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 March, 1998 through April, 1999

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Cosme Water Treatment Plant, ICR # 318

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 Cosme 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 water sample was collected from the effluent of the softening units, just before application of chlorine. Full-scale filtration was simulated at bench-scale. Full-scale distribution system conditions (pH, temperature, free chlorine residual, average residence time) were simulated during chlorination testing.

Seasonal variability had no significant impact on the control of DBP formation using GAC and thus on the cost of the process. This is expected since the Cosme WTP is served by a groundwater aquifer that undergoes minimal changes in water quality. Nevertheless, the Spring and Summer 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 SDS-TTHM concentration in the chlorinated influent, rather than a high TOC 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. However, only the "placeholder" Stage 2 TTHM MCL was exceeded. In all cases, the Stage 2 HAA5 MCL was not exceeded during the course of the column runs.

In the 10-min EBCT contactor, the GAC replacement cost was estimated at $0.24/1000 gal of treated water during the Spring quarter, and at $0.32/1000 gal during the Summer quarter. In the 20-min EBCT contactor, the GAC replacement cost was estimated at $0.28/1000 gal of treated water during the Spring quarter, and at $0.37/1000 gal during the Summer quarter. The annual average GAC replacement cost was estimated at $4,905,600 for a 10-min EBCT, and at $5,694,000 for a 20-min EBCT. On-site GAC thermal reactivation costs were also estimated using the amount of GAC used to reach 80% of the Stage 2 TTHM MCL. Total annual costs (including amortized capital costs for a reactivator) were estimated at $1,089,424 for a 10-min EBCT, and at $1,197,313 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 a 48 mgd average flowrate. Annual amortized capital costs for a 10-min EBCT were estimated at $677,991, and for a 20-min EBCT at $1,101,088. When including the annual GAC reactivation costs to the annual O&M costs, the total annual costs were estimated at $1,955,057 for a 10-min EBCT, and at $2,486,042 for a 20-min EBCT. Using a 10-min EBCT instead of a 20-min EBCT resulted in an overall cost saving of 21%.

2. Background Information

2.1 Cosme Water Treatment Plant Description

The City of Saint Petersburg owns and operates the Cosme Water Treatment Plant. The plant overall design capacity is 68 MGD. The WTP draws its water supply year-round primarily from groundwater wells connected to the Floridan aquifer. The treatment plant ranks in the complex parallel train/softening category and consists of aeration, softening, chlorination, filtration and a clearwell. Free chlorine is applied after softening and after filtration (at the influent of the clearwell). Filter washwater is returned back to the treatment train and blended in with the effluent of the aeration tank (influent of the softening units). A proportion of the aeration tank effluent (before blending with washwater) bypasses the washwater return and softening tanks and mixes with the softened water at a 45% bypass water and 55% softened water proportion. The resulting composite water represents the water that mixes in the flume and flows into the junction chamber adjacent to the prechlorination basin. The current average daily flow through the WTP is 37 MGD.

2.1.1 Treatment plant schematic

Figure 1 illustrates a simplified schematic of the water treatment processes applied at the Cosme WTP and also shows the sample locations and analytes covered under the 18-months of monthly ICR monitoring.

