



Project Summary



Relationships Between Water Quality and Corrosion of Plumbing Materials in Buildings

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A study was conducted on the interrelationships of corrosion rates, metal concentrations, and water quality occurring within galvanized steel and copper plumbing systems. A comprehensive water sampling program was implemented to quantify the total metal concentrations and the major inorganic constituents found in standing and running water samples. Corrosion rates were measured by using the ASTM D2688 corrosion tester.

Lead, zinc, copper, iron, and manganese exceeded the MCL in 10.6% to 25.6% of the standing samples and in 2.2% to 16.0% of the running samples collected. Chrome-plated brass sampling valves were found to contribute significantly to the lead, zinc, and copper contents of the samples. Cadmium did not exceed 0.0005 mg/L in any sample. During the two years the sites were operating, significant water quality variations were noted in the six public water supplies investigated. Multiple linear regression analyses of the data were unsuccessful because of the exceedingly large numbers of variables encountered under uncontrollable field conditions.

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

Introduction

Corrosion has been a long-standing and serious problem in public water supply distribution systems. The potential health effects of corrosion led to federal regulations establishing maximum contaminant levels (MCL's) for certain metal concentrations in drinking water. The regulations state that water supplies should be noncorrosive to all plumbing materials. Though some researchers have attempted to identify or predict which waters are corrosive, none have found a universally acceptable identification method that considers all piping materials and conditions of exposure. Some of the controversy in establishing the Secondary Drinking Water Regulations was in defining noncorrosive water and acceptable methods for determining the corrosivity of water.

Two materials that have found widespread use in plumbing systems are copper and galvanized steel pipe. Experience has shown that both materials offer good corrosion resistance to drinking water when the materials are properly selected and installed. However, many corrosion failures have been documented for both copper and galvanized steel piping. The impact of these corroded materials on water quality has not been adequately investigated. Brass valves, lead-based solders, bronze meters, and other fittings associated with copper and galvanized steel also make significant contributions to soluble or

particulate metal concentrations in drinking water.

The ASTM D2688, Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Methods), Method C was developed by the Illinois State Water Survey (ISWS) in 1955 and has been used extensively in state facilities. The method has been a reliable indicator for corrosion and/or scale deposition, and it has been used primarily to indicate the effectiveness of various water treatment programs. Attempts were made by the ISWS to correlate the mineral content of the water supplies with the observed corrosion rates for copper and galvanized steel. The correlations met with only limited success because important chemical parameters were not determined or evaluated.

Complete water chemistries are required for many water supplies if significant correlations are to be found between the water quality parameters and the corrosion rates of metals. Both corrosion-inhibiting and aggressive influences have been reported for various constituents of drinking water. The chemical constituents commonly cited as influencing the corrosivity of water are calcium, alkalinity, pH, carbon dioxide, sulfate, chloride, dissolved oxygen, silica, temperature, and dissolved solids. Other constituents, such as chlorine, organics, and polyphosphates, are also suspected to influence the corrosivity of water. Interaction among the various influences can be observed only by prolonged, complicated laboratory testing or by determining the corrosivity of water in real distribution systems.

Project Objectives

The principal objective of the corrosion study was to determine the influence of various water quality characteristics on the corrosion rates of galvanized steel and copper pipe specimens installed in the potable water systems of residences and large buildings. A second objective was to monitor the trace metal concentrations contributed by galvanized steel and copper plumbing materials to the drinking water.

Methods

Because of cost limitations, the investigation was limited to six public water supplies in Illinois representing both groundwater and surface water sources. Each water supply used various water treatment methods that included lime

softening, ion-exchange softening, polyphosphate, and silicate programs.

The 19 corrosion test sites selected for the study were located in different sections of the distribution system of each water supply. A planned-interval corrosion test was considered the best procedure for evaluating the effects of time and water corrosivity on the corrosion of metals. Corrosion specimens prepared according to ASTM D2688, Method C, are easily adapted to the planned-interval method of evaluation. Installing two of the ASTM corrosion test assemblies (each containing two corrosion specimens) at each test site, and replacing each of the specimens in turn with another specimen at 6-month intervals during the corrosion study provided seven weight loss measurements, each representing a different period during the study. The use of duplicate specimens was considered and would have provided useful information, but the additional plumbing and handling costs prohibited their installation.

