# PILOT PLANT STUDIES OF CHLORINE AND CHLORAMINE DISINFECTION OF MISSOURI RIVER WATER

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The Interim Primary Drinking Water Regulations proposed by the U.S. Environmental Protection Agency in 1976 initiated one of the most animated debated over the past years between the waterworks industry and a federal regulatory agency. Much of the controversy has resulted from the proposed use of activated carbon for the reduction of trihalomethanes and total organic carbon. One specific subject of debate has been the use of combined chlorine as a disinfectant to avoid the formation of THMs. Although in-

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terim regulations would permit "alternate technology" to achieve the 100 ug/l THM limit in place of GAC, restrictions on the use of alternate disinfectants disallow the application of combined chlorine in excess of 1 mg/l.

Regulations restricting the use of chloramine will affect the established treatment practices of numerous water suppliers not originally subject to the proposed organics regulations. Both large and small water utilities who are dependent on river water sources have claimed that it is very difficult to establish a free chlorine residual without employing large dosages of chlorine. Moreover, those utilities currently utilizing chloramine believe that their operational experience indicates that chloramines provide satisfactory disinfection. Moreover, as USEPA studies have demonstrated, disinfection with chloramines also reduces the formation of THMs.[1]

In late 1978, the U.S. Environmental Protection Agency directed an investigation through the University of Missouri-Columbia, Department of Civil Engineering, to obtain in-field data relating to combined chlorine disinfection. The primary objective was to compare the disinfection properties of **chlorine** and **chloramine** when applied to conventionally treated Missouri River water. The disinfection capability of each chemical species would be evaluated by comparing the microbial kills at similar points throughout two identical pilot water treatment plant systems.

In addition to the microbiological aspects of the disinfection study, a secondary objective was to collect individual water samples for analyses of trace organic substances. These analyses included: 1) gas chromatography for the determination of trihalomethanes and their forming potential, 2) ultra-low level TOC measurement for "purgable" and "non-purgable" organic carbon, and 3) microcoulometric analyses for the evaluation of carbon adsorbable halogenated organic compounds (CAOX). The purpose of the trace organics analyses was to observe the combined effects of disinfection and physicochemical treatment on the levels of naturally-occurring organic materials, including TTHM "Precumsors", and the formation of organohalides.

## BACKGROUND

The pilot plant used in the chorine-chloramine disinfection study was designed and constructed by the Department of Civil Engineering, University of Missouri-Columbia. The facility consists of two identical treatment systems contained within a 40-foot tractor-trailer. Each unit models conventional physicochemical treatment, i.e., coagulation/flocculation, sedimentation, dual-media filtration and granular activated carbon post-absorbers, is designed for an average flow of 5 gpm. This mobile pilot plant was constructed such that various aspects of water treatment could be researched in the field using natural waters under prevailing environmental conditions. The plant was completed in January 1978 as part of a USEPA grant to study the removal of naturally-occuring enteroviruses from public water supplies.

## MISSOURI RIVER DISINFECTION STUDY

Figure 1 shows the flow and treatment scheme used in the chlorine-chloramine disinfection study. Points 1 through 7 indicate where samples were collected for microbiological and trace organics analyses. Note that disinfectants were applied by injecting chlorine (NaOCl solution) into both plant influent waters just prior to the rapid mix units. Chloramines were formed within one system by supplying a source of ammonium ion (ammonium sulfate solution) to the river water ahead of the chlorine injection point.

During the six month investigation, plant operations were separated into

two phases. Phase I (12/3/78 through 2/23/79) compared bacterial removal between alum-coagulated and coagulated-disinfected river water to obtain baseline data on the effectiveness of physicochemical processes alone and with distinfection. Phase II (4/4/79 through 5/30/79) compared the characteristics of chlorine versus chloramine for disinfection efficiency as measured by bacterial indicators: Total Coliforms, Fecal Coliforms, Standard Plate Counts and Yeast organisms. Phase II also studies the formation and removal of trihalomethanes from each system.

