

CORROSION CONTROL IN SMALL PUBLIC WATER SYSTEMS

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MIDWEST WORKSHOP FOR SMALL PUBLIC WATER SYSTEMS

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BACKGROUND

In December 1998, The Midwest Technology Assistance Center (MTAC) issued a Request for Proposal for a study "to address corrosion control in small public water systems." Specifically, the study was to "evaluate the effect of chlorine on small distribution systems that have not previously used chlorination for disinfection."¹

The impetus for this study came from two Federal drinking water regulations that apply to small public water systems. The first regulation, The Lead and Copper Rule, was implemented in 1991.² Small public water systems, which are defined as serving less than or equal to 3300 people, have been involved in sampling for lead and copper as prescribed by the Rule. At this time, the systems have either been shown to have optimal corrosion control or have implemented corrosion control techniques bringing them into compliance. The concern is for the effect of the second regulation, The Groundwater Rule, which was proposed in September 1999. The final rule will be implemented in November 2000.^{3,4} The Groundwater Rule will require all water systems to be reevaluated for disinfection needs. The majority of medium and large public water supplies already disinfect the water. A larger percentage of small public water supplies do not disinfect and will be most affected by this new regulation.

DILEMMAS OF WATER CHEMISTRY

The question arises as to if the introduction of chlorine as required by the Groundwater Rule will push a water system out of compliance with the Lead and Copper Rule and possibly affect other metals in the system.

The answer to the question is that three situations can occur by the introduction of chlorine to a water system:

- Chlorine can sometimes increase the corrosion rate in the system.
- It can sometimes decrease the corrosion rate.
- Or, sometimes, it has no significant effect.

Elaboration upon this answer leads small and large water utilities alike into a frontier of science that has yet to be adequately mapped. There are complex interrelationships between multitudes of factors that affect corrosion control in a system.

For example, the effect of chlorine addition on copper corrosion in soft drinking waters has been addressed by Sprague and Edwards.⁵ Their literature survey found that "chlorine has been observed to both increase and decrease the corrosion of copper in drinking water pipes." They cited studies where free chlorine concentrations were found to increase the dissolution of copper

especially at lower pH. They also cited studies where the free chlorine decreased the corrosion rate of copper at a high pH of 9.3. They then noted that the experiments described in the literature were short in duration and may not be representative of the phenomena occurring in a distribution system over a long period of time. Sprague and Edwards' own project ran for six months exposing copper tubing to chlorinated water at 0.7 mg/L and 2.0 mg/L as free chlorine. It was found that copper corrosion did not increase in the chlorinated water at pH 7.0 in comparison to unchlorinated water. It did significantly increase at pH 9.5. These findings are contrary to the previous studies because other factors (here, possibly pipe age) cause confounding results.

More factors to consider are the type of disinfectant used and the type of pipe material. A study where deionized water (that is, water with very low alkalinity and hardness) kept at a pH of 7.0 in contact with iron pipe showed that a 4 mg/L free chlorine residual was much more corrosive than an equivalent amount of monochloramine residual as a disinfectant.⁶

There is, in addition, the circle of events where free chlorine may cause corrosion and corrosion by-product buildup on the pipe wall. This, in turn, may provide an environment on the pipe wall for biofilm growth. It has been found in iron pipes that the corrosion by-products consume the free chlorine before it can penetrate the biofilm to destroy the microorganisms.⁶ With the reduced efficiency of the free chlorine as a disinfectant, higher doses of free chlorine might be used which would, in turn, might increase corrosion.

To break the circle, LeChevallier, et. al. found that implementing corrosion control techniques increased the efficiency of the free chlorine as a disinfectant.⁶ The researchers were most impressed with the addition of a polyphosphate blend for corrosion control. Using this chemical, they held the corrosion to a very low rate and found a biofilm inactivation of 2.0 log reduction of viable plate counts versus less than 0.5 for the same chlorinated water without polyphosphate addition.⁶

Other researchers do not like the idea of adding phosphorus in any form to a water system. Phosphorus addition was observed to consistently stimulate microbial counts.⁷ There are other nutrients found in water systems such as nitrogen, carbon, iron, and nitrate. However, phosphorus proved to be the limiting factor for microbial growth in a number of experiments.⁷

Then, there is the issue of using polyphosphate as a corrosion control chemical. It has been found that in some instances, polyphosphate can increase the concentrations of lead and copper in a water system instead of decreasing them. The factors where this detrimental phenomenon occurs have not been identified by scientific means. Therefore, the use of polyphosphates for corrosion control is risky.⁸

If a disinfectant is not added to the water, there exists a possibility of the growth of microorganisms in the system. Depending on the microbial species, the nutrients available, and the water chemistry, the microbes can greatly affect both pH and alkalinity.⁹ With a change in pH and alkalinity comes a change in the corrosive state of the water. Thus, the presence of microorganisms can cause increased corrosion in a water system. The remedy to this calls for the addition of a disinfectant. In this case, corrosion will be reduced by the addition of chlorine. Of course, there may be confounding factors . . .