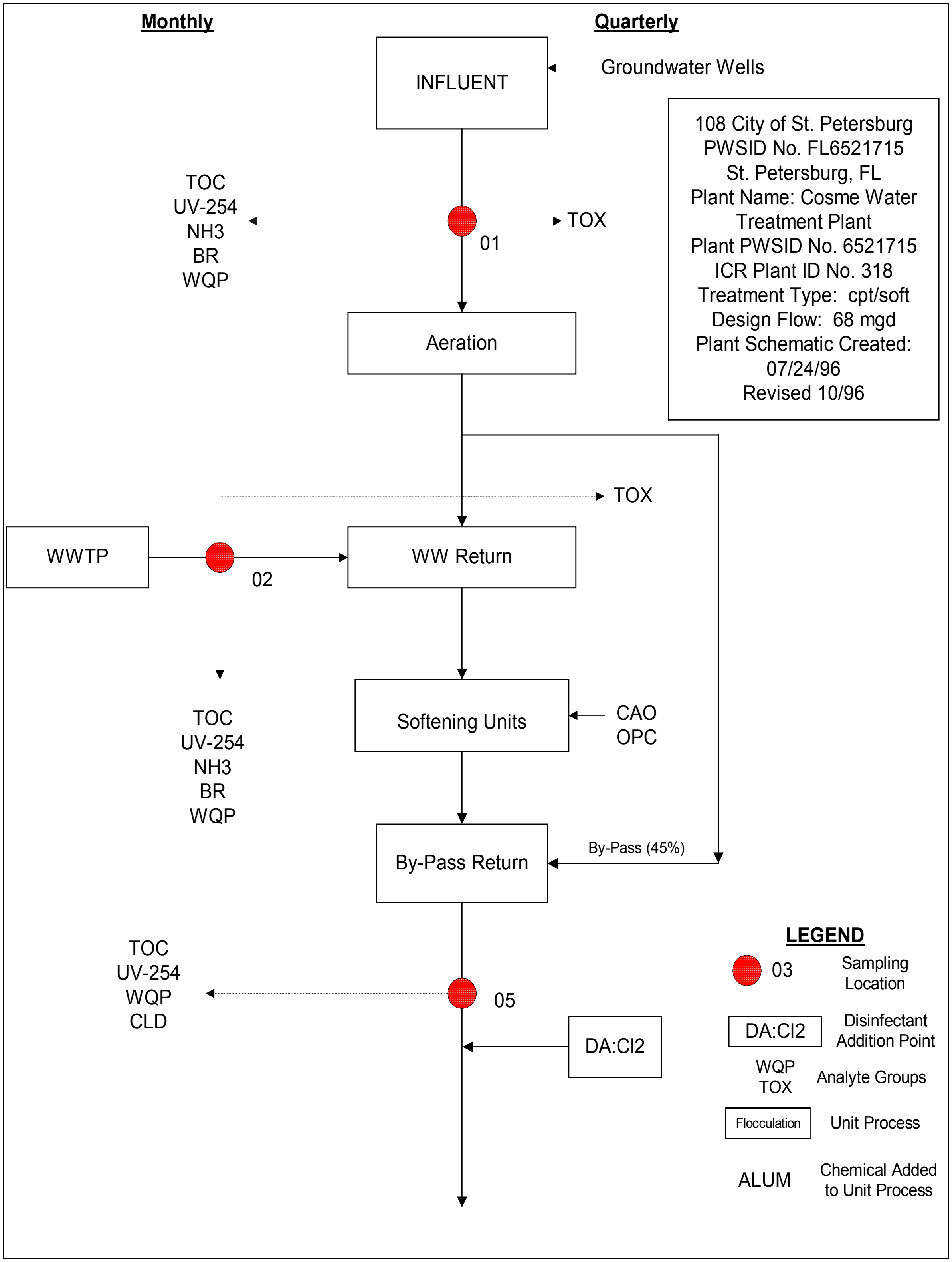

Figure 1. Cosme WTP Schematic

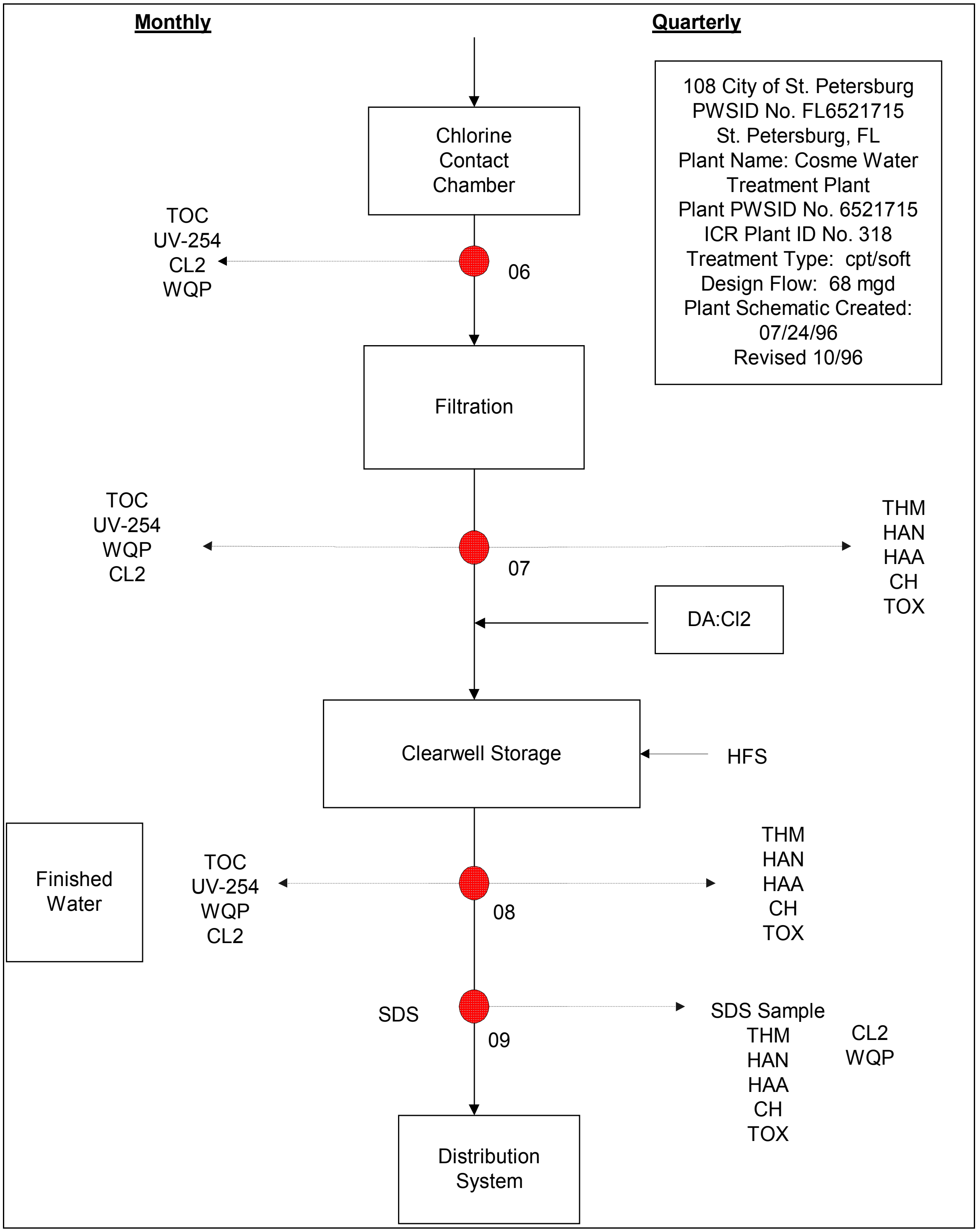

Figure 1 (continued).Cosme WTP Schematic

2.1.2 Treatment plant design information

The following Table 1 summarizes the Cosme WTP design data.

Table 1
Treatment Plant Design Data

Unit Process	Process Description	
	By-Pass Train	**Softening Train**
Aeration	Surface Area (ft2): 12,554 Liquid Volume (gal): 125,188	Surface Area (ft2): 12,554 Liquid Volume (gal): 125,188
Lime Softening	N/A	Surface Area (ft2): 26,934 Liquid Volume (gal): 3,164,616 Organic polymer: Magnifloc 844A, dosage rate: 0.04 mg/L Calcium oxide, dosage rate: 59.0 mg/L
Disinfection	Cl_2 Average Dose rate: 5.78 mg/L	Cl_2 Average Dose rate: 5.78 mg/L
Pre-chlorination Contact Chamber	Surface Area (ft2): 2,300 Liquid Volume (gal): 371,526	Surface Area (ft2): 2,300 Liquid Volume (gal): 371,526
Filtration	Surface Area (ft2): 9,600 Liquid Volume (gal): 682,460 Total Media Depth (in): 34 Media Type: Anthracite: 12 in Filter sand: 10 in Gravel: 12 in Minimum Water Depth to Top of Media (ft): 6.2 Depth from top of media to top of backwash trough (ft): 3.4 Filter run: 240 hours	Surface Area (ft2): 9,600 Liquid Volume (gal): 682,460 Total Media Depth (in): 34 Media Type: Dual Anthracite: 12 in Filter sand: 10 in Gravel: 12 in Minimum Water Depth to Top of Media (ft): 6.2 Depth from top of media to top of backwash trough (ft): 3.4 Filter Run: 240 hours
Disinfection	Cl_2 Average Dose Rate: 0.72	Cl_2 Average Dose Rate: 0.72
Clearwell	Surface Area (ft2): 10,132 Liquid Volume (gal): 814,689 Minimum Liquid Volume (gal): 606,280	Surface Area (ft2): 10,132 Liquid Volume (gal): 814,689 Minimum Liquid Volume (gal): 606,280
	Hydrofluorosilic acid, dosage rate: 0.60 mg/L	Hydrofluorosilic acid, dosage rate: 0.60 mg/L

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 Cosme 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 Cosme WTP
(January 1998 through December 1998)

Source Water Quality Parameter	Average Value	Standard Deviation	Minimum Value	Maximum Value
Temperature (°C)	24.54	0.71	23.40	25.40
pH	7.41	0.09	7.22	7.51
Turbidity (NTU)	0.20	0.08	0.10	0.33
Total Alkalinity (mg/L as $CaCO_3$)	200	27	117	213
Total Hardness (mg/L as $CaCO_3$)	204	4	198	212
TOC (mg/L)	2.45	0.28	1.9	2.8
UV-254 (cm^{-1})	0.107	0.011	0.090	0.124
Bromide (mg/L)				

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

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

Finished Water Quality Parameter	Average Value	Standard Deviation	Minimum Value	Maximum Value
Temperature (°C)	24.79	0.75	23.40	25.80
pH	7.70	0.28	7.14	8.14
Turbidity (NTU)	0.25	0.15	0.12	0.54
TOC (mg/L)	2.20	0.28	1.60	2.60
UV_{254} (cm^{-1})	0.064	0.006	0.054	0.076
TTHM (µg/L)*	86.35	16.91	58.00	107.30

* Based on four quarterly sampling campaigns (01/98; 04/98; 07/98; 10/98). Measured in the distribution system at the two average residence time sites (008A and 006A).

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 Cosme WTP, since free chlorine is first added in the influent of the granular media, the feed water for the study was collected from the blended softened and by-passed waters. 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	March 27, 1998
Summer	July 2, 1998
Fall	September 17, 1998
Winter	November 19, 1998

A total of 200 gallons of softened water were collected during each quarter. Two 100-gal polyethylene tanks were used for sample collection. Tanks were rinsed with tap water and deionized (DI) water prior to shipping. Samples were shipped to Montgomery Watson's Applied Research Laboratory via FFE refrigerated trucks. Upon arrival at the laboratory, the samples were immediately refrigerated at 4ºC until the day of testing.

Upon receipt of the samples, the softened water was analyzed for general water quality parameters to verify sample representativeness. Table 5 presents general water quality of the four collected softened water samples.

Table 5
General Water Quality of Collected Softened Water Samples

Parameter	Unit	Spring	Summer	Fall	Winter
pH	---	8.4	8.8	8.3	8.5
TOC	mg/L	3.3*	2.8*	3.8*	3.5*
Turbidity	NTU	2.0	2.20	0.39	1.80
Alkalinity	mg/L as $CaCO_3$	135	125	110	125
Total Hardness	mg/L as $CaCO_3$	62.0	n.a.	n.a.	n.a.
Apparent Color	Pt. Co. C.U.	13	13	30	35
True Color	Pt. Co. C.U.	10	8	13	9
Apparent UV-254	cm^{-1}	0.090	0.078	0.085	0.103
Filtered UV-254	cm^{-1}	0.089	0.078	0.083	0.085

*After 0.45 -µm cartridge filtration; n.a: not available

3.2 Pretreatment Processes

3.2.1 Description of pretreatment processes

Since free chlorine was added first to the influent of the filters, 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 GAC Adsorption Process

3.3.1 RSSCT set-up information

Figure 2 illustrates the RSSCT column set-up. 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.

