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AN EVALUATION OF ION EXCHANGE SOFTENING ON THE LEACHING OF METALS FROM HOUSEHOLD PLUMBING MATERIALS

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INTRODUCTION

The leaching of lead, copper and other metals from metallic components of household plumbing systems is impacted by the corrosivity of the distribution water.[1,2] Lead is present in a variety of plumbing materials such as lead service lines, galvanized steel pipe, solders, and faucets. Copper is the main component of copper pipe and also a major component of the brass in faucets. Zinc occurs in galvanized steel pipe and is also a component of the brass in faucets.

Water quality plays a significant role in the corrosion process. The most significant factors that influence the rate of corrosion are pH, total inorganic carbon (TIC), dissolved oxygen, chlorine, and temperature.[1] Other factors that also play a role in corrosivity are calcium, silicate, organic material, ammonia, chloride, sulfate, phosphate, nitrate, and fluoride. The relative significance of each factor varies by the material and the nature of corrosion process.

Naturally soft, low mineralized (hardness <25 mg/L as $CaCO_3$ and total dissolved solids (TDS) <50 mg/L) waters with low pH's have been widely demonstrated to have a corrosive effect on most household plumbing materials. These types of waters are common in surface waters of the Pacific northwest, New England area, and the southeastern United States.[1,3-5] Naturally soft waters contain low levels of calcium and magnesium ions, and are generally low in pH, (TIC and TDS). Primarily because of their pH and paucity of dissolved minerals, such waters are often inherently corrosive and frequently result in the leaching of excessive levels of lead and copper from common plumbing materials.

Moderately hard mineralized waters (hardness = 25-125 mg/L $CaCO_3$ and TDS = 50-300 mg/L) and hard mineralized water (hardness = >125 mg/L> $CaCO_3$ and TDS >300 mg/L) usually having pH above 7 is generally considered to be nonaggressive, although this concept does not always hold true[1]. Hard mineralized waters are frequently scale forming, and municipalities will reduce the hardness to a moderate level by either lime softening or ion exchange. Where municipal softening is not practiced, or lower hardness water is desired, consumers commonly install home ion exchange water softeners.

Ion exchange softening removes essentially all of the calcium and magnesium ions by exchanging them with sodium ions. Municipalities using ion exchange treatment will blend a portion of the source water with the treated water to provide a low or moderate level of hardness to their consumers. Because blending is not a design feature of household water softener systems, the hardness level of this water distributed through the home is near zero. The pH, alkalinity and TDS, three key corrosion parameters, remain approximately the same.

Although naturally soft waters are known to have corrosive effects on plumbing materials, the effect of ion exchanged softened waters have not been extensively evaluated. Furthermore, little data exist on the fate of various water quality constituents that play an integral role in protective surface film development or the corrosion of metals, as they pass through domestic water softeners.

STUDY OBJECTIVES

The potential effects of ion exchange softening on the corrosivity of household plumbing materials can be divided into three possible areas. First is the potential effect of a direct increase in the metallic corrosion by-products. The second potential effect is a change in the chemical characteristics of the water that would either remove or alter film forming constituents in the water. The last one, that is very difficult to achieve with short term testing, is the potential for producing reversible changes in passivation surface films of aged plumbing systems.

The Drinking Water Research Division (DWRD) began to address these issues by conducting a controlled pilot plant study designed to evaluate the impact of home water softeners on the leaching of metals on new plumbing materials. This project was conducted with the cooperation and financial assistance of the Water Quality Association (WQA) through a Cooperative Research and Development Agreement under the Federal Technology Transfer Act.[6]

A research plan was developed to conduct two studies using two different water qualities at the City of Cincinnati Bolton Water Treatment Plant. One study was conducted on a finished tap water that had a total hardness near 160 mg/L as $CaCO_3$ and a pH of 9.1-9.3. The second study was to be conducted on untreated groundwater (well water) that had a hardness of around 330 mg/L as $CaCO_3$, about twice the hardness as the finished tap water, and a lower pH of 7.1-7.3. This report presents the test results of the first study (Phase I) on the finished tap water.

TEST PROCEDURE

The research plan consisted of conducting a pilot plant study using two pipe loop systems: one fed with the control water (finished tap water) and the second one fed with the test water (ion exchanged softened water). The goal was to operate the systems for a minimum of nine months and to measure and compare the metal leaching levels from the household plumbing materials that made up the pipe loop systems. After the nine months of planned operation, the data would be evaluated and the study extended to a year or longer as time and resources permitted.

SOURCE WATER

The source water was finished tap water from the City of Cincinnati's Bolton Water Treatment Plant (BWTP). The BWTP treats groundwater with about 330 mg/L (as $CaCO_3$) of hardness by lime softening reducing the hardness to around 160 mg/L (as $CaCO_3$). The lime softening process also increases the pH of the groundwater to about 9. Treatment also includes the addition of a low level of polyphosphate (approximately 0.4-0.5 mg PO_4/L) for protection against $CaCO_3$ scaling of their filters, chlorination, and fluoridation. A summary of the major chemical constituents in the source water (control water) is shown in Table 1.

PIPE LOOP SYSTEMS

Two pipe loop systems similar, but not identical, to the system outlined in the American Water Works Association Research Foundation's Lead Control Strategies manual were designed and constructed (Figure 1). One system used for the control was fed BWTP tap water. The second system was fed the ion exchange softened tap water having only a trace of hardness. Each pipe loop system contained two loops of lead pipe, copper tubing, copper pipe connected with 50:50 lead-tin solder joints, galvanized pipe, and two brass faucets. Each pipe loop was 50 feet in length. Faucet selection was based upon the DWRD study metal leaching study of 1987.[8] A summary of the plumbing materials used in the pipe loop system is shown in Table 2.

All connecting pipe and other materials, such as flow meters and sampling valves to support the system, were made of plastic (PVC) or stainless steel. Sample taps were installed before and after the water softener and after each individual pipe loop. A flowmeter was installed before each pipe loop for flow control and the entire system was pressurized by using a solenoid valve at the end of the discharge line of the loops. Check valves were not installed before and after each loop as given in AWWARF design.

To achieve isolation of the loops during sampling, manual valves were placed before and after each loop. The faucets themselves maintained water pressure and a electrically controlled hydraulic arm attached to the faucet handle automatically opened and closed the faucets. A water meter was also installed in the main line before each system to measure the total amount of water that passed through each system.

All piping materials and faucets were purchased new from local plumbing supply firms. The piping material was formed into 50 ft loops or rectangular sections. The copper soldered pipe loops were joined with 50:50 lead-tin solid-core solder by a skilled technician. Each loop contained 18 elbows and 36 soldered joints. The galvanized steel pipe loops were joined by threaded 90 degree elbows. All the loops were connected to the PVC system with PVC reinforced flexible hose and clamps. The faucets were all of the same model having a single handle, brass interior and an internal volume of approximately 100 mL.

WATER SOFTENER

The water softener was provided by Culligan International Company, Northbrook, IL. The softening system, MARK 512, Model 3526-46, is listed by the National Sanitation Foundation (NSF) under Standard 44. The softener was installed by a local Cincinnati dealer who programmed the system to regenerate every other day at noon time. The regeneration cycle consisted of three operational cycles: (a) backwash (15 min), (b) brine (64 min), and (c) rinse (4 min).

SYSTEM OPERATION

The pipe loop test systems were connected to a tap water source having a line pressure of over 100 psi. A pressure regulator provided approximately 54 psi to the pilot systems. Each pipe had an inline flow controller set to provide a flow rate of near 1 gpm through each loop and about 0.5 gpm through each faucet. The programmable on/off timing system was set to open and close the solenoid valves and the hydraulic faucet handle system to provide 105 minutes of flow time each day through each pipe loop and faucet. A water meter was installed before each system to provide a rough check of the total flow.

The flow pattern consisted of 5-15 minute and 1-30 minute flow times with 1-½ to 2-½ hour of off times between the flowing periods (Table 3). The flowing/standing periods were provided to simulate daily water usage in a home. A 8.5 hour standing period occurred from each morning to late afternoon to represent over night standing.

WATER SAMPLING

Water samples from both the control and the test systems were collected twice a week on Monday and Wednesday, except on a few occasions because of holidays, plant or pipe-rig operational problems, or other special problems. Background water samples were also collected before each system during the last flowing period prior to the 8.5 hour standing period. These samples were collected to characterize the difference in the control and test waters and to document variations of the source water during the study period.

One liter standing water samples were collected from the pipe loops and 500 mL samples from the faucets. To isolate the loop during sampling, all valves of the test system were closed during sampling, except for the influent line valve of the loop being sampled. Because of system design and sample tap location, 250 mL's of water was wasted from each loop prior to collecting the liter sample. This two step procedure was done to assure that the 1-liter sample was in direct contact with the pipe loop. The 1-liter sample was selected because it was consistent with compliance sampling required by the Lead and Copper Rule.[8]

A 500 Ml sample size was selected for the faucets because the contact volume of the faucet was approximately 100 Ml and the DWRD Faucet Study suggested that about four to five bed volumes of water are required to collect 95-99 percent of the lead and other metals leached from the brass surfaces in a faucet.[7]

CHEMICAL ANALYSES

Because of sample instability, pH, chlorine, and dissolved oxygen analyses were conducted immediately on-site by CWW personnel. All other analyses were conducted by DWRD personnel at the EPA Research Center.

Atomic absorption (AA) flame and furnace methods were used to analyze for metals on water samples collected prior to June 30, 1994. After this date an inductively coupled argon plasma spectrometer (ICAP) was used for the metals, except leads, plus silicon, sulfur and phosphorus and a number of other elements. Because of lower detection limits, lead continued to be analyzed by the graphite furnace AAS method and potassium by the flame AAS method throughout the study.

Laboratory quality assurance procedures for analytical precision and accuracy for all samples followed the procedures established by the I&PCB, DWRD for all research studies. These procedures are documented in a QA laboratory operation plan and included analytical duplicates, spikes, and external quality controls (USEPA, USGS reference standards).[9] Approximately 15 percent of the analytical measurements performed by the I&PCB laboratory consisted of spikes, duplicates, and QC standards.[9]

RESULTS

Water Usage and Sampling

The pipe loop corrosion study began on November 2, 1992 and officially ended on February 24, 1994, the last day for bi-weekly routine sampling (483 days). The number of sampling days during the 16-month study period ranged from 6 to 10 per month as shown in Table 4 for a total of 119 sampling days.

