

ICR Treatment Study Summary Report

Evaluation of GAC Adsorption Using the Rapid Small Scale Column Test for Compliance with the Information Collection Rule

Conducted during the period of April 20, 1998 through March, 1999

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City of Shreveport T.L. Amiss Water Treatment Plant, ICR # 391

Attachments:
1 diskette containing the *Summary Report* (.pdf)
1 diskette containing the *Data Collection Spreadsheets* (.xls)
1 diskette containing the *Summary Report Spreadsheets* (.xls)
1 diskette containing quarterly QA/QC data and detailed lab results (.xls)

1. Conclusions and Recommendations

A treatment study was conducted by Montgomery Watson for the City of Shreveport T.L. Amiss Water Treatment Plant (WTP) to evaluate the removal of disinfection by-products (DBPs) precursors by granular activated carbon (GAC). As prescribed by the USEPA, the Rapid Small-Scale Column Test (RSSCT) was utilized as a bench-scale method to simulate full-scale GAC performance. The test was designed and conducted as required by the ICR Manual for Bench- and Pilot-Scale Treatment Studies. Four quarterly sessions were conducted to evaluate seasonal variability, and two empty-bed contact times (EBCTs) were evaluated during each session (10 and 20 minutes). During all four quarters, the chlorine dioxide feed was interrupted at least 24 hours before the sampling time, and the water sample was collected from the effluent of the intermediate ozonation basins. The water sample was then filtered on site through a 5- μ m and a 1- μ m cartridge filter before shipping to the laboratory. Full-scale distribution system conditions (pH, temperature, free chlorine residual, average residence time) were simulated during chlorination testing.

Seasonal variability had some impact on the control of DBP formation using GAC and thus on the cost of the process. This is expected since the T.L. Amiss WTP is served by a surface water source (Cross Lake) that undergoes some changes in water quality. The Summer and Fall quarters were observed to be the most critical for SDS-TTHM control. The higher SDS-TTHM concentration in the column effluent during these quarters was based on a higher influent TOC concentration and a high influent SDS-TTHM concentration.

The control of TTHMs was observed to be the critical issue for purposes of designing and estimating the costs of replacing GAC to meet upcoming regulations. Both the Stage 1 TTHM MCL and the “placeholder” Stage 2 TTHM MCL were exceeded during the four quarters, with the exception of the Winter quarter, during which the Stage 2 TTHM MCL was not exceeded for either EBCT. The Stage 2 HAA5 MCL was not exceeded during the course of the study.

In the 10-min EBCT contactor, the GAC replacement cost ranged from \$0.76/1000 gal of treated water during the Spring quarter to \$1.66/1000 gal during the Fall quarter. In the 20-min EBCT contactor, the GAC replacement cost ranged from \$0.57/1000 gal of treated water during the Winter quarter to \$1.92/1000 gal during the Summer quarter. The annual average GAC replacement cost was estimated at \$28,620,000 for a 10-min EBCT, and at \$29,647,500 for a 20-min EBCT. These high costs render GAC replacement an infeasible approach for the City of Shreveport. On-site GAC thermal reactivation costs were also estimated using the amount of GAC used to reach 80% of the Stage 2 TTHM MCL. Since the carbon usage rates fell beyond the range of the existing empirical equations, the costs for a fourth of the required hearth area were estimated, and then multiplied by a factor of four. Total annual costs (including amortized capital costs

for a reactivator) were estimated at \$5,258,356 for a 10-min EBCT, and at \$5,391,976 for a 20-min EBCT.

Annual capital and O&M costs for a conventional concrete gravity GAC adsorber were also calculated. These costs were based on an 63 mgd average flowrate. Annual amortized capital costs for a 10-min EBCT were estimated at \$509,843 and for a 20-min EBCT at \$829,277. When including the annual GAC reactivation costs to the annual O&M costs, the total annual costs were estimated at \$5,918,822 for a 10-min EBCT, and at \$6,371,876 for a 20-min EBCT.

2. Background Information

2.1 T.L. Amiss Water Treatment Plant Description

The City of Shreveport owns and operates the T.L. Amiss water treatment plant (WTP). The plant overall design capacity is 90 MGD. The WTP draws its water supply year-round primarily from the Cross Lake. The current average daily flow through the WTP is 42 MGD. The treatment plant is conventional and consists of pre-ozonation, rapid mix, flocculation, sedimentation, intermediate ozonation, filtration and a clearwell. Chlorine dioxide is applied in the influent to the WTP. Chloramines and chlorine dioxide are added to the ozonated water, before media filtration.

2.1.1 Treatment plant schematic

Figure 1 illustrates a simplified schematic of the water treatment processes three parallel identical trains, consisting of pre-ozonation, rapid mix, flocculation, and sedimentation. The flow from the first train is diverted into the second train following sedimentation. Two identical trains consisting of intermediate ozonation and filtration are then blended into the clearwell.

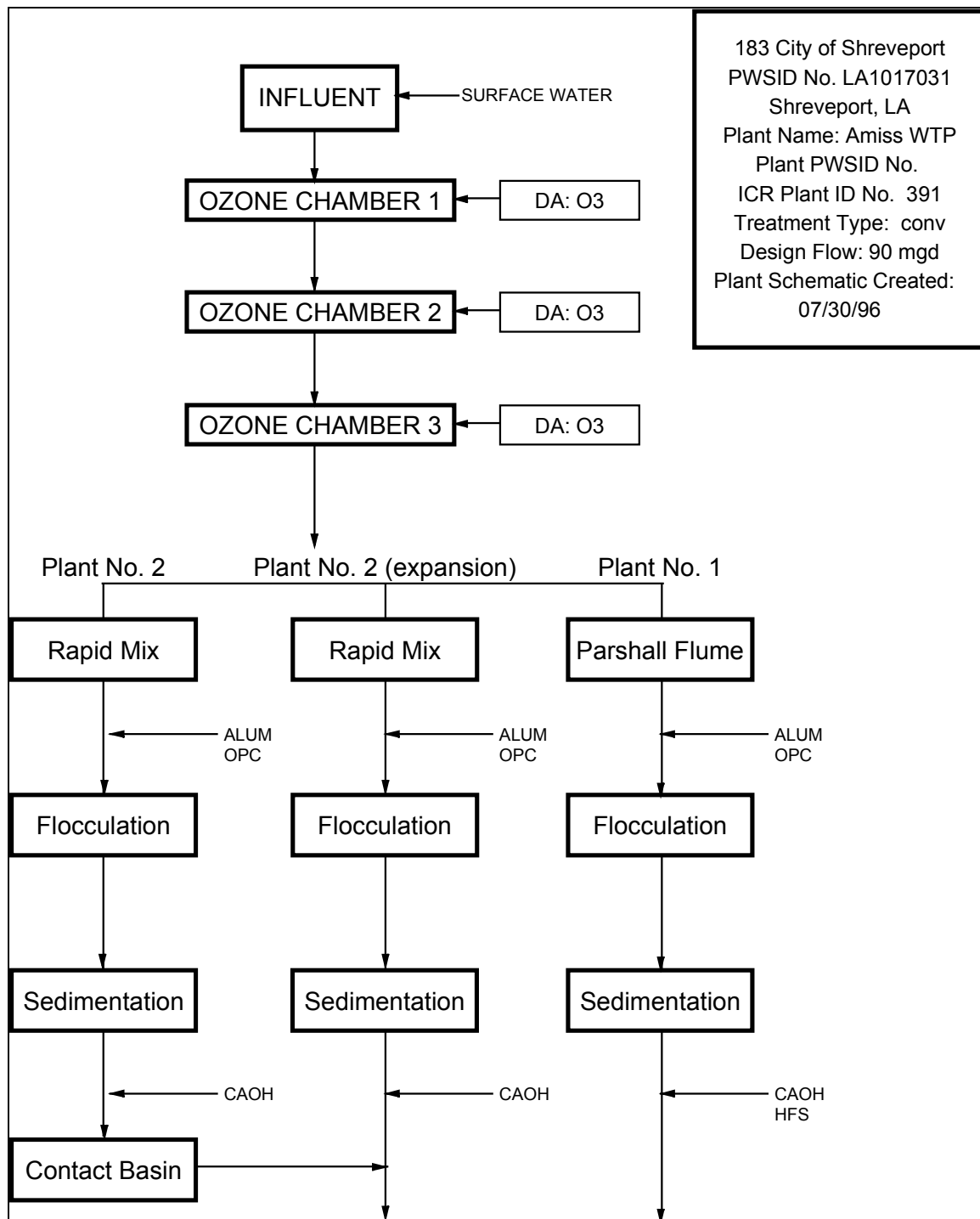


Figure 1. City Of Shreveport Amiss WTP Schematic

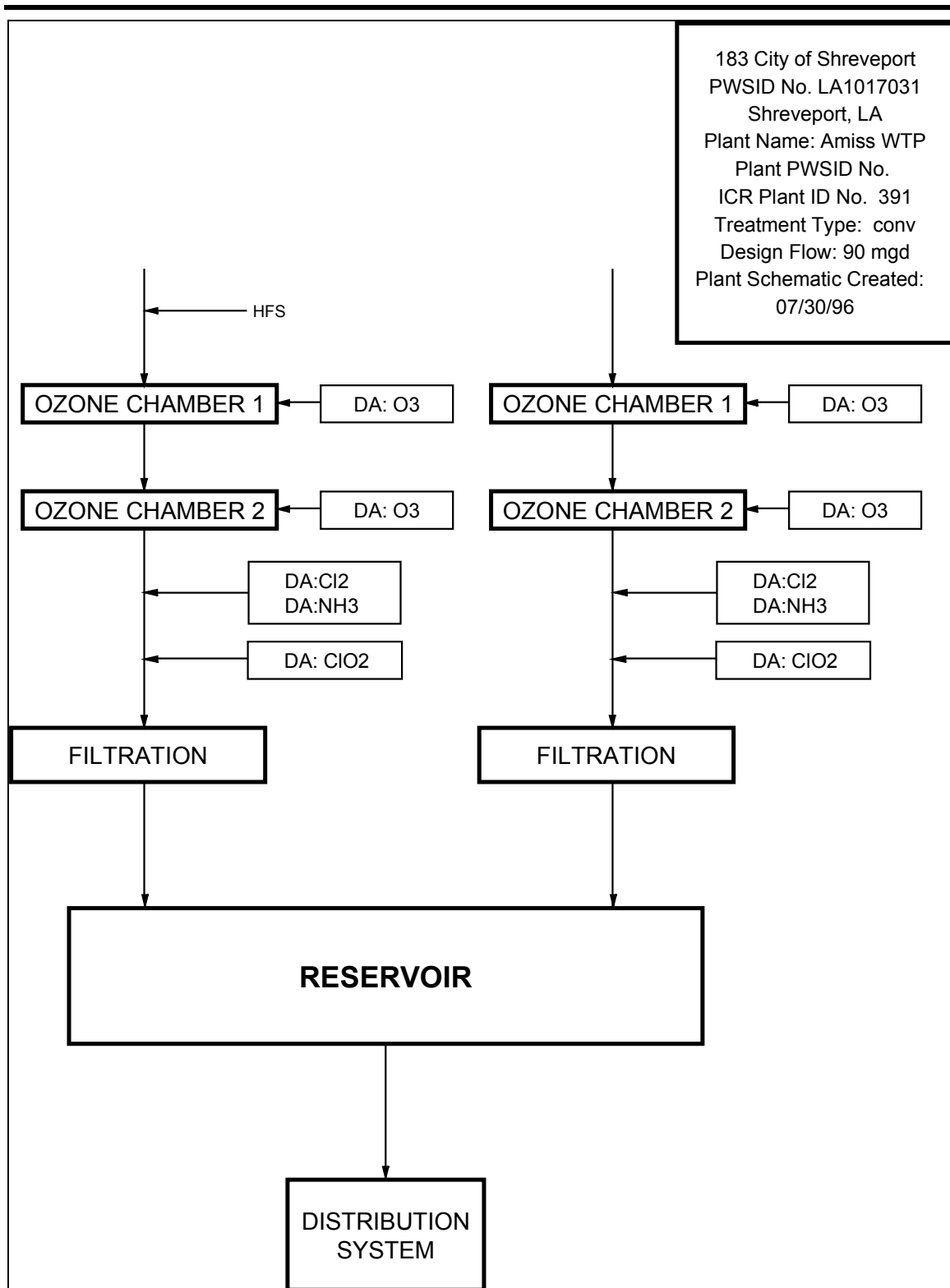


Figure 1 (continued).City of Shreveport Amiss WTP Schematic

2.1.2 Treatment plant design information

The following Table 1 summarizes the Amiss WTP design data. Rapid mix, flocculation and sedimentation design data are presented for the total of the three parallel trains.

Table 1
Treatment Plant Design Data

Unit Process	Process Description
Pre-oxidation	Chemical type: Chlorine dioxide (measured as: ClO_2) Dose rate (mg/L): 0.85
Pre-ozonation	Two chambers, Three cells per chamber Volume of each cell (cu-ft): 17,502 Depth of each cell (ft): 18.5 Ozone O_3 dose rate (mg/L): 2.5
Rapid Mixing	Type of Mixer: ME Baffling Type: UN Total Liquid Volume (gal): 33,896 Depth (ft): 8.33 Mean Velocity Gradient (sec-1): 760.0
Coagulation	Coagulant addition in rapid mixer: $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$ Alum dose (mg/L): 46.22 Organic Polymer addition in rapid mixer: OPC (coagulant aid) OPC dose (mg/L): 1.0
Flocculation	Type of Mixer: 3 stages Liquid Volume per Stage (gal): 272,073 Total Volume (gal): 816,218 per 40 MGD Depth (ft): 12.4 Baffling Type: UN Stage 1 Mean Velocity Gradient (sec-1): 80 Stage 2 Mean Velocity Gradient (sec-1): 60 Stage 3 Mean Velocity Gradient (sec-1): 40
Sedimentation	Surface Area (ft ²): 48,510 Total Liquid Volume (gal): 4,862,254 Depth (ft): 13.4 Baffling Type: UN
Lime Addition	Chemical type: CaOH Dose rate (mg/L): 20.54
Hydrofluosilicic Acid Addition	Chemical type: HFS Measured as: F^- Dose rate (mg/L): 0.8
Post-Ozonation	Two chambers, Two cells per chamber Volume of each cell (cu-ft): 14,430 Depth of each cell (ft): 18.5 Ozone O_3 dose rate (mg/L): 1.0
Final Disinfection	Cl_2 dose rate (mg/L): 4.6 NH_3 dose rate (mg/L): 1.0 ClO_2 dose rate (mg/L): 0.2
Filtration (8 filters)	Total Surface Area (ft ²): 8,880 Total Liquid Volume (gal): 664,000 Total Media Depth (in): 28 Media type: DUAL Minimum Water Depth to Top of Media (ft): 3.0 Depth from Top of Media to Top of Backwash Trough (ft): 3.0
Clearwell	Surface Area (ft ²): 109,350 Liquid Volume (gal): 15,000,000 Minimum Liquid Volume (gal): 3,000,000 Baffling Type: AV

2.2 Tabular summary of source/finished water quality

Table 2 presents the average, minimum and maximum values for selected water quality parameters in the influent to the Amiss WTP using data collected monthly between January 1998 and December 1998. The water quality data can also be found in the Treatment Study Summary Report Spreadsheet. A printout of the spreadsheet is attached at the end of the document as Appendix B.