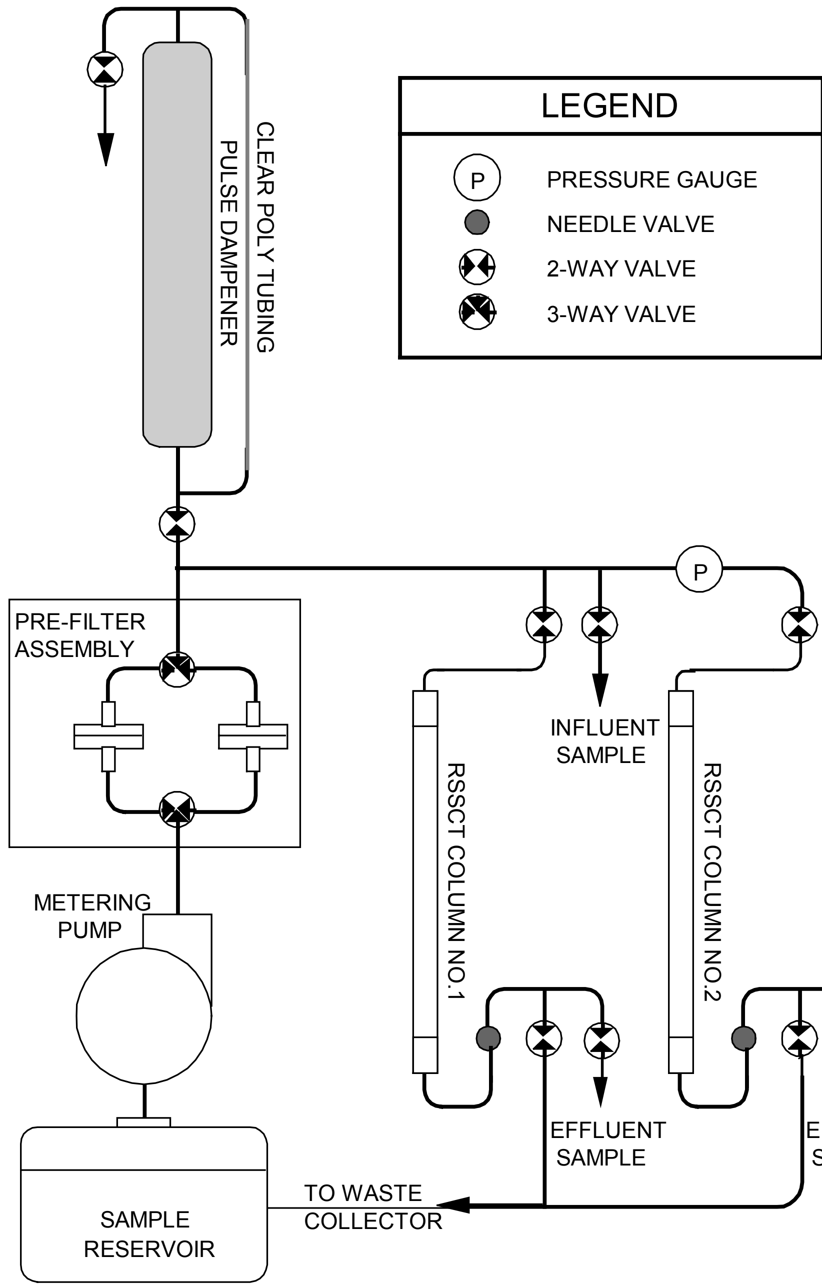

Figure 2. RSSCT Flow Diagram

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 9.4. A bituminous coal based GAC from Calgon Carbon Corp. (F-400), was used in this study. A minimum Reynolds number $Re_{SC}min$ of 0.5 was used as recommended value by the ICR Guidance Manual. An 8-mm RSSCT column diameter was used in the two columns. An on-line pre-filter consisting of a 0.2-µm membrane was used to reduce the headloss build-up in the GAC columns. The design parameters applied during each quarter are summarized in Table 6.

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 weight was checked to make sure that it did not differ by more than 5% from the previous 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 degassed 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 though a 0.45-µm cartridge filter to minimize potential headloss buildup in the column.

Table 6
RSSCT Design Parameters

DESIGN PARAMETERS	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**
RSSCT influent TOC (mg/L)	**3.3**	**2.8**	**3.8**	**3.5**
Inner diameter of the RSSCT column, D_{SC} (mm)	**8.0**	**8.0**	**8.0**	**8.0**
Minimum RSSCT Reynolds number, $Re_{SC,\ min}$	0.5	0.5	0.5	0.5
Full-scale operating temperature, T^oC (^oC)	20.0	20.0	20.0	20.0
Full-scale bed porosity, e_{LC}	0.45	0.45	0.45	0.45
Measured RSSCT dry bed density, r_{SC} (g/cm^3)	**0.5**	**0.5**	**0.55**	**0.55**
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}	4525	5691	3826	4258
Estimated run length, BV_T (= 2 x BV_{50})	9049	11381	7652	8515
BV_T + 30% safety factor, $BV_{T+30\%}$ (= 2.6 x BV_{50})	11764	14795	9948	11070
General RSSCT Design Parameters				
Kinematic viscosity at T^oC, n_{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, v_{SC} (m/hr)	7.39	7.39	7.39	7.39
RSSCT flow rate, Q_{SC} (mL/min)	6.19	6.19	6.19	6.19
Estimated total influent volume required, V_{SC}^T (L)	234	294	198	220
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)	82	103	69	77
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	1.07	1.07	1.07	1.07
Estimated RSSCT run time, t_{SC}^T (days)	8.73	10.98	7.38	8.22
RSSCT bed length, l_{SC} (cm)	13.2	13.2	13.2	13.2
Estimated volume required for 10-minute EBCT, V_{SC} (L)	78	98	66	73
Mass GAC required, m_{SC} (g)	3.31	3.31	3.64	3.64
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)	163	205	138	154
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	2.14	2.14	2.14	2.14
Estimated RSSCT run time, t_{SC}^T (days)	17.46	21.96	14.77	16.43
RSSCT bed length, l_{SC} (cm)	26.3	26.3	26.3	26.3
Estimated volume required for 20-minute EBCT, V_{SC} (L)	156	196	132	147
Mass GAC required, m_{SC} (g)	6.62	6.62	7.28	7.28

3.4 Experimental Design

The experimental design summary is presented in Table 7. 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 7
Experimental Design Summary

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

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 Saint Petersburg staff. These conditions included the average residence time, free chlorine residual, pH and temperature at the average residence time. Table 8 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 8
Target SDS Chlorination Testing Conditions

Parameter	September 1997		December 1997		March 1998		June 1998	
	Value	Tolerance	Value	Tolerance	Value	Tolerance	Value	Tolerance
Incubation time, hrs	24.0	1.0	24.0	1.0	24.0	1.0	24.0	1.0
Incubation temp.,°C	23.2	2.0	24.0	2.0	25.0	2.0	25.0	2.0
pH	7.6	0.4	8.4	0.4	7.6	0.4	7.6	0.4
Free Cl_2 residual, mg/L	1.0	0.4	1.0	0.4	1.0	0.4	1.0	0.4

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 9.

Table 9
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	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 551, 502.2	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 10 presents a listing of the laboratories involved in analytical reporting and the period over which analyses were conducted by each laboratory. Following Table 10 is additional information on the location and contact person at each individual laboratory. More information is included in Appendix B.