## RESULTS

### Phase I

Table 1 represents typical data obtained for disinfected and non-disinfected pilot plant treated river water. Results indicate that the average total bacterial removal for the alum-coagulated system along (Unit #2) was 90% with the majority of the microorganism removal, 80% to 85%, occurring in the sedimentation process. The parallel chlorine-treated system (Unit #1) achieved 99.9% and greater bacteria removals by the end of the sedimentation process.

It should be noted that on days of low influent microorganism populations, such as sample date 1/29/79, physicochemical treatment alone produced a finished water which met the required coliform limits for safe drinking water. Additionally, GAC adsorbers in both units exhibited no consistent significant influence on the microorganism populations throughout Phase I operations.

### Phase II—Microbiological Results

Table 2 presents typical data obtained during the chlorine-chloramine disinfection comparisons. Results indicate that for **both** units: 1) no Fecal Coliforms or Yeast organisms were detectable beyond the influent sampling point, 2) prior to filtration, Total Coliforms were reduced to levels below the statistical significance of the membrane filter technique, and 3) Standard Plate Counts, after sand/anthracite filtration, were generaly reduced to levels approaching the statistical lower limit of testing reliability established as 30 plate counts/ml.

Based on these pilot plant data, a comparison of the microorganism removals between corresponding system sampling points would indicate that chlorine and chloramine are equivalent in disinfecting power.

In addition to the tabulated results, Figures 2 and 3 show levels of Standard Plate Count organisms following settling, sand/anthracite filtration and GAC filtration for chlorine and chloramine treated systems, respectively. From these figures it would appear that chloramine treatment provided substantial consistency and stability with respect to bacterial removal within the treatment system. This added stability may be in part due to the less reactive (i.e., oxidative) nature of the chloramines versus the "free' chlorine species.

### Phase III—Results of Analysis for Organic Substances

Analysis for organic substances corresponding to the microbiological data of Table 2 is presented in Table 3. Trihalomethane data indicates that chlorine disinfection produced approximately ten times the concentration of THMs as did disinfection with chloramine. In both systems, however, effluent trihalomethane levels were consistently below the proposed 100 ug/l maximum concentration limit.

Data for the trihalomethane forming potentials (THMFP) indicates that much of the "precursors" to the formation of THMs were removed by the conventional physiochemical treatment. Coagulation/flocculation with aluminum sulfate, followed by settling generally reduced THMFPs by 45% to 96% based on influent water trihalo-