Besides the factors mentioned above, other delicate balances of water chemistry exist involving pH, dissolved inorganic carbonate or alkalinity, dissolved oxygen, temperature, hardness, organic material, chloride, sulfate, nitrate, fluoride, ammonia, system flow patterns, and system configuration. Even the type of chlorine product added for disinfection can have either negative or positive effects on corrosion control.

THE MTAC CORROSION CONTROL PROJECT

SCOPE

Given the complex nature of corrosion control, a project was developed to demonstrate an accepted technique for exploring the nature of a given water system.¹⁰ The scope of this project was narrowed down to two major concerns expressed by the MTAC:

1. Characterization of the effects of chlorination on the test systems.
2. Characterization of the effects of introducing corrosion control techniques in the chlorinated water.

DESIGN OF EXPERIMENT

The first factors to be considered for the experiment were water quality parameters of which there are many. Past research has shown that alkalinity and dissolved inorganic carbonate come to the forefront as water quality parameters that greatly influence the corrosivity of water.^{10,11} For that reason, two sites were chosen in this project that differ in these concentrations.

At each site, it was desired to test the corrosivity of the untreated water and compare it to the corrosivity of the same water with chlorine added at the required disinfection dosage.

Three metals representative of typical residential plumbing materials were chosen to be exposed to the water -- lead, copper, and galvanized iron. Although lead piping has been banned in modern drinking water systems, some older systems remain in use. In addition, some older systems contain lead solder. The measurement of the leaching of lead into water also helps to compare the results of this study to past research.

Finally, it is desired to demonstrate corrosion control techniques. Available corrosion control techniques include pH adjustment, alkalinity adjustment, and addition of corrosion inhibitors.¹⁰ For hard, alkaline water, pH and alkalinity adjustment is not an option because excessive precipitation of calcium carbonate can occur and diminish the hydraulic capacity of the pipes.¹⁰ Operators with this type of system water typically add a corrosion inhibitor.

Corrosion inhibitors create a passivating film on the pipe wall. This is a film that inhibits the electrochemical processes resulting in corrosion.¹⁰ One such corrosion inhibitor, silicate, has not been greatly researched. Plus, systems using silicate take a long time to come to a steady state where conclusions can be drawn about the chemical's effectiveness. Therefore, it was not chosen to study in this project.

Many water systems use a phosphate compound as a corrosion inhibitor. Blends of poly- and orthophosphates are commonly used. As mentioned previously, some studies have shown that polyphosphates can actually increase the leaching of pipe metal into the water under certain conditions.^{8,10,11,12,13,14} Polyphosphates were not considered for this project.

Much success has been found with the use of orthophosphate as a corrosion control chemical for hard, alkaline water.^{8,15} An orthophosphate chemical was chosen to add into chlorinated water at the site with high alkalinity.

Orthophosphate has been found to be effective in lower alkalinity water also. However, in the interest of demonstrating a second corrosion control technique, pH adjustment using sodium hydroxide was chosen to add into chlorinated water at the site with lower alkalinity.

High and low alkalinity sites were chosen near Madison, Wisconsin. Lead, copper and iron pipe metals were tested under the three conditions: untreated (non-chlorinated) water, chlorinated water, and chlorinated water with potassium phosphate or sodium hydroxide added for corrosion control. Nine pipe loops were installed at each site. The experimental conditions for this study are summarized in Table 1. The data from all loops will be compared with one another using nonparametric statistical procedures described in the literature.¹⁶

Table 1. Experimental conditions of this study.

Run No.	Site	Chemical Treatment	Pipe Metal
1	High Alkalinity Site	Untreated Water	Lead
2			Copper
3			Iron
4		Chlorinated Water	Lead
5			Copper
6			Iron
7		Chlorinated Water with Potassium Phosphate Added for Corrosion Control	Lead
8			Copper
9			Iron
10	Lower Alkalinity Site	Untreated Water	Lead
11			Copper
12			Iron
13		Chlorinated Water	Lead
14			Copper
15			Iron
16		Chlorinated Water with Sodium Hydroxide Added for Corrosion Control	Lead
17			Copper
18			Iron

It should be noted that there are many factors in this type of experiment that cannot be controlled. For instance, the two sites differ in air temperature around the apparatuses and in system static and dynamic pressures. There are also constituents in the water at the two sites that cannot be compared or held steady. For this reason, data on many extraneous factors are being recorded. Later, analysis of variance techniques¹⁷ will be applied to the data to observe a given factor's influence. Nevertheless, on-site pipe loop studies cannot be construed as rigorous scientific research. They are useful for generating theories about the corrosivity of water. They are also useful in monitoring corrosion in an individual water system.