Table 2
Summary of Raw Water Quality at the Amiss WTP
(January 1998 through December 1998)

Source Water Quality Parameter	Average Value	Standard Deviation	Minimum Value	Maximum Value
Temperature (°C)	20	7	9	30
pH	7.2	0.3	6.6	7.7
Turbidity (NTU)	9.97	5.55	4.73	24.2
Total Alkalinity (mg/L as CaCO ₃)	49	23	24	83
Total Hardness (mg/L as CaCO ₃)	72	36	37	147
TOC (mg/L)	7.2	0.8	6.0	8.7
UV-254 (cm ⁻¹)	0.221	0.071	0.144	0.384
TSUVA (L/mg-m)	3.11	1.01	2.22	5.49

Table 3 summarizes average finished water quality at the Amiss WTP.

Table 3
Summary of Finished Water Quality at the Amiss WTP
(January 1998 through December 1998)

Finished Water Quality Parameter	Average Value	Standard Deviation	Minimum Value	Maximum Value
pH	9.0	0.4	8.5	9.6
Turbidity (NTU)	0.21	0.09d	0.09	0.35
TOC (mg/L)	4.3	0.5	3.7	5.0
UV ₂₅₄ (cm ⁻¹)	0.073	0.009	0.057	0.092
TTHM (µg/L)*	20.6	6.3	13.3	26.2

* Based on four quarterly sampling campaigns (03/98; 06/98; 09/98; 12/98). Measured in the distribution system at the average residence time site (Reily #21)

3. Materials and Methods

3.1 Raw Water Collection Procedures

Under the ICR, the feed water to the treatment study must be collected from a location in the treatment train before any application of oxidant that could form chlorinated by-products. For the Amiss WTP, chlorine dioxide is added at the beginning of the treatment train. However, for the purpose of the RSSCT, the chlorine dioxide feed was interrupted at least 24 hours before and during the course of sample collection. The sample was hence collected from the effluent of the post-ozonation basins. Four quarterly samples were collected throughout the year to investigate seasonal variability. Table 4 presents the four sampling dates.

Table 4
Quarterly Sampling Dates

Quarter	Sampling Dates
Spring	April 20, 1998
Summer	July 28, 1998
Fall	October 8, 1998
Winter	January 7, 1999

A total of 200 gallons of water were collected during each quarter from the effluent of the post-ozonation tanks and filtered on-site through a 5- and a 1- μ m cartridge filters to reduce potential biological growth during sample shipping. Two 100-gal polyethylene tanks were used for sample collection. Tanks were rinsed with tap water and deionized (DI) water prior to shipping. Upon arrival at the laboratory, samples were shipped to Montgomery Watson's Applied Research Laboratory via FFE refrigerated trucks. Samples were immediately refrigerated at 4°C until the day of testing.

Upon receipt of the samples, the ozonated/filtered water was analyzed for general water quality parameters to verify sample representativeness.

3.2 Pretreatment Processes

3.2.1 Description of pretreatment processes

Since chlorine dioxide feed to the influent of the WTP was interrupted, full-scale filtration was the only treatment process removing TOC that was simulated. This

consisted of a sequential filtration through a 0.45- μm cartridge filter and through an on-line 0.2- μm membrane.

3.3 Design Data for the Advanced Treatment Processes

3.3.1 RSSCT set-up information

Figure 2 illustrates the RSSCT column set-up.

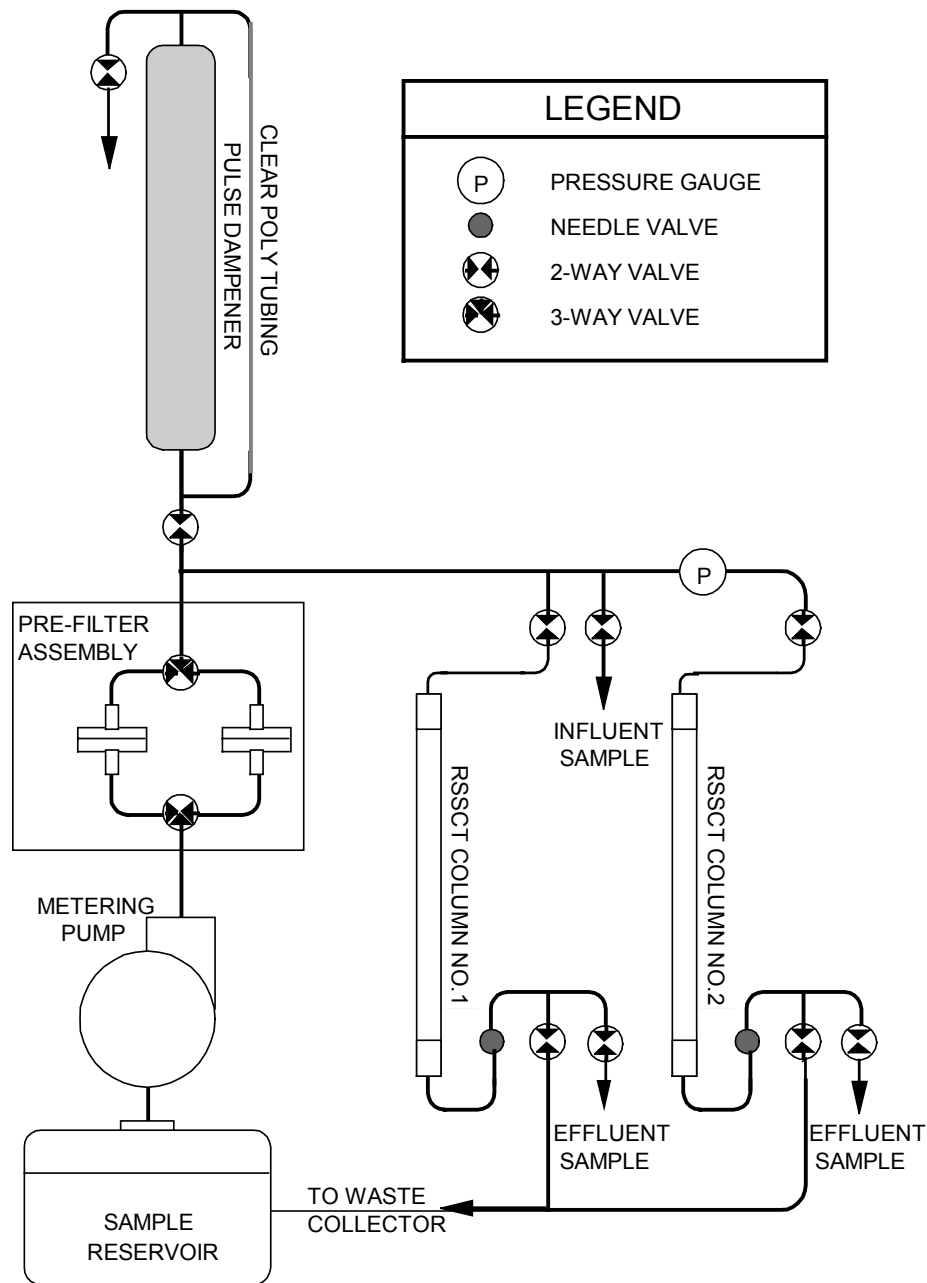


Figure 2. RSSCT Flow Diagram

All components were made of stainless steel, glass, or Teflon construction. Glass columns were used. The batch influent water was held in collapsible 5-gallon low-density poly-ethylene (LDPE) cubitanors. The influent water was pumped to each column using a single metering pump. A pre-filter (0.2 μm) on-line assembly was set-up at the influent of the columns to minimize headloss build-up in the columns. The metering pump had a flowrate range of 0 to 51.8 mL/min and was operated at a range of

10 to 40 psi (capacity of 100 psi). A stainless-steel cylinder was used as a pulse dampener. Two pressure gauges were used to monitor (1) the influent pressure to the pre-filter and (2) the pressure build-up in the columns. Flow-rates were monitored by determining sample volumes and time intervals. In the case where the measured flow-rates were determined to differ from the design value by more than 5%, Nupro needle valves, connected at the effluent of each column, were adjusted to balance the flow-rates.

3.3.2 Design data for the GAC process

During the four quarters of testing, two columns were operated to simulate full-scale empty-bed contact times (EBCTs) of 10 and 20 minutes, as prescribed by the ICR. A sample of 12×40 US Standard Mesh GAC (apparent particle diameter, d_{LC} , of 1.053 mm) was ground to a 100×200 US Standard Mesh (particle diameter, d_{SC} , of 0.1125 mm), resulting in a scaling factor of 9.36. A bituminous coal based GAC from Calgon Carbon Corp. (F-400), was used in this study. A minimum Reynolds number Re_{SC} of 0.5 was used as recommended by the ICR Guidance Manual. An 8-mm RSSCT column diameter was used in the two columns during the Spring quarter, while an 11-mm RSSCT column diameter was used in the two columns during all other quarters. An on-line pre-filter consisting of a 0.2- μ m membrane was used to reduce the headloss build-up in the GAC columns. The design parameters applied during each quarter are summarized in Table 5.

Table 5
RSSCT Design Parameters

Design Parameters	Quarter 1	Quarter 2	Quarter 3	Quarter 4
RSSCT influent TOC (mg/L)	3.7	5.0	4.4	4.6
Inner diameter of the RSSCT column, D_{SC} (mm)	8.0	11.0	11.0	11.0
Minimum RSSCT Reynolds number, $Re_{SC, min}$	0.5	0.5	0.5	0.5
Full-scale operating temperature, T^0 ($^{\circ}C$)	20.0	20.0	20.0	20.0
Full-scale bed porosity, ϵ_{LC}	0.45	0.45	0.45	0.45
Measured RSSCT dry bed density, ρ_{SC} (g/cm ³)	0.5	0.5	0.5	0.5
RSSCT GAC mesh size, upper (US standard mesh)	100	100	100	100
RSSCT GAC mesh size, lower (US standard mesh)	200	200	200	200
Estimated Run Length				
Bed volumes to 50% TOC breakthrough, BV_{50}	3961	2678	3162	2985
Estimated run length, BV_T ($= 2 \times BV_{50}$)	7922	5356	6324	5969
$BV_T + 30\%$ safety factor, $BV_{T+30\%}$ ($= 2.6 \times BV_{50}$)	10298	6963	8221	7760
General RSSCT Design Parameters				
Kinematic viscosity at T^0C , ν_{LC} (m ² /s)	1.027E-06	1.027E-06	1.027E-06	1.027E-06
RSSCT carbon particle diameter, d_{SC} (mm)	0.1125	0.1125	0.1125	0.1125
Scaling factor, SF	9.36	9.36	9.36	9.36
RSSCT hydraulic loading rate, ν_{SC} (m/hr)	7.39	7.39	7.39	7.39
RSSCT flow rate, Q_{SC} (mL/min)	6.19	11.71	11.71	11.71
Estimated total influent volume required, V_{SC}^T (L)	204	261	309	291
10-Minute EBCT Run				
Full-scale empty bed contact time, $EBCT_{LC}$ (min)	10	10	10	10
Estimated full-scale run time, t_{LC}^T (days)	72	48	57	54
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	1.07	1.07	1.07	1.07
Estimated RSSCT run time, t_{SC}^T (days)	7.64	5.17	6.10	5.76
RSSCT bed length, l_{SC} (cm)	13.2	13.2	13.2	13.2
Estimated volume required for 10-minute EBCT, V_{SC} (L)	68	87	103	97
Mass GAC required, m_{SC} (g)	3.31	6.26	6.26	6.26
20-Minute EBCT Run				
Full-scale empty bed contact time, $EBCT_{LC}$ (min)	20	20	20	20
Estimated full-scale run time, t_{LC}^T (days)	143	97	114	108
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	2.14	2.14	2.14	2.14
Estimated RSSCT run time, t_{SC}^T (days)	15.29	10.34	12.21	11.52
RSSCT bed length, l_{SC} (cm)	26.3	26.3	26.3	26.3
Estimated volume required for 20-minute EBCT, V_{SC} (L)	136	174	206	194
Mass GAC required, m_{SC} (g)	6.62	12.51	12.51	12.51

3.3.3 Procedures Specific to the treatment study

3.3.3.1 Carbon Preparation

Each column contained two threaded Teflon fittings at the top and bottom. A stainless-steel screen was placed at the bottom of each column. Glass-wool was packed on top of the screen to prevent fines from going into the effluent and from clogging the column. The F-400 Calgon carbon was ground and sieved to the 100×200 US Standard Mesh size (particle diameter of 0.1125 mm), and washed with DI water. Washing the carbon consisted of mixing it and allowing it to settle for 30 seconds to two minutes. The supernatant was wasted and the procedure was repeated several times until the supernatant becomes clear. After washing, the carbon was dried overnight to a constant weight at a temperature of 80°C. The temperature was then increased to 100°C for 4 hours. After the carbon was dried and dessicated, the mass was checked to make sure that it did not differ by more than 5% from the previous recorded weight. The required amount of carbon was then prewetted by placing it into an Erlenmeyer flask and adding DI water to a level of about one inch over the carbon surface. The GAC was then de-gassed by applying vacuum for 5 minutes to remove the air pockets from the carbon particles. The carbon was then transferred to the columns and allowed to settle making sure that no air bubbles were introduced to the column. The top cap was screwed on allowing no head-space formation in the column. Once the columns were loaded and connected to the RSSCT setup, DI water was used to set the flow-rates in the system.

3.3.3.2 RSSCT monitoring

The effluent flow rate was monitored frequently and adjusted as necessary to maintain it within 5 percent of the design flow rate. The system pressure was also monitored. The effluent TOC concentration was monitored frequently to ensure samples were taken at 5 to 8 percent increments of the average influent TOC concentration. Samples were analyzed for all required parameters using ICR-approved analytical methods.

3.3.3.3 Headloss buildup

Since a pre-filter set-up was connected to the influent of the columns, headloss was not a problem in general. The water was filtered through a 0.45-µm cartridge filter to minimize potential headloss buildup in the column.

3.4 Experimental Design

The experimental design summary is presented in Table 6. Two EBCTs were evaluated during the course of the study. Four quarterly RSSCTs were conducted to investigate the impact of seasonal variability on the treatability of the water.

Table 6
Experimental Design Summary

Season	Pretreatment	EBCT, min
Spring	Coagulation/ Flocculation and Sedimentation/Cartridge Filtration	10 & 20
Summer	Coagulation/ Flocculation and Sedimentation/Cartridge Filtration	10 & 20
Fall	Coagulation/ Flocculation and Sedimentation/Cartridge Filtration	10 & 20
Winter	Coagulation/ Flocculation and Sedimentation/Cartridge Filtration	10 & 20

3.5 Simulated Distribution System (SDS) Chlorination Testing

The distribution system conditions existing on the day of sampling were provided to Montgomery Watson each quarter by the City of Shreveport staff. These conditions included the average residence time, free chlorine residual, pH and temperature at the average residence time. Table 7.a presents the target SDS conditions. The tolerances on the SDS target conditions were presented in the USEPA *ICR Treatment Study Fact Sheet* (November 1997).