Total zinc, copper, lead, iron, manganese, and cadmium concentrations were determined for both flowing and non-flowing samples collected from taps in the buildings where corrosion test sites were located. Water samples were collected for a complete chemical analysis at 2-week intervals throughout the corrosion study. To evaluate the reliability of the data and to improve the accuracy of interpretation, additional studies were performed at some of the sites to assess the rates of polyphosphate reversion, the contribution of metals associated with suspended particulates to the total metal load, and the contribution of the chrome-plated brass sampling taps to the observed metal levels.

On completion of the data collection phase of the corrosion study, the water quality, corrosion, and trace metal data were evaluated by a multiple linear regression method in an attempt to identify significant factors influencing the corrosivity of water.

Sample Collection and Analysis

Sampling procedures were demonstrated, documented, and standardized before the study began because ISWS field personnel were responsible for sample collection at only five sites. These experts visited the remaining sites every 6 weeks to monitor compliance with the specified procedures.

At corrosion test sites located in homes or buildings, water samples were collected from the cold water tap before early morning use. The simulated corrosion test loops were regulated with times and solenoid valves to enable sample collection at convenient times and to control the running and standing intervals.

Water samples were first taken from the sampling tap immediately following the galvanized pipe loop to preserve the nonflowing conditions in the copper section.

At all corrosion test sites, water samples were collected from a chrome-plated brass faucet or service tap. Screen filters were removed from the faucets before sampling. The first 50 to 100 mL of water was collected from the tap for a temperature measurement of the nonflowing sample. The next 125 mL of water drawn from the tap was collected in a 125-mL polyethylene bottle containing 2.5 mL of 1:1 nitric acid for use in determining the metal concentrations of the standing water in the test loop.

The sampling valve was then opened to allow approximately 0.5 gpm of water to flow to waste until the water temperature appeared stable and representative of the distribution water. The temperature of the running sample was recorded, and a second 125 mL of water was collected in a polyethylene bottle containing nitric acid. This second sample was for use in determining the metal concentrations of the flowing water. Two polyethylene sample bottles (one 125-mL and one 500-mL, each containing 1 mL of concentrated sulfuric acid) and a glass vial for TOC analyses were filled with the flowing water from the tap.

Free and combined residual chlorine and pH measurements were made on the running water after the samples were collected. Every 6 weeks, dissolved oxygen was analyzed in the field as well. The electrometric pH value, residual chlorine concentrations, temperature, and meter reading were then recorded on a prepared form for enclosure with the sample bottles.

Styrofoam-insulated cartons containing two ice packs were used to ship water samples to the laboratory. Water samples from some corrosion test sites were shipped by 1-day express delivery services. Samples from the remaining test sites were delivered directly to the laboratory by ISWS or utility sampling personnel. The water samples were

refrigerated until time of shipment if delays were experienced.

Upon receipt of the water samples in the laboratory, the 500-mL unpreserved samples were filtered and immediately analyzed for alkalinity. When two sites were located in tandem, only one of the unpreserved samples was taken for analysis because of time and cost constraints. Every tenth sample (as received) was split into duplicates to use as precision quality controls.

Analyses for trace metals (iron, zinc, manganese, copper, lead, cadmium), major cations (calcium, magnesium, sodium, potassium), and major noncarbonate anions (chloride, sulfate, nitrate) were performed by the Analytical Chemistry Unit of the State Water Survey.

Analytical rechecks of suspicious anion values were performed with somewhat different procedures to verify freedom from interferences. Quality control checks included visual inspection of analytical reports, ion balance computations, submission of U.S. Geological Survey (USGS) and U.S. Environmental Protection Agency (EPA) reference standards as knowns and unknowns, and use of the aforementioned split samples.

Some special studies were conducted to determine whether the trace metal levels were attributable to particulate material or to dissolved species. The study was complicated by the inability to separate the metal contribution from the sampling taps, and definitive conclusions could not be drawn.

