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Project Summary

Seattle Distribution System Corrosion Control Study Volume 1. Cedar River Water Pilot Plant Study

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For 6 months, the Seattle Water Department conducted a corrosion treatment pilot plant study, obtaining data on the treatment of Cedar River water with lime and lime/sodium bicarbonate. Continuous-flow pipe, coupon tests were conducted to determine corrosion rates, penetration rates, and corrosion types for copper, galvanized steel, and black steel pipes. Metal leaching tests were conducted using small diameter pipes. Research showed that using lime and lime plus sodium bicarbonate will significantly reduce corrosion in home plumbing systems. Copper and galvanized steel showed corrosion rate reductions of 65% and 69%, respectively, when lime alone was used, and 56% and 58% when lime plus sodium bicarbonate was used. Both treatments significantly reduced lead and copper leaching in the metal leaching tests. The leaching of zinc and cadmium from galvanized pipe into standing water, however, increased with both treatments. Based on this pilot study, lime treatment is recommended for the Cedar River water supply at an average dosage of 1.7 mg/L CaO. This dose should achieve an average distribution system pH of 7.9 and an alkalinity of 18 mg/L $CaCO_3$.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The Seattle Water Department (SWD) serves an average of 161 MGD of high quality water to nearly 1 million people in the greater Seattle area. The water originates in the Cascades from two mountain sources — the Cedar and Tolt Rivers. The watersheds are well protected and the water requires only disinfection with gaseous chlorine to meet Federal standards. The Cedar River system, developed in 1901, serves about two-thirds of the area; the remaining third comes from the newer Tolt supply. These mountain waters, which are predominantly rainfall and snowmelt runoff, are very soft in nature and tend to be highly corrosive to the unlined, metallic pipes in home plumbing systems. Corrosion of the plumbing systems and the associated water quality degradation has been a major concern of the Seattle Water Department for many years. Corrosion has caused three types of problems - aesthetic, economic, and health. This summary discusses these problems and the approach to reducing corrosion in the Cedar distribution area.

Customer complaints of aesthetically undesirable rusty water, red and blue stained fixtures, and metallic tastes are frequently received from within the Cedar water distribution system. This problem has been documented by accurate complaint records and by a questionnaire survey conducted by SWD in 1973. The survey, which was distributed to 10% of all services within the direct service area (15,000 customers), showed that 16.7% of customers in the Cedar water distribution system experienced corrosion-related problems.

Piping corrosion in the premise plumbing systems served by the Cedar supply also places a significant economic burden on the homeowner. The average estimated life span on hot water galvanized and copper pipes is approximately 35 years. The forecasted average annual cost in 1978 for maintaining serviceability in these pipes is estimated to be approximately $4 million.

Metals from corroded pipe leach into the water. Studies performed from 1972 to 1976 demonstrate that the levels of lead, copper, and iron in overnight standing Cedar tap water often exceed the levels defined by the National Interim Primary Drinking Water Regulations and the National Secondary Drinking Water Regulations. Cadmium and zinc were also found to increase after overnight standing in home plumbing; however, they rarely exceeded their levels. These metals originate from copper, galvanized pipes, and the solders used in home plumbing systems. Although the health impact of metal levels from overnight standing water is not an acute problem, it is certainly desirable to reduce exposure where possible.

Causes of Corrosion

The corrosiveness of Cedar water results from several related factors, including:

- *Acidity* as indicated by low pH. The raw Cedar water pH is approximately 7.6; after chlorination and fluoridation, pH is reduced to a range of 6.8 to 7.2.
- *Dissolved oxygen* concentration at saturated conditions.
- *Insufficient calcium and bicarbonate* alkalinity in the water to form protective calcium carbonate films on pipe surfaces.
- *A relatively high [halogen + sulfate]/alkalinity ratio ([halogen + $SO_4^{=}$]/ alk)* of 0.5 to 0.8 that results in conditions favorable to pitting corrosion.