Table 7.a
Target SDS Chlorination Testing Conditions

Parameter	April 1998		July 1998		October 1998		January 1999	
	Value	Tolerance	Value	Tolerance	Value	Tolerance	Value	Tolerance
Incubation time, hrs	24	1.0	23	1.0	23	1.0	23	1.0
Incubation temp., °C	20	2.0	20*	2.0	30**	2.0	7	2.0
pH	9.4	0.4	8.9	0.4	9.3	0.4	9.0	0.4
Free Cl ₂ residual, mg/L	1.0	0.4	1.0	0.4	1.0	0.4	1.0	0.4

*The actual distribution system temperature was 30°C during the Summer quarter.

**The actual distribution system temperature was 23°C during the Fall quarter.

The actual distribution system temperature was 30°C during the Summer quarter. The samples were erroneously incubated at 20°C. Instead of repeating the experiments, EPA approved to conduct the SDS testing at a target temperature of 30°C during the Fall quarter in order to obtain DBP formation data that is representative of the warmer temperatures experienced during the Summer quarter. The actual distribution system

temperature recorded during the Fall quarter was 23°C. Besides the distribution system temperature, the Summer and Fall quarters had similar distribution system conditions (incubation time, and pH) and RSSCT influent water quality conditions. Table 7.b presents the water quality of the influent to the RSSCT during the Summer and Fall quarters.

Table 7.b
Water Quality of the Influent to the RSSCT for the Summer and Fall Quarters

	Summer Quarter Influent to the RSSCT (average of three values)	Fall Quarter Collected Filtered Water
TOC, mg/L	4.87	4.40
Turbidity, NTU	0.28	0.20
Alkalinity, mg/L as CaCO ₃	50	58
UV-254, 1/cm	0.068	0.057
Ammonia-N, mg/L	0.10	0.10
True Color, PCU	NA	3
pH	8.3	8.7

3.6 Analytical Methods

The list of all the analytical methods used during the RSSCT and their corresponding Minimum Reporting Limits (MRLs) are presented in Table 8.

Table 8
List of Analytical Methods and MRLs

Analyte	Method	Minimum Reporting Level (MRL)
Alkalinity	SM 2320 B	5 mg/L CaCO ₃
Ammonia	SM 4500-NH ₃ D	0.10 mg/L NH ₃ -N
Bromide	EPA 300.0	40 µg/L
Calcium Hardness	SM 200.7	5 mg/L CaCO ₃
Total Hardness	SM 2340 B	7 mg/L CaCO ₃
Chlorine Residual/Dose	SM 4500-Cl D	0.2 mg/L as Cl ₂
All nine HAAs, HAA5 and HAA6	SM 6251B, 552.2	1 µg/L for each analyte 2 µg/L for CDBAA&MCAA 4 µg/L for TBAA
pH	SM 4500-H ⁺	Not Applicable
Turbidity	SM 2130 B	0.05 NTU
Temperature	SM 2550 B	Not Applicable
All four THMs and THM4	EPA 502.2/551	0.5 µg/L for all analytes
TOC	SM 5310 C	0.5 mg/L
TOX	SM 5320	10 µg/L and 25 µg/L
UV ₂₅₄	SM 5910	0.009 cm ⁻¹

Table 12 presents a listing of the laboratories involved in analytical reporting and the period over which analyses were conducted by each laboratory. Following Table 9 is additional information on the locating and contact person at each individual laboratory. More information is included in Appendix B.

Table 9
Listing of Laboratories involved in the Analytical Reporting

Laboratory	Dates of Service	Analyses Performed
RCFF (ARD Lab)	Quarters 1 through 4	Alkalinity, Turbidity, TOC (SM 5310 C), Temperature, pH, UV ₂₅₄ , Chlorine residual, Ammonia
Montgomery Watson Labs	Quarters 1 through 4	THM4 (EPA 502.2 and 551), HAA9 (SM 6251B), TOX (SM 5320), Bromide, Ca-hardness, Tot-hardness
E.S. Babcock & Sons	Quarter 1	TOX (SM 5320B) HAA6 (SM 6251B) and THM (EPA 502.2)
Summers and Hooper Inc	Quarters 3 and 4	HAA9 (552.2)

RCFF Laboratory

Montgomery Watson
ARD Shop & Laboratory
327 West Maple Avenue
Monrovia, CA 91016
Contact Person: Mr. Joe Marcinko
Phone #: (626) 303-5845
Fax #: (626) 359-3593

Montgomery Watson Laboratories

Montgomery Watson
555 East Walnut Street
P.O.Box 7009
Pasadena, CA 91101
Contact Person: Mr. Jim Hein
Phone #: (626) 568-6489
Fax #: (626) 568-6324

E.S. Babcock & Sons

6100 Quail Valley Court

Riverside, CA 92507

Contact Person: Mrs. Kathy Ljima

Phone #: (909) 653-3351

Fax #: (909) 653-1662

Environmental Laboratory Certification #1156

Summers and Hooper, Inc

6 Knollcrest drive

Cincinnati, OH 45237

Contact Person: Mr. Malcolm Hooper

Phone #: (513) 679-2200

Fax #: (513) 679-2201

4. Results and Discussion

4.1 Challenges Encountered (study observations)

4.1.1 Carbon Rinsing

Carbon rinsing proved to be a tedious operation. It was however, essential to remove the fines to avoid potential head-loss problems in the columns. The carbon rinsing operation was repeated several times, and even then, some fines remained in the carbon.

4.2 Water Quality Data

4.2.1 Water quality of pretreated influent to the RSSCT

Table 10 summarizes the water quality in the pretreated influent to the RSSCT. Some seasonal variability was observed in organic parameters (TOC concentration, UV-254 absorbance). Both TOC concentration and UV-254 absorbance were lower during the Spring quarter, measured at 3.3 mg/L and 0.050/cm, respectively. The highest values of TOC and UV-254 occurred during the Summer quarter. Alkalinity was low, ranging from 33 mg/L CaCO₃ during the Spring quarter to 68 mg/L CaCO₃ during the Fall. The influent pH did not vary significantly between each quarter. Total hardness was moderate throughout the quarters, ranging from 62 mg/L CaCO₃ in Spring to 116 mg/L CaCO₃ in Fall. Ammonia-nitrogen concentration was not significant in the RSSCT influent. SDS-chlorine demand was low, and ranged from 1.79 mg/L to 2.88 mg/L as Cl₂. The SDS TTHM concentration ranged from 72 µg/L during the Winter quarter to 142 mg/L during the Fall quarter. The HAA5 concentration was low during all quarter, and did not exceed the “placeholder” value of 30 µg/L proposed in the Stage 2 D/DBP Rule. The SDS

temperature varied substantially during the four quarters, and ranged from 7°C during the Winter quarter, to 30°C during the Fall quarter (the actual Fall temperature was 23°C and the actual Summer distribution system temperature was 30°C per Section 3.5). All other SDS parameters were more or less equivalent during the four rounds of testing. Bromide concentration was moderate, ranging from a low of 99 µg/L to a high of 210 µg/L.

Table 10
Water Quality of the Influent to the RSSCT

Water Quality Parameter	Spring Average (SD)*	Summer Average (SD)*	Fall Average (SD)*	Winter Average (SD)*
pH	7.93 (0.01)	8.27 (0.01)	8.37 (0.020)	8.13 (0.010)
Turbidity (ntu)	0.19 (0.24)	0.28 (0.00)	0.23 (0.25)	0.27 (0.22)
Alkalinity mg/L CaCO ₃	33	50	68	50
Calcium Hardness mg/L CaCO ₃	47	79	75	59
Total Hardness mg/L CaCO ₃	62	111	116	80
Bromide (µg/L)	99	180	210	115
Ammonia-N (mg/L)	0.20	0.10	<0.10	<0.10
TOC (mg/L)	3.3 (0.0)	4.9 (0.1)	4.1 (0.0)	4.5 (0.0)
UV ₂₅₄ (cm ⁻¹)	0.050 (0.030)	0.068 (0.009)	0.053 (0.010)	0.069 (0.015)
SUVA (L/mg-cm)	1.50 (0.07)	1.39 (0.01)	1.28 (0.04)	1.55 (0.02)
SDS-THM4 (µg/L)	86 (0)	92 (0)	142 (0)	72 (0)
SDS-HAA5 (µg/L)	15 (0.1)	24 (0)	27 (0)	18 (0)
SDS-HAA6 (µg/L)	21 (0.1)	34 (0)	39 (0)	26 (0)
SDS-TOX (µg Cl ⁻ /L)	133 (0)	233 (0)	233 (0)	42 (0)
SDS-chlorine demand (mg/L)	2.25 (0.02)	2.69 (0.02)	2.88 (0.03)	1.79 (0.09)

*SD: Standard Deviation

4.1 Impact of Seasonal Variability

4.3.1 Impact of Seasonal Variability on TOC Breakthrough

The impact of seasonal variability on the TOC breakthrough in the 10-min and 20-min EBCT columns is illustrated in Figures 4 and 5. Some seasonal variation between the four quarters was observed in the TOC breakthrough curves. In both 10-min and 20-min EBCT column, the fastest 70% TOC breakthrough was observed during the Summer quarter (July sampling). During this quarter, the highest influent TOC concentration and UV354 absorbance were recorded at 4.9 mg/L and 0.068/cm, respectively. The rates of TOC breakthrough in both the 10-min column were somewhat constant, at 1.0 percent per day. In the 20-min EBCT columns, the rates of TOC breakthrough varied from quarter to the other. A 60 to 65% plateau was reached during the Spring and Winter quarters.

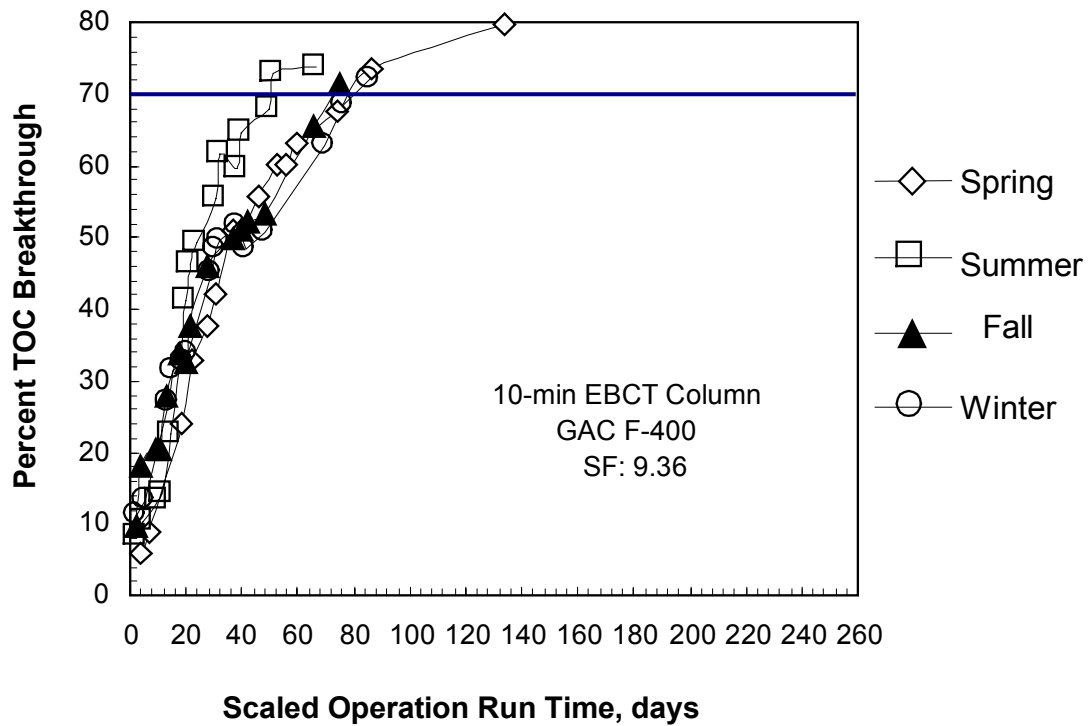


Figure 4. Impact of Seasonal Variability on Percent TOC Breakthrough in the 10-min EBCT Column

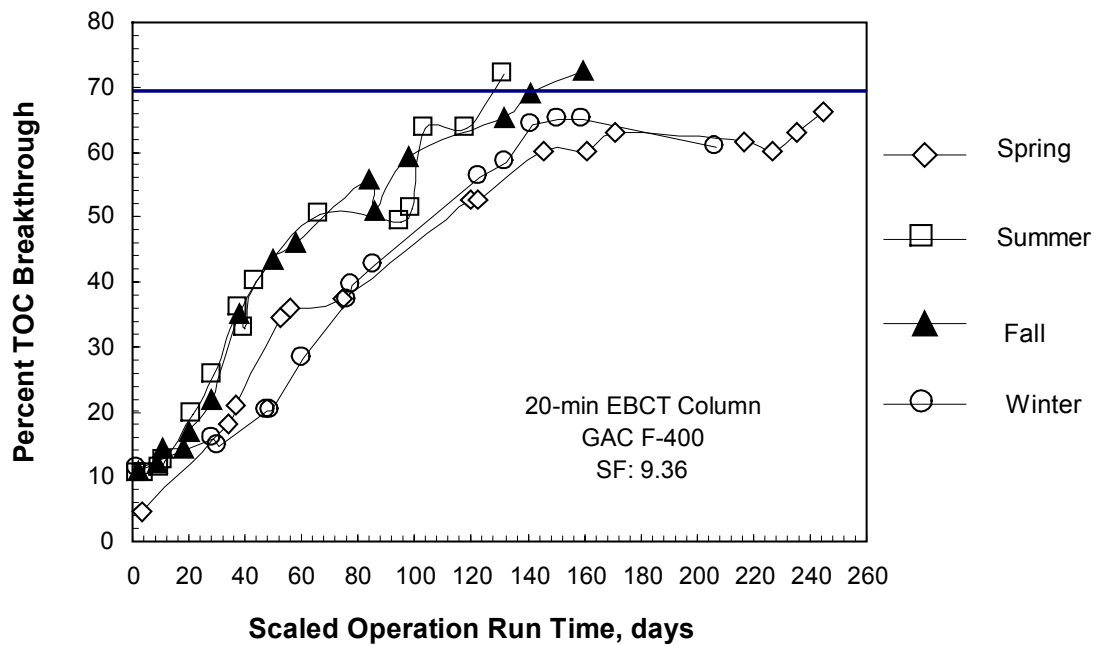


Figure 5. Impact of Seasonal Variability on TOC Breakthrough in the 20-min EBCT Column

4.3.2 Impact of Seasonal Variability on SDS-TTHM Breakthrough

Figures 6 and 7 illustrate the SDS-TTHM breakthrough versus run time in the 10-min and 20-min EBCT columns during the four quarters. The order of the SDS-TTHM breakthrough curves appears to be correlated with both the influent TOC concentration and the influent TTHM concentration. For both EBCTs, the fastest SDS-TTHM breakthrough occurred during the Summer and Fall quarters, during which the highest TOC concentration, and the highest influent SDS-TTHM concentration were recorded respectively. The slowest breakthrough occurred during the Winter quarter (low influent SDS-TTHM concentration). Influent SDS-TTHM concentrations were high, and ranged from a high of 142 µg/L during the Fall quarter, to a low of 72 µg/L during the Winter quarter. In the 10-min EBCT column, the Stage 2 TTHM MCL was exceeded first during the Summer and Fall Winter quarters, after 14 scaled days of operation run time. The Stage 2 TTHM MCL was exceeded during the Spring quarter after 28 scaled days of operation run time, and after 24 scaled days during the Winter quarter. In the 20-min column, the Stage 2 TTHM MCL was again exceeded first during the Spring and Fall quarters, after 30 scaled days of operation, while the Stage 2 TTHM MCL was exceeded during the Winter quarter after 80 scaled days of operation, and after 45 scaled days during the Spring quarter.

