ICR Treatment Study Summary Report

Evaluation of Granular Activated Carbon Pilot-Scale Testing for Compliance with the Information Collection Rule

Conducted during the period June, 1998 through May, 1999

Prepared by:
Ken DelRegno
Geri Wellborn
City of Oklahoma City
Water Utilities Department
3827 W. Hefner Road
Oklahoma City, OK 73120

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City of Oklahoma City, PWSID# OK 1020902
Water Utilities Department
420 W. Main
Oklahoma City, OK 73102

Lake Hefner Water Treatment Plant
ICR #545

Attachments: Three diskettes containing the Data Collection Spreadsheets, Summary Report Spreadsheet and QA/QC Data

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Section I. Conclusions and Recommendations

The Lake Hefner Water Treatment Plant GAC Treatment Study commenced in May 1998 and operated for 8000 hours, at which time the study was stopped. Following the initial 4000 hour run period, no Total Organic Carbon (TOC) breakthrough occurred, therefore an additional 4000-hour phase was added. Samples were collected at twenty-three intervals, including four duplicates.

The pilot GAC filter apparatus consisted of two filter elements connected in series to simulate 10 minute and 20 minute empty bed contact times (EBCT). Both filter times significantly reduced TOC concentrations from the influent water's average concentration of 3.21 mg l^{-1}. The 10-minute effluent TOC was reduced to 2.46 mg l^{-1} and the 20-minute effluent was reduced to 2.06 mg l^{-1}, reductions of 23.4 and 35.8 percent, respectively. These reductions alone could provide the necessary TOC removal suggested in the Interim Enhanced Surface Water Treatment Rule (IESWTR) for many plants. It has been our experience, however, that the effective life of the GAC is somewhat short of one year. If free chlorine were used as a primary disinfectant, this short effective life for organics removal would be very expensive. The Lake Hefner Plant has ten filters that contain 60 tons of GAC each. The cost for GAC in each filter is about $60,000.00 X 10 = $600,000.00 annually to achieve the TOC reduction. This would add a treatment cost of $22.00 per MG treated at Hefner at design flows.

During the 8000 hours of Pilot Plant operation in this Treatment Study, TOC breakthrough did not occur. The removal rate did appear to be reduced toward the end, however, wide fluctuations in applied water TOC concentrations did not allow for an idealized, smooth breakthrough curve.

It has been our experience at the Lake Hefner Plant that TOC removal by the full-scale Plant filters has continued beyond one year, principally due to biological activity made possible by pretreatment with ozone for disinfection. The filters continue to remove between 0.30 and 0.90 mg l^{-1} of TOC after being on-line for four years.

During the course of this treatment study, full-scale plant influent (raw) TOC averaged 5.3 mg l^{-1} with full-scale finished water TOC that was reduced to 3.1 mg l^{-1}, a removal rate of 42 percent. The difference between the TOC raw water levels and the pilot plant influent reflects the TOC removal that occurs in the ozone pretreatment and the solids-contact upflow clarifiers. The major TOC removal at the Lake Hefner Plant occurs during this pretreatment (greater than 30 percent reduction of influent TOC).

The use of ozone for disinfection coupled with chloramines for post-filtration distribution system disinfection has resulted in very low Plant effluent total trihalomethane (THM4) concentrations during the course of the ICR study (mean THM4 = 8.6 $\mu g\ l^{-1}$, s.d. = 2.4). Haloacetic Acids (HAA5) levels were also low (mean = 13.4 $\mu g\ l^{-1}$, s.d. = 6.9). These low levels of disinfection byproducts produced at Hefner are a result of the avoidance of free chlorine use anywhere in the process. It is not anticipated that any modifications to the Lake Hefner Plant will be necessary to comply with more stringent disinfection byproducts rules as they develop.

The advanced treatment process studied here is already in place at the Lake Hefner Plant, with the exception of pilot plant EBCT's. However, until additional filters are built at the Plant, the EBCT's that were investigated in this study (10 minute and 20 minute) cannot be achieved.

Section II. Background Information

The Lake Hefner Water Treatment Plant is an advanced ozonation facility that uses softening and biologically active granular activated carbon filtration in the treatment process. The general schematic of the Plant (Figure 1) describes the process and the chemical addition points. An expansion of Plant treatment capacity to its present 75 MGD was completed in summer, 1995. As part of that expansion, the entire process was changed to its present configuration.

The raw water source for Hefner Plant is Lake Hefner, a 2600-acre (75,000 acre-feet) off-channel impoundment of the North Canadian River in Central Oklahoma. The North Canadian River drains the Texas and Oklahoma panhandles, areas that contribute high salt and dissolved solids loading to the source water. Canton Lake is a U.S. Army Corps of Engineers in-channel impoundment of the North Canadian River located 90 miles upstream of Lake Hefner. The typical hardness in Canton Lake water is 500 mg l^{-1} with total dissolved solids ranging above 1000 mg l^{-1}. Because of the potential to impound such marginal water, Lake Hefner was constructed in the 1940's as an off-channel impoundment. It is filled by diverting North Canadian River water through a canal system. Lake Hefner has no outlet other than the Hefner Plant. Typically, water is diverted into Lake Hefner only after rainfalls that drain the River's watershed below Canton Lake. This results in hardness and TDS values that are about half of those normally present in the River.

The raw water from Lake Hefner is pumped from a lowlift pump station to the headworks of the Ozone Building. Sludge lagoon and filter backwash lagoon supernatants are recycled at this point. Ozone production capacity is 2300 pounds per day and is generated on-site. All disinfection credits at the Plant are generated with ozone. The ozone disinfection system is backed up with free chlorine, which has not been needed in the four years since startup.

Following ozone disinfection, the water flows through the Plant by gravity. Liquid ferric sulfate coagulant is added post-ozone at about 4.0 mg l^{-1}. The flow is split into three EIMCO solids contact upflow reactor/clarifiers. Slaked lime is added into the reaction zone of each clarifier at a rate of about 120 mg l^{-1}. The reaction zone pH is maintained at about 10.6. Reactor blowdown is sent to sludge lagoons at variable rates, depending on total solids in the reaction zone.

The water that overflows through the effluent launders of the clarifiers is subjected to first stage recarbonation to an initial setpoint of pH 9.8. Although a two-stage recarbonation system was installed that envisioned a second ferric sulfate dose at this point, experience has not demonstrated ant benefit, and therefore the second dosing point is not used. Two 1.5 MG sedimentation basins further remove some suspended solids.