In 1970, three factors combined to intensify the corrosiveness of this water supply. (1) To decrease the occurrence of positive bacteriological samples within the distribution system, the chlorine dosage at the open distribution reservoir outlets was increased. (2) At the request of the U.S. Public Health Service, ammoniation of the water supply was stopped to enable a free chlorine residual to be maintained throughout the distribution system. This change from combined chlorination to free chlorination was implemented to provide quicker, more effective disinfection of the unfiltered water supply. (3) Based on a vote of the Seattle citizens in 1968, fluoridation with hydrofluosilicic acid began in 1970.

Internal Corrosion Study

In December 1975, the City of Seattle retained a consulting engineering firm to perform a detailed analysis of the corrosion problem and to recommend possible solutions. The Internal Corrosion Study, which included a 9-month pilot plant investigation, confirmed the corrosiveness of Seattle water, the causes of corrosion, and the impacts associated with the corrosive water and evaluated alternative measures to reduce the corrosiveness of the water supply. Alternative methods to reduce corrosion included changing the methods of disinfection and fluoridation, blending the water supply with groundwater supplies, and adding corrosion inhibitor chemicals.

Based on the findings of this study, an Internal Corrosion Control Management Plan was developed. Because the very low level of mineral solids, pH, and alkalinity constitutes the major causes of the waters' corrosiveness, this plan was designed to correct the natural deficiency of minerals in Seattle's water through chemical addition.

The consultant recommended water quality goals using various chemical combinations that included the addition of lime and sodium bicarbonate. The actual selection of chemical combinations and optimum dosages became the task of the Seattle Water Department.

Purpose and Scope of Work

This research effort was done to determine which treatment better controls plumbing corrosion caused by Cedar water — lime plus sodium bicarbonate or lime alone. The scope of work included:

1. Determining the corrosion rates, penetration rates and corrosion types for copper, galvanized steel, and iron pipe exposed to control, lime treated, and lime/sodium bicarbonate treated water.
2. Predicting increases or reductions of residential pipe life spans.
3. Determining metal leaching levels from galvanized pipe, copper pipe, and lead/tin solder associated with each treatment.
4. Establishing the required optimal full-scale chemical dosages for both treatments.

From June 1979 to December 1979, three continuous flow corrosion test apparatus (control, lime, and lime/bicarbonate treatment) were operated at Seattle's Beacon Hill Gate House. This test site was chosen because it was close to the laboratory and had the same water quality that is delivered to the SWD customer. The targeted water quality characteristics for tests are presented in Table 1.

Corrosion coupon tests were used to document average corrosion rates based on weight loss, penetration rates based on pit depths, and corrosion types based on visual observations.

To evaluate the effects of treatment on overnight standing, SWD developed a new test method: small diameter pipe sections attached to the main test apparatus were used in determining copper, lead, cadmium, and zinc leaching levels from galvanized pipe, copper pipe, and lead/tin solder.

Operation, Results, and Evaluation

The pilot test apparatus consisted of a continuous flow test unit and a metal pick-up test unit (Figure 1).

The continuous flow test unit contained four 10.2-cm-long pipe segment coupons (2.54-cm diameter) of copper, galvanized iron, and black steel pipe. A velocity of 0.30 m/s through the pipe coupons was held stable by the use of a constant head reservoir. Periodically throughout the study, the coupons were removed from the test loop, cleaned, and weighed. Knowing the original weight of each coupon, weight loss was calculated and plotted versus time for each metal and treatment (Figure 2). Average corrosion rates were then calculated from these curves.

As shown in Table 2, both treatments showed substantially lower corrosion rates than the control. For each pipe analyzed, lime treatment produced lower corrosion than the lime/bicarbonate treatments.

Penetration rates were determined for the copper and black steel coupons.