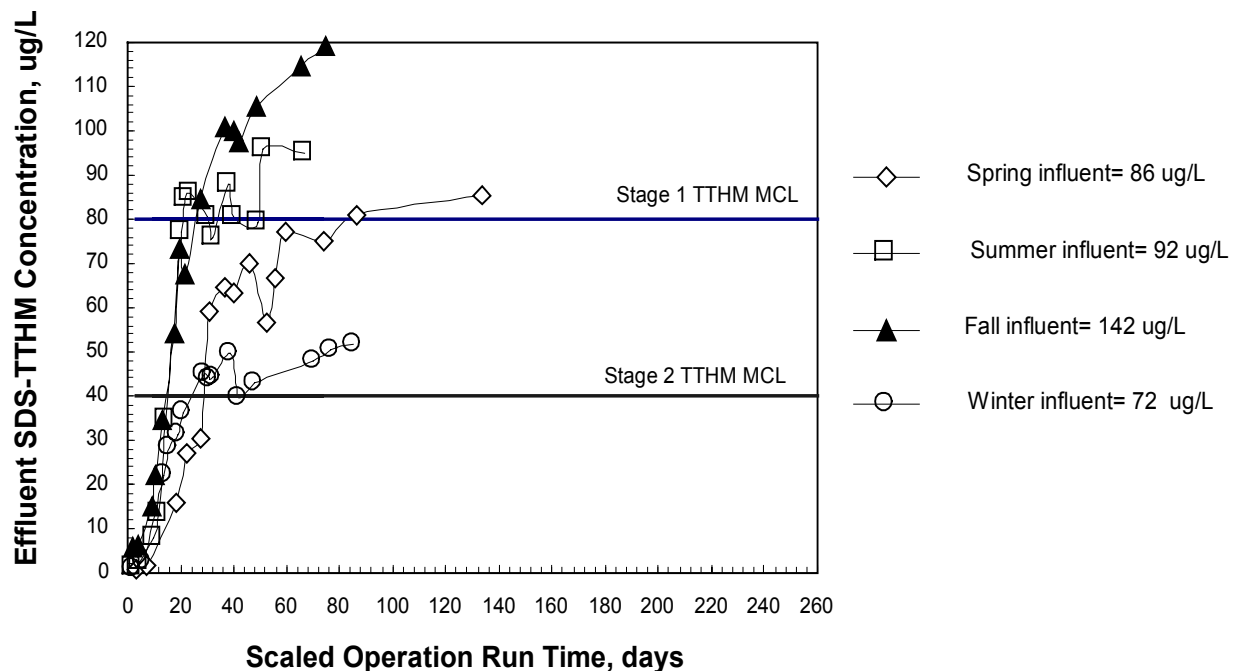


Figure 6. Impact of Seasonal Variability on SDS-TTHM Breakthrough in the 10-min EBCT Column

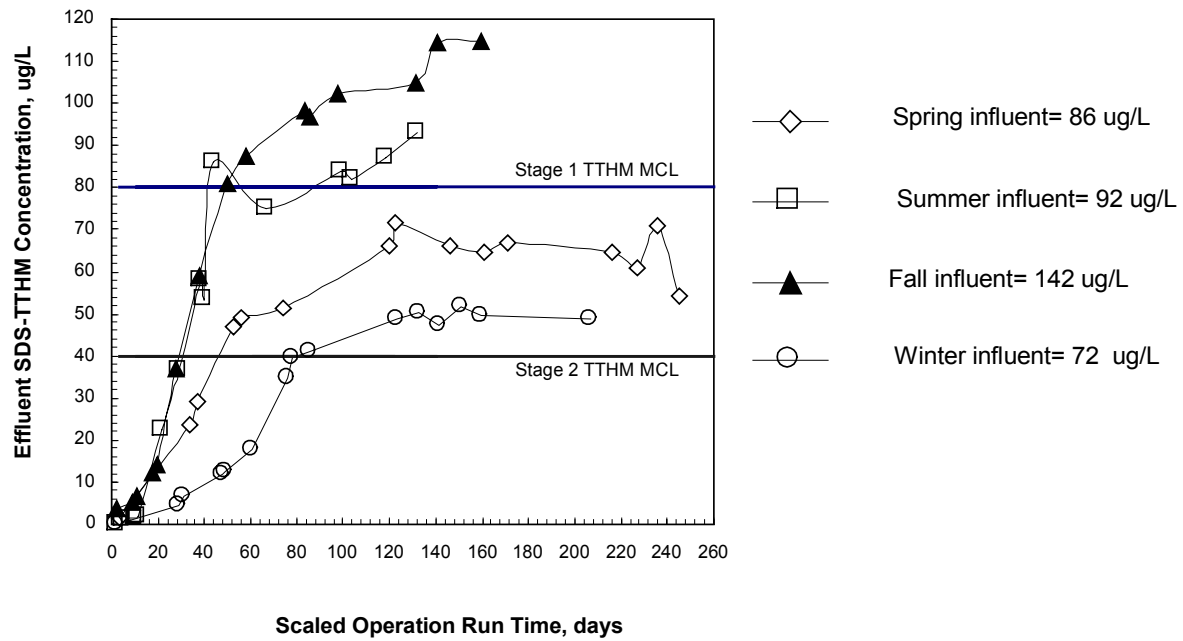


Figure 7. Impact of Seasonal Variability on SDS-TTHM Breakthrough in the 20-min EBCT Column

4.3.3 Impact of Seasonal Variability on SDS-HAA5 Breakthrough

The impact of seasonal variability on SDS-HAA5 breakthrough is illustrated in Figures 8 and 9. Due to the low influent SDS-HAA5 concentration neither the Stage 1 nor the Stage 2 HAA5 MCLs were exceeded in either column. The SDS-TTHM concentration in the GAC contactor effluent will be the limiting factor in contactor design, regeneration scenario, and costing.

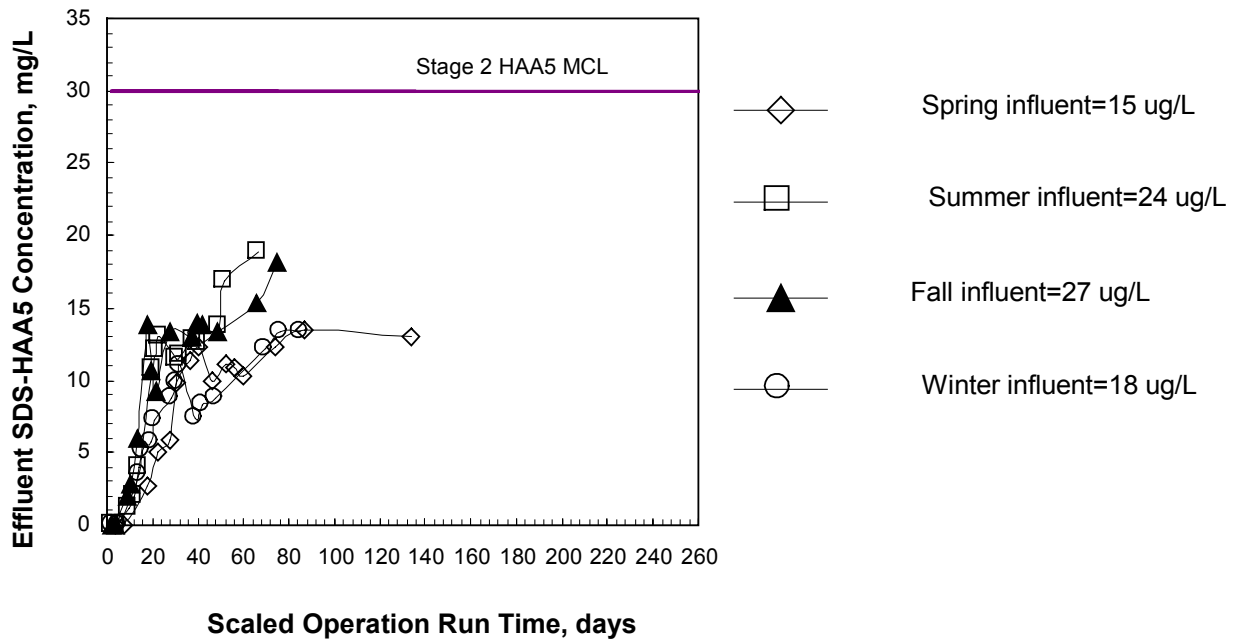


Figure 8. Impact of Seasonal Variability on SDS-HAA5 Breakthrough in the 10-min EBCT Column

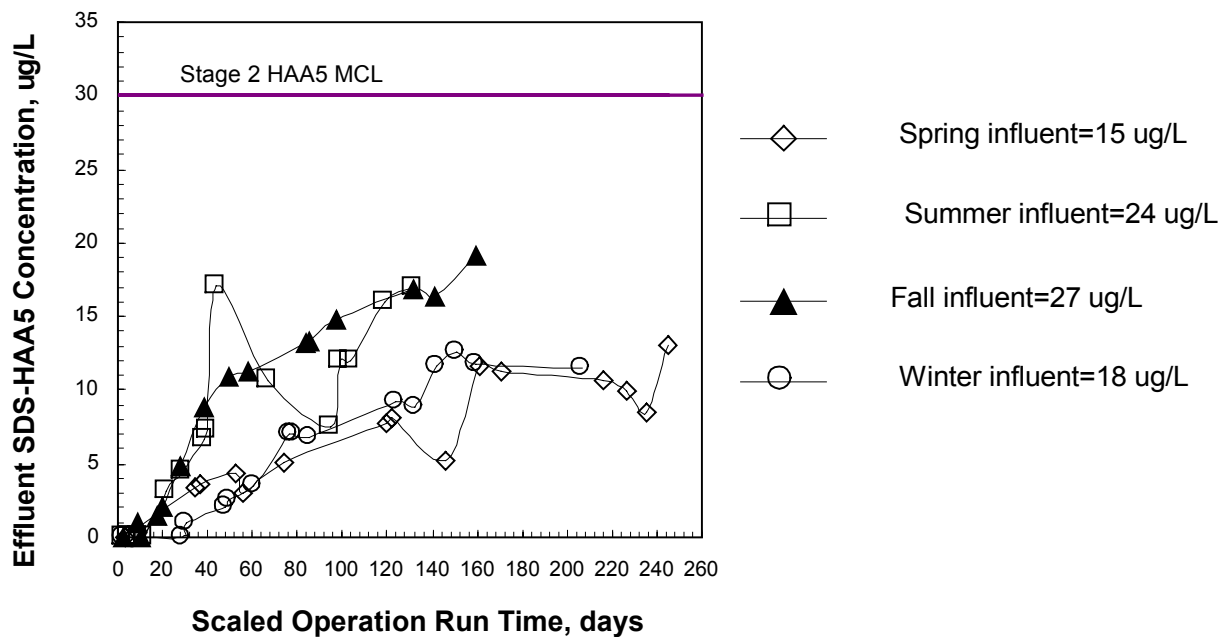


Figure 9. Impact of Seasonal Variability on SDS-HAA5 Breakthrough in the 20-min EBCT Column

4.3.4 Impact of Seasonal Variability on DBPs Speciation

The intermediate concentration of bromide in the influent to the RSSCT shifted the speciation of SDS-DBPs in the effluents of the GAC columns towards both chlorinated and brominated SDS-DBPs, with a higher tendency towards the brominated SDS-DBPs. Table 11 presents the range of SDS-THMs and SDS-HAAs formed in the effluent samples during the four quarterly RSSCTs. This tendency was more visible during the Summer and Fall quarters which recorded higher influent bromide concentrations. The dominant SDS-THM species was observed to be dibromo-chloromethane, whereas the SDS-HAAs were dominated by dibromo-acetic acid.

Table 11
Impact of Bromide Concentration on DPBs Speciation

		Spring	Summer	Fall	Winter
Influent to RSSCT	Bromide, µg/L	99	180	210	115
10-min EBCT	CHCl ₃ , µg/L	BMRL to 24.0	BMRL to 15.0	BMRL to 11.0	BMRL to 9.0
	BDCM, µg/L	BMRL to 27.0	BMRL to 26.0	BMRL to 29.0	BMRL to 14.0
	DBCM, µg/L	BMRL to 26.0	BMRL to 36.0	1.7 to 46.0	BMRL to 21.0
	CHBr ₃ , µg/L	BMRL to 8.6	1.2 to 18.0	4.3 to 41.0	0.70 to 15.0
	MCAA, µg/L	BMRL	BMRL	BMRL	BMRL
	DCAA, µg/L	BMRL to 5.2	BMRL to 5.3	BMRL to 4.3	BMRL to 4.5
	TCAA, µg/L	BMRL to 1.5	BMRL	BMRL	BMRL to 2.0
	MBAA, µg/L	BMRL	BMRL	BMRL	BMRL
	DBAA, µg/L	BMRL to 6.3	BMRL to 11.0	BMRL to 12.0	BMRL to 7.2
	BCAA, µg/L	BMRL to 6.4	BMRL to 7.9	BMRL to 8.1	BMRL to 6.5
	TBAA, µg/L	BMRL	NR	BMRL to 6.0	BMRL
	CDBAA, µg/L	BMRL to 2.5	BMRL to 4.5	BMRL to 6.7	BMRL to 3.0
	DCBAA, µg/L	BMRL to 2.1	BMRL to 3.0	BMRL to 4.9	BMRL to 2.8
20-min EBCT	CHCl ₃ , µg/L	BMRL to 14.0	BMRL to 11.0	BMRL to 8.8	BMRL to 6.9
	BDCM, µg/L	BMRL to 20.0	BMRL to 24.0	BMRL to 26.0	BMRL to 12.0
	DBCM, µg/L	BMRL to 26.0	BMRL to 37.0	BMRL to 47.0	BMRL to 22.0
	CHBr ₃ , µg/L	1.3 to 17.0	BMRL to 30.0	BMRL to 40.0	BMRL to 15.0
	MCAA, µg/L	BMRL to 2.5	BMRL	BMRL	BMRL
	DCAA, µg/L	BMRL to 4.2	BMRL to 4.4	BMRL to 4.0	BMRL to 3.5
	TCAA, µg/L	BMRL	BMRL	BMRL to 1.5	BMRL to 1.8
	MBAA, µg/L	BMRL	BMRL	BMRL to 1.6	BMRL
	DBAA, µg/L	BMRL to 5.9	BMRL to 10.0	BMRL to 12.0	BMRL to 7.3
	BCAA, µg/L	BMRL to 5.0	BMRL to 7.4	BMRL to 8.4	BMRL to 6.0
	TBAA, µg/L	NA	NR	BMRL to 6.4	BMRL
	CDBAA, µg/L	NA	BMRL to 4.3	BMRL to 7.6	BMRL to 3.5
	DCBAA, µg/L	NA	BMRL to 3.1	BMRL to 5.3	BMRL to 2.8

BMRL: Below Minimum Reporting Level; NA: Not Analyzed

4.4 Impact of Empty Bed Contact Time

The impact of the EBCT on the removal of DBP precursors by GAC can be evaluated when plotting breakthrough curves versus bed volumes (BVs), instead of run time (days). This will normalize the difference in the EBCT values between the two columns. Figures 10, 11 and 12 illustrate respectively the average percent breakthrough (from four quarters) of TOC, SDS-TTHMs and SDS-HAA5 from the 10-min and 20-min EBCT columns, versus throughput bed volumes. Even though the 10-min EBCT and the 20-min EBCT breakthrough curves exhibited somewhat similar shapes and slopes, using a 20-min EBCT versus a 10-min EBCT resulted in an additional benefit for removing DBPs. This would affect the GAC replacement or regeneration costs. Capital costs of a 20-min GAC contactor are substantially higher than those of a 10-min EBCT contactor. More details on costing are presented in section 4.6.