Table 10
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, Total hardness*
Montgomery Watson Labs	Quarters 1 through 4	THM4 (EPA 524.2) , HAA6 (SM 6251B), TOX (SM 5320), Bromide, Ca-hardness Total hardness TOX (SM 5320B) HAA6 (SM 6251B) and THM (EPA 551.1)

* During quarter 1 only

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

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 11 summarizes the water quality in the pretreated influent to the RSSCT. No major seasonal variability was observed in organic parameters (TOC concentration, UV-254 absorbance). Organic content was observed to be highest during the Fall, as represented by the TOC concentration of 3.18 mg/L and UV-254 absorbance of 0.085/cm. Alkalinity ranged from 101 during the Summer to 125 mg/L $CaCO_3$ during the Winter. The influent pH varied from 7.9 during the Spring to 8.4 during the Winter. Total hardness was moderate throughout the quarters, ranging from 117 mg/L $CaCO_3$ during the Fall to 133 mg/L $CaCO_3$ during the Summer. Ammonia-nitrogen concentration was measured highest during the Spring and Winter quarters, at approximately 0.45 mg/L as nitrogen. Bromide concentration was low, and ranged from 24.5 to 35.0 µg/L. A higher proportion of chlorinated DBPs would therefore be expected. The highest chlorine demand was measured during the Spring quarter at 5.1 mg/L. The SDS-TTHM concentration in the chlorinated influent was low, and ranged from 46.2 µg/L during the Winter to 55.0 µg/L during the Summer. The SDS-HAA5 concentration was somewhat more significant, and ranged from 27.0 µg/L during the Summer to 45.5 µg/L during the Spring. The SDS temperature did not vary significantly during each quarter (range of 23°C to 25°C). The SDS pH did not vary significantly and was measured highest at 8.4 during the Summer quarter (Table 8).

Table 11
Water Quality of the Influent to the RSSCT

Water Quality Parameter	Spring Average (SD)*	Summer Average (SD)*	Fall Average (SD)*	Winter Average (SD)*
pH	7.87 (0.00)	8.30 (0.00)	8.13 (0.00)	8.40 (0.01)
Turbidity (ntu)	0.19 (0.21)	0.21 (0.05)	0.20 (0.00)	0.23 (0.24)
Alkalinity mg/L $CaCO_3$	117	101	120	125
Calcium Hardness mg/L $CaCO_3$	107	113	102	104
Total Hardness mg/L $CaCO_3$	NR	133	117	122
Bromide (μg/L)	28	25	35	30
Ammonia-N (mg/L)	0.50**	<0.10	<0.10	0.40
TOC (mg/L)	3.2 (0.0)	2.9 (0.0)	3.2 (0.0)	2.9 (0.0)
UV_{254} (cm^{-1})	0.083 (0.007)	0.071 (0.073)	0.085 (0.007)	0.076 (0.008)
SUVA (L/mg-cm)	2.63 (0.02)	2.41 (0.06)	2.66 (0.02)	2.60 (0.03)
SDS-THM4 (μg/L)	53 (0)	55 (0)	51 (0)	46 (0.1)
SDS-HAA5 (μg/L)	45 (0)	27 (0)	36 (0)	34 (0)
SDS-HAA6 (μg/L)	49 (0)	29 (0)	38 (0)	37 (0)
SDS-TOX (μg Cl^- /L)	198 (0)	207 (0)	188 (0)	195 (0)
SDS-chlorine demand (mg/L)	5.1 (0.01)	3.0 (0.0)	1.8 (0.0)	3.5 (0.08)

* SD: Standard Deviation; NR: not reported; ** Based on the analysis result from one sample

4.3 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 3 and 4. The columns were kept running until the 70% TOC breakthrough criterion was exceeded. Seasonal variation was not observed to impact significantly TOC breakthrough from either GAC column. There seems to be no correlation with respect to column run between the 10-min and the 20-min EBCT columns. For the 10-min EBCT design, the column ran longest during the Fall quarter (100 scaled days of operation), and shortest during the Spring quarter (51 scaled days of operation). For the 20-min EBCT design, the column ran longest during the Winter quarter (169 scaled days of operation), and shortest during the Summer quarter (126 scaled days of operation). The rate of breakthrough (slope of curves) was observed to be somewhat constant for both EBCT designs. The rate of breakthrough was estimated at approximately 0. 77 percent/day for the 10-min EBCT, and at approximately 0. 44 percent/day for the 20-min EBCT.

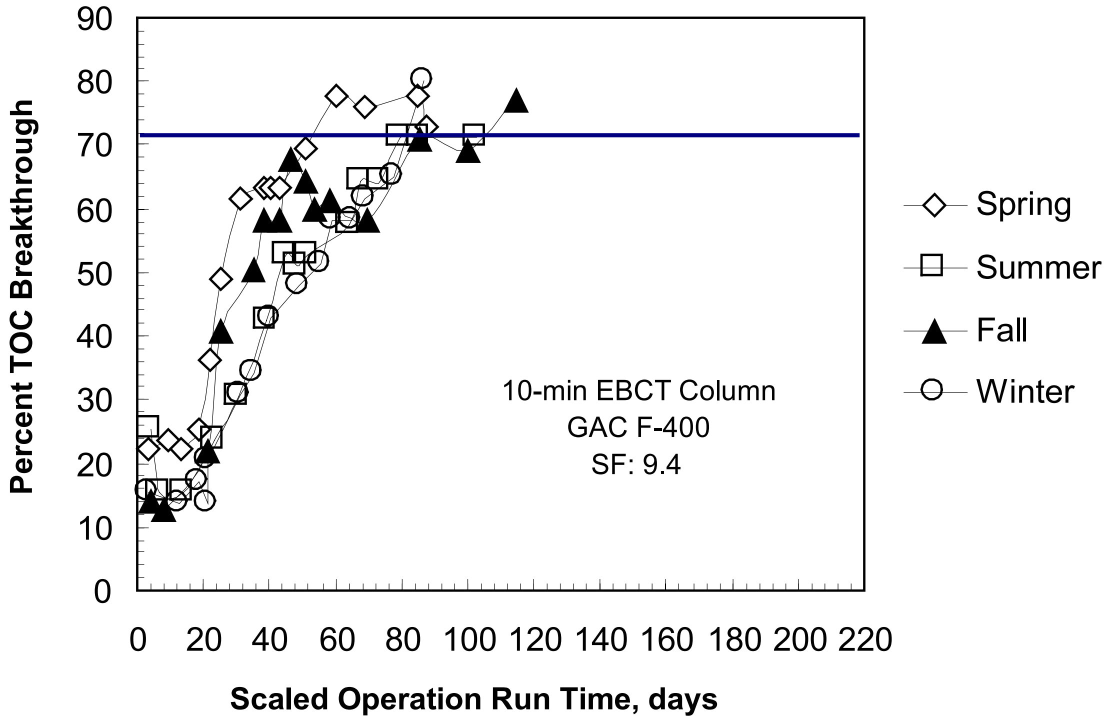

Figure 3. Impact of Seasonal Variability on Percent TOC Breakthrough in the 10-min EBCT Column