The total flow through the pipe loop systems obtained from the water meter readings are shown in Figure 2. Over the 483 day study period, the total flow through the control and test pipe loop systems was 458,173 gallons (948.6 gpd) and 440,822 gallons (912.8 gpd), respectively.

Although the total flows and daily rates are not identical for each system, they were within 4 percent of each other. Water meters were not installed on each loop and faucet, therefore, the amount of water that flowed through loop and faucet could not be exactly determined. Any differences in total flow from one loop to another are believed to be small, however, considering the manifold design and the closeness of the total flows for the two systems.

Water Quality Monitoring

The control and test waters to the pipe loop systems were monitored to meet two objectives. One objective was to determine any water quality difference between the control (unsoftened) water and the test (softened) water, and the second objective was to monitor any temporal changes of the source water that might impact the study results.

Source Water Quality

Because the source water was BWTP finished water, the quality did not undergo significant changes during the study period. Variation in several water quality parameters did occur, however, because of seasonal temperature changes, subsurface hydrochemical changes, and variations in plant operation. The water quality parameters affected the most significantly by these factors were water temperature, pH, hardness, chlorine, dissolved oxygen, and total ortho-phosphate.

The pH of the source water did not vary substantially but some temporal variation was noted (Figure 3). The pH of the source water ranged between 8.8 and 9.4 (except for two unexplained outliers), with a mean of 9.1. The temperature of the source water varied from a high of near 18°C to a low of near 13°C during the winter periods (Figure 4). Dissolved oxygen concentration varied from a high of near 8.5 mg/L to a low of near 4.5 mg/L (Figure 5). The variation in dissolved oxygen was due to operational changes of the treatment plant and dissolved oxygen solubility.

Total hardness of the source water ranged from about 150 to 189 mg/L (as $CaCO_3$). The average hardness level was calculated at 159 mg/L (as $CaCO_3$) with a standard deviation (SD) was 22.6. The results of the hardness tests are plotted in Figure 6.

Chlorine is added to the finished tap water to provide a concentration of near 1 mg/L (Figure 7). Total chlorine averaged 1.12 mg/L and the standard deviation was 0.09 mg/L. Free available chlorine was only slightly less at a mean of 1.04 mg/L with a SD of 0.09 mg/L.

Sodium hexametaphosphate (~.5mg/L as PO_4) was added to the partially treated water prior to filtration to prevent the encrustation of the sand filters with calcium carbonate. Total phosphate averaged 0.4 mg/L and orthophosphate 0.09 mg/L. Little change of either parameter occurred during the study (Figure 8).

The TIC of the source water averaged approximately 16 mg/L with a range of about 13 to 18 mg/L during the first 150 days of the study (Figure 9). Because of laboratory analytical problems, the TIC was not measured during the latter part of the study.

Softened--Unsoftened Water Quality

A comparison of the mean values of measured water parameters of unsoftened (control) and ion exchanged softened waters (test) is shown in Table 1. The most significant differences between the two waters occurred with five measurements, calcium, magnesium, potassium, sodium and pH. As expected, the ion exchange softener reduced the calcium (26 mg/L) and magnesium (24 mg/L) concentrations in the control water to near zero while increasing the sodium (25 mg/L) level to 101 mg/L. Potassium, a monovalent cation, (3.6 mg/L) was reduced by 68 percent to 1.1 mg/L and the pH was increased slightly from 9.1 to 9.3. Polyphosphate and orthophosphate species passed through the exchange resin indicating that they were in anionic or uncharged complex forms.

METAL LEACHING DATA--DATA EVALUATION

The metal leaching data for all of the lead pipe loops are shown in Figures 10-16. All of the metal leaching data were examined visually and statistically to determine whether the ion exchange softened water produced higher metal levels. The first step of the statistical process consisted of determining whether metal leaching from the loops and faucets reach "stabilization". This was determined by identifying the point in time at which the slopes of all of the four curves for each loop type achieved zero within 95% confidence using linear regression tests. Using this procedure, only two complete sets were determined to reach stabilization; lead leaching of the lead loops (69 days) and zinc leaching of the faucets (153 days). For all other sets, at least one of the four curves did not test for zero slope.

True "stabilization" times may range from weeks to years, depending upon the nature of the surficial passivation films formed for a given material. Recent research has indicated that with copper, for example, initial $Cu(OH)_2$ films will "age" into less soluble $Cu_2(OH)_2CO_3$ or CuO over periods of perhaps more than 15 to 20 years.[10] Stabilization is also difficult to achieve for materials such as soldered joints and brass, where physical depletion of source material, such as lead, occurs. Long term slow drift may be present even for the two sets of loops that had apparently stabilized. Another factor that likely interfered with the stabilization tests was the variation in the leaching data caused by the changes in water quality.

For the sets of loops and faucets that did not stabilize based upon the zero slope test, a stabilization time was selected from a visual inspection of the curves in order to complete the statistical analysis. Using the metal leaching data from the stabilization time to the end of the study, statistical tests (paired t-test or non-parametric equivalent tests) were conducted on each duplicate loop to determine whether the two data sets could be paired (averaged). The results of these tests showed that 10 sets were considered statistically different and six sets were not different. Visual examination of the data suggests that pair testing of many of the loops failed because of short periods of metal leaching variation (increases) of one loop. These short period increases cannot be explained, but are typical of pipe loop testing.

The results of the tests for reproducibility of duplicate loops/faucets are shown in Table 5. If the duplicates agreed statistically, the results were paired (averaged) for statistical tests to determine whether the metal leaching levels between the non-softened and softened conditions were statistically different.

T-tests (normal data sets) or non-parametric equivalent tests (non-normal data sets) were used to determine significant differences between softened and unsoftened conditions for the same type of loops/faucets. As stated above, comparisons were made using mean values of duplicate sets, if duplicates tested as the "same". If the duplicate loops/faucets did not test as the "same", each loop or faucet was tested against the other mean (set) or individual loop/faucet.

Lead Leaching Results

Results of the lead sampling data from the lead pipe loops are shown in Figure 10. Statistical tests showed the lead levels from the nonsoftened and softened water conditions to be different. A visual interpretation of the data (Figure 10) suggests that lead levels of the non-softened water pipe loops were slightly higher than the lead levels of the softened water pipe loops by about 0.2 to 0.3 mg/L for each month of the 16-month study.

The results of the lead leaching data of the copper soldered pipes are shown in Figure 11. Treatment comparison tests indicated statistical differences between the individual loops of each set. The majority of the lead levels of all loops was at the detectable level of 0.001 mg/L except for some increase between the 8 and 16 month period for several of the pipes. Consequently, although the statistical tests indicated lead leaching differences between the non-softened and softened water pipe loops, the very low levels of all loops indicate that the softened water had no real impact on increased lead leaching.

The results of the lead leaching from the faucets (containing brass) are shown in Figure 12. The statistical tests for reproducibility of the duplicate faucets showed that the softened-water faucet data of the two could be paired, but the non-softened water faucet data could not. Statistical tests for treatment comparison showed statistical difference for the two conditions. Examination of the data in Figure 12 shows that the lead leaching from the softened water faucets were generally higher, but because of the lead levels for both were very low, 0.003 to 0.008 mg/L, the trend probably had little meaning. Furthermore, the results show that during the last three months, the lead levels from the two systems were within 0.002 mg/L of each other in the 0.003 to 0.005 mg/L range. The results indicate, therefore, that the softened water had no effect on increased lead levels.

Copper Leaching Results

The results of copper levels from the copper tubing loops average are plotted in Figure 13. The reproducibility tests for the duplicate loops showed that the softened water loops could be paired, but the non-softened water loops could not be paired. Tests for treatment comparison was conducted by using the paired averages of the softened loops against each of the two nonsoftened water loops. The statistical tests showed the copper levels of the two to be statistically different indicating differences in copper leaching of the non-softened and softened loops. The data plotted in Figure 13 showed that the copper levels from the softened water loops to be higher than the non-softened loops during the last six months by about 0.2 to 0.4 mg/L. Copper levels from all loops were within a range of 0.07 to 0.13 mg/L that significantly lower than the USEPA copper action level of 1.3 mg/L. Consequently, although the softened water had slightly higher levels, the level of increase was small and may not be significant.

The copper leaching data of the soldered pipes are shown in Figure 14. The reproducibility tests were similar to the copper tubing results. The softened water loop data could be paired, but the nonsoftened water loop data could not be paired. Two treatment comparison tests were, therefore, conducted using the average of the softened water loop data and the individual loop data for the non-softened loops. One test showed a statistical difference and the second one did not. Examination of the data from Figure 14 indicates little or no difference between the two sets of loops suggesting that the softened water did not have an impact on copper leaching.

The copper leaching data of the faucets are plotted in Figure 15. The reproducibility tests showed that one set (nonsoftened water) could be paired, but the other set (softened water) could not. Treatment comparison tests, conducted with the paired set against the individual loops of the softened water, resulted in both being statistically different. Visual examination of the monthly average data of Figure 15 suggests that copper leaching levels were about the same for both the nonsoftened and softened water. Moreover, the copper levels of both sets were very low, 0.01 - 0.05 mg/L in comparison to the copper action level of 1.3 mg/L. The data suggests that the softened water did not increase the copper levels.

Zinc Leaching Results

The zinc leaching data from the galvanized loops are plotted in Figure 16. The statistical tests for reproducibility of duplicate loops showed that neither set could be paired and averaged, therefore, treatment comparison tests were performed on the four possible pairs. The test results indicated significant differences of zinc leaching between the nonsoftened and softened water galvanized steel test loops. Examination of the monthly average plotted data of Figure 16 indicates that the zinc levels may be higher in the softened water loops than nonsoftened water loops. Because the paired loop data did not show good agreement for either condition, and because on one nonsoftened water loop and one softened water loop had a very comparable zinc level, concluding that the softened water produces higher zinc levels cannot be supported by the data.

The zinc leaching data from the faucets averaged on a monthly basis are plotted in Figure 17. The statistical tests of reproducibility of duplicate faucets showed that the softened water faucet data could be paired, but the nonsoftened data could not. Treatment comparison tests were therefore conducted by averaging the paired softened water levels and testing this average against each of the two loops of the nonsoftened water. The results of the two plots showed significant differences between the two exposures for both tests. However, visual examination of the monthly averaged data suggests no differences between the leaching levels of each set. Except for the first few months, the zinc levels from all faucets were very low in the 0.002 to .1 mg/L range.

DISCUSSION OF RESULTS

The objective of this study was to determine whether water softened by ion exchange treatment to approximately zero hardness is more corrosive to household plumbing materials than the nonsoftened water. Naturally soft waters are low hardness, low mineral content waters with pH's often at or below neutrality and have been widely demonstrated to have a corrosive effect on most household plumbing materials. This suggests that ion exchange softened water would have the same type of corrosive effect on these materials.

