results could be used in place of the original samples collected improperly, the 90th percentile lead level for the second round of monitoring would be 0.006 mg/L and the system would be considered optimized. Because of this, and the risk of re-equilibration by implementing a corrosion control program, the City of Fresno will not implement the recommended corrosion control strategy unless the follow-up monitoring demonstrates that the system is not truly optimized for corrosion control.

SECTION 1
INTRODUCTION

SECTION 1

INTRODUCTION

GENERAL

The Lead and Copper Rule (LCR) compliance monitoring program identified low lead and copper levels in the City of Fresno's water system. The 90th percentile levels for lead were 0.0025 and 0.008 mg/L during the two rounds of initial monitoring, well below the LCR action limit of 0.015 mg/L. In addition, the 90th percentile levels for copper were 0.43 mg/L during both rounds of initial monitoring, well below the LCR action limit of 1.3 mg/L. However, the difference in lead levels of the source waters and the 90th percentile level for the second round of initial monitoring was greater than 0.005 mg/L. Therefore, according to the LCR, corrosion control within the City of Fresno's water system is not "optimized."

However, six of the samples were determined to be collected improperly during the second round of monitoring. When these residences were resampled, the new results showed the 90th percentile lead level was 0.006 mg/L and the City of Fresno's water system was optimized for corrosion control. This Desktop Corrosion Control Evaluation addresses the "optimization" of lead corrosion levels, should follow-up monitoring indicate the need for implementation of a corrosion control program.

REPORT ORGANIZATION

This Desktop Corrosion Control Evaluation was prepared in accordance with the USEPA Lead and Copper Rule Guidance Manual, Volume II: Corrosion Control Treatment. This report is presented in the following six sections. Sections 2 and 3 describe the existing water system and water quality conditions of the City of Fresno's water system. Section 3 also discusses the status of the initial LCR monitoring program. Section 4 presents lead corrosion theory and discusses specific water quality parameters of the source waters that have a fundamental role in lead corrosion release rates. Section 5 identifies corrosion control approaches. Section 6

compares and ranks the seven specific corrosion control strategies against evaluation criteria. In Section 7, two preferred alternatives are identified for future investigation, if necessary.

SECTION 2
FACILITIES

SECTION 2

FACILITIES

GENERAL

The City of Fresno's service area is located within Fresno County in the southern San Joaquin valley of central California. The City of Fresno serves all of the city and some parts of the county with water taken exclusively from groundwater supplies. The City provides water to a population of approximately 400,000. This population classifies the City of Fresno as a large public water supplier under the requirements of the Lead and Copper Rule (LCR).

SOURCE WATER SUPPLY

The source water used by the City of Fresno comes from a groundwater supply. The City has nearly 200 pump stations throughout the service area to provide water to its customers. Total production from these pumping stations averages 106 mgd. Chlorine is added at 61 of these pump stations for disinfection. Eight pump stations were identified as the water sources for the 538 high risk corrosion site residences identified during the LCR Materials Survey. Table 2.1 lists the average water production capacities as well as the chlorination status for each of the eight pump stations.

The City of Fresno's distribution system radiates out from the individual pump stations with interties between some of the neighboring pump station supply regions. There is no network of large diameter water mains throughout the system and no operationally centralized water storage facilities.

PIPING MATERIAL

Distribution System

No lead distribution system lines were identified during the Materials Survey. Distribution system maps and interview of long-time and retired employees were used to determine that lead distribution system lines do not exist.

Types of materials found in the distribution system include:

- Ductile Iron (400 miles)
- Cast Iron (400 miles)
- Steel (400 miles)
- Asbestos Cement (300 miles)
- Plastic (100 miles)

Service Lines

The City of Fresno maintains approximately 97,000 service connections. Based upon the Materials Survey, since the 1960's the material used for service lines is typically one inch copper. No lead service lines were identified. The City of Fresno's policy is to remove lead service lines if they are found during maintenance procedures.

Interior Plumbing

The interior plumbing in the City of Fresno's service area is approximately 90 to 95 percent galvanized piping in the homes built before 1988. The remainder of the pre-1988 homes contain mostly copper plumbing, which is assumed to be assembled with tin/lead solder. Since 1989, copper plumbing has become prevalent in new home construction. This information was confirmed during the Material Survey with plumbing and building contractor surveys as well with the building inspectors for the City of Fresno. The LCR Materials Survey identified

538 locations defined as high corrosion risk residences by the LCR (residences with copper plumbing assembled with tin/lead solder between 1982 and 1987).

The presence of tin/lead solder was confirmed during the Materials Survey at 18 random LCR tap water sample sites.

Table 2.1 - Pump Station Production Rates and Chlorination Status

Pump Stations	Average Production Rate (mgd)	Chlorine Added?
79	1.3	Yes
86	0.4	No
91	1.5	Yes
97	2.3	Yes
99	0.6	Yes
121	0.0003	No
131	0.6	Yes
140	0.5	Yes

POTENTIAL TREATMENT SITE LOCATIONS

The optimal treatment site locations are not dependent upon the selected alternative. Because of the lack of any centralized points of entry to the distribution system, it appears that the preferred locations are at the individual pumping stations providing water to the high corrosion risk residences.

Most of the pump stations are located within 20 foot square enclosures. It appears that space is available at all the pump stations for chemical storage tanks and metering equipment. If corrosion control equipment needed to be installed, care should be taken to leave space for any arsenic, radon, or organic chemical removal that may be required in the future.

SECTION 3
WATER QUALITY

SECTION 3

WATER QUALITY

GENERAL

The water quality data for the City of Fresno for the monitored sources, distribution system, and customer taps were compiled and evaluated to facilitate the identification of corrosion control strategies.

SOURCE WATER

The water quality data for the City of Fresno source water is summarized in Figures 3.1 and 3.2. The parameters presented include pH, calcium, alkalinity, specific conductance, and temperature. Also presented in Figure 3.2 is the computed Langelier Index. The total number of analyses for each parameter ranged from four to seven. Appendix A lists the actual data. Analytical results were presented for the eight source water pump stations (PS-79, PS-86, PS-91, PS-97, PS-99, PS-121, PS-131, and PS-140) from January 1990 through September 1993. These eight pumping stations are in the same areas as the tap water monitoring sites and represent the source waters for all tap water monitoring sites in the LCR Tier 1-C sampling pool. Table 3.1 presents the locations of the source waters. All but two of these pump stations have chlorine treatment at this time (see Table 2.1). The remaining pump stations are expected to add chlorine treatment in the near future.

pH

The pH of these source waters is moderately low, with a range of 7.1 to 7.9. Pump Station (PS) No. 140 has the lowest pH at 7.1, as well as the highest at 7.9. The minimum pH level recorded at all the other sources is between 7.3 and 7.5. Low pH levels are associated with corrosive waters.

In addition, as discussed in Section 4, the adverse effects of alkalinity on lead release rates are enhanced in waters with low pH. Adjustments to pH play a fundamental role in all of the corrosion control strategies discussed in Section 5.

Table 3.1: Source Water Locations

Pump Station Number	Address	Location	Associated Tap Water Sample No.
79	6779 N. Valentine	Herndon & Valentine	2
86	8755 N. Millbrook	Millbrook/Clovis WHS	10
91	2602 W. Alluvial	Alluvial & Van Ness	1 & 3
97	3998 W. Herndon	Herndon & McCampbell	Tract D*
99	4410 W. Austin	Austin & Blythe	Tract C*
121		Blackstone & Sierra	4,144,158
131	7886 N. Millbrook	Cedar & Teague	Tract E*
140	10202 N. Millbrook	Millbrook & Ft. Washington	Tract B*

* Tract B contains 63 sample sites, Tract C contains 46 sample sites, Tract D contains 29 sample sites, and Tract E contains 17 sample sites.

Calcium and Langelier Index

Calcium levels ranged from 16 to 33 mg/L in the source waters. The calcium values were highest at PS-86 (30 to 33 mg/L) and lowest at PS-99 (16 to 18 mg/L). The calculated Langelier Indices for all the source waters were negative ranging between -0.04 and -0.8. Negative values of the Langelier Index indicate that the water is undersaturated with respect to $CaCO_3$. One of the corrosion control strategies is to shift the $CaCO_3$ equilibrium to supersaturated conditions, thereby promoting the deposition of a $CaCO_3$ barrier.

Alkalinity

Source water alkalinity levels (in units of mg/L $CaCO_3$) ranged from 79 to 180. The average alkalinity was highest at PS-86 (144) and lowest at PS-99 (85). The alkalinity range for these City of Fresno source waters is moderate. Alkalinity levels are important to the lead release rates, due to the solubility relationship between the protective scales and alkalinity levels. The

effects are most pronounced at low pH levels. The influence of alkalinity on lead release rates is discussed in depth in Section 4. A corrosion control strategy involving the adjustment of alkalinity is discussed in Section 5.

Specific Conductivity

The specific conductivity levels were found to be in a range from 200 to 360 μmhos/cm. The average specific conductivity was highest at PS-86 (337 μmhos/cm) and lowest at PS-99 and PS-131 (234 μmhos/cm).

Temperature

The temperature of the source waters was found to range between 20.6 and 31.8°C. The highest temperature was measured at PS-140 (31.8°C) on April 28, 1993. The average temperature for all the sources ranges between 21.9 and 24.7°C.

Lead and Copper

Lead was detected at levels between 0.001 and 0.005 mg/L in single samples from PS-99, PS-121, and PS-131 (four to six samples collected from each source). All other lead analysis from the eight pumping stations did not detect any lead above 0.001 mg/L. The average lead concentration from the source waters was 0.001 mg/L.

Copper was found at levels between 0.01 and 0.05 mg/L in all samples from PS-99 and in a single sample from PS-121. All other copper analysis from the pumping stations did not detect copper above 0.01 mg/L.

Sulfate and Chloride

Sulfate and chloride were only monitored at PS-140 during the last three years. Sulfate was detected at 12 mg/L and chloride was detected at 15 mg/L.

DISTRIBUTION WATER

Figures 3.3 and 3.4 summarize the water quality data from the distribution system for water from pumping stations 79, 86, 91, 97, 99, 121, 131, and 140 during the time period of April through July 1993. The parameters measured include pH, alkalinity, calcium, specific conductivity, and temperature. Appendix A lists the individual data.

Levels of pH from the distribution locations ranged between 7.0 and 7.7, slightly lower than the source waters. Calcium distribution levels ranged from 16 to 44 mg/L, with the average values consistently higher than the source water. Alkalinity levels were in the range of 75 to 170 mg/L as $CaCO_3$, consistent with the source waters. Specific conductivity levels ranged from 190 to 470 µmhos/cm, with the upper end values higher than for the source waters. The temperature levels of the distribution locations ranged from 20.8 to 32.0°C, at values that were on the average 2 to 3 degrees higher than the source water.

The average distribution system temperature during the first monitoring round was 22.2°C and 26.5°C during the second round. None of the other water quality parameters changed significantly between the two rounds of monitoring.

CUSTOMER TAP WATER

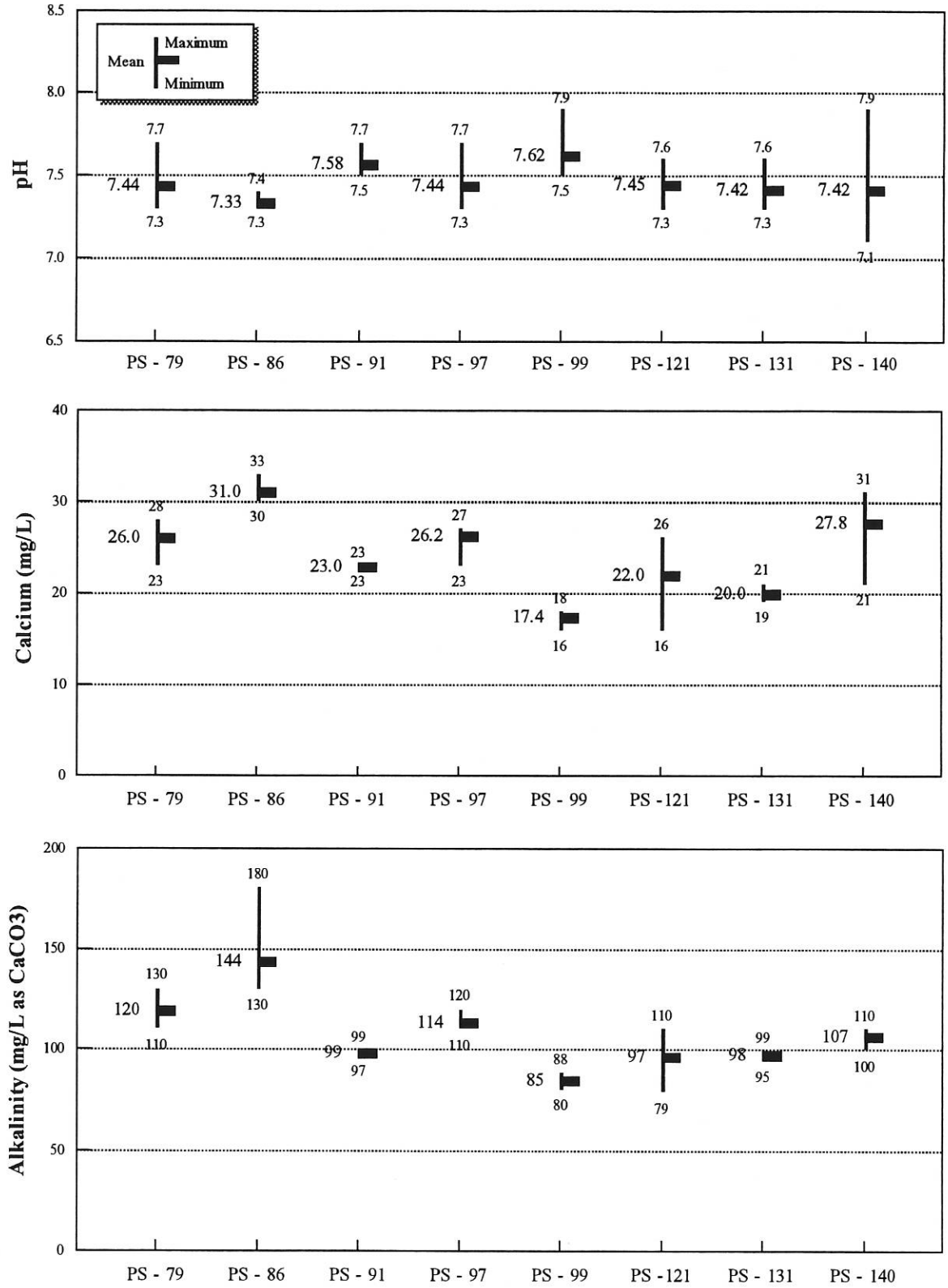
Two rounds of tap water samples for lead and copper analyses were obtained from 130 residences in the City of Fresno's service area. The first round of samples was collected between April 20 and May 12, 1993. The second round of samples was collected between June 21 and July 11, 1993. Sampling protocol included collection of the immediate water flowing from the cold kitchen or bathroom faucet, following a stagnation period of 6 to 8 hours. The distribution of results is graphically presented in Figure 3.5. A listing of the sample results for each residence is presented in Appendix A.

It is apparent from Figure 3.5 that copper is not a problem in the City of Fresno. The 90th percentile levels were 0.43 mg/L for each round of monitoring. None of the samples collected contained copper levels above the LCR action limit of 1.3 mg/L.

Figure 3.5 also shows that lead is generally not a problem either. The 90th percentile levels were 0.0025 mg/L for the first round of monitoring and 0.008 mg/L for the second. The median (50th percentile level) during both rounds of monitoring was 0.0025 mg/L. However, seven of the samples collected contained lead levels above the LCR action limit of 0.015 mg/L. All of the seven had the same source of water, PS-140. Six of these samples were collected during the second round of monitoring.

The residents at the seven locations with sample results above the LCR action limit were interviewed to determine the source of lead in their samples. None of the seven collected their sample from recently installed faucets. Four of the residents believe that they may have collected the sample from the middle (hot/cold mixture) setting on their single handle faucets. Two residents collected their samples from faucets where the water had been stagnant in the pipe for at least 72 hours. The final resident had a faucet that wasn't working on the day he collected the sample and disconnected the tubing leading to the faucet to collect a sample from the tubing underneath the kitchen sink. None of these seven collected their samples in accordance with the sampling protocol. All the residences were resampled by the residents and the lead levels were all well below the LCR action limit. Figure 3.6 presents the sample results for these seven residences.