SITE SELECTION

As described above, the experimental design for this project calls for two sites with different concentrations of alkalinity and dissolved inorganic carbonate. With the help of the Wisconsin Rural Water Association and the Wisconsin Department of Natural Resources, two such sites were found

within fifty miles of Madison, Wisconsin. The Village Boards and the Water Utility Managers of the two sites have been quite hospitable to the project.

The site with hard, alkaline water is the Village of Dane (population 620) located twenty miles northwest of Madison. The project apparatus draws water from their distribution system which is a mixture of water from two wells. The utility does not chlorinate or fluoridate the water.

The site with softer, less alkaline water is the Village of Lone Rock (population 630) located fifty miles west of Madison. The distribution system is composed of two wells, but the project apparatus draws water from Well No. 2 only. The pump for Well No. 2 is set to turn on every evening at 10:00 PM and run for about two hours until the water tower is filled. The apparatus is set to turn on at 10:15 PM and run for one hour ensuring that water only flows through the apparatus when the well pump is running. The utility does not chlorinate but does fluoridate the water. The apparatus is tapped into the well pump discharge line upstream from the fluoride addition.

DESIGN, INSTALLATION, AND STARTUP OF APPARATUS

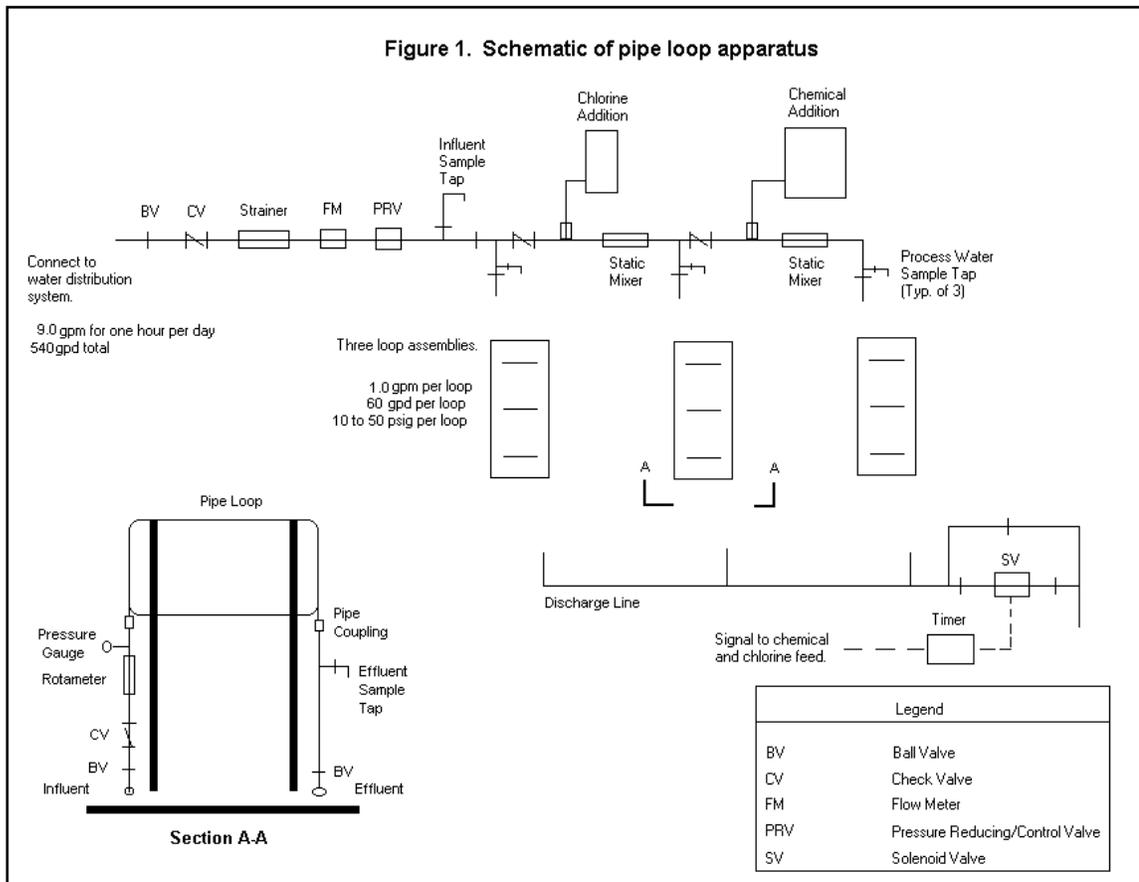
The apparatuses were designed similar to the AWWARF Pipe Loop Model.¹⁰ The AWWARF model is intended to simulate the plumbing of a residence.