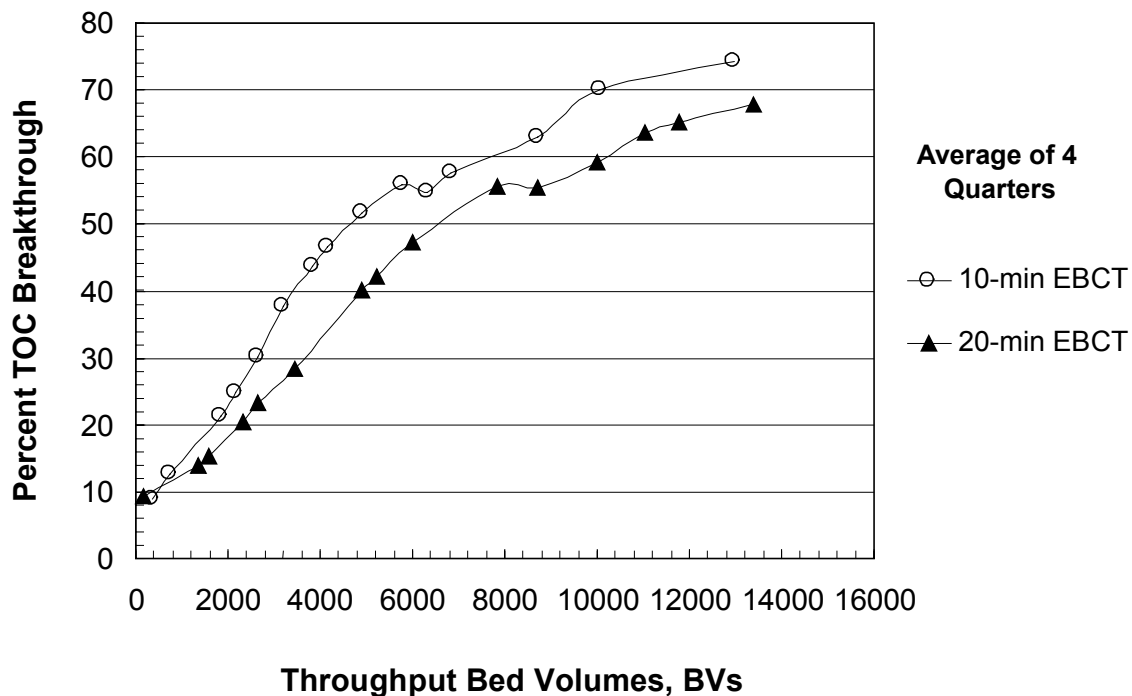


Figure 10. Impact of EBCT on Percent TOC Breakthrough

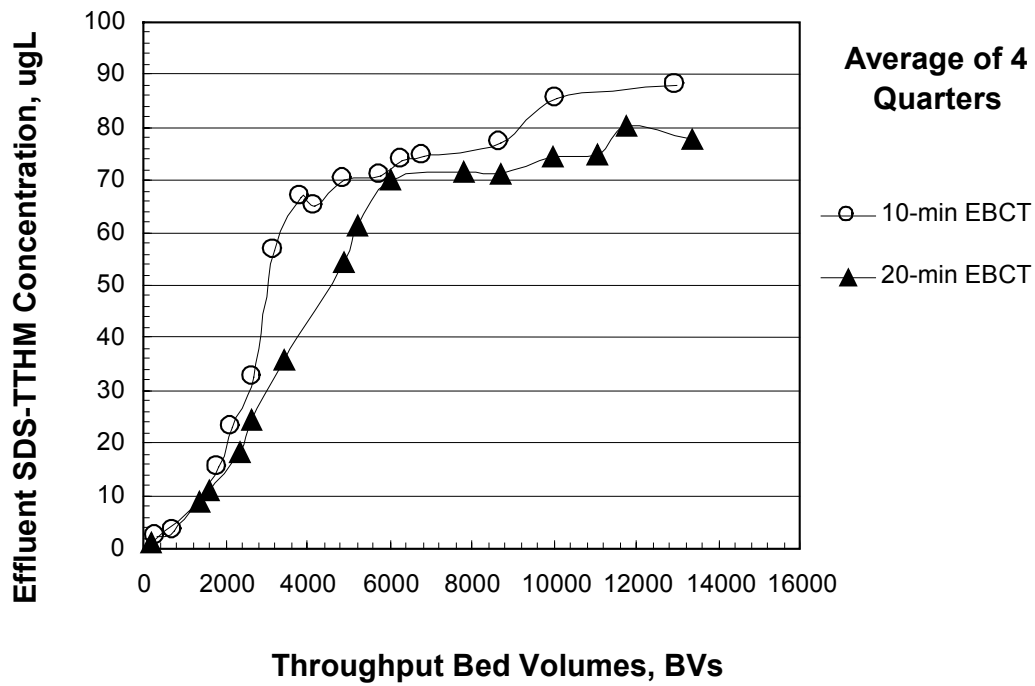


Figure 11. Impact of EBCT on SDS-TTHM Breakthrough

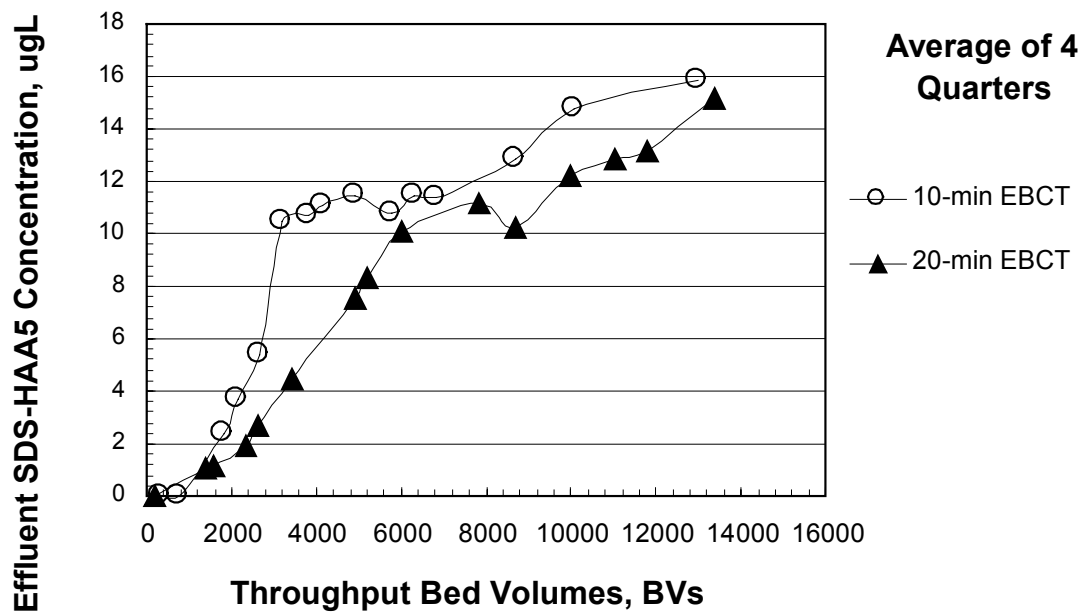


Figure 12. Impact of EBCT on SDS-HAA5 Breakthrough

4.5 Indicators of DBP Formation

To evaluate the use of TOC concentration and UV-254 absorbance as indicators of DBP precursors, normalized breakthrough curves of TOC, UV-254, TTHM and HAA5, are plotted against the scaled operation run time, for both the 10-min and the 20-min EBCT columns. Figure 13 and 14 illustrate, respectively, the breakthrough of the above parameters from the 10-min and 20-min EBCT GAC contactors.

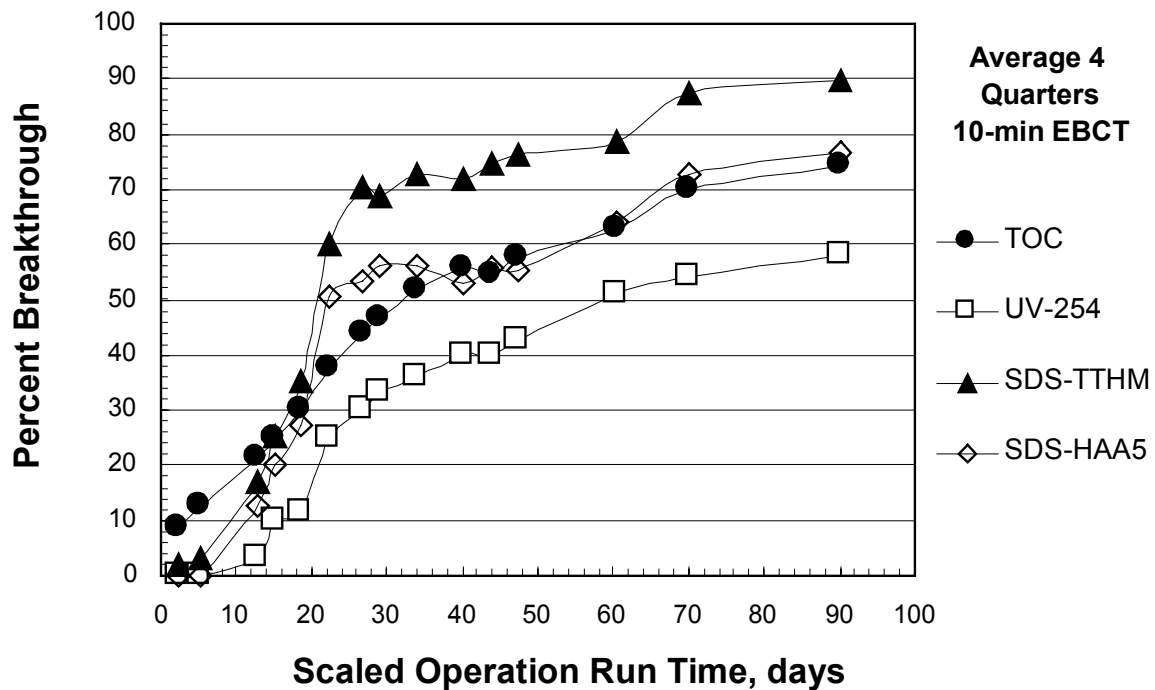


Figure 13. Breakthrough of TOC, UV-254 and SDS-DBPs from 10-min EBCT GAC Column

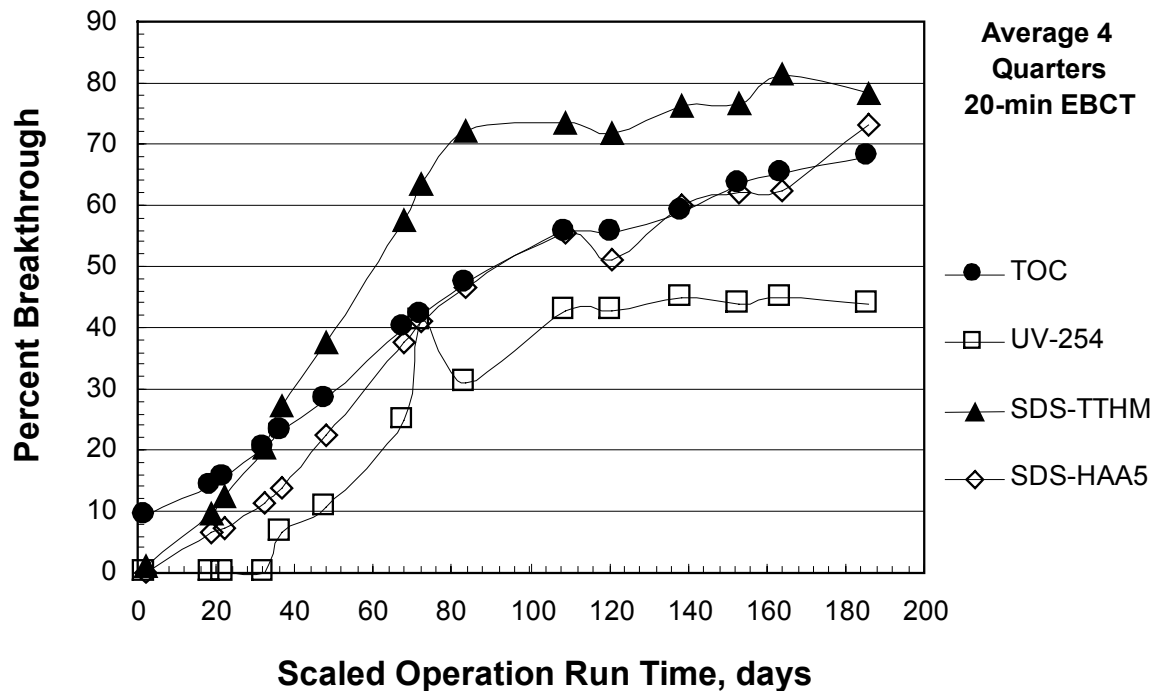


Figure 14. Breakthrough of TOC, UV-254 and SDS-DBPs from 20-min EBCT GAC Column

Based on the average percent breakthrough curves from the 10-min and the 20-min EBCT contactors, the following observations can be formulated: (1) TOC and UV-254 breakthrough curves correlate well with the TTHM and HAA5 breakthrough curves. The rate of breakthrough, represented by the slope of the curves, is more or less constant, calculated at approximately 0.8 percent/day for the 10-min EBCT design, and at approximately 0.4 percent/day for the 20-min EBCT design. (2) TOC concentration and UV-254 absorbance are not conservative enough to be good indicators of DBP precursors. Nevertheless, the monitoring of TOC and UV-254 is a simpler and less costly analysis than that of THMs or HAAs. The percent breakthrough of HAA5 is observed to be equivalent to that of the TOC concentration. However, only five of the nine HAAs are reported in the data analysis (the Stages 2 and 1 MCL for HAAs are based on HAA5 concentration, which is the sum of five of the nine HAAs).