The difference between the lead level of the source waters and the 90th percentile tap water sample was 0.0015 mg/L for the first round of monitoring and 0.007 mg/L for the second. The LCR definition of a water system with optimized corrosion control is one where the difference between the source and tap water lead levels is less than 0.005 mg/L. Therefore, the City of Fresno's water system is not "optimized" with respect to lead corrosion and corrosion control strategies will be focused on addressing lead corrosion. However, using the resample results for the seven samples collected improperly, the 90th percentile lead levels drop to 0.0025 mg/L and 0.006 mg/L in the first and second rounds, respectively (see Figure 3.7). These results indicate that the City of Fresno's water system is optimized for corrosion under the LCR.



SOURCE WATER QUALITY AT PUMPING STATIONS

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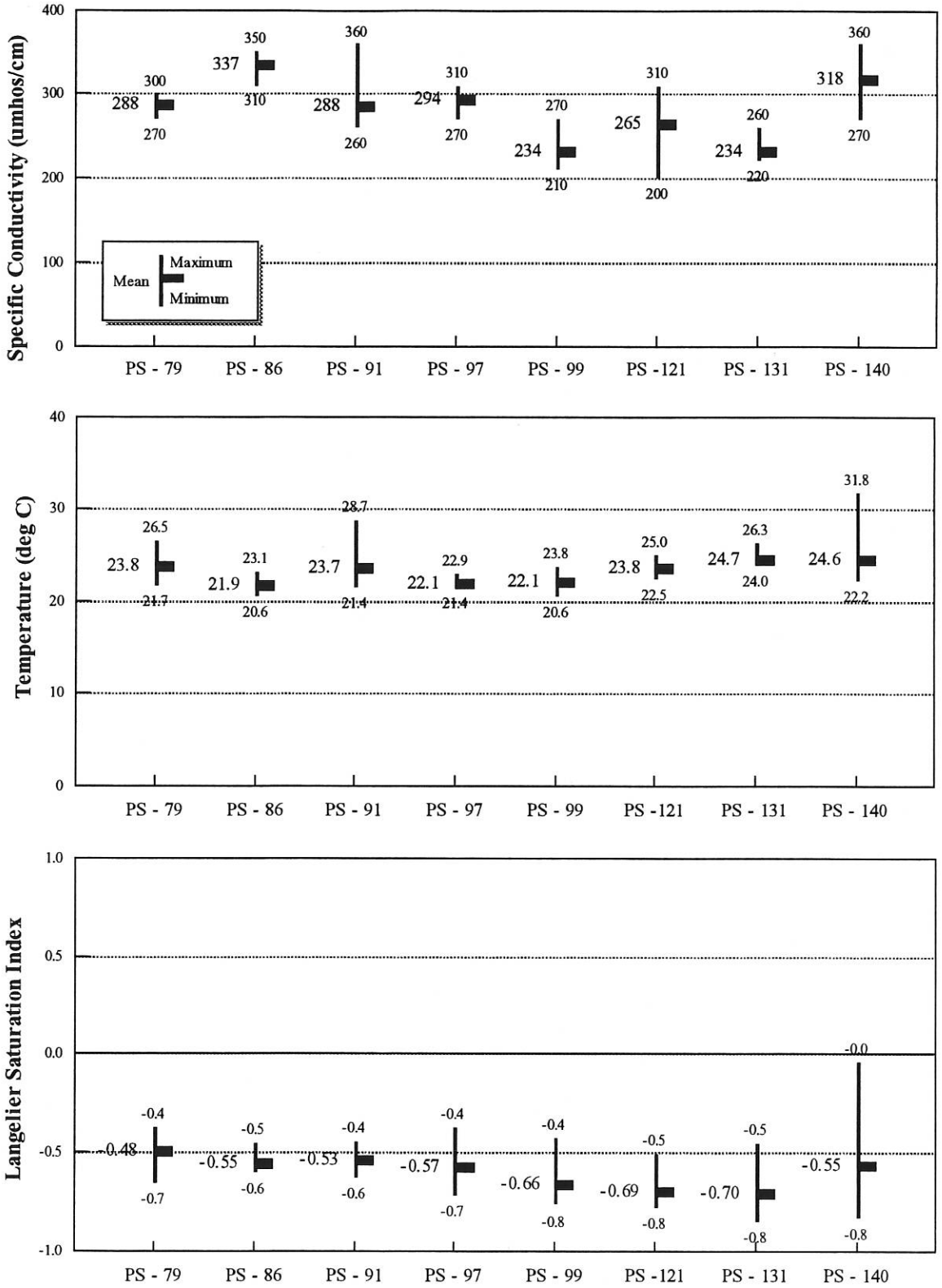
FIGURE 3.1



SOURCE WATER QUALITY AT PUMPING STATIONS

City of FRESNO

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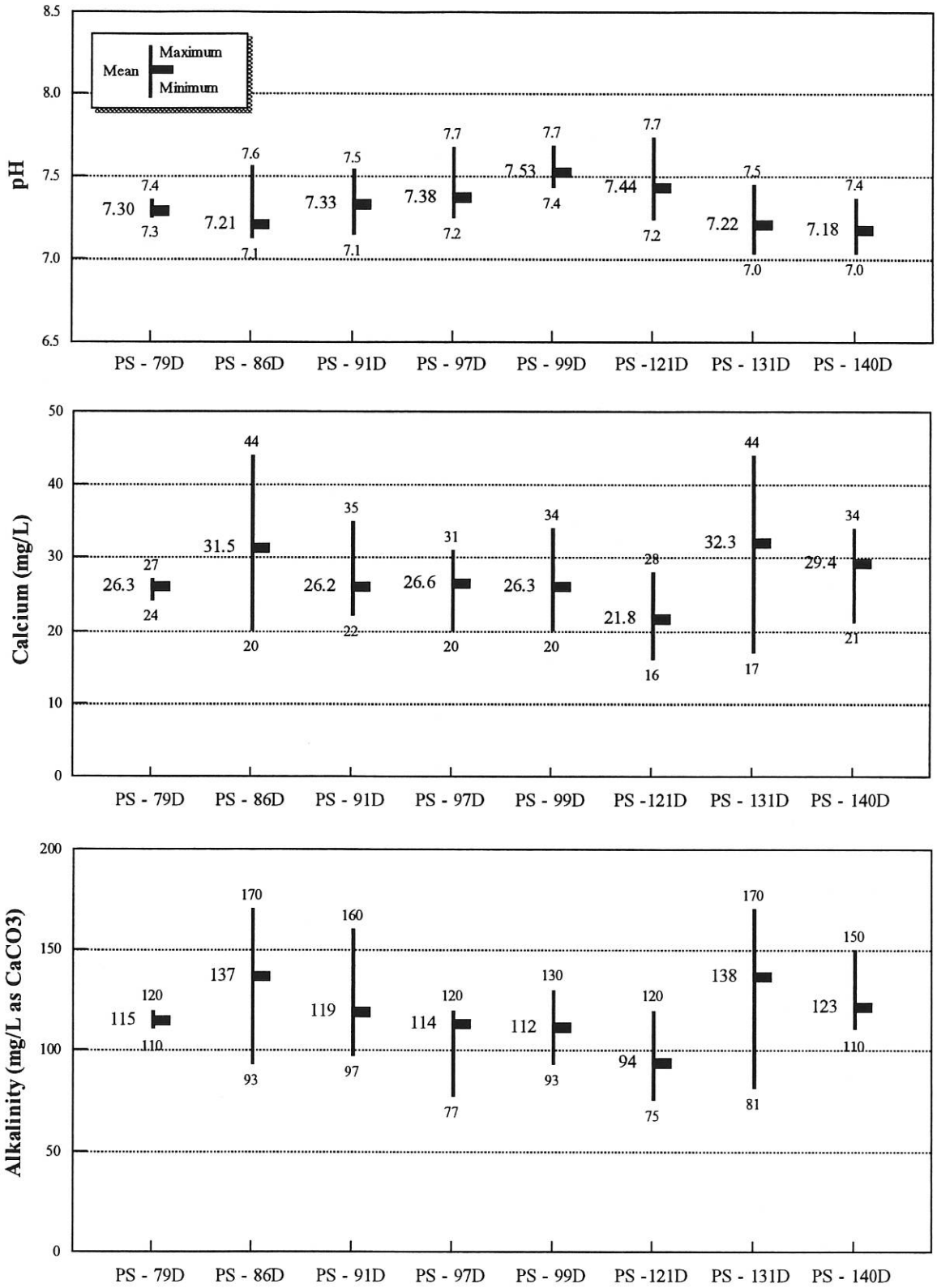
FIGURE 3.2



DISTRIBUTION SYSTEM WATER QUALITY

City of FRESNO

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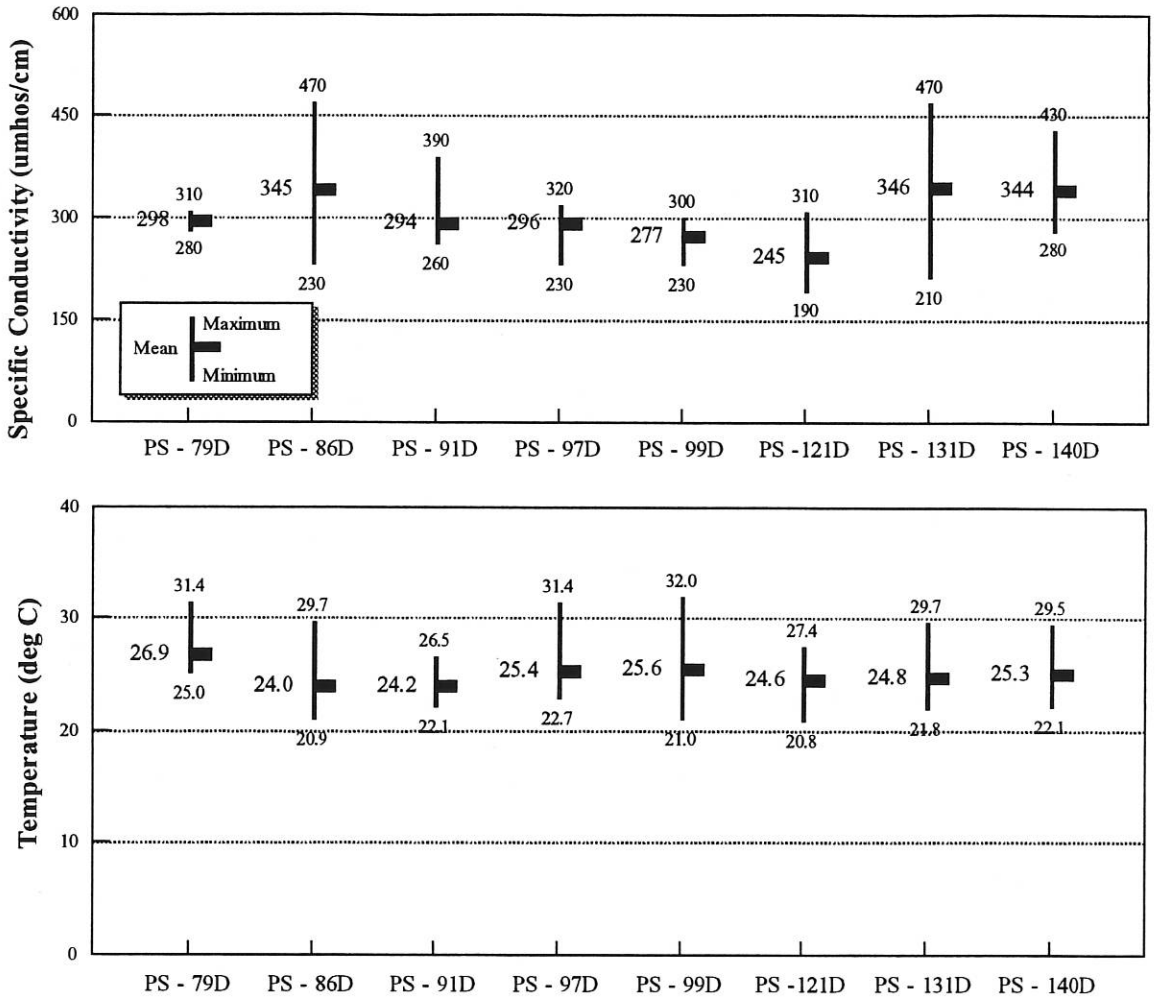
FIGURE 3.3



DISTRIBUTION SYSTEM WATER QUALITY

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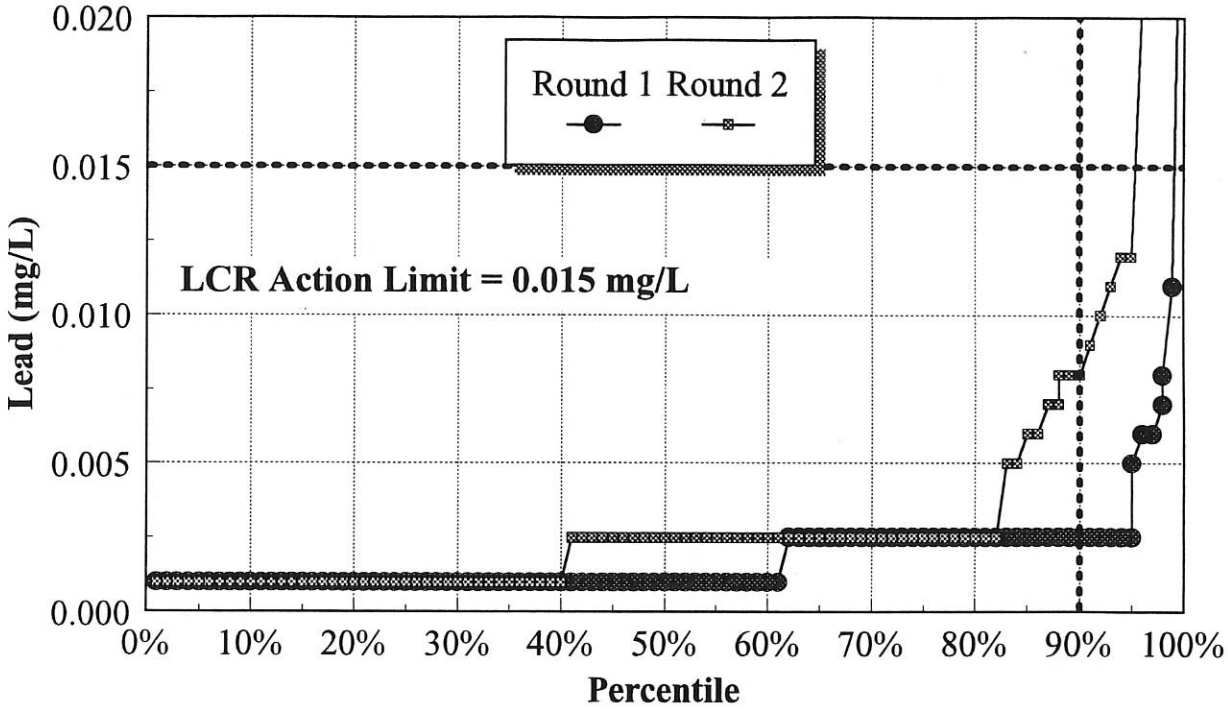
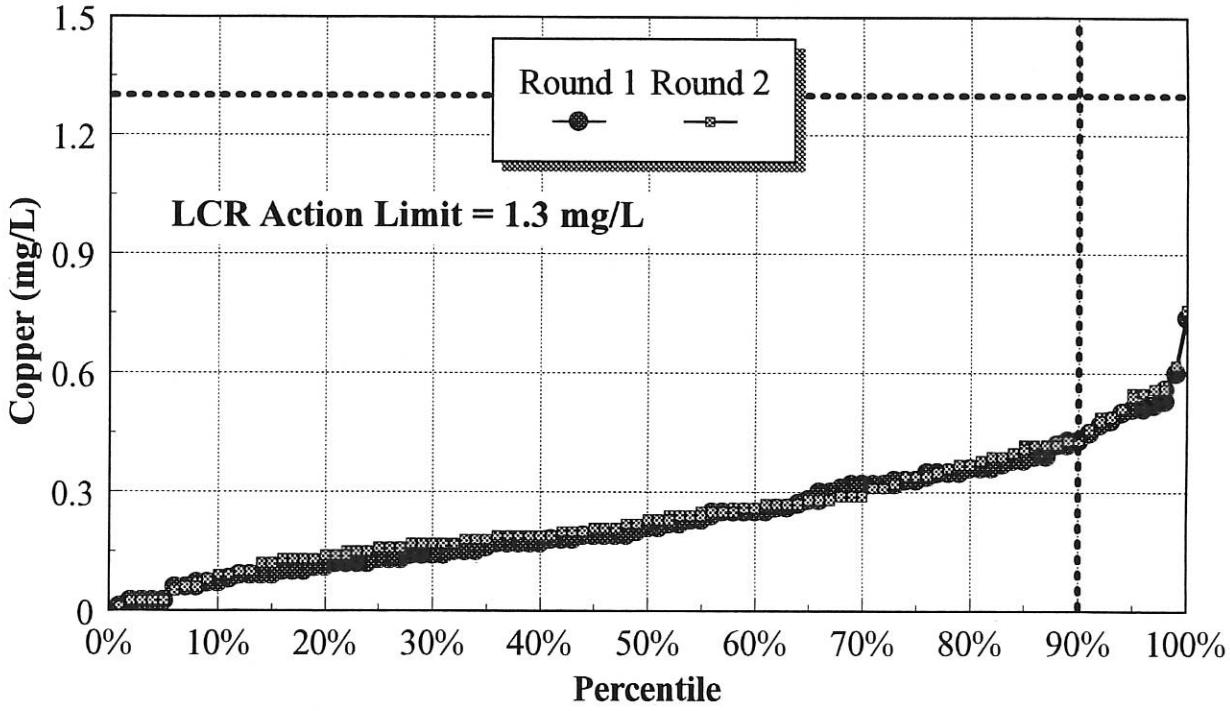
FIGURE 3.4