One difference between the AWWARF model and this project's apparatuses is that the AWWARF model is designed for loops that can hold a liter of sample. This project uses loops that hold a little more than 250 mL of sample. The smaller loops are more economical and take up less space in this situation where nine loops are installed at each site.

Other differences with the AWWARF model involve the operating parameters of flow, pressure, and stagnation time. Because of site constraints, the flow in this project is 1.0 gpm per loop and 60 gallons per loop per day. The static pressure is 60 to 80 psig and the dynamic pressure is 10 to 35 psig. The flow and dynamic pressure values are at the lower end of the range that is seen in residential plumbing.

Because the apparatus at the Lone Rock site cannot operate unless the well pump is running, the experiment is restricted to operating only once for an hour a day. Typically, a pipe loop would be operated over a number of on and off periods throughout the day as is seen in a residence. This also implies that the water stagnation time in this project is 23 hours. The time that the water sits in the metal pipe loops effects the concentration of metal that is leached from the pipe into the water. At a later date in this project, stagnation time studies will be planned and data collected to look at the effects of stagnation time.

A schematic of the apparatuses is shown in Figure 1. Photos of the apparatuses installed at the two sites are shown in Appendix A.



The apparatus at the Village of Dane is installed in a heated maintenance building and garage. The building's three-quarter inch galvanized iron water line running across the ceiling has been teed off to supply water to the apparatus. The waste from the apparatus runs a short distance across the floor to a floor drain.

The apparatus at the Village of Lone Rock is installed in the Well No. 2 pump house. The apparatus is tapped into an existing three-quarter inch copper pipe that in turn is tapped into the discharge line from the well pump. The waste from the apparatus is piped to a floor drain with at least a two-inch air gap.

Three safeguards have been installed to totally separate the public water supply from the processed water in the apparatuses:

1. A backflow preventer is located immediately after the tap to the public water supply.
2. A series of check valves throughout the apparatus also prevents backflow.
3. All chemical feed pumps include anti-siphon devices.

Installation and startup activities occurred as follows:

1. August 17, 1999 – Installation at Village of Dane
2. August 24, 1999 – Installation at Village of Lone Rock
3. August 26, 1999 – Startup of both apparatuses
4. September 7, 1999 – First sampling at Village of Dane
5. September 9, 1999 – First sampling at Village of Lone Rock

6. September 14, 1999 – Second sampling at both sites; begin routine weekly sampling of both sites on Tuesdays.

SELECTION OF CHEMICALS

A chlorine residual of 0.2 mg/L is obtained in the experiment based on the U.S. Environmental Protection Agency's Proposed Groundwater Rule.¹⁸ The chlorine used is in the form of sodium hypochlorite with 12.5% available chlorine and a density of 10 lb/gal. The chemical was purchased from a local swimming pool supply store.

A dosage of orthophosphate of 1.0 mg P/L is obtained in the experiment based on optimum dosages discussed in the literature.^{15,19} The orthophosphate used is in the form of potassium orthophosphate with 27% total phosphate and a density of 12.7 lb/gal. The chemical was donated by the Carus Chemical Company.

A dosage of 50% sodium hydroxide was estimated using the RTW Model.²⁰ Estimated water quality parameters from the Lone Rock Well No. 2 water were entered into the RTW spreadsheet. A dosage of sodium hydroxide (caustic soda) was changed until a maximum desired calcium carbonate precipitation potential (CCPP) of 10 mg/L was reached. Care is being taken to not exceed a recommended CCPP range so that excessive calcium carbonate does not precipitate out and clog the pipe loop apparatus. At Lone Rock, the pH is adjusted from about 7.7 to 8.2. The chemical was donated by the Carus Chemical Company.

EXPERIMENTAL METHOD

The sample taps installed in 18 pipe loop apparatuses are summarized in Table 2.

Table 2. Summary of sample taps installed in a pipe loop apparatus.

