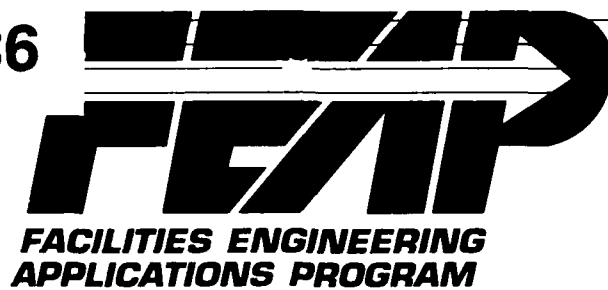


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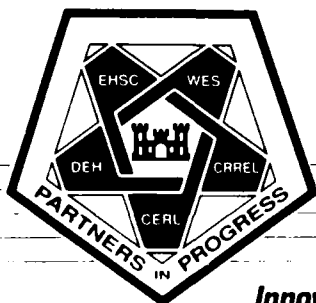


**INTERIM
REPORT**

Lead Monitoring Strategies for Drinking Water Systems: Lessons Learned

by
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13. ABSTRACT (Maximum 200 words) Like private sector utilities, Army installations that operate potable water supply and distribution systems must comply with the regulations that govern drinking water quality. The U.S. Environmental Protection Agency (USEPA) has proposed a new rule to regulate the levels of lead and copper present at the consumer's tap. Under this rule, installations will have to implement a monitoring program to test residential tapwater and take remedial action if lead and/or copper concentrations are found to be unacceptably high. This report reviews the proposed Lead and Copper Rule and discusses some other regulations that will either be affected by or have impact on this rule. The proposed compliance schedule is summarized. The results of this study will serve as background for developing guidelines to assist installations in meeting new lead and copper regulations. Development of these guidelines awaits the final ruling on the proposed Lead and Copper Rule.				
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FOREWORD

This work was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC) by the U.S. Army Construction Engineering Research Laboratory (USACERL) under Project FEAP-NN-F99, "Pipe Loop System." The project was part of the FY89 Facilities Engineering Applications Program (FEAP). The USAEHSC technical monitor was T. Wash, CEHSC-FU.

The work was performed by the USACERL Environmental Division (EN). Dr. R. K. Jain is Chief of USACERL-EN. Appreciation is expressed to Jocelyn Clark of USACERL Environmental Division for review. Appreciation is also expressed to Vicki Van Blaricum of USACERL Engineering and Materials Division for additional comments.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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LEAD MONITORING STRATEGIES FOR DRINKING WATER SYSTEMS: LESSONS LEARNED

1 INTRODUCTION

Background

Army installations that have their own water supply meeting the definition of public water supply as described in the Safe Drinking Water Act (SDWA)¹ are subject to the same drinking water enforcement regulations as private sector utilities. In August 1988, the U.S. Environmental Protection Agency (USEPA) proposed a rule to regulate lead and copper in drinking water. Under the rule, utilities would have to comply with a maximum contaminant level (MCL) at distribution system entry points and implement corrosion control treatment if monitoring at customer taps indicates elevated lead levels.

Water sources, water treatment chemicals, and transmission and distribution systems are usually not significant contributors to lead levels in drinking water. The major source of lead in potable water is plumbing--lead service lines, solders containing lead which are used to join copper plumbing, and faucet fixtures made of brass which can contain up to 8 percent lead.

The degree of lead contamination in tapwater is influenced by several factors. In addition to the plumbing materials used, water quality has an important role, influenced mostly by pH, alkalinity, temperature, and the presence of corrosion inhibitors. Physical factors such as the age of the plumbing material and the time the water has been in contact with the lead material also affect the lead content.

The presence of lead in drinking water supply systems is an issue with health implications. As the purveyor of water, the installation commander has the primary responsibility for regulatory compliance monitoring. Installations therefore must take the initiative and assess their water systems for potential lead leaching and consumer exposure. This evaluation is necessary whether the installations produce and distribute their own water or purchase it outside for distribution to their personnel.

Unlike private sector water utilities, where ownership of the distribution system ends at the main service line connection, Army installations are responsible for and have authority over all aspects of the distribution and facility plumbing systems on their property. Due to the treatment and monitoring implications of the proposed Lead and Copper Rule, many installations (as well as private sector utilities) have initiated monitoring programs for lead and copper at their customer's taps. These case studies provide a valuable data base in terms of determining the magnitude of the lead problem in drinking water systems. However, the monitoring protocols have been specifically geared toward individual studies such that the results are virtually impossible to compare.

The final Lead and Copper Rule from USEPA is expected to provide guidance on monitoring for compliance. In the interim, a comprehensive strategy for lead monitoring and control that takes into account the forthcoming SDWA regulations needs to be developed for Army installations.

¹Public Law (PL) 93-523, *Safe Drinking Water Act of 1974*, 88 Stat. 1660.

Objective

The overall objective of this project is to provide guidelines for Army installations to identify and assess the extent of lead contamination, and propose strategies for regulatory compliance.

The specific objective of this interim report is to review regulatory aspects of the proposed Lead and Copper Rule, identify sources of lead in drinking water, and delineate important factors associated with lead control in drinking water systems. This information will assist installations in meeting regulations.

Approach

The regulatory aspects of the USEPA proposed Lead and Copper Rule, as applicable to Army installations, were reviewed and summarized. Other final or proposed regulations currently scheduled for implementation that may be impacted by or potentially affect the proposed Lead and Copper Rule also were reviewed. The literature was reviewed to determine the primary sources of lead contamination. Strategies used by various public water utilities to identify and assess lead in drinking water were documented. The information gathered was summarized and evaluated to determine major factors for a successful lead monitoring program. Various elements of a comprehensive lead monitoring and control strategy were developed by investigating techniques reported by the private sector and from lessons learned during demonstrations of the Pipe Loop System. This system was developed by the U.S. Army Construction Engineering Research Laboratory (USACERL) as a noninvasive, low-cost method of monitoring water quality at various Army installations.²

Scope

This report provides guidance for identification, assessment, and control of lead in drinking water systems. The discussion covers the sources of lead, a literature search to learn what several utilities have accomplished in terms of water quality monitoring and lead materials studies, and lessons learned from the USACERL Pipe Loop studies. A test protocol for operation, data collection, and interpretation of the Pipe Loop System data will be provided after USEPA passes the final Lead and Copper Rule.

Mode of Technology Transfer

It is recommended that the information in this report be transmitted as a U.S. Army Engineering and Housing Support Center (USAEHSC) Technical Note to all permanent Army installations that have water supplies meeting the definition of public water supply as described in the SDWA. USAEHSC will be the primary technology transfer agency. The information in this report also should be used to update Technical Manual (TM) 5-813-3, *Water Supply, Water Treatment*.

² P. Temkar, *Development of the Pipe Loop System for Determining Effectiveness of Corrosion Control Chemicals in Potable Water Systems*, Technical Report N-88/12/ADA200105 (U.S. Army Construction Engineering Research Laboratory [USACERL], 1988); P. Temkar, et al., "Pipe Loop System for Evaluating Effects of Water Quality Control Chemicals in Water Distribution Systems," *Proceedings, AWWA Water Quality Technology Conference* (AWWA, 1987).

2 REVIEW OF REGULATIONS

By passing SDWA in 1974, the U.S. Congress authorized USEPA to develop national regulations to control contaminants in drinking water "which may have any adverse affects on health" or the overall aesthetics of drinking water. In 1986, SDWA was amended. Future regulations resulting from these amendments will propel the water supply industry in the United States into a new era of monitoring and compliance requirements.

Since SDWA was amended, several new regulations have been either proposed or finalized. The 1986 SDWA amendments set schedules for regulating 83 compounds by June 1989 with an additional 25 compounds to be added every 3 years. The amendments also specified a ban on the use of lead materials for public water systems. Lead materials are defined as:

- Pipe and pipe fittings with more than 8 percent lead
- Solder or flux containing more than 0.2 percent lead.

The Proposed Rule for Maximum Contaminant Level Goals and National Primary Drinking Water Regulations for Lead and Copper (Proposed Lead and Copper Rule) is discussed below. Other final or proposed regulations are currently scheduled for implementation that may be impacted by or potentially affect the proposed Lead and Copper Rule. These regulations include the Surface Water Treatment Rule (SWTR), the Total Coliform Rule, and upcoming rules covering disinfectants and disinfectant byproducts. These regulations and their relationship to the proposed Lead and Copper Rule are also discussed in this chapter. Regulatory timing and compliance requirements for these rules are shown in Figure 1.

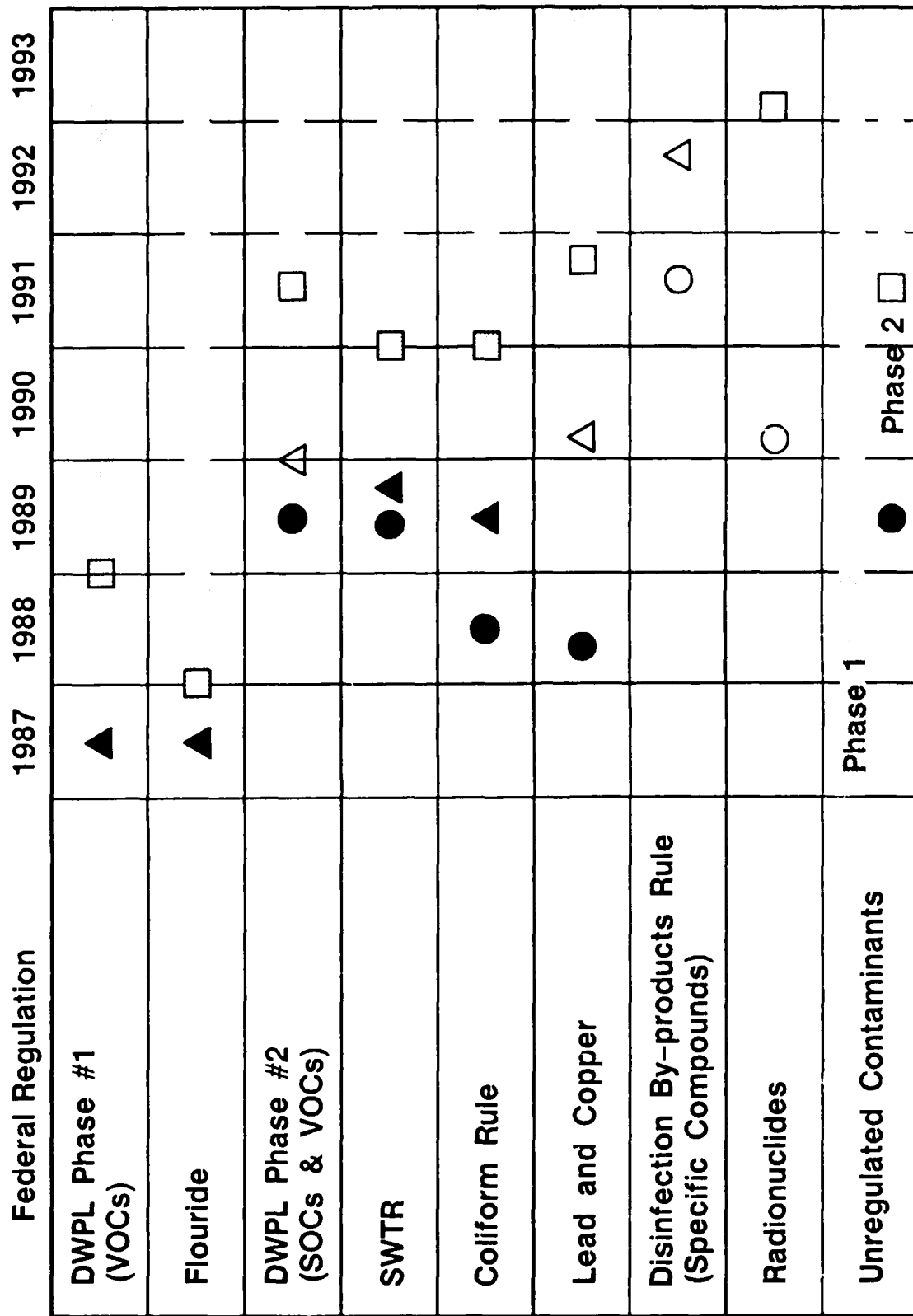
Proposed Lead and Copper Rule

The proposed Lead and Copper Rule was published in the August 18, 1988 *Federal Register* (53 FR 31516). The proposed rule addresses both lead and copper levels in source waters and entry of lead and copper into the water from corrosion of distribution piping and household plumbing. It would require public water utilities to take the following actions:

- Evaluate lead and copper levels in source water
- Conduct a materials survey to target corrosion sampling sites
- Conduct a sampling program to determine compliance.

Depending on results of the sampling program, the following actions may be required:

- Preparation of a treatment plan for approval by the primacy agency
- Optimization of treatment
- Initiation of a public education program.



Notes: ● Proposed Rule ▲ Final Rule □ Effective Date Monitoring Period

Filled pattern indicates proposed target and open fill indicates an estimated target

Figure 1. Proposed and existing drinking water regulation timeline.