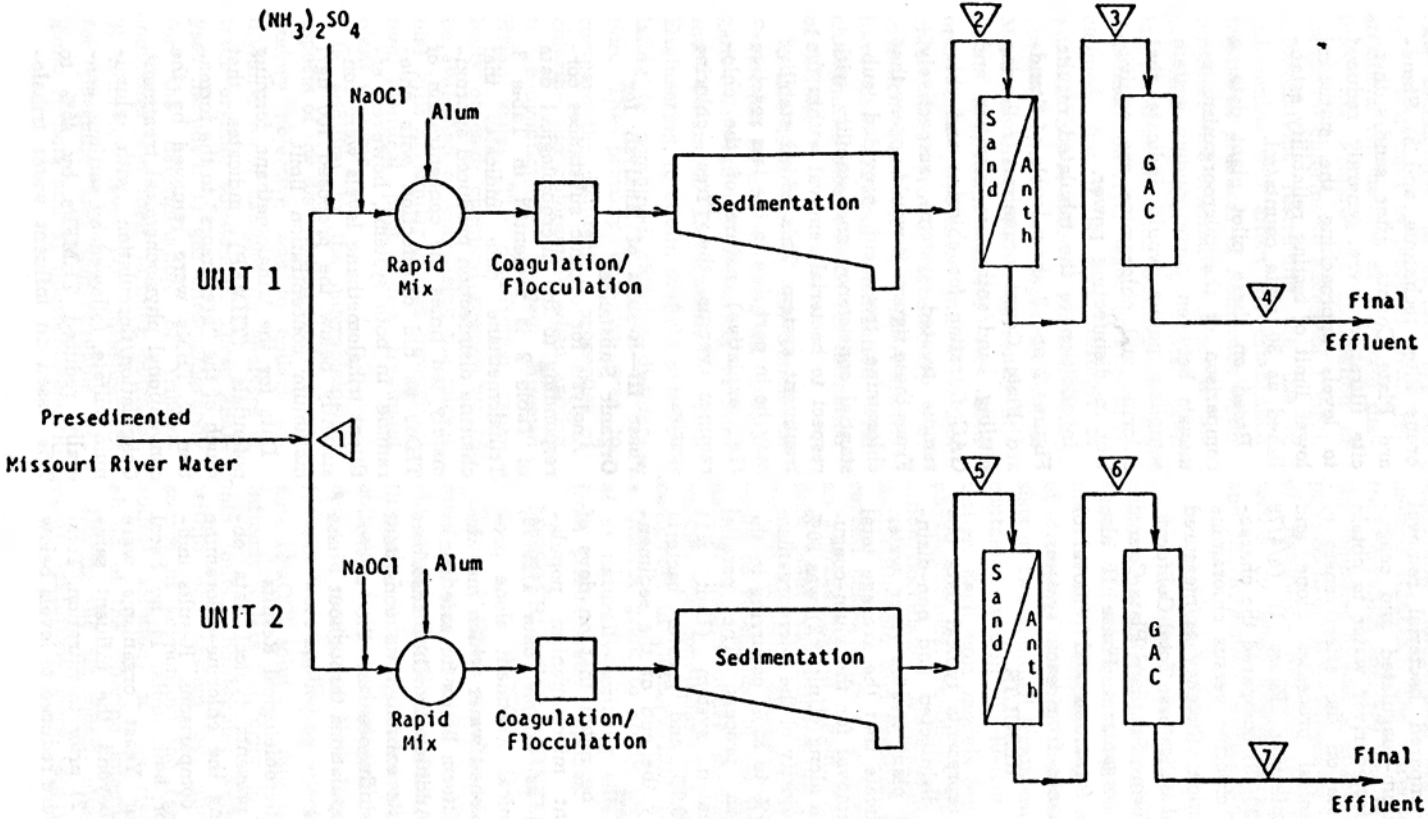


Figure 1: Treatment Process Flow Diagram for Missouri River Pilot Plant Disinfection Studies

methane-forming potentials after 48 hours reaction time with 5 mg/l initial $Cl_2$ dosage.

Figure 4 presents a graphical overview of the organics data. Included in the figure are plant influent dissolved TOC, plant influent, THMFP, and the THMFP for both units after settling. Preliminary observations show influent TOC and THMFP to be relatively constant over the two month period. Post-settling trihalomethane forming potentials, in both the chlorinated and chloraminated systems, exhibit similar trends. Most interesting, however, is the gradual increase observed in the post-settling THMFP. Based on the consistency of the influent TOC and THMFP data, it would appear unlikely that a major change in source water dissolved organic species was occurring. Instead, the efficacy of the treatment process may have been changing. If so, this loss in ability to remove precursor material may indicate that plant operational factors may strongly influence the removal of naturally occurring organics by coagulation. In-

Table 1: Results Typical of Phase I Missouri River Pilot Plant Disinfection Studies