Sample Tap	Site No.	No. of Taps
Influent	1	1
	2	1
Process Water	1	3
	2	3
Loop Effluent		
Lead	1	3
Copper		3
Iron		3
Lead	2	3
Copper		3
Iron		3

Samples taken from the sample taps during the study fulfill one of three goals:

1. Document influent water quality
2. Show that operational parameters are steady
3. Document the loop effluent metals concentrations and the factors that may effect them

The analyses performed per sample tap are summarized in Table 3.

Table 3. Sampling frequencies and water quality parameters measured.

Analysis	Influent	Process	Effluent
pH	w2	w6	w18
Temperature	w2	w6	w18
Residual Chlorine	q2	w6	
Total Phosphorus	q2	w6	
DO	q2		
TDS	q2	q6	
Calcium	q2		
Magnesium	q2		
Alkalinity	w2	w6	
Chloride	q2		
Sulfates	q2		
Manganese	q2		
Iron	w2		w6
Lead	w2		w6
Copper	w2		w6

Legend: w= weekly sampling; q=quarterly sampling; the number indicates the number of sample taps to be monitored.

As seen in Table 3, process control and effluent samples were obtained weekly. Most influent water quality samples were obtained quarterly. A set protocol was followed for the sampling routine.

ANALYSES

Water samples were analyzed using the methods summarized in Table 4.

Table 4. Analytical Methods per Standard Methods²¹

Analyte	Method
Alkalinity, Total	Titration Method 2320-B
Calcium	EDTA Titrimetric Method 3500-Ca D
Chloride	Ion Chromatography 4110
Chlorine, Residual	Hach Kit (Cat No. 46700-00)
Copper	Atomic Absorption (Frame Method) 3113-B
Iron	Atomic Absorption (Frame Method) 3113-B
Lead	Atomic Absorption (Graphite Furnace Method) 3113-B
Magnesium	EDTA Titrimetric Method 2340-C & 3500-Ca D
Oxygen, Dissolved	Azide Modification 4500-O C
pH	pH meter
Phosphate, Ortho	Ascorbic Acid Method 4500-P
Solids, Total Dissolved	Gravimetric 2540-C
Sulfates	Ion Chromatography 4110
Temperature	Thermometer

INTERIM RESULTS

This project is less than halfway completed. No conclusions should be drawn at this point based on the interim data. Results shown here have not undergone statistical analysis. Also, after twenty-one weeks of operation, the metals concentrations do not appear to have reached steady state. In addition, future stagnation curves of metals concentrations per hours of water/metal contact time will give more information about the nature of the corrosion observed in this experiment. Without the stagnation curves, maximum metals concentrations may not be observed and erroneous conclusions could be drawn.²²

WATER QUALITY PARAMETERS

Water quality characteristics of the two project sites are shown in Table 5.

Table 5. Water quality characteristic of project sites.

Parameter	Dane	Lone Rock	Units
Alkalinity	290	140	mg/L as CaCO ₃
pH	7.4	7.7	Standard units
Total Dissolved Solids	400	180	mg/L
Calcium	90	40	mg/L as Ca
Magnesium	40	20	mg/L as Mg
Temperature	15	15	Degrees C
Chloride	70	9	mg/L
Sulfate	30	20	mg/L

LEAD PIPE LOOP EFFLUENT CONCENTRATIONS

The concentrations of lead in the effluent of the lead pipe loops over twenty-one weeks are shown in Figure 2 for the high alkalinity site of Dane and Figure 3 for the low alkalinity site of Lone Rock.

At Dane, the influent temperature was 14 C while the loop effluent temperature after stagnation was 16 C. The chlorinated water had a concentration of 0.2 mg/L free chlorine. The phosphate was dosed at 1.2 mg/L as P. Figure 2 shows that the lead in the untreated water is high and is not dropping over time. Chlorine addition appears to decrease the lead concentrations. Phosphate addition to the chlorinated water does not produce a different effect than that observed with the chlorine addition alone.