Ion exchange softened waters are different in chemical characteristics than naturally softened waters, however. Ion exchange softened waters do not necessarily have a low mineral content, nor are they necessarily low in pH. Ion exchange softening fundamentally removes the calcium and magnesium and replaces these elements with sodium. The process does not substantially alter the mineralization level, alkalinity or pH. In other words, ion exchange softening does not produce water with chemical characteristics commonly associated with naturally soft waters. The process does remove calcium an element that is commonly thought to give some beneficial protective effort to corrosion. Because of this change, ion exchange softening is often portrayed as a treatment process that could increase the corrosivity of the water, thereby increasing the metals level. Little or no data exist to confirm or disprove this hypothesis, however.

By erroneously using calcium carbonate saturation indices as a surrogate measure for "corrosivity", much misinformation has been generated in the past. High pH and high alkalinity also produce higher (less corrosive) values for the $CaCO_3$ saturation state. However, that combination has been demonstrated theoretically,[10-17] by controlled experiments [10-12,14,17,18], and by field data[19,20] to be detrimental in some substances to either lead or copper solubility.

Water quality plays a very significant role in causing corrosion and calcium is only one of many factors that influence the rate of corrosion. Moreover, calcium is normally not considered one of the major ones. The AWWARF Lead Control Strategies Manual states "In spite of the fact that there is little evidence in the research literature that adherent, continuous $CaCO_3$ films actually form to seal lead pipe against leaching, calcium carbonate deposition has gained wide acceptance as a viable lead control strategy." The Manual further states that the water quality factors that have the greatest influence on lead mobilization are pH, alkalinity, and dissolved inorganic carbon (DIC). The treatment strategies stressed, therefore, are pH, alkalinity and DIC adjustment and the use of corrosion inhibitors such as orthophosphate and silicate compounds. The addition of calcium is not considered a corrosion control treatment strategy. It can be reasoned, therefore, that the removal of calcium may not necessarily increase the corrosivity of water.

The water softening study was designed to evaluate the effect of ion exchanged softened water of one water quality on household plumbing materials under controlled conditions. The study was conducted to measure and compare metal leaching of the materials exposure to nonsoftened and softened water, and also to examine the potential effect of changes of key water quality factors that might remove or alter the film forming constituents in the water. The key factors would certainly include pH, alkalinity, and DIC.

Statistical evaluation of the metal leaching, generally data followed the recommendations outlined in a recent AWWARF document.[21] The problem in applying these procedures centers on the variable nature of the metal leaching data and inclusion of high or low levels that may be considered outliers. Occasional high concentration of metal levels are common in home tap samples and to pipe loop studies. They generally result from chemical and physical factors of the systems and not sampling or analytical error. They reflect the variable nature of corrosion and metal solubility. They also present problems in evaluating and interpreting the results.

The statistical tests to determine metal level stabilization indicated that many of the loops and faucets did not reach stabilization. Statistical tests to determine whether data from duplicates could be paired (averaged) also showed that many of duplicates could not be paired although visual examination suggests otherwise. And, finally, based upon an arbitrarily selected stabilization time, statistically testing to determine whether the metal leaching levels of the two systems were the same or different indicate that most results were different. Visual examination of the data (Figures 10 - 19) suggest little difference in metal levels between the two systems and where differences were apparent, there was no pattern of the softened water metal levels being higher than the nonsoftened water levels. The only observed data to have a consistent difference in metals levels throughout the study was the lead levels from the lead pipe. In this case, the levels of the nonsoftened water loops were always 0.2 to 0.3 mg/L higher than the softened levels, which is contrary to the hypothesis that softened water is more corrosive than nonsoftened water.

The lead levels from the faucets are observed to be slightly higher in the softened water system, but the absolute levels were below 0.003 to 0.007 mg/L suggesting little or no difference. The lead levels from the copper solder pipe were both near the minimum detectable limit of 0.001 mg/L except for several spikes during the last eight months of the study.

During the last six months of the study, the copper levels of the copper tubing loops were about 0.01 to 0.02 mg/L higher in the softened water loops while there was essentially no difference between the copper levels of copper pipes or faucets of the two systems.

The zinc levels of one galvanized steel loop from each system were essentially the same. The second loop of the softened water had zinc levels higher than the three other ones while the zinc level from the second nonsoftened water system was lower than the other three. If the duplicate sets are averaged, the zinc levels for the softened system show higher levels throughout the entire study. The zinc leaching levels from the faucets were essentially the same after the fifth month.

The lead levels observed for the lead pipe are much higher (even approximately by a factor of 3) than would be expected for a water of the same pH and DIC. This model was also verified experimentally.[10-12] Therefore, the behavior of lead in this study suggests an interferant to normal passivation film formation. X-Ray diffraction analyses of pipe specimens showed almost no film formation, and not significant basic lead carbonate as would be expected.

At this DIC/pH combination, the difference in lead solubility for the small pH difference between the softened and unsoftened water should be minimal. Therefore, some surface reaction not directly resulting from hydroxide or carbonate ion is possibly occurring.

Additionally, copper levels from soft and hard copper pipe are higher than would be expected based on current experimental and theoretical work.[15-17] X-ray diffraction analyses of pipe specimens from this project did not show normal film formation of Cu(II) solids, such as CuO or $Cu(OH)_2$ under controlled conditions.

Abnormally higher copper levels were previously observed in presence of 60-120 mg/L Sulfate at pH 8.1-8.8. However, this study water also contains, in addition to significant sulfate, appreciable polyphosphate known to increase lead solubility at least at pH 8.[22-24] Similar effects on copper would be expected. Field observations have shown the only lead action level exceediences for major utilities at pH >8.4 were in 13 systems dosing polyphosphates.

CONCLUSIONS

Considering all of the lead, copper, and zinc leaching data from all loops and faucets, there is no clear evidence that the ion exchange softened water produced higher metal levels than the nonsoftened water. Furthermore, the water quality data show little difference between the two water qualities for alkalinity, DIC, two significant corrosion factors.

The ion exchange softening process increased the pH of the control water by 0.2 to 0.3 units which could have a beneficial effect on the metal level. Consequently, except for the decrease in calcium levels, the softened water did not change any of the significant water quality corrosion parameters that would cause a prediction of higher metals leaching in the softened water system.

This study involved one water quality test of a non-aggressive water and, therefore, the results cannot be extrapolated to all water qualities. Currently, a second study is being conducted by DWRD using a more aggressive water with a pH of about 7.3 and a hardness of near 300 mg/L as $CaCO_3$.

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TABLE 1. COMPARISON OF THE NON-SOFTENED AND SOFTENED WATER

ANAYTE, UNITS	CONTROL WATER Non-softened*		TEST WATER Softened	
	Mean	Std Dev	Mean	Std Dev
Lead, µg/L	<0.002	0.001	0.002	0.001
Calcium, mg/ L	25.6	1.183	<0.002	0.001
Copper, mg/L	<0.003	0.003	<0.003	0.003
Iron, mg/L	<0.05	0.016	<0.05	0.009
Potassium, mg/L	3.55	0.54	1.13	0.41
Magnesium, mg/L	23.7	1.17	<2.0	0.19
Manganese, mg/L	<0.02	0.003	<0.02	0.002
Sodium, mg/L	26.4	3.13	101	6.28
Aluminum, mg/L	<0.025	0.01	0.01	0.01
Sulfur, mg/L	22.4	1.11	22.39	1.03
Zinc, mg/L	<0.01	0.007	<0.01	0.006
Alkalinity, mg $CaCO_3$/L	76.7	4.39	76.8	4.29
Hardness, mg $CaCO_3$/L	159.8	22.63	0.13	1.22
Sulfate, mg SO_4/L	67.3	5.72	67.7	6.32
Chloride, mg/L	45.9	4.30	46.0	4.33
Silica, mg SiO_2/L	10.0	0.69	10.0	0.66
Nitrate, mg N/L	2.19	0.68	2.05	0.56
Ammonia, mg NH_3/L	<0.03	0.02	<0.03	0.03
Orthophate, mg PO_4/L	0.09	0.06	0.09	0.04
Total Phosphate,mg PO_4/L	0.42	0.11	0.45	0.19
Dissolved oxygen, mg/L	6.86	0.97	6.82	0.98
Total inorganic carbon, mg/Cl	15.9	1.41	16.0	1.34
Free chlorine, mg Cl_2/L	1.04	0.09	1.02	0.10
Total chlorine, mg Cl_2/L	1.12	0.09	1.09	0.10
pH, pH units	9.09	0.19	9.31	0.15
Temperature, degrees Celsius	15.1	0.98	15.2	0.96

* Source water, City of Cincinnati, Bolton Water Treatment Plant, finished water.

TABLE 2. PLUMBING MATERIALS FOR PIPE LOOP SYSTEMS

Plumbing Material	Identification (nominal size)	Dimension ID(in)	Dimension OD(in)	Volume mL foot
Lead Pipe	1/2 in ID	0.47	0.94	87
Copper tubing	1/2 in ID type L Drawn	0.53	0.625	46
Copper pipe	3/8 in ID type M, schedule 40	0.37	0.45	60
Galvanized pipe	1/2 in ID, schedule 40	0.56	0.75	59
Solder	50:50 Pb:Sn	--	--	--
Faucet	single handle	--	--	--

TABLE 3. DAILY FLOW PATTERN OF PIPE LOOP SYSTEMS

Control System (Unsoftened)	Time (Minutes)	Test Sytstem (Softened)	Time (Minutes)
5:00 - 5:15 pm	15	5:15 - 5:30 pm	15
8:00 - 8:15 pm	15	8:15 - 8:30 pm	15
11:00 - 11:15 pm	15	11:15 - 11:30 pm	15
2:00 - 2:15 am	15	2:15 - 2:30 am	15
5:00 - 5:15 am	15	5:00 - 5:15 am	15
8:30 - 9:00 am	30	9:00 - 9:30 am	30
TOTAL	105	TOTAL	105

TABLE 4. NUMBER OF SAMPLE COLLECTION DAYS PER MONTH

Year and Month	Sample Collection Number of Days
1992	
November	6
December	9
1993	
January	7
February	6
March	10
April	8
May	8
June	7
July	7
August	9
September	8
October	7
November	7
December	8
1994	
January	7
February	5
TOTAL	119