| Sample Date | Sample Type | Total Coliform No./100 ml | Fecal Coliform No./100 ml | Std. Plate Ct. No./ml | Yeast No./100 | Applied Disinfectant | Disinfectant Residual (mg/l) Free | Disinfectant Residual (mg/l) Combined | Turb. (NTU) |
|---|---|---|---|---|---|---|---|---|---|
| 12/10 | Raw Mo. River | 120,000 | 4,900 | 3,400 | 0 | | | | |
| | Influent | 100,000 | 4,000 | 5,400 | 4 | | | | 28 |
| | UNIT 1 | | | | | Chlorine $C_1$= | 2.56 | 0.44 | |
| | Settled | 4 | 0 | 5 | 0 | " | 1.68 | 0.42 | 15 |
| | Filtered | 2 | 0 | 2 | 0 | " | 1.48 | 0.36 | 1.5 |
| | Post GAC | 0 | 2 | 6 | 0 | " | NM | NM | 0.39 |
| | UNIT 2 | | | | | No Disinfectant Applied | | | |
| | Settled | 3,200 | 70 | 550 | 0 | " " | " | | 13 |
| | Filtered | 790 | 30 | 120 | 0 | " " | " | | 1.5 |
| | Post GAC | 50 | 45 | 45 | 0 | " " | " | | 0.36 |
| 12/17 | Raw Mo. River | 91,000 | 3,100 | 3,900 | 0 | | | | |
| | Influent | 83,000 | 2,300 | 3,200 | 0 | | | | |
| | UNIT 1 | | | | | Chlorine $C_1$= | 0.54 | 0.10 | |
| | Settled | 270 | 0 | 65 | 0 | " | 0.05 | NM | |
| | Filtered | 25 | 0 | 60 | 0 | " | NM | NM | |
| | Post GAC | 0 | 0 | 80 | 0 | " | NM | NM | |
| | UNIT 2 | | | | | No Disinfectant Applied | | | |
| | Settled | 5,300 | 65 | 850 | 0 | " " | " | | |
| | Filtered | 2,200 | 110 | 920 | 0 | " " | " | | |
| | Post GAC | 1,100 | 45 | 190 | 0 | " " | " | | |
| 1/29 | Raw Mo. River | 3,600 | 62 | 2,700 | 4 | | | | |
| | Influent | 4,900 | 28 | 1,800 | 0 | | | | |
| | UNIT 1 | | | | | Chlorine $C_1$= | 0.12 | 3.03 | |
| | Settled | 0 | 0 | 90 | 0 | " | 0.10 | 3.00 | |
| | Filtered | 0 | 0 | 22 | 0 | " | NM | NM | |
| | Post GAC | 0 | 0 | 22 | 0 | " | NM | NM | |
| | UNIT 2 | | | | | No Disinfectant Applied | | | |
| | Settled | 70 | 0 | 1,400 | 0 | " " | " | | |
| | Filtered | 20 | 0 | 140 | 0 | " " | " | | |
| | Post GAC | 20 | 0 | 35 | 0 | " " | " | | |

creasing influent water temperature may have also promoted the kinetics of formation of trihalomethane in the pilot plant.

## CONCLUSIONS

From the results of the present study, several conclusions may be drawn:

1) Based on monitoring standard indicator organism removals in pilot plant treatment of raw Missouri River water, over a two month study period, chlorine and chloramine each made it possible to continually produce a potable water which met the coliform standard.
2) Chloramine produced an order of magnitude less trihalomethanes as compared to chlorine as determined by the liquid-liquid extraction GC technique.
3) Trihalomethane levels in both systems were reduced by GAC filtration over the April-May study period.
4) Trihalomethane "Precursors" as measured by THMFP were removed to varying degrees with alum coagulation and settling.

Table 2: Results Typical of Phase II Missouri River Pilot Plant Disinfection Studies

