WILLMAR, MINNESOTA BATTLES COPPER CORROSION

Part 1

Considering the competitive chemical oxidizing and reducing conditions, as well as the potential for microbial mediation of these chemical processes, the problem Willmar, Minnesota is confronted with, owing to the new federal and state regulations governing copper, is an exceptionally complex one. It has defied both definition and resolution to this date.

From recent specialty conferences and published literature, it appears clear that the magnitude of the problem nationally was unexpected until the results of monitoring at the state level became available. To make matters worse, neither the literature or active researchers in the field of drinking water can offer generally effective alternative methods for control of copper corrosion, even in hard waters. This is leading to the marketing of costly "remedies" whose effectiveness is not universal and, often, has not been confirmed. As a result, state regulatory agencies are unable to offer effective alternative remedies for compliance with the problem of copper corrosion.

BACKGROUND FOR STUDY PROGRAM

Because studies cited in the EPA 1987 Criteria Document have determined that "acute copper intoxication is associated with higher exposure levels among a wide variety of populations", EPA established a Maximum Contaminant Level Goal (MCLG) of 1.3 milligrams per liter for copper in drinking water. The concentration of copper is to be determined on samples withdrawn from the consumer's tap after 6 hours of storage (static conditions) in the (copper pipe) plumbing system. Under the EPA Lead and Copper Rule (56 FR 26460, promulgated June 7, 1991), monitoring for both lead and copper by public water systems in Minnesota began in 1992.

Following completion of the first round of the Minnesota copper/lead monitoring program, public water systems in Minnesota were found to be exceeding "action exceedance levels" more frequently with respect to copper than with respect to lead. Moreover, the Minnesota Department of Health, Section of Drinking Water Protection, Public Water Supply Unit, reported that all copper exceedances were observed in water systems utilizing ground water. Overall, 129 community public water systems exceeded the limit of 1.3 mg Cu/L applied to "first draw" samples taken from household taps.

A second round of copper/lead monitoring was conducted in 1993. The results appeared to be substantially the same as those observed in the first round of sampling. However, some water utilities had started to apply chemical additives to their finished water to reduce copper corrosion. The efficacy of these additives appeared to be mixed. Even where reductions in copper levels were observed, copper concentrations remained near the 1.3 mg Cu/L "copper action level."

CHARACTERIZATION OF MINNESOTA GROUNDWATERS

Minnesota ground waters are characteristically hard (5 to 9 meq/L; 250 to 450 mg $CaCO_3$ equivalent/L) and similarly high in alkalinity as a result of equilibration with calcium carbonate. Sulfate and chloride concentrations vary widely, while nuisance levels of iron and manganese are frequently present. As a result, iron and manganese removal is commonly practiced. Because the waters are highly buffered by the carbonate system, pH reactions are generally neutral, ranging from 6.8 to 7.7 before aeration. The presence of iron and manganese indicate that reducing conditions commonly prevail in Minnesota groundwaters.

Aeration of Minnesota groundwaters characteristically results in the release of carbon dioxide, increasing pH and thereby causing supersaturation of the water with respect to calcium carbonate (positive calcium carbonate saturation indices). Since the ground waters are normally cool, oxygen solubility in fully aerated waters may be in the range of 9 (@ 20°C) to 12 (@ 7°C) mg O/L.

LEVELS OF COPPER IN TAP SAMPLING

Two seasonal series of monitoring of

TABLE 1. WILLMAR MUNICIPAL UTILITIES - WATER SUPPLY SYSTEM DATA

Willmar, Minnesota - Public Water Supply ID No. 1340016
Bart Murphy, Superintendent of Water, (612) 235-4422

Water Sources:	Southwest Wells, Northeast Wells		
Treatment Plants (2):	Southwest Plant, Northeast Plant		
Treatment:	Packed Tower Aeration, Permanganate Oxidation, Pressure Greensand Filtration, Chloramination, Fluoridation		
Population Served:	22,000		
Water Production:	3.4 mgd (average); 6.9 mgd (peak)		
Finished Water Characteristics:			
	pH: 8.1	Temperature: 5-15 °C	
	Alkalinity:	400 mg $CaCO_3$ equiv./L (8.0 meq/L) - Northeast 441 mg $CaCO_3$ equiv./L (8.8 meq/L) - Southwest	
	Calcium:	150 mg $CaCO_3$ equiv./L (3.0 meq/L) - Northeast 260 mg $CaCO_3$ equiv./L (5.2 meq/L) - Southwest	
	Ammonium Ion:	3.0 mg N/L (NE); 2.8 mg N/L (SW)	
Iron and Manganese Removal Effectiveness			
Iron (Southwest):		1.67 mg Fe/L (Raw)	0.00 mg Fe/L (Finished)
Manganese (Southwest):		0.109 mg Mn/L (Raw)	0.05 mg Mn/L (Finished)
$KMnO_4$ Consumed:		1.6 mg KMnO4/L (after 10 minute reaction time)	
August-December 1992 - First Round Lead/ Copper Tap Monitoring Results			
Lead:	Min. <5 μg Pb/L	Maximum: 43 μg Pb/L	90% Value: 11 μg Pb/L
Copper:	Min. <50 μg Cu/L	Maximum: 7.0 mg Cu/L	90% Value: 4.08 mg Cu/L
Corrosion Control Treatment:		Aeration to increase pH from 7.5 to 8.1	