Data Evaluation Methods

Following checks of analytical accuracy and internal consistency, the analytical data for the major ionic constituents (plus silica) were put into the WATSPEC3 computer aqueous equilibrium chemistry speciation model to compute the saturation states of several important film-forming solids, aggressivity parameters such as Larson's ratio (chloride plus sulfate to bicarbonate), and the free CO₂ concentration. The program makes corrections for complexation and ion pairing of major water constituents. The absence of analytical speciation and thermodynamic data for polyphosphate species made many of the computations inaccurate for the polyphosphate-containing systems. Thus they were not included in the overall water chemistry data base.

The weight losses and calculated corrosion rates for the ISWS tester coupons were entered in a separate data

base to be accessed by computer programs that would find water quality/corrosivity relationships.

The following three statistical evaluations were performed by using the statistical analysis system (SAS) on the University of Illinois IBM 4341* computer:

1. The relationship of the trace metal concentrations at each site to the independent variables (major constituents and physical parameters such as temperature and velocity) at each site.
2. The relationship of the trace metal concentrations to the independent variables among all the sites.
3. The relationship of the measured weight losses of the test pipe specimens to the measured water quality variables among sites.

Various stepwise linear regression and general linear model analyses were performed on untransformed data, but significant correlations were not observed. Regressions were not performed for cadmium, iron, and manganese. All cadmium concentrations were at or below the analytical detection limit. Many source waters contained considerable iron, so its presence could not be attributed to corrosion. Manganese is not a significant component of any of the piping materials.

Additional Laboratory Studies

Three laboratory studies were conducted during the course of this project to determine the significance of some problems that were appearing in the chemical data. These involved investigations of (1) polyphosphate hydrolysis before sample analysis at four sites, (2) the contribution of zinc, copper, and lead from the chrome-plated brass sampling valves at two sites, and (3) the amount of trace metal (copper, zinc, iron, lead, cadmium) leaching into solution from chrome-plated brass taps exposed overnight to deionized or tap water.

To determine whether prior piping contamination of new chrome-plated brass sampling taps could be responsible for a significant part of the observed trace

metal levels, a new test faucet was installed before the water meter and test loop 306. A 125-mL standing water sample was initially taken at this location. After 97 days of operation, three successive 125-mL unfiltered samples were taken, and this procedure was continued through the end of the operation at this site. After 130 days the chrome-plated brass faucet was replaced with one of low-density linear polyethylene.

To further pursue the leaching from the chrome-plated sampling taps, a 2-week benchtop experiment was set up. Six new faucets were rinsed copiously with deionized water, inverted, and filled to capacity (approximately 20 mL) with either tap water or deionized water. The faucets were sealed with new silicone stoppers and mounted with finger clamps on a flexiframe stand in an inverted position until the next day. After samples were withdrawn, the silicone stoppers were rinsed with 1:1 HNO₃ and deionized water, the faucets were filled, and the stoppers were replaced. Water samples were taken on alternate days for either lead or cadmium, or zinc, iron, and copper.

Corrosion Testing Methods

The corrosion test assembly was reduced in size from 1 in., as specified by the ASTM D2688 method, to 0.5 in. to conform with the nominal pipe dimensions encountered in household plumbing systems. The smaller test assemblies successfully simulated the actual surface conditions found in a straight length of pipe where the flow of water is not distorted. Visual inspection of the corrosion specimens and the associated piping of the test loop after 2 years of exposure showed that the interior surfaces were identical in appearance. Construction details for the smaller test assemblies will be provided to ASTM for inclusion in ASTM Method D2688, Corrosivity of Water in the Absence of Heat Transfer. An estimate of procedure variability for the ASTM D2688 method is presented for the first time.

Results

Corrosion Data

The corrodibility of both copper and galvanized steel decreased during the 24-month exposure in the more aggressive public water supplies. This decrease is attributed to the formation of films that reduce the rate of corrosion. In less

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use

aggressive water supplies, the corrodibility of the metals remained relatively constant at low corrosion rates, indicating a slow development of surface films.

The weight loss data for galvanized steel specimens were more erratic than similar data for copper specimens. This result was attributed to the spotty nature of the surface film on the galvanized steel and to the uniform, continuous surface film on copper. The use of multiple specimens for each interval of exposure would have been beneficial in reducing the variance in the galvanized steel corrosion data.

For a single corrosion measurement to provide reliable information on the corrodibility of copper or galvanized steel in public water supplies, the minimum exposure period should equal or exceed 12 months for copper and 18 months for galvanized steel.