(a) Tap Water Monitoring - Lead Concentration Data Distribution



(b) Tap Water Monitoring - Copper Concentration Data Distribution

City of FRESNO

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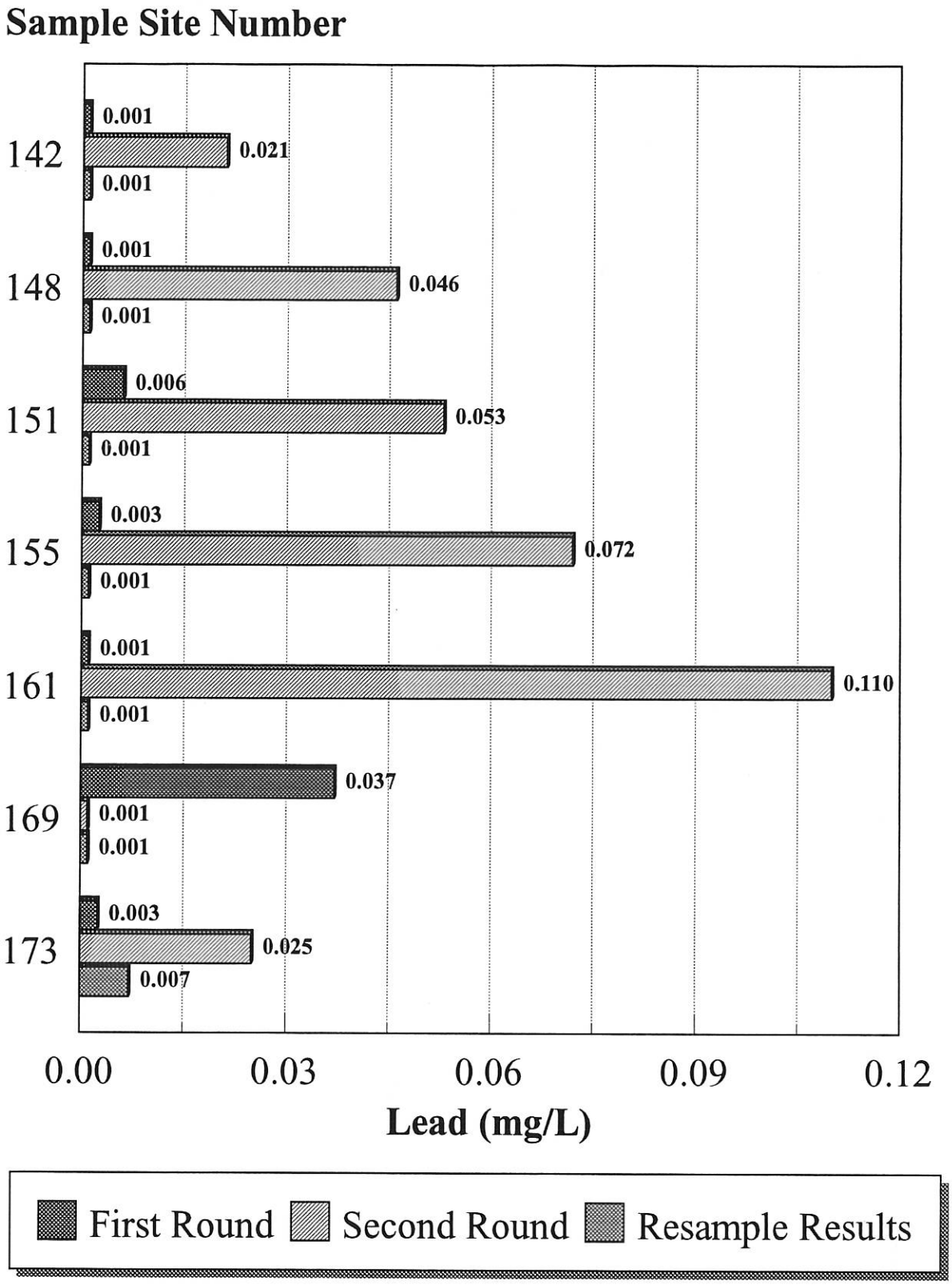
FIGURE 3.5



Sample Results Exceeding Lead LCR Action Limit

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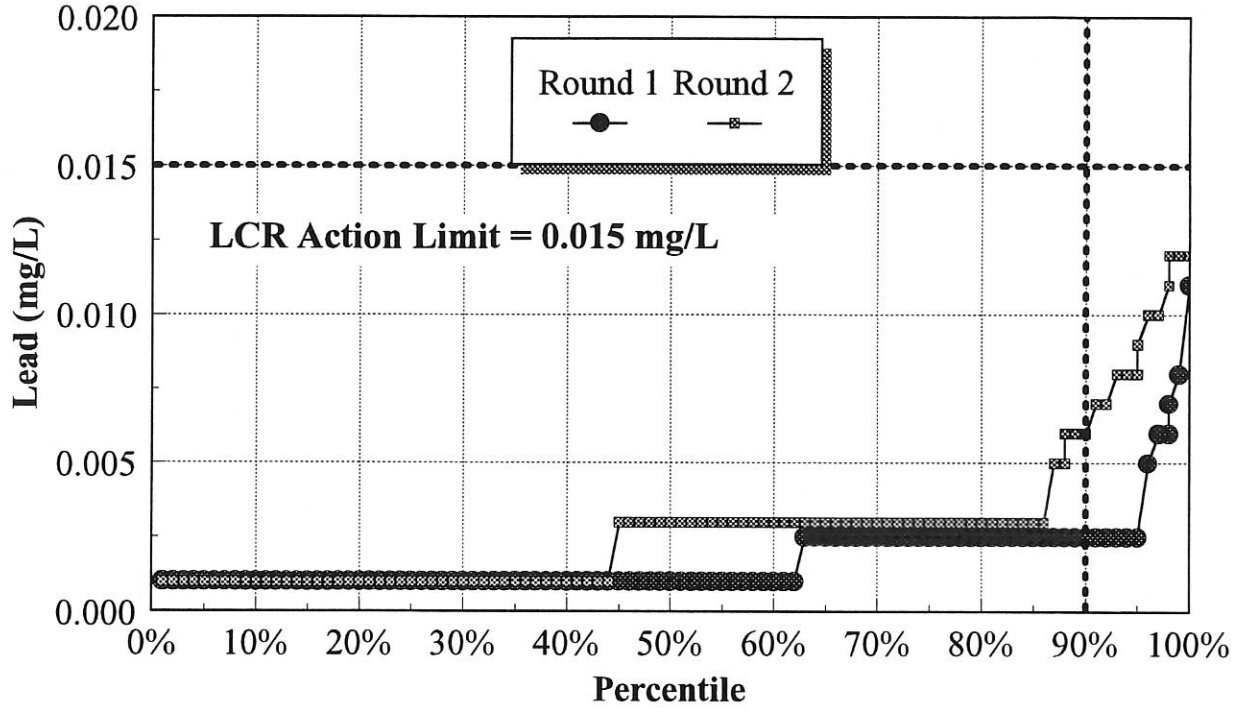
FIGURE 3.6



Tap Water Monitoring - Lead Concentration Data Distribution with Resample Data

City of FRESNO

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FIGURE 3.7

SECTION 4
LEAD CORROSION

SECTION 4

LEAD CORROSION

CITY OF FRESNO OVERVIEW

The City of Fresno's LCR initial monitoring program has demonstrated that lead and copper levels in tap water are well below the LCR action limits. Overall, the 90th percentile lead level of these samples was as high as 0.008 mg/L. Under the stringent standards applied to large water systems (greater that 50,000 population) this lead level does not qualify as optimal corrosion control. Therefore, the focus of this study will be on the lead corrosion issue only.

The lead corrosion problem, as it exists, is isolated to one part of the City of Fresno's service area. All seven residences with lead levels greater than the LCR action limit are located within the same subdivision, that for purposes of the Materials Survey was designated as Tract B. This subdivision is in the Woodward Park area of Fresno and contains 63 of the 130 sample sites monitored. Figure 4.1 presents the distribution of lead levels for the sample sites within Tract B. Figure 4.1 shows that the samples with lead levels greater than the action limit are so skewed in the distribution profile that there is little doubt that appropriate sample collection or handling procedures were not applied.

It should be noted that the selected lead corrosion control strategy must be sensitive to the possibility of exacerbating lead corrosion conditions, and possibly increasing the current, favorably low lead release rates that exist throughout the system. This is an important point. Given the sensitivity of lead release to pH, and given the moderately low pH conditions that exist in some parts of the system, the pseudo-equilibrium that exists between lead corrosion surfaces and the current water chemistry is subject to upset.

LEAD AS A PLUMBING MATERIAL

Lead piping has been used in the past for water distribution systems, service lines, and interior plumbing. However, lead piping was not identified in the City of Fresno's service area as still being used during the LCR Materials Survey.

Lead is also found in tin/lead solder used to join copper pipe. The American Water Works Service Company (AWWSC) conducted a survey of its systems in 1988 and concluded that lead solder in copper plumbing is the most significant source of lead found in drinking water at the tap. They also found that lead leaching rates from newer tin/lead solder were considerably higher than in older solders. The galvanic cell action between tin/lead solder and copper accounts for the significant amount of lead release. The percent ratios of tin to lead for commonly used plumbing solders were 50:50 and 60:40. The 1986 amendments to the Safe Drinking Water Act prohibit the use of lead solders which contain more that 0.2 percent lead.

Brass plumbing fixtures and fittings are another source of lead in drinking water. Brass is a copper-zinc alloy commonly used in potable water. The brasses most commonly used in household fixtures contain about 1.5 to 7.5 percent lead. The major form of corrosion in brass is selective leaching of zinc and it is thought that this corrosion process also releases lead from the brass. The rate of lead leaching from brass in potable waters usually drops sharply after a few weeks to months (AWWA, 1990). A survey for the AWWSC on lead levels throughout their system estimated that 33 percent of the lead in the tap water samples was contributed by brass faucet fixtures.

CHEMISTRY OF LEAD CORROSION

Corrosion of lead-containing materials occurs when an oxidizing agent, such as dissolved oxygen or various chlorine species, causes metallic lead to be converted to an oxidized form, usually Pb^{+2}. This oxidized form is sparingly soluble in water.

The solubility and mobilization of lead is governed by the pH level and the complexation of Pb^{+2} by various ions or molecules in the water (ligands), such as hydroxide (OH^-), carbonate (CO_3^{-2}), ammonia (NH_3), orthophosphates (PO_4^-), polyphosphates (polymerized PO_4^-), and silicates (SiO_2). The corrosion of lead can be restricted by the formation of relatively insoluble films on the surface of lead containing materials. These films, called passivating films, can act as a barrier to movement of metallic lead into solution or movement of the oxidizing agent to the lead containing surface. Some important passivating deposits that have been identified include $Pb_3(CO_3)_2(OH)_2$ (hydrocerussite), $Pb_{10}(CO_3)_6(OH)_6O$ (plumbonacrite), $PbCO_3$ (cerussite), and PbO_2 (plattnerite, a Pb^{+4} oxide). The forms of lead orthophosphate solids, some of which may be less soluble the hydrocerussite, have not been well defined; two possibilities, however, are $Pb_5(PO_6)_3OH$ (hydroxypyromorphite) and $Pb_3(PO_4)_2$ (tertiary lead orthophosphate).

Understanding the chemistry of lead corrosion and the formation and behavior of lead complexes has generally been accomplished by using chemical solubility models. With these models, simple systems can be simulated and the controlling solids identified and evaluated theoretically. Much work remains to be done in understanding the behavior of lead and lead complexes in actual drinking water systems. The current knowledge, however, can be used to estimate the water quality changes needed to reduce lead levels at the tap. The parameters usually considered most important are: pH, oxidant concentrations (e.g. dissolved oxygen, chlorine, and chloramine), dissolved inorganic carbonate, alkalinity, temperature, and corrosion inhibitor concentrations.

pH

The pH of the water is a highly important factor in corrosion. Copper and lead corrosion is pH dependent in soft, low-mineralized water. Corrosion rates increase substantially as the pH drops below 7.0.

The effectiveness of corrosion inhibitors is also pH dependent. The optimum pH for polyphosphates is generally considered to be in the range of 6 to 7. With zinc addition, this pH range can be increased to about 7.5. Orthophosphate inhibitors have an optimum pH range of

7.0 to 7.8 for controlling lead and copper. Sodium silicates have a broad range of pH effectiveness and provide corrosion protection up to a pH of 8.

Dissolved Oxygen

The concentration of dissolved oxygen is particularly important in the corrosion of steel, cast iron, and ductile iron piping. The presence of dissolved oxygen at concentrations of at least 0.25 mg/L is necessary for silicate inhibitors to form films on oxidized metal surfaces. Dissolved oxygen concentration is less important when using polyphosphate or orthophosphate inhibitors.

Chlorine

The presence of reactive HOCl and OCl^- is a contributing factor to pitting corrosion of copper, which is not a concern for the City of Fresno. Another important consideration is that the disinfection strength of chlorine is pH dependent. These impacts on disinfection should be considered prior to raising the pH for corrosion control.

Dissolved Inorganic Carbonate and Alkalinity

The level of dissolved inorganic carbonate (DIC) is an important parameter in lead solubility. DIC is the total concentration of all dissolved inorganic carbonate species including bicarbonates and carbonates. The predominant factors affecting DIC are pH and alkalinity. Alkalinity is a measure of a water's capacity to neutralize acids. In natural waters alkalinity is primarily a result of bicarbonates, carbonates, and hydroxides. Waters with higher alkalinity can better resist changes in pH. In addition, chemicals used to change pH, such as lime, soda ash, and sodium hydroxide, are difficult to control in low alkalinity waters because the pH changes so easily.

Temperature

Water temperature can be an important factor in corrosion. Generally, the oxidation and diffusion rates of metals increase with temperature. Water that is undersaturated with calcium carbonate at temperatures found in domestic hot water systems will usually be more corrosive. Temperature also affects the solubilities of various solids that form passivating films on pipe surfaces.

ANALOGOUS SYSTEM EXPERIENCE

Analogous systems are other water utilities with water quality characteristics similar to the City of Fresno's that have undertaken various approaches for identifying and mitigating corrosion in their systems. Analogous system experience is used to both identify and validate potential corrosion control mitigation strategies that might be employed in the City of Fresno's water system.

Prior to the advent of the LCR the water works industry had developed a limited database on specific water chemistries and materials specific control strategies. In the case of lead corrosion, it has been difficult to identify utilities in the San Joaquin Valley region with documented corrosion control programs. However, there are two groundwater utilities in the western United States with similar water quality and documented corrosion control programs.