| Sample Date | Sample Type | Total Coliform No./100 ml | Fecal Coliform No./100 ml | Std. Plate Ct. No./ml | Yeast No./100 | Applied Disinfectant | Disinfectant Residual (mg/l) Free | Disinfectant Residual (mg/l) Combined | Turb. (NTU) |
|---|---|---|---|---|---|---|---|---|---|
| 4/9 | Influent | 200,000 | 4,800 | 24,000 | 120 | | | | 125 |
| | UNIT 1 | | | | | $Cl_2 + NH_3$ $Cl_1$" | NM | 1.36 | |
| | Settled | 10 | 0 | 120 | 0 | " | NM | 1.40 | 6.8 |
| | Filtered | 0 | 0 | 20 | 0 | " | NM | 1.47 | 1.1 |
| | Post GAC | 0 | 0 | 10 | 0 | " | NM | 0.24 | 0.4 |
| | UNIT 2 | | | | | Chlorine $Cl_1$" | 0.03 | 2.16 | |
| | Settled | 0 | 0 | 180 | 0 | " | NM | 1.43 | 12 |
| | Filtered | 0 | 0 | 36 | 0 | " | NM | 1.43 | 2.0 |
| | Post GAC | 0 | 0 | 64 | 0 | " | NM | 0.09 | 0.2 |
| 4/16 | Influent | 95,000 | 4,000 | 25,000 | 270 | | | | 140 |
| | UNIT 1 | | | | | $Cl_2 + NH_3$ $Cl_1$" | NM | 1.40 | |
| | Settled | 30 | 0 | 260 | 0 | " | NM | 1.31 | 14 |
| | Filtered | 12 | 0 | 36 | 0 | " | NM | 1.30 | 3.0 |
| | Post GAC | 4 | 0 | 6 | 0 | " | NM | 0.15 | 0.35 |
| | UNIT 2 | | | | | Chlorine $Cl_1$" | 1.62 | 1.08 | |
| | Settled | 6 | 0 | 90 | 0 | " | 0.27 | 0.39 | 15 |
| | Filtered | 3 | 0 | 35 | 0 | " | 0.15 | 0.36 | 6.0 |
| | Post GAC | 4 | 0 | 200 | 0 | " | NM | 0.12 | 1.7 |
| 5/14 | Influent | 63,000 | 5,000 | 19,000 | 17 | | | | 170 |
| | UNIT 1 | | | | | $Cl_2 + NH_3$ $Cl_1$" | NM | 1.24 | |
| | Settled | 27 | 0 | 130 | 0 | " | NM | 1.19 | 5.6 |
| | Filtered | 2 | 0 | 3 | 0 | " | NM | 1.19 | 0.43 |
| | Post GAC | 0 | 0 | 16 | 0 | " | NM | 0.06 | 0.15 |
| | UNIT 2 | | | | | Chlorine $Cl_1$" | 0.90 | 0.57 | |
| | Settled | 27 | 0 | 60 | 0 | " | 0.15 | 0.24 | 8.5 |
| | Filtered | 0 | 0 | 7 | 0 | " | 0.03 | 0.21 | 0.92 |
| | Post GAC | 0 | 0 | 160 | 0 | " | NM | 0.06 | 0.20 |
| 5/30 | Influent | 28,000 | 2,600 | 8,000 | 1 | | | | 50 |
| | UNIT 1 | | | | | $Cl_2 + NH_3$ $Cl_1$" | NM | 1.34 | |
| | Settled | 0 | 0 | 51 | 0 | " | NM | 1.15 | 5.2 |
| | Filtered | 0 | 0 | 7 | 0 | " | NM | 1.19 | 1.0 |
| | Post GAC | 0 | 0 | 320 | 0 | " | NM | NM | 0.15 |
| | UNIT 2 | | | | | Chlorine $Cl_1$" | 1.28 | 0.36 | |
| | Settled | 4 | 0 | 20 | 0 | " | 0.24 | 0.27 | 3.7 |
| | Filtered | 1 | 0 | 1 | 0 | " | 0.12 | 0.21 | 0.78 |
| | Post GAC | 0 | 0 | 350 | 0 | " | NM | 0.12 | 0.20 |