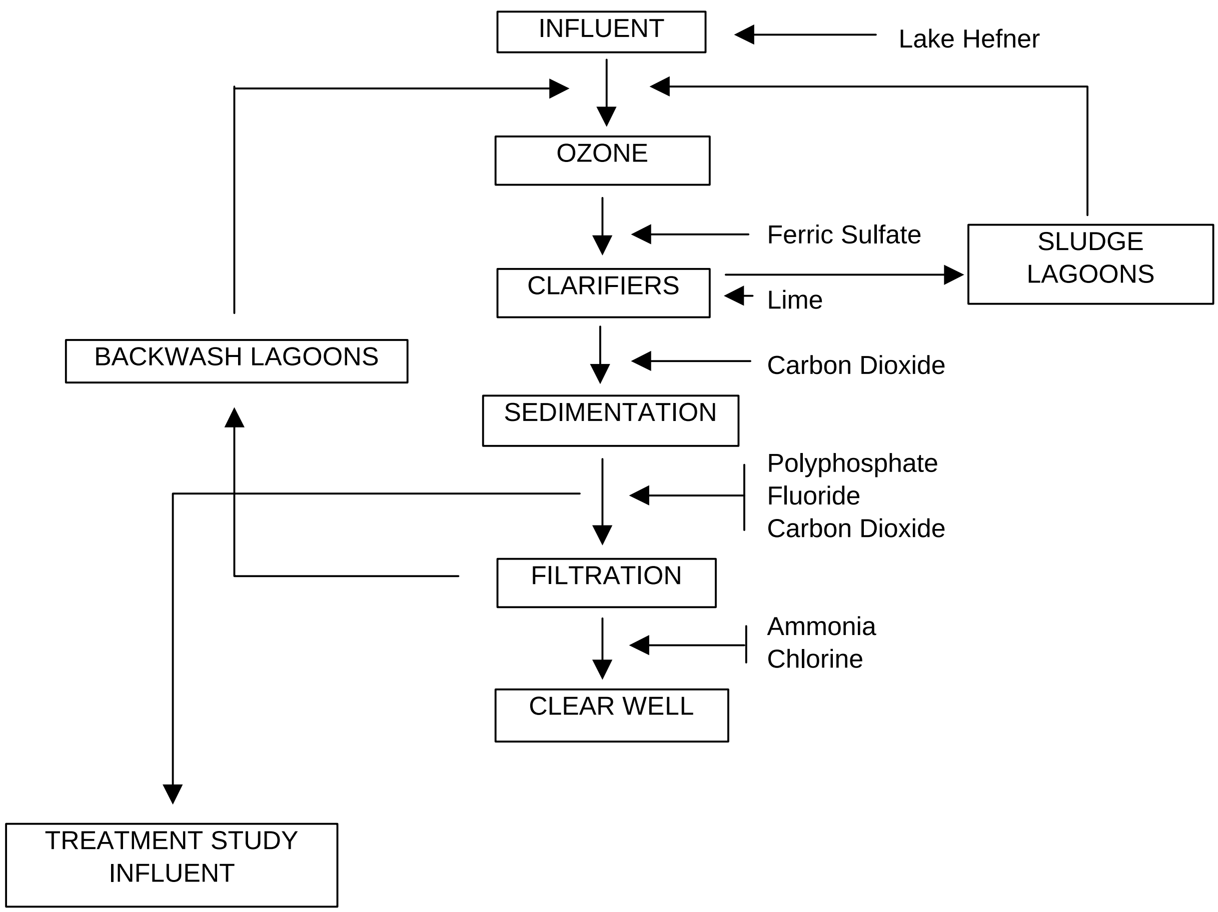

Figure 1. Schematic of Lake Hefner Water Treatment Plant

After the water exits the sedimentation basins, it flows into a junction structure where polyphosphate and fluorosilicic acid are added and second-stage recarbonation is accomplished. The pH setpoint is typically around 9.0, depending on Langelier Index results. Water from this point is applied to the filters and was the source water for the GAC Pilot Scale Treatment Study.

Following second-stage recarbonation, the water is filtered through ten high capacity filters that use a 36 inch bed depth of 8 X 20 mesh bituminous-based granular activated carbon. Empty bed contact time is as low as 6 minutes. Following filtration, the water is dosed with chlorine and ammonia at a ratio of 4.5:1 to achieve a finished water combined chlorine residual of 3.5 mg l^{-1}. This step causes a further reduction in pH that cannot be easily controlled. It is, however, fairly consistent and allows for effective control of finished water stability. The chloraminated water is stored in two 5 MG clear wells and is then pumped to the distribution system according to demand.

Table 1 contains a summary of basic engineering data for the Lake Hefner Plant. This is the same data that was submitted with the initial ICR plan report A.2, Design Plant Parameters. Table 2 contains a summary of Design Plant Chemical Parameters, first reported as report A.3 in the ICR *Water Utility Data Base System.*

Source water quality data for the final 12 months of the ICR sampling period (January – December, 1998) are presented in Table 3. The only constituent besides temperature that had a large fluctuation during the sampling period was turbidity, which ranged from 1.8 to 17.6 NTU (mean = 4.27). All other factors had much lower variability through the seasons.

Table 4 presents finished water quality data for the same sampling interval. One factor apparent from this data is the very low level of disinfection byproducts produced by the Lake Hefner Plant.

One of our concerns in the operation of the Lake Hefner Plant is the total hardness of our "softened" finished water (mean ~ 190 mg l^{-1}). The noncarbonate component of the finished water hardness ranges as high as 150 mg l^{-1}. Further increases in reaction zone pH in the clarifiers that would be needed to remove more noncarbonate hardness are not cost effective using lime. The Plant is not equipped at this time to use caustic soda or other chemicals for those pH increases.

Table 1. Summary of Basic Engineering Data for Lake Hefner WTP

Treatment Plant Name: Hefner Treatment Plant
ICR Treatment Plant ID: 545
Treatment Plant PWS ID: OK1020902
Treatment Plant Category: SOFT

State Approved Plant Capacity (MGD): 75.0
Historical Min. Water Temperature (deg C): 4.0
Installed Sludge Handling Capacity (DPD): 0.00
Blending Indicator: N

Water Resource Name: Hefner Lake
Water Resource Type: Reservoir/lake
Average Residence Time (Days): 1061
Intake Name: Hefner Intake Structure
Watershed Control: Y

Hydrologic Unit Code:
River Reach:
Latitude (degrees, minutes, seconds): +35°34'54"
Longitude (degrees, minutes, seconds): -97°35'24"
River Reach Miles:

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
	Influent	INF	1	
Process Train Name: Hefner Main Process				
Process Train Category: SOFT				
1	Washwater Retur	Washwater Return	3	Washwater Treated: Y Coagulation/Sedimentation: N Filtration: N Disinfectant Addition: N Plain Sedimentation: Y Other Treatment: 24 hr average Water flow Returned (MGD): 1.0
2	WWR Sample	Washwater Return Sample Point	15	

Table 1. (Cont'd)