The weight loss data for copper corrosion specimens indicated that the Dwight Correctional Center water supply was the most aggressive. Here corrosion rates ranged from 3.6 to 1.4 milligrams per square decimeter per day (mdd) for 6- and 24-month exposure intervals, respectively. The distinguishing characteristics of this water supply were very high concentrations of chloride, sulfate, sodium, and (consequently) total dissolved solids.

Water from Springfield, Illinois, was the least aggressive toward copper materials, with corrosion rates ranging from 0.4 to 0.2 mdd for 6- and 24-month exposure intervals, respectively. This supply was characterized by a high pH, low alkalinity, high dissolved oxygen, high chlorine, and high nitrate content.

Champaign, Illinois, had the water supply that was least aggressive toward galvanized steel materials, with galvanized steel corrosion rates ranging from 0.6 to 0.9 mdd for all seven corrosion specimens. This water supply is a lime-soda-softened supply in which the Langelier index is maintained near +0.4 and mineral content is moderate in concentration.

The weight loss data for galvanized steel corrosion specimens indicated that the City of Carbondale, Dwight Correctional Center, and City of Dwight water supplies were equally aggressive toward galvanized steel. Corrosion rates ranged from 6.3 to 2.8 mdd for 6- and 24-month exposure intervals, respectively. The galvanized steel weight loss data must be evaluated with caution, as the cor-

rosion of the zinc surface was not uniform and accounted for a large variance in weight loss data for galvanized specimens.

The corrosivity of the water supplies (evaluated by the planned interval test method) did not change significantly as a result of major fluctuations in water quality of short-term or cyclic nature. The varying concentrations of several chemical constituents known to influence the corrosivity of water were apparently averaged out over the long exposure interval.

A change in the corrosion treatment program in the Carbondale, Illinois, water supply from a zinc polyphosphate program to a pH control program resulted in a pH increase from 7.0 to 8.3 and reduced the corrosivity of the water. The change in corrosivity was more significant for galvanized steel than for copper plumbing.

The corrosivity of the City of Dwight water supply decreased significantly during the last 18 months of the study. Total copper concentrations of samples collected from a copper plumbing system installed in this water supply also decreased, which confirmed the reduction in corrosivity. The reason for the decrease in corrosivity was not identified, and apparently it was due to one of the unknown factors influencing corrosion in public water supplies.

Copper tubing was susceptible to increased corrosion at water velocities exceeding 1.22 m/s. The increase in corrosion because of velocity was observed before the actual erosion of surface films and the exposure of bare metal occurred.

Copper corrosion rates were not influenced by stagnant water conditions in the Springfield, Illinois, water supply, but galvanized steel experienced an appreciably higher corrosion rate for the same exposure. Very low corrosion rates were observed for both metals under flowing conditions in this system.

Quality of Public Water Supplies

Significant variations in water chemistry occurred for the six water supplies studied, although each supply was originally conceived of as being stable in quality. A comprehensive chemical analysis of water samples collected every 15 days over a 2-year period was required to observe the real stability of the water supplies.

The variation in water quality was caused by changes in water treatment programs, changes in operational procedures, and unanticipated equipment failures. Excursions in water quality were observed to be both random and cyclic, with cyclic variations occurring at 3-day, monthly, or seasonal intervals. Random changes in water quality occurred when equipment failed or when a major change was made in the treatment program.

The surface water supplies experienced normal seasonal changes in chemical content and temperature. However, major fluctuations in water quality were observed in groundwater supplies using multiple wells when various wells were put into or taken out of operation. An increased sampling frequency is required to observe the cyclic fluctuations in water quality.

Water supplies with multiple sampling sites showed no evidence of a significant change of water chemistry within the distribution systems, although corrosion tests indicated a difference in corrosivity. At the Fox Developmental Center water supply, a microbiologically mediated change was presumed to slightly increase the nitrate concentration and reduce the phosphate concentration during the filtration and softening process.

Variations in water quality appear to be commonplace in public water supplies. Change in water chemistry may adversely influence the corrosivity of the water supply and therefore should be controlled whenever possible.