"first draw" tap samples (5,255 sites) conducted by the Minnesota Department of Health in 1993 and 1994 yielded average copper concentrations of 0.24 mg Cu/L (August to October) and 0.28 mg Cu/L (January to April), respectively. The maximum copper concentration reported was 7.0 mg Cu/L.

Water supply system data for Willmar Municipal Utilities are given in Table 1. Raw and finished water alkalinities are very high at both plants. At 8 to 9 meq/L, alkalinity is two to four times greater than many hard Midwestern groundwaters. Similarly, the hardness is about five times greater than what has been described by an AWWA Committee (Elwood Bean, 1972) as "ideal" for finished water (1 meq/L).

Aeration is used to increase raw water pH from 7.5 to 8.1. This is the key corrosion control treatment provided to limit lead and copper corrosion. The solubility of both metals decrease significantly with pH. Because Willmar's water is supersaturated with respect to calcium carbonate solubility (has a positive Langelier Saturation Index), any increase in pH above that currently maintained in the finished water (8.1) is likely to initiate precipitation in the mains. Otherwise, increasing the pH values to 8.5 or even 9 should remediate the corrosion problems. This could be done if Willmar's water was softened by lime precipitation. Alternately, pH decreases during distribution as a result of the acid production from the microbial process of nitrification.

Treatment for iron and manganese removal is consistently effective at Willmar through the use of potassium permanganate and greensand filters. Finished water residual color is the result of natural organic matter rather than iron or manganese residuals.

TREATMENT APPROACHES FOR COPPER CORROSION CONTROL

Four methods have been cited by EPA for optimum copper corrosion control treatment (OCCT): pH/alkalinity adjustment — to decrease solubility of carbonates, oxides; calcium adjustment — to increase calcium carbonate supersaturation; polyphosphate addition — to cause formation of phosphate films on piping; and silicate addition — to cause formation of silicate films on piping.

The first, and most obvious, treatment, requires the adjustment of pH and alkalinity. Lead and copper are known to corrode most rapidly in low pH, low alkalinity waters, such as in the soft waters of New England and the Southeastern United States. In Minnesota groundwaters, however, pH and alkalinity are initially sufficiently high that corrosion rates would be expected to be moderated without further adjustment. Only very small additional increases in either pH or alkalinity can be accomplished without initiating large-scale precipitation of calcium carbonate (i.e., softening by precipitation).

The hard waters of Minnesota are also rich in calcium. The application of additional calcium salts (generally, lime), similarly, will result in calcium carbonate precipitation (lime softening). Therefore, neither of these two control methods offers a suitable option for most Minnesota groundwaters.

By default, the optimal corrosion control option in Minnesota appears to be limited to treatment of the distributed water by the addition of a chemical "inhibitor." Since there are at least 200 commercially available variants of these compounds, Minnesota water utilities are currently faced with the need for complex evaluations of numerous proprietary chemical formulations.

ALTERNATIVE TREATMENT OPTIONS

Limited to the sole remaining option (addition of a sequestering agent), which has previously proven ineffective (and troublesome) in the control of iron and manganese in their distribution system, Willmar authorized the implementation of a research program to identify and evaluate alternative strategies for the control of copper corrosion.

Nitrification and the Removal of Ammonium Ion. Willmar, using a comprehensive distribution system monitoring program, had previously demonstrated the progress of nitrification (biologically-mediated conversion of ammonium ion to nitrite and nitrate accompanied by the stoichiometric depletion of oxygen) in its distribution system (Table 2). This process takes place as chloramine residuals are dissipated in the system, permitting bacterial processes to proceed.

Willmar had determined that there was sufficient ammonium ion in its well water sources ($NH_4^+ \approx 2$ to 3 mg N/L) to completely consume the oxygen (10-11 mg O/L) introduced during packed tower aeration. (One milligram of ammonium ion, expressed as N, will consume 64/14 = 4.57 milligrams of oxygen through nitrification.) Preliminary indications were that both nitrification and copper corrosion proceeded simultaneously during water distribution, so that there might be a causal relationship between the two phenomena.