TABLE 5. RESULTS OF STATISTICALLY TESTS TO DETERMINE REPRODUCIBILITY OF DUPLICATE PIPES/FAUCETS

Pipe Loops/Faucets (Metal Leached)	Normality Tests	Reproducibility Tests
Lead Loops (lead)		
Non-Softened pair	Non-normal	Passed
Softened pair	Normal	Passed
Copper/Soldered pipes (lead)		
Non-softened	Non-normal	Failed
Softened	Non-normal	Failed
Brass faucets (lead)		
Non-softened	Non-normal	Failed
Softened	Non-normal	Passed
Copper Tubing (copper)		
Non-softened	Non-normal	Failed
Softened	Non-normal	Passed
Copper/Soldered pipes (copper)		
Non-softened	Non-normal	Failed
Softened	Non-normal	Passed
Faucets (copper)		
Non-softened	Non-normal	Passed
Softened	Non-normal	Failed
Galvanized pipes (zinc)		
Non-softened	Non-normal	Failed
Softened	Non-normal	Failed
Faucets (zinc)		
Non-softened	Non-normal	Failed
Softened	Normal	Passed

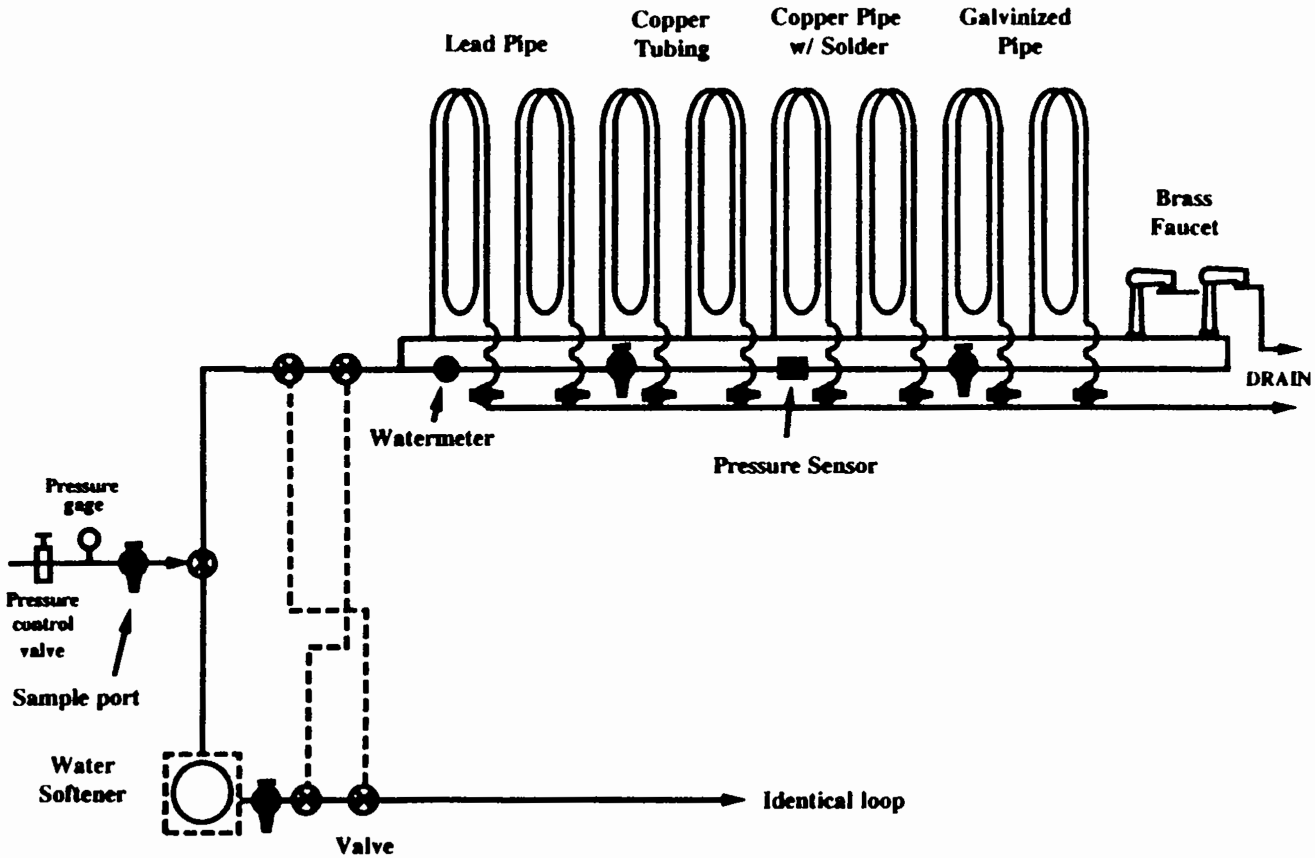

Figure 1. Pipe Loop System.

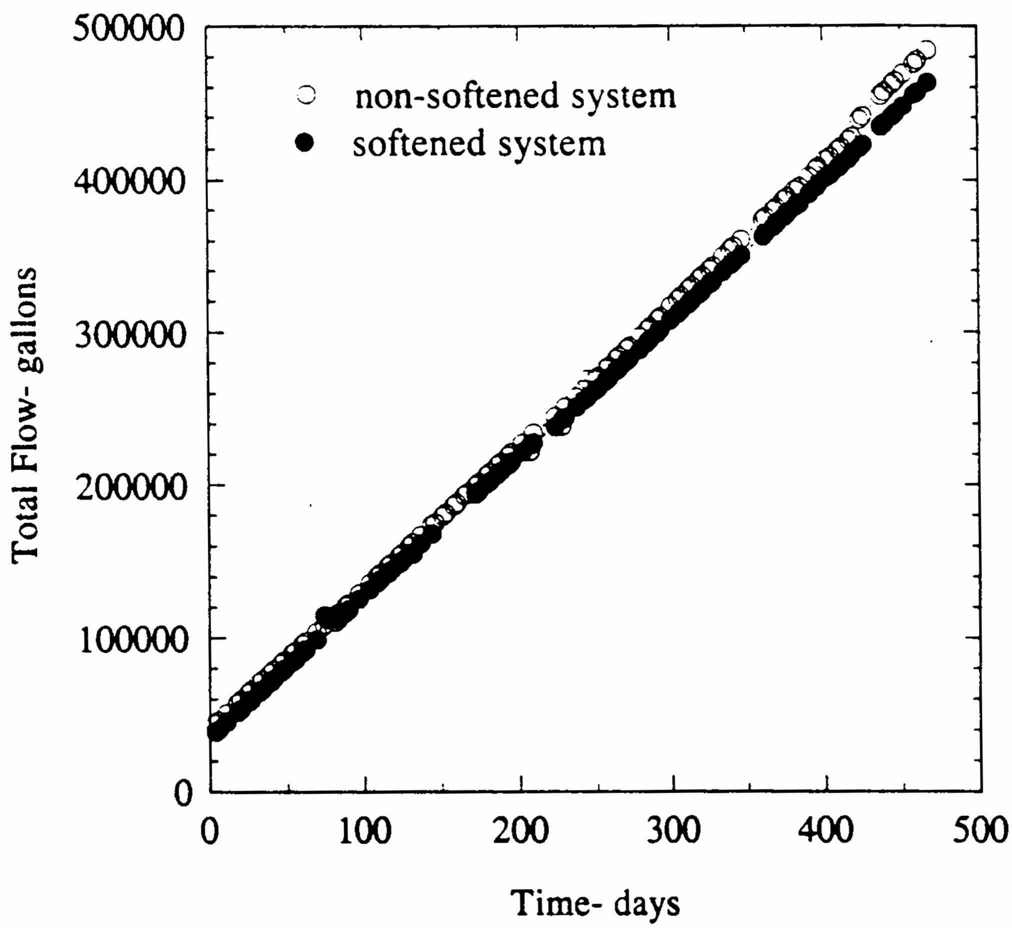

Figure 2. Water flow (total) through pipe loop systems.

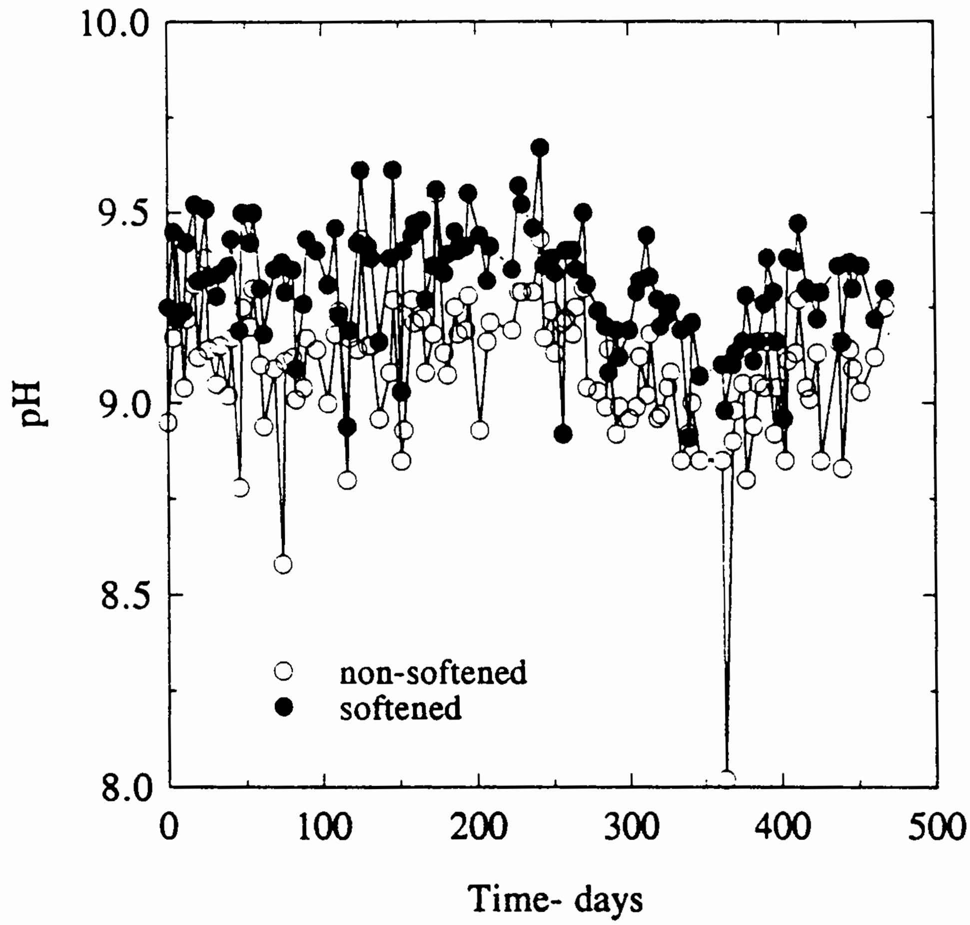

Figure 3. pH of the unsoftened and softened water.