Total Metal Concentrations of Samples

The maximum contaminant level (MCL) for iron was exceeded in 25.6% of the standing water samples and in 16.0% of the running water samples. Manganese exceeded the MCL in 14.5% of the standing samples and 11.6% of the running samples.

The naturally occurring iron or manganese content of the water source was observed to be more significant than corrosion processes or water quality in influencing the total iron or manganese concentrations in samples. The presence of polyphosphate in the water supplies was observed to complex both iron and manganese, maintaining the concentrations above the MCL in some supplies.

Cadmium concentrations were very low in all samples, both running and standing. Most samples were below the

minimum detection limit of 0.3 µg/L for cadmium. The MCL for cadmium was not exceeded by any sample collected during the study, with the maximum observed concentration being 4.8 µg/L cadmium.

The zinc, copper, and lead concentrations of the water samples were found to be associated with corrosion in systems containing either copper or galvanized steel plumbing materials, although multiple linear regression models were unable to identify any significant relationships between metal concentrations and water quality.

The MCL for lead was exceeded in 17.1% of the standing samples and in 3.1% of the running samples (Figures 1 and 2). The running samples exceeding the MCL for lead were collected from one galvanized and five copper plumbing systems. The corrosion of lead-tin solder and the brass sampling valves was responsible for the lead content of samples.

Copper concentrations exceeded the MCL in 10.6% of the standing samples and 4.5% of the running samples. Zinc exceeded the MCL in 11.8% of standing samples and 2.2% of the running samples.

The concentrations of copper, zinc, and lead in both standing and running samples generally decreased over the 24-month sampling period and approached an apparent mean concentration plateau around which the metal concentrations fluctuated. Before reaching the concentration plateau, the metal content fluctuated over a wide concentration range from sample to sample. The overall distribution of the trace metal concentrations appeared to be approximately log-normal rather than Gaussian.

In one water supply, the metal concentrations sharply increased during the latter stages of the study after apparently attaining stable concentrations. Similar observations have been made in Seattle, Washington, although the possible metal contribution by sampling valves was not considered.

The total metal concentrations in samples were influenced by other factors such as piping configurations before the sampling valve, quantity and rate of flushing before sample collection, and water quality.

Additional Laboratory Studies

In the polyphosphate hydrolysis study, substantial changes were observed in the concentration of orthophosphate over time at two of the sites examined.

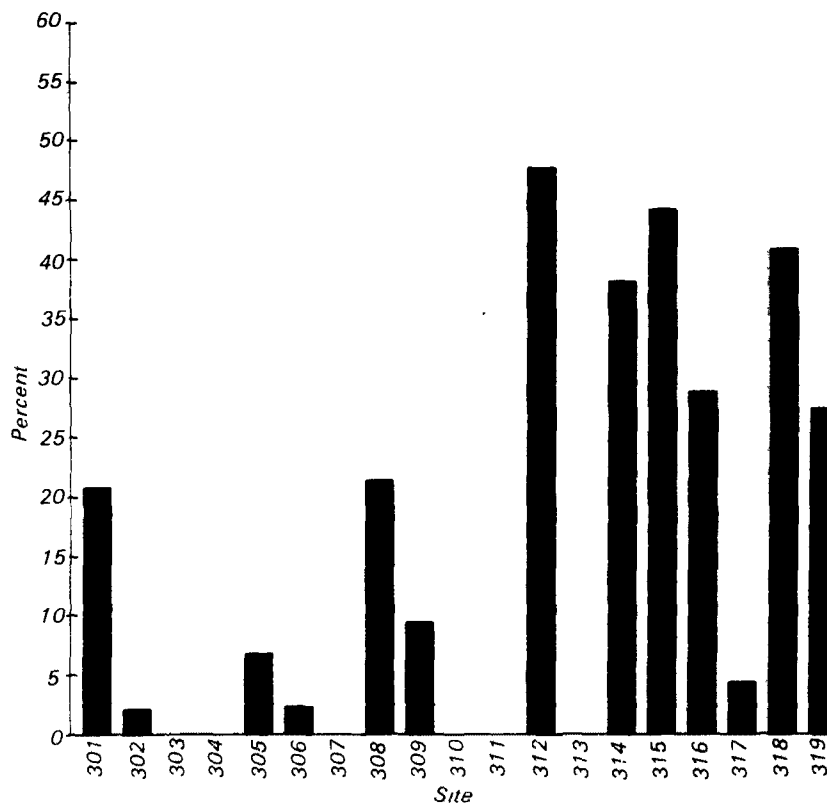


Figure 1. Percent of standing water samples exceeding the MCL for lead.