The proposed rule will affect two classifications of water systems:

- Community water systems: public water systems with at least 15 service connections used year-round or with 25 year-round residents
- Noncommunity, nontransient water systems: public water systems with fewer than 15 service connections used year-round or fewer than 25 year-round residents.

The community water system classification is further subdivided based on system size into:

- < 500 people
- 500 to 3300 people
- > 3300 people.

The timetable for complying with certain provisions of the proposed rule depends on system size, as shown in Table 1. Although the Lead and Copper Rule has not been finalized, the expected promulgation date of December 1991, can be used to estimate deadlines for the various required actions.

Maximum Contaminant Level--Source Waters

The proposed Lead and Copper rule establishes MCLs for lead and copper in source waters. The current proposed MCLs are 5 µg/L for lead and 1300 µg/L for copper. These levels must be obtained from samples at the entry point of the distribution systems (leaving the treatment plant if the water is treated). USEPA has identified several treatment technologies as representing the best available technology (BAT) for removing lead and copper in source waters. They are:

- Coagulation/filtration
- Ion exchange
- Lime softening
- Reverse osmosis.

USEPA has recommended these methods as effective for reducing lead and copper in source waters to the proposed MCLs of 5 µg/L and 1300 µg/L, respectively.

"Trigger" Levels at the Tap

Under the proposed regulation, utilities will have to sample tapwater for lead and copper after the water has been standing in the interior plumbing for 8 to 18 hr. This sampling will evaluate the amount of lead and copper entering the water as the result of corrosion. Samples must be taken from homes with the highest potential risk (e.g., lead service lines or copper plumbing, new homes). If unacceptable levels

Table 1

**Proposed Lead and Copper Rule
Regulatory Timetable Overview**

Action	Persons Served	Deadline*
1. Complete materials survey	>3300	3 months after promulgation of final rule
	500 - 3300	15 months after promulgation of final rule
	<500	27 months after promulgation of final rule
2. Initiate monitoring	>3300	3 months after promulgation of final rule
	500 - 3300	15 months after promulgation of final rule
	<500	27 months after promulgation of final rule
3. Conclude initial monitoring program	All sizes	12 months after initiating monitoring program
4. Meet no-action levels or a) Submit Treatment Plan for state b) Apply to state for Treatment Plan	All sizes	a) 12 months after concluding initial monitoring program b) 12 months after concluding initial monitoring program
5. Installation of corrosion control treatment	>3300	
	<3300	
	All sizes	3 years after state approves Treatment Plan

*Deadline dates will be added upon promulgation of the final rule.

of lead and/or copper are found, this will be used to "trigger" corrosion control treatment and possibly a public education program. Lower levels of copper and lead will be termed "no-action" levels. The no-action levels currently proposed are:

- Average lead level less than 10 µg/L from monitoring high-risk homes
- Less than 5 percent of samples contain more than 20 µg/L lead from monitoring high-risk homes
- Less than 5 percent of samples contain more than 1300 µg/L copper
- pH more than 8.0 in less than 5 percent of homes.

Exceeding any of these no-action levels will "trigger" submittal of a treatment plan. This plan must be submitted within 1 year after the deadline for completing the monitoring. A treatment plan involves:

- Initiating pipe loop or laboratory studies
- Analyzing data gathered from these studies to estimate treatment and operational requirements to minimize corrosion in morning first-draw samples
- Implementing corrosion control treatment
- Monitoring to evaluate treatment effectiveness.

In addition, if the initial monitoring reveals an average lead level above 10 µg/L or lead levels in more than 5 percent targeted samples above 20 µg/L, public education would be required.

Water Quality Monitoring Requirements

Source Water Monitoring. Utilities will have to demonstrate that their source waters do not exceed the MCLs of 5 µg/L and 1300 µg/L for lead and copper, respectively. Samples must be taken at the entry points to the distribution system once per year per entry point for groundwater sources, and quarterly per entry point for surface waters. Historical data can be used to prove compliance with the MCL if the samples were taken at the correct frequency from the proper locations.

Tapwater Monitoring. Before initiating a monitoring program to evaluate corrosion, the utility must complete a materials survey to identify "targeted" residences, or those with the highest potential risk, for sampling. Important materials to be located and identified include lead service lines, lead goosenecks/pigtails, lead solder, copper tubing, and faucets containing lead. Residences selected for monitoring must be located at the end of the distribution system and fulfill the following requirements:

- Contain lead solder less than 5 years old in the home plumbing and/or--
- Have lead service lines or interior lead pipes.

The utility must identify 50 percent more sampling sites than the number actually needed for compliance (Table 2) and sampling must be done in July, August, or September.

Table 2
Proposed Lead and Copper Rule
Tapwater Sampling Frequency

System Size (Persons Served)	Minimum No. of Samples
>100,000	50/quarter
10,001 to 100,000	30/quarter
3,301 to 10,000	20/quarter
500 to 3,300	10/year, every other year
<500	10/year, every 5 years

The sampling protocol calls for 1-L samples drawn from cold water taps after the water has been standing 8 to 18 hr. The collection procedure depends on whether the residence is targeted for its lead-soldered plumbing or the presence of a lead service line. For sample sites containing lead-soldered plumbing, a morning first-draw sample from the cold water kitchen tap can be used. For sites where there are lead service lines, the 1-L sample can be drawn one of three ways:

- Immediately following a temperature change at the kitchen faucet
- After a volume of water equal to that in the home plumbing has been flushed at the kitchen faucet
- Directly from the service line.

For all samples, the water must have been standing for the required 8 to 18 hr before being allowed to run.

Public Education

Public water systems must initiate a public notice and education program if they fail to meet the average and maximum no-action levels at the tap. This program would be part of their submitted treatment plan. For community water systems, the program would provide information on sources of lead in drinking water and elsewhere in the environment, potential health risks associated with lead, and actions

consumers can take to reduce their exposure to lead in the water supply. The utility must also offer to sample any customer's water and provide the results of the analysis. Community water systems that service more than 10,000 people must evaluate this program at regular intervals. Nontransient, noncommunity water systems must post their notice and educational information in a public place, hold at least one public meeting, and distribute pamphlets on lead in drinking water on a quarterly basis.

Guidance Manual

USEPA has prepared a draft guidance manual to supplement the proposed Lead and Copper Rule. This manual provides information on implementing treatment to control lead and copper levels at the tap. It discusses how to conduct a materials survey, how to identify sampling sites, what sampling protocol to use, and how to interpret the data. Treatment alternatives and optimization are also covered. The final guidance manual will be published when, or shortly after, the final Lead and Copper Rule is promulgated.

Related Federal Regulations

Several related regulations are pending at USEPA, which when enacted, may impact the compliance status of a specific water supply. Some of the final or proposed regulations that need to be considered while planning for lead corrosion control measures are summarized below.

Lead Contamination Control Act (LCCA)

On November 1, 1988, a new amendment to the SDWA, the Lead Contamination Control Act (LCCA), was signed into law. LCCA is intended to help reduce exposure, particularly for children, to lead in drinking water. This amendment contains regulations covering the manufacture and use of water coolers with lead-lined tanks or other parts containing lead. It establishes penalties for the manufacture and sale of water coolers containing lead and requires USEPA to assist the states and local entities in testing for and reducing lead contamination at schools and daycare centers. It also includes a mandate for the Consumer Products Safety Commission to recall drinking water coolers that USEPA has identified as containing lead-lined tanks. USEPA published a proposed list of these coolers in the April 10, 1989, *Federal Register* (54 FR 14320).

Surface Water Treatment Rule (SWTR)

The 1986 amendments to SDWA required USEPA to promulgate a National Public Drinking Water Regulation (NPDWR) specifying filtration criteria and procedures. USEPA finalized a Surface Water Treatment Rule (SWTR) in the June 29, 1989, *Federal Register* (54 FR 27486) which it believes will fulfill the requirements of regulating *Giardia* organisms and turbidity, as well as providing significant protection from viruses, Legionella, and HPC. The purpose of the SWTR is to specify filtration and disinfection performance criteria for all treatment facilities using surface waters, whether or not they currently use filtration. Figure 1 is the timetable for regulation and compliance.

The general performance criteria for filtration and disinfection to be met by water systems are primarily directed toward acute health risks from waterborne microbiological contaminants. The requirements are:

- 99.9 percent removal and/or inactivation of *Giardia lamblia* cysts (equivalent to a 3-log reduction), and

- 99.99 percent removal and/or inactivation of enteric viruses (equivalent to a 4-log reduction).

Systems that achieve this performance level—whether through disinfection alone or a combination of disinfection and filtration—are in compliance with the new rule. The SWTR gives performance level credit for removal or inactivation for both filtration and disinfection. Filtration systems that meet minimum turbidity performance criteria are assumed to be well operated and are given credit for a 2-log removal of *Giardia* cysts and a 1-log removal of viruses. Because the SWTR requires a 3-log removal of *Giardia* and a 4-log removal of enteric viruses, and the credit given for proper filtration is only 2-log for *Giardia* and 1-log for viruses, the balance of the removal/inactivation requirements must be accomplished through disinfection. For systems wishing to remain unfiltered, this reduction would have to be achieved with disinfection alone. The exact disinfection credit awarded a treatment facility is a function of the calculated "CT" values(s) for that system, where "CT" is defined as the residual disinfectant concentration (C, in mg/L) times the contact time (T, min). The log inactivation/ removal credit associated with a calculated CT value is dependent on pH and temperature, and can be determined using the CT tables found in the final SWTR. In general, for chlorine, the required CT value to achieve inactivation of *Giardia* and viruses becomes larger as the pH increases. To achieve the same inactivation at a higher pH, more chlorine would have to be added or the contact time would have to be increased.

Total Coliform Rule

The final Coliform Rule was published in the June 29, 1989, *Federal Register* (54 FR 27544). The rule sets MCLs based on the presence or absence of total coliforms in a sample rather than on estimates of coliform density. Systems that analyze fewer than 40 samples per month could have no more than 1 coliform-positive sample per month. For systems that analyze 40 or more samples per month, no more than 5 percent of the samples could be coliform-positive.

If total coliforms are detected in any repeat sample, the system must collect another set of repeat samples from the same location. Any routine or repeat sample that is total coliform positive must be analyzed to determine if fecal coliforms are present. *Escherichia coli* determinations can be used instead of fecal coliform. Any repeat sample containing fecal coliform or *E. coli* would be a violation of the MCL for total coliforms.

BATs identified to meet the Coliform Rule include protection of wells, maintaining adequate residual in the distribution system, filtration/disinfection of surface water sources, and disinfection of groundwater sources. Most systems will use primary and secondary disinfection practices to comply with the new Coliform Rule.

Disinfectants and Disinfection Byproducts

USEPA is preparing a disinfection treatment rule and a rule for disinfection byproducts. These rules are estimated to be proposed in September 1991. Disinfection of natural waters may result in the formation of disinfection byproducts (DBP), the majority of which are trihalomethanes (THMs). The concentration of DBP depends on disinfectant dose, DBP precursor concentration, pH, temperature, presence of other disinfectant-demanding materials, and contact time. The primary DBPs that have been identified, including THMs, are related to the use of chlorine. Total THMs are currently the only DBPs regulated by USEPA, at 100 µg/L (Trihalomethane Regulation amendment to the NIPDWR, 1979). Indications from USEPA are that future regulations will lower this current MCL, and may also involve a treatment technique for regulation of DBPs. Disinfectants and DBPs are currently listed on the Drinking Water Priority List. The recently finalized SWTR and Total Coliform Rule may mean utilities will have

to increase dosages and/or contact times for disinfectants. Both situations could enhance the formation of disinfection byproducts.

Discussion

The major regulatory issues related to the proposed Lead and Copper Rule have been described: SWTR, the Total Coliform Rule, and the upcoming Disinfectants/Disinfectant Byproducts regulations. Treatment for corrosion control must be evaluated not only based on its effectiveness, but also for its potential impact on these regulatory issues as well as other water quality parameters. Table 3 lists common corrosion control treatments and relates them to potential impacts on water quality and regulatory compliance.

For most utilities, increasing pH will be an adequate treatment technique. This approach should be evaluated carefully due to secondary impacts such as reduction in disinfection efficiency. This reduction could jeopardize bacterial water quality and the ability of the utility to meet requirements of the Total Coliform Rule. If disinfectant dosages or contact times were increased to compensate for the reduction in efficiency, the potential for formation of disinfection byproducts would also be increased. Although proposed rules for disinfectants and disinfectant byproducts probably will not be published until 1991, the indication is that there will be many compounds regulated beyond THMs alone, and that THM levels will be more stringent. Other impacts of concern would be filtration efficiency and higher required CT values related to compliance with the SWTR.

Addition of phosphates for corrosion control poses other problems such as increased potential for algal blooms in open reservoirs and overloading wastewater with additional zinc and/or phosphate. Adding nutrients could impact bacterial regrowth in the system, creating both turbidity and coliform problems. These impacts and others listed in Table 3 should be evaluated before making final corrosion treatment decisions.