One alternative control option under investigation, therefore, was the removal of ammonium ion on cation exchange resin to assess the effect of reduced ammonium ion on nitrification and, possibly, copper corrosion.

Willmar had also previously determined that its well water sources were also high in dissolved organic carbon, presumably the result of refractory (persistent) humic and fulvic substances extracted from the rich Minnesota soil. Copper is known to be complexed more readily than most other metals by such organic ligands (Irving-Williams Series {organic complex stability sequence of the transition metals}: $Mn^{2+} < Fe^{2+} < Co^{2+} < Ni^{2+} < Cu^{2+} > Zn^{2+}$).

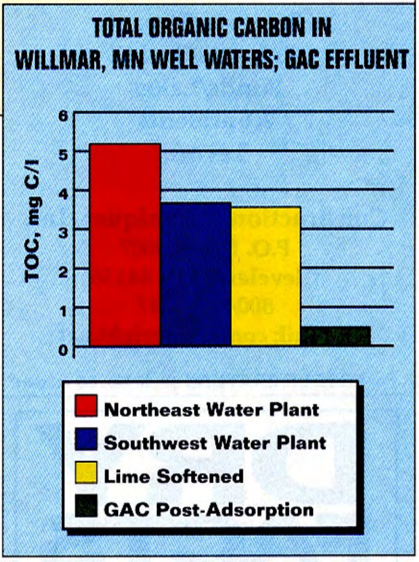
Removal of Dissolved Organic Carbon on Granular Activated Carbon. A second alternative control measure investigated was the use of granular activated carbon post-adsorption for the reduction of the dissolved organic carbon content of the well waters. The effect that this treatment has on copper corrosion was observed using copper pipe test loops installed at the Willmar Southwest treatment plant.

TABLE 3 - TOTAL ORGANIC CARBON IN SOURCE AND TREATED WATER, WILLMAR, MN SOUTHWEST WATER TREATMENT PLANT - MARCH 19-22, 1996: TOTAL ORGANIC CARBON, MG C/L

Date	Well Water	SW WTP Influent	SW WTP Filtered	GAC Adsorption Col. Effl.
3/19/96		3.6	3.8	<0.5
3/22/96	W-7:3.8	3.8	3.5	<0.5
	W-8:2.8	3.6 (After Bench-Scale Lime Softening)		
	W-9:3.9			
	W-12:3.8			
	W-14:3.8			
	W-15:3.5			
	W-16:3.5			
	W-18:4.2			
Mean:	3.7 mg C/L			
Northeast Water Treatment Plant - March 19-22, 1996: Total Organic Carbon, mg C/L				
3/22/96	E-10:5.6	5.2	5.4	
	E-19:5.2			
	E-20:5.4			
	E-21:4.8			
Mean:	5.2 mg C/L			

Total Organic Carbon in Willmar Well Waters and Finished Waters. Previous analyses had indicated that TOC concentrations were high in the treated water from both treatment plants. Additional samples were collected as part of the present study. The results, presented in Table 3, indicate that the Southwest wells and finished waters are comparable and range from 2.8 to 4.2, averaging 3.7 mg C/L. TOC in the Northeast wells and plant finished water ranged from 4.8 to 5.6, averaging 5.2 mg C/L.

A comprehensive survey of 101 Missouri water supplies by the authors, first conducted in 1980 and repeated in 1989 for validation, indicates that Willmar's TOC concentrations are very high as compared with other hard, alkaline, Midwestern groundwaters. Of the 101 Missouri water supplies analyzed for TOC, 16 were from shallow wells (<30 m), which averaged 1.2 mg C/L while 42 were from deep wells (>30 m) which averaged 0.18 mg C/L.



The substantial amount of organic matter derived from the Willmar wells may have several important influences on copper corrosion and organism growth in the Willmar

TABLE 2 - INDICATORS OF MICROBIALLY-MEDIATED NITRIFICATION IN WILLMAR, MN WATER DISTRIBUTION SYSTEM

Samp. Location (No.)	Date	Temp., pH	Oxygen, °Celsius	Chloramine, mg O/L	Ammonium, mg Cl/L	Nitrite, mg N/L	Nitrate mg N/L	mg N/L
Southwest WTP		8.0	7.0	10.9	2.8	2.8	<0.01, 0.01	<0.1, 0.03
Northeast WTP		8.1	7.0	10.8	2.8	3.0	<0.01,0.01	<0.1, 0.17
Dist. Sys. (10)	5/24/94	-	-	-	-	-	0.42	1.01
Dist. Sys. (10)	8/3/94	8.0	12.7	8.2	-	-	0.26	0.79
Dist. Sys. (8)	3/13/96	7.2	7.8	3.9	(0.2-2.4)	0.93, 0.96	-	-
Dist. Sys. (8)	3/14/96	7.7	6.3	2.8	(0.3-2.0)	1.11	-	-

water distribution system:

Organic Chelation. Since terrigenous humic compounds are typically 50 percent carbon (by weight), Willmar's Northeast well field may be yielding approximately 10 mg/L of humic substances. This concentration may be able to complex (and solubilize) metals by chelation with their associated carboxyl and phenolic groups. The effect of copper chelation on solubility and the rate of copper solution may be only partially responsible for the high concentrations of copper observed in household plumbing, however.

Peptization. To further complicate matters, high concentrations of humic substances are known to peptize (disperse or stabilize) precipitates (such as calcium carbonate, iron oxide), thereby preventing deposits from accumulating on pipe surfaces. In contrast with observations made in other regions of the Midwest that supply high hardness well waters, few significant surface deposits were observed on the inside of copper pipe sections removed from Willmar households. The failure to establish such protective barriers may also contribute to the accelerated corrosion of copper.

Stimulation of Microbial Growth. Finally, it is not generally recognized that the organic substances derived from groundwaters, although months or years old, may still be partially labile. This means that this organic matter may be more rapidly degraded by aerobic microorganisms once the water is brought to the surface and oxygenated through aeration. As evidenced by the presence of iron and manganese in the groundwater, there is no oxygen present in the groundwater up to the time it is withdrawn. This precludes any microbial activity by those organisms that require oxygen for their respiration.

Upon being withdrawn from the wells, Willmar's water is, first, aerated. From a chemical standpoint, aeration introduces oxygen and rapidly precipitates the dissolved iron present in the ground water, The iron oxides formed can subsequently be removed by filtration. Aeration also discharges carbon dioxide, markedly increasing the pH of the water. In some cases, hydrogen sulfide and methane are also among the gases stripped by aeration.

In some groundwaters containing filamentous, iron-precipitating bacteria, a significant biological transformation is observed. The strictly anaerobic organisms withdrawn along with the ground water lyse (self-destruct) in the presence of oxygen. They are rapidly replaced by aerobic (oxygen-utilizing) heterotrophic organisms. If this is occurring in Willmar, it is not evident from direct observation, because filamentous, iron-precipitating bacteria are notably absent from the well waters.

Considering the competitive chemical oxidizing and reducing conditions, as well as the potential for microbial mediation of these chemical processes, the problem Willmar is confronted with, owing to the new federal and state regulations governing copper, is an exceptionally complex one. It has defied both definition and resolution to this date.

Next month, Part 2 of this three-part series, "Nitrification, Bacteria and Copper Corrosion in Household Plumbing," will present the results of in-situ investigations of the progress of nitrification and copper corrosion in household plumbing. In addition, data will be presented on direct total bacterial cell counts and heterotrophic plate counts in the well water source, treated water, distributed water, and after storage in a household plumbing system. **PW**

Bart Murphy, John T. O'Connor, and Thomas L. O'Connor

Bart Murphy, BSCE, is Superintendent of Water, Willmar (Minnesota) Municipal Utilities; John T. O'Connor, EngD, P.E. is Principal, H_2O'C, Limited, Champaign, Illinois; and Thomas L. O'Connor, BSEE, MBA, is Environmental Engineer, H_2O'C, Limited, Columbia, Missouri.

WILLMAR, MINNESOTA BATTLES

COPPER CORROSION

Part 2

Part 2 of this three-part series, "Nitrification, Bacteria and Copper Corrosion in Household Plumbing," presents the results of in-situ investigations of the progress of nitrification and copper corrosion in household plumbing. In addition, data is presented on direct total bacterial cell counts and heterotrophic plate counts in the well water source, treated water, distributed water, and after storage in a household plumbing system.

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In the present study, the progress of copper corrosion in a household plumbing system was profiled using a sequential sampling procedure. The procedure involves the sequential collection of each 250 ml aliquot from a household or building tap. While intermixing of water occurs progressively, this procedure provides insight into the quantity (usually, 2 to 5 liters) and quality of water within the (heated) household plumbing system; the quantity and quality of water in the service connection to the home; and the quality of water in the distribution mains prior to entering the home.