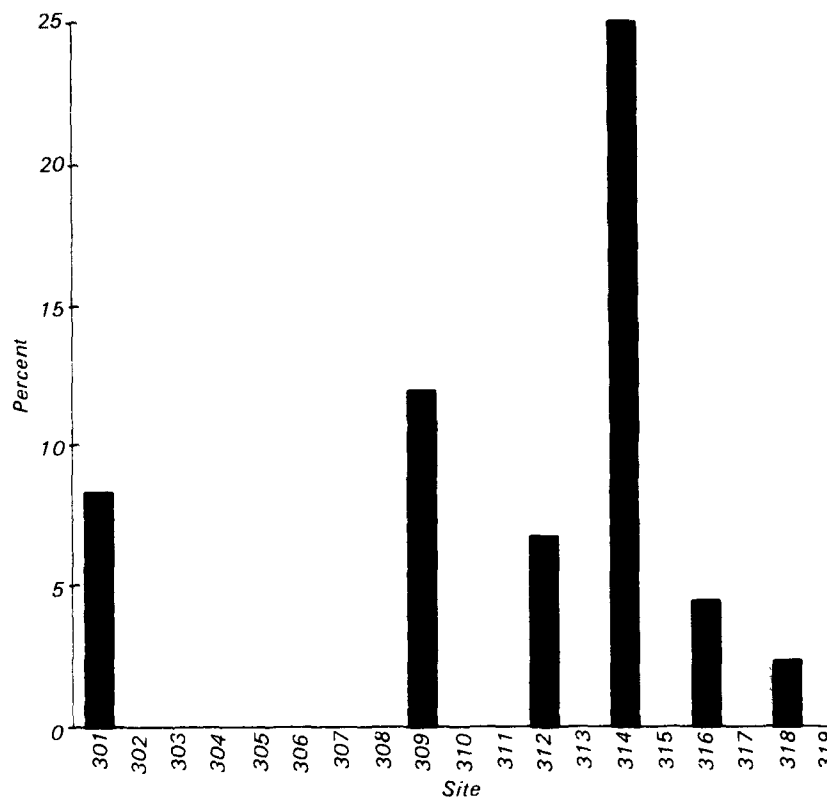


Figure 2. Percent of running water samples exceeding the MCL for lead

The conclusion reached was that the orthophosphate data from these sites are probably not very accurate. No quantitative correction could be applied to the data collected before or after discovery of the problem.

In the study of new faucets to determine whether old piping or new chrome-plated brass sampling taps were responsible for the observed trace metal levels, the data (Table 1) clearly show that the chrome-plated sampling tap contributed large amounts of lead and zinc and a somewhat smaller amount of copper and iron to the standing samples. The contamination decreased with time but was still considerable after more than 5 months. The elevated zinc values for the first 125-mL samples with the polyethylene faucet represent a contribution from the relatively new, short, galvanized section. These data are particularly enlightening because the low metal levels shown with the plastic tap corroborate the low corrosion rates measured in the weight-loss coupon tests. The metal levels obtained during the main portion of the study seemed unusually high compared with the measured corrosion rates. The low lead levels indicate insignificant contamination from the galvanized pipe coating.

Results from the 2-week benchtop experiment with new faucets showed that extremely high levels of lead were leached from the tap, even after 2 weeks. The MCL was exceeded by all samples taken. A small amount of cadmium was removed in the first equilibration from the taps containing Champaign tap water, but it was not detectable afterwards. More cadmium was removed by deionized water, and leaching was continuing at detectable levels after 2 weeks.

Iron leaching was odd in that more was generally taken into the tap water than the deionized water. As expected, there was considerable zinc leaching with both water types, although there was less from the faucets containing tap water. The leaching of copper was similar in the two water types and showed a fairly consistent level after about 4 days.