Table 3
Regulatory and Water Quality Issues

Corrosion Control Treatment Lead and Copper	SWTR Filtration/Disinfection	Disinfection Byproducts	Bacteriological Quality Total Coliform Rule	Iron and Manganese	Corrosion
Increase pH	Turbidity removal efficiency decrease	Increased THM formation	Lower disinfection efficiency may cause bacterial quality to degrade	Increased precipitation of iron and manganese possible	Can reduce corrosivity of water
	Lower disinfection efficiency	Increase in disinfectant dosage due to lowered efficiency will increase potential for DBP formation	Lower disinfection efficiency could cause violation of Total Coliform Rule	Tendency for "red water" problems to decrease	Slower rate of uniform copper corrosion possible
	Higher CT's for chlorine required				Pitting corrosion of copper may be reduced
	Higher CTD's for ozone required				May decrease corrosion rate of galvanized pipe
	Use of coagulant aids at higher pH may increase residual aluminum concentrations				
Orthophosphate Addition	Reduces optimum pH for aluminum precipitation				Can reduce lead solubility
	If zinc orthophosphate is used, potential precipitation of zinc carbonate could increase turbidity		Decrease in bacterial quality possible with addition of nutrients, i.e. reservoir blooms, bacterial regrowth		Zinc orthophosphate may reduce A/C pipe deterioration
	Increased turbidity from algal blooms in open reservoirs is possible				Zinc deposits could reduce effectiveness of corrosion inhibition
Alkalinity Adjustments	May decrease floc strength				
	Coagulation chemical dosage may need to be adjusted to achieve optimal pH				
Silicate Addition	Bicarbonate or carbonate addition will increase ozone half life, i.e. more efficient disinfection				
	High Silica levels can form precipitates in hot water				

3 SOURCES OF LEAD IN DRINKING WATER SYSTEMS

There are two main sources of lead contamination in drinking water: (1) lead from raw water sources and from chemicals added during treatment and (2) corrosion of lead-bearing materials in plumbing systems. The potential for lead exposure from water sources (either ground or surface water) is limited. The primary source of lead in drinking water comes from the contact between lead-containing plumbing materials and corrosive water. This chapter discusses the major sources of lead in drinking water.

Lead From Raw Water and Chemical Additives

Naturally Occurring Lead

Lead is a relatively minor constituent in the Earth's crust, with the average content of lead in soil estimated at 10 mg/kg. Lead in soil generally occurs as carbonates and hydroxides and the solubilities of these species impose an upper limit on the lead concentrations in surface and groundwaters. In general, naturally occurring lead does not represent a significant source of lead in drinking water supplies. Through nationwide sampling of ground- and surface water supplies, USEPA has estimated that approximately 900 public water systems or only 1 percent of the population served by public water supplies uses source water containing greater than 0.005 mg/L lead,³ the proposed regulatory limit for lead entering distribution systems from the source or treatment plant.

Nonpoint-Source Pollution

The main source of lead in surface waters is particulates from the combustion of leaded gasoline, fossil fuels, and ore smelting. These particulates, 75 percent of which are less than 0.9 μm in diameter, are available for solution and/or suspension in rainfall and runoff to surface waters. A study by Widmer⁴ showed that concentrations of lead in the upper portions of the Cambridge Reservoir, MA, which is adjacent to heavily traveled roads, were two to three times higher than those in lakes not exposed to transportation systems. However, because the residence time of lead introduced into the aqueous phase was less than the residence time of water in the reservoir, the lead was consistently being removed by sedimentation. It can be concluded that, in light of the USEPA study of lead concentrations in source waters,⁵ surface and groundwater supplies are generally not significant sources of lead in potable waters for most of the U.S. population.

Well Packers and Plugs

Many state regulations for construction and maintenance of water wells require that the well screen be connected to the well casing with a corrosion-resistant, watertight seal.⁶ This seal, called a "packer," was most commonly made of lead in the past, but now neoprene or grouting is used. Of the water wells placed before the lead ban of 1988, as many as 80 percent may contain lead packers. Also, plugs made of lead were commonly used for anchoring the well screen in the aquifer media. However, the time water

³ 40 Code of Federal Regulations (CFR), Parts 141 and 142, *Drinking Water Regulations; Maximum Contaminant Level Goals and National Primary Drinking Water Regulations for Lead and Copper; Proposed Rule* (1988).

⁴ H. Widmer, *Effects of an Urban Road System on Lead Content of an Urban Water Supply Source* (University of Massachusetts, 1976).

⁵ J.W. Patterson, *Corrosion in Water Distribution Systems* (Office of Drinking Water, USEPA, 1981).

⁶ Washington State Department of Ecology, *Minimum Standards for Construction and Maintenance of Wells*, Chapter 173-160, Washington Administrative Code (1988).

is exposed to the lead packer and/or plug surfaces during pumping is very short, minimizing lead levels from those sources. Water standing in the pump screen/packer area may accumulate higher lead concentrations when the well is off. Thus, intermittent pumping schedules and long-term seasonal shutdowns could result in a relatively small volume of water with a high concentration of lead.

Water Treatment Chemicals

Potential impurities in chemicals added directly to the water for treatment have recently become a major issue. A consortium led by the National Sanitation Foundation (NSF) has developed a voluntary third-party consensus standards and certification program for water treatment chemical additives quality assurance. The program is contained in NSF Standards 60 and 61 and is intended to replace the USEPA's Additives Advisory Program for water treatment chemicals. Standard 60 was developed to establish minimum requirements to avoid potential adverse health effects from water treatment products.⁷

Before Standards 60 and 61 became available, the Committee on Water Treatment Chemicals of the National Research Council's Food and Nutrition Board released the *Water Chemical Codex*,⁸ which provides recommended standards for impurity levels in drinking water additives. The committee found little evidence that the amounts of impurities in chemical additives may contaminate water supplies. The *Codex* established Recommended Maximum Impurity Contents (RMIC) for lead in treatment chemicals to ensure that the National Interim Drinking Water Regulations (NIDWR) MCL for lead of 0.05 mg/L is not approached or exceeded due to treatment chemical additions. The RMIC is in units of mg/kg (ppm) for the chemical. A safety factor of 10 was used to ensure that no more than 10 percent of a given MCL value would be contributed by a given impurity from a water treatment chemical.

The RMICs vary inversely with the dosage concentration of any chemical used. For instance, the RMIC is 1000 ppm lead if the chemical dosage level is 5 mg/L, but decreases to 50 ppm if the dosage is increased to 100 mg/L. Thus, knowledge of the standard inorganic content of a water treatment chemical and its dosage level in the water allows an easy determination of the acceptable lead impurity level (RMIC). If the lead content is equal to or less than the specified RMIC, it can be assumed that the use of a particular chemical at a particular dosage does not constitute a significant source of lead in the finished water. It should be recognized that even a minor addition from any source could possibly place the utility over the limit, depending on the level before its addition.

Table 4 presents the RMIC values for varying chemical use levels to meet the MCL for lead of 0.05 mg/L and possible levels of 0.01 mg/L and 0.005 mg/L. The 0.005 mg/L value is the USEPA proposed MCL for lead in source waters and 0.01 mg/L is the trigger level that applies at the top. Note that these values include the safety factor of 10.

The *Codex* identifies the following treatment chemicals as potentially having lead impurities:

- Aluminum sulfate (alum)
- Ammonium sulfate
- Calcium hydroxide (slaked lime)
- Calcium oxide (quicklime)

⁷ J. Montgomery, *Water Treatment Principles and Design* (John Wiley & Sons, 1985).

⁸ Committee on Water Treatment Chemicals, *Water Chemicals Codex* (National Academy Press, 1982).

Table 4

RMIC Values of Lead for Various Chemical Additive Use Levels

Chemical Additive Chemical Use Level (mg/L)	RMIC* (mg/kg) to Meet a Lead MCL of:		
	0.05 mg/L	0.01 mg/L	0.005 mg/L
1	5,000	1,000	500
5	1,000	200	100
10	500	100	50
50	100	20	10
100	50	10	5
150	40	8	4
200	30	6	3
400	15	3	2
600	10	2	1

*RMICs contain a safety factor of 10.

- Carbon, activated, granular (GAC)
- Carbon, activated, powdered (PAC)
- Ferric chloride
- Ferric sulfate
- Ferrous sulfate
- Sodium aluminate
- Sodium carbonate (soda ash).

Fluoride additives, such as fluosilicic acid and sodium fluosilicate, also contain traces of lead but at levels far below that which would necessitate RMIC values based on a maximum dosage of 1.2 fluoride ion/L.

Lead From Corrosion

Lead is relatively resistant to serious deterioration by waters with the chemical and physical characteristics normally encountered in drinking water supplies—hence its historical popularity as a plumbing material. Even though the deterioration is not physically destructive, leaching can result in high concentrations of lead in tapwater due to corrosion mechanisms. The use of lead pipe and the presence of significant amounts of lead in brass plumbing fixtures and solders are potential concerns when the water is corrosive. Selective leaching and galvanic corrosion as mechanisms for lead release from these

commonly used alloys and solders have been well documented. The following section reviews the major contributing sources of lead in water distribution and plumbing systems that are impacted to some degree by internal corrosion.

Transmission and Distribution System Piping and Appurtenances

Leaching of lead due to corrosion of transmission and distribution piping has not been identified as a significant lead source in drinking water. The water flow in most distribution system pipes makes it unlikely that high concentrations of lead will accumulate. In addition, in areas where the distributed water is aggressive to piping materials, pipes are frequently lined with cement or enamel, which further reduces the potential that lead present in a pipe will enter the water.

Steel Pipe and Appurtenances. Steel pipe is often used in larger transmission mains (greater than 61 cm) and is usually lined. An American Water Works Association (AWWA) survey of 22 water utilities across the United States revealed that steel pipe comprised an average of 3.4 percent of the total length in these systems.⁹ The very low lead content of steel pipe, the higher flow velocities encountered in transmission mains (up to 1.55 m/sec), and the internal lining make steel transmission pipe an unlikely source of lead in drinking water.

Cast and Ductile Iron Pipe. Cast iron is used extensively in distribution systems. The AWWA survey of water utilities mentioned above indicated that 59 percent of the total length of distribution piping in the utilities responding was composed of cast iron. Cast iron pipe contains lead in very small amounts and may be quite susceptible to corrosive attack if unlined, but has good corrosion resistance when lined with cement. Nearly all cast iron pipe installed since the 1930s has been lined. Ductile iron pipe has always been lined since its introduction in the early 1960s. The low lead contents of cast and ductile iron pipes, the coating normally present, and the relatively large volume of water flowing through the pipe make these materials unlikely sources of significant lead levels in drinking water.

Lead Pipe. Lead piping has not seen common use in U.S. water distribution systems (as opposed to service lines) for many years. Little information is available on the number of lead distribution lines remaining in the United States. No lead distribution lines were reported by any of the respondents to the recent AWWA internal corrosion survey. The classic lead survey by Donaldson published in 1924 focused on service lines only.¹⁰

Large Water Meters. Some larger water meters used in water distribution systems incorporate a check valve that opens automatically for large flows, such as for fire fighting. The counterweight for the check valve was often made of or contained lead, and these lead weights may be as large as 27.2 kg. Although numerous companies manufacture water meters and valves, it is currently not known what percentage of these components contained lead in the past; the use of lead in water meters was discontinued in 1982. Thermoplastics and vulcanized rubber over iron are now used for check valve materials. Also, at normal flow rates, the water would not be exposed to the weight containing lead; therefore, these water meters do not appear to be a significant source of lead in distribution systems.

Resetters. A resetter is a piping fixture inserted into a small distribution or service line to make a water meter more accessible and easier to read. It is usually made of copper tubing and brass. Resetters

⁹ American Water Works Association (AWWA) Research Foundation, *Economics of Internal Corrosion*, AWWA-RF (in press, 1989).

¹⁰ D. Chin and P. C. Karalekas, Jr., "Lead Product Use Survey of Public Water Supply Distribution Systems Throughout the United States in Plumbing and Drinking Water Quality," *Proceedings*, Seminar (USEPA, 1984).

also commonly have soldered joints. If lead-based solders were used, resolders are a possible source of lead.

Caulking Compounds. Caulking compounds containing lead have not been commonly used for sealing joints in water mains since the 1950s. Lead-containing materials that were used as sealants have been completely replaced by synthetic materials that have better overall performance. Should lead-containing sealants still be in place, the surface area exposed and water contact time would be very small, thus making caulk an insignificant lead source.

Lead Gaskets. Lead gaskets have been used as flanges for joining large valves and pipes in distribution and treatment systems. However, the exposed lead surface areas are relatively small and water contact times short, minimizing the potential for lead contamination.¹¹

Service Piping and Household Plumbing

Lead Pipe. Lead service lines are very common in water distribution systems in the United States. A survey conducted by the USEPA of 153 water systems in 41 states indicated that 73 percent had installed lead service lines in the past.¹² The AWWA internal corrosion survey (described earlier) found that the estimated percentage of lead service lines in 17 water utilities across the United States ranged from 0 to 84, with an average of about 10 percent. Lead service pipe has a useful life expectancy of much greater than 50 years; therefore, many of these pipes will be operating well into the future. Many older municipalities in the nation have a large number of lead service lines that range in length from 9.15 to 30.5 m.¹³ Lead pipe in service lines is a significant source of lead in North American water supplies.