4.6 Cost Information and Analysis

4.6.1 GAC Replacement and Regeneration costs

The carbon usage rate (CUR) in lb GAC/1000 gal of processed water required to meet the Stages 1 and 2 MCLs for TTHMs and HAA5, have been estimated for the four quarters. The CURs for a 10-min EBCT and a 20-min EBCT, and for each quarter are presented in Tables A1 through A8 in Appendix A. The average CURs over four quarters for each EBCT are presented in Table 12 and 13. The amount of GAC (in million pounds per

year) was estimated based on 70% of the plant capacity, a value of 63 mgd. The cost for GAC replacement and GAC thermal reactivation were both estimated. As a general rule, when carbon requirements are greater than 2000 lb/day, on-site reactivation is considered to be more effective than GAC replacement. In the case of Shreveport, based on the calculated CURs, on-site reactivation would be the most practical and cost-effective technology. Regardless, both GAC replacement and reactivation costs were calculated for comparison.

Table 12
Average CURs over Four Quarters for the 10-min EBCT Design

Parameter	Units	Influent Concentration	Target Concentration*	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/1000 gal	CUR Million lbs/yr
TTHM	µg/L	98	64	69	>1595	<1.0	<22.0
			32	35	662	1.7	38.2
HAA5	µg/L	21	48	241	>3245	<0.3	<7.6
			24	121	>3245	<0.3	<7.6

* 80% of the Stage 1 and Stage 2 MCLs for each DBP

Table 13
Average CURs over Four Quarters for the 20-min EBCT Design

Parameter	Units	Influent Concentration	Target Concentration*	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/1000 gal	CUR Million lbs/yr
TTHM	µg/L	98	64	69	>1811	<0.9	<19.9
			32	35	722	1.7	39.5
HAA5	µg/L	21	48	241	>3344	<0.3	<7.3
			24	121	>3344	<0.3	<7.3

* 80% of the Stage 1 and Stage 2 MCLs for each DBP

4.6.1.1 GAC Replacement Costs

Based on the CUR and the GAC price of \$0.75/lb, the GAC replacement costs have been estimated for a 10-min EBCT and 20-min EBCT designs. The costs of GAC in \$/1000 gal to meet target DBP MCL criteria are plotted in Figures 13 and 14. These costs were estimated with a 20% contingency (i.e., 80% of the MCL). Due to the low concentration of SDS-HAA5 and the high SDS-TTHM in the chlorinated influent to the RSSCT, the Stages 1 and 2 TTHM MCL were the only limits to have been exceeded. In the 10-min EBCT contactor, the GAC replacement costs to meet 80% of Stage 2 MCL of TTHMs ranged from \$0.76/1000 gal during the Spring quarter to \$1.66/1000 gal during the Fall quarter. In the 20-min EBCT contactor, the costs to meet the Stage 2 MCL for TTHMs ranged from \$0.57/1000 gal during the Winter quarter to \$1.92/1000 gal during the Summer quarter. It can therefore be stated that GAC replacement costs for a 10-min EBCT and a 20-min EBCT are virtually the same.

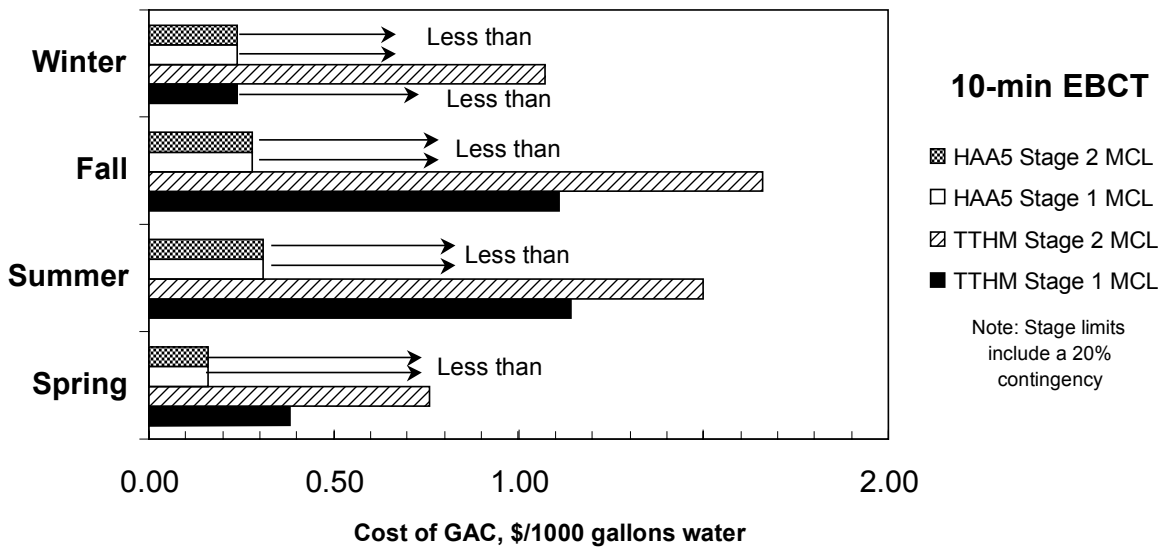


Figure 13. Cost of GAC Replacement from the 10-min EBCT Contactor to Meet Target DBP MCL Criteria

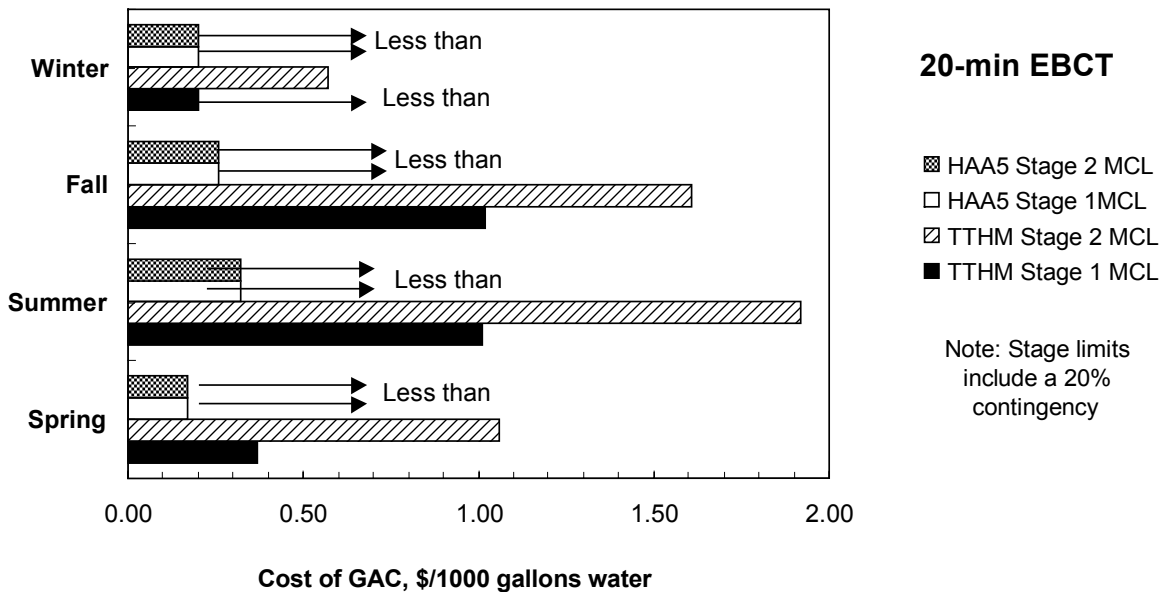


Figure 14. Cost of GAC Replacement from the 20-min EBCT Contactor to Meet Target DBP MCL Criteria

The average annual GAC replacement costs can be estimated from the average cost of GAC replacement per 1000 gal treated water (over the four quarters) to meet 80% of the Stage 2 TTHM MCL, and an average flowrate of 63 mgd. For a 10-min EBCT, the

average annual GAC replacement cost was estimated at \$28,620,000. The average annual GAC replacement cost for a 20-min EBCT was estimated at \$29,647,500. These costs may seem high. It should be kept in mind however that these costs were based meeting the “placeholder” Stage 2 TTHM MCL with a 20% contingency. Nevertheless, GAC replacement cannot be considered to be a feasible option. The next section presents GAC reactivation costs.

4.6.1.2 GAC Reactivation Costs

GAC reactivation design is based on the amount of GAC used (in Million pounds/year) to reach a certain design target (80% of the Stage 2 TTHM MCL). The average GAC amounts were calculated based on an average flowrate of 63 mgd, and are presented in Tables 12 and 13. Given that the Stage 2 MCL for HAA5 was not exceeded in all four quarters, GAC reactivation costs will be based on the Stage 2 MCL for TTHM. According to these high carbon usage rates, GAC reactivation would not be a practical technology, given that the costs incurred would be too high. Typical carbon usage rates vary from 1 to 10 million pounds per year. Based on the 10-min EBCT average CUR of 38 million lbs/yr (4337.9 lbs/hr) to reach 80% of the Stage 2 TTHM MCL, the size of the total required effective hearth area of a single reactivator is estimated at approximately 1735 square feet. Based on the 20-min EBCT average CUR of 39 millions lbs/yr (4512.5 lbs/hr) to reach 80% of the Stage 2 TTHM MCL, the size of the total required effective hearth area of a single reactivator is estimated at approximately 1805 square feet. Since these surface area falls out from the range of the developed existing cost equations presented in the next section, 4 reactivators will be assumed for the purpose of analysis, with the effective hearth area per reactivator at 433.8 square feet for the 10-min EBCT and at 451.3 square feet for the 20-min EBCT. The capital and O&M costs will be estimated for one reactivator and multiplied thereafter by a factor of 4. Capital and O&M costs for thermal GAC reactivation and using a 10- and 20-min EBCTs are presented in Table 14.

Parameter	Assumption
Single reactivator area, sq-ft	433.8 (10-min); 451.3 (20-min)
Total reactivator are, sq-ft	1735 (10-min); 1805 (20-min)
Capital amortization	$I = 6$ percent over $N = 30$ years
Capital recovery factor CRF	0.117
Labor and fringe rate	\$25/hr
Electric rate	\$ 0.02/kwh
Natural gas rate	\$0.0055/scf
ENR Construction Cost Index (1983)	5064
ENR Construction Cost Index (1998)	6859
Producers Price Index (1983)	102
Producers Price Index (1998)	130.5

According to Adams and Clark (1988), the following equations can be used to estimate construction costs (CC), cost estimates for electrical energy requirement (Process Energy

(PE), and Building Energy (BE)), maintenance-materials MM costs, and O&M labor requirements (OL) costs for a multihearth reactivator.

$$CC = 144000 + 198300.4 * (EFAREA)^{0.434}$$

where: CC = construction costs in 1983 dollars,

EFAREA = effective surface area in square feet of one reactivator,

CC in current dollars = CC* current CCI / 4,114.6, with CCI = construction cost index

Annual capital costs = CC *CRF

where CRF = capital recovery factor = $I(1+I)^N / [(1+I)^N - 1]$

where I = period lending interest rate and N = payback period.

$$PE = 354600 + 6387 * (EFAREA)^{0.755}$$

where: PE = process energy requirement in kWh/year,

total filter area is in square feet.

PE* electric rate (in \$/kWh) = annual PE costs

$$BE = 12250 + 312.1 * (EFAREA)^{0.649}$$

where: BE = building energy requirements in kWh/year,

total filter area is in square feet.

BE* electric rate (in \$/kWh) = annual BE costs

$$MM = 4456.6 * (EFAREA)^{0.401}$$

where: MM = maintenance-materials costs in 1983 dollars per year,

total filter area is in square feet.

MM in current dollars = MM * current PPI / 287.1

Where PPI = producers price index for finished goods

$$OL = 2920 + 282 * (EFAREA)^{0.7}$$

Where: OL = O&M labor requirements in workhours per year,

total filter area is in square feet,

OL* labor rate (in \$/hr) = labor cost

$$NG = 648400 + 287714.9 * (EFAREA)^{0.899}$$

Where: NG = natural gas requirement in standard cubic-feet per year,
 NG* gas rate (\$/standard cubic-feet) = annual gas cost.

Table 14
Capital and O&M Costs for a GAC Reactivation using Multihearth Technology

Parameter	10-min EBCT	20-min EBCT
DESIGN PARAMETERS		
Total lbs of GAC per hour (to meet 80% Stage 2 TTHM MCL) at 0.4 sq-ft required per lb/hr	4338	4512.5
Surface area per reactivator, sq-ft (total 4 reactivators)	433.8	451.3
CAPITAL COSTS		
CC, 1998 \$	3,941,925	4,006,647
Annual capital costs, \$/yr	\$286,376	\$291,078
O&M COSTS		
PE, kWh/yr	980411	999336
Annual PE costs, \$/yr	\$19,608	\$19,987
BE, kWh/yr	28315	28732
Annual BE costs, \$/yr	\$566	\$575
MM costs, 1998 \$/yr	\$65,097	\$66,136
OL, workhours/yr	22705	23259
Annual OL costs, \$/yr	\$567,635	\$581,488
NG requirement, scft/yr	68237499	70678288
Annual NG cost, \$/yr	\$375,306	\$388,731
Total O&M Annual Costs, \$/yr	\$1,028,213	\$1,056,916
TOTAL ANNUAL COSTS, \$/yr	\$1,314,589	\$1,347,994

The costs incurred for the amount of GAC used were estimated using one fourth (1/4) of the actual amount of GAC used (since the empirical equations were developed for a certain range of carbon usage rate). To be conservative, the actual costs for the given carbon usage rates can be estimated as approximately four times greater than those shown in Table 14. Although these costs are much lower than those for replacing the carbon, they remain high and on-site thermal GAC reactivation may not be considered to be a feasible and practical technology.

4.6.2 Annual Capital and O&M Costs

According to Adams & Clark (1991), concrete gravity adsorbers are assumed for GAC contactors greater than 10 mgd. Concrete gravity contactors will be assumed for the City of Shreveport.

$$CC = 93700 + 1999.1 * (CUFT)^{0.712} * (1.027)^z$$

where: CC = construction costs in 1983 dollars,

CUFT = total effective GAC bed volume in cubic feet of all contactors,

z = 1 if CUFT > 5,000 cubic feet and z=0 if CUFT ≤ 5,000 cubic feet.

CC in current dollars = CC* current CCI / 4,114.6, with CCI = construction cost index

Annual capital costs = CC *CRF

where CRF = capital recovery factor = $I(1+I)^N / [(1+I)^N - 1]$

where I = period lending interest rate and N = payback period.

$$PE = 12 * (\text{total filter area})$$

where: PE = process energy requirement in kwh/year,

total filter area is in square feet.