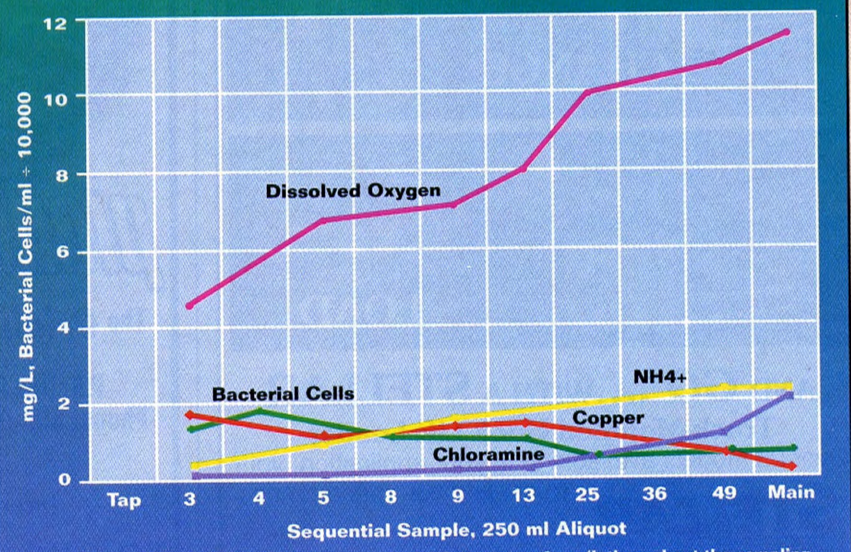
A representative number of the sequential samples are normally analyzed for:

- **Temperature.** Generally, warm in the home; cool in the service connection and main.
- **Total Bacteria.** Cell counts may be exceptionally high in the household plumbing and, progressively, lower in the service connection and main.
- **Disinfectant Residual.** While frequently low or absent in the household plumbing, residuals generally persist in the service connection and main.
- **Dissolved Oxygen.** While generally present in the main, oxygen may be progressively depleted in the household plumbing in proportion to the period of storage and the activity of nitrifying bacteria.
- **Ammonium Ion.** Ammonium ion may be depleted in household plumbing in proportion to the oxygen depletion caused by bacterial nitrification.

The unique feature of the present sequential sampling program is the measurement of copper. The data shown in Figure 1, for the Bart Murphy residence near the Southwest treatment plant, is likely the first such complete representation of the water quality in a household plumbing system.

Figure 1 indicates a dramatic

Figure 1. SEQUENTIAL HOUSEHOLD TAP SAMPLING AT BART MURPHY RESIDENCE



Notes: Chloramine and Dissolved Oxygen remained at or near 0 mg/L throughout the sampling. Water temperature was about 13 °C in the household plumbing; 5 °C in the flushed sample (main).

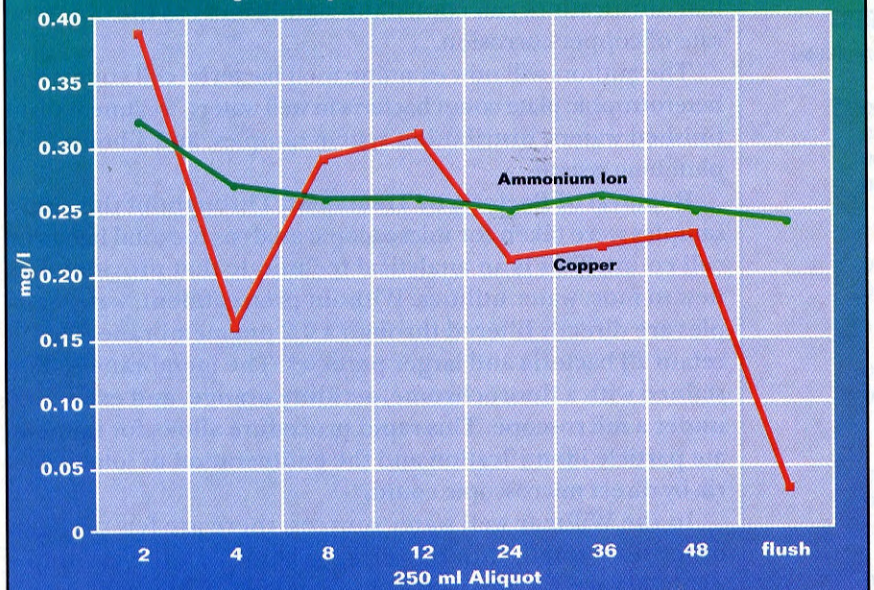


Figure 2. SEQUENTIAL SAMPLING AT NEW HOUSE

Notes: Chloramine and Dissolved Oxygen remained at or near 0 mg/L throughout the sampling. Water temperature was about 13 °C in the household plumbing; 5 °C in the flushed sample (main).

reduction in the amount of oxygen in household plumbing as the water progresses from the tap, where oxygen was depleted to 4.5 mg O/L, to the main (with 11.5 mg O/L). The reduction of ammonium ion from 2.2 (main) to 0.5 mg N/L (tap) is consistent with the stoichiometry for microbial nitrification.