Lead Goosenecks. A gooseneck or pigtail is pipe that connects the service line to the distribution main (Figure 2). Lead goosenecks have been used widely because lead's malleability is suited to the wide variety of shapes required to connect the service pipe to the distribution main. In the 1984 USEPA lead survey,¹⁴ nearly 62 percent of the respondent's water systems had used lead goosenecks. The 1989 AWWA survey indicated that 45 percent of the responding utilities had lead goosenecks. Goosenecks are a significant source of lead beyond the utility main in North American water systems.

Galvanized Steel Pipe. Galvanized steel pipe has a coating of zinc. Because zinc is anodic to iron, where iron is exposed, the zinc will corrode first, providing cathodic protection for the iron.

The hot-dipped zinc coating method is required inside and outside the pipe by the American Society ASTM B 6 and results in a zinc slab thickness of about 3 mils.¹⁵ ASTM B 6 establishes three grades of zinc slab: special high-grade, high-grade, and Prime Western. Prime Western is normally used to manufacture galvanized pipe for domestic plumbing and has maximum limits of 1.4 percent lead, although for galvanized steel pipe commonly used in the United States, including imported Korean and Australian sources, the lead content is 0.10 percent or less.¹⁶ The 1989 AWWA internal corrosion survey results found the percentage of galvanized steel or iron service pipes in the responding utilities to range between 0 and 60 with an average of about 10 percent. While copper and plastic have almost completely

¹¹ D. W. DeBerry, et al., *Final Report on Corrosion in Potable Water Systems*, Contract No. 68-01-5834 (USEPA, 1982).

¹² D. Chin and P. C. Karalekas, Jr.

¹³ D. W. DeBerry, et al.

¹⁴ D. Chin and P. C. Karalekas, Jr.

¹⁵ American Society for Testing and Materials Standard ASTM-B-6, "??," *Annual Book of ASTM Standards* (1989).

¹⁶ AWWA Research Foundation and DVGW Forschungsstelle, *Internal Corrosion of Water Distribution Systems*, AWWA-RF (1985).

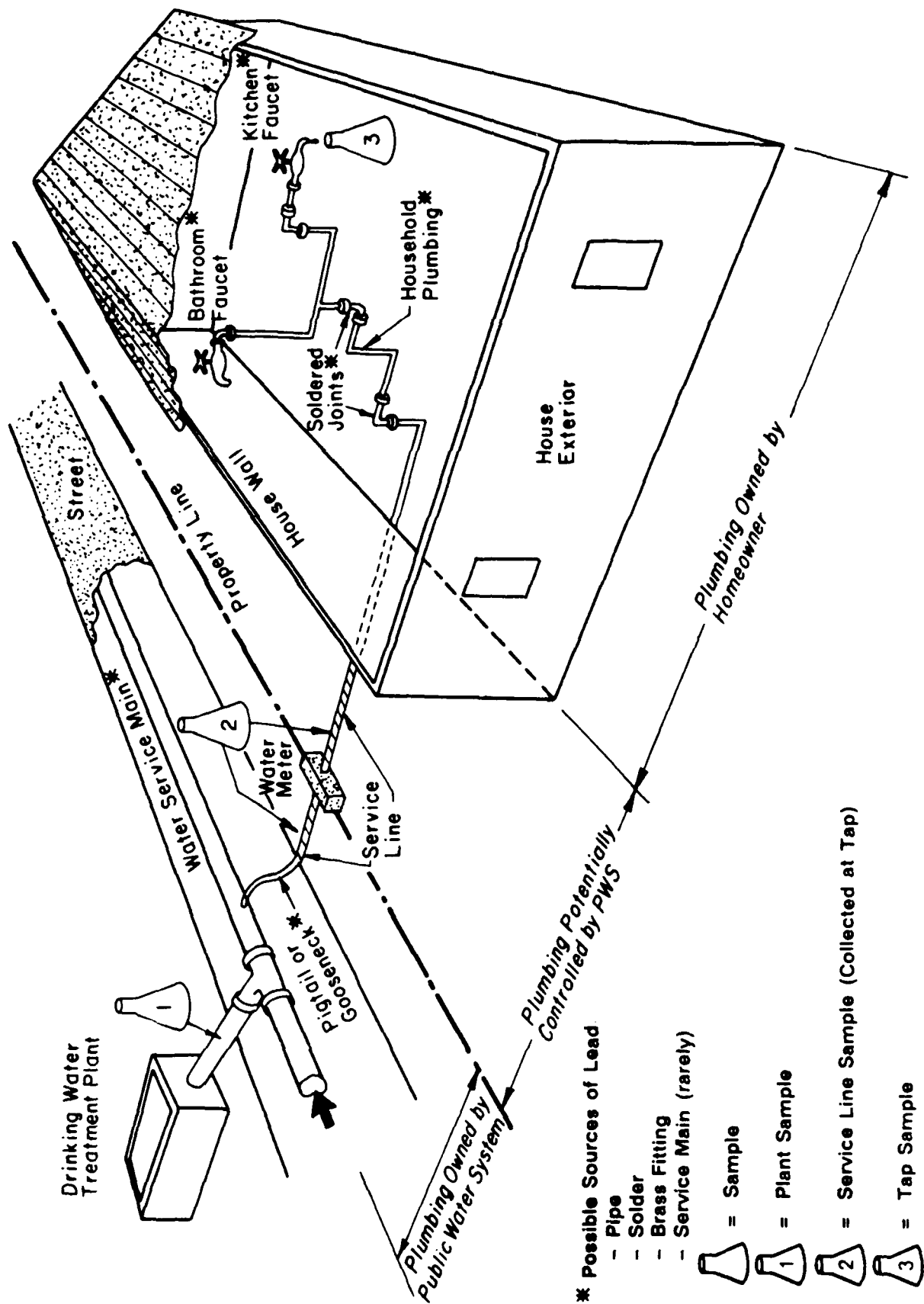


Figure 2. Gooseneck connecting service line to distribution main.

replaced galvanized steel in home plumbing, most areas in North America will have galvanized steel piping well into the future, and it is a potential source of lead where used. Leaching of lead from galvanized pipe has been confirmed in tap monitoring surveys.

Copper Pipe. Copper is the most widely used residential piping material in the United States and Canada, accounting for 70 to 80 percent of all piping installed in water service systems.¹⁷ Copper is highly resistant to oxidation and failures of copper tubing are relatively rare when pH levels are 7 or higher. Low pH, soft waters can cause rapid thinning and pitting of copper pipe. Because the copper material in copper piping is relatively pure (> 99 percent Cu) and the lead content very small (100 to 500 ppm), corrosion of copper pipe is not considered a major source of lead contamination. The most important impact on lead mobilization in copper piping is due to the galvanic effect that occurs between lead-tin solder and copper pipe. This effect is discussed further below.

Lead-Tin Solder. A common use of lead in water piping systems, in addition to lead service pipes, has been in lead-based solders.¹⁸ The percentage ratios of tin to lead for commonly used plumbing solders are usually 50:50 and 60:40. The galvanic cell action between lead solder and copper pipe accounts for a significant amount of lead mobilization. Studies by Lyson and Lenihan,¹⁹ Wong and Berrang,²⁰ and Herrera, et al.²¹ describe this action and document the lead concentrations in tapwater samples from lead-based solder/copper pipe systems. A survey for the American Water Works Service Company (AWWSC) concluded that lead solder in copper plumbing systems is the most significant source of lead found in drinking water at the tap in its systems. Premise piping that contains lead solder and is 2 years old or less is of particular concern as the lead leaching rates from newer lead solder are considerably higher than from older solders.²²

Alternative lead-free solders are readily available, several of which have been used for many years. Table 5 lists the composition and properties of common solders.

Brass Fixtures and Fittings. Brass is a copper-zinc alloy used very commonly in potable water systems in valve parts, faucets, and some water meters. Zinc may constitute 10 to 50 percent of a brass component and brasses contain lead in the 0.1 to 12 percent range.²³ Red brasses containing 85 percent or more copper are more resistant to corrosion than yellow brasses, which contain about one-third zinc. The brasses most commonly used in household fixtures contain about 1.5 to 7.5 percent lead. Table 6 lists some of the more common brasses and the percentage composition of copper and lead. The major form of corrosion in brass is selective leaching of the zinc—dezincification. The lead present in brass may also be mobilized during dezincification, but literature on the extent of lead mobilization from brass fixtures is extremely limited. The survey for AWWSC on lead levels throughout that utility's system concluded that an estimated 33 percent of the lead in first draw, 1-L samples were contributed by brass faucet fixtures.²⁴ The results of this survey also indicated that brass fixtures were a more significant lead

¹⁷ D. Chin and P. C. Karalekas, Jr.

¹⁸ D. W. DeBerry, et al.

¹⁹ T. Lyson and J. Lenihan, "Corrosion in Solder Jointed Copper Tubes Resulting in Lead Contamination of Drinking Water," *British Corrosion Journal*, Vol 12, No. 1 (1977).

²⁰ C. Wong and P. Berrang, "Contamination of Tap Water by Lead Pipe and Solder," *Bulletin of Environmental Contamination and Technology*, Vol 15, No. 5 (1976).

²¹ C. E. Herrera, et al., *Seattle Distribution System Corrosion Control Study, Vols 1 through 3* (Seattle Water Department and USEPA Municipal Environmental Research Laboratory, 1981-83).

²² "Lead at the Tap - Sources and Control," *Survey of the American Water System* (American Water Works Co., 1988).

²³ H. Uhlig, *The Corrosion Handbook* (John Wiley & Sons, 1948).

²⁴ "Lead at the Tap - Sources and Control."

Table 5
Composition and Properties of Common Solders

Composition (%)	Components	Working Range (Fo)	National Standard*
50-50	Sn-Pb	356-421o	ASTM B 32-87
95-5	Sn-Sb	452-464o	ASTM B 32-87
97-3	Sn-Cu	446-482o	None
85-15	Sn-Pb	356-408o	None
85-15	Sn-Sb	550-610o	None
96-4	Sn-Ag	430-430o	ASTM B 32-87
94-6	Sn-Ag	430-535o	ASTM B 32-87
95-5	Sn-Ag	430-473o	ASTM B 32-87

*Annual Book of ASTM Standards (1989).

Table 6
Brasses Commonly Used in Valves of Household Plumbing*

Copper Alloy No.	Composition (% max.)			Zn
	Cu	Sn	Pb	
C36000	60.0-63.0	--	2.5-3.7	Rem
C84400	78.0-82.0	2.3-3.5	6.0-8.0	7.0-10.0
C84500	77.0-79.0	2.0-4.0	6.0-7.5	10.0-14.0
C84800	75.0-77.0	2.0-3.0	5.5-7.0	13.0-17.0
C85200	70.0-74.0	0.7-2.0	1.5-3.8	20.0-27.0
C85400	65.0-70.0	0.5-1.5	1.5-3.8	24.0-32.0

*Source: Copper Development Association... used with permission.

source than were lead service lines in their systems. Schock and Neff²⁵ found that brass faucets can be a significant source of lead contamination, even when lead-free solders and fluxes are used in copper and galvanized steel plumbing systems, and even in water samples collected during running, well flushed conditions.

Shock and Gardels Sorg²⁶ tested 12 faucets representing various designs, construction materials, and manufacturers to determine the extent to which lead and other metals leach from common kitchen faucets. New cast-brass faucets were shown to contribute lead to drinking water in excess of the proposed no-action level of 10 µg/L. The study showed that, to determine the amount of lead leaching solely from the faucet in a household system, samples no larger than 100 to 125 mL should be collected.

Bronze Components. Bronze is a general term applied to copper-tin alloys. Tin may be present from 0.5 to 35 percent, and lead from 0.5 to 15 percent. There is little information on the corrosion behavior of bronze in fresh water. Selective leaching of tin (destannification) apparently occurs only under high temperatures,²⁷ but no information on lead leaching from bronzes in potable waters is available at present; therefore, the contribution of bronze components to lead levels in water supply systems is not known.

Water Coolers. The USEPA, in response to a Congressional survey, has estimated that close to 1 million water coolers in the United States were manufactured with lead components and that most of these are likely to still be in use.²⁸ Some of these water coolers have water reservoir tanks lined with lead-containing materials. The Lead Contamination Control Act of October 31, 1988 established that a water cooler is considered lead-free when no component which comes into contact with drinking water contains more than 8 percent lead and no solder, flux, or storage tank interior that may come into contact with drinking water contains more than 0.2 percent lead. A guidance document from USEPA provides model numbers of water coolers (made since 1978 by three manufacturers) that contain some lead.²⁹

Plastic Pipe. Plastic piping is becoming increasingly common in residential plumbing, as well as in distribution piping systems. It has been reported that some foreign-manufactured polyvinyl chloride (PVC) pipe contains lead-based stabilizing compounds.³⁰ Studies by Tiedeman in the 1950s on plastic pipe use for potable water showed that PVC pipe containing lead was extractable under extreme conditions of temperature, exposure duration, and area of plastic exposed per unit volume of test waters.³¹ Tiedeman's studies found that the potable water which is most aggressive toward specially prepared test plastics was a soft water with the pH adjusted to 5 using carbon dioxide. However, the lead extraction results were negative for all specimens of plastic pipe recommended for use with potable water.