<u>Redmond, Washington</u>

- Medium Sized System
- Water Sources:
  - Four major wells (all draw from a shallow aquifer <150 ft deep)
  - Intertie with the Seattle system (seasonal use)
- Source Water Quality:
  - pH range of 7.0 to 7.3
  - Alkalinity range of 70 to 95 mg/L as $CaCO_3$
  - Chloride levels < 5 mg/L
  - Sulfate levels < 5 mg/L

The Redmond system is similar to the City of Fresno in terms of water source and water quality. Redmond had, prior to implementation of their corrosion control program, a long history of corrosion related water quality problems. In the mid-1980s the city instituted a corrosion control program designed to increment the distributed water pH above 7.8. Prior to this time the distributed water pH dropped as low as 6.7. pH adjustment is achieved using caustic soda injected at the individual wellheads. The utility director feels that the program has substantially reduced the number of red and blue water complaints as well as distribution line failures.

There is no information available on standing water tap sample metals concentrations prior to implementation of the pH adjustment program. However, in both rounds of the recently completed LCR compliance monitoring, the 90th percentile lead and copper levels have been well below the action levels. Under the LCR, the city has qualified as optimized for corrosion control.

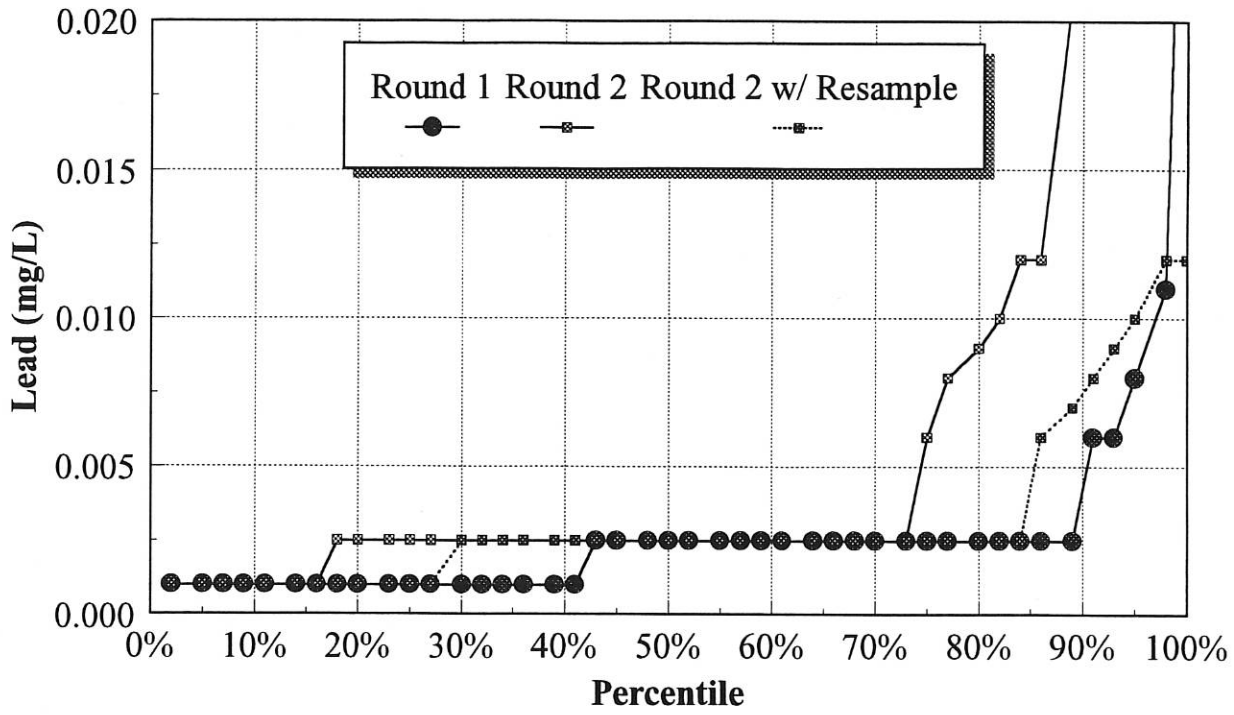
Phoenix, Arizona

- Large Sized System
- Water Sources
  - Multiple groundwater and surface water sources
- Distributed Water Quality
  - pH range of 7.4 to 7.8
  - Alkalinity range of 130 to 150 mg/L as $CaCO_3$
  - Chloride levels > 50 mg/L
  - Sulfate levels > 10 mg/L

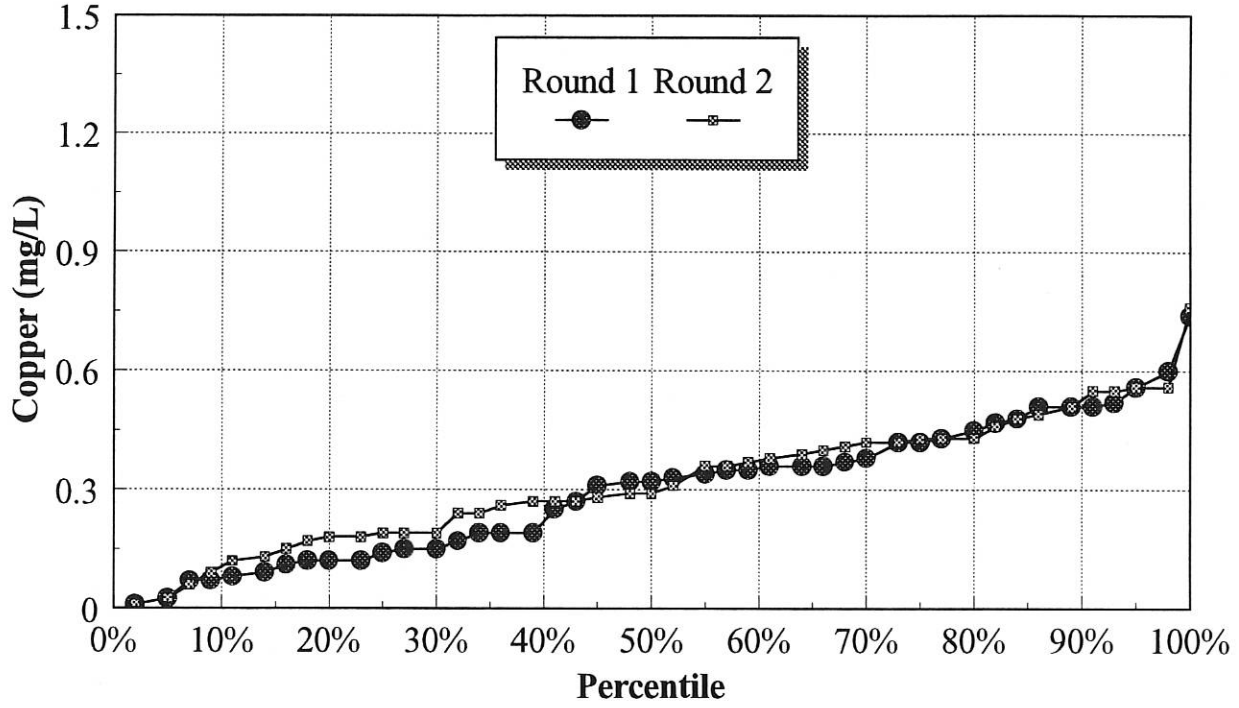
The Phoenix water is more highly mineralized than the City of Fresno's. It is presented here because a corrosion control bench-scale screening program has recently been completed that demonstrates the effectiveness of some phosphate based inhibitors on leaded surfaces exposed to Phoenix water. The study was undertaken to identify a corrosion control strategy to reduce lead release. The test methodology relied on electrochemical corrosion rate measures to track

the corrosion processes on pipe samples drawn from the Phoenix distribution system. The pipe samples were mounted in closed-loop systems where water quality conditions could be controlled and monitored.

A summary of Phoenix bench-scale screening results is given in Figure 4.2. The figure shows the percentage change in corrosion rates on copper, pure lead and lead/tin solder pipe specimens relative to their respective baseline corrosion rates. The figure summarizes the corrosion conditions after several weeks of conditioning in water qualities representative of the indicated corrosion control strategy. Of importance to the City of Fresno is the substantial reductions in lead corrosion from lead/tin solder using both a zinc-orthophosphate and a simple orthophosphate inhibitor. Both inhibitor formulations diminished lead corrosion rates by at least 50 percent. A polyphosphate inhibitor formulation was shown to have little impact on lead or copper corrosion rates.



(a) Tract B Tap Water Monitoring - Lead Concentration Data Distribution

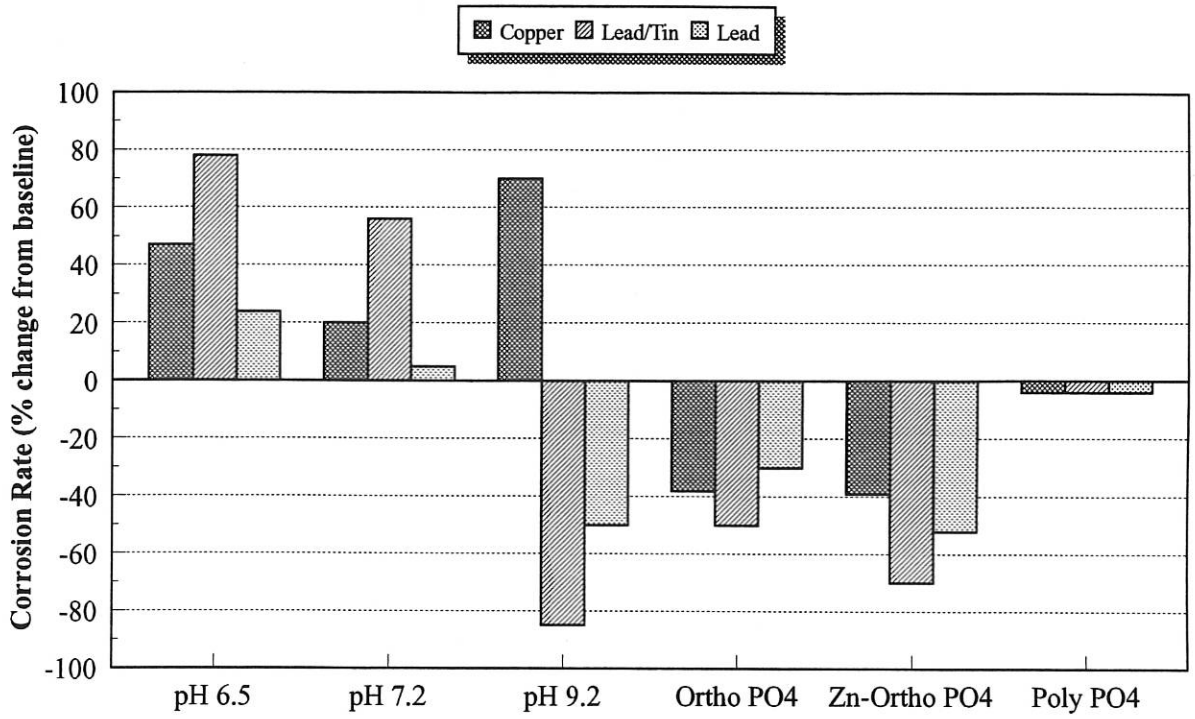


(b) Tract B Tap Water Monitoring - Copper Concentration Data Distribution

City of FRESNO

HDR

FIGURE 4.1



Summary of Phoenix Bench-Scale Screening of Corrosion Control Alternatives

The results demonstrate that orthophosphate based inhibitors are effective at reducing corrosion on both lead and copper surfaces. Extremely high pHs (> 9.0) are highly effective at lead corrosion reduction but may be detrimental to copper surfaces.

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FIGURE 4.2

SECTION 5
CORROSION CONTROL FOR LEAD

SECTION 5

CORROSION CONTROL FOR LEAD

INTRODUCTION

The label "corrosion control" has historically been applied to a variety of water treatment techniques which are frequently used to meet differing water quality objectives. Until quite recently, corrosion control practices by water systems were typically designed to improve aesthetics, protect marginal hydraulic capacity, and/or reduce long-term pipeline maintenance. Although these objectives remain worthwhile, they may not directly address LCR compliance, which essentially has redefined corrosion control solely on the basis of public health impacts. The objective of the LCR is to minimize the concentration of lead and copper in drinking water without compromising other health-related water quality goals. This has created some confusion where long-standing corrosion control procedures are now being found "ineffective" with respect to the new objectives.

A wide variety of proprietary chemicals have evolved to control pipeline and valve deterioration, eliminate "dirty water" complaints, reduce laundry staining, etc. Some of these corrosion inhibitors can also help reduce lead and copper levels in drinking water, although many will not, and some could even increase lead concentrations. Comparison of corrosion inhibitors is often controversial because of the proprietary nature of the specific chemical formulations. This issue is further complicated by a lack of understanding about the differences between chemical products (e.g. ortho- and poly-phosphates) and their relationship to the formation of metallic precipitates and protective films in potable water systems. The use of chemical treatment to reduce lead and copper in drinking water is dependent upon many chemical and physical interrelationships and usually requires side-by-side testing to assess performance.

THE DESKTOP STUDY

The purpose of the "Desktop Study" is to identify the feasible corrosion control strategies appropriate to a particular material type and water quality condition. At a minimum, the study should identify, based on literature review or analogous system performance, corrosion control treatment strategies for the City of Fresno's water quality conditions. It must also determine the potential ease of implementation, operation, and maintenance.

As a minimum, the LCR mandates that utilities must consider three basic approaches for achieving corrosion control:

- pH/alkalinity adjustment
- Calcium adjustment ($CaCO_3$ deposition)
- Inhibitor addition

Characterizing corrosion control in this fashion tends to oversimplify the range of options available to a utility when tailoring a program to its specific needs. A more accurate approach is to recognize that corrosion control technologies can be characterized by two very general mechanisms, each of which has a multitude of variations that carry specific advantages and disadvantages:

- *Barrier Protection* - the deposition of a precipitate film on plumbing surfaces to prevent oxidizing agents in the water from reaching the plumbing surface and/or oxidized metals from the plumbing material from leaching into the water.

- *Passivation* - the manipulation of the water quality causing the plumbing material and a number of water constituents to form metal complexes and/or insoluble oxide layers that change the electrochemical nature of the metal surface and limit the underlying rate of the corrosion process.

As summarized in Table 5.1, various chemical treatment systems are available to promote barrier protection and/or passivation. Each of these systems must be evaluated relative to dosage range and specific water quality concerns. Moreover, it should be realized that a particular treatment system will not be universally effective on all metal types, and that corrosion control must be tailored to the plumbing material of interest.

Table 5.1 - Conceptual Framework for Corrosion Control Approaches

Control Mechanism	**Passivation**		**Barrier**
Treatment Approach	pH/alkalinity adjustment	Corrosion inhibitor	Calcium adjustment
Key Water Quality Parameters	pH, alkalinity, TDS, and temperature	pH, metals, hardness, and temperature	Calcium, pH, alkalinity, TDS, and temperature
Appropriate Chemical Feed Systems	Lime Soda ash Sodium bicarbonate Caustic soda Carbon dioxide	Orthophosphate Polyphosphate Phosphate blends Silicates Silicate/ Phosphate blends	Lime Soda ash Sodium bicarbonate Caustic soda Carbon dioxide Glassy/Silicates

The secondary corrosion control impacts associated with each potential strategy must also be evaluated, including compatibility with future disinfection practices, inhibitor impacts on microbial regrowth within the distribution system, commercial and industrial water users, and potential impacts to wastewater treatment plant operations and wastewater NPDES discharge permit status. This assessment follows in Section 6.

Barrier Protection

The primary technique for barrier protection is calcium and/or carbonate addition coupled with pH control. The technique of $CaCO_3$ deposition for barrier protection is described below.

$CaCO_3$ Deposition--

$CaCO_3$ deposition refers to the adjustment of the calcium-carbonate system equilibrium such that a tendency for calcium carbonate precipitation results. This method of corrosion control

depends upon precipitation as the means of forming a protective barrier on the plumbing systems. The term "calcium adjustment" is frequently used to describe this process, but in many cases this may be a misnomer since calcium addition may not be required. Instead, modifying the pH and/or alkalinity through treatment may be the mechanism for achieving precipitation.

The success of this treatment depends on delivering a finished water slightly supersaturated with calcium and carbonate (at a specified pH condition) such that calcium carbonate precipitation occurs. The availability of the supersaturated conditions throughout the distribution system and the reliability of existing techniques to predict the potential formation of calcium carbonate precipitates are key factors to providing adequate corrosion control. Success also depends on the ability to control the formation of scale build-up to ensure that hydraulic capacity is not significantly reduced in the course of providing corrosion protection.

The calcium-carbonate equilibrium is a dynamic system which will change continuously from the point of entry to the final service connection throughout the distribution system. Achieving a continuous coating of calcium carbonate precipitate is difficult without causing excessive precipitation in some portions of the system. This can result in significant reductions to the supply capacity of the distribution system, especially in the vicinity of the treatment facilities, and require those lines to be cleaned in order to restore adequate hydraulic conditions.