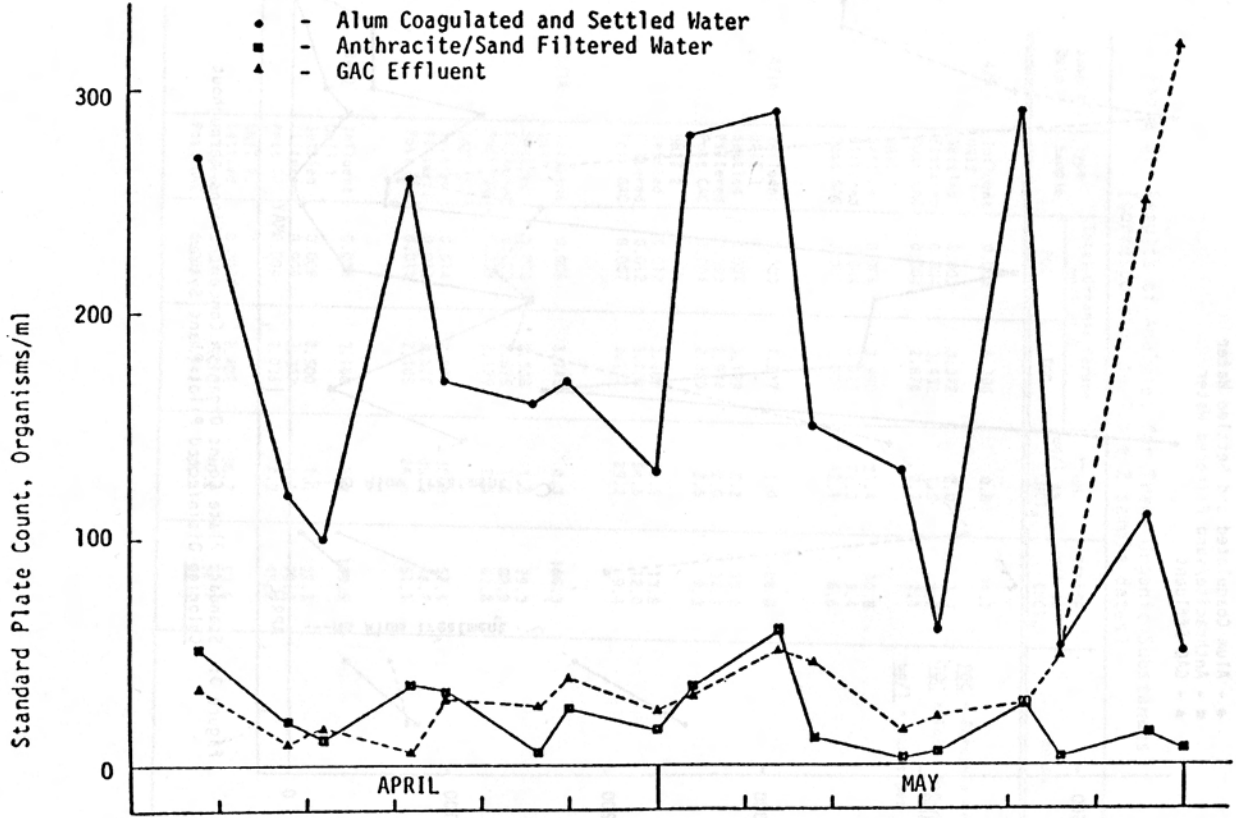


Figure 2: Standard Plate Count Organism Concentrations Throughout Chloramine Disinfected Pilot Plant System