Summary

Based on the review of potential lead sources and the available literature, lead service piping, solders containing high levels of lead, and household plumbing fixtures are the most likely contributors to high lead levels at the tap. Water sources, water treatment chemicals, and transmission and distribution systems usually do not add significantly to lead levels in drinking water.

²⁵ M. R. Schock and C. H. Neff, "Trace Metal Contamination From Brass Fittings," AWWA, Vol 80, No. 11 (1988).

²⁶ M. R. Schock and M. C. Gardels, "Plumbosolvency Reduction by High pH and Low Carbonate-Solubility Relationships," JAWWA, Vol 75, No. 2 (1983).

²⁷ D. W. DeBerry, et al.

²⁸ USEPA, *Reducing Exposure to Lead in Drinking Water of School Children*, EPA/570 19/89/001 (1989).

²⁹ USEPA, 1989.

³⁰ D. W. DeBerry, et al.

³¹ D. W. DeBerry, et al.

4 TAPWATER SAMPLING AND LEAD MATERIALS SURVEY STRATEGIES

The proposed Lead and Copper Rule requires water utilities to (1) evaluate lead and copper levels in source water, (2) survey materials potentially contributing to lead in drinking water, and (3) conduct a water sampling program to determine compliance. Lead and copper levels in source water are determined by sampling and analysis of water entering the distribution system. This type of monitoring is conducted routinely as a part of overall water quality control at the treatment plant. However, the proposed MCL for lead in drinking water entering the distribution system has been reduced to 5 $\mu\text{g/L}$ and, hence, the analytical procedure selected may need to be changed to detect lower concentrations. The graphite furnace atomic absorption analytical procedure for lead determination described in ASTM provides an adequate detection limit of 1 $\mu\text{g/L}$.³²

The strategies for lead materials and tapwater quality surveys in a water distribution system vary greatly as evident in the available literature. This chapter summarizes the survey strategies adopted by private sector water utilities. Data collected from three Army installations are provided in Chapter 5.

Lead Materials Investigation Strategies

Evaluating sources of lead and making decisions about possible replacement of these materials vary considerably among utilities. The form in which historical records are kept, the relative contribution of various materials to lead levels at the tap, and the public's perception and willingness to direct funds towards monitoring and removal determine the type of program each utility implements. In the overview of tap sampling in Chapter 3, several monitoring protocols were described that yielded information on the source of lead levels at the tap. In this chapter, information from several utilities on methods of locating and removing lead sources from household piping and water distribution systems is presented. Table 7 summarizes the current status of utility lead materials investigation and replacement programs, some of which are described in more detail below.

San Francisco, CA

San Francisco's Water Department (SFWD) serves more than 2 million people (160,000 services) with unfiltered surface water, which is low in alkalinity and dissolved solids. The City Board of Supervisors mandated that SFWD remove all lead service lines and goosenecks from its system in 1982. SFWD conducted a comprehensive lead source investigation and replacement program and, by the end of 1988, the program was 95 to 99 percent complete.

The original investigation into the source of lead in San Francisco's water system was initiated through a customer complaint. A sample taken at the site in question indicated an elevated lead concentration which was traced back to a lead water service line. SFWD initiated a program for locating all lead service lines and goosenecks through a computerized search of records. Fortunately, SFWD has its entire system in a computerized data base except for materials installed before the 1906 earthquake. The data base was accessed for the following information:

- Lead service lines
- Lead goosenecks

³² ASTM D 3559-78A or B, "Atomic Absorption, Direct Aspiration," *Annual Book of ASTM Standards* (1989).

Table 7

Lead Material Identification and Replacement Programs

Utility	Distribution Materials	Service Lines	Utility/Ownership	Removal Strategy	Costs
Portland Water Bureau	Lead Goosenecks	No lead service lines	To the meter (check)	Scheduled Replacement 10,000 goosenecks have been removed 1000/year	\$300 each
Hackensack Water Company Hackensack, N.J.	Lead Goosenecks: 21%	Lead 4% Copper 95% Plastic 1%	To the meter	Replace during routine maintenance	Not available
Northern Illinois Water Company	No Lead Pipes Lead caulked mains (<10%)		To property line	Not available	Not available
Washington D.C.	No lead goosenecks	30% to 50% of services are lead	To the property line (meters are currently located just outside the house. These are being moved to the property line.)	Currently replaces during street construction and by customer request (under special circumstances)	\$3000-\$5000/service

- Locations
- Date of installation.

To identify locations of lead services installed around the turn of the century, old service books with handwritten information were analyzed. In general, lead service lines were installed only up to 1910 or 1911, which limited the total number to be located.

Once the materials were located, an ongoing schedule for replacement was established. SFWD attempted to replace lead services and goosenecks during periods of road maintenance when the roadbed would already be disturbed. In addition to the scheduled search and replacement, a tracking method was incorporated into SFWD's routine maintenance schedule. Staffers were instructed to report any lead services they encountered during their maintenance rounds. Meter readers were also instructed to report any lead service lines they noticed. The combination of record searches and ongoing reporting provided the SFWD with the information needed to initiate replacement of the more than 10,000 lead services found.

With the mandate by the City Board of Supervisors to replace lead service lines, the SFWD organized a replacement schedule based on the locations of these lines. Approximately 10,000 have been replaced in the 6 years since the mandate at a cost of about \$1200 to \$1400/service. These costs reflect the difficult working conditions in San Francisco (i.e., steep terrain, busy intersections, the need for nighttime replacement in some cases). Scheduling replacement to coincide with road resurfacing saved time and money compared with performing the work independently.

In addition to the aggressive gooseneck and service line replacement program, SFWD began monitoring for lead levels at their customers' taps in 1985/86. The intent of monitoring is not specifically to locate lead source materials within the home plumbing, but to assess the overall concentrations in standing tapwater.

Philadelphia, PA

The City of Philadelphia serves water to approximately 1.6 million people (500,000 connections), including some wholesale water customers. The source is a filtered surface water from the Delaware and Schuylkill Rivers. As with many other utilities in the eastern half of the United States, Philadelphia's water system has several lead-containing materials. An estimated 10 to 20 percent of service lines and 1 to 2 percent of goosenecks in the system are lead. The location and replacement of these materials are confounded by the fact that all service lines are privately owned. The city owns only the transmission and distribution system; therefore, its authority ends at the main/service line connection. This arrangement severely hampers the water department's efforts in implementing an active location and replacement program. Even with these constraints, however, the City of Philadelphia has a program for replacing lead goosenecks when they are found during routine maintenance procedures.

A water quality monitoring program to determine the main sources of lead in home tapwater was initiated by the water department staff. Water samples from lead service lines had much lower lead levels than samples taken from home plumbing with lead solder or samples representative of the faucet.

Since service lines are privately owned from the main into the house, retrieving information on piping materials proved difficult (pipes are installed by private contractors). Most records to which the utility has access are for the utility distribution system rather than the service lines. The city made an effort, however, to survey installation records to locate both service line and distribution system materials that contain lead. The filing system for service lines consisted of index cards filed by address and, in most cases, the information was incomplete. Once started, this task proved too laborious to continue.

particularly since the information obtained was questionable and the utility had no authority to replace privately owned services.

Portland, OR

The City of Portland's Water Bureau serves a population of more than 700,000 (approximately 124,000 service connections) with a soft, unfiltered surface water. Although there are no lead service lines, lead goosenecks have been used to connect galvanized service lines to the distribution main. The Bureau located these goosenecks and is currently replacing them.

Locating lead goosenecks involved a combination of searching through utility records and conducting random field visits to verify the accuracy of the records. Most information was kept on microfilm and contained house service information related to size, material used, and location. All service lines were listed by either the pipe material used in construction or as unknown material. The galvanized lines were assumed to have a lead gooseneck connection to the main, and this assumption was verified in the field for several representative locations. When unknown material was listed in the records, the service line was checked visually. In virtually all cases, these unknown service lines were galvanized with a lead gooseneck connection.

The Bureau is currently conducting scheduled replacement of these lead goosenecks in its system. Of some 10,000 goosenecks, 2500 had been replaced by the end of 1988. Estimated costs for the replacement are \$300/service.

Hackensack Water Company, Hackensack, NJ

The Hackensack Water Company is an investor-owned utility that provides water service to several incorporated areas in New Jersey. A filtered surface water source provides water to more than 168,000 connections, of which 79 percent are wholesale customers.

The Hackensack Water Company completed an extensive search of its service installation and repair records to determine what types of materials were used in the system. These records were examined for the presence of lead pipe, lead goosenecks, and caulking material, and the type of solder. Results from these surveys indicated that there were no lead pipes in the transmission and distribution system; however, about 20 percent of the goosenecks were lead. Service lines were found to be approximately 4 percent lead, 95 percent copper, and 1 percent plastic.

A maintenance program to replace lead goosenecks was established at Hackensack. An estimated 150 lead services and 100 lead goosenecks have been replaced each year since the program began.

American Water Works Service Company (AWWSC)

During the extensive tap sampling program described in Chapter 3, AWWSC gathered data from each sampling site on factors that influence lead dissolution. This information included the type and age of plumbing, pH, use of phosphate inhibitors, and presence of electrical grounds to premise plumbing. AWWSC used a computer data base to organize the information on materials use and contributing factors, as well as the water quality results.

Before collecting samples, a utility representative visited sites to gather information on materials used in the service line, the main, and the household plumbing. A questionnaire was completed by both

the water company/district and the customer (who took the sample). This survey allowed utility personnel to segregate the sampling sites by materials used for the home plumbing and service lines. Results of the materials survey for the sampling sites are:

Household Plumbing

<u>Material</u>	<u>No. of sites</u>
Copper	1026
Galvanized	186
Mixed	160
Plastic	33

Service Lines

<u>Material</u>	<u>No. of sites</u>
Nonlead	1451
Lead	27
Unknown	6

AWWSCs current policy is to replace lead-containing materials as they are found during routine maintenance.

Water Quality Tap Sampling Surveys in Private Sector Utilities

The treatment and monitoring implications created by the proposed Lead and Copper Rule have caused many utilities around the country to initiate monitoring for lead and copper at their customers' taps. Table 8 summarizes published studies investigating lead levels measured at the tap. In each case, the monitoring protocol has been specific toward the individual study. Different sample volumes, standing times, and collection protocols were used, depending on whether the purpose was to identify the lead source, what levels the typical customer might consume, or the effect of standing time or plumbing age on lead concentrations. Lack of a standard monitoring protocol has made results from several studies virtually impossible to compare. These following case studies were selected from a representative cross section of large and small utilities that use both surface and groundwater sources.

Nationwide Survey by Patterson

In 1977, the Office of Drinking Water for USEPA commissioned a study by Patterson³³ to investigate tapwater quality in the United States. This study included a nationwide survey to evaluate the relationship between corrosion indices and other water quality parameters potentially affecting corrosion, and the levels of corrosion byproducts measured at the kitchen tap. Altogether, 782 samples were collected from 580 cities throughout the United States, representing 47 states. Samples were collected at the kitchen tap between 10 a.m. and 8 p.m. by Culligan dealership representatives. The sampling procedure is outlined below (from the instruction sheet provided to Culligan dealerships):

1. Use only the plastic Culligan sample bottles supplied.

³³ J.W. Patterson.