PE* electric rate (in \$/kWh) = annual PE costs

$$BE = 15150 + 350 * (\text{total filter area})^{0.916}$$

where: BE = building energy requirements in kwh/year,

total filter area is in square feet.

BE* electric rate (in \$/kWh) = annual BE costs

$$MM = 540 + 23.6 * (\text{total filter area})^{0.753}$$

where: MM = maintenance-materials costs in 1983 dollars per year,

total filter area is in square feet.

MM in current dollars = MM * current PPI / 287.1

Where PPI = producers price index for finished goods

$$OL = 1160 + 0.3 * (\text{total filter area})^{1.068} * 1.152^z$$

Where: OL = O&M labor requirements in workhours per year,
 total filter area is in square feet,
 $z = 1$ if total filter area < 7,000 square feet and $z = 0$ if area \geq 7,000 square feet.

OL* labor rate (in \$/hr) = labor costs.

In this analysis, the following parameters were assumed:

Parameter	Assumption
GAC Contactor System Operation	70 percent of design capacity
Systems > 10 mgd	Use concrete gravity adsorbers
Capital amortization	$I = 10$ percent over $N = 20$ years
Capital recovery factor CRF	0.117
Labor and fringe rate	\$25/hr
Electric rate	\$ 0.02/kwh
ENR Construction Cost Index (1983)	5064
ENR Construction Cost Index (1998)	6859
Producers Price Index (1983)	102
Producers Price Index (1998)	130.5

For the City of Shreveport, the following design parameters were assumed:

- Total plant capacity $Q' = 90$ mgd; $70\% Q' = Q = 63$ mgd = 43750 gpm = 5848.5 cu-ft/min;
- Hydraulic loading $Q/A = 5$ gpm/sq ft = 0.6685 cu-ft/min/sq ft;
- Ten GAC concrete gravity contactors.

Table 15
Capital and O&M Costs for a Concrete Gravity Adsorber

Parameter	10-min EBCT	20-min EBCT
DESIGN PARAMETERS		
Bed volume per contactor, cu-ft	5848	11,696
Total GAC effective volume, cu-ft	58,480	116,960
CAPITAL COSTS		
z (in CC equation)	1	1
CC, 1998 \$	7,017,898	11,414,853
Annual capital costs, \$/yr	\$509,843	\$829,277
O& M COSTS		
PE, kwh/yr	104,975	104,975
Annual PE costs, \$/yr	\$2,099	\$2,099
BE, kwh/yr	1,443,563	1,443,563
Annual BE costs, \$/yr	\$28,871	\$28,871
MM costs, 1998 \$/yr	\$28,757	\$28,757
z (in OL equation)	1	1
OL, workhours/yr	6,025	6,025
Annual OL costs, \$/yr	\$150,6323	\$150,6323
Total annual O&M costs	\$150,623	\$150,623
GAC annual reactivation costs	\$5,258,356	\$5,391,976
TOTAL ANNUAL COSTS	\$5,918,822	\$6,371,876

According to Table 15, annual capital costs of a 10-min EBCT contactor are estimated to be 38% lower than those for a 20-min EBCT contactor. Annual O&M costs (including GAC reactivation) were observed to be less than 3% higher when using a 20-min EBCT instead of a 20-min EBCT. Total annual costs (including GAC reactivation costs) were observed to be 7% lower when using a 10-min EBCT instead of a 20-min EBCT.

4.7 Summary of Significant Results

- Seasonal variability was observed in the breakthrough curves of indicators of natural organic matter (TOC) and precursors of TTHMs and HAA5 upon SDS chlorination. The TOC breakthrough rate was somewhat constant at 1.0 percent per day in the 10-min EBCT column. In the 20-min EBCT column, the rate of TOC breakthrough varied

between the quarters, with a 60-65% breakthrough plateau was reached during the Spring and Winter quarters.

- The breakthrough of SDS-DBPs was affected by both the influent TOC concentration and by the influent SDS-DBP concentration. The Stage 2 MCL for TTHMs was exceeded first for both EBCTs during the Summer and Fall quarters. The slowest SDS-TTHM breakthrough occurred during the Winter (low influent SDS-TTHM concentration). Since the influent SDS-HAA5 concentration was low, neither the Stage 1 nor the Stage 2 MCLs for HAA5 were exceeded during the column runs.
- The intermediate bromide influent concentration (range of 99 to 210 µg/L) shifted the speciation of DBPs towards both chlorinated and brominated species, with a tendency towards brominated species. SDS-TTHMs were dominated by dibro-chloromethane, whereas HAAs were dominated by dibromoacetic acid.
- When normalizing for EBCT, a benefit was observed for DBP control by using a 20-min EBCT versus a 10-min EBCT. The 20-min EBCT column was observed to run for longer bed volumes before exceeding a specific target level. Lower GAC replacement or reactivation costs are therefore expected with the use of a 20-min EBCT.
- TOC and UV-254 breakthroughs were observed to correlate well with those of SDS-TTHMs and SDS-HAA5. However, neither TOC concentration nor UV254 absorbance was observed to be conservative enough to be good indicator of DBP precursor. Nevertheless, the low cost and simplicity of TOC and UV-254 analyses render them practical indicators of DBPs.
- The GAC replacement and regeneration costs were evaluated for all quarters using 80% of the Stage 2 MCL for TTHMs criterion. GAC replacement costs were limited by the SDS-TTHM concentration in the effluent of the columns since the Stage 2 HAA5 MCL was not exceeded. In the 10-min EBCT contactor, the GAC replacement costs ranged from \$0.76/1000 gal during the Spring quarter to \$1.66/1000 gal during the Fall quarter. In the 20-min EBCT contactor, the GAC replacement costs ranged from \$0.57/1000 gal of treated water during the Winter quarter, to \$1.92/1000 gal during the Summer quarter. The average GAC replacement annual cost was estimated at \$28,620,000 for a 10-min EBCT, and at \$29,647,500 for a 20-min EBCT. These costs are too high and GAC replacement would not a feasible approach. Based on the carbon utilization rates, total annual costs (assuming cost of 4 reactivators = $4 \times$ cost of single reactivator) incurred by on-site thermal regeneration of GAC were estimated at \$5,258,356 for a 10-min EBCT, and at \$5,391,976, for a 20-min EBCT. Although much lower than GAC replacement costs, reactivation costs remain high, and GAC reactivation would not be a practical and feasible approach.

- Annual capital and O&M costs for a conventional concrete gravity GAC adsorber were also calculated. These costs were based on an 63 mgd average flowrate. Annual capital costs for a 10-min EBCT were estimated at \$509,843, and for a 20-min EBCT at \$829,277. When including the annual GAC reactivation costs to the annual O&M costs, the total annual costs were estimated at \$5,918,822 for a 10-min EBCT, and at \$6,371,876 for a 20-min EBCT.

5. QA/QC Summary

All analyses were performed according to QA/QC procedures described in the DBP/ICR Analytical Methods Manual. All field duplicates were collected at the rate specified. In addition, all methods used are found in the Standard Methods. These data sheets describe the sampling date, the date of analysis, the method of analysis, the result, the result, the minimum reporting level (MRL), and the QC batch identification label when appropriate. Quarterly QA/QC laboratory sheets are included in a separate diskette. These sheets describe for each type of analysis (TOC, UV-254, Br, THM, HAA, and TOX): the QC batch labels, standard calibration results, method blank results, and matrix spike results. These results include spikes and recoveries, yield coefficients and relative percent difference (RPD) coefficients for duplicate samples.

TOC and UV-254 analyses were all conducted by Montgomery Watson's Applied Research Department staff. All TOC and UV-254 analyses were analyzed in duplicate. Quality control checks on TOC and UV-254 analyses are included in the ICR summary spreadsheet. All other regulated analyses, including Br, TOX, THMs, and HAAs were performed by MW laboratories, with the exception of the Spring quarter, during which THMs, HAAs, and TOX analyses were performed by Babcock laboratory, and the Fall quarter, during which HAAs analyses were performed by Summers & Hooper Inc.

The *Summary Report Spreadsheets*, which include general QA/QC data for each laboratory involved in this study, are included in Appendix B.

6. References

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APPENDIX A

CURs for 10-min and 20-min EBCTs

Table A1
CURs during the Spring Quarter for the 10-min EBCT Design

Parameter	Units	Influent Concentration	Target Concentration *	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	86	64	74	1975	0.5	11.6
			32	37	989	1.0	23.2
HAA5	µg/L	15	48	320	>4810	<0.2	<4.8
			24	160	>4810	<0.2	<4.8

* 80% of the Stage 1 and Stage 2 MCLs for each DBP

Table A2
CURs during the Summer Quarter for the 10-min EBCT Design

Parameter	Units	Influent Concentration	Target Concentration *	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	92	64	70	658	1.5	34.9
			32	35	501	2.0	45.9
HAA5	µg/L	24	48	200	>2405	<0.4	<9.6
			24	100	>2405	<0.4	<9.6

* 80% of the Stage 1 and Stage 2 MCLs for each DBP

Table A3
CURs during the Fall Quarter for the 10-min EBCT Design

Parameter	Units	Influent Concentration	Target Concentration *	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	142	64	45	676	1.5	34.0
			32	22	453	2.2	50.8
HAA5	µg/L	27	48	178	>2696	<0.4	<8.5
			24	89	>2696	<0.4	<8.5

* 80% of the Stage 1 and Stage 2 MCLs for each DBP

Table A4
CURs during the Winter Quarter for the 10-min EBCT Design

Parameter	Units	Influent Concentration	Target Concentration *	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	72	64	89	>3071	<0.3	<7.5
			32	44	704	1.4	32.7
HAA5	µg/L	18	48	267	>3071	<0.3	<7.5
			24	133	>3071	<0.3	<7.5

* 80% of the Stage 1 and Stage 2 MCLs for each DBP

Table A5
CURs during the Spring Quarter for the 20-min EBCT Design

Parameter	Units	Influent Concentration	Target Concentration *	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	86	64	74	2044	0.5	11.2
			32	37	707	1.4	32.5
HAA5	µg/L	15	48	320	>4408	<0.2	<5.3
			24	160	>4408	<0.2	<5.3

* 80% of the Stage 1 and Stage 2 MCLs for each DBP

Table A6
CURs during the Summer Quarter for the 20-min EBCT Design

Parameter	Units	Influent Concentration	Target Concentration *	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	92	64	70	743	1.3	31.0
			32	35	391	2.6	58.8
HAA5	µg/L	24	48	200	>2371	<0.4	<9.7
			24	100	>2371	<0.4	<9.7

* 80% of the Stage 1 and Stage 2 MCLs for each DBP

Table A7
CURs during the Fall Quarter for the 20-min EBCT Design

Parameter	Units	Influent Concentration	Target Concentration *	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	142	64	45	738	1.4	31.2
			32	22	465	2.1	49.4
HAA5	µg/L	27	48	178	>2876	<0.3	<8.0
			24	89	>2876	<0.3	<8.0

* 80% of the Stage 1 and Stage 2 MCLs for each DBP

Table A8
CURs during the Winter Quarter for the 20-min EBCT Design

Parameter	Units	Influent Concentration	Target Concentration *	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	72	64	89	>3721	<0.3	<6.2
			32	44	1323	0.8	17.4
HAA5	µg/L	18	48	267	>3721	<0.3	<6.2
			24	133	>3721	<0.3	<6.2

* 80% of the Stage 1 and Stage 2 MCLs for each DBP

APPENDIX B

Summary Report Spreadsheets

Miscellaneous Information

PWSID	LA1017031
Plant ICR #	391

Full-Scale Plant Information

Item	Result
Primary Disinfectant	Ozone and ClO2 (Pri Disinf, Free Cl2, Chloramines, Chlorine Dioxide, Ozone)
Residual Disinfectant	chloramines (Sec Disinf, Free Cl2, Chloramines, Chlorine Dioxide)
Source Type	Surface (River/Stream, Lake, Reservoir, Aquifer)
Source Name	

Laboratory Information

Item	ICR ID or Abbrev	Lab Name	Lab Type	Lab City	Lab State
Lab #1	CA013	Montgomery Watson	commercial	Los Angeles	CA
Lab #2	RCFF	MW Applied Research Departm	consultant	Los Angeles	CA
Lab #3	CA009	E.S. Babcock & Sons	commercial	Riverside	CA
Lab #4	OH033	Summers & Hooper	consultant	Cincinnati	OH

(Commercial, Consultant, State, University, Utility)

Batch Sampling Dates for Quarterly Bench-Scale Testing

Item	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Sample Collection Date	4/20/98	7/28/98	10/8/98	1/7/99

1998 Flow and Population Information

Source	Flow (mgd)	Population Served
Total Population Served		210749
Surface Water	42	42
Ground Water	0	0
Purchased Finished Water	0	0
Total	42	

Full-Scale Water Quality Data

Full-Scale Influent Water Quality Data

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	20	7	9	30	12
pH	Unit	7.2	0.3	6.6	7.7	12
Turbidity	ntu	9.97	5.55	4.73	24.2	12
Alkalinity	mg/L as CaCO ₃	49	23	24	83	12
Total Hardness	mg/L as CaCO ₃	72	36	37	147	12
Calcium Hardness	mg/L as CaCO ₃	na	na	na	na	na
TOC	mg/L	7.2	0.8	6	8.7	12
UV ₂₅₄	1/cm	0.221	0.071	0.144	0.384	12
Bromide	µg/L	na	na	na	na	na
TSUVA*	L/(mg*m)	3.11	1.01	2.22	5.49	12

*TSUVA = [UV₂₅₄ (1/m)] / [TOC (mg/L)]. Summary information for TSUVA should only be calculated from TSUVA values with paired TOC and UV₂₅₄ measurements

Full-Scale Finished Water Quality Data

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	20	7	9	30	12
pH	unit	9	0.4	8.5	9.6	12
Turbidity	ntu	0.21	0.09	0.094	0.35	12
TOC	mg/L	4.3	0.5	3.7	5	12
UV ₂₅₄	1/cm	0.073	0.009	0.057	0.092	12
DS-THM4	µg/L	20.6	6.3	13.3	26.2	4
DS-HAA5	µg/L	na	na	na	na	4
DS-HAA6	µg/L	na	na	na	na	4