These experiments conclusively demonstrated that chrome-plated brass sampling taps can be a considerable source of readily leachable lead and zinc, when lead solder, lead pipes, and galvanized pipes are not present. The use of such materials might constitute a health risk under some conditions, and they can render data from corrosion studies such as this difficult or impos-

sible to interpret in a framework of relating analyzed metal levels to corrosion rates, mechanisms, or pipe solubility.

Conclusions

Public water supplies experience variations in water quality that may affect the corrosion of plumbing materials and the concentration of trace metals found in drinking water. Statistical analyses of the water quality and corrosion data failed to identify any meaningful relationships because of the variation in quality. There are more factors and interrelationships affecting corrosion than can be taken into account by simple statistical regression models. Controlled laboratory studies are necessary for pursuing correlations between water quality, corrosion rates, and trace metal concentrations.

Corrosion of plumbing materials was responsible for the lead, copper, and zinc concentrations found in drinking water. Iron and manganese concentrations were primarily derived from naturally occurring substances in the source. Application of polyphosphate to the water supply complexed both iron and manganese and may have partially solubilized corrosion products of lead, copper, and zinc. Cadmium concentrations were not significantly influenced by the corrosion of galvanized steel or copper plumbing materials. Chrome-plated brass valves, commonly used for sampling, contributed significant quantities of lead, copper, and zinc to water, particularly in standing samples. The corrosion of lead-tin solder in copper plumbing also contributed to the lead content of drinking water as reported in previous studies; however, the contribution of lead by common household faucets may not have been recognized or differentiated in past studies. Lead, copper, and zinc concentrations exceed the MCL in samples collected from new plumbing systems at a greater frequency than MCL's are exceeded in older systems. In more aggressive waters, the metal concentrations of water from new plumbing decrease gradually for several months before reaching a minimum concentration plateau. In a few instances, the metal concentrations exhibited an initial decrease, followed by a gradual increase which eventually exceeded the initial concentrations. Proper flushing of plumbing prior to use will reduce the occurrence and concentration of trace metals in drinking water.

Corrosion rate measurements, made by using the ASTM D2688 corrosion testers and the planned interval test method, were effective in assessing the corrosivity of the water and the corrodibility of exposed plumbing materials. Under controlled field conditions, the procedures provided reliable information on the effects of treatment and changes in water quality on corrosion rates during long-term (>6-month) test intervals. Short-term variations in treatment of water quality are not detected by the testing procedures used in this study.

Recommendations

1. A standard procedure should be adopted for determining and reporting corrosion measurements in public water supplies. The planned interval test method, which compares the weight loss of specimens over various time frames, is the ideal approach for detecting significant changes in the corrosivity of potable water. The conversion of weight loss values to corrosion rates assumes a linear relationship with time. Such conversions are applicable in controlled environments where the corrodibility of a metal is of interest. Satisfactory weight loss measurements are obtained by the ASTM D2688 method for either purpose, but multiple corrosion specimens are recommended for each test interval.
2. A procedure should be developed to produce instantaneous measurement of corrosion rates and to detect short-term variations in the corrosivity of public water supplies.
3. The trace metal content of drinking water was strongly influenced by abnormalities in the sampling process; sampling protocols should therefore be developed to meet the specific requirements of environmental health studies, corrosion studies, or water quality studies.
4. The impact of brass, bronze, and other copper alloy plumbing materials on the trace metal content of drinking water should be given high priority in future studies. Chrome-plated brass faucets were found to be a major source of lead, copper, and zinc concentrations found in the public water supplies.

Table 1. Metal Concentrations (mg/L) in Successive 125-mL Unfiltered Standing Samples from the Sampling Tap Installed Before Site 306