Figure 2. Dane, Wisconsin: Lead Pipe Loops

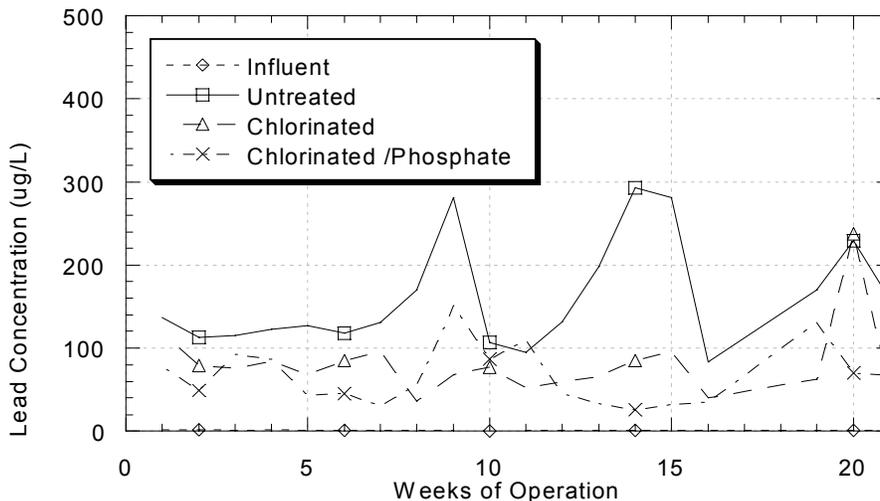
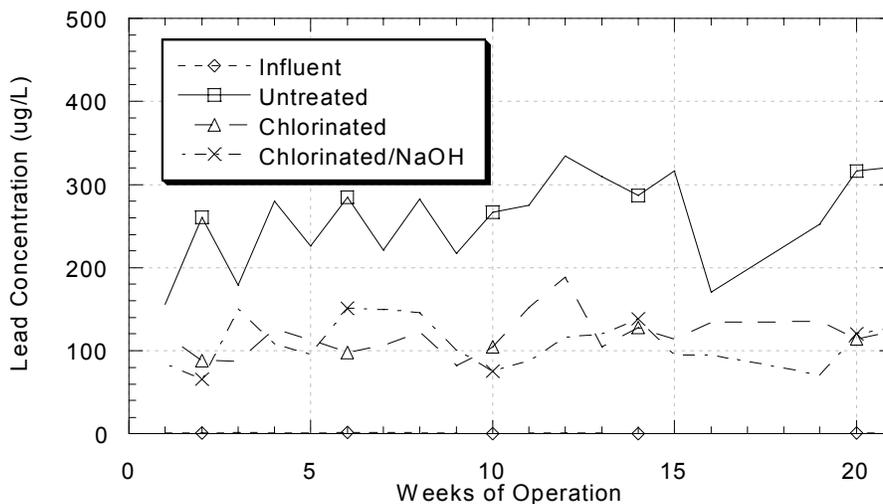


Figure 3. Lone Rock, Wisconsin: Lead Pipe Loops



At Lone Rock, the influent temperature was 13 C while the loop effluent temperature after stagnation was 20 C. The chlorinated water had a concentration of 0.2 mg/L free chlorine. Sodium hydroxide (NaOH) addition increased the pH from about 7.8 to about 8.2. Figure 3 shows that the lead in the untreated water is high and is not dropping over time. The lead concentrations here are typically higher than those seen in the untreated water at Dane. Chlorine addition appears to decrease the lead concentrations. Adjustment of pH with sodium hydroxide does not produce a different effect than that observed with the chlorine addition alone.

COPPER PIPE LOOP EFFLUENT CONCENTRATIONS

The concentrations of copper in the effluent of the copper pipe loops over twenty-one weeks are shown in Figure 4 for the high alkalinity site of Dane and Figure 5 for the low alkalinity site of Lone Rock. Figure 4 shows that the copper in the untreated water at Dane drops over time. Chlorine addition appears to increase the copper concentrations. Phosphate addition to the chlorinated water does not produce a different effect than that observed with the chlorine addition alone.