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
3	Ozone Addition1	Disinfectant Addition		Chemical Code: O3 Measurement Formula: O3 Dose Rate (mg/L): 1.00
4	Ozone Chamber 1	Ozone Chamber	16	Type of Contactor: DI Ozone CT (mg/L x min): 0.6 Ozone Giardia Inactivation (log): 2.5 Ozone Virus Inactivation (log): 2.0 Ozone Concentration in Feed Gas (%): 2.5 Total Ozone Gas Flow Rate (SCFM): 900 Feed Gas Type: AI Chamber Volume (ft3): 21,138 Chamber Surface Area (ft2): 950 Water/Ozone Flow Regime in Chamber: Counter Current Flow Ozone Gas Flow Split (%): 10.0
5	Ozone Chamber 2	Ozone Chamber	18	Chamber Volume (ft3): 21,138 Chamber Surface Area (ft2): 950 Water/Ozone Flow Regime in Chamber: Counter Current Flow Ozone Gas Flow Split (%): 10.0
6	Ozone Addition3	Disinfectant Addition		Chemical Code: O3 Measurement Formula: O3 Dose Rate (mg/L): 1.00

Table 1. (Cont'd)

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
7	Ozone Chamber 3	Ozone Chamber	19	Chamber Volume (ft3): 21,138 Chamber Surface Area (ft2): 950 Water/Ozone Flow Regime in Chamber: Counter Current Flow Ozone Gas Flow Split (%): 10.0
8	Ozone Chamber 4	Ozone Chamber	20	Chamber Volume (ft3): 21,138 Chamber Surface Area (ft2): 950 Water/Ozone Flow Regime in Chamber: Counter Current Flow Ozone Gas Flow Split (%): 10.0
9	Ozone Chamber 5	Ozone Chamber	25	Chamber Volume (ft3): 21,138 Chamber Surface Area (ft2): 950 Water/Ozone Flow Regime in Chamber: Counter Current Flow Ozone Gas Flow Split (%): 10.0
10	Rapid Mix	Rapid Mix		Type of Mixer: HY Baffling Type: UN Liquid Volume (gal): 20,106 Short Circuiting Factor: Mean Velocity Gradient (sec-1): 0.0
11	Reactor Clar	Solids Contact Clarifier		Clarifier Type: SB Clarifier Type: RC Clarifier Type: UP Brand Name: EIMCO

Table 1. (Cont'd)

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
				Surface Area (ft2): 39,819 Liquid Volume (gal): 5,508,000 Short Circuiting Factor: Baffling Type: PR Plate Settler Surface Area (ft2): Tube Settler Surface Area (ft2): Plate Settler Brand Name: Tube Settler Brand Name:
12	Recarb 1	Recarbonation Basin		Surface Area (ft2): 300 Liquid Volume (gal): 17,952 Baffling Type: UN Short Circuiting Factor:
13	Sed Basin	Sedimentation		Surface Area (ft2): 24,192 Liquid Volume (gal): 2,950,000 Baffling Type: AV Short Circuiting Factor: Plate Settler Surface Area (ft2): Plate Settler Brand Name: Tube Settler Surface Area (ft2): Tube Settler Brand Name:
14	Recarb 2	Recarbonation Basin	10	Surface Area (ft2): 120 Liquid Volume (gal): 15,260 Baffling Type: UN

Table 1. (Cont'd)

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
				Short Circuiting Factor:
15	Filtration	Filtration	11	Surface Area (ft2): 8,880 Liquid Volume (gal): 431,745 Total Media Depth (in): 42 Depth of GAC (in): 36 Media Type: GACS Type of Activated Carbon: OT Minimum Water Depth To Top of Media (ft): 3.5 Depth From Top of Media to Top of Backwash Trough (ft): 2.5
16	Chlorine gas	Disinfectant Addition		Chemical Code: CL2 Measurement Formula: Cl2 Dose Rate (mg/L): 5.00
17	Anhydrous ammon	Disinfectant Addition		Chemical Code: NH3A Measurement Formula: NH3 Dose Rate (mg/L): 1.40
18	Clearwell	Clearwell	12	Surface Area (ft2): 105,780 Liquid Volume (gal): 10,000,000 Minimum Liquid Volume (gal): 3,000,000 Baffling Type: SP Short Circuiting Factor: Covered Indicator Code: Y

Table 2. Summary of Design Plant Chemical Parameters for Lake Hefner WTP

Sep. No.	Sample Location Name	Sample Location Type	Sample Location Number	Chemical Name	Measurement Formula	Dose (mg/L)
Treatment Plant Name: Hefner Treatment Plant						
ICR Treatment Plant ID No: 545						
Treatment Plant Category: SOFT						
Process Train Name: Hefner Main Process						
Process Train Category: SOFT						
1	Washwater Retur	Washwater Return	3			
2	WWR Sample	Washwater Return Sample Point	15			
3	Ozone Addition1	Disinfectant Addition		Ozone	O3	1.00
4	Ozone Chamber 1	Ozone Chamber	16			
5	Ozone Chamber 2	Ozone Chamber	18			
6	Ozone Addition3	Disinfectant Addition		Ozone	O3	1.00
7	Ozone Chamber 3	Ozone Chamber	19			
8	Ozone Chamber 4	Ozone Chamber	20			
9	Ozone Chamber 5	Ozone Chamber	25			
10	Rapid Mix	Rapid Mix		Ferric sulfate	FOS	9.40

Table 2. (Cont'd)

Sep. No.	Sample Location Name	Sample Location Type	Sample Location Number	Chemical Name	Measurement Formula	Dose (mg/L)
11	Reactor Clar	Solids Contact Clarifier				
				Calcium oxide	CaO	127.00
12	Recarb 1	Recarbonation Basin				
				Carbon dioxide	CO2	30.90
				Ferric sulfate	FOS	5.00
13	Sed Basin	Sedimentation				
14	Recarb 2	Recarbonation Basin	10			
				Carbon dioxide	CO2	15.40
15	Filtration	Filtration	11			
16	Chlorine gas	Disinfectant Addition				
				Chlorine gas	Cl2	5.00
17	Anhydrous ammon	Disinfectant Addition				
				Anhydrous ammonia	NH3	1.40
18	Clearwell	Clearwell	12			
				Other chemical	POS	2.00
				Hydrofluorosilic acid	HFS	0.60

**Table 3. Lake Hefner Water Treatment Plant
Source Water Quality Data**

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	17.21	9.07	3.4	27.8	12
pH	Unit	8.2	0.4	7.1	8.6	12
Turbidity	ntu	6.7	4.27	1.8	17.6	12
Alkalinity	mg/L as $CaCO_3$	142	10.8	129	158	12
Total Hardness	mg/L as $CaCO_3$	294	10.3	278	310	12
Calcium Hardness	mg/L as $CaCO_3$	157	12.9	124	170	12
TOC	mg/L	5.3	1.7	4.5	10.6	12
UV_{254}	1/cm	0.112	0.03	0.067	0.186	12
Bromide	µg/L	0.17	0.03	0.12	0.21	12