Date	Elapsed Days	Zinc			Copper			Lead			Iron		
		1	2	3	1	2	3	1	2	3	1	2	3
3/8/83	1	1.30	--	--	0.73	--	--	0.099	--	--	0.11	--	--
4/6/83	30	0.99	--	--	0.31	--	--	0.056	--	--	0.03	--	--
4/14/83	38	2.09	--	--	0.18	--	--	0.059	--	--	0.28	--	--
4/21/83	45	2.66	--	--	0.77	--	--	0.060	--	--	0.93	--	--
5/3/83	57	2.08	--	--	0.06	--	--	0.031	--	--	0.29	--	--
5/14/83	68	1.98	--	--	0.07	--	--	0.075	--	--	0.32	--	--
5/24/83	78	0.65	--	--	0.29	--	--	0.021	--	--	0.09	--	--
6/13/83	98	1.10	0.41	0.48	0.04	0.03	0.04	0.030	0.011	0.008	0.42	0.07	0.10
6/22/83	107	1.01	0.42	0.30	0.06	0.03	0.04	0.019	0.008	0.005	0.36	0.06	<0.06
6/27/83	112	0.75	0.28	0.26	0.08	0.02	0.04	0.015	0.005	0.004	0.52	0.06	<0.07
7/12/83	127	0.68	0.69	0.25	0.03	0.04	0.04	0.013	0.023	0.004	0.28	0.72	0.09
-----Plastic Tap Installed-----													
7/16/83	131	0.30	0.20	0.24	<0.01	<0.01	<0.01	0.001	0.001	0.001	0.12	<0.07	<0.07
7/21/83	137	0.22	0.16	0.14	<0.01	<0.01	<0.01	0.001	0.001	0.001	0.13	<0.07	0.07
8/5/83	151	0.35	0.26	0.22	<0.01	<0.01	<0.01	0.002	0.001	0.002	0.17	<0.08	<0.08
8/15/83	161	0.55	0.22	0.01	<0.01	<0.01	<0.01	0.001	0.001	0.001	<0.08	<0.06	<0.06
8/22/83	168	0.46	0.21	0.17	<0.01	<0.01	<0.01	0.001	0.001	0.001	<0.06	<0.06	<0.06

sampled. The factors influencing the trace metal content of drinking water contributed by these materials should be examined and identified.

A testing protocol should be developed to determine the leaching potential of metals from faucets delivering water for human consumption, and the faucets should be tested before marketing. A certification and testing program developed in Denmark may serve as a useful model.

5. The widespread application of various commercial polyphosphate chemicals to public water supplies should be critically examined. The benefits of polyphosphate usage have been well documented for sequestering iron and manganese, inhibiting mineral deposition, and controlling tuberculation in distribution systems. The potential health hazards from increased metal solubility and distribution system problems associated with the use of polyphosphate in public water supplies have not been adequately investigated, however.
6. Methods should be developed for preconditioning newly installed galvanized and copper plumbing systems to minimize the potential health risks associated with the consumption of water containing

excessive trace metal concentrations. The trace metal content of water samples from new systems decreases with time of exposure; however, the metal content may remain at high levels for several months after installation.

7. Extensive studies are needed to identify the interrelationships and unknown factors that influence the corrosion rate and dissolution of metals in public water supplies. Field studies were inadequate for this purpose because of an excessive number of known variables, unknown or missing variables, lack of control of the variables, and interactions among the many variables. Future studies should be conducted under closely controlled laboratory conditions where a few selected variables are examined at one time. As the basic chemical relationships are established, a general model could be developed and extended to systems of increasing complexity.
8. Further research is required to identify and quantify the minerals formed by corrosion or deposition on the surfaces of plumbing materials exposed to potable water. X-ray diffraction studies of the surface films would help explain the basic corrosion mechanisms responsible for the film formation,

and they would also help determine which water chemistry parameters are significant in the process of formation. This information would be useful for designing water treatment programs that would enhance the development of protective surface films.

- 9.. Further statistical analysis is recommended for the corrosion and analytical data presented in this report. Meaningful relationships between the chemical factors and the trace metal content of samples may have been obscured by the numerous variables evaluated by multiple linear regression analyses. The number of independent variables should be selectively reduced, and when variables are interrelated, only one should be evaluated. In this study, the most common independent variables found in models predicting the metal concentrations in water samples were temperature, chlorine, pH, silica, and nitrate. To a smaller extent, chloride, sodium, potassium, sulfate, magnesium, and alkalinity appeared in some models. These parameters should be considered for continued modeling studies.

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"Volume I. Galvanized Steel and Copper Plumbing Systems," (Order No. PB 87-192 548/AS; Cost: \$18.95)

"Volume II. Appendices," (Order No. PB 87-192 555/AS; Cost: \$18.95)

The above reports will be available only from: (costs subject to change)

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