Figure 4. Dane, Wisconsin: Copper Pipe Loops

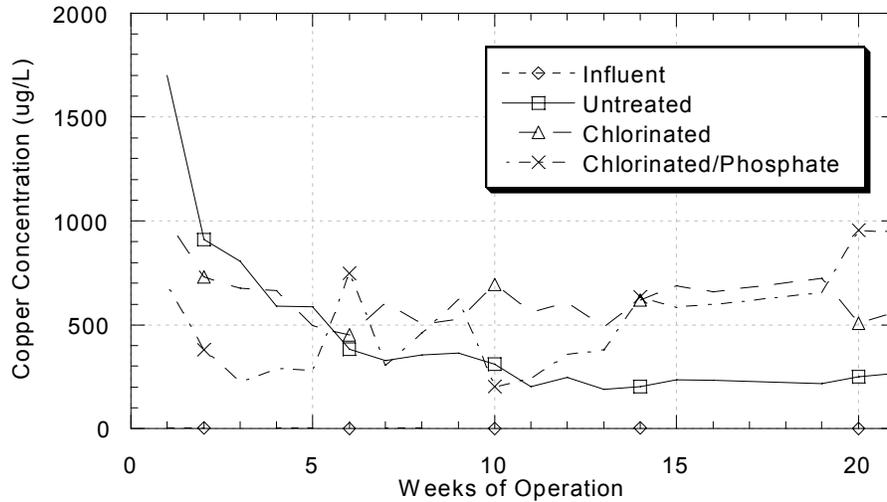


Figure 5. Lone Rock, Wisconsin: Copper Pipe Loops

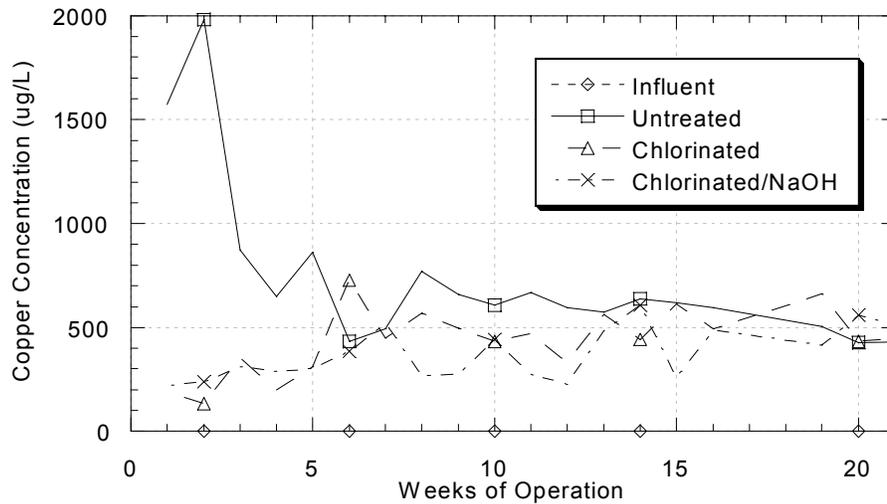


Figure 5 shows that the copper in the untreated water at Lone Rock drops over time but not as low as at Dane. Chlorine addition does not appear to make a difference in copper concentrations. Adjustment of pH with sodium hydroxide does not produce a different effect than that observed with the chlorine addition alone.

IRON PIPE LOOP EFFLUENT CONCENTRATIONS

The concentrations of iron in the effluent of the iron pipe loops over twenty-one weeks are shown in Figure 6 for the high alkalinity site of Dane and Figure 7 for the low alkalinity site of Lone Rock.

Figure 6 shows that the iron in the untreated water at Dane drops over time. Chlorine addition does not cause significant changes in iron concentrations. Phosphate addition to the chlorinated water does not produce a different effect than that observed with the chlorine addition alone.