One of the principal reasons microbial activity is facilitated in household plumbing systems relates to the surface area provided by small diameter piping. A high ratio of surface area to stored water volume increases the potential for the accumulation of sediments, organic matter, and microbial growths (biological films or slimes). In contact with the chloraminated water, these attached reducing agents rapidly consume disinfectant residuals that retard bacterial growths. Figure 1 illustrates this phenomena. Whereas chloramine exceeds 2 mg Cl/L in the main, it is virtually absent at the tap and in the first three liters withdrawn from the household plumbing during the sequential sampling.

Similarly, the concentration of copper is about 1.5 mg Cu/L, marginally exceeding the "copper action level," in the first three liters of the Bart Murphy household plumbing system.

Based on this profile, it is evident that both microbially-mediated nitrification and copper corrosion are occurring simultaneously within this residential plumbing system.

The results of a similar study are given on Figure 2 for a newly constructed house. Although ammonium ion concentrations at this site are low, there is little evidence of nitrification within the plumbing system itself. Ammonium ion remains near-constant at 0.25 to 0.3 mg N/L in both the plumbing and the flushings from the distribution main.

Copper concentrations in the household plumbing, while variable, are low, averaging 0.25 mg Cu/L. Chloramine and dissolved oxygen were absent throughout the sampling. From these results, it appears that extensive copper corrosion did not occur immediately in the new copper pipe, but may develop over a period of time. In addition, the limited availability of the oxidizing agents, chloramine, and oxygen, likely retarded the rate of copper corrosion.

Although more limited in scope, the results of an early study of the plumbing system at the South (Electrical) Sub-Station, presented in Figure 3, show the significant depletion of oxygen that occurs even before water enters the sub-station. Oxygen in finished water leaving the Southwest Water Treatment Plant was averaging 11 mg O/L, while about 3 mg O/L arrived at the sub-station. This result indicates that significant oxygen depletion due to nitrification takes place in the distribution system mains even at low water temperatures.

Within the sub-station plumbing, pH was found to have declined from

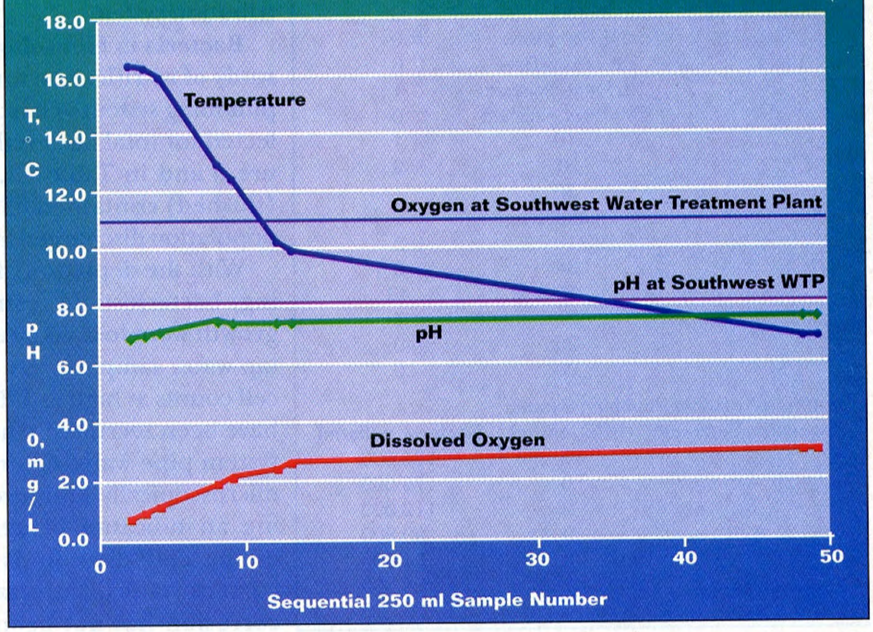


Figure 3.
SEQUENTIAL SAMPLING AT SOUTH SUB-STATION: 6 HOURS RETENTION, 13 MARCH 1996

TABLE 4A. TOTAL BACTERIA IN RAW AND FINISHED SOUTHWEST AND NORTHEAST PLANT WATERS

Date/Sample	Bacteria, cells/milliliter
19 Mar 1996	
SW plant raw	56,200
SW plant finished	85,800
NE plant raw	114,000
NE plant finished	139,000
20 Mar 1996	
SW plant raw	142,000
SW plant finished	149,000
21 Mar 1996	
NE plant raw	87,900
NE plant finished	31,000
22 Mar 1996	
NE plant raw	103,000
NE plant finished	245,000
23 Mar 1996	
SW plant raw	89,400
SW plant finished	45,800