**Table 4. Lake Hefner Water Treatment Plant
Finished Water Quality Data**

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	18.44	7.56	8.1	27.9	12
pH	unit	8.5	0.22	8.2	8.9	12
Turbidity	ntu	0.23	0.09	0.16	0.45	12
Alkalinity	mg/L as $CaCO_3$	49	9.8	37	69	12
Total Hardness	mg/L as $CaCO_3$	205	14.1	186	227	12
Calcium Hardness	mg/L as $CaCO_3$	111	11.2	98	136	12
TOC	mg/L	3.1	0.79	2.2	5	12
UV_{254}	1/cm	0.042	0.01	0.022	0.058	12
DS-THM4	µg/L	8.6	2.4	6	12.1	5
DS-HAA5	µg/L	13.4	6.9	1	20.7	6

Section III. Materials and Methods

The pretreatment processes used prior to the advanced process (GAC filtration) in the Pilot Study were described in Section II of this report and are shown in Figure 1. Briefly, these processes involve ozonation for disinfection; liquid ferric sulfate addition for coagulation and flocculation; lime addition for softening; carbon dioxide addition at first-stage recarbonation; sedimentation; additions of polyphosphate for calcium sequestration, fluorosilicic acid for prevention of tooth decay and carbon dioxide for second-stage recarbonation. At this point in the process, a sample pump delivered the water to the pilot scale GAC plant, which was installed in the Hefner Plant Operations Laboratory. This configuration constituted the entire process leading up to the pilot plant and remained constant throughout the treatment study.

Figure 2 presents a schematic representation of the Pilot Scale GAC Plant Design used in the treatment study. The device was designed by the author and was constructed entirely from Teflon materials, including columns, end caps and tubing. Stainless steel valves connected the tubing. To prevent escape of the media, the ends of the 2 inch I.D. columns were lined with glass wool. The GAC media used in the investigation was Calgon Carbon Corporation Filtrasorb 820; an 8 X 20 mesh, bituminous-based product. A valve was attached to the full-scale Plant's applied water sample line located in the Operations Building laboratory. Flow to the pilot plant influent was controlled initially at this point.

The individual columns were connected in series to simulate 10 minute and 20 minute EBCT's. Valving allowed sampling and backwash, as necessary. An influent line valve further controlled the flow to the Pilot Plant. Flow was calibrated daily during the duration of the study and flow was adjusted accordingly to maintain the desired EBCT's. Backwash was only needed to clear air binding, which occasionally occurred during winter as the warmer laboratory air temperatures liberated dissolved gases from the water.

The entire full-scale plant processes and pilot-scale design are shown in Figure 3, which is essentially a merging of Figures 1 and 2. If one follows the arrows, the sequence of processes is fairly easy to understand.

The principal variable under investigation in the Treatment Study is the ability of GAC filtration to reduce total organic carbon (TOC), since its concentration in the raw water was the primary reason this study was required. The ability of GAC to affect other variables, primarily simulated distribution system disinfection byproducts, was also investigated. These variables are listed in Table 5, along with methods used in analysis and minimum reporting levels (MRL's). Seasonal variability in these analytes was not an