The complications associated with $CaCO_3$ deposition are increased by difficulties in determining the degree of calcium carbonate precipitation potential in the treated water. Several indices have been proposed to describe the calcium-carbonate equilibrium, and the tendency of water to form precipitates, although it is often difficult to use to predict corrosion control performance.

Passivation

Passivation alternatives include pH/alkalinity adjustment and phosphate and silicate based inhibitors. While seemingly simple in practice, the nature of passivation is complex and not

well understood. It involves solubility considerations for the oxidized species of the targeted piping material (Pb^{+2} in the case of lead), but the presence of an insoluble scale alone does not determine the degree of passivation. Passivation is ultimately a change in the electrochemical process of corrosion. By methods not understood, the presence of a passivating film changes the nature and rate of the underlying electron exchange reactions. Manipulating water chemistry to promote the formation of an insoluble metal oxide film may achieve passivation in some circumstances, but solubility considerations alone cannot guarantee successful passivation. The solubility of metals is dependent on the species in which that metal is found. Elemental lead and copper will form complexes with hydroxyl (OH^-), carbonate (CO_3^{-2}), bicarbonate (HCO_3^-), orthophosphate (PO_4^{-3}), and silicate (SiO_2).

pH/Alkalinity Adjustment--

pH/alkalinity adjustment refers to the modification of pH and/or alkalinity (as a surrogate for dissolved inorganic carbonate) to induce the formation of less soluble compounds on the targeted piping materials. The pH/alkalinity adjustment method relies upon the formation of less soluble species consisting of hydroxyl-carbonate complexes. This method is referred to as carbonate passivation.

Corrosion Inhibitors--

Corrosion inhibitors are specially formulated chemicals characterized by their ability to form insoluble metal complexes and thereby enhance passivation. The corrosion inhibitors generally available include orthophosphate, polyphosphate, poly-orthophosphate blends, and silicates.

The critical parameters to operating an inhibitor corrosion control treatment program are: (1) maintaining a stable pH in the inhibitor's effective range throughout the distribution system, (2) determining the inhibitor composition best-suited for the specific water quality objectives and conditions, and (3) applying the appropriate dosage to accommodate background orthophosphate demand as well as the corrosion control protection sought.

Since the use of inhibitors is most effective over a narrow pH range, maintaining that range throughout the distribution system is an important component of implementing a corrosion

control program with inhibitors. For poorly to moderately buffered systems, pH fluctuation within the system can be significant and should be tracked during any implementation program.

Phosphate-based inhibitors are manufactured in a variety of compositions, including sodium orthophosphate, zinc orthophosphate, polyphosphates, and poly-orthophosphate blends. Each of these groups of compounds amy have differing formulations as to the percentage of effective phosphate (PO_4^{-3}) present. The selection of a specific inhibitor may require some preliminary testing. Extraordinary product claims have been made by the various vendors of inhibitor products, and oftentimes the formulation of a specific tradename product will remain proprietary. It is important to realize that there is little evidence to suggest that the proprietary formulations are in any way more effective that the generic blends for which the formulations are known.

Finally, the proper application rate for a specific inhibitor should be determined through testing. As a preliminary assessment, the necessary dosage should include the phosphate demand exerted by the water quality constituents present in the finished water. Beyond the dosage required for effective lead corrosion control, other metals in the supply will combine with phosphates to differing degrees. This imposes an effective "phosphate demand" in the following order of preferential sequence.

- Highest phosphate demand
  Manganese → Iron → Copper → Aluminum → Zinc/Lead

- Moderate phosphate demand
  Calcium ↔ Magnesium ↔ Barium ↔ Radium

- Lowest phosphate demand
  Sodium ↔ Potassium

The final dosage required should be sufficient to accommodate the phosphate demand and provide the effective residual inhibitor necessary to achieve lead corrosion control.

Orthophosphates. Lead forms at least one orthophosphate solid of low solubility under typical drinking water conditions. Two typical orthophosphates are sodium orthophosphate and zinc orthophosphate. The pH range across which orthophosphates are most effective for lead and copper is between 7.0 and 7.8. At pH values above 8.0, metal phosphate precipitates can form causing turbid water, scale build-up, and hydraulic capacity losses. Water with low hardness (calcium < 20 mg/L and calcium:magnesium ratio of 0.7) are well suited to use the orthophosphate inhibitors, regardless of the alkalinity of the water supply.

Polyphosphates. Polyphosphates are controversial corrosion inhibitors because they are typically proprietary chemicals. There is evidence that polyphosphates revert back to orthophosphates with time and water quality. Certain studies have also indicated that use of polyphosphates can increase lead solubility by dissolving existing protective films on pipelines. The optimum pH for polyphosphates is generally considered to be in the range of 6 to 7. With zinc addition, this pH range can be increased to about 7.5. Sodium and zinc hexametaphosphates are examples of polyphosphates, with the zinc formulation outperforming the sodium. The most common application form for polyphosphates is in a blend with orthophosphate.

Silicates. The use of silicates in water treatment has had a long history and yet the mechanism involved in controlling corrosion is unclear for silicate applications. Silicate based inhibitors are produced as various weight silicate (SiO_2) to alkali (Na_2O or K_2O) ratios ranging from 0.5 to 3.8. The most common form of silicate in water treatment is the 3.22 weight ratio sodium silicates at 41° Baume' solution with 38 percent solids. This has been used successfully for corrosion control treatment when targeting reductions in iron corrosion. Sodium silicates have a broad range of pH effectiveness and provide corrosion protection up to a pH of 8.

The method of controlling corrosion attributed to silicates appears to be a combination of absorption and formation of less soluble metal-silicate compounds. Silicates are considered anodic inhibitors, combining with the free metal released at the anode site of corrosion activity and forming an insoluble metal-silicate compound. These corrosion products crystallize to form a protective barrier on the face of plumbing surfaces. However, microscopic and x-ray

examination have shown two layers of film on pipes conveying water treated with silicates. The majority of the silicate appears in the uppermost layer adjacent to the water. This film is an amorphous silicate film adhered to the underlying silicate-metal surface. A silicate corroded surface may be necessary to form the protective silicate film. Simultaneously, the application of silicates in a distribution system with extensive corrosion by-product build-up may result in their release, causing red and turbid water problems.

Like the use of phosphate inhibitors, silicates can combine with other constituents in the supply water besides the materials targeted from protection. Therefore, sufficient dosages must be applied to compensate for the consumption of silicate by other metals or cations. Specifically, calcium and magnesium will readily react with silica over a large pH range and silica can sequester soluble iron and manganese present in the source water.

SECTION 6
CORROSION CONTROL STRATEGY ASSESSMENT

SECTION 6

CORROSION CONTROL STRATEGY ASSESSMENT

ASSESSMENT PRIORITIES

The LCR requires water systems to "optimize" corrosion control to minimize their customers' exposure to lead and copper in their water supply. For the City of Fresno this means an emphasis on mitigating lead corrosion impacts, while not aggravating copper release. In the USEPA Guidance Manual the challenge of balancing various issues is recognized. For example, the preamble to the LCR explicitly recognizes that "...adverse secondary effects on the quality of water and the potential for reduced public health protection can occur in the process of installing corrosion control treatment for lead or copper..." The LCR states that corrosion control treatments may be limited if they:

- Adversely impact process and cause a violation of a national primary drinking water regulation, or

- Otherwise are ineffective for the public water system.

The preamble goes beyond strictly drinking water concerns and states that "the EPA is aware of the potential problems with the use of zinc orthophosphate, such as wastewater treatment effluent guidelines for zinc, or problems with the reuse of wastewater sludges."

Recognizing these constraints, the concept of "optimum control strategy" needs to consider a broad range of factors which include treatment effectiveness, cost, operability, and aesthetics, in addition to water quality regulations. Balancing these issues for different utilities must be done on a case by case basis.

Each water system will assign its own priority to the different factors, and each system will have additional constraints that are unique to its facilities, water sources, and political geography.

Table 6.1 presents a listing and description of the principal corrosion control objectives for the City of Fresno corrosion control program. These objectives reflect what is both desirable and achievable in this type of program. The LCR is a substantial burden to most utilities, but the burden is partially offset by the opportunity to address water quality issues that go beyond immediate corrosion concerns.

Each of the six objectives presented in Table 6.1 is a significant issue, but their relevance to the selection of a corrosion control strategy varies. There are technical priorities that dictate the direction and success potential for the treatment program, while there are regulatory and secondary impacts with firm constraints that limit the implementation of the various strategies.

As suggested by the USEPA's LCR Guidance Manual, the assessment protocol used in the overall evaluation has been to group the City of Fresno corrosion control objectives into five different evaluation criteria (see Table 6.2). Each criteria is assigned a maximum point total relative to its overall importance to the selection process, with the highest point totals representing the most favorable status. The sum of potential point totals is 100 for the five categories.

The two most important of the individual criteria are a technical assessment of the effectiveness of the different strategies for limiting lead corrosion, and an assessment of the potential for water quality changes associated with each strategy relative to existing or proposed SDWA regulations. Together, these criteria account for 55 of the potential 100 point total. The re-equilibration, regrowth, and water quality criterion directly address the likelihood that different control strategies may create new water quality problems. This criterion is assigned a point total of 20. The functionality criterion addresses the ease with which particular strategies can be incorporated into the City of Fresno's system and compatibility with wastewater discharge goals and permits. A total of 20 points is also assigned to this criterion.
The corrosion control economics, while important, will not govern the selection process. It is assigned a total of 5 points.

Table 6.1 - Summary of Corrosion Control Objectives for the City of Fresno

Objective
1. **Achieve compliance with the Lead and Copper Rule.** *Lead and copper release rates from residential plumbing are well below the LCR action limits. Lead release, however, exceeds the exceeds the "optimal" rate. In order to comply with the LCR it will be necessary to reduce the 90th percentile lead level from 0.008 mg/L to less than 0.007 mg/L.*
2. **SDWA regulatory compliance.** *Compatibility of the control strategy with existing and planned USEPA regulations is critical. Potential regulatory constraints include the Proposed Groundwater Disinfection Rule and Disinfectants/Disinfection Byproducts Rule.*
3. **Minimize re-equilibration and regrowth problems.** *All distribution and plumbing systems contain corrosion scales and microbial films that have developed over the life of the system. Such surfaces are in equilibrium with the water chemistry they contact. A substantial change in water chemistry will produce a re-equilibration of the surfaces that may lead to dissolution of scales and release of corrosion byproducts. A change in water quality chemistry may also stimulate microbial growth. An important corrosion control evaluation criterion is to ensure that taste, odor, and colored water problems are not generated by the re-equilibration of these surfaces upon implementation of the selected control strategy.*
4. **Compatibility with the existing system.** *This includes the functionality issues of implementation and operability.*
5. **Minimize cost of implementation.** *Implementation costs include construction, chemical usage, and O&M costs.*
6. **Minimize impacts to the wastewater system.** *Corrosion inhibitor application rates may be limited by NPDES criteria.*

Table 6.2 - Optimal Strategy Evaluation Criteria - Point Assignment

Evaluation Criteria	Maximum Possible Points
1. **Overall Corrosion Control Effectiveness** *the ability to minimize lead corrosion*	40
2. **SDWA Regulatory Constraints** *compatibility with existing and proposed regulations*	15
3. **Functionality** *including ability to implement and operate and wastewater impacts*	20
4. **Minimize Re-Equilibration and Regrowth**	20
5. **Corrosion Control Economics** *including capital, chemical, and O&M costs*	5
TOTAL	100

Each of the feasible lead corrosion control strategies will be assessed in each of the categories and assigned a point value not to exceed the category total. The overall point total from the five categories will determine the strategy rank in the completed assessment. The two top ranking strategies will be recommended for further testing, if required by follow-up monitoring program results.

CORROSION CONTROL EFFECTIVENESS

The issues surrounding the selection of a corrosion strategy are complex. The evaluation of corrosion control effectiveness need to recognize that:

- Optimizing corrosion for one material (lead) does not necessarily optimize corrosion control for all materials. yes, but lead is a sign. Health R. sK

- Minimization of standing water metals concentrations does not necessarily imply minimization of corrosion.

- The strategy cannot be so focused on residential tin/lead solder and brass fixtures that it neglects corrosion of other distribution system materials. The distribution system itself is the one of the largest single investments the City of Fresno's water division has, and must be protected accordingly.

- Failure to maintain overall water quality and consumer satisfaction has serious political consequences.

The principal approaches to controlling corrosion of lead have been discussed in Sections 4 and 5. This portion of the report puts forward those seven potential control strategies that have been identified as having a high probability of successfully addressing the City of Fresno's lead issue without severely aggravating corrosion on other materials. Table 6.3 presents a description of the seven corrosion control strategies, along with an assessment of their relative effectiveness for lead control. A nominal dosing range and operational control parameters are also included. The effectiveness evaluation for the different strategies is based on reports available in the literature and the experience of other groundwater utilities (analogous systems).

Effectiveness Evaluation

A total of forty points is allocated to the overall corrosion control effectiveness criteria. All seven strategies presented are capable of reducing lead corrosion rates to some extent. The effectiveness rating, however, is based on the likelihood of success, and the potential for reduction in lead corrosion rates in excess of the minimum required to comply with the LCR.

Based on a proven track record in analogous systems, carbonate passivation, zinc-orthophosphate, and orthophosphate are the highest rated strategies. $CaCO_3$ deposition, while effective for lead corrosion control, is not considered optimum for this water quality (due to high buffering capacity). The silicate and silicate orthophosphate blend addition are promising alternatives, but cannot be ranked as highly because of a lack of practical application experience.

The blended ortho-polyphosphate inhibitor is rated poorly because of the potential to exacerbate corrosion on lead bearing surfaces. The point assignments for the different strategies are given in Table 6.4.

Table 6.3 - Description of Alternative Lead Control Strategies

Strategy Description	Lead Corrosion Control Effectiveness	Operational Control Parameter	Nominal Dosage[a] Range
1. $CaCO_3$ Deposition Deposit a diffusion barrier consisting primarily of $CaCO_3$ by maintaining a distribution water quality that exceeds the $CaCO_3$ solubility limits. Because of the calcium and alkalinity levels in Fresno well water, the most cost effective approach to achieve supersaturation will be to raise the pH, rather than add Ca^{+2} or soda ash.	Likely to be effective, high pH may resolubilize some existing corrosion scales.	Positive Langelier Index Target pH will range from 8.0 to 8.5 depending on well field	20 mg/L of 25% NaOH[b]
2. Carbonate Passivation Form passivating lead films. The desired film represents a true passivation layer, not a diffusion barrier. Hence, the scale development on the pipe wall will be minimal and hydraulic impacts negligible.	Highly effective, demonstrated capability in limited analogous systems.	Distributed pH > 7.6	8 mg/L of 25% NaOH[b]

Table 6.3 - Description of Alternative Lead Control Strategies (Continued)

Strategy Description	Lead Corrosion Control Effectiveness	Operational Control Parameter	Nominal Dosage[a] Range
3. Orthophosphate Addition Develop a lead phosphate passivation film.	Likely to be effective, demonstrated capability in limited analogous systems.	Distributed PO_4 level of 0.5 mg/L	approx. 1 mg/L as product
4. Zinc Orthophosphate Addition Develop a lead phosphate passivation film enhanced by the presence of a $ZnPO_4$ synergistic film.	Likely to be effective, demonstrated capability in limited analogous systems.	Distributed Zn level of 0.1 mg/L Distributed PO_4 level of 0.5 mg/L	approx. 1 mg/L as product
5. Ortho-Polyphosphate Blend Addition Develop a lead phosphate passivation film. The presence of polyphosphates offer the benefit of Fe and Mn sequestration.	Some lead benefits, polyphosphates may solubilize some existing lead corrosion scales.	Distributed PO_4 level of 0.5 mg/L	approx. 1 mg/L as product
6. Silicate Addition Develop lead silicate passivation film, coupled with pH shift and carbonate passivation. At 20 mg/L the caustic silicate solution will shift the source water pH by an estimated 0.6 units. The silicates also offer the benefit of Fe and Mn sequestration.	Likely to be effective at very high dosage levels.	Distributed SiO_2 level of 10 mg/L	approx. 20 mg/L as product
7. Silicate-Orthophosphate Blend Addition Develop synergistic passivation films, coupled with modest positive pH shift and Fe and Mn sequestration.	A promising alternative, widely used in Germany, little US experience	Distributed PO_4 level of 0.5 mg/L	approx. 7 mg/L as product

[a] Estimated long-term dosage rate, start-up dosage may be higher. Long range dosage rate will be used in economic analysis.