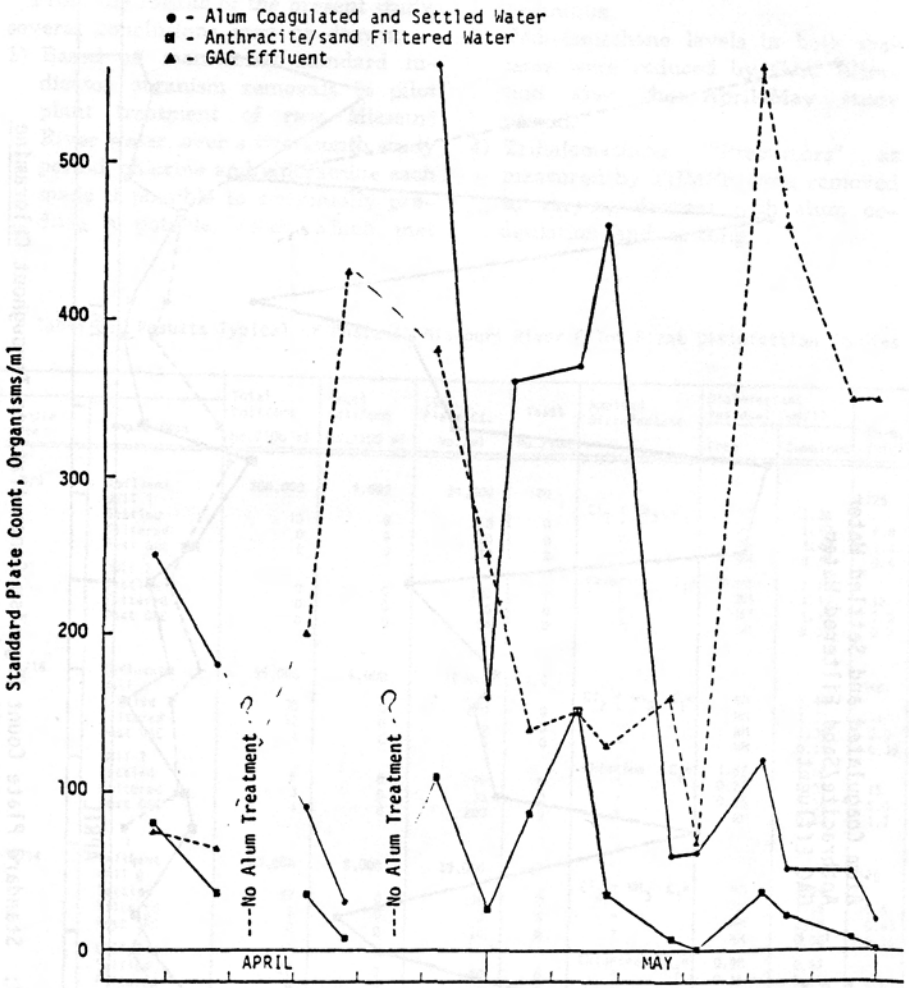


Figure 3: Standard Plate Count Organism Concentrations throughout Chlorine Disinfected Pilot Plant System

Table 3: Results of Analyses for Trace Organic Substances (corresponding to Table 2 sample dates)

| Sample Date | Type Sample | Total Organic Carbon mg/l as C | | TTHM ug/l as $CHCl_3$ | TTHMFP ug/l as $CHCl_3$ | Notes |
|---|---|---|---|---|---|---|
| | | POC | TOC | | | |
| 4/9 | Influent | 0.002 | 5.306 | 0.8 | 94.7 | |
| | UNIT 1 | | | | | |
| | Settled | 0.003 | 3.372 | 2.0 | 7.7 | |
| | Filtered | 0.004 | 3.433 | 1.9 | 8.2 | |
| | Post GAC | 0.002 | 2.876 | 2.1 | 7.1 | |
| | UNIT 2 | | | | | |
| | Settled | 0.006 | 3.980 | 21.4 | 10.8 | |
| | Filtered | 0.004 | 3.927 | 22.3 | 9.4 | |
| | Post GAC | 0.001 | 3.077 | 12.1 | 6.6 | |
| 4/16 | Influent | 0.003 | 4.917 | 1.0 | 108.0 | |
| | UNIT 1 | | | | | |
| | Settled | 0.004 | 3.129 | 2.2 | 10.0 | |
| | Filtered | 0.003 | 2.974 | 2.0 | 12.1 | |
| | Post GAC | 0.004 | 2.389 | 2.5 | 9.3 | |
| | UNIT 2 | | | | | |
| | Settled | 0.012 | 3.680 | 49.8 | 13.8 | |
| | Filtered | 0.012 | 3.724 | 54.6 | 12.0 | |
| | Post GAC | 0.007 | 3.135 | 29.2 | 9.4 | |
| 5/14 | Influent | 0.006 | 3.745 | 0.3 | 166.3 | |
| | UNIT 1 | | | | | |
| | Settled | 0.010 | 2.538 | 1.5 | 79.3 | |
| | Filtered | 0.009 | 2.675 | 1.6 | 80.9 | |
| | Post GAC | 0.009 | 2.129 | 2.6 | 63.8 | |
| | UNIT 2 | | | | | |
| | Settled | 0.014 | 2.505 | 38.3 | 57.4 | |
| | Filtered | 0.011 | 2.522 | 36.3 | 48.7 | |
| | Post GAC | 0.011 | 2.165 | 24.6 | 51.1 | |
| 5/30 | Influent | 0.003 | 3.160 | 0.2 | 149.5 | |
| | UNIT 1 | | | | | |
| | Settled | 0.006 | 2.500 | 1.1 | 32.3 | |
| | Filtered | 0.006 | 2.377 | 1.1 | 70.3 | |
| | Post GAC | 0.004 | 2.036 | 2.3 | 45.9 | |
| | UNIT 2 | | | | | |
| | Settled | 0.009 | 2.402 | 36.7 | 53.6 | |
| | Filtered | 0.008 | 2.270 | 40.2 | 36.7 | |
| | Post GAC | 0.006 | 1.941 | 26.1 | 51.6 | |