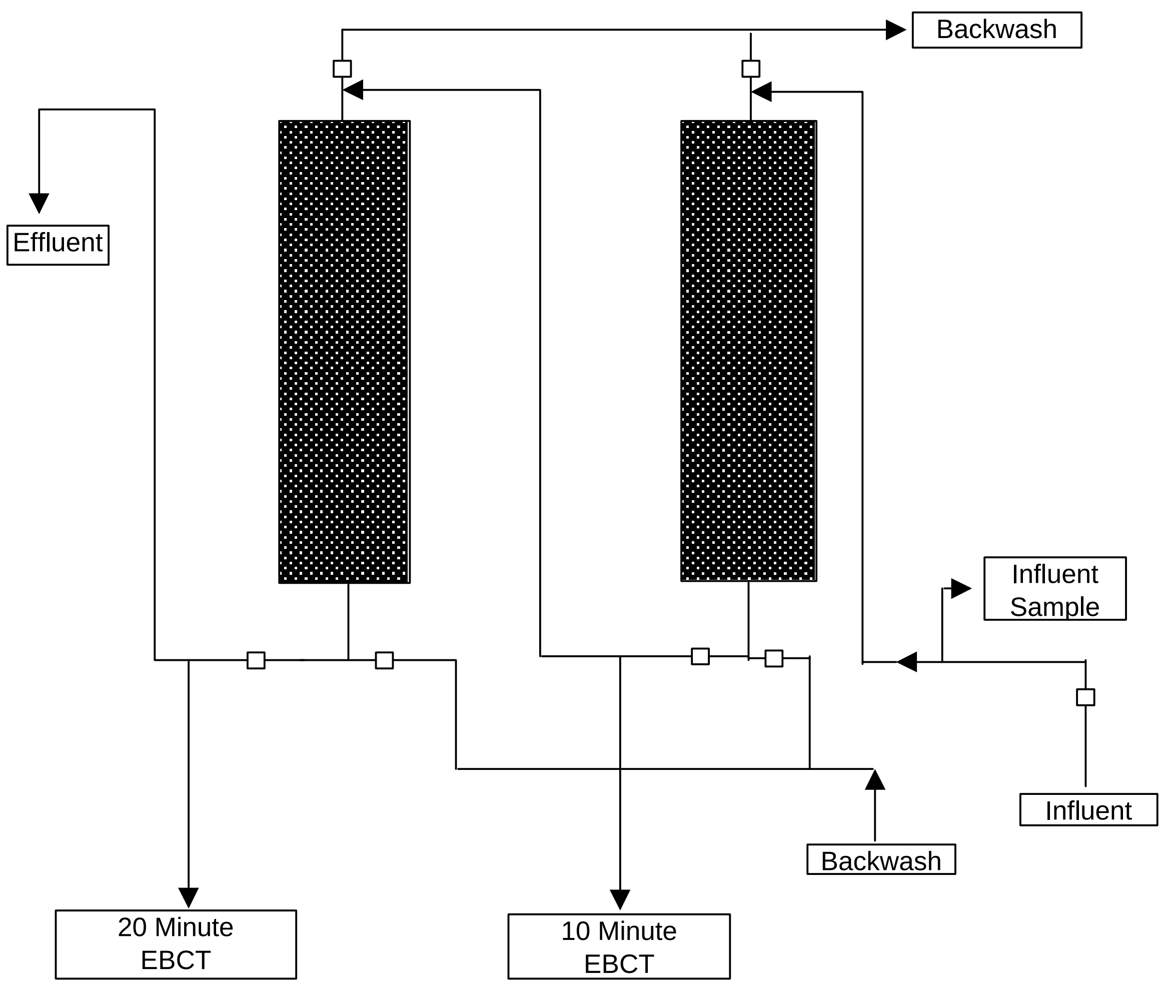

Figure 2. Pilot Scale GAC Plant Design

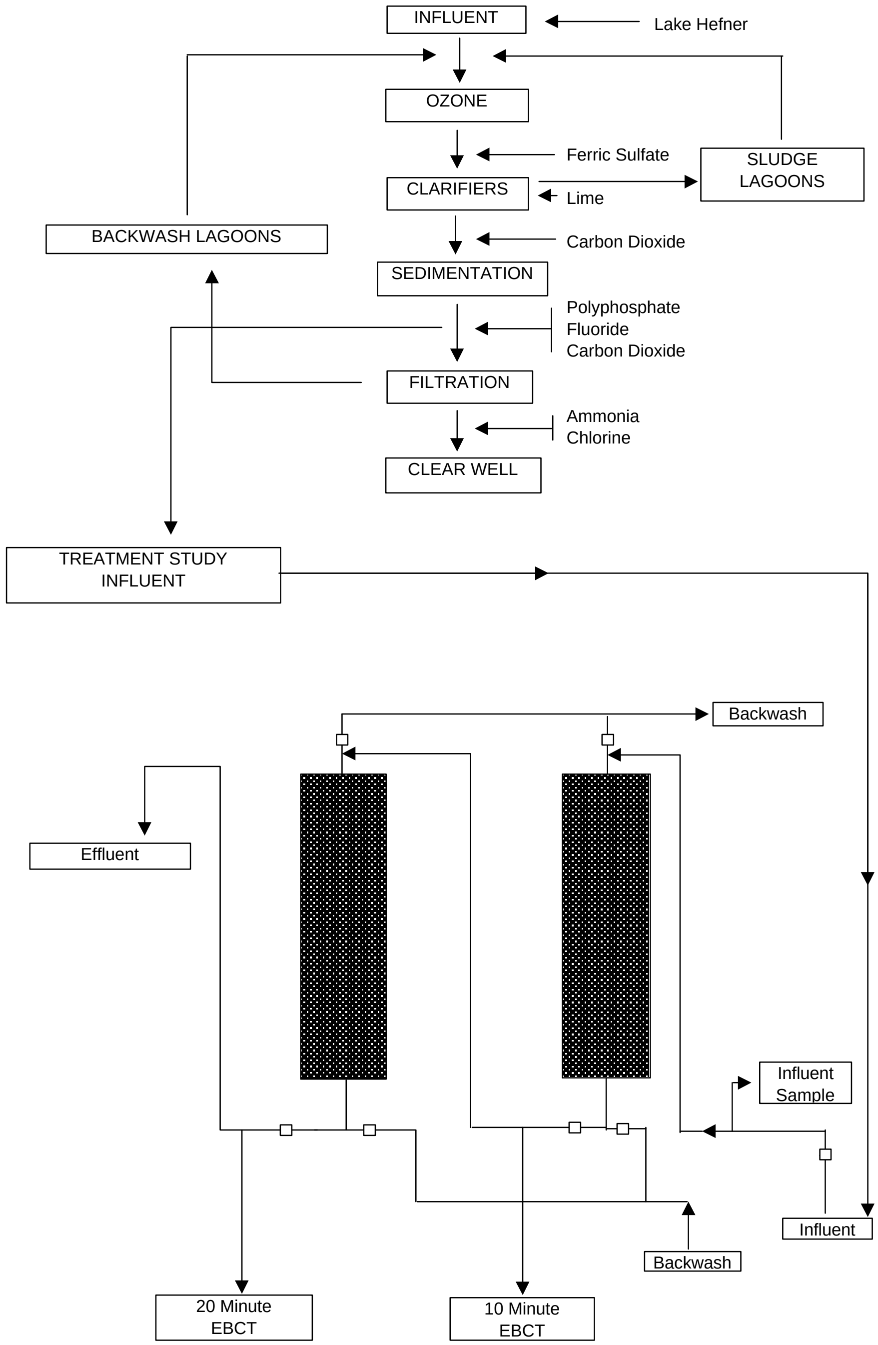

Figure 3. Pretreatment Processes and Pilot Plant Schematics

Table 5. Analytes and Methods for the Pilot Study

Analyte	Method	Minimum Reporting Level
Alkalinity	SM 2320 B	5 mg/L CaCO3
Ammonia	SM 4500-NH3D	0.10 mg/L NH3-N
Bromide	EPA 300.0	10 ug/L
Calcium Hardness	SM 3500-Ca D	5 mg/L CaCO3
Chlorine Residual	SM 4500-Cl D	0.2 mg/L
Haloacatic Acids	EPA 552.1	0.5 ug/L each
pH	SM 4500-H+	N/A
TDS	SM 2510 B	5.0 mg/L
Temperature	SM 2550 B	N/A
Trihalomethanes	EPA 551	0.5 ug/L each
Total Hardness	SM 2340 B	5 mg/L CaCO3
TOC	SM 5310 C	0.20 mg/L
TOX	SM 5320 B	10 ug/L
Turbidity	SM 2130 B	0.05 ntu
UV254	SM 5910	0.003/cm

initial focus of this study, however this variability is addressed in the subsequent section of this report.

Analyses of the samples were performed by the co-author in the Hefner Plant Laboratory and by two contract laboratories, E E & T Laboratories and Gannett Fleming Environmental Laboratory (Table 6). The duration of the analyses covered the length of the study, May 1998 through April 1999.

Table 6. Laboratories Performing Pilot Study Analyses

Laboratory	Dates of Service	Analyses Performed
Hefner WTP Laboratory 3827 W. Hefner Road Oklahoma City, OK 73120 ICR ID# OK 005 Jerry Sturm, Lab Supervisor Phone (405) 751-3001 FAX (405) 755-2357	May 1998-April 1999	Alkalinity, Calcium Hardness, Chlorine Residual, pH, TDS, Temperature, Total Hardness, TOC, Turbidity, UV254
E E & T Laboratories 712 Gum Rock Court Newport News, VA 23606 ICR# VA 001 Mark LaGuardia Phone (757) 873-1534 FAX (757) 873-2392	May 1998-April 1999	THM4, HAA6, TOX, Ammonia
Gannett Fleming Env. Lab. 209 Senate Avenue Camp Hill, PA 17011 ICR# N/A N/A Phone (717) 763-7211 FAX (717) 763-8150	May 1998-April 19	Bromide

Section IV. Results and Discussion

Seasonal variability was not seen to be a large factor in the pretreated water that was applied to the Treatment Study pilot plant. Table 7 presents a breakdown of mean pretreated water analytes for the four seasons of the study. Alkalinity varied temporally and was highest in winter and spring. It is believed that this was a result of the higher lime doses that are needed to maintain reaction zone sludge density in the clarifiers during colder weather. Mean Total Organic Carbon concentration was lowest in summer and may reflect the lack of rainfall during that season in 1998. The low standard deviation of summer data indicates a stable TOC source during that period.

All of the mean simulated distribution system (SDS) disinfection byproducts concentrations were significantly higher during the fall sampling periods. These higher levels were not related to a higher TOC concentration in the applied water. The high DBP levels may be related to a change in the nature of the components of the TOC, perhaps algae concentrations or factors related to lake turnover. This is only speculation since environmental factors in the Lake were not a focus of this study.