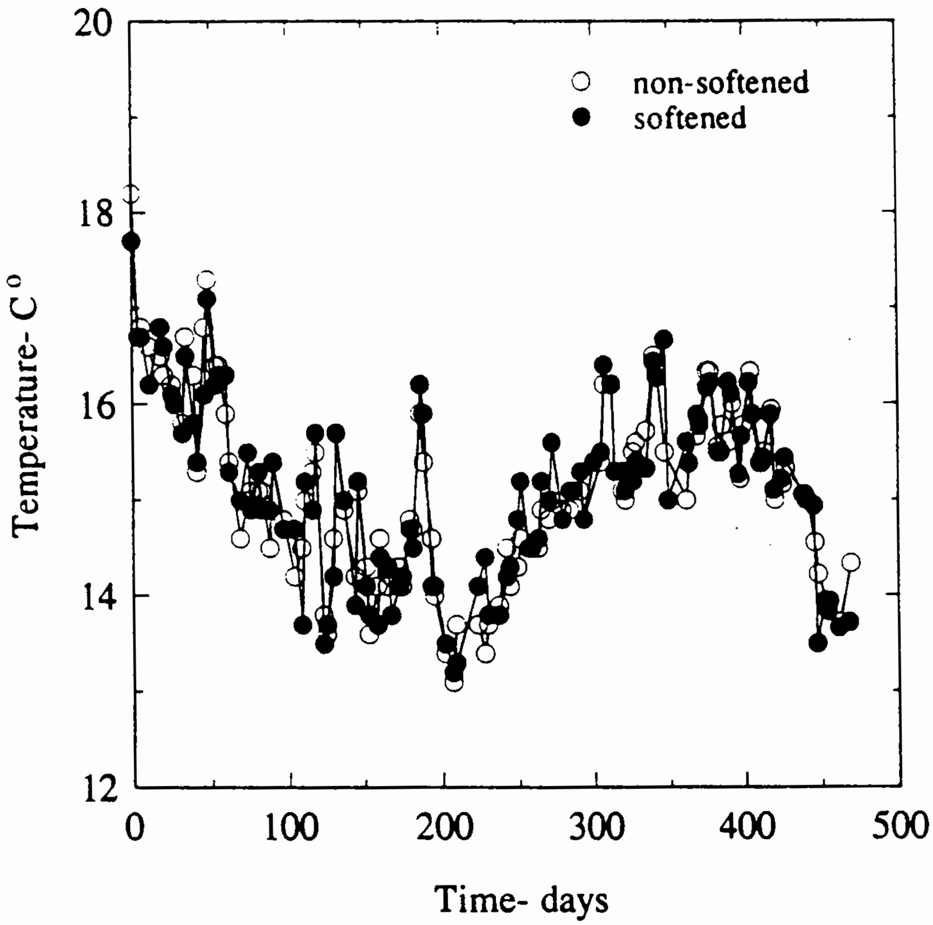

Figure 4. Temperature of the unsoftened and softened water.

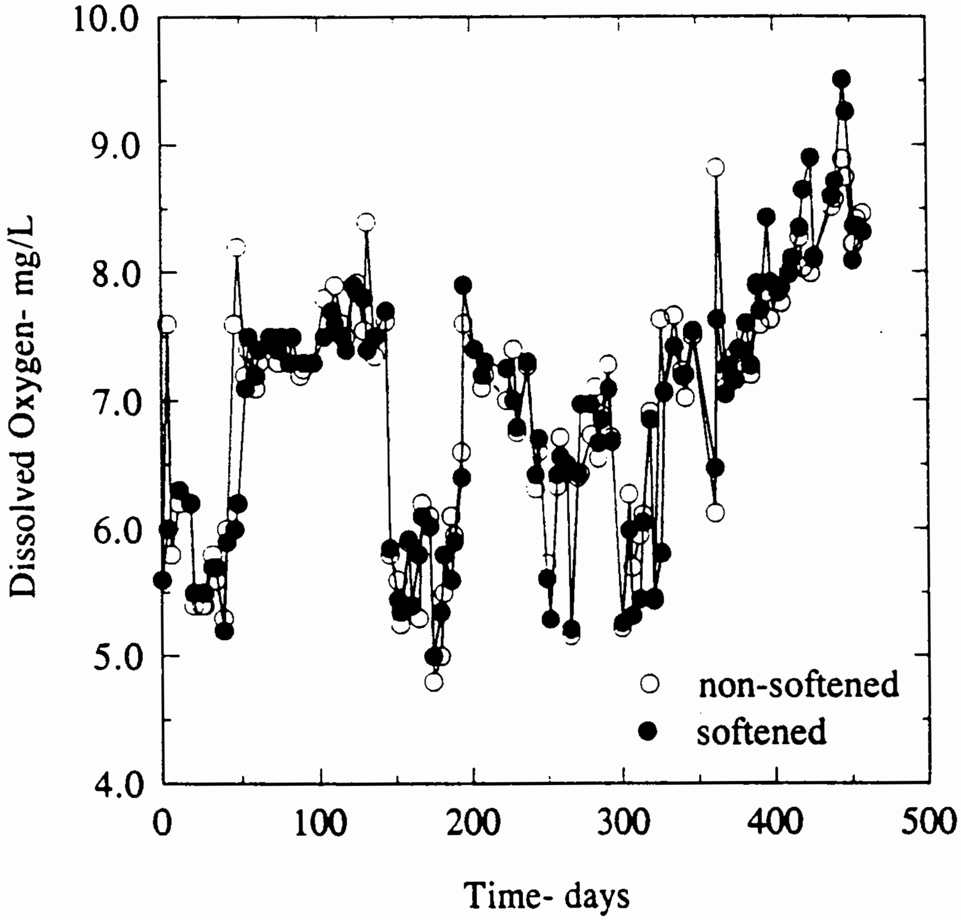

Figure 5. Dissolved oxygen concentration of the unsoftened and softened water.

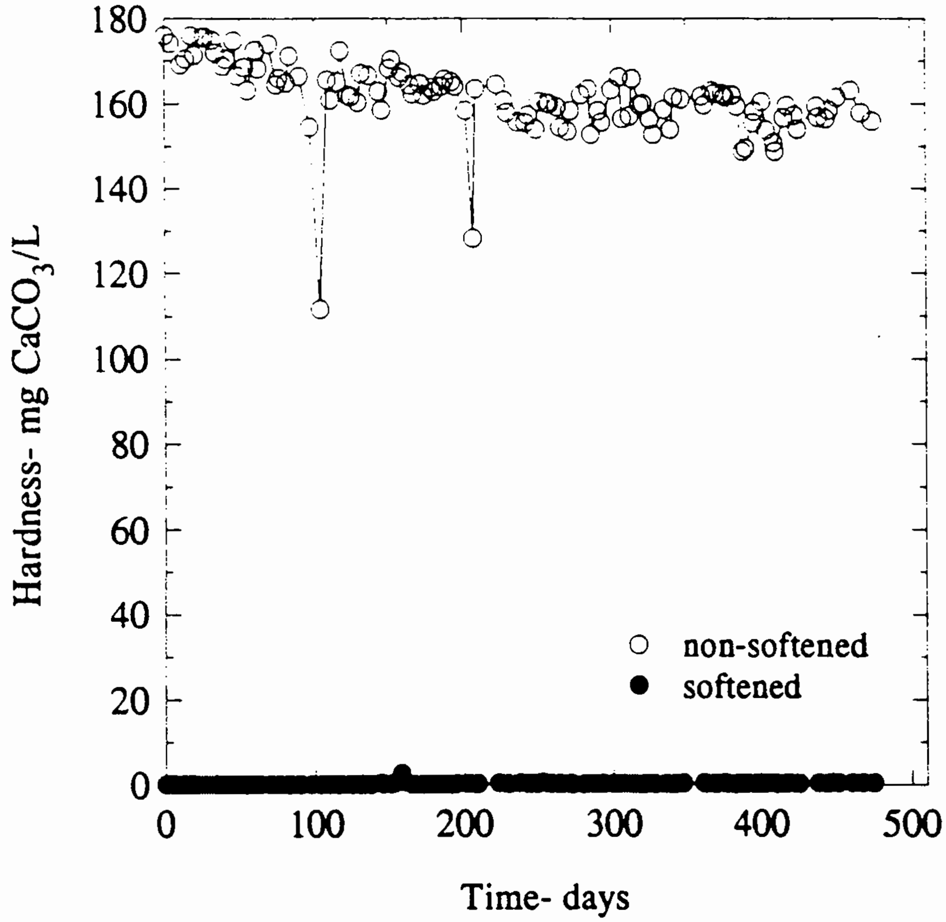

Figure 6. Hardness concentration (as $CaCO_3$) of the unsoftened and softened water.

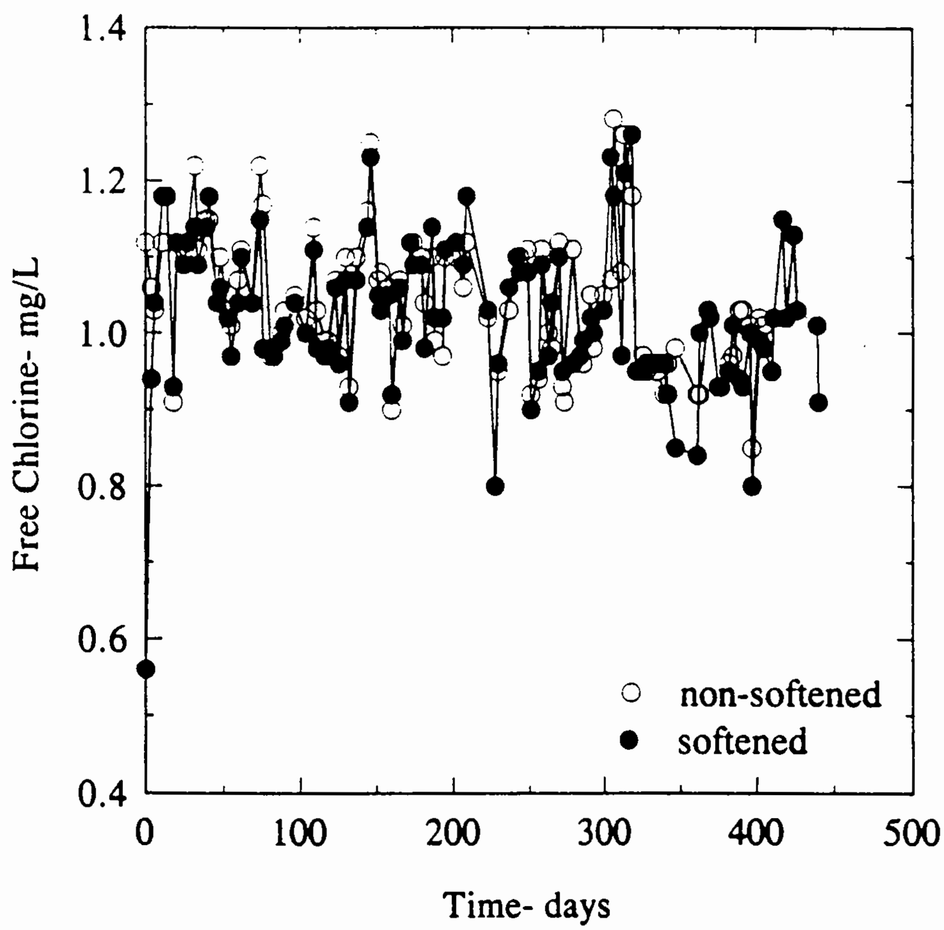

Figure 7. Chlorine (total) concentration of the unsoftened and softened water.