Table 1. Target Water Quality Characteristics

Treatment	*pH*	*Total Alkalinity*	*Hardness*
None	*7.2*	*16*	*19*
Lime	*7.90*	*19*	*20*
Lime + Bicarbonate	*7.95*	*22*	*20*

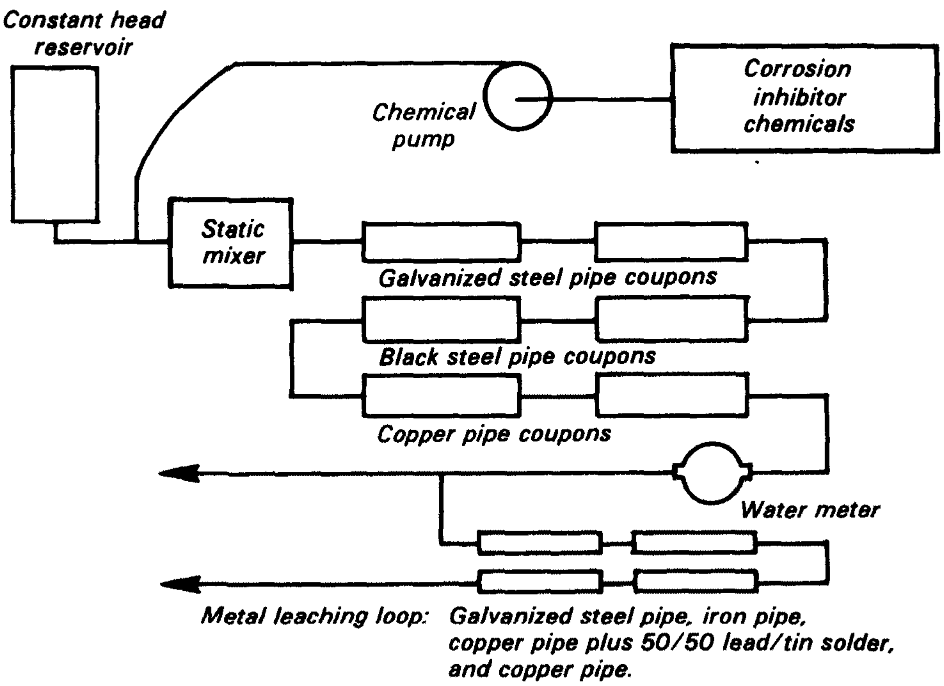

Figure 1. Pilot plant flow schematic.

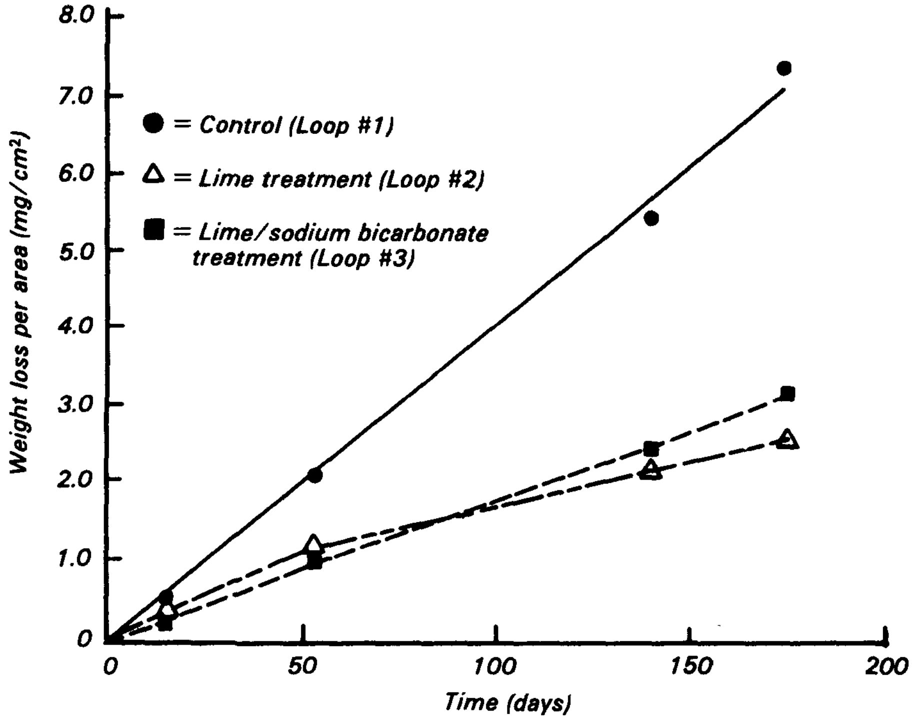

Figure 2. Cedar pilot plant test results - copper coupons weight loss.