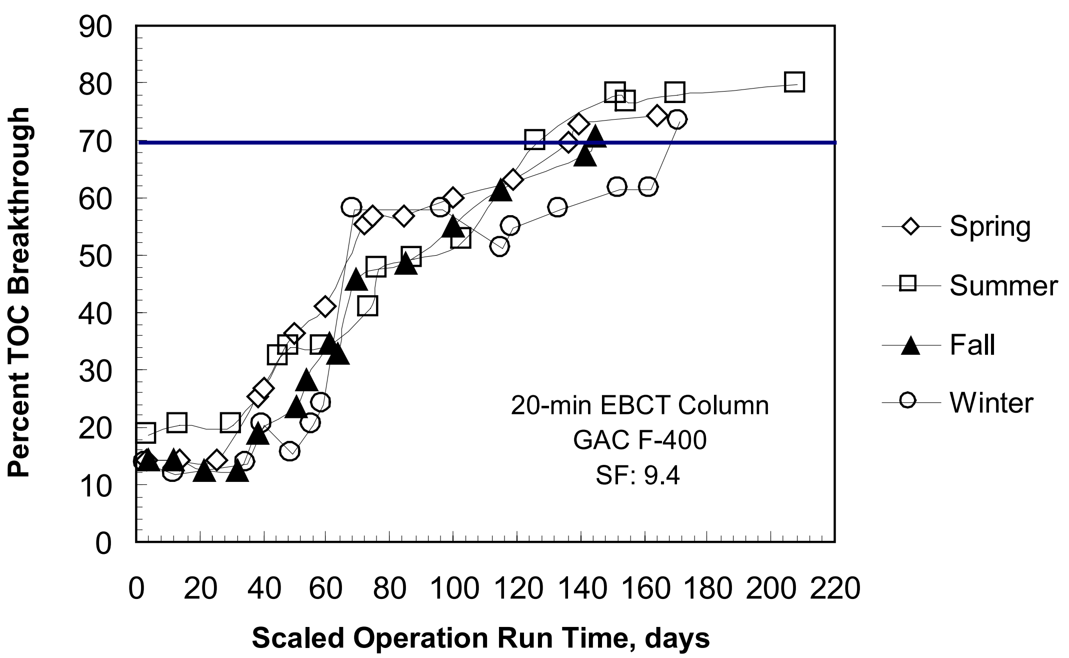

Figure 4. Impact of Seasonal Variability on TOC Breakthrough in the 20-min EBCT Column

4.3.2 Impact of Seasonal Variability on SDS-TTHM Breakthrough

Figures 5 and 6 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 the influent SDS-TTHM concentration. For the Winter quarter, during which the lowest influent SDS-TTHM concentration was measured (46.2 µg/L), the SDS-TTHM broke through last relative to the previous three quarters (after approximately 20 scaled days of operation for the 10-min EBCT column, and after approximately 50 scaled days for the 20-min EBCT column). The SDS-TTHM concentrations in the chlorinated influent were low, and ranged from a high of 55 µg/L during the Summer quarter, to a low of 46.2 µg/L during the Winter quarter. The rates of SDS-TTHM breakthrough were however somewhat similar, and measured at 0.43 µg/L/day for the 10-min EBCT column, and at 0.22 µg/L/day for the 20-min EBCT column. In the 10-min EBCT column, Stage 2 TTHM MCL was only exceeded during the Summer quarter, after 102 scaled days of operation run time. In the 20-min column, the Stage 2 TTHM MCL was exceeded first during the Summer quarter, after 136 scaled days of operation, while the column was operated for 156 scaled days, before the Stage 2 TTHM MCL was exceeded during the Spring quarter. As expected, the Stage 1 TTHM MCL was not exceeded during operation for either EBCT.

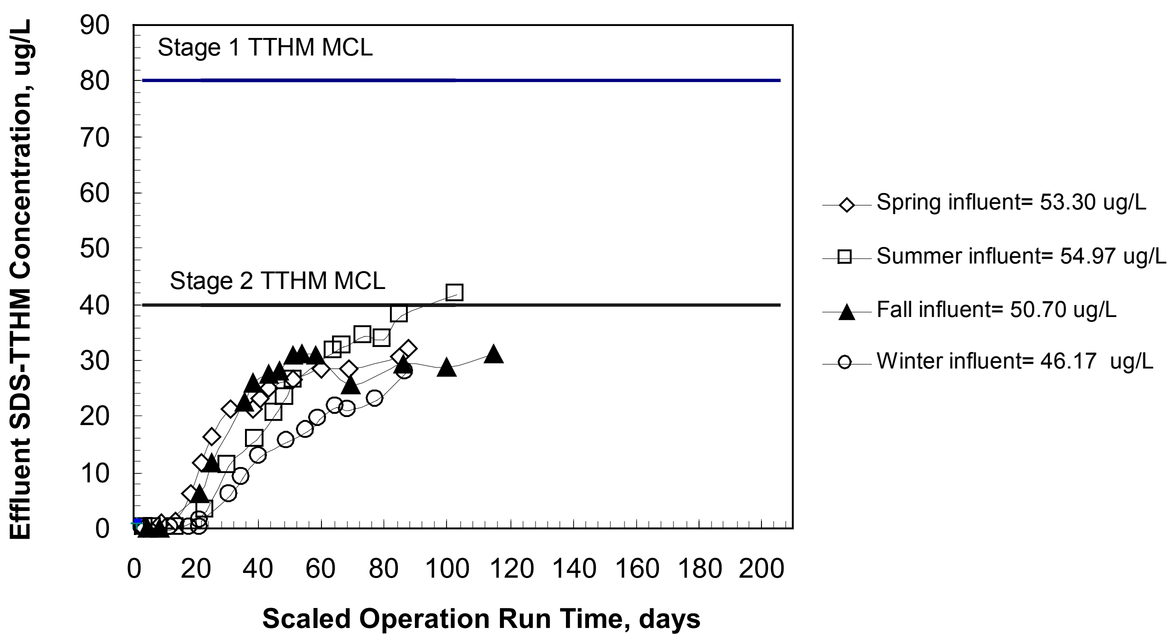

Figure 5. Impact of Seasonal Variability on SDS-TTHM Breakthrough in the 10-min EBCT Column

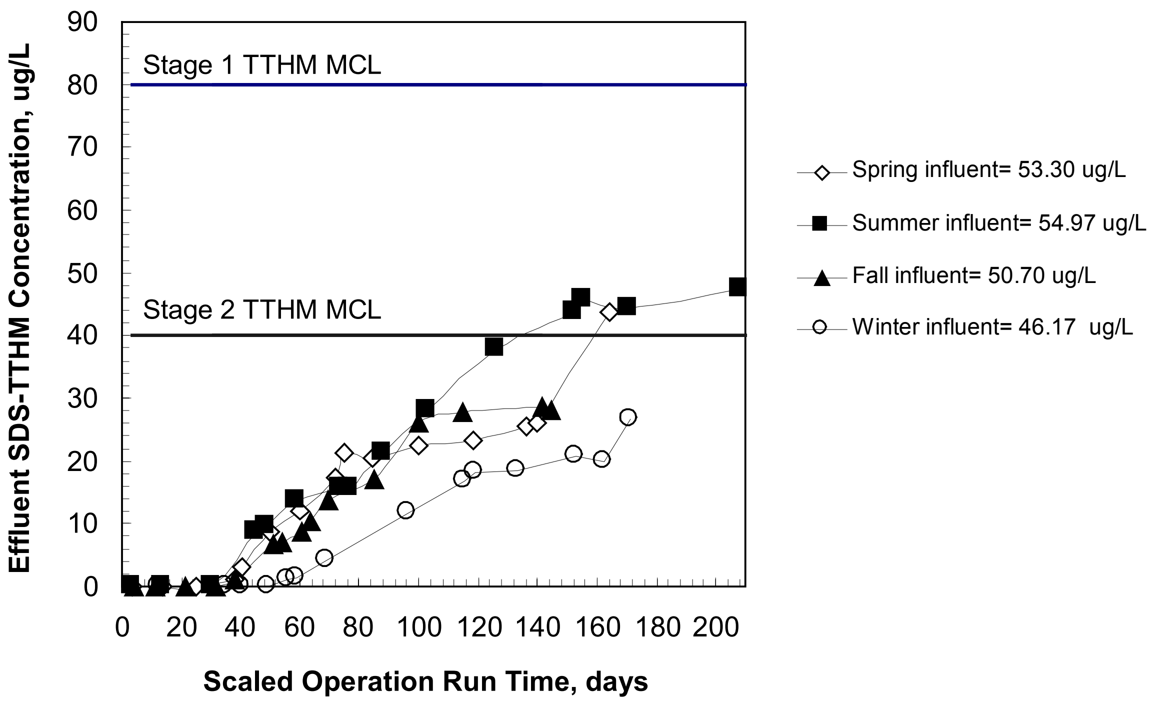

Figure 6. Impact of Seasonal Variability on SDS-TTHM Breakthrough in the 20-min EBCT Column

4.3.3 Impact of Seasonal Variability on SDS-HAA5 Breakthrough

The impact of seasonal variability on SDS-HAA5 breakthrough is illustrated in Figures 7 and 8. Due to the low SDS-HAA5 concentration in the chlorinated influent, neither the Stage 1 nor Stage 2 HAA5 MCLs were exceeded during either column operation. The SDS-TTHM concentration in the GAC contactor effluent will therefore be the limiting factor for contactor design, regeneration scenario, and costing. The rates of SDS-HAA5 breakthrough were somewhat constant, and measured at approximately 0.19 µg/L/day for the 10-min EBCT column, and at approximately 0.12 µg/L/day for the 20-min EBCT column.