[b] NaOH selected as the most cost effective caustic source for the individual applications at the City of Fresno. 25% solution chosen because of potentially low temperature storage conditions.

TABLE 6.4 - Corrosion Control Effectiveness - Point Assignment (40 maximum)

Strategy	Point Assignment
1. $CaCO_3$ Deposition	20
2. Carbonate Passivation	35
3. Orthophosphate Addition	30
4. Zinc Orthophosphate Addition	35
5. Ortho-Polyphosphate Blend Addition	10
6. Silicate Addition	25
7. Silicate - Orthophosphate Addition	25

POTENTIAL SDWA REGULATORY IMPACTS

With the Surface Water Treatment Rule mandating greater disinfection, the Disinfectant/Disinfection By-Product (D/DBP) Rule lowering DBP levels, the Coliform Rule requiring better residual persistence and the LCR pushing utilities to optimize their current corrosion control practices, many agencies perceive they have encountered "regulatory gridlock" in which it is difficult to move in any direction without negative consequences.

The challenge facing utilities is how to balance multiple, often times conflicting, water quality objectives. For some surface water utilities the LCR seems to offer an almost insurmountable hurdle, because many of the chemical adjustments required to achieve corrosion control are at odds with other mandates of the SDWA. Table 6.5 presents a summary of the SDWA compliance issues as a function of potential chemical additions.

Regulatory Evaluation

Remaining in compliance with all aspects of the SDWA is critical to implementing a corrosion control strategy. While potential problems associated with pH adjustment and disinfection efficiency are important, they can be accommodated by manipulation of

operational parameters (e.g. enhanced contact time or residual levels) and do not rule out any of the identified control strategies. Accordingly, the point assignments for SDWA impacts are presented in Table 6.6.

Table 6.5 - Potential Regulatory Impacts of Selected Chemical Addition

SDWA Constraints	Chemical Addition			
	Caustic	**Orthophosphate**	**Polyphosphate**	**Silicates**
Groundwater Disinfection	Slight increase in viral contact time due to pH increase. Can be addressed by secondary chlorination if necessary.	Inhibitor addition to systems with existing corrosion byproducts can result in the depletion of disinfectant residuals within the distribution system. Under certain conditions phosphate based inhibitors may stimulate biofilms in the distribution system.	Inhibitor addition to systems with existing corrosion byproducts can result in the depletion of disinfectant residuals within the distribution system. Under certain conditions phosphate based inhibitors may stimulate biofilms in the distribution system.	May reduce disinfection effectiveness due to pH impacts.
Disinfection Byproducts	Slightly higher THM formation potential.	No apparent effects.	No apparent effects.	pH effects may enhance THM formation potential.
Coliform Rule	Potential for higher total plate counts, confluent growth, or presence of total coliform when chlorination is practiced.	If corrosion byproducts are released after the application of inhibitors, coliforms may be detected more frequently and confluent growth is more likely.	If corrosion byproducts are released after the application of inhibitors, coliforms may be detected more frequently and confluent growth is more likely.	No apparent effects.
Radionuclides	No effect in distribution system.	No apparent effects.	No apparent effects.	No apparent effects.
Arsenic Rule	No effect in distribution system.	Unknown.	Unknown.	Unknown.

Table 6.6 - SDWA Regulatory Constraints - Point Assignment (15 maximum)

Strategy	Point Assignment
1. $CaCO_3$ Deposition	10
2. Carbonate Passivation	12
3. Orthophosphate Addition	13
4. Zinc Orthophosphate Addition	13
5. Ortho-Polyphosphate Blend Addition	10
6. Silicate Addition	12
7. Silicate - Orthophosphate Addition	12

FUNCTIONALITY

Table 6.7 presents a review of the critical elements for each of the functionality issues as they apply to the seven corrosion control strategies. For purposes of this study the functionality of a control strategy is defined by two separate issues: operability (including implementation and operation) and wastewater impacts.

Table 6.7 - Functionality of Corrosion Control Alternatives

Strategy	Operability	Wastewater Impacts
$CaCO_3$ Deposition	Process optimization is essential. Proportional feed equipment, feedback controls and substantial operator attention is required. Corrosion rates and tuberculation on unlined cast iron mains may be increased. NaOH is a moderately hazardous chemical. Special storage and containment facilities required.	Not significant.
Carbonate Passivation	Process optimization is essential. Proportional feed equipment, feedback controls and substantial operator attention is required. NaOH is a moderately hazardous chemical. Special storage and containment facilities required.	Not significant.

Table 6.7 - Functionality of Corrosion Control Alternatives (Continued)

Strategy	Operability	Wastewater Impacts
Orthophosphate Addition	Simple chemical feed facilities required. Storage requirements are minimal compared to NaOH. Most orthophosphate solutions are classified non-hazardous. Long-term benefit on iron and steel surfaces.	Negligible increase in phosphate load to Fresno/Clovis Regional Wastewater Reclamation Facility.
Zinc Orthophosphate Addition	Simple chemical feed facilities required. Storage requirements are minimal compared to NaOH. Zinc orthophosphate solutions are classified as hazardous (pH < 2). Long-term benefit on iron, steel and AC pipe surfaces.	Negligible increase in phosphate and zinc load to Fresno/Clovis Regional Wastewater Reclamation Facility.
Ortho-Polyphosphate Blend Addition	Simple chemical feed facilities required. Storage requirements are minimal compared to NaOH.	Negligible increase in phosphate load to Fresno/Clovis Regional Wastewater Reclamation Facility.
Silicate Addition	Simple chemical feed facilities required. Storage requirements are minimal compared to NaOH.	Not significant.
Silicate-Orthophosphate Blend Addition	Simple chemical feed facilities required. Storage requirements are minimal compared to NaOH.	Negligible increase in phosphate load to Fresno/Clovis Regional Wastewater Reclamation Facility.

Operability

Operability represents the ease with which the treatment strategy can be incorporated into the existing water treatment and distribution system. It includes questions of equipment compatibility, process control, instrumentation, additional manpower requirements, siting, chemical storage and chemical handling. The siting of treatment facilities in the City of Fresno can take two approaches. The first is to assume that corrosion control treatment is only required at PS-140 because it is the only source supplying water to high risk residences that is not currently optimized for lead and copper corrosion.

The second alternative is to install well head treatment at all eight wells supplying water to the high risk residences in the City of Fresno. The issue of facility siting will be addressed in greater depth if corrosion control treatment is actually required.

Problems associated with on-site chemical storage are a large part of the operability issue. The storage and handling facilities needed for the silicate and phosphate based inhibitors are relatively modest because the chemicals are concentrated, have a low hazard rating, and are dosed at relatively low levels. Caustic soda, however, is classified as a hazardous chemical. Article 80 of the Uniform Fire Code lists caustic soda as both a health and physical hazard, with H-7 and H-3 Occupancy Ratings, respectively. The storage area for caustic soda must have secondary containment with overflow control, mechanical ventilation, and a fire sprinkler system.

Wastewater Impacts

Because of the Clean Water Act, Publicly Owned Treatment Works (POTWs) are particularly sensitive to drinking water corrosion control issues. The limitations on heavy metals in treated effluent are becoming increasingly stringent. Stringent limitations are also being applied to wastewater sludges. Sludges, which are commonly disposed of by land application, serve as repository for most of the particulate metals that reach the POTW. The USEPA recognizes that zinc orthophosphate inhibitors may be a problem in certain situations and recommends that water systems "...be aware of limits on effluent standards and work with local wastewater treatment authorities to protect against any unintended problems that could be avoided with other corrosion control treatment methods..."

Water from the City of Fresno's water system is ultimately delivered to the Fresno-Clovis Regional Wastewater Reclamation Facility. Based upon the water usage in the high risk residential areas relative to the system-wide water usage, the impacts of zinc and phosphate at the wastewater treatment facility are expected to be negligible. If system-wide corrosion control treatment is required in the future, the impact of zinc from zinc orthophosphate will need to be determined.

Functionality Evaluation

Table 6.8 gives the priority point assignments for the functionality of the different strategies. Because of the numerous application sites for corrosion control treatment, phosphate and silicate based inhibitors were rated highest. Silicate inhibitors were rated slightly lower because of their larger volume of storage required. Carbonate passivation and $CaCO_3$ deposition were rated lowest because of the extensive storage requirements and the more sophisticated process control mechanisms.

RE-EQUILIBRATION, REGROWTH, AND WATER QUALITY

The imposition of a corrosion control strategy in the affected areas of the City of Fresno's service area represents a major chemical change that has significant implications beyond the immediate water quality and metals release issues. Changing the chemical makeup of the distributed water forces all surfaces in contact with water to come to a new equilibrium with that water chemistry. This new equilibrium may involve changes in corrosion rate and surface morphology. In the process, substantial solubilization of scales and mineral deposits may take place, the consequences of which may be very serious for distributed water quality. Microbial populations colonizing the plumbing surfaces may also be affected, either as a result of growth stimulation or inhibition, or because the corrosion scales which they permeate are disrupted. Table 6.9 presents a review of the re-equilibration, regrowth, and water quality issues as they apply to the seven corrosion control strategies.

Table 6.8 - Functionality - Point Assignment (20 maximum)

Strategy	Point Assignment
1. $CaCO_3$ Deposition	10
2. Carbonate Passivation	12
3. Orthophosphate Addition	20
4. Zinc Orthophosphate Addition	18
5. Ortho-Polyphosphate Blend Addition	20
6. Silicate Addition	16
7. Silicate - Orthophosphate Addition	16

Table 6.9 - Re-Equilibration, Regrowth, and Other Water Quality Issues Associated With the Corrosion Control Alternatives

Strategy	Re-equilibration of Corrosion Surface	Water Quality and Aesthetics	Regrowth Issues
$CaCO_3$ Deposition	Increased tuberculation of unlined cast iron and steel pipe. Increased iron corrosion rates. Reduced spalling on AC pipe	Potential short-term "red-water" problem. Improved pH stability. Marginal Na increase Excessive $CaCO_3$ precipitation may cause "white-water" problems in a portion of the system.	Potential stimulus to bacterial growth.
Carbonate Passivation	Minor increase in tuberculation on unlined cast iron pipe. Minor AC pipe benefits.	Potential short-term "red-water" problem. Marginal Na increase.	Minor stimulus to bacterial growth.
Orthophosphate Addition	Reduced long-term Fe corrosion rate. Substantial time required for passivation.	Serious potential for short-term colored water problem during re-equilibration.	Bacterial growth stimulus. Algae stimulus in open reservoir (not applicable to Fresno).
Zinc Orthophosphate Addition	Reduced Fe corrosion rate. AC pipe benefits.	Serious potential for short-term colored water problems.	Retards bacterial growth
Ortho-Polyphosphate Blend Addition	Increased Fe solubility and corrosion rate. Probable destabilization of lead passivation scales.	Will likely diminish "red and black water" complaints by sequestering Fe and Mn.	Minor bacterial stimulus.
Silicate Addition	Decreased Fe corrosion rates.	Diminished "red and black water" complaints by sequestering Fe and Mn. Increased pH stability.	No bacterial effect. Possible diatom stimulus in open reservoirs (not applicable to Fresno).
Silicate-Ortho-phosphate Blend Addition	Beneficial impact to most corrosion surfaces.	Minor potential for Fe and Mn sequestration.	Minor bacterial stimulus.

System Re-Equilibration

The City of Fresno's distribution and residential plumbing systems have an abundance of metal types, each of which in time achieves a pseudo-equilibrium, or steady state, corrosion scale. The scale constituents reflect the character of both the metal surface and the system water quality. The mass of corrosion scale formed on the plumbing surface, and the form in which the metal is released from the scale are functions of water quality, solubility, and complexation. Moreover, the physical character of the scale, including scale thickness, morphology, and in some cases even the corrosion form, will be influenced by operational conditions such as flow velocities, stagnation, and hydraulic scour.

Scales characteristic of a particular water quality and material type may require several years to form. The scale is both a reaction surface and a reactor vessel for the redox processes associated with corrosion of the underlying metal surface. As such, it is in a constant state of flux and subject to the variety of chemical factors which determine the rate of metal oxidation, as well as solubility of the metal oxide constituents. Changes in water quality that affect either of these considerations ultimately force a re-equilibration of the existing corrosion scale. This process can have serious water quality consequences, and may even impact the service life of the distribution system materials.

In a practical and operational sense, the aesthetic impacts of re-equilibration (rust staining, zinc sand, colored or turbid water) are probably the paramount concern to the system operator. If not because of its intrinsic importance, because of the immediacy of consumer complaints and associated financial and political ramifications.

The dynamics of distribution system re-equilibration associated with new corrosion control strategies are poorly understood. A recent situation highlights the potential magnitude of such changes. In Tucson, Arizona, significant red water problems were experienced concurrent with a shift in corrosion control strategy and a change in water source. Failure to effectively and immediately address the problem generated a firestorm of consumer dissatisfactions and complaint. The situation has generated political consequences that threaten continued funding on a major public works project.

Water Quality and Aesthetics

Implementation of a corrosion control strategy may produce unintended water quality changes as a result of the re-equilibration issues discussed above. Because of potential consumer dissatisfaction, water quality aesthetics are an important part of the selection criterion. Aesthetics considerations consist of appearance, taste, and odor. Appearance (red water, blue water) may be influenced by re-equilibration of existing corrosion scales, leading to particulate and corrosion byproduct release. Control strategies may influence taste and odor by altering the pH, and/or stimulation of microbial growth.

Regrowth

The City of Fresno's water system is a partially chlorinated system. While this may change in the future to complete chlorination as a result of the Groundwater Disinfection Rule, the issue of microbial regrowth in the distribution system is important to the maintenance of current biological standards. The lack of disinfection residual in portions of the distribution system makes these areas of the system particularly susceptible to regrowth. Hence, recognizing the potential to exacerbate microbial growth is an important corrosion control strategy selection criteria.

The major regrowth concerns associated with corrosion inhibitors are bacteria and algae stimulation. Fungi can also be a concern, though very little is known about fungal growth in distribution systems. General regrowth considerations are discussed below.

Bacteria--

Several factors may influence bacterial growth in the distribution system:

- environmental variables (e.g., temperature)
- nutrient availability
- disinfectant residuals
- corrosion and sediment accumulation
- hydraulic effects

For the most part, corrosion control alternatives should reduce regrowth problems rather than promote them. While some work has been done to indicate that carbonate addition could stimulate bacterial growth in eutrophic water, the most significant concern is associated with the use of phosphates. Experiments on Lake Michigan water have indicated that phosphorous is the limiting nutrient for bacterial growth. Additions of a phosphate based inhibitor have substantially degraded overall microbial quality in distribution systems using this water. On the other hand, high levels of zinc orthophosphate show an inhibitory effect on certain coliform species.

Algae--

Depending on the background phosphorous concentration, it has been well documented that the addition of a phosphate (either in ortho or polyphosphate form) stimulates the growth of algae in open reservoirs. This is of little consequence for the City of Fresno because of the lack of open reservoirs in the system.

Work done by the Los Angeles Department of Water and Power has shown inhibitory affects associated with zinc orthophosphate addition at doses above 1 mg/L in their source waters.

For the City of Fresno, the principal regrowth issue centers on the possible stimulus of bacterial growth by the addition of phosphates. This concern should not rule out the application of phosphate chemicals in the system, but it may require that additional monitoring (heterotrophic plate counts) be implemented to track microbial populations at the time of start-up in non-chlorinated areas of the system.

Re-Equilibration/Water Quality/Regrowth Evaluation

Table 6.10 gives the point assignments for the different strategies (20 points maximum). $CaCO_3$ deposition ranked lowest in this analysis because of the potential for serious short-term "red water" and "white water" problems. It is also ranked low because it increases corrosion and tuberculation on unlined iron pipes. Silicate addition ranked highest in the evaluation because of its beneficial impact to iron surfaces with little bacterial regrowth

impact. The orthophosphate ranking recognizes a bacterial regrowth concern. Zinc orthophosphate, however, is ranked more highly than orthophosphate because of zinc's inhibitory effect on bacterial growth.