Table 8
Literature Summary
Drinking Water Quality Monitoring Programs

Utility	Investigator	Number of Samples	Collection	Purpose	Results
94 districts	AWWSCo (AWWSCo 1988)	1484 sites Services: 1451: non-lead 27: lead 6: unknown	Non-lead services: Sample 1 - first 100 mi. 6 hour standing Sample 2 - next 1 liter Sample 3 - 1 liter after flushing 2-3 min.	Assess extent of lead and determine controlling factors	Brass faucets contribute approx. 33% of avg. Pb in 1 liter first draw samples Alkalinity did not influence lead levels at the tap.
			Lead services: A sampling tap was located next to service line. Six hour standing time. Volume between tap and service line wasted (plus 500ml). Sample 1 - next 1 liter Sample 2 - 1 liter after 2-3 min. flushing		Sites < 5 years old may have problem meeting 20 µ/L max. and 10 µ/L avg. regardless of corrosion control. Lead levels could not be predicted from water quality characteristics. Significant variations.
Several, but weighted towards	AWWA Lead Information Survey (AWWA 1988)	40 utilities with lead monitoring data at tap	Standing tap sample Service line sample Distribution sample	Determine impact of proposed lead regula- tion on member	% of utilities meeting 10 µg/L average lead level at tap: Age <2 years - 49% Age 2-5 years - 60% Age >5 years - 83%

Table 8 (Cont'd)

Literature Summary
Drinking Water Quality Monitoring Programs

Utility	Investigator	Number of Samples	Collection	Purpose	Results
8 Cities 30 Supply Areas (Netherlands)	KIWA (AWWA 1986)	50 homes in eight cities (total=400)	Proportional sampler at the tap, collected 1 week	Lead pipe performed, Lead measured in passi- vated pipes (different stagnation times)	Lead solubility decreased increasing pH and decreasing temperature
South Huntington Water District (SHWD)	USEPA/SHWD (Griggs 1987)	251	Eight 125 ml samples at 0 to 2 minutes	Determine effect of pH on lead concentrations.	Of the 251 sites sampled: 1. pH < 6.4 82.9% exceeded 20 µg/L Pb 2. pH 7.0-7.4 42.3% exceeded 20 µg/L Pb 3. pH > 8.0 37.6% exceeded 20 µg/L Pb 3. pH > 8.0 37.6% exceeded 20 µg/L Pb
Rural Nova Scotia	Dalhousie University Halifax, Nova Scotia (Macessen 1985)	55 homes. daily samples for three days	samples taken at cold water tap: standing overnight and running 250 mL	Investigate mobiliza- tion of lead due to home plumbing.	Highest metal concentrations were found in community highest pH and alkalinity
City of Tacoma		Dec. 1984 27 sites total 2 at Headworks 1 Reservoir 8 distribution 16 consumer taps	Standing and running samples	Internal corrosion investigation.	Of 20 consumer taps surveyed, Standing samples for Lead: 4 exceed 20 µg/L (20%) 2 exceed 50 µg/L (10%) Running samples all < 20 µg/L

Table 8 (Cont'd)
Literature Summary
Drinking Water Quality Monitoring Programs

Utility	Investigator	Number of	Collection	Purpose	Results
			Aug 1985 12 sites total 8 distribution 4 consumer taps		
Nationwide	Patterson (ISEPA, 1981)	55 Cities 782 samples 47 states	Random daytime samples flushed 30 seconds	Nationwide survey of tap water quality.	60% less than or equal to 10 µg/L 84% less than or equal to 20 µg/L 97% less than or equal to 50 µg/L 3% less greater or equal to 50 µg/L
Seattle Water Department	Dangel, R.A. (Dangel 1976)	34 running samples 22 standing samples	Two samples at each site: 1. Standing overnight Vol. approx. 2 quarts after 30 second flush	Study of corrosion pro- ducts in the Tolt dis- tribution system.	Standing samples Avg. Pb=5 µg/L Range = 1-22 µg/L
Seattle Water Department	Summary of several monitoring surveys from 1972-1976		Running and Standing	To determine impact of corrosion treatment. Samples taken before and after corrosion control.	Percentage of samples above 50 µg/L Cedar System 1972-1982 Before Running: 0 Standing: 6-16 Cedar System 1983-1984 After Running: 0 Standing: 0 Toft System: 1972-1982 Before Running: 0 Standing: 9-23 Toft System 1983-1984 After Running: 0 Standing: 1

Table 8 (Cont'd)
Literature Summary
Drinking Water Quality Monitoring Programs

Utility	Investigator	Number of	Collection Samples	Purpose	Results
Boston, MA	Karalekas (Karalekas 1983)	14 homes through course of study	1 liter: first draw sample service line sample main sample	Determine effects of corrosion control on lead levels at the tap. Samples taken before and after treatment	Average lead level well above 50 µg/L before treatment. After NaOH treatment, average level dropped from 128 µg/L to 35 µg/L
Glasgow, Scotland	Richards/Moore (Richards & Moore, 1984)	232 Samples	1 liter: random samples taken at any time of day without flushing	Evaluate lead levels at the tap	Mean value = 244 µg/L Max. = 2000 µg/L Min. = 5 µg/L S.D. = 326
New England Municipalities Bridgeport, CN Marlborough, MA New Bedford, MA Providence, RI	USEPA (Karalekas 1978)	10 houses/city 3 samples/house	1. Morning first flush 2. Flush until temp. change 3. Flush for 3 minutes after collecting #2	Correlate lead levels at the tap to raw and finished water quality	Less corrosion, i.e. lower lead levels in system with high pH and hardness.
Portland Water Bureau	Montgomery Engineers (1982)	40 homes	Home tap samples: hot and cold taps standing - first draw running-after 5 minutes Sample tap at meter box: flushed for 5 minutes before collection 3 houses with lead pigtail 1 house without lead pigtail: overnight standing samples taken (All samples, 1 liter)	Determine corrosion by-products at tap Determine contribution of lead pigtail to lead levels	98 percent of maximum lead concentration were below 50 µg/L Lead pigtail samples all above 50 µg/L

2. Sample only the cold water.
3. Turn tap on at a moderate flow rate and allow to run for 30 sec.
4. Rinse plastic sample bottle several times with water to be sampled.
5. Fill the sample bottle to neck with water and secure cap on bottle.
6. Place sample bottle with identification tab in the preprinted cardboard mailer.
7. Immediately mail water sample to the laboratory.

Samples were acidified when they arrived at the laboratory. Thirteen parameters were analyzed from each sample: pH, alkalinity, copper, zinc, iron, lead, conductivity, chloride, silica, sulfate, calcium, magnesium, and sodium. A major ion charge balance was performed on each of the samples. Ten samples were discarded from the analysis because the anion/cation balance was out of balance by more than 20 percent, indicating an error in analysis. The amount of lead that may have sorbed onto the plastic container bottles during transit to the laboratory was also determined. This analysis revealed that lead levels measured for each sample were decreased by 3 $\mu\text{g/L}$ due to sorption, i.e., the lead levels reported were approximately 3 $\mu\text{g/L}$ lower than what actually existed during sample collection. The collection protocol from this survey did not capture "worst case" lead levels at the tap, but the flushing time (30 sec plus) may be more representative of water ingested by the consumer.

The national average for lead concentration was 29 $\mu\text{g/L}$ and for pH, alkalinity, and hardness 7.2, 106 mg/L as CaCO_3 , and 145 mg/L as CaCO_3 , respectively. For all samples, 2.5 percent had lead levels greater than 50 $\mu\text{g/L}$, and 16 percent were greater than 20 $\mu\text{g/L}$. Results from this survey were also segregated by geographic region, and are listed below:

<u>U.S. Region</u>	<u>Average Lead Level ($\mu\text{g/L}$)</u>	<u>Range ($\mu\text{g/L}$)[*]</u>
Northeast	19	ND-400
Southeast	13	ND-200
Midwest	47	ND-10,000
South Central	12	ND-45
West	18	ND-500

American Water Works Service Company (AWWSC)

AWWSC provides water service to approximately 100 areas throughout the United States, from California and Arizona in the West to the Midwest to several locations in the eastern half of the nation.

AWWSC surveyed 1484 sites from 94 of its member companies/districts to determine lead levels and other water quality parameters at the customer's tap, as well as factors contributing to these levels.**

A monitoring protocol to assess the relative contribution of various plumbing and service line materials to lead levels at the tap was developed for the 1484 randomly chosen sites. Homeowners were contacted by letter and/or telephone about the upcoming sampling. Before collecting samples, a utility

^{*}ND = not detected--detection limit was $\mu\text{g/L}$.

^{**}AWWSC, 1988.

representative visited each site to gather information on materials used in the service line, the main, and the household plumbing. The materials survey was used to develop different sampling procedures for sites with lead service lines so that the contribution from the service line could be determined. For houses with nonlead service lines, two consecutive samples were taken after the water had been standing for 6 hr, along with a third flushed sample. The first 100 mL represented the faucet, the next 1 L represented the home plumbing, and the flushed sample represented the main. This protocol was also used to evaluate proposed compliance levels by adding the results of the first 100 mL to 90 percent of the next liter, since current USEPA protocol establishes a 1 L standing sample for compliance monitoring. The equation for calculating the 1-L concentration is:

$$\text{Conc. of 1 L} = (\text{Conc. of 100 mL sample}) + 0.9 \times (\text{Conc. of 1-L sample}) \quad [\text{Eq 1}]$$

Houses with lead service lines were tapped as closely as possible to the service line to enable sampling without having the water pass through extensive lengths of plumbing. The volume of water between the tap and the service line was wasted and the next 1 L was collected as representative of the lead service line. The water was then flushed for 2 to 3 min and another sample was taken to be representative of the water in the main. These protocols are outlined below.

Monitoring Protocol for Nonlead Service Lines

<u>Sample</u>	<u>Protocol</u>	<u>Represents</u>
#1	First draw standing sample at the tap (100 mL)	Faucet
#2	1-L sample directly after #1	Home plumbing
#3	1-L after 2-3 min flushing	Main

Monitoring Protocol for Lead Service Lines

<u>Sample</u>	<u>Protocol</u>	<u>Represents</u>
#1	Waste volume between tap and service line, then collect 1 L	Service line
#2	Flush for 2-3 min and take 1-L sample	Main

This extensive monitoring and information gathering program provided an excellent data base that allowed conclusions to be made about which lead-containing materials were responsible for lead concentrations at the tap, as well as what factors may affect these levels. Some major findings of this study include:

- Thirty-three percent of average lead levels in the first-draw samples were from brass faucet fixtures.
- Lead solder was the most significant source of lead in home tap samples.
- Lead service lines contributed to the lead levels measured at the tap, but not as much as lead-soldered plumbing or brass faucets.
- Alkalinity did not influence lead levels at the tap.
- The pH significantly influenced lead levels measured at the tap for systems not using corrosion inhibitors. Average lead levels decreased with increasing pH for homes with copper plumbing.
- Zinc orthophosphate was the most effective treatment for reducing lead levels at the tap.
- Chlorine residual did not influence lead levels at the tap.
- Age of household plumbing had a significant impact on lead levels at the tap. Newer plumbing exhibited higher lead levels.
- Particulate lead from lead solders and faucets caused extreme lead concentrations to be measured at certain sites.

Portland Water Bureau

The Portland Water Bureau provides drinking water to the greater Portland, OR area. As noted earlier, the source is a low pH, low alkalinity, soft surface water. Bureau personnel have initiated numerous monitoring programs to assess lead corrosion in their system. As part of a system-wide internal corrosion study, a home water quality sampling program was initiated in 1981.³² The purpose of this sampling was to determine the concentrations of corrosion byproducts at the home tap, in the service line, and in the distribution system. In addition to taking water samples, pipe sections were removed for visual inspection and scale analysis.

For the study, 40 homes were chosen as representative of customer plumbing systems throughout Portland. U.S. Census Bureau data were used to determine the number of homes built between 1940 and 1980 for each reservoir service area. This information was classified into various age groups by the service area in which they were located. The 40 sample sites were chosen to exhibit the same percentage of homes in each classification as in the Census Bureau data. This selection would ensure that the program was representative of the system as a whole. A four-step process was used to select these sample homes:

1. 400 services under 2.54 cm in diameter were selected randomly from computerized records.
2. Residences were classified by age and by reservoir service area.

³² James Montgomery Consulting Engineers, *Internal Corrosion Mitigation Study Final Report* (Bureau of Water Works, Portland, OR, 1982).

3. The appropriate number of residences within each classification was selected randomly.

4. Additional residences were selected randomly if there were not enough within one of the classifications.

Customers whose homes were chosen were notified by mail and asked to participate. For those agreeing to participate, homes were inspected for the type of plumbing and the homeowner was asked to complete a sampling survey.

Highest lead levels measured at the inside taps were generally found in the hot water standing samples; however, the average lead level in all samples was only 2 µg/L. The average lead level measured from running samples taken at the meter was less than 5 µg/L. Samples from the services with lead pigtails all had lead levels above 50 µg/L, but the home tap samples at the same locations all had less than 5 µg/L lead.

Numerous other monitoring programs have been initiated by the Bureau more recently in response to the Federal regulations for lead and copper in drinking water. Both employee and nonemployee homes have been monitored with samples collected by the customer in some cases. When nonemployees are asked to collect the sample, a letter is sent and a followup telephone call is made. The utility has sent personnel to the homes the evening before in some cases to collect a running sample and also demonstrate the proper collection procedure to the homeowner for the standing sample the next morning.

New England Municipalities

Several monitoring programs to determine lead levels at the tap have been initiated in the New England area. In one program, 936 samples were taken from homes throughout Boston, Cambridge, and Somerville, MA to determine what contribution plumbing systems made to trace metal concentrations measured at the tap.³³ These communities were known to have several lead service lines. Occupants were contacted and if they agreed to the monitoring, a utility representative was sent to the house to collect the samples and identify the type of piping material on either side of the water meter. Four types of samples were taken:

<u>Sample</u>	<u>Protocol</u>	<u>Represents</u>
1	Collect sample immediately after turning on tap and rinsing bottle (1 qt')	Interior plumbing
2	Collect after flushing for 4 min (1 qt)	Service line/interior plumbing
3	Collect 1 qt at each meal to total 1 gal (this was done in 30 homes)	Human ingestion

³³ P. C. Karalekas, et al., "Lead and Other Trace Metals in Drinking Water in the Boston Area," *Journal of the New England Water Works Association*, Vol 90 (1970)

*1 qt = 0.95 L

4

Collect 1 qt immediately
after turning on tap and
noticing a temperature change

Service line

Results from this program indicated high lead levels, as 15.4 percent of all the samples were greater than 50.0 µg/L.