QA/QC Data - Sheet 1

											Percentiles		
Analyte Identification	Units	Laboratory Identification	Start Service Date	End Service Date	Method	MRL		Count	Average	Std Dev	25th	50th	75th
pH	unit												
Temperature	C												
Alkalinity	mg/L as CaCO3												
Ammonia	mg NH3-N/L												
Calcium Hardness	mg/L as CaCO3	ICRCA013	9/1/97	5/1/99	EPA 200.7	5							
SDS-Cl2 Residual	mg/L												
Total Hardness	mg/L as CaCO3	ICRCA013	9/1/97	5/1/99	SM 2340B	10							
Turbidity	ntu												
Bromide	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 300.0	20	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	192 392 5	2.7% 102% 100%	4.9% 7% 2%	0.0% 98% 99%	0.9% 101% 100%	3.9% 105% 100%
UV254	1/cm												
TOC	mg/L												
SDS-TOX	µg Cl-/L	ICR-CA013	9/1/97	5/1/99	SM5320B	25	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	865 883 5	4% 100% 88%	4% 20% 8%	1% 92% 85%	3% 98% 86%	6% 105% 88%
SDS-CHCl3	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	254 300 5	5% 112% 93%	7% 74% 9%	0% 93% 86%	3% 100% 93%	6% 113% 99%
SDS-BDCM	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	250 300 5	4% 99% 96%	5% 30% 3%	0% 90% 95%	2% 98% 96%	5% 103% 98%
SDS-DBCM	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	203 301 5	4% 103% 102%	6% 36% 4%	0% 93% 99%	2% 100% 101%	6% 108% 103%
SDS-CHBr3	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	113 301 4	6% 99% 106%	9% 21% 4%	0% 95% 103%	4% 100% 106%	9% 103% 109%
THM4	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	269 301 4	4% 103% 100%	5% 29% 4%	1% 94% 97%	3% 100% 99%	6% 105% 100%
SDS-MCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	2	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	94 447 5	11% 107% 92%	12% 25% 5%	3% 97% 90%	6% 105% 91%	13% 115% 93%
SDS-DCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	367 444 5	4% 106% 90%	6% 41% 9%	0% 97% 85%	2% 100% 88%	6% 106% 88%
SDS-TCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	325 444 5	3% 108% 96%	6% 57% 12%	0% 97% 90%	2% 100% 92%	5% 110% 93%
SDS-MBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	48 448 5	10% 112% 89%	12% 27% 7%	0% 100% 84%	7% 105% 93%	16% 110% 94%
SDS-DBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	199 447 5	5% 105% 98%	6% 24% 15%	0% 97% 91%	3% 100% 94%	7% 106% 95%
SDS-BCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	325 447 5	4% 103% 95%	6% 19% 12%	0% 97% 90%	3% 100% 91%	6% 105% 92%
SDS-TBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	4	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	11 320 0	3% 113% 113%	2% 24% 24%	1% 103% 104%	2% 115% 110%	4% 125% 120%
SDS-CDBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	2	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	133 407 0	4% 113% 113%	5% 24% 24%	0% 104% 104%	3% 110% 110%	5% 120% 120%
SDS-DCBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	325 435 0	4% 113% 113%	6% 22% 22%	0% 103% 103%	3% 110% 110%	6% 120% 120%
HAA5	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	385 448 5	5% 108% 100%	5% 23% 8%	1% 99% 87%	4% 103% 93%	6% 109% 93%
HAA6	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	385 448 5	5% 107% 100%	5% 20% 9%	2% 99% 87%	4% 103% 92%	6% 108% 93%
HAA9	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	387 448 5	5% 109% 109%	4% 17% 17%	2% 102% 102%	4% 106% 106%	6% 111% 111%

QA/QC Data - Sheet 1											Percentiles		
Analyte Identification	Units	Laboratory Identification	Start Service Date	End Service Date	Method	MRL	Count	Average	Std Dev	25th	50th	75th	
pH	unit												
Temperature	C												
Alkalinity	mg/L as CaCO3												
Ammonia	mg NH3-N/L												
Calcium Hardness	mg/L as CaCO3												
SDS-Cl2 Residual	mg/L												
Total Hardness	mg/L as CaCO3												
Turbidity	ntu												
Bromide	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
UV254	1/cm						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
TOC	mg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-TOX	µg Cl-/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-CHCl3	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	109 145 5	4% 84% 102%	4% 40% 8%	0% 75% 97%	4% 85% 104%	7% 95% 108%
SDS-BDCM	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	117 145 5	3% 98% 100%	4% 129% 9%	0% 80% 94%	2% 90% 105%	5% 100% 105%
SDS-DBCM	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	117 146 5	3% 104% 100%	4% 54% 11%	0% 90% 94%	2% 96% 101%	4% 100% 105%
SDS-CHBr3	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	86 146 4	4% 122% 93%	5% 77% 13%	0% 98% 88%	2% 100% 90%	6% 120% 95%
THM4	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	144 146 5	3% 102% 100%	3% 47% 9%	1% 88% 97%	3% 95% 99%	4% 103% 106%
SDS-MCAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-DCAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-TCAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-MBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-DBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-BCAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-TBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-CDBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-DCBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
HAA5	µg/L						Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:						
HAA6	µg/L						Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:						
HAA9	µg/L						Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:						

QA/QC Data - Babcock laboratory											Percentiles		
Analyte		Laboratory	Start	End									
Identification	Units	Identification	Service Date	Date	Method	MRL		Count	Average	Std Dev	25th	50th	75th
pH	unit												
Temperature	C												
Alkalinity	mg/L as CaCO ₃												
Ammonia	mg NH ₃ -N/L												
Calcium Hardness	mg/L as CaCO ₃												
SDS-Cl ₂ Residual	mg/L												
Total Hardness	mg/L as CaCO ₃												
Turbidity	ntu												
Bromide	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
UV ₂₅₄	1/cm						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
TOC	mg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-TOX	µg Cl-/L	Babcock	6/13/99	6/17/99	SM5320B	25	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	62 30 3	6.4 109 93	5.4 19.7 8.5	3.1 97 83	6.1 107 96	8.2 112 99
SDS-CHCl ₃	µg/L	Babcock	6/17/98	6/18/98	EPA 502.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1 3 3	0 95 100	NA 13 4.9	0 80 97	0 98 98	0 107 106
SDS-BDCM	µg/L	Babcock	6/17/98	6/18/98	EPA 502.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1 3 3	2.3 103 108	NA 3.5 9.1	2.3 100 98	2.3 103 109	2.3 107 116
SDS-DBCM	µg/L	Babcock	6/17/98	6/18/98	EPA 502.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1 3 3	0 116 110	NA 8.5 3	0 108 107	0 116 110	0 125 113
SDS-CHBr ₃	µg/L	Babcock	6/17/98	6/18/98	EPA 502.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1 3 3	0 96 105	NA 46.8 12.7	0 42 90	0 120 111	0 126 113
THM4	µg/L	Babcock	6/17/98	6/18/98	EPA 502.2		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	1 3 3	0.6 103 106	1.2 17.7 6.7	0.6 82.5 98	0.6 109 9	0.6 116 110
SDS-MCAA	µg/L	Babcock	6/17/98	6/18/98	SM6251 B	2	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	0 106 93	0 10.6 17.9	0 100 78	0 105 89	0 115 113
SDS-DCAA	µg/L	Babcock	6/17/98	6/18/98	SM6251 B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	1 97 82	2 7 15	0 95 67	0 95 83	1 105 97
SDS-TCAA	µg/L	Babcock	6/17/98	6/18/98	SM6251 B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	0.3 103 86	0.8 11 8.5	0 95 77	0 105 87	0 115 94
SDS-MBAA	µg/L	Babcock	6/17/98	6/18/98	SM6251 B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	0 102 82	0 12.8 11.3	0 95 69	0 100 88	0 120 89
SDS-DBAA	µg/L	Babcock	6/17/98	6/18/98	SM6251 B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	0.3 101 78	0.8 12.7 14.4	0 90 61	0 105 86	0 115 86
SDS-BCAA	µg/L	Babcock	6/17/98	6/18/98	SM6251 B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	0.5 101 77	1.2 10.3 12.9	0 95 66	0 105 73	0 110 91
SDS-TBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-CDBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-DCBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
HAA5	µg/L	Babcock	6/18/98	7/7/98	SM6251 B		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	6 8 3	0.5 102 83	0.4 8.9 11.6	0.3 94 70	0.5 103 88	1 113 91
HAA6	µg/L	Babcock	6/18/98	7/7/98	SM6251 B		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:						
HAA9	µg/L						Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:						

QA/QC Data - S&H											Percentiles		
Analyte Identification	Units	Laboratory Identification	Start Service Date	End Service Date	Method	MRL	Count	Average	Std Dev		25th	50th	75th
pH	unit												
Temperature	C												
Alkalinity	mg/L as CaCO3												
Ammonia	mg NH3-N/L												
Calcium Hardness	mg/L as CaCO3												
SDS-Cl2 Residual	mg/L												
Total Hardness	mg/L as CaCO3												
Turbidity	ntu												
Bromide	µg/L												
						RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
UV254	1/cm												
						RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
TOC	mg/L												
						RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-TOX	µg Cl-/L												
						RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-CHCl3	µg/L												
						RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-BDCM	µg/L												
						RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-DBCM	µg/L												
						RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-CHBr3	µg/L												
						RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
THM4	µg/L												
						Avg RPE of Indiv Anal Dupl:							
						Avg % Recov for Indiv Lab Fort Matrix:							
						Avg % Recov for Indiv PE Samples:							
SDS-MCAA	µg/L	OH033	12/2/98	12/3/98	EPA 552.2	2							
						RPE of Analytical Duplicates:	1	2.2					
						% Recovery for Lab Fortified Matrix:	2	101.3	3.0	100.5	101.3	102.0	
						% Recovery for PE Samples:	4	86.9	18.9	80.2	91.4	98.1	
SDS-DCAA	µg/L	OH033	12/2/98	12/3/98	EPA 552.2	1							
						RPE of Analytical Duplicates:	2	7.8	8.9	5.6	7.8	10.0	
						% Recovery for Lab Fortified Matrix:	2	99.0	0.5	98.9	99.0	99.1	
						% Recovery for PE Samples:	4	88.5	13.8	85.2	93.7	97.0	
SDS-TCAA	µg/L	OH033	12/2/98	12/3/98	EPA 552.2	1							
						RPE of Analytical Duplicates:	2	12.3	3.3	11.4	12.3	13.1	
						% Recovery for Lab Fortified Matrix:	2	103.5	11.0	100.8	103.5	106.3	
						% Recovery for PE Samples:	4	81.8	8.2	75.3	81.1	87.5	
SDS-MBAA	µg/L	OH033	12/2/98	12/3/98	EPA 552.2	1							
						RPE of Analytical Duplicates:	2	100.5	10.5	97.9	100.5	103.1	
						% Recovery for Lab Fortified Matrix:	4	82.2	16.0	80.7	88.2	89.7	
SDS-DBAA	µg/L	OH033	12/2/98	12/3/98	EPA 552.2	1							
						RPE of Analytical Duplicates:	1	18.0					
						% Recovery for Lab Fortified Matrix:	2	106.6	14.3	103.1	106.6	110.2	
						% Recovery for PE Samples:	4	89.7	9.1	86.0	91.9	95.5	
SDS-BCAA	µg/L	OH033	12/2/98	12/3/98	EPA 552.2	1							
						RPE of Analytical Duplicates:	2	8.4	8.4	6.3	8.4	10.5	
						% Recovery for Lab Fortified Matrix:	2	105.1	10.8	102.4	105.1	107.8	
						% Recovery for PE Samples:	4	84.4	10.7	82.6	88.3	90.1	
SDS-TBAA	µg/L	OH033	12/2/98	12/3/98	EPA 552.2	4							
						RPE of Analytical Duplicates:	1	19.6					
						% Recovery for Lab Fortified Matrix:	2	99.5	27.0	92.8	99.5	106.3	
						% Recovery for PE Samples:							
SDS-CDBAA	µg/L	OH033	12/2/98	12/3/98	EPA 552.2	2							
						RPE of Analytical Duplicates:	1	20.7					
						% Recovery for Lab Fortified Matrix:	2	102.0	24.5	95.9	102.0	108.1	
						% Recovery for PE Samples:							
SDS-DCBAA	µg/L	OH033	12/2/98	12/3/98	EPA 552.2	1							
						RPE of Analytical Duplicates:	2	13.7	13.5	10.3	13.7	17.0	
						% Recovery for Lab Fortified Matrix:	2	106.8	22.0	101.3	106.8	112.3	
						% Recovery for PE Samples:							
HAA5	µg/L	OH033	12/2/98	12/3/98	EPA 552.2								
						Avg RPE of Indiv Anal Dupl:	2	10.1	9.4	7.7	10.1	12.4	
						Avg % Recov for Indiv Lab Fort Matrix:	2	102.2	7.8	100.2	102.2	104.1	
						Avg % Recov for Indiv PE Samples:	4	85.8	12.3	83.5	90.8	93.1	
HAA6	µg/L	OH033	12/2/98	12/3/98	EPA 552.2								
						Avg RPE of Indiv Anal Dupl:	2	9.6	9.1	7.4	9.6	11.9	
						Avg % Recov for Indiv Lab Fort Matrix:	2	102.7	8.3	100.6	102.7	104.8	
							4	85.6	12.0	83.6	90.4	92.3	
HAA9	µg/L	OH033	12/2/98	12/3/98	EPA 552.2								
						Avg RPE of Indiv Anal Dupl:	2	11.1	11.4	8.3	11.1	14.0	
						Avg % Recov for Indiv Lab Fort Matrix:	2	102.7	13.7	99.3	102.7	106.1	

QA/QC Data - Applied Research Department RCFF										Percentiles		
Analyte Identification	Units	Laboratory Identification	Start Service Date	End Service Date	Method	MRL	Count	Average	Std Dev	25th	50th	75th
pH	unit	RCFF	Apr-98	Mar-99	SM 4500-H+							
Temperature	C	RCFF	Apr-98	Mar-99	SM 2550 B							
Alkalinity	mg/L as CaCO ₃	RCFF	Apr-98	Mar-99	SM 2320 E5 mg/L as CaCO ₃							
Ammonia	mg NH ₃ -N/L	RCFF	Apr-98	Mar-99	SM 4500-10.10 mg/L as N							
Calcium Hardness	mg/L as CaCO ₃											
SDS-Cl ₂ Residual	mg/L	RCFF	Apr-98	Mar-99	SM 4500-C0.2 mg/L							
Total Hardness	mg/L as CaCO ₃	RCFF	Apr-98	Mar-99	SM 2340 E7 mg/L as CaCO ₃							
Turbidity	ntu	RCFF	Apr-98	Mar-99	SM 2130 E0.05 ntu							
Bromide	µg/L		Apr-98	Mar-99		RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
UV ₂₅₄	1/cm	RCFF	Apr-98	Mar-99	SM 5910 0.009 1/cm	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	65 NA NA	1.11 NA NA	2.6 NA NA	0 NA NA	0 NA NA	0.5 NA NA
TOC	mg/L	RCFF	Apr-98	Mar-99	SM 5310 C0.5 mg/L	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	65 24 NA	6.43 104.45 NA	11.02 7.27 NA	0.87 103 NA	4.44 105 NA	7.41 109 NA
SDS-TOX	µg Cl-/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-CHCl ₃	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-BDCM	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-DBCM	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-CHBr ₃	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
THM4	µg/L					Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:						
SDS-MCAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-DCAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-TCAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-MBAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-DBAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-BCAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-TBAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-CDBAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-DCBAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
HAA5	µg/L					Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:						
HAA6	µg/L					Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:						
HAA9	µg/L					Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:						