Table 6.10 - Re-Equilibration/Regrowth - Point Assignment (20 maximum)

Strategy	Point Assignment
1. $CaCO_3$ Deposition	10
2. Carbonate Passivation	15
3. Orthophosphate Addition	13
4. Zinc Orthophosphate Addition	15
5. Ortho-Polyphosphate Blend Addition	13
6. Silicate Addition	17
7. Silicate - Orthophosphate Addition	15

CORROSION CONTROL ECONOMICS

The objective of this section is to present cost information related to capital facilities, and operation and maintenance functions associated with each of the identified control strategies. This analysis focuses only on the comparative cost of implementing the various control strategies. The cost data presented is general in nature and derives from a series of studies on chemical feed and corrosion control systems performed by the USEPA. A detailed engineering study of each of the installation sites must be conducted before a precise estimate of capital costs can be developed.

Table 6.11 presents capital construction, chemical, and operations and maintenance (O&M) cost estimates for the respective strategies. The comparative capital cost estimates include bulk storage, feeders, injection equipment, and necessary process control instrumentation for each of the eight well sites, if needed.

The chemical costs are based on dosage rates established in the earlier section on strategy identification (see Table 6.3). The cost analysis is focused on the eight current well sites, supplying the high risk residences, and their water production rates.

Economic Evaluation

A total of five points has been allocated to the cost evaluation criteria. The cost analysis is based on the present worth of a twenty year total cost using a 5 percent inflation rate. O&M costs exclude the cost of chemical addition. The twenty year cost assumes a constant daily water production rate of 7.2 mgd from the eight pump stations.

From Table 6.11, the lowest total present worth costs belong to the three phosphate based inhibitor alternatives. Silicate-orthophosphate addition and carbonate passivation are roughly equivalent and somewhat more costly. Silicate addition and $CaCO_3$ deposition options have the highest costs because of the heavy chemical cost. Point assignments are given in Table 6.12.

Table 6.11 - Comparative Cost Evaluation of Corrosion Control Alternatives

Strategy	Capital[1] Cost, $	Chemical[2] Costs, $/Mgal	O&M Costs, $/Mgal	20 Year Present[3] Worth Cost
1. $CaCO_3$ Deposition	300,000	40	0.5	$1,626,000
2. Carbonate Passivation	250,000	23	0.5	$1,020,000
3. Orthophosphate Addition	120,000	16	0.25	$ 652,000
4. Zinc Orthophosphate Addition	120,000	18	0.25	$ 718,000
5. Ortho-Polyphosphate Blend Addition	120,000	20	0.25	$ 783,000
6. Silicate Addition	200,000	30	0.25	$1,191,000
7. Silicate - Ortho-phosphate Addition	120,000	25	0.25	$ 947,000

[1] Capital costs include separate chemical storage, handling, injection, and process control instrumentation at eight of the City's pump stations.
Chemical cost data derived from "Economics of Corrosion Control," (EES, 1989)
[3] The twenty year cost is not adjusted for growth and assumes an average of 7.2 mgd of treated water over the entire 20 year period.

Table 6.12 - Comparative Cost - Point Assignment (5 maximum)

Strategy	Point Assignment
1. $CaCO_3$ Deposition	1
2. Carbonate Passivation	3
3. Orthophosphate Addition	5
4. Zinc Orthophosphate Addition	5
5. Ortho-Polyphosphate Blend Addition	5
6. Silicate Addition	3
7. Silicate - Orthophosphate Addition	3

SECTION 7
STRATEGY RANKING AND RECOMMENDATIONS

SECTION 7

STRATEGY RANKING AND RECOMMENDATIONS

STRATEGY RANKING

Table 7.1 presents a summary of the evaluation point assignments and a ranking of the seven strategies. The evaluation indicates that, largely on the strength of its effectiveness and functionality, the zinc orthophosphate addition strategy ranks highest. The orthophosphate addition and carbonate passivation strategies scored very close, and are collectively ranked second. The silicate based inhibitors scored at nearly equivalent level and are ranked third. The $CaCO_3$ deposition and ortho-polyphosphate blend addition strategies ranked significantly lower than all the other options.

RECOMMENDATIONS

Based upon the corrosion control rankings, it is recommended that zinc orthophosphate be evaluated in the future, if necessary. This strategy was chosen because of its high ranking in the corrosion control effectiveness, functionality, and economics criteria. The addition of zinc orthophosphate achieves corrosion control by forming an insoluble passivating scale on the pipe surface that changes the electrochemical nature of the metal surface. Orthophosphate corrosion inhibitor addition is also ranked high and is recommended for future evaluation because of its operability and economics.

Implementation of any corrosion control strategy is not expected to significantly reduce the low 90th percentile lead concentrations (0.0025 and 0.008 mg/L). In general, unnecessary changes to a system's water quality are to be avoided. Any change to the chemical makeup of a distributed water, such as the implementation of corrosion control, forces the water to come to a new equilibrium with the new water chemistry. In this process of re-equilibration, substantial solubilization of scales and mineral deposits may take place, the consequences of which may be serious for distributed water quality. Under a strict interpretation of the LCR,

the City of Fresno's water system is not optimized for corrosion control. Optimized corrosion control is defined in the LCR as having the 90th percentile lead level for tap water no greater than the source water lead level plus 0.005 mg/L. For the City of Fresno, the source water average lead level is 0.001 mg/L and the 90th percentile level for the second round (0.008 mg/L) defines the system as not optimized. However, if the resample results could be used in place of the original samples collected improperly, the 90th percentile lead level for the second round of monitoring would be 0.006 mg/L and the system would be considered optimized. Because of this, and the risk of re-equilibration by implementing a corrosion control program, the City of Fresno will not implement the recommended corrosion control strategy unless the follow-up monitoring demonstrates that the system is not truly optimized for corrosion control.

Table 7.1 - Overall Corrosion Strategy Evaluation and Ranking

Strategy	Corrosion Control Effectiveness	Regulatory Impacts	Functionality	Re-Equilibration Regrowth	Economics	Total	Rank
1. $CaCO_3$ Deposition	20	10	10	10	1	51	4
2. Carbonate Passivation	35	12	12	15	3	77	2
3. Orthophosphate Addition	30	13	20	13	5	81	2
4. Zinc Orthophosphate Addition	35	13	18	15	5	86	1
5. Ortho-Polyphosphate Blend Addition	10	10	20	13	5	58	4
6. Silicate Addition	25	12	16	17	3	73	3
7. Silicate - Ortho - phosphate Addition	25	12	16	15	3	71	3

APPENDIX A

CITY OF FRESNO WATER QUALITY DATA
PS - 79

Constituent	Sample Date						Units
	11/09/90	05/03/93	05/24/93	06/24/93	06/25/93	07/21/93	
Arsenic					5.5		mg/L
Bicarbonate							mg/L as HCO3
Calcium	23	28	26	27		26	mg/L
Chloride							mg/L
Copper	< 0.01	< 0.01	< 0.01	< 0.01		< 0.01	mg/L
Langelier's Index	-0.4	-0.5	-0.5	-0.4		-0.7	
Lead	< 0.001	< 0.001	< 0.001	< 0.001		< 0.001	mg/L
Magnesium							mg/L
Nitrate							mg/L
pH	7.7	7.4	7.4	7.4		7.3	
Potassium							mg/L
Sodium							mg/L
Spec. Conductance	280	300	300	270		290	umhos
Sulfate							mg/L
TDS	170	170*	170*	170*		170*	mg/L
Temperature	21.7	23.1	24.6	26.5		23.3	deg C
Total Alkalinity	110	130	120	120		120	mg/L as CaCO3
Total Hardness							mg/L as CaCO3
Turbidity		0.1	0.1				NTU

* Assumed for Langelier Index Calculation

CITY OF FRESNO WATER QUALITY DATA
PS - 86

Constituent	Sample Date						Units
	11/13/90	04/29/93	05/24/93	07/01/93*	07/22/93*		
Arsenic							mg/L
Bicarbonate							mg/L as HCO3
Calcium	33	30	30	49	31		mg/L
Chloride							mg/L
Copper	< 0.01	< 0.01	< 0.01	0.22	0.056		mg/L
Langlier's Index	-0.5	-0.6	-0.6				
Lead	< 0.001	< 0.001	< 0.001	0.006	0.0025		mg/L
Magnesium							mg/L
Nitrate							mg/L
pH	7.4	7.3	7.3				
Potassium							mg/L
Sodium							mg/L
Spec. Conductance	350	310	350				umhos
Sulfate							mg/L
TDS	220	220**	220**				mg/L
Temperature	20.6	23.1	22.1				deg C
Total Alkalinity	140	130	130	180	140		mg/L as CaCO3
Total Hardness							mg/L as CaCO3
Turbidity		0.2	0.1	0.2	0.1		NTU

* Pump Station out of service for replacement.
** Assumed for Langelier Index Calculation

CITY OF FRESNO WATER QUALITY DATA
PS - 91

Constituent	Sample Date						Units
	05/03/93	05/24/93	06/25/93	07/20/93			
Arsenic			1.9				mg/L
Bicarbonate							mg/L as HCO3
Calcium	23	23	23	23			mg/L
Chloride							mg/L
Copper	< 0.01	< 0.01	< 0.01	< 0.01			mg/L
Langelier's Index	-0.4	-0.5	-0.5	-0.6			
Lead	< 0.001	< 0.001	< 0.001	< 0.001			mg/L
Magnesium							mg/L
Nitrate							mg/L
pH	7.7	7.5	7.6	7.5			
Potassium							mg/L
Sodium							mg/L
Spec. Conductance	260	360	270	260			umhos
Sulfate							mg/L
TDS	200*	200*	200*	200*			mg/L
Temperature	21.4	28.7	22.3	22.4			deg C
Total Alkalinity	99	99	97	99			mg/L as CaCO3
Total Hardness							mg/L as CaCO3
Turbidity		0.3					NTU

* Assumed for Langelier Index Calculation

CITY OF FRESNO WATER QUALITY DATA
PS - 97

Constituent	Sample Date						Units
	11/13/90	05/03/93	05/26/93	06/23/93	06/28/93	07/21/93	
Arsenic				2.0	3.0		mg/L
Bicarbonate							mg/L as HCO3
Calcium	23	27	27	27		27	mg/L
Chloride							mg/L
Copper	< 0.01	< 0.01	< 0.01	< 0.01		< 0.01	mg/L
Langlier's Index	-0.4	-0.7	-0.7	-0.6		-0.5	
Lead	< 0.001	< 0.001	< 0.001	< 0.001		< 0.001	mg/L
Magnesium							mg/L
Nitrate							mg/L
pH	7.7	7.3	7.3	7.4		7.5	
Potassium							mg/L
Sodium							mg/L
Spec. Conductance	270	300	310	300		290	umhos
Sulfate							mg/L
TDS	170	190*	190*	190*		190*	mg/L
Temperature	21.7	21.9	22.5	22.9		21.4	deg C
Total Alkalinity	110	110	120	120		110	mg/L as CaCO3
Total Hardness							mg/L as CaCO3
Turbidity							NTU

* Assumed for Langelier Index Calculation

CITY OF FRESNO WATER QUALITY DATA
PS - 99

Constituent	Sample Date						Units
	11/13/90	04/22/93	05/26/93	06/23/93	06/28/93	07/21/93	
Arsenic					2.9		mg/L
Bicarbonate							mg/L as HCO3
Calcium	16	17	18	18		18	mg/L
Chloride							mg/L
Copper	< 0.01	0.025	0.025	0.025		0.025	mg/L
Langelier's Index	-0.4	-0.7	-0.7	-0.8		-0.7	
Lead	< 0.001	< 0.001	< 0.001	< 0.001		0.0025	mg/L
Magnesium							mg/L
Nitrate							mg/L
pH	7.9	7.6	7.5	7.5		7.6	
Potassium							mg/L
Sodium							mg/L
Spec. Conductance	210	210	240	270		240	umhos
Sulfate							mg/L
TDS	130	130*	130*	130*		130*	mg/L
Temperature	20.6	21.5	23.8	22.1		22.7	deg C
Total Alkalinity	88	80	87	85		85	mg/L as CaCO3
Total Hardness							mg/L as CaCO3
Turbidity		0.2		0.1		0.1	NTU

* Assumed for Langelier Index Calculation

CITY OF FRESNO WATER QUALITY DATA
PS - 121 (KVDS)

Constituent	Sample Date						Units
	04/29/93	05/24/93	06/24/93	06/29/93	07/20/93		
Arsenic			3.3				mg/L
Bicarbonate							mg/L as HCO3
Calcium	16	24		26	22		mg/L
Chloride							mg/L
Copper	<0.01	<0.01		0.025	<0.01		mg/L
Langelier's Index	-0.8	-0.8		-0.5	-0.7		
Lead	<0.001	<0.001		0.0025	0.0025		mg/L
Magnesium							mg/L
Nitrate							mg/L
pH	7.6	7.3		7.5	7.4		
Potassium							mg/L
Sodium							mg/L
Spec. Conductance	200	310		280	270		umhos
Sulfate							mg/L
TDS	200*	200*		200*	200*		mg/L
Temperature	22.5	25		23.3	24.3		deg C
Total Alkalinity	79	100		110	97		mg/L as CaCO3
Total Hardness							mg/L as CaCO3
Turbidity	0.1	0.1		0.1	0.7		NTU

* Assumed for Langelier Index Calculation

CITY OF FRESNO WATER QUALITY DATA
PS - 131

Constituent	Sample Date						Units
	04/21/91	04/29/93	05/12/93	05/24/93	06/28/93	07/21/93	
Arsenic							mg/L
Bicarbonate							mg/L as HCO3
Calcium	19	19		21	21	20	mg/L
Chloride							mg/L
Copper	<0.01	<0.01	0.19	<0.01	<0.01	<0.01	mg/L
Langelier's Index	-0.8	-0.8		-0.5	-0.7	-0.7	
Lead	<0.001	<0.001	<0.001	0.0025	<0.001	<0.001	mg/L
Magnesium							mg/L
Nitrate							mg/L
pH	7.3	7.4		7.6	7.4	7.4	
Potassium							mg/L
Sodium							mg/L
Spec. Conductance	220	230		230	260	230	umhos
Sulfate							mg/L
TDS	140	140*		140*	140*	140*	mg/L
Temperature	24.0*	24.0		26.3	24.4	24.0	deg C
Total Alkalinity	98	97		99	95	99	mg/L as CaCO3
Total Hardness							mg/L as CaCO3
Turbidity		0.2		0.1	0.1	0.1	NTU

* Assumed for Langelier Index Calculation

CITY OF FRESNO WATER QUALITY DATA
PS - 140

Constituent	Sample Date							Units
	11/19/90	06/18/91	04/28/93	05/24/93	06/29/93	07/20/93	08/26/93	
Arsenic							2.1	mg/L
Bicarbonate							140	mg/L as HCO3
Calcium	24	21	31	30	31	30	31	mg/L
Chloride							15	mg/L
Copper	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		mg/L
Langelier's Index	-0.3	-0.2	-0.6	-0.6	-0.8	-0.8	-0.0	
Lead	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		mg/L
Magnesium							12	mg/L
Nitrate							6.8	mg/L
pH	7.7	7.9	7.2	7.4	7.1	7.2	7.9	
Potassium							4.0	mg/L
Sodium							21	mg/L
Spec. Conductance	280	270	350	340	360	310	340	umhos
Sulfate							12	mg/L
TDS	170	170	210*	210*	210*	210*	210	mg/L
Temperature	22.2	23.4*	31.8	22.8	23.4	22.7	22.7*	deg C
Total Alkalinity	110	100	110	110	110	100	110	mg/L as CaCO3
Total Hardness							130	mg/L as CaCO3
Turbidity			0.2	0.2	0.1	0.1	0.1	NTU