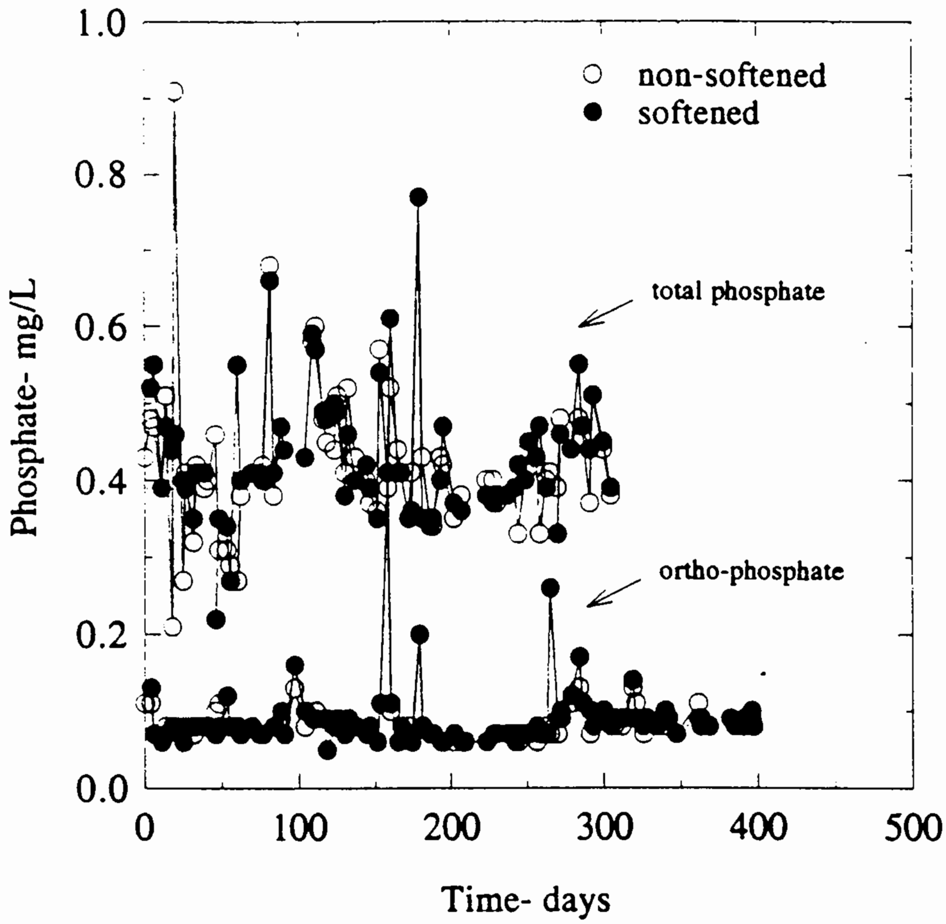

Figure 8. Total and ortho-phosphate concentration of the unsoftened and softened water.

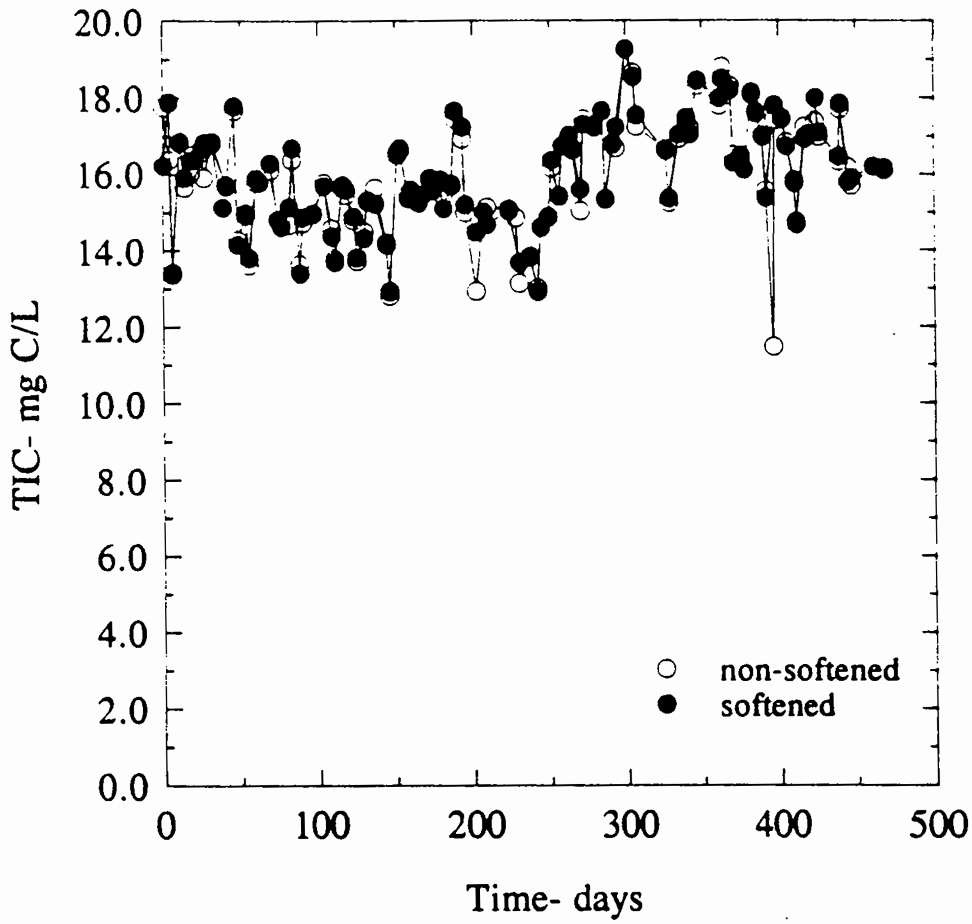

Figure 9. Total inorganic carbon of the unsoftened and softened water.

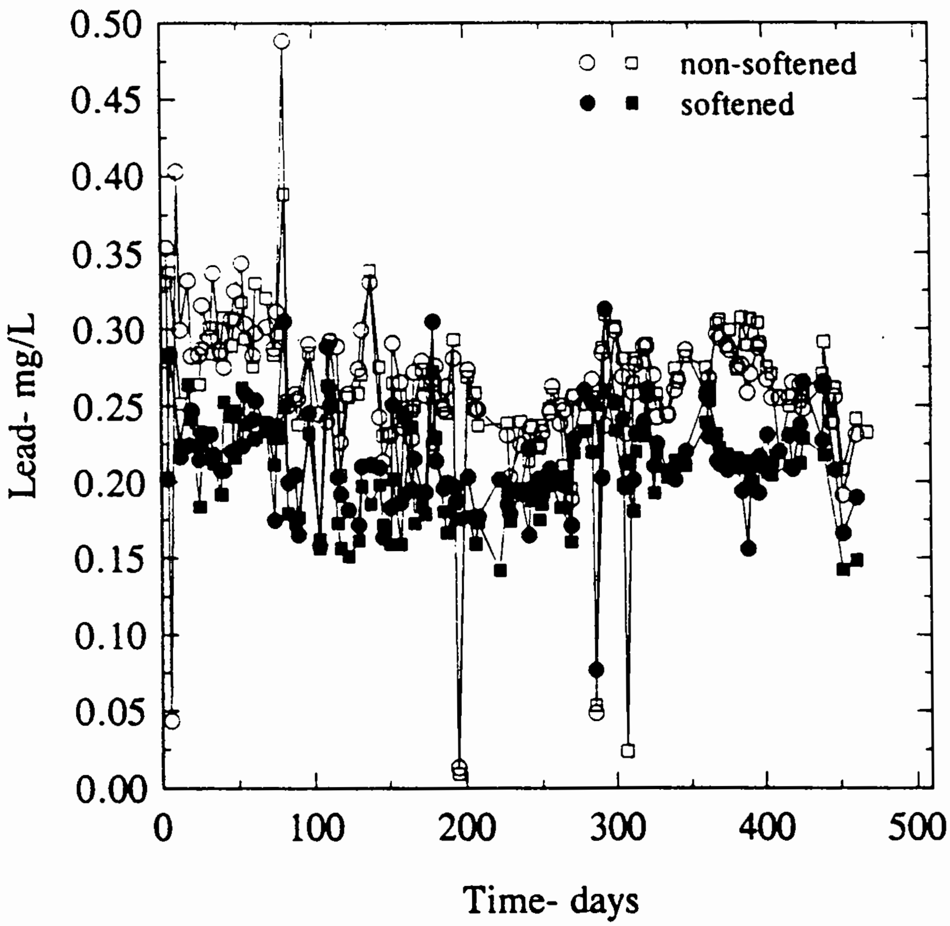

Figure 10. Lead leached from lead-pipe loops.