Three municipalities in Massachusetts, one in Connecticut, and one in Rhode Island have also been monitored for lead levels at the tap. This study was developed to determine the effects of water quality on lead corrosion.³⁴ Three different 1-L samples were taken:

<u>Sample</u>	<u>Protocol</u>	<u>Represents</u>
1	Standing overnight	First drawHome plumbing
2	Cold	After water turnsService line
3	Has run for 3 min following sample #2	Collect after waterMain

The following sampling instructions were provided to customers who took the samples:

After 11:00 p.m., do not use the kitchen cold water faucet until you collect the water samples the next morning. Using the following directions, in the morning, collect the water samples at the faucet before using any faucet or flushing any toilets in the house. Fill the provided containers to 1 in.* below the top and put the caps on tightly.

SAMPLE 1. Open the cold water faucet and immediately fill bottle #1 and turn off the water: recap this bottle.

SAMPLE 2. Turn the faucet on and place your hand under the running water, and immediately upon noticing that the water turns colder, fill bottle #2. Cap bottle #2.

SAMPLE 3. Allow the water to run for three additional minutes and then fill bottle #3. Cap Bottle #3.

Results from this monitoring indicated that municipalities with higher pH values and alkalinities experienced less lead leaching.

³⁴P. C. Karalckas. et al.

*1 in. = 2.54 cm

Summary

The review of utility monitoring programs for lead levels at the tap has shown a wide variety of sampling protocols which make comparisons between utilities very difficult. Standing and flushing times before sample collection have not been the same and different sample volumes have been used, ranging from 60 mL to 3.79 L. There has been considerable variation in who collects the sample, whether it is the homeowner or utility personnel. This situation has led to additional differences in when the samples were acidified and, if the homeowner took the sample, whether it was truly collected after 8 hr standing time. To make results from lead monitoring programs more comparable, procedures need to be standardized. Sample volumes, collection procedures, and the analytical methods for testing the sample must be controlled by the utility if there is to be confidence in the results.

5 WATER SAMPLING SURVEY RESULTS AT ARMY INSTALLATIONS

Several Army installations have done tapwater sampling surveys, often due to complaints of aesthetically poor water quality (e.g., discolored water) or due to health concerns. Also, because of a concerted effort by the Army Environmental Hygiene Agency (AEHA) and USAEHSC in publicizing the pending Lead and Copper Rule impact on Army installation water supplies, many installations have begun conducting tapwater sampling surveys for lead and copper. This chapter describes tapwater surveys at three Army installations and these sites' efforts to mitigate lead in drinking water.

Fort Lewis, WA

A comprehensive water sampling survey was conducted throughout the Fort Lewis distribution system before publishing the required public notification regarding lead in drinking water. The sampling program was intended to assess the status of plumbing systems installation-wide. The results of this initial screening indicated that, except for several isolated locations, the lead levels were well within the proposed limits. Elevated concentrations of lead in drinking water were identified at the three newly constructed child development centers (CDCs) and at the new Special Forces Complex. The plumbing systems at these locations were identified to be mostly copper pipes joined with 50/50 lead-tin solder. The lead concentrations at the CDCs during the initial screening are presented in Table 9. The data indicate lead concentrations in a sample volume of 500 mL taken from faucets at the CDCs. The data presented in Table 9 show that the Madigan CDC (Bldg. 6995) had the highest concentration of lead (1.220 mg/L) in the first draw sample after the water had stood overnight in the plumbing system. The water samples collected sequentially at various times during flushing of the plumbing system showed a decrease in lead concentration, as expected, indicating that the source of lead was indeed the plumbing system materials. Further evidence of the plumbing materials as the source of lead is also shown in Table 9, where the lead concentration in water samples increased with increasing standing times.

The high lead concentration at the CDCs posed a hazard due to the ready accumulation of lead in young children, which can cause a variety of adverse health impacts. Lead concentrations ranging up to greater than 1.80 mg/L were identified at the CDCs. Consequently, the Fort Lewis Directorate of Engineering and Housing (DEH) initiated actions to reduce lead levels at point-of-entry (POE) to the CDCs. A commercial water treatment consultant was contracted to install individual treatment systems at the CDCs and provide routine maintenance/chemical replacement for an unspecified period.

The POE treatments provided at each of the three CDCs were identical. The treatment unit consisted of a timed device that injected sodium silicate and sodium hexametaphosphate solutions into the incoming water pipe to the building based on a metered volume of water usage. The selection of chemicals and dosages was at the discretion of the consultant, but was apparently based on experience. Sodium silicate was added for raising the water pH from an initial pH of 6.7 to a final pH of about 7.2. The sodium hexametaphosphate was added to provide a protective coating on the interior surface of the plumbing system and also to help sequester some soluble lead. Based on the concentration of the chemicals injected and the timer adjustment, the following dosages were calculated during a site visit in September 1988:

<u>Site</u>	<u>Sodium Silicate (mg/L)</u>	<u>Sodium Hexametaphosphate (mg/L)</u>
Beachwood CDC	24.65	2.11
Madigan CDC	22.81	1.41
Clarkmoore CDC	22.90	1.41

Table 9

**Fort Lewis, WA: Lead Sampling at Child Development Centers June 7-8, 1988,
Before Installing Silicate-Hexametaphosphate Treatment**

Sample	Lead Conc. (mg/L)		
	Clarkmoore Bldg. 2095	Madigan Bldg. 6995	Beachwood Bldg. 8300
First draw overnight sit	0.048	1.22	0.207
1 Min flush	0.007	0.086	0.051
2 Min flush	0.004	0.077	0.034
3 Min flush	0.004	0.12	0.018
4 Min flush	0.004	0.12	0.02
5 Min flush	0.005	0.03	0.016
15-Min wait	0.001	0.102	0.052
30-Min wait	0.009	0.099	0.057
1-Hr wait	0.015	0.054	0.063
2.5-Hr wait	0.022	0.191	0.103
5-Hr wait	0.12	0.71	0.31
10-Hr wait	0.023		0.260

The POE treatment provided at each of the CDCs was effective in reducing the lead concentration in drinking water to acceptable levels. Table 10 presents lead concentrations in first draw overnight standing water samples collected from the CDCs after 2 to 3 months of silicate/hexametaphosphate treatment. The lead concentrations were reduced to near detection limits (0.001 mg/L) after just 60 days of treatment.

Although the silicate/hexametaphosphate treatment was effective, the rationale for selecting the dosage and chemicals was subjective. The levels of sodium silicate injected are considerably higher than the normal maximum dosage of 10 mg/L recommended for a cost-effective corrosion control. To arrive at the optimal solution, several alternative treatments could have been screened by pilot-scale experiments using a pipe-loop system.

Table 10

**Fort Lewis, WA: Lead Sampling at Child Development Centers,
August 18 - September 15, 1988,
After Installing Silicate-Hexametaphosphate Treatment**

Sample	Lead Conc. (mg/L)			
	Date	Clarkmoore Bldg. 2095	Madigan Bldg. 6995	Beachwood Bldg. 8300
Aug 18, 1988		0.012	0.136	0.004
Sept 1, 1988		0.001	0.001	0.002
Sept 15, 1988		0.002	0.001	0.003

Subsequently, the sodium silicate dosage was reduced to 10 mg/L and treatment at the CDCs continued. The data, as of September 1989, indicate that the lead concentrations in overnight standing water samples are well below the current MCL of 0.050 mg/L and will be able to meet the proposed Lead and Copper Rule requirements.

A pilot-scale experiment was conducted during August 1989 at Fort Lewis' water plant using the USACERL pipe-loop system. The purpose was to optimize water treatment for minimizing lead dissolution from lead-base-soldered plumbing systems.

Aberdeen Proving Ground, MD - Edgewood Area

High lead concentrations in drinking water at consumers' taps were discovered at Aberdeen Proving Ground, Edgewood Area, during a water quality survey initiated due to complaints of discolored water at some points in the distribution system. The survey, conducted by the Water Quality Division of AEHA in March 1988, was comprehensive and tested for heavy metals, including lead, copper, zinc, and cadmium, in the first flush water samples at the consumer's tap. Except for lead, all other water quality parameters met USEPA standards. Table 11 presents the pH and lead concentrations in the overnight stagnant and completely flushed water samples. As seen in Table 11, the average stagnant and flushed water pH was 7.9. The average lead concentration in stagnant water samples was 0.053 mg/L. Over 18 percent of the samples exceeded the present maximum contaminant level of 0.050 mg lead/L. About 45 percent of the samples contained more than 0.010 mg lead/L which is the proposed maximum concentration allowed at the consumer's tap. The water samples taken at the water plant were below 0.005, well within the proposed lead levels for water entering the distribution system. After a complete flushing of the household systems, none of the samples exceeded the proposed lead concentration of 0.010 mg/L at the tap.

As a result of this survey, several actions were taken to alleviate the high lead levels found in the overnight standing water. The installation commander issued a notification to all grounds personnel to flush water lines in buildings each morning. All family housing units were requested to flush kitchen taps each morning before using the water for drinking and cooking. At the water plant, the lime dosage was adjusted to increase the distribution water pH to 8.6.

Table 11
March 1988 Water Quality Survey

Sample number	pH		Lead (mg/L)	
	Initial	Flushed	Initial	Flushed
1				
2			0.002	<0.001
3	7.4	7.5	0.014	0.001
4	8.5	8.6	0.021	<0.001
5	8.5	8.4	0.008	<0.001
6	8.0	7.4	0.086	0.002
7	7.7	7.4	0.065	<0.001
8	8.1	7.4	1.200	0.003
9	8.4	7.4	0.011	<0.001
10	8.2	7.4	0.006	<0.001
11	6.7	7.5	0.029	<0.001
12	7.2	7.4	0.019	<0.001
13	7.4	7.6	0.002	<0.001
14	8.1	8.3	0.087	<0.001
15	7.8	8.3	0.024	0.003
16	8.5	8.5	0.005	<0.001
17	9.0	8.9	0.004	<0.001
18	7.9	8.1	0.006	<0.001
19	8.0	8.1	0.004	<0.001
20	8.1	8.2	0.002	<0.001
21	8.2	8.2	0.009	<0.001
22	8.1	8.2	0.09	0.003
23	8.1	8.2	0.018	<0.001
24	8.1	8.0	<0.001	<0.001
25	7.8	7.6	0.003	<0.001
26	8.3	8.4	<0.001	<0.001
27	7.8	8.1	0.040	0.003
28				
29				
30	7.0	7.1	0.001	<0.001
31	7.3	7.4	0.004	0.002
32	7.1	7.2	<0.001	<0.001
33	7.3	6.9	0.081	0.002
34	8.3	8.2	0.020	<0.001
35	8.4	7.8	0.040	<0.001
36	7.7	7.8	0.003	<0.001
37	7.6	7.6	<0.001	<0.001
38	8.0	8.1	<0.001	<0.001
39				
40	6.5	6.6	0.077	0.005
41	8.2	8.2	0.037	<0.001
42	9.2	9.2	0.005	<0.001

In June 1988, another water quality survey was conducted to determine the status of lead dissolution in plumbing systems. The results of this survey are presented in Table 12. The major change noted in this survey is that the average distribution water pH was 8.5. Only 5 percent of the water samples were reported to have pH less than 8.0. The average lead concentration of stagnant water samples was 0.030 mg/L which is within current lead MCL. However, 21 percent of the samples exceeded the 0.050 mg lead/L level. The proportion of water samples exceeding 0.005 and 0.010 mg/L were 79 and 67 percent, respectively. After complete flushing, the average lead concentration was 0.001 mg/L—well within the proposed rules.

Although the distribution water pH increase reduced the average lead concentration, the percentage of samples exceeding the proposed MCL for lead increased by more than 20 percent. The March 1988 water quality survey lead average was strongly influenced by an extremely high value (1.200 mg lead/L) observed in one sample. This value could be considered an outlier, but it is not unusual for lead concentrations in drinking water supplies to show this variability. When the median lead concentrations are compared for the two surveys, the distribution water pH increase resulted in the median lead values increasing from 0.010 to 0.024 mg lead/L. In this case, the median lead concentration was more indicative of the pH effect than was the average lead concentration.

A pipe-loop study can evaluate and identify various treatment programs that could have either a negative or positive impact on lead dissolution without disrupting water quality in the distribution system.

Fort Irwin, CA

The water supply at Fort Irwin, CA consists of a dual distribution system with a dedicated pipe network for drinking water. Water for general use (e.g., washing, cleaning) comes from a separate pipe network supplied directly from several deep wells after disinfection. The drinking water supply is treated by a reverse osmosis water treatment plant (ROWTP) to reduce high natural fluoride and selenium concentrations found in the groundwater. Due to removal of most of the dissolved solids during the reverse osmosis (RO) treatment, the water is highly corrosive, especially to plumbing system materials, which could cause high lead and copper levels at the tap. Further, due to long detention times in the piping system and infrequent use of the drinking water taps, the lead and copper dissolution potential is higher.

A water quality survey conducted by the Fort Irwin DEH in 1988 showed elevated concentrations of lead and copper at several locations. This finding resulted in comprehensive evaluation of the ROWTP system for corrosion control measures, after which a comprehensive flushing program for the drinking water pipe network was instituted. AEHA and USACERL evaluated several alternatives for minimizing water corrosiveness to reduce concentrations of lead and copper in the drinking water.