* Assumed for Langelier Index Calculation

CITY OF FRESNO WATER QUALITY DATA
DISTRIBUTION SYSTEM ANALYSES - FIRST ROUND

Sample No.	Samples Taken 4/29/93 - 5/4/93					Samples Taken 5/24/93 - 5/26/93				
	Alkalinity (mg/L CaCO3)	Calcium (mg/L)	pH	Temp. (deg C)	Cond. (mS/cm)	Alkalinity (mg/L CaCO3)	Calcium (mg/L)	pH	Temp. (deg C)	Cond. (mS/cm)
D-31	140	29	7.19	22.4	0.34	160	35	7.14	24.9	0.39
D-34	120	26	7.58	22.7	0.29	120	25	7.43	23.1	0.28
D-36	110	27	7.44	22.8	0.30	110	25	7.58	23.3	0.29
D-66	91	18	7.48	20.8	0.20	120	28	7.23	24.8	0.31
D-68	160	37	7.15	21.8	0.38	130	31	7.17	23.1	0.35
D-69	140	35	7.22	23.6	0.35	150	33	7.18	23.3	0.35
D-70	93	20	7.56	21.5	0.23	140	32	7.16	20.9	0.38
D-76	110	22	7.56	20.6	0.25	110	25	7.30	24.3	0.33
D-79	97	23	7.54	22.1	0.26	97	22	7.43	23.6	0.26
D-81	110	28	7.38	23.5	0.31	110	28	7.33	25.5	0.32
D-82	110	26	7.63	22.8	0.28	110	24	7.43	23.3	0.30
D-116	140	34	7.22	24.3	0.33	110	33	7.14	22.6	0.43
D-117	130	33	7.39	23.6	0.32	120	28	7.26	24.7	0.29
D-126	79	17	7.55	22.5	0.19	110	25	7.27	24.9	0.27
D-128	170	35	7.10	22.5	0.36	110	25	7.14	23.8	0.31
D-129	110	27	7.33	25.4	0.31	110	24	7.36	25.0	0.29
D-130	110	23	7.41	22.4	0.27	110	22	7.35	23.2	0.28
D-133	120	25	7.47	21.0	0.28	120	26	7.43	24.8	0.30
D-134	110	26	7.46	23.8	0.28	99	20	7.46	25.1	0.27
D-155	81	17	7.44	23.4	0.21	130	31	7.22	24.9	0.33
D-156	130	25	7.27	23.2	0.29	120	33	7.12	24.5	0.41
D-158	120	25	7.37	24.0	0.29	110	31	7.16	22.1	0.36
D-159	130	26	7.17	23.5	0.31	150	33	7.23	23.3	0.40
D-181	120	27	7.44	22.9	0.32	120	27	7.33	23.2	0.31
D-202	120	28	7.34	23.0	0.31	120	28	7.39	24.6	0.32
Average	116	26	7.43	22.2	0.29	123	28	7.31	23.6	0.32
Minimum	91	18	7.15	20.6	0.20	97	22	7.14	20.9	0.26
Maximum	160	37	7.63	23.6	0.38	160	35	7.58	25.5	0.39

CITY OF FRESNO WATER QUALITY DATA
DISTRIBUTION SYSTEM ANALYSES - SECOND ROUND

Sample No.	Samples Taken 6/23/93 - 7/1/93					Samples Taken 7/20/93 - 7/21/93				
	Alkalinity (mg/L CaCO3)	Calcium (mg/L)	pH	Temp. (deg C)	Cond. (mS/cm)	Alkalinity (mg/L CaCO3)	Calcium (mg/L)	pH	Temp. (deg C)	Cond. (mS/cm)
D-31	140	29	7.26	26.1	0.35	140	30	7.20	25.1	0.32
D-34	120	29	7.68	28.6	0.30	130	34	7.67	32.0	0.27
D-36	110	26	7.51	25.8	0.30	110	30	7.60	26.5	0.28
D-66	75	16	7.47	25.4	0.21	79	20	7.37	27.4	0.23
D-68	170	44	7.13	24.9	0.47	170	40	7.21	22.5	0.41
D-69	160	38	7.03	26.7	0.47	160	38	7.17	27.0	0.37
D-70	120	28	7.12	29.7	0.28	130	30	7.24	25.1	0.27
D-76	91	21	7.30	24.5	0.23	91	23	7.53	27.1	0.31
D-79	130	28	7.43	26.5	0.27	97	23	7.43	23.6	0.26
D-81	110	26	7.24	29.7	0.29	120	31	7.50	25.7	0.29
D-82	110	26	7.34	25.6	0.28	110	30	7.45	25.1	0.30
D-116	110	29	7.03	25.8	0.36	120	31	7.11	26.7	0.34
D-117	130	29	7.32	28.1	0.31	120	25	7.30	27.7	0.26
D-126	99	24	7.74	23.9	0.29	99	26	7.39	27.3	0.26
D-128	110	21	7.21	26.2	0.27	180	36	7.13	25.4	0.32
D-129	120	27	7.25	25.8	0.28	120	27	7.26	31.4	0.31
D-130	110	24	7.28	25.2	0.26	100	26	7.33	24.7	0.27
D-133	99	22	7.45	25.4	0.25	120	33	7.69	27.7	0.28
D-134	93	21	7.50	26.7	0.23	100	25	7.53	29.7	0.23
D-155	110	24	7.23	29.7	0.25	91	19	7.45	27.1	0.21
D-156	110	21	7.20	29.5	0.28	120	30	7.17	28.1	0.35
D-158	120	30	7.16	27.8	0.35	120	32	7.16	27.0	0.35
D-159	130	29	7.22	25.7	0.37	120	28	7.20	26.5	0.29
D-181	120	27	7.32	26.6	0.31	110	24	7.32	28.4	0.29
D-202	77	20	7.68	22.8	0.23	120	27	7.62	22.7	0.24
Average	115	26	7.32	26.5	0.30	119	29	7.36	26.7	0.29
Minimum	75	16	7.03	22.8	0.21	79	19	7.11	22.5	0.21
Maximum	170	44	7.74	29.7	0.47	180	40	7.69	32.0	0.41

CITY OF FRESNO WATER QUALITY DATA
TAP WATER SAMPLE ANALYSIS - FIRST ROUND

Ranking		Sample No.	Lead mg/L		Sample No.	Copper mg/L
131		169	0.037		153	0.74
130		154	0.011		159	0.60
129		157	0.008		18	0.56
128		10	0.007		54	0.53
127		18	0.006		174	0.52
126		151	0.006		137	0.51
125		90	0.005		156	0.51
124		1	0.0025*		175	0.51
123		2	0.0025*		21	0.50
122		3	0.0025*		128	0.48
121		11	0.0025*		1	0.47
120		41	0.0025*		166	0.47
119		48	0.0025*		171	0.45
118	90th %	53	0.0025*	90th %	80	0.43
117		54	0.0025*		151	0.43
116		60	0.0025*		146	0.42
115		64	0.0025*		152	0.42
114		65	0.0025*		53	0.39
113		72	0.0025*		72	0.39
112		81	0.0025*		20	0.38
111		93	0.0025*		83	0.38
110		95	0.0025*		176	0.38
109		102	0.0025*		133	0.37
108		109	0.0025*		67	0.36
107		110	0.0025*		132	0.36
106		113	0.0025*		150	0.36
105		114	0.0025*		169	0.36
104		117	0.0025*		27	0.35
103		118	0.0025*		81	0.35
102		119	0.0025*		90	0.35
101		129	0.0025*		141	0.35
100		130	0.0025*		145	0.35
99		132	0.0025*		161	0.34
98		134	0.0025*		41	0.33
97		135	0.0025*		46	0.33
96		136	0.0025*		142	0.33
95		137	0.0025*		10	0.32
94		140	0.0025*		95	0.32
93		141	0.0025*		113	0.32
92		152	0.0025*		130	0.32
91		155	0.0025*		168	0.32
90		163	0.0025*		26	0.31
89		166	0.0025*		148	0.31
88		168	0.0025*		88	0.30
87		170	0.0025*		93	0.30
86		171	0.0025*		42	0.28
85		172	0.0025*		48	0.28

CITY OF FRESNO WATER QUALITY DATA
TAP WATER SAMPLE ANALYSIS - FIRST ROUND

Ranking		Sample No.	Lead mg/L		Sample No.	Copper mg/L
84		173	0.0025*		11	0.27
83		174	0.0025*		65	0.26
82		175	0.0025*		107	0.26
81		176	0.0025*		120	0.26
80		4	< 0.001		2	0.25
79		20	< 0.001		30	0.25
78		21	< 0.001		64	0.25
77		25	< 0.001		115	0.25
76		26	< 0.001		149	0.25
75		27	< 0.001		163	0.25
74		30	< 0.001		165	0.25
73		36	< 0.001		79	0.24
72		38	< 0.001		75	0.23
71		39	< 0.001		102	0.23
70		40	< 0.001		114	0.23
69		42	< 0.001		51	0.22
68		43	< 0.001		62	0.22
67		46	< 0.001		39	0.21
66		50	< 0.001		63	0.21
65		51	< 0.001		124	0.21
64		52	< 0.001		109	0.20
63		55	< 0.001		55	0.19
62		56	< 0.001		76	0.19
61		57	< 0.001		100	0.19
60		58	< 0.001		119	0.19
59		61	< 0.001		131	0.19
58		62	< 0.001		136	0.19
57		63	< 0.001		170	0.19
56		66	< 0.001		71	0.18
55		67	< 0.001		78	0.18
54		69	< 0.001		112	0.18
53		71	< 0.001		4	0.17
52		74	< 0.001		40	0.17
51		75	< 0.001		50	0.17
50		76	< 0.001		89	0.17
49		78	< 0.001		110	0.17
48		79	< 0.001		143	0.17
47		80	< 0.001		164	0.17
46		83	< 0.001		25	0.16
45		84	< 0.001		125	0.16
44		86	< 0.001		38	0.15
43		87	< 0.001		157	0.15
42		88	< 0.001		173	0.15
41		89	< 0.001		56	0.14
40		91	< 0.001		58	0.14
39		92	< 0.001		66	0.14
38		98	< 0.001		87	0.14

CITY OF FRESNO WATER QUALITY DATA
TAP WATER SAMPLE ANALYSIS - FIRST ROUND

Ranking		Sample No.	Lead mg/L		Sample No.	Copper mg/L
37		100	< 0.001		118	0.14
36		103	< 0.001		167	0.14
35		105	< 0.001		91	0.13
34		107	< 0.001		105	0.13
33		108	< 0.001		108	0.13
32		111	< 0.001		122	0.13
31		112	< 0.001		3	0.12
30		115	< 0.001		98	0.12
29		116	< 0.001		129	0.12
28		120	< 0.001		139	0.12
27		122	< 0.001		172	0.12
26		123	< 0.001		43	0.11
25		124	< 0.001		135	0.11
24		125	< 0.001		57	0.10
23		126	< 0.001		60	0.10
22		127	< 0.001		92	0.10
21		128	< 0.001		116	0.10
20		131	< 0.001		144	0.10
19		133	< 0.001		36	0.09
18		139	< 0.001		61	0.09
17		142	< 0.001		111	0.09
16		143	< 0.001		127	0.09
15		144	< 0.001		86	0.08
14		145	< 0.001		155	0.08
13		146	< 0.001		126	0.07
12		147	< 0.001		134	0.07
11		148	< 0.001		147	0.07
10		149	< 0.001		103	0.06
9		150	< 0.001		117	0.06
8		153	< 0.001		123	0.06
7		156	< 0.001		52	0.025**
6		158	< 0.001		69	0.025**
5		159	< 0.001		74	0.025**
4		161	< 0.001		84	0.025**
3		164	< 0.001		140	0.025**
2		165	< 0.001		158	0.025**
1		167	< 0.001		154	<0.01

* The laboratory reports lead values between 0.0010 and 0.0049 mg/L as 0.0025 mg/L.

** The laboratory reports copper values between 0.010 and 0.049 mg/L as 0.025 mg/L.

CITY OF FRESNO WATER QUALITY DATA
TAP WATER SAMPLE ANALYSIS - SECOND ROUND

Ranking		Sample No.	Lead mg/L		Sample No.	Copper mg/L
130		161	0.110		153	0.76
129		155	0.072		27	0.62
128		151	0.053		80	0.57
127		148	0.046		130	0.56
126		173	0.025		139	0.56
125		142	0.021		137	0.55
124		87	0.012		166	0.55
123		145	0.012		10	0.54
122		170	0.012		142	0.51
121		114	0.011		83	0.49
120		18	0.010		175	0.49
119		92	0.010		141	0.48
118		154	0.009		152	0.46
117	90th %	25	0.008	90th %	18	0.43
116		119	0.008		128	0.43
115		140	0.008		143	0.43
114		65	0.007		46	0.42
113		120	0.007		113	0.42
112		79	0.006		172	0.42
111		102	0.006		173	0.42
110		135	0.006		146	0.41
109		30	0.005		149	0.40
108		108	0.005		55	0.39
107		1	0.0025*		114	0.39
106		2	0.0025*		169	0.39
105		10	0.0025*		127	0.38
104		11	0.0025*		81	0.37
103		20	0.0025*		129	0.37
102		26	0.0025*		147	0.36
101		27	0.0025*		159	0.36
100		38	0.0025*		79	0.35
99		39	0.0025*		51	0.34
98		41	0.0025*		63	0.34
97		43	0.0025*		88	0.34
96		48	0.0025*		89	0.34
95		53	0.0025*		90	0.32
94		54	0.0025*		102	0.31
93		60	0.0025*		163	0.31
92		64	0.0025*		171	0.31
91		66	0.0025*		1	0.29
90		75	0.0025*		107	0.29
89		78	0.0025*		161	0.29
88		81	0.0025*		168	0.29
87		89	0.0025*		52	0.28
86		90	0.0025*		53	0.28
85		93	0.0025*		111	0.28
84		100	0.0025*		132	0.28

CITY OF FRESNO WATER QUALITY DATA
TAP WATER SAMPLE ANALYSIS - SECOND ROUND

Ranking		Sample No.	Lead mg/L		Sample No.	Copper mg/L
83		109	0.0025*		42	0.27
82		112	0.0025*		64	0.27
81		116	0.0025*		131	0.27
80		117	0.0025*		140	0.27
79		118	0.0025*		150	0.27
78		122	0.0025*		54	0.26
77		127	0.0025*		66	0.26
76		128	0.0025*		174	0.26
75		130	0.0025*		25	0.25
74		131	0.0025*		109	0.25
73		132	0.0025*		112	0.25
72		133	0.0025*		125	0.25
71		134	0.0025*		100	0.24
70		137	0.0025*		120	0.24
69		139	0.0025*		133	0.24
68		141	0.0025*		155	0.24
67		143	0.0025*		2	0.23
66		146	0.0025*		76	0.23
65		147	0.0025*		119	0.23
64		149	0.0025*		30	0.22
63		150	0.0025*		48	0.22
62		152	0.0025*		65	0.22
61		156	0.0025*		40	0.21
60		163	0.0025*		50	0.21
59		166	0.0025*		105	0.21
58		167	0.0025*		124	0.21
57		168	0.0025*		39	0.20
56		171	0.0025*		58	0.20
55		172	0.0025*		78	0.20
54		175	0.0025*		98	0.20
53		176	0.0025*		60	0.19
52		3	<0.001		71	0.19
51		4	<0.001		115	0.19
50		21	<0.001		134	0.19
49		36	<0.001		144	0.19
48		40	<0.001		151	0.19
47		42	<0.001		156	0.19
46		46	<0.001		61	0.18
45		50	<0.001		93	0.18
44		51	<0.001		136	0.18
43		52	<0.001		148	0.18
42		55	<0.001		38	0.17
41		56	<0.001		41	0.17
40		57	<0.001		69	0.17
39		58	<0.001		110	0.17
38		61	<0.001		126	0.17
37		63	<0.001		158	0.17

CITY OF FRESNO WATER QUALITY DATA
TAP WATER SAMPLE ANALYSIS - SECOND ROUND

Ranking		Sample No.	Lead mg/L		Sample No.	Copper mg/L
36		67	<0.001		170	0.17
35		69	<0.001		4	0.16
34		71	<0.001		26	0.16
33		72	<0.001		87	0.16
32		74	<0.001		108	0.16
31		76	<0.001		91	0.15
30		80	<0.001		92	0.15
29		83	<0.001		135	0.15
28		84	<0.001		36	0.14
27		86	<0.001		56	0.14
26		88	<0.001		57	0.14
25		91	<0.001		86	0.13
24		95	<0.001		118	0.13
23		98	<0.001		122	0.13
22		103	<0.001		145	0.13
21		105	<0.001		164	0.13
20		107	<0.001		67	0.12
19		110	<0.001		95	0.12
18		111	<0.001		176	0.12
17		113	<0.001		103	0.10
16		115	<0.001		84	0.10
15		123	<0.001		72	0.10
14		124	<0.001		11	0.09
13		125	<0.001		43	0.09
12		126	<0.001		75	0.08
11		129	<0.001		117	0.07
10		136	<0.001		123	0.06
9		144	<0.001		167	0.06
8		153	<0.001		165	0.05
7		157	<0.001		154	0.025**
6		158	<0.001		116	0.025**
5		159	<0.001		74	0.025**
4		164	<0.001		21	0.025**
3		165	<0.001		20	0.025**
2		169	<0.001		3	0.025**
1		174	<0.001		157	<0.01

* The laboratory reports lead values between 0.0010 and 0.0049 mg/L as 0.0025 mg/L.

** The laboratory reports copper values between 0.010 and 0.049 mg/L as 0.025 mg/L.