The coupons were split into quarters and the pit depths were measured using either a pointed tip micrometer (iron specimens) or a binocular microscope with a graduated fine focus adjustment (iron and copper specimens). Penetration rates were then calculated in mils per year (mpy) based on the average of the 10 deepest pits on each specimen.

The penetration rate results were not as promising as the corrosion rate results. Average iron penetration rates for the control, lime treatment, and lime/bicarbonate treatment were 26.7, 25.2, and 23.5 mpy, respectively; these results demonstrated only small rate reductions with treatment.

The metal leaching test unit consisted of 25-cm and 51-cm lengths of 0.635-cm diameter pipes attached to the continuous flow test unit. The leaching pipe sections were made of copper, copper plus 50/50 lead-tin (Pb-Sn) solder, galvanized steel (new), and black iron pipe. These sections were analyzed for copper, lead, zinc, cadium, and iron leaching. Two velocities were used (0.061 m/s and 0.15 m/s) in establishing corrosion films in the metal leaching sections. The pipe sections were then periodically removed and dissolved metals were measured in the laboratory after approximately a 24-hour contact with test water.

The treatments resulted in substantial reductions of lead and copper leaching from copper pipe plus 50/50 lead-tin solder, and lead leaching from galvanized pipe. The treatment, however, increased the zinc and cadmium leaching from galvanized pipe. This occurred from the localized breakdown of the zinc passivation film under high pH and standing water conditions.

The metal leaching tests were conducted at an initial velocity of 0.061 m/s; to determine the possible effect of scouring at higher velocities, the velocity was later increased to 0.15 m/s. In most cases, as exemplified in Figure 3, the velocity increase caused a very noticeable increase in the metals leached from the control loops. These increases, however, did not occur in the loops that were exposed to chemically treated water.

Conclusions

The SWD pilot plant test program demonstrated that lime treatment is the more appropriate chemical treatment for the Cedar water supply (Table 3). Based on weight loss analysis, it proved superior to lime/bicarbonate treatment

Table 2. *Corrosion Rates*

Treatment	*Copper Corrosion Rate (mpy)*	*Iron Corrosion Rate (mpy)*	*Galvanized Pipe Corrosion Rate (mpy)*
None	*0.66*	*6.66*	*2.32*
Lime	*0.23*	*6.28*	*0.74*
Lime + Bicarbonate	*0.29*	*—[a]*	*0.94*