The ROWTP was installed in 1981 to treat the groundwater for removal of high natural fluoride and selenium. The ROWTP provided prefiltration through two high-pressure sand filters, sulfuric acid addition for pH adjustment, and final filter through a 5-micron cartridge filter before RO treatment. The pretreated water was then pumped through high-pressure spiral wound RO membranes, followed by degasification to remove accumulated carbon dioxide. Finally, the effluent water was treated with sodium silicate for pH control and with calcium hypochlorite for disinfection. The treated water was stored in reservoirs for distribution.

The liquid sodium silicate added to the RO-treated water was used mainly for raising pH, although some corrosion protection was also expected. However, due to the very low concentration of silicate needed for pH adjustment, the silicate treatment was not adequate for corrosion protection.

Table 12

June 1988 Water Quality Survey

Sample number	pH		Lead (mg/L)	
	Initial	Flushed	Initial	Flushed
1	8.5	8.5	0.001	0.005
2				
3	8.6	8.6	0.032	0.001
4	8.5	8.6	<0.001	<0.001
5	8.5	8.6		
6	8.8	8.8	0.072	<0.001
7	8.8	8.8	0.018	<0.001
8	8.3	8.8	0.146	<0.001
9	8.8	8.8	0.004	0.007
10	8.4	8.6	0.007	0.001
11	8.8	8.9	0.004	<0.001
12	8.6	8.8	0.024	<0.001
13	8.5	8.6		
14	8.4	8.5	0.095	0.002
15	8.0	8.5	0.025	0.002
16	8.4	8.4		
17				
18	8.3	8.5		
19				
20	8.3	8.4		
21	8.5	8.6		
22	8.5	8.5	0.062	0.002
23	8.6	8.6	0.016	0.002
26	8.7	8.7		
27	8.9	8.9	0.016	0.001
28	8.1	8.5		<0.001
29	8.5	8.4	0.049	<0.001
30	8.3	8.7		
31	8.3	8.7		
32	8.5	8.6		
33	8.6	8.5	0.024	0.001
34	8.7	8.7	0.024	0.001
35	8.2	8.7	0.061	0.005
36	8.6	8.7		
37	8.6	8.7		
38	8.9	8.9		
39	7.8	8.1	0.005	<0.001
40	7.6	8.1	0.028	0.004
41	8.6	8.7	0.007	<0.001
42	9.3	9.1		
43	8.8	8.8	0.008	<0.001
44	8.7	8.7	<0.001	0.002
45	8.2	8.7	0.033	0.001

Hence, alternative treatment procedures were considered. Increasing the alkalinity and calcium concentrations was ruled out due to high capital costs and maintenance required for such treatment. Blending of treated and untreated water was also not practical due to unacceptable fluoride levels in blended water. Finally, treatment by zinc orthophosphate (ZnOP) was chosen due to ease of implementation and the positive experience in reducing lead dissolution reported in literature. Several jar tests were conducted to determine the dosages of ZnOP and sodium silicate necessary to maintain a pH of 7.5 to 8.0 and a ZnOP dosage of 0.5 to 1.5 mg zinc/L. The ZnOP dosage was selected per the manufacturer's recommendation. Treatment was implemented in February 1989. To ensure that the ZnOP was distributed throughout the drinking water pipe network, the system was flushed frequently. Water samples from the edges of the distribution system were analyzed for zinc concentration. An elevated level of zinc in water, compared to conditions before the ZnOP treatment was implemented, ensured that the ZnOP was reaching all points in the distribution system.

Table 13 lists copper, zinc, and lead concentrations in drinking water samples collected at three time periods. The October/November 1988 sampling period is the baseline data before initiation of either the flushing program or ZnOP treatment. As seen in the table, several locations indicated very high lead levels. The first two sample locations, 43 and 44, represent water entering the distribution system which had lead concentrations below the detection limit. The February 1989 samples were collected after initiation of the flushing program and at the onset of ZnOP treatment. The data indicate that lead levels decreased significantly at locations where very high lead concentrations were previously found. There is one location (237) where the lead concentration increased. The May 1989 samples were collected after routine flushing and continuing the ZnOP treatment program. A significant increase in Zn concentration is evident in all samples (except for 43—a raw water source) due to the ZnOP treatment. The lead and copper concentrations in all samples, except 222, are noted. Perhaps the reason for an increase in lead at 222 is the infrequent or nonuse of the tap. However, in general, the combined flushing program and ZnOP treatment resulted in a significant decrease in lead dissolution from the plumbing system bringing it into compliance with the proposed Lead and Copper Rule.

Table 13

Fort Irwin Drinking Water Survey

Sample Location	Metal Concentration, ($\mu\text{g/L}$)					
	Oct/Nov 1988			Feb 1989		
	Cu	Zn	Pb	Cu	Zn	Pb
43 Well 2A	<10	<10	<10		31	17
44 ROWTP	<10	160	<10		<10	224
222	-	-	82	-	56	176
237	150	40	<10	54	51	112
226	60	10	26		28	138
362	830	110	2905	18	17	188
383	540	1030	101	62	12	361
385	110	110	<10	34	16	431
505	40	<10	<10		28	174
918	290	60	<10		28	180
1322	-	-	522	-	<10	244
2620	-	-	223	<10	198	307
IS-1				12	83	154
						<10

6 CONCLUSIONS AND RECOMMENDATIONS

In August 1988, USEPA proposed a rule to regulate lead and copper in drinking water. The proposed rule addresses both lead and copper levels in source waters and entry of lead and copper into the water from corrosion of distribution piping and household plumbing. This report has presented a comprehensive overview of the regulations and a summary of the compliance schedule.

A detailed review of lead sources in drinking water systems has indicated that lead service piping and high lead solders, as well as household plumbing fixtures, are the most likely contributors to high lead levels at the tap. Water sources, water treatment chemicals, and transmission and distribution systems are usually not significant contributors to lead in drinking water supplies.

A survey of private sector utility monitoring programs for lead levels at the tap has shown a wide variety of sampling protocols, which makes comparisons between utilities very difficult. Standing and flushing times before sample collection have not been the same and different sample volumes have been used, ranging from 60 mL to 3.8 L. There has been considerable variation in who collects the sample—the homeowner or utility personnel. This situation creates additional differences in when the samples are acidified and, if the homeowner takes the sample, whether it was truly collected after 8 hr standing time.

Several Army installations also have conducted tapwater monitoring surveys for lead and copper. Three case studies from Fort Lewis, WA, Aberdeen Proving Ground-Edgewood Area, MD, and Fort Irwin, CA have been described.

To make results from lead monitoring programs more comparable, sampling and analysis procedures need to be standardized. The utility must control sample volumes, collection procedures, and analytical test methods if confidence is to be obtained in the results.

CITED REFERENCES

- 40 Code of Federal Regulations (CFR), Parts 141 and 142, *Drinking Water Regulations; Maximum Contaminant Level Goals and National Primary Drinking Water Regulations for Lead and Copper; Proposed Rule* (1988).
- American Water Works Association (AWWA) Research Foundation, *Economics of Internal Corrosion* (in press, 1989).
- AWWA Research Foundation and DVGW Forschungsstelle, *Internal Corrosion of Water Distribution Systems* (1985).
- American Water Works Service Company, "Lead at the Tap - Sources and Control," *Survey of the American Water System* (1985).
- Chin, D., and P.C. Karalekas, Jr., "Lead Product Use Survey of Public Water Supply Distribution Systems Throughout the United States in Plumbing Materials and Drinking Water Quality," *Proceedings, Seminar* (U.S. Environmental Protection Agency [USEPA], Water Engineering Research Laboratory, 1984).
- Committee on Water Treatment Chemicals, *Water Chemicals Codex* (National Academy Press, 1982).
- DeBerry, D. W., et al., *Final Report on Corrosion in Potable Water Systems*, Contract No. 68-01-5834 (Office of Drinking Water, USEPA, 1982).

- Herrera, C.E., et al., *Seattle Distribution System Corrosion Control Study, Vols 1 through 3* (Seattle Water Department and USEPA Municipal Environmental Research Laboratory, 1981-83).
- James M. Montgomery, Consulting Engineers, *Internal Corrosion Mitigation Study, Final Report* (Bureau of Water Works, Portland, OR, 1982).
- Karalckas, P.C., et al., "Lead and Other Trace Metals in Drinking Water in the Boston Area," *Journal of the New England Water Works Association*, Vol 90 (1976).
- Lyson, T., and J. Lenihan, "Corrosion in Solder Jointed Copper Tubes Resulting in Lead Contamination of Drinking Water," *British Corrosion Journal*, Vol 12, No. 1 (1977).
- Montgomery, James Consulting Engineers, *Internal Corrosion Mitigation Study Final Report* (Bureau of Water Works, Portland, OR, 1982).
- Patterson, J.W., *Corrosion in Water Distribution Systems* (Office of Drinking Water, USEPA, 1981).
- Public Law (PL) 93-523, *Safe Drinking Water Act of 1974*, 88 Stat. 1660.
- Schock, M.R., and M.C. Gardels, "Plumbosolvency Reduction by High pH and Low Carbonate-Solubility Relationships," *Journal of the American Water Works Association*, Vol 75, No. 2 (1983).
- Schock, M.R., and C.H. Neff, "Trace Metal Contamination From Brass Fittings," *Journal of the American Water Works Association*, Vol 80, No. 11 (1988).
- Temkar, P., *Development of the Pipe Loop System for Determining Effectiveness of Corrosion Control Chemicals in Potable Water Systems*, Technical Report N-88/12/ADA200105 (U.S. Army Construction Engineering Research Laboratory [USACERL], 1988).
- Temkar, P., et al., "Pipe Loop System for Evaluating Effects of Water Quality Control Chemicals in Water Distribution Systems," *Proceedings AWWA Water Quality Technology Conference* (AWWA, 1987).
- Uhlig, H., *The Corrosion Handbook* (John Wiley & Sons, 1948).
- U.S. Environmental Protection Agency (USEPA), *Reducing Exposure to Lead in Drinking Water of School Children*, EPA/570/9-89-001 (1989).
- Washington State Department of Ecology, *Minimum Standards for Construction and Maintenance of Wells*, Chapter 173-160, Washington Administrative Code (1988).
- Widmer, H., *Effects of an Urban Road System on Lead Content of an Urban Water Supply Source* (University of Massachusetts, 1976).
- Wong, C., and P. Berrang, "Contamination of Tap Water by Lead Pipe and Solder," *Bulletin of Environmental Contamination and Technology*, Vol 15, No. 5 (1976).

UNCITED REFERENCES

- Cohen, A., and J. Myers, "Mitigating Copper Pitting Through Water Treatment," *Journal of the American Water Works Association*, Vol 77, No. 10 (1987).

- EES, Inc., *Greater Vancouver Regional District Water Quality Improvement Plan - Corrosion Control Initiative - Phase II* (Greater Vancouver Regional District, Vancouver, B.C., 1988).
- James M. Montgomery, Consulting Engineers, *Internal Corrosion Mitigation Study Addendum Report* (Bureau of Water Works, Portland, OR, 1983).
- Karalekas, P.C., Jr., et al., "Alternative Methods for Controlling the Corrosion of Lead Pipe," *Journal of the New England Water Works Association*, Vol 92, No. 2 (1978).
- Karalekas, P.C., Jr., et al., "Control of Lead, Copper, and Iron Pipe Corrosion in Boston," *Journal of the American Water Works Association*, Vol 75, No. 2 (1983).
- Macsson, O., et al., "Metal Mobilization in Home Well Water Systems in Nova Scotia," *Journal of the American Water Works Association* (1985).
- Molnar, W., and E. Haden, *Treated Water Corrosion Inhibition Using Zinc Orthophosphate* (Santa Clara Valley Water District, Santa Clara, CA, 1986).
- Neff, C.H., et al., *Relationships Between Water Quality and Corrosion of Plumbing Materials in Buildings*, EPA/600/S2-87/036 (USEPA, 1987).
- Oliphant, W., *Dezincification of Potable Water of Domestic Plumbing Fittings: Measurement and Control*, Technical Report TR-88 (Water Research Centre, 1978).
- Reiber, S.R., et al., *Internal Corrosion Within the Everett Distribution System*, Draft Report (Utilities Division, Public Works Department, Everett, WA, 1988).
- Richards, W., and M. Moore, "Lead Hazard Controlled in Scottish Water Systems," *Journal of the American Water Works Association*, Vol 76, No. 8 (1984).
- Ryder, R.A., "Methods of Evaluating Corrosion," *Proceedings, 6th Water Quality Technology Conference*, AWWA (AWWA, 1978).
- Schock, M.R., "Response of Lead Solubility to Dissolved Carbonate in Drinking Water," *Journal of the American Water Works Association*, Vol 72, No. 120 and Vol 73, No. 3 (1980 and 1981).
- Treweek, G.P., et al., "Pilot-Plant Simulation of Corrosion in Domestic Pipe Materials," *Journal of the American Water Works Association*, Vol 77, No. 10 (1985).
- Van Den Hoven, T., "How To Determine and Control Lead Levels in Tap Water: The Dutch Approach," *Proceedings, Water Quality Technology Conference*, AWWA (1985).

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