Figure 6. Dane, Wisconsin: Iron Pipe Loops

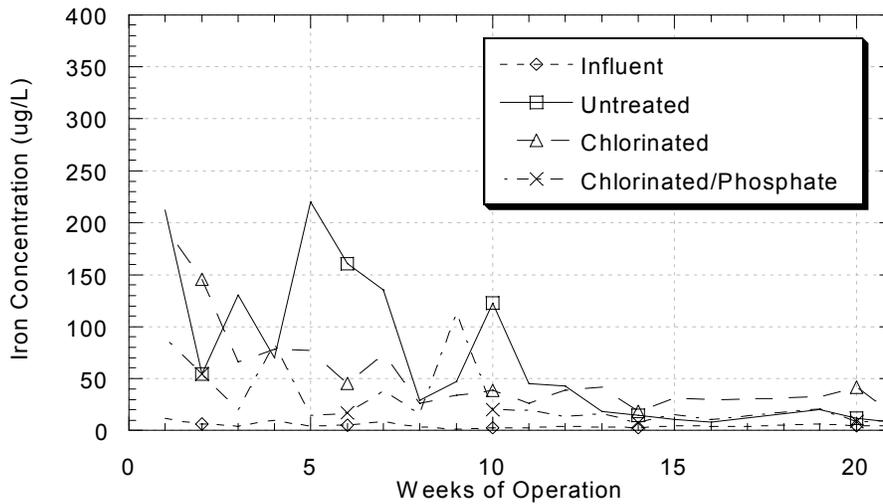


Figure 7. Lone Rock, Wisconsin: Iron Pipe Loops

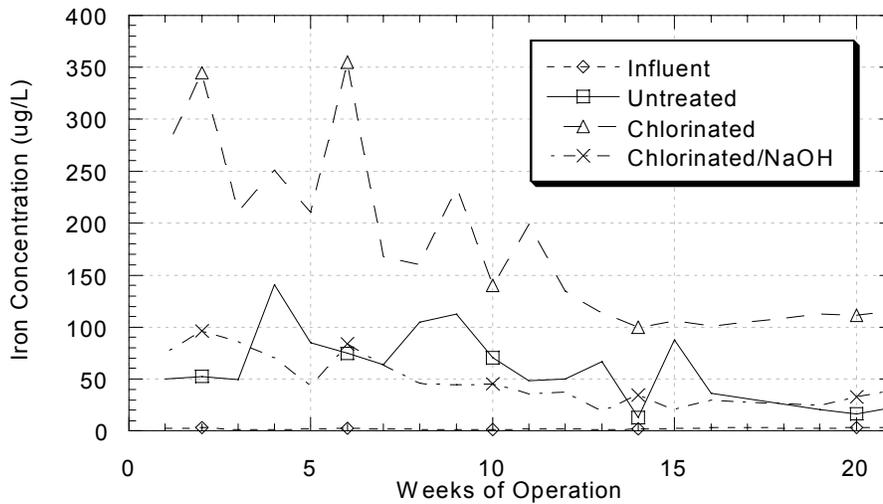


Figure 7 shows that the iron in the untreated water at Lone Rock drops slightly over time. Chlorine addition creates a significant increase in iron concentrations. Adjustment of pH with sodium hydroxide counteracts the effects of the chlorine by bringing the iron concentrations down to those similar to untreated water.

GUIDELINES FOR CORROSION CONTROL

It has been acknowledged in the technical literature that the corrosivity of water on any given metal cannot be quantitatively predicted.²³ Theoretical models of metals solubility as well as pipe loop and laboratory experiments have provided a qualitative understanding of corrosion and corrosion control in drinking water. From this information, “decision trees” have been developed to guide the water system manager.^{10,23}

In addition, recommendations have been made for off-line testing and monitoring of distribution systems concerning corrosion control issues.^{8,10}

The main goal of this project is to make corrosion control information readily available to the small water utility manager. The technical literature will be summarized and a corrosion monitoring protocol will be introduced.

PROJECT SCHEDULE AND GOALS

This project will continue as follows:

1. April 1, 2000 Twelve-month interim report
2. August 29, 2000 Final week of sampling
3. October 1, 2000 Final report

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- Mr. Dan Lynch, Water Utility Manager at the Janesville Water Utility, for loan of equipment
- Mr. Dave Martelle, Technical Representative at the Carus Chemical Company, for donation of chemicals

THE PROJECT TEAM

The project was funded by the MTAC. This organization provides technological assistance to small public water systems and water systems serving Native American communities. MTAC is described in its literature as "a collective effort of the University of Illinois and the Illinois State Water Survey in collaboration with the land grant universities of Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, and Wisconsin. The mission of the Center is to provide small system administrators and operators with the information necessary to make informed decisions on planning, financing, and the selection and implementation of technological solutions to address their needs."²⁴

The funding for this project was awarded jointly to Jae K. Park, Ph.D., professor of Civil and Environmental Engineering at the University of Wisconsin - Madison and to Abigail F. Cantor, P.E. of Process Research in Madison. Professor Park has a background in water chemistry and water treatment process design. Ms. Cantor has been a chemical engineering consultant in water treatment process design since 1980. She has run various corrosion control studies involving pipe loop apparatuses since 1992. A Masters Degree candidate from the Civil and Environmental Engineering Department at the University of Wisconsin - Madison, Prasit Vaiyavatjamai, is also on the project team. Mr. Vaiyavatjamai performs the weekly sampling of the apparatuses and analyzes the samples for various water quality parameters.

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APPENDIX A

Photographs of Project Sites



Pipe loop apparatus at the Village of Dane Maintenance Building



Side view of the pipe loop apparatus at the Village of Dane. Along the back wall are chemical tanks and pumps for sodium hypochlorite and potassium orthophosphate. The timer which controls the drain line solenoid valve and the chemical pump electrical outlet is the rectangle on the back wall.



Prasit Vaiyavatjamai measuring pH of samples at the Village of Dane site.



A close-up picture of the lead, copper, and galvanized iron pipe loops.



Pipe loop apparatus at the Village of Lone Rock Well No. 2 pump house. The loop racks extend along the side wall of the pump house. In the back corner are chemical tanks and pumps for sodium hydroxide and sodium hypochlorite.

Another view of the pipe loop apparatus at the Village of Lone Rock. Well Pump No. 2 and discharge piping are in the forefront of the picture.



A close up view of a pipe loop rack at the Village of Lone Rock. The pipe above the floor drain discharges the apparatus' water. The rectangular box on the wall is the controlling timer. (The water on the floor comes from a dehumidifier in the left hand corner of the picture.)