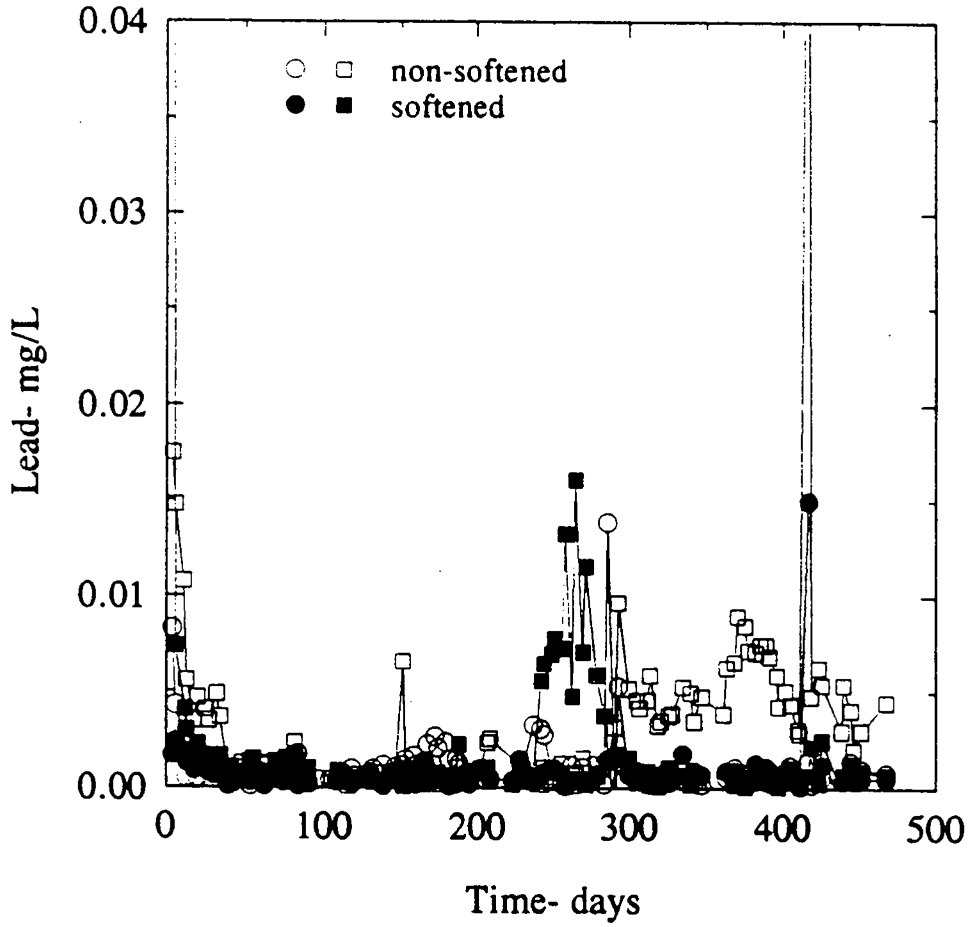

Figure 11. Lead leaching from copper/solder pipe loops.

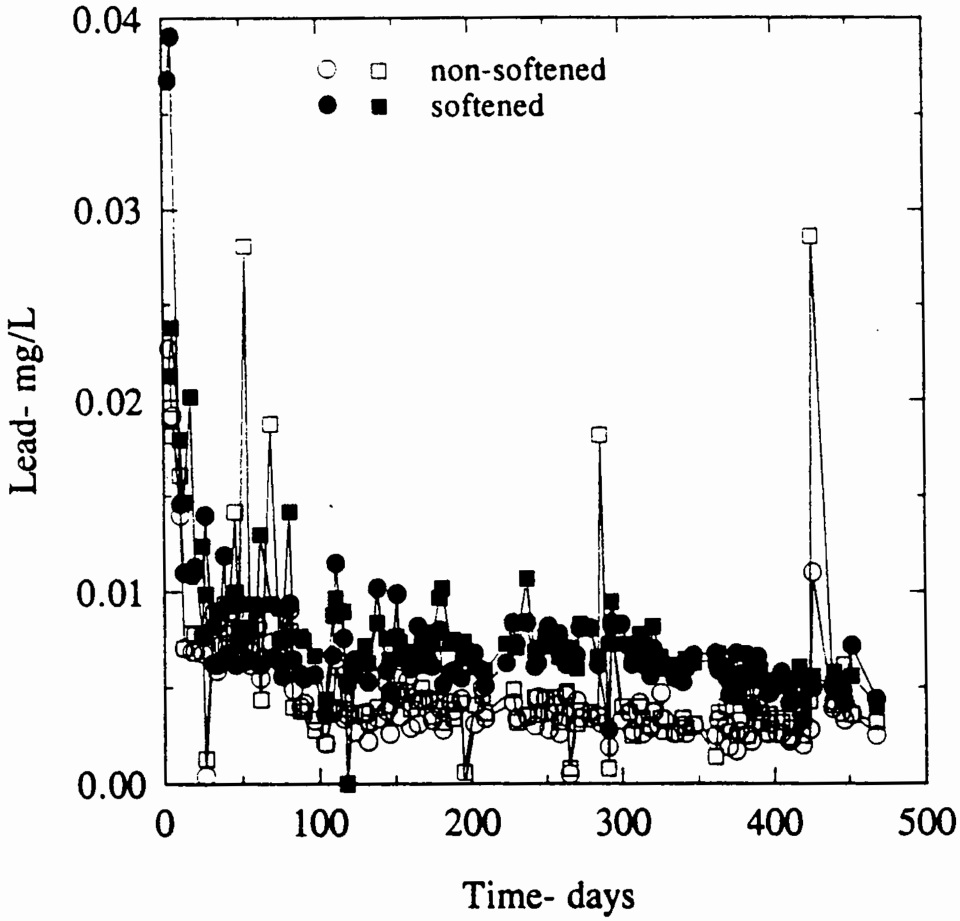

Figure 12. Lead leached from brass faucet loops.

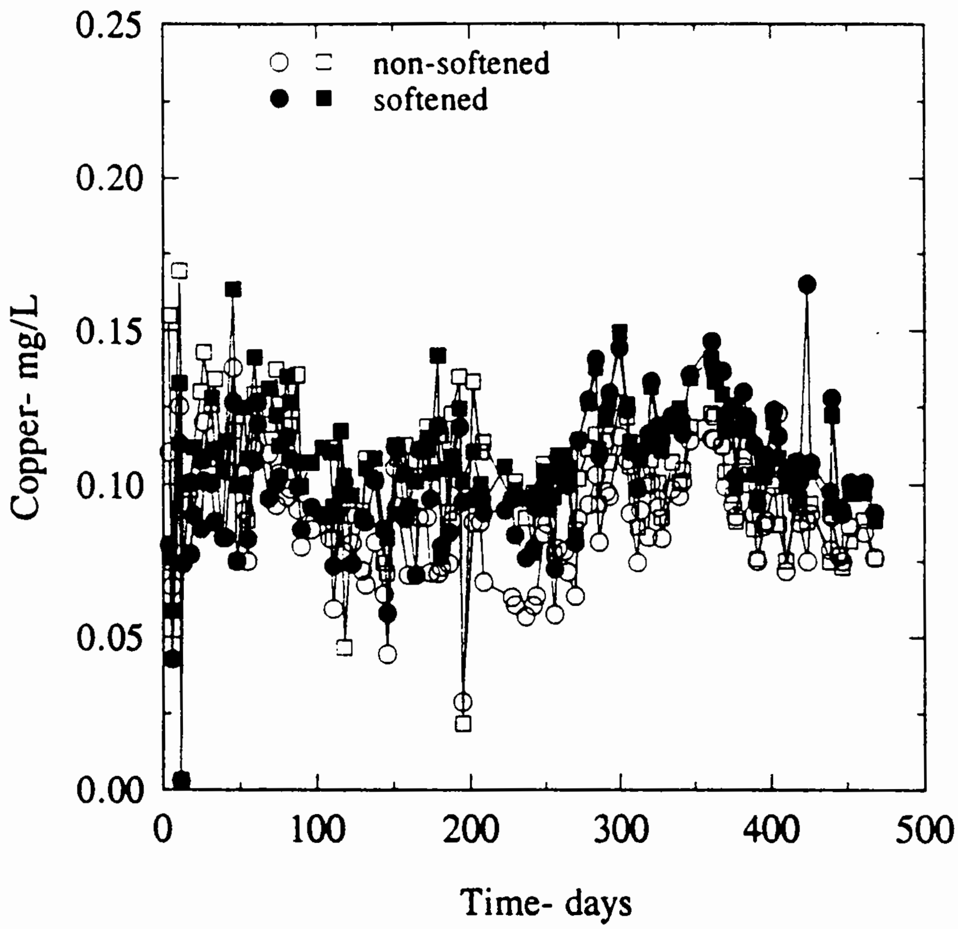

Figure 13. Copper leached from copper tubing loops.

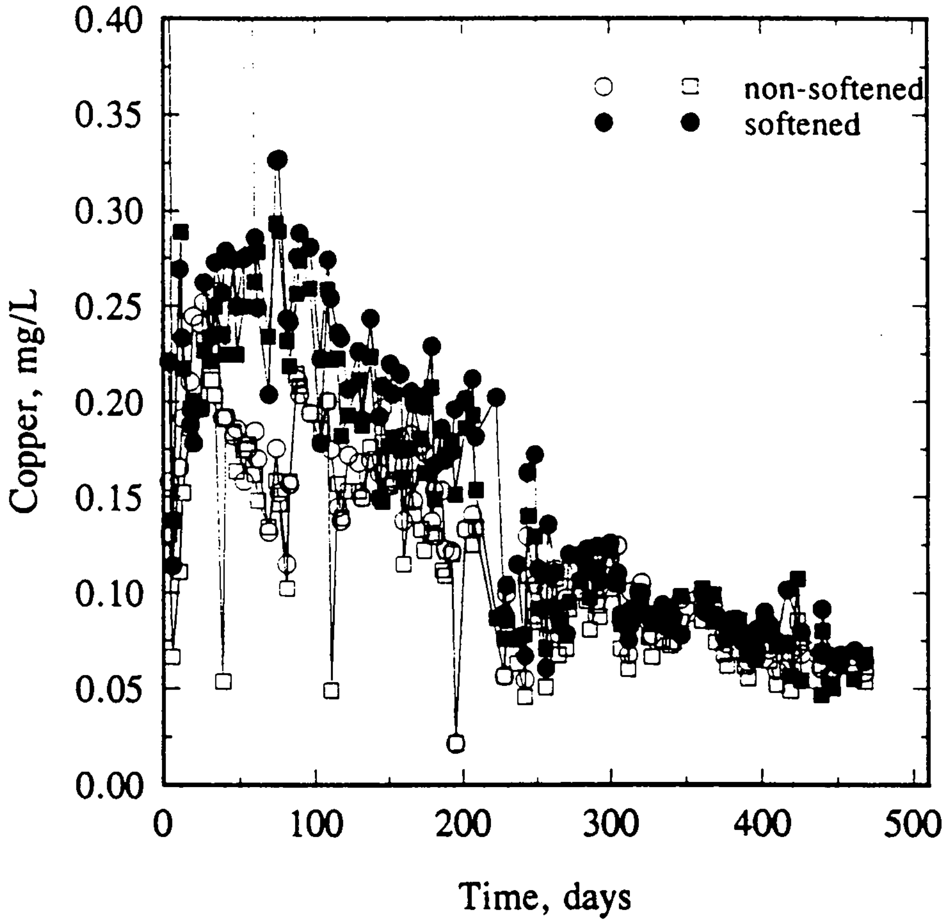

Figure 14. Copper leached from copper/solder pipe loops.