POC = Purgable Organic Carbon
TOC = Total Organic Carbon
ug/l = parts per billion

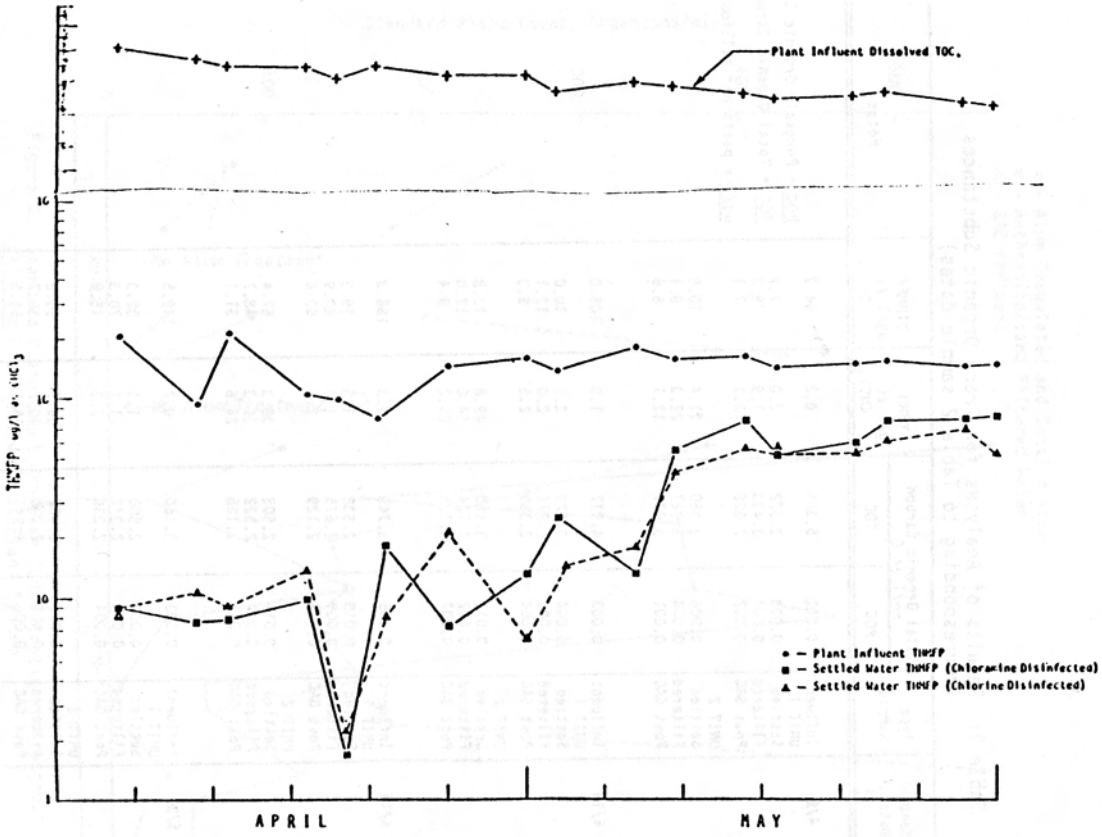


Figure 4: Trihalomethane Forming Potentials for Pilot Plant Treated Missouri River Water