The source water quality data (Table 3) has a similar lack of variation with the exception of turbidity and TOC. As mentioned previously, Lake Hefner is an off-channel impoundment and is not directly influenced by rainfall runoff. Following rain events in the upstream watershed, water quality in the North Canadian River is monitored for total dissolved solids (as specific conductance). When TDS drops from around 1000 to about 500, the river water has been replaced by rainfall runoff and water is then diverted to Lake Hefner. This method also avoids “first flush” runoff and the resultant nutrient and organic compound loading associated with it. The turbidity peak in the source water occurred in November 1998 and most likely arose from a phenomenon where the inflow water from the canal moves directly across the lake to the Hefner Plant intake instead of mixing with the Lake water. This is exacerbated during higher withdrawals through the intake. Fall turnover can also have such an effect on lake turbidity.

The mean finished water data (Table 4) has even less variation than the other two data sets. This is primarily due to the excellent operation of the new facilities at the Lake Hefner Plant. Total Organic Carbon concentrations had the only large variability and reflected the wide ranges in raw water (4.5 – 10.6 mg l^{-1}). It is apparent from this and other in-house studies that TOC removal at the Hefner Plant is proportional to initial raw water concentrations. It cannot be removed to a constant final concentration the way turbidity or bacteria can regardless of initial loading.

Table 7. Seasonal Variability in Mean Pretreated Feedwater Analytes.

Parameter	Spring Mean (sd)	Summer Mean (sd)	Fall Mean (sd)	Winter Mean (sd)
pH	9.04 (0.17)	8.94 (0.36)	9.02 (0.18)	9.12 (0.06)
Turbidity (ntu)	0.30 (0.14)	0.33 (0.11)	0.35 (0.15)	0.40 (13)
Alkalinity (mg/L)	55.5 (7.01)	44.7 (4.57)	48.7 (8.35)	65.0 (4.53)
Temperature C	16.1 (3.37)	25.4 (2.43)	21.9 (4.98)	10.1 (3.46)
Tot. Hardness (mg/L)	204 (12.5)	189 (12.3)	217 (7.7)	216 (8.5)
Ca Hardness (mg/L)	111 (10.4)	116 (13.3)	123 (9.5)	122 (11.6)
Ammonia (mg/L)	BMRL	BMRL	BMRL	BMRL
Bromide (ug/L)	180 (14.1)	N/A	151 (13.5)	165 (30.0)
TOC (mg/L)	3.8 (1.47)	2.6 (0.47)	3.47 (0.96)	3.33 (0.52)
Uv254 A/cm	0.03 (0.01)	0.03 (0.01	0.03 (0.01)	0.03 (0.01)
SDS-TOX (ugCl/L)	80.3 (23.1)	78.1 (19.3)	113.9 (36.8)	65.9 (17.9)
SDS-THM4 (ug/L)	39.8 (17.1)	36.2 (23.4)	60.7 (16.4)	29.9 (5.7)
SDS-HAA5 (ug/L)	18.0 (14.1)	19.9 (15.9)	23.2 (8.1)	16.2 (5.3)
SDS-HAA6 (ug/L)	20.1 (15.2)	23.4 (16.9)	27.4 (8.9)	18.5 (6.0)

The impact of the pilot plant on the concentrations of the feedwater analytes can be seen in breakthrough curves that were constructed for this study. As mentioned previously, no breakthrough of TOC, UV_{254} or SDS DBP formation occurred during the 8000+ hours duration of the Treatment Study. The GAC performed its task well, producing a consistent reduction in TOC (Figure 4) throughout the study. Although breakthrough did not occur, reductions in the removal efficiency were apparent near the end of the process. UV_{254} had a similar response (Figure 5) and was nearing breakthrough as the study ended.

The effects of free chlorine dosing prior to SDS-DBP analyses were obvious. Free chlorine had a strong ability to produce relatively high levels of DBP's (influent SDS-THM_4 ranged as high as 76 ug l^{-1}). The GAC showed an excellent ability to reduce the levels of THM's (Figure 6). Again, no breakthrough behavior occurred, although late study reductions were obvious.

Simulated distribution system Haloacetic Acids (HAA_5 and HAA_6, Figures 7 and 8) showed similar reductions as the result of GAC filtration. Initial reductions in concentrations were small, however the removal increased through the middle of the study and then decreased toward breakthrough near the end.

These data support the initial expectation that longer EBCT's through the GAC produce lower levels of DBP precursors. Chlorine dosing prior to SDS sampling confirms that the reduction in DBP's is related to EBCT.

One of the goals of EPA, as stated in the *ICR Treatment Studies Data Collection Spreadsheet Users Guide*, is to use the results of the treatment study to estimate both the capital and O & M costs for incorporating the advanced treatment process into the existing plant. The advanced treatment process that was investigated here, GAC filtration, is already in place at the Lake Hefner Water Treatment Plant. As stated previously, the 10 minute and 20 minute EBCT's cannot be achieved with the existing ten filters. Preliminary plans have been made, however, to build an additional eight filters at the Hefner Plant in the near future. This would allow longer EBCT's that would be in the range of those used in this treatment study. The principal rationale for the construction of additional filters is the anticipation of further expansion of Plant capacity.

One issue that must be restated is the importance of using chloramines instead of free chlorine for distribution system residual disinfection. The data in Table 4 show the effects of chloramination on the Hefner Plant finished water during the main ICR sampling program. Total THM's averaged 8.6 ug l^{-1} and Haloacetic Acids averaged 13.4 ug l^{-1} even in the presence of finished water TOC concentrations of 3.1 mg l^{-1}. A previous study by the author (DelRegno and Rossen 1997) attributes the low concentrations of DBP's produced at Hefner more to the avoidance of free chlorine than to any other factor.