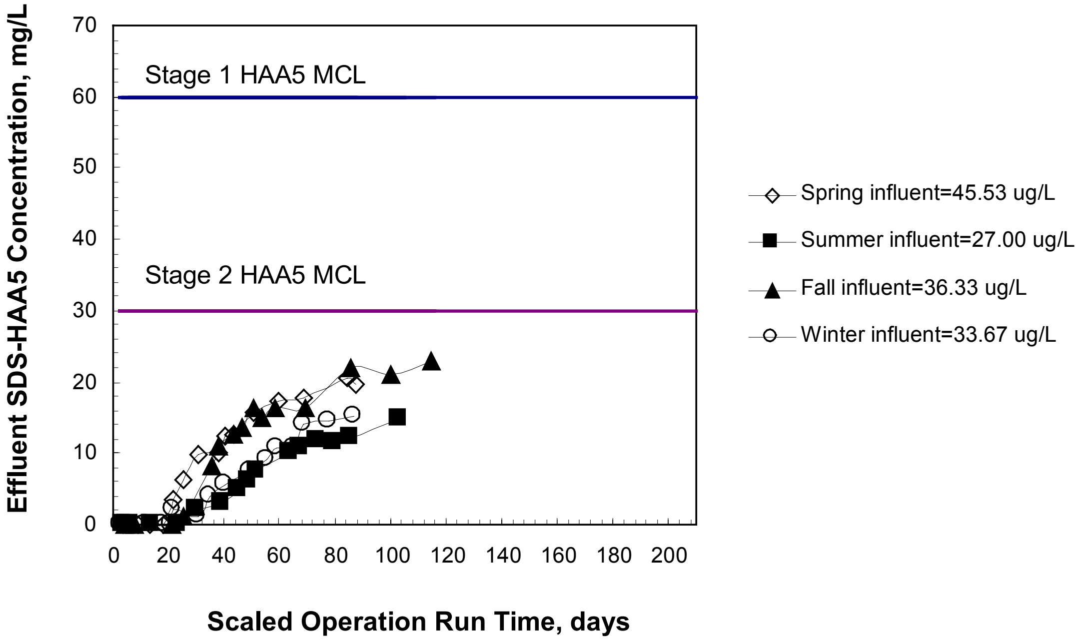

Figure 7. Impact of Seasonal Variability on SDS-HAA5 Breakthrough in the 10-min EBCT Column

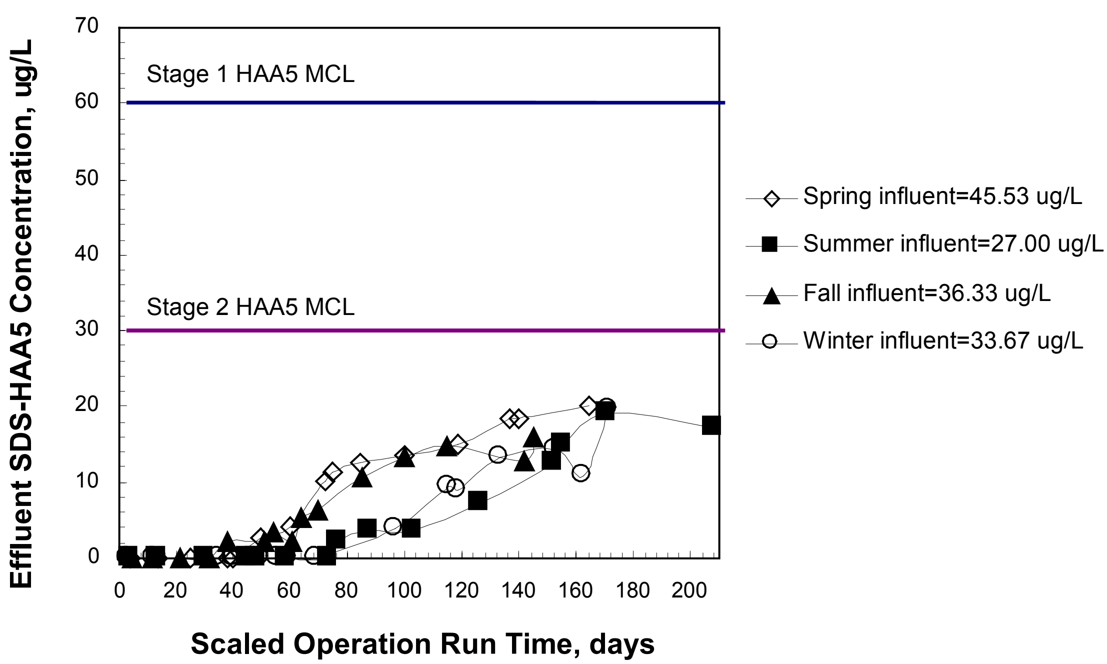

Figure 8. Impact of Seasonal Variability on SDS-HAA5 Breakthrough in the 20-min EBCT Column

4.3.4 Impact of Seasonal Variability on SDS-DBP Speciation

The low concentration of bromide in the influent to the RSSCT tends to shift the speciation of SDS-DBPs in the effluents of the GAC columns towards chlorinated SDS-DBPs. Table 11 presents the range of SDS-THMs and SDS-HAAs formed in the effluent samples during the four quarterly RSSCTs. As observed in Table 11, the SDS-DBPs formed were highly chlorinated species, with most of the brominated species reported below minimum levels. The dominant SDS-THM species was observed to be chloroform, whereas the SDS-HAAs were dominated by dichloro- and trichloro- acetic acids.