TABLE 4B. HETEROTROPHIC PLATE COUNT (HPC) BACTERIA - WILLMAR, MN DISTRIBUTION SYSTEM

Sampling Date	Sample Location	HPC, cfu/ml
19 March 1996	22	2
	14	2
	24	1
	NE Plant-Raw	0
	15	0
	16	0
	4	0
	7	0
	Control	0
	9	3
	SW Plant-Raw	0
	SW Plant-Finished	0
	NE Plant-Finished	2
	SW Sub-Station	0
	11	0
20 March 1996	33	0
	NE Plant-Raw	0
	SW Plant-Raw	0
	NE Plant-Finished	1
	SW Plant-Finished	0
	19	1
	31	2
	30	1
	Control	0
	18	3
	34	0
	22	49
	24	7
	20	0
	20	0

Bart Murphy Home Plumbing System

Sequential Sample #	HPC, cfu/ml	Bacteria, cells/ml
2	0	136,000
4	0	175,000
8	0	112,000
12	0	99,800
24	0	54,600
48	0	58,600
flush	0	68,000

8.1 at the Southwest Plant to 7.0. This effect, a result of microbial nitrification, can contribute significantly to the observed rate of copper corrosion.

The authors will now examine total bacterial cell counts and heterotrophic plate count bacteria in well waters, treatment plant finished waters, distribution system samples, and a household plumbing system.

Removal of Bacteria by Treatment. Throughout this study, samples were taken for microscopic analysis for total bacterial cell count. This is an analytical technique that provides data new to most water utilities. Without pretreatment, water samples are directly filtered through a 0.2 μm membrane filter to retain all bacteria and larger particles. The membrane is then stained with a fluorochrome, acridine orange, and examined under a microscope. This rapid procedure allows for immediate particle identification and the enumeration of total bacteria by direct microscopic count.

In the Willmar well water sources, there are few particles other than small, thin bacteria. As shown on the accompanying Figure 4A, the number of bacteria in the well waters (raw) ranged from 56,200 to 142,000 cells/ml, averaging about 100,000 cells/ml. This cell count is typical of many Midwestern groundwaters that are not as sterile as many have assumed. Since most of the organisms are not culturable on plate count media, these waters typically exhibit low heterotrophic plate counts (HPC). This is especially true of Willmar's system, which was found to contain almost no culturable (HPC) organisms either in the well water sources or the distribution system.

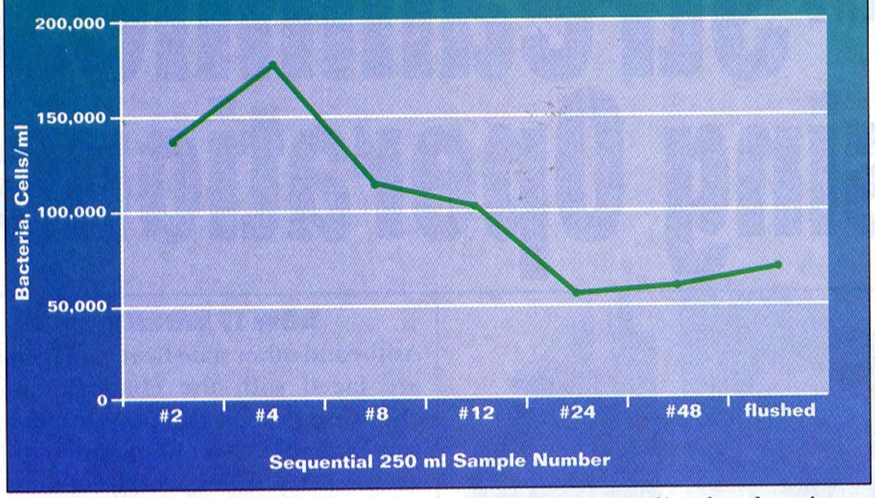
Total bacterial populations, as shown in Figure 4A, rather than being reduced by filtration, generally increased during treatment. An exception was observed on March 23, 1996 when a significant reduction in cell count was observed at the Southwest Plant.

From these initial observations, it appears that the cells entering the treatment plant with the source water were increasing in number during treatment and entering the distribution system.