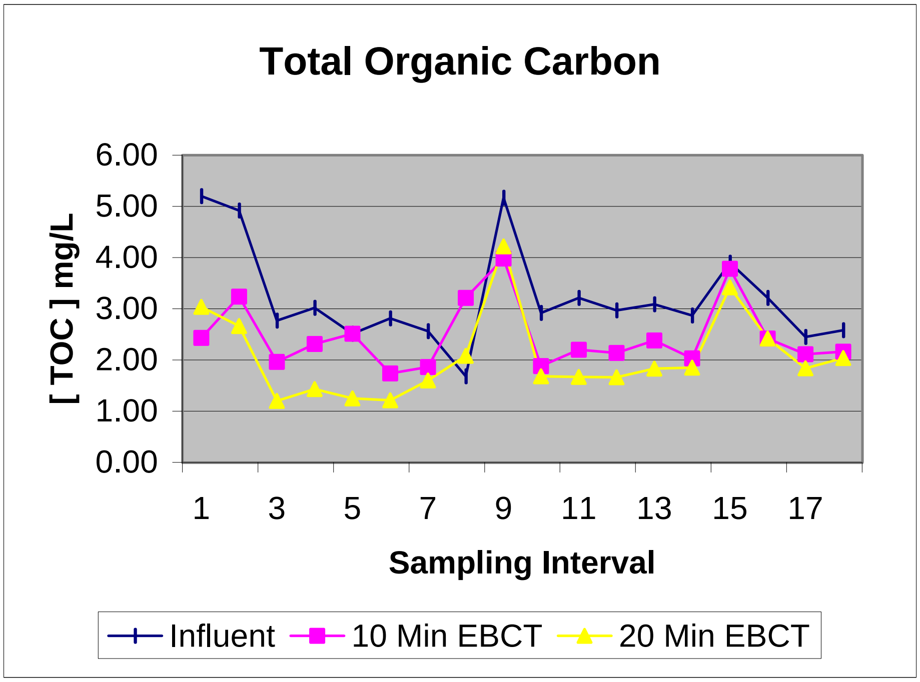

Figure 4. Total Organic Carbon Breakthrough Curve

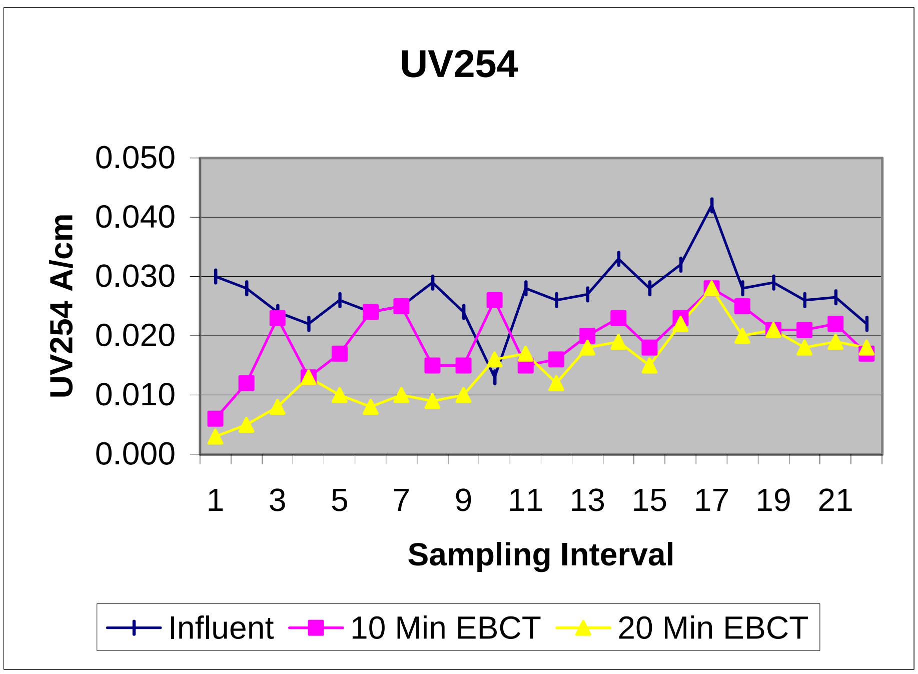

Figure 5. UV254 Breakthrough Curve.

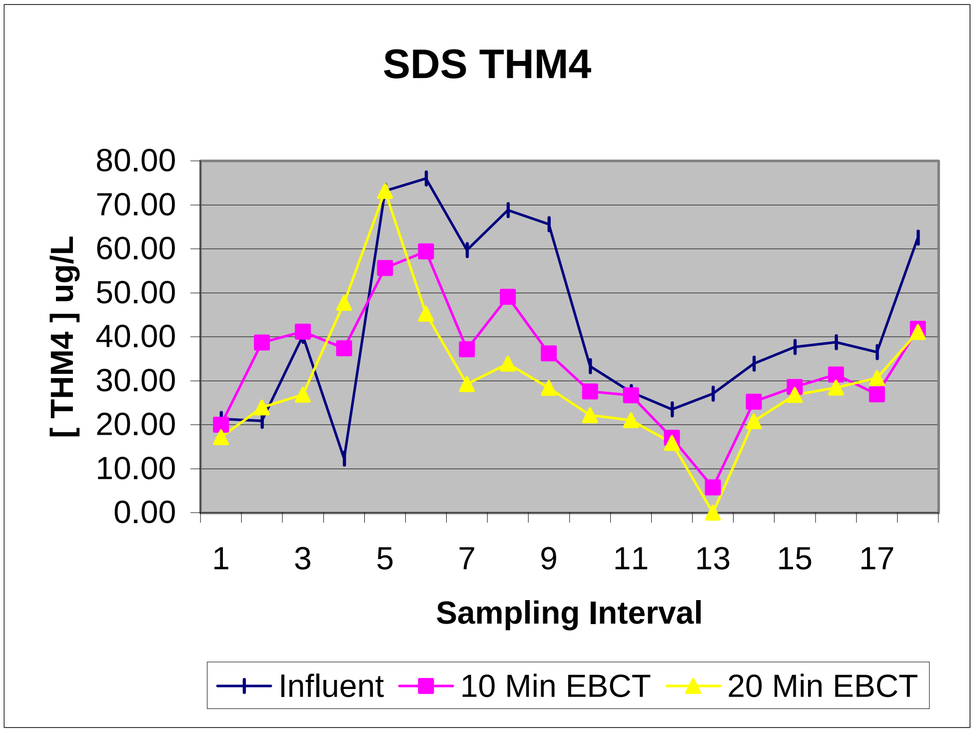

Figure 6. Total Trihalomethane (THM4) Breakthrough Curve.

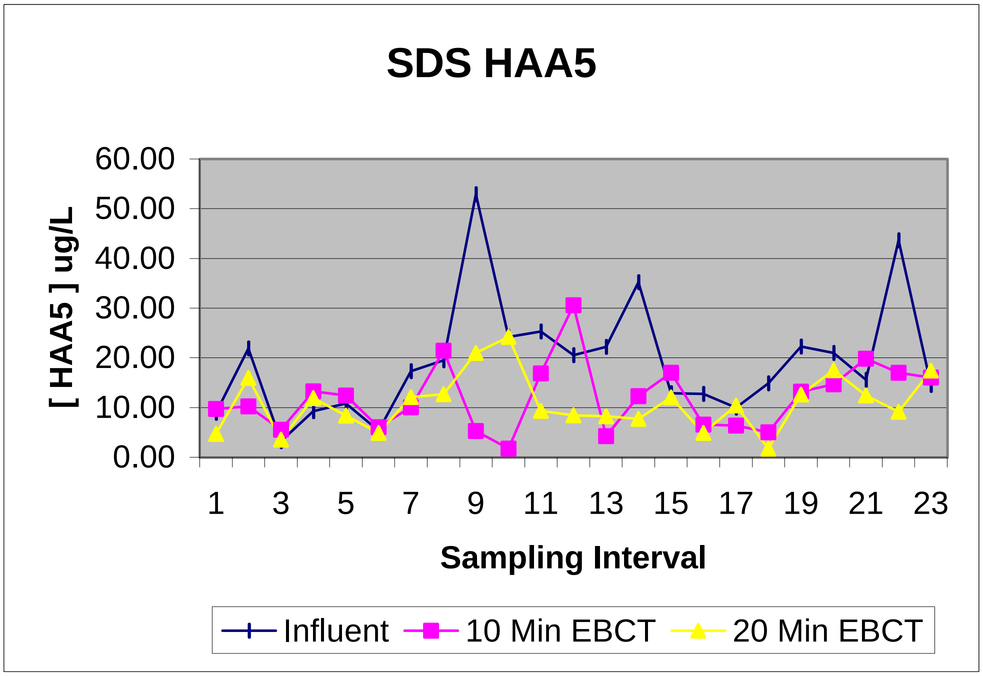

Figure 7. Haloacetic Acids (HAA5) Breakthrough Curve.