Table 11
Impact of Low Influent Bromide Concentration on DPBs Speciation

		Spring	Summer	Fall	Winter
Influent to RSSCT	Bromide, µg/L	27.5	24.5	35.0	30.5
10-min EBCT	$CHCl_3$, µg/L	BMRL to 23.0	BMRL to 32.0	BMRL to 23.0	BMRL to 18.0
	BDCM, µg/L	BMRL to 7.0	BMRL to 8.1	BMRL to 8.0	BMRL to 7.6
	DBCM, µg/L	BMRL to 3.1	BMRL to 4.9	BMRL to 4.6	BMRL to 3.4
	$CHBr_3$, µg/L	BMRL	BMRL	BMRL	BMRL
	MCAA, µg/L	BMRL	BMRL	BMRL	BMRL
	DCAA, µg/L	BMRL to 8.5	BMRL to 7.5	BMRL to 8.9	BMRL to 6.6
	TCAA, µg/L	BMRL to 12.0	BMRL to 7.2	BMRL to 14.0	BMRL to 8.7
	MBAA, µg/L	BMRL	BMRL	BMRL	BMRL
	DBAA, µg/L	BMRL	BMRL	BMRL	BMRL
	BCAA, µg/L	BMRL to 2.3	BMRL to 2.0	BMRL to 2.5	BMRL to 2.4
	TBAA, µg/L	BMRL	BMRL	NR	BMRL
	CDBAA, µg/L	BMRL	BMRL	BMRL to 2.4	BMRL
	DCBAA, µg/L	BMRL to 3.2	BMRL to 2.1	BMRL to 4.0	BMRL to 2.6
20-min EBCT	$CHCl_3$, µg/L	BMRL to 33.0	BMRL to 37.0	BMRL to 19.5	BMRL to 18.0
	BDCM, µg/L	BMRL to 9.0	BMRL to 9.2	BMRL to 7.5	BMRL to 7.1
	DBCM, µg/L	BMRL to 3.5	BMRL to 5.1	BMRL to 4.0	BMRL to 2.9
	$CHBr_3$, µg/L	BMRL	BMRL	BMRL	BMRL
	MCAA, µg/L	BMRL	BMRL	BMRL	BMRL to 2.9
	DCAA, µg/L	BMRL to 9.2	BMRL to 7.6	BMRL to 7.2	BMRL to 6.9
	TCAA, µg/L	BMRL to 11.0	BMRL to 8.5	BMRL to 11.0	BMRL to 10.0
	MBAA, µg/L	BMRL	BMRL	BMRL	BMRL
	DBAA, µg/L	BMRL	BMRL	BMRL	BMRL
	BCAA, µg/L	BMRL to 2.4	BMRL to 2.0	BMRL to 2.1	BMRL to 2.0
	TBAA, µg/L	BMRL	BMRL	BMRL	BMRL
	CDBAA, µg/L	BMRL	BMRL	BMRL	BMRL
	DCBAA, µg/L	BMRL to 3.8	BMRL to 2.4	BMRL to 4.6	BMRL to 2.6

BMRL: Below Minimum Reporting Level

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 9, 10, and 11 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. Based on the similarity in shape and slope of the curves in Figures 9, 10, and 11, using a 20-min EBCT instead of a 10-min EBCT was observed to result in no benefit for removing DBPs. This would affect the GAC replacement or regeneration costs. Capital costs of a 20-min EBCT GAC contactor are substantially higher than those of a 10-min contactor. More details on costing are presented in section 4.6.