Bacteria in Household Plumbing. In conjunction with the study of nitrification and copper corrosion in the household plumbing system of Bart Murphy's home, samples were also collected for total bacterial cell count. The results, shown on Figure 5 and in Table 4B, indicate that the water in the main (flushed) contained 68,000 cells/ml, probably reflecting the population discharged into the system from the treatment plant.

With the depletion of chloramine in the household plumbing, bacteriostatic restraints on bacterial cell recovery and growth were lost. As a result, bacterial populations in the first tap water samples were found to have more than doubled to cell counts as high as 175,000 cells/ml. Some of these cells may have been recruited (sheared) from the household plumbing system pipe walls. Clumps and sheets of cells were observed microscopically. Moreover, many cells were observed to be dividing, an indication of active cell growth. Cell growth as indicated by cell division is not observed in the presence of bacteriostatic disinfectant residuals. While its role in copper corrosion has not been defined, at least, the simultaneous

Figure 5.
BACTERIA IN SEQUENTIAL 250 ML SAMPLE-BART MURPHY'S HOUSEHOLD PLUMBING SYSTEM



progress of bacterial activity has been observed in a Willmar household plumbing system.

Effectiveness of Chloramine Residual. The presence of a chloramine residual is expected to be essential in preventing the regrowth of bacteria during distribution. Accordingly, samples were taken from the distribution system on two dates. The results of total bacterial cell counts are plotted as a function of chloramine residual at these locations on Figures 6 and 7.

The results show a wide range of chloramine residuals in the distribution system, indicating the rapid consumption of chloramines in the mains. Whereas the March 19 sampling shows no significant response of bacterial population to chloramine residual, the March 21 data indicates that higher bacterial populations were present when chloramine residuals declined to 0.5 mg Cl/L or less.

The management of the concentration of chloramine in the Willmar distribution system poses a troublesome dilemma. Low disinfectant residuals facilitate the development and activity of the nitrifying organisms, which are creating nitrite ion and lowering pH. At the same time, chloramine is a strong oxidizing agent, relative to oxygen, and is likely involved in the direct oxidation of copper metal to cuprous and cupric ion.

Ongoing studies by the city at the Southwest Water Treatment Plant are revealing that higher chloramine dosages are resulting in increased copper concentrations in copper piping. To minimize chemically-induced copper corrosion in household plumbing, minimization of the chloramine dosage is indicated.

Heterotrophic Bacteria. Preliminary results (Table 4B) appear to indicate that, despite the degree of nitrification taking place throughout the distribution system, there is virtually no heterotrophic activity. This result is surprising and warrants further investigation. In some instances, the absence of competitors enhances the activity of an ecologically-advantaged microbial population.

Next month, Part 3 of this three-part series, "Results of Pilot Plant Column and Copper Pipe Test Loop Studies," will describe the results of in-plant studies conducted using pilot plant columns containing cation exchange resin, granular activated carbon, and plastic contact media. In addition, it will present the results of copper corrosion studies utilizing specially-constructed copper pipe test loops to simulate corrosion in full-scale household plumbing systems. **PW**

Figure 6.
BACTERIA IN DISTRIBUTION SYSTEM VERSUS CHLORINE

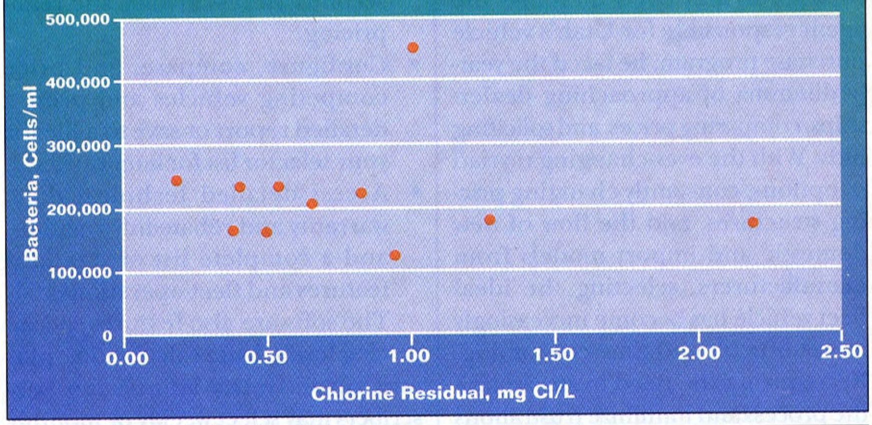


Figure 7.
BACTERIA IN WILLMAR, MN DISTRIBUTION SYSTEM VERSUS CHLORINE RESIDUAL-21 MARCH 1996