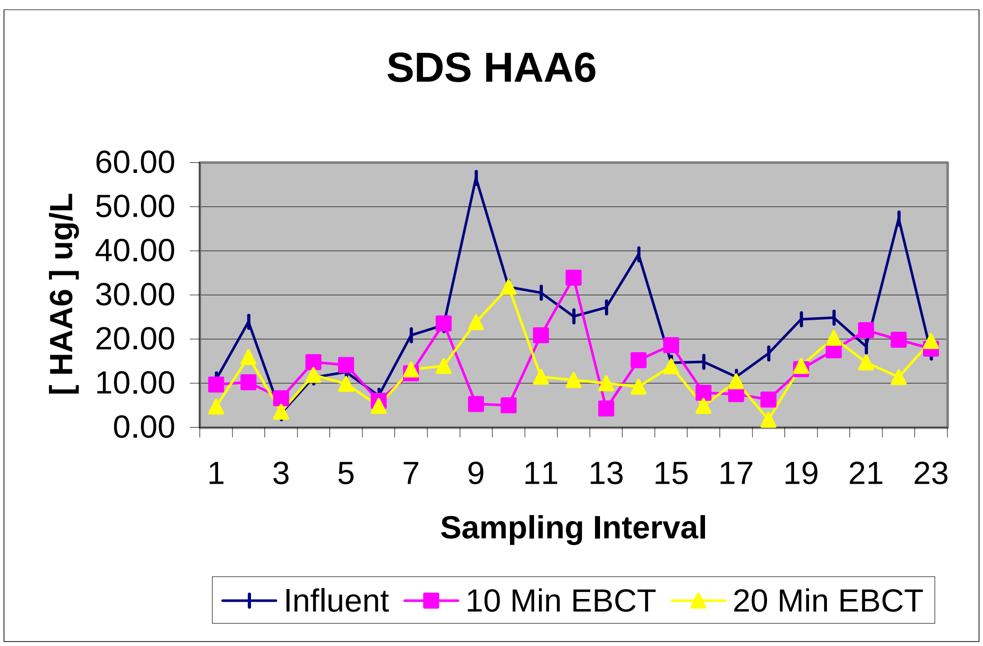

Figure 8. Haloacetic Acids (HAA6) Breakthrough Curve.

A final topic to mention is the problems encountered with the setup and operation of the GAC pilot plant. The materials used for the plant were difficult to obtain and fairly expensive. The Teflon tubing was stiff and very difficult to work with. In addition, this translucent tubing allowed algae to grow on the inside (remember, there is no prechlorination at Hefner). This was addressed by replacing the tubing and taping it to make it opaque to light.

The other main problem involved air binding in colder months when the air temperature in the lab warmed the water and released previously dissolved gases. When design flows could no longer be maintained, the apparatus was backwashed. This occurred four times during the study.

On one occasion, the pilot plant had to be disassembled to replace the glass wool after it was fouled with debris. No carbon loss occurred in this process. Flow was always easy to maintain by calibrating outflow and adjusting the influent valve accordingly.

Section V. QA/QC Summary

All analyses performed during the Lake Hefner WTP Treatment Study were conducted according to the QA/QC procedures described in the *DBP/ICR Analytical Methods Manual*. Field duplicates were collected for all analytes monitored during the study at the rate specified in the *ICR Manual for Bench- and Pilot-Scale Treatment Studies*. These results are reported in the *Data Collection Spreadsheets*, as required.

The results of all laboratory duplicates and spikes not listed in the *Data Collection Spreadsheets* are located in the respective laboratories. The Hefner Laboratory has retained a complete record of required QC. The analytes analyzed in the Hefner Lab for this treatment study include Alkalinity, Calcium Hardness, Chlorine Residual, pH, TDS, Total Hardness, Turbidity, UV_{254} and TOC. Independent QA/QC checks (Performance Evaluations) are included in the disk attachment titled HefnerQAQC.xls.

THM4, HAA6, TOX and Ammonia analyses were performed at E E & T Laboratory. They have retained the associated calibration procedures. The same is true for Bromide analysis at Gannett Fleming Environmental Lab. QA/QC data from these two contract labs are included in the *Summary Report Spreadsheet* that is included with this report.

At the Hefner Lab, TOC calibration involves the following procedures. The instrument is calibrated using 0.5, 4.0 and 10 mg l^{-1} standards. When a 0.5 mg l^{-1} standard is run, the result must be within 50 percent of the actual concentration. Then the samples are analyzed in duplicate with two matrix spikes analyzed every 10 samples. A midlevel standard of 4.0 mg l^{-1} is run after 10 samples and a high level standard is run after 20 samples. After the last sample is analyzed, a blank and check standard are run to confirm that the calibration curve is still accurate. All samples and standards are run in duplicate. The RPD is 20 percent for TOC values [2.0 mg l^{-1}. RPD is 10 percent for TOC values μ 2.0 mg l^{-1}. Check standards are 0.5 ! 50%, 4.0 mg l^{-1} ! 10 % and 10.0 mg l^{-1}. All matrix spikes are 4.0 mg l^{-1}.

For UV 254 analyses at Hefner Lab, no calibration curve is used. Samples are run at 254 nm in a 1 cm cell. All samples and standards are run in duplicate. A blank and a 0.5 mg l-1 standard are run to check the instrument's sensitivity and accuracy. The reading must be within 50% of 0.009 cm –1 every 10 samples. Halfway through the analysis, a 6.0 mg l-1 standard is analyzed. It must be within 15% of 0.088 cm –1. At the end of the run or after 10 samples, a 60 mg l-1 standard is analyzed and must be within 15% of 0.87 cm^{-1}. The RPD is [20% for [0.045 cm^{-1} and [10% for > 0.045 cm^{-1}. A batch consists of 30 samples or less run within a 24 hour period.

The QA/QC data for TOC and UV254 are included in the disk labeled HefnerQAQC.xls.

Appendix.

Hard Copy of Data Collection Spreadsheet