[a] *Rate not calculated because of weight loss determination errors.*

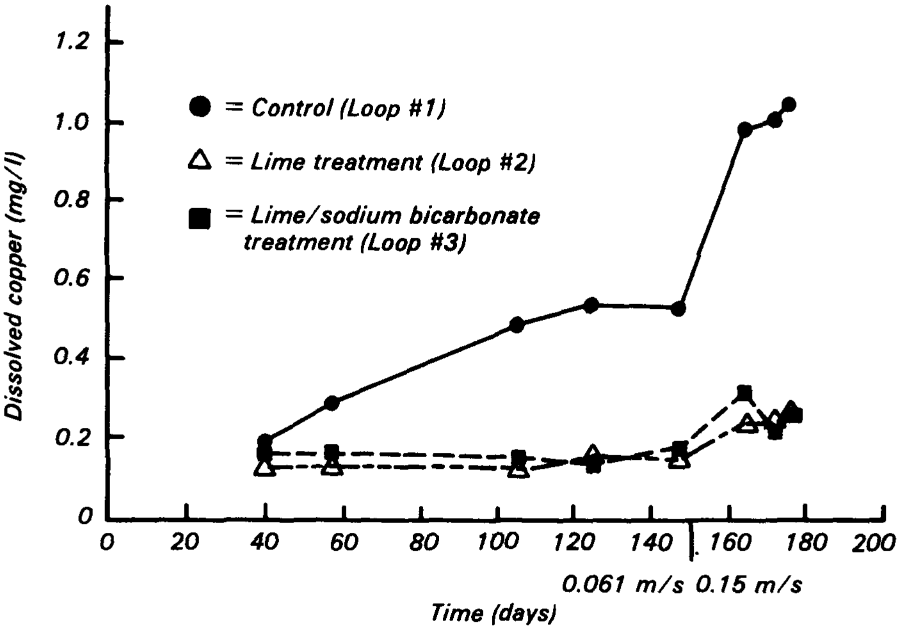

Figure 3. ***Cedar pilot plant test results - copper leaching from copper piping and 50/50 lead/tin solder.***

in reducing copper, galvanized steel, and black steel corrosion rates. As a result, estimated pipe life spans for these materials were greatly increased. Comparable copper and lead leaching reductions (from the copper plus lead-tin solder test sections) and copper leaching reductions (from the copper test sections) were obtained using both treatment methods.

The lime/bicarbonate treatment produced distinctly better reduction than the lime treatment in only two evaluation criteria: lead leaching from galvanized steel pipe and black steel penetration rates.

The control tests demonstrated the greatest corrosion rates and the shortest estimated pipe life spans. Metal leachate levels were also greater than under treatment conditions, with two exceptions — zinc and cadmium leaching from new galvanized steel pipe actually increased with treatment.

Recommendations

Since lime treatment produced the better overall protection against corrosion and metal leaching, it should be used for full-scale treatment of the Cedar supply. Table 4 details the recommended lime dosage, target water quality , and chemical costs for this treatment.

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Table 3. *Percent Reductions In Cedar Pilot Test Results*

	Copper Corrosion		*Copper/ Lead/Tin Solder Corrosion*		*Galvanized Steel Corrosion*				*Black Steel Corrosion*	
Treatment	*Corrosion Rate by Weight Loss[a]*	*Copper Leaching[b] (0.15 m/s)[c]*	*Copper Leaching (0.15 m/s)*	*Lead Leaching (0.15 m/s)*	*Corrosion Rate by Weight Loss*	*Lead Leaching (0.15 m/s)*	*Zinc Leaching (0.15 m/s)*	*Cadmium Leaching (0.15 m/s)*	*Corrosion Rate by Weight Loss*	*Pitting[d]*
None	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Lime	*65*	*46*	*78*	*81*	*69*	*49*	*-138*	*-32*	*6*	*6*
Lime + Bicarbonate	*56*	*47*	*76*	*84*	*58*	*72*	*-152*	*-51*	*—[e]*	*12*

[a] *Corrosion rate by weight loss - The percent reduction of corrosion rates based on 1 weight loss.*

[b] *Metal leaching - The average reduction of metal concentrations during the 0.15 m/s flow testing period.*

[c] *m/s - meters per second.*

[d] *Pitting - The percent reduction of penetration rates based on pitting data.*

[e] *Reduction not calculated because of weight loss determination errors.*

Table 4. Recommended Lime Dosage, Target Water Quality And Chemical Costs

Parameter	*Present Conditions*	*With Lime Treatment*
Treatment Plant CO_2 (mg/L)	2.7	0.0
Treatment Plant pH	7.21	8.3
Average Total Alkalinity (mg/L $CaCO_3$)	16	19
Atmospheric Equilibrium pH (@ 15°C)	7.79	7.86
Minimum Distribution pH	7.0	7.65[a]
Estimated Average Distribution pH	7.15	7.90
Average Distribution Conductivity (µmho)	54.5	58.2
[Halogen + $SO_4^=$]/Alk	.5-.8	0.4-0.7
Average Lime Dosage (mg/L CaO)	—[b]	1.7
Lime Cost per Year (1980 $)	—[b]	13,000

[a] *By calculation.*

[b] *No present treatment.*

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The complete report, entitled "Seattle Distribution System Corrosion Control Study. Volume I. Cedar River Water Pilot Plant Study," (Order No. PB 82-231 820; Cost: $9.00, subject to change) will be available only from:

National Technical Information Service
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