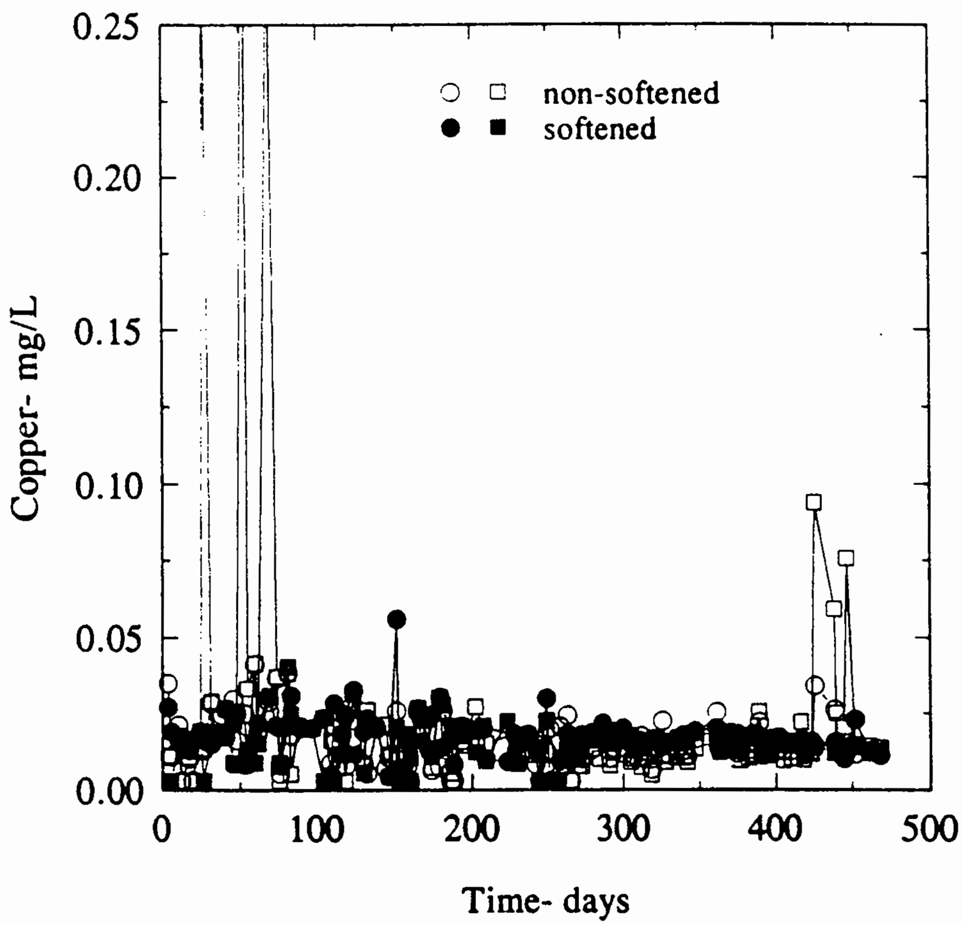

Figure 15. Copper leached from brass faucet loops.

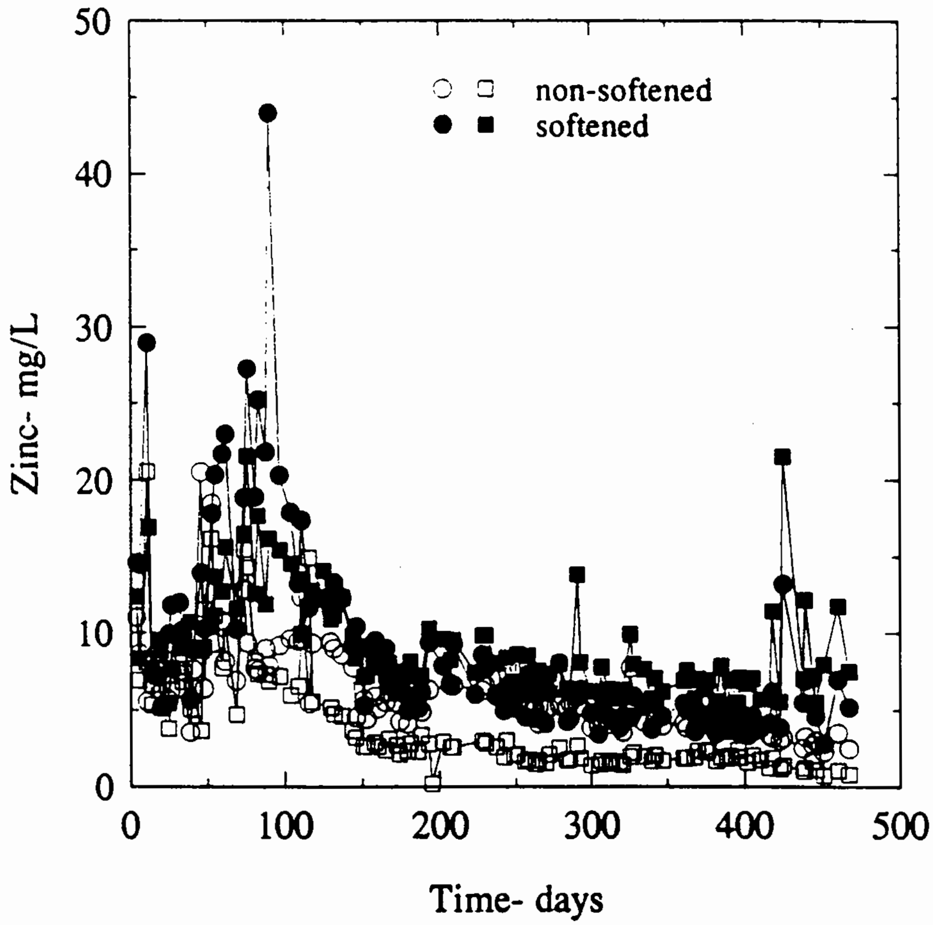

Figure 16. Zinc leached from galvanized pipe loops.

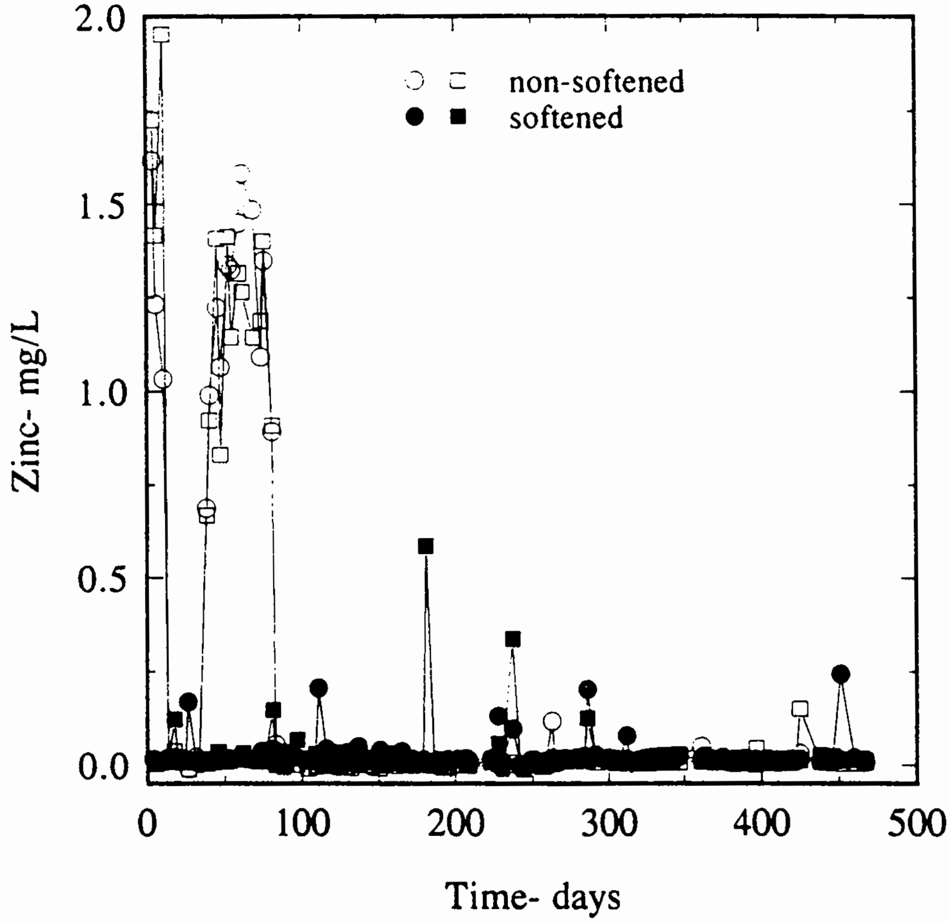

Figure 17. Zinc leached from brass faucet loops.

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7. AUTHOR(S) Thomas J. Sorg, Darren A. Lytle, Michael R. Schock		8. PERFORMING ORGANIZATION REPORT NO.
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16. ABSTRACT
A 16 month pilot plant study was conducted to determine the effect of ion exchange softening on the leaching of metals from household plumbing materials. Two pipe loop pilot plant systems were assembled. Each system consisted of duplicate loops of lead pipe, copper pipe with 50:50 lead-tin soldered joints, copper tubing, galvanized pipe, and brass faucets. The source water had a pH of about 9 and a hardness of about 160 mg/L as $CaCO_3$. One system (control) was fed non-softened water and the second system (test) ion exchange softened water. Water samples were collected from each loop, twice a week, for 16 months. The metal leaching results of lead, copper, and zinc indicated that there was no consistent pattern of higher metal levels from the softened water leading to the general conclusion that the softened water was not more corrosive to the plumbing materials than the non-softened water with the water quality used for this study.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Corrosion Ion Exchange Softening Water Supply		

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