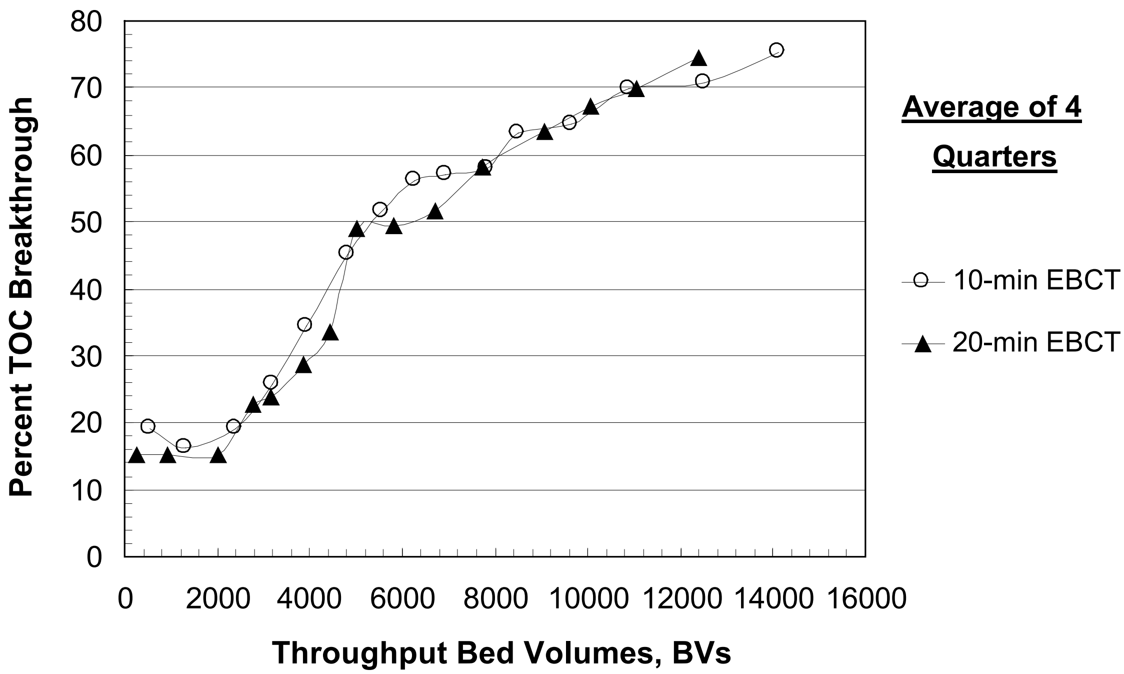

Figure 10. Impact of EBCT on Percent TOC Breakthrough

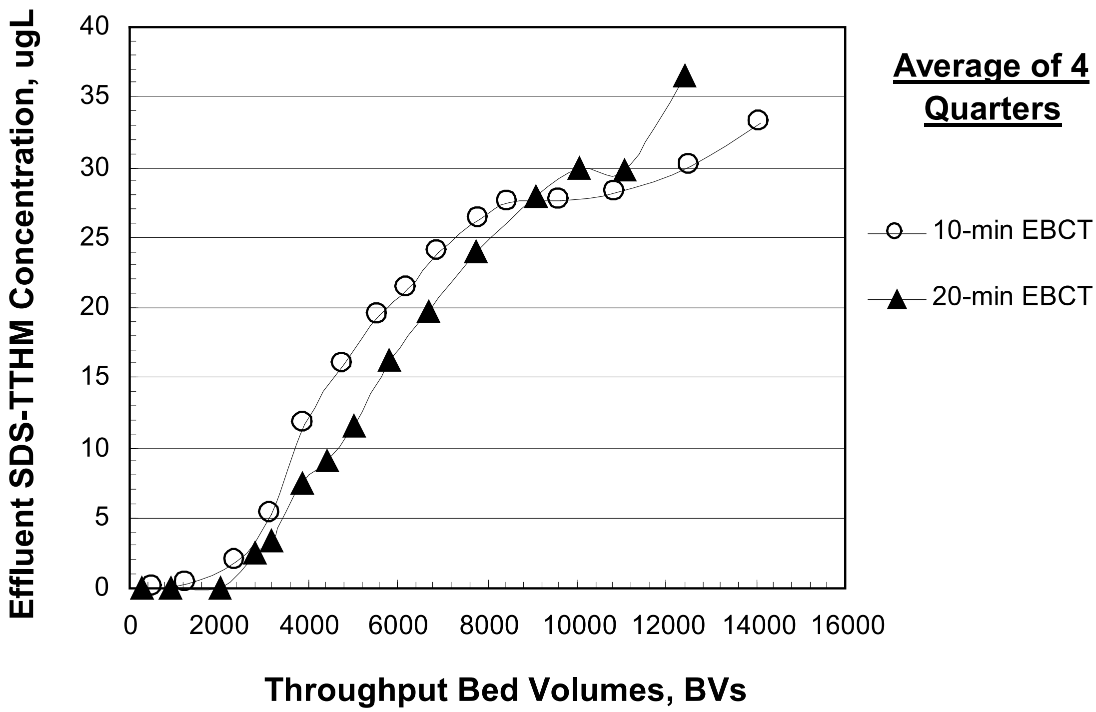

Figure 11. Impact of EBCT on SDS-TTHM Breakthrough

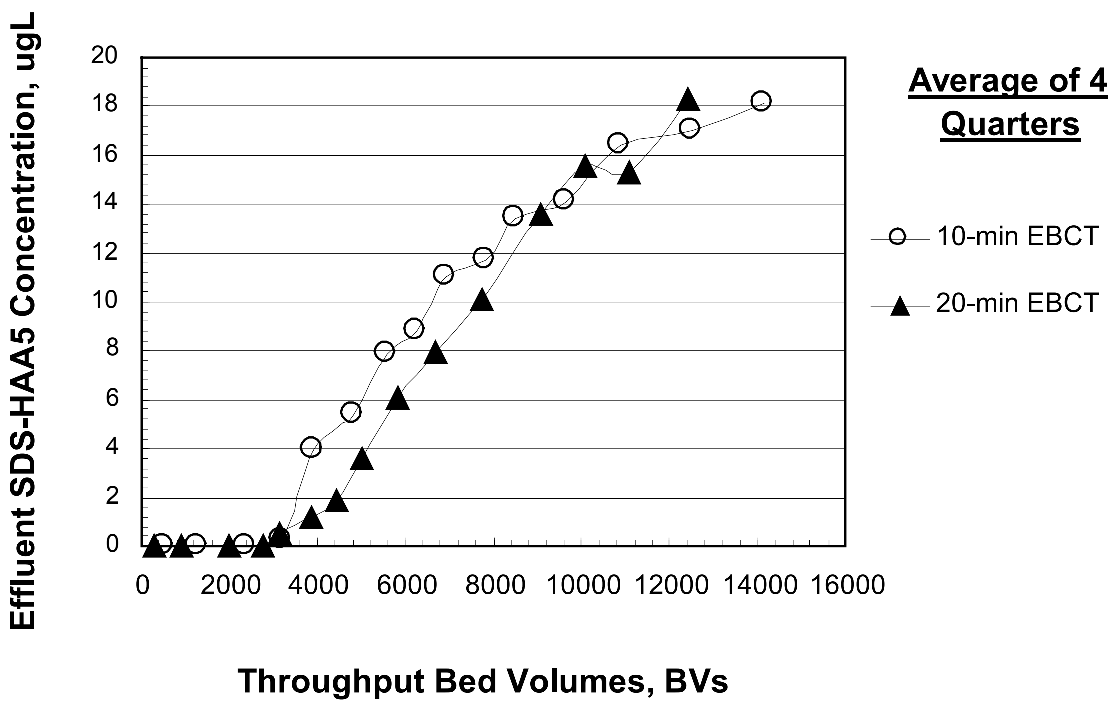

Figure 12. Impact of EBCT on SDS-HAA5 Breakthrough

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. Figures 12 and 13 illustrate, respectively, the breakthrough of the above parameters from the 10-min and 20-min EBCT GAC contactors.

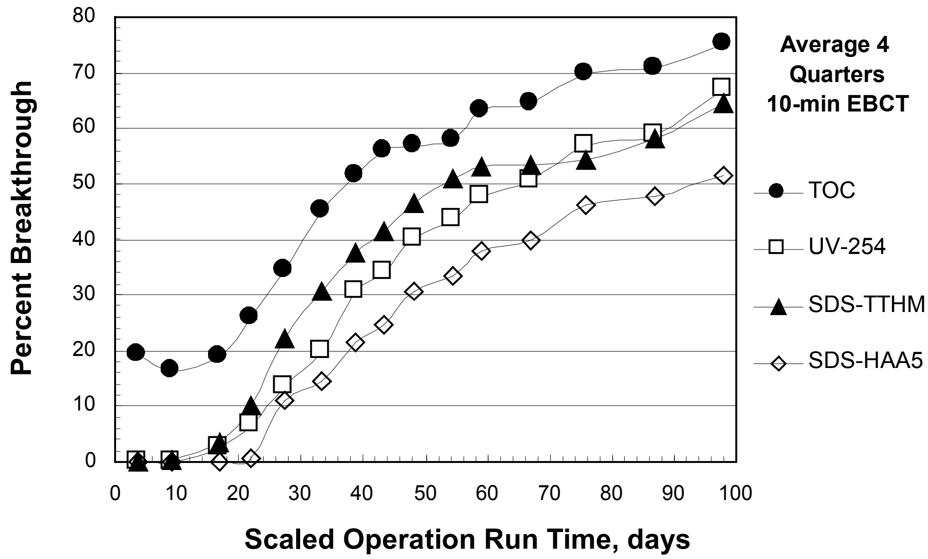

Figure 12. Breakthrough of TOC, UV-254 and SDS-DBPs from 10-min EBCT GAC Column

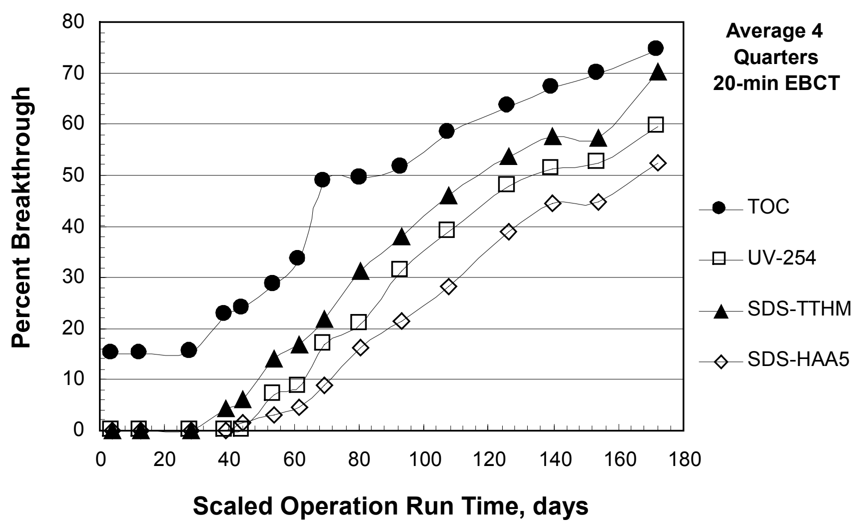

Figure 13. Breakthrough of TOC, UV-254 and SDS-DBPs from 20-min EBCT GAC Column

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 0.4 percent/day for the 20-min EBCT design. (2) TOC concentration is conservative enough to be a good indicator of DBP precursors breakthrough. UV-254 absorbance, on the other hand, appears to be less conservative, but nonetheless, would be still considered a good indicator of DBP precursors breakthrough since its analysis is simple and less costly than TOC. The percent breakthrough of HAA5 is observed less significant than that of TOC. However, it should be kept in mind that 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 an average flowrate of 48 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 Saint Petersburg, 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	51	64	125.34	>3531.6	<0.29	<5.1
			32	62.67	>3213.25	<0.30	<5.3
HAA5	µg/L	36	48	139.47	>3531.5	<0.29	<5.1
			24	69.74	>3531.5	<0.29	<5.1

* 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	51	64	125.34	>3098.75	<0.33	<5.7
			32	62.67	>2596.49	<0.36	<6.9
HAA5	μg/L	36	48	139.47	>3098.75	<0.33	<5.7
			24	69.74	>3098.75	<0.33	<5.7

* 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-TTHM and SDS-HAA5 in the chlorinated influent to the RSSCT, the Stage 2 TTHM MCL was the only limit to have been exceeded. In addition, this only occurred in the Spring and Summer quarters (March 1998 and July 1998). In the 10-min EBCT contactor, the GAC replacement costs to meet 80% of Stage 2 MCL of TTHMs ranged from $0.24/1000 gal during the Spring quarter to $0.32/1000 gal during the Summer quarter. During the Fall and Winter quarters, these costs were evaluated as being less than $0.18/1000 gal, and less than $0.24/1000 gal, respectively. In the 20-min EBCT contactor, the costs to meet the Stage 2 MCL for TTHMs ranged from $0.28/1000 gal during the Spring quarter to $0.37/1000 gal during the Summer quarter. During the Fall and Winter quarters, these costs were evaluated as being less than $0.29/1000 gal, and less than $0.24/1000 gal, respectively. Although the 20-min EBCT GAC replacement costs to meet 80% of Stage 2 TTHM MCL were estimated to be slightly lower than those for a 10-min EBCT, it can be stated that GAC replacement costs for a 10-min EBCT and a 20-min EBCT are virtually the same. Referring to Figure 11, the 20-min EBCT was shown to be more efficient that the 10-min EBCT for only the high bed volumes bracket (> 9000 bed volumes). The bed volumes to reach 80% of the Stage 2 TTHM MCL were all greater than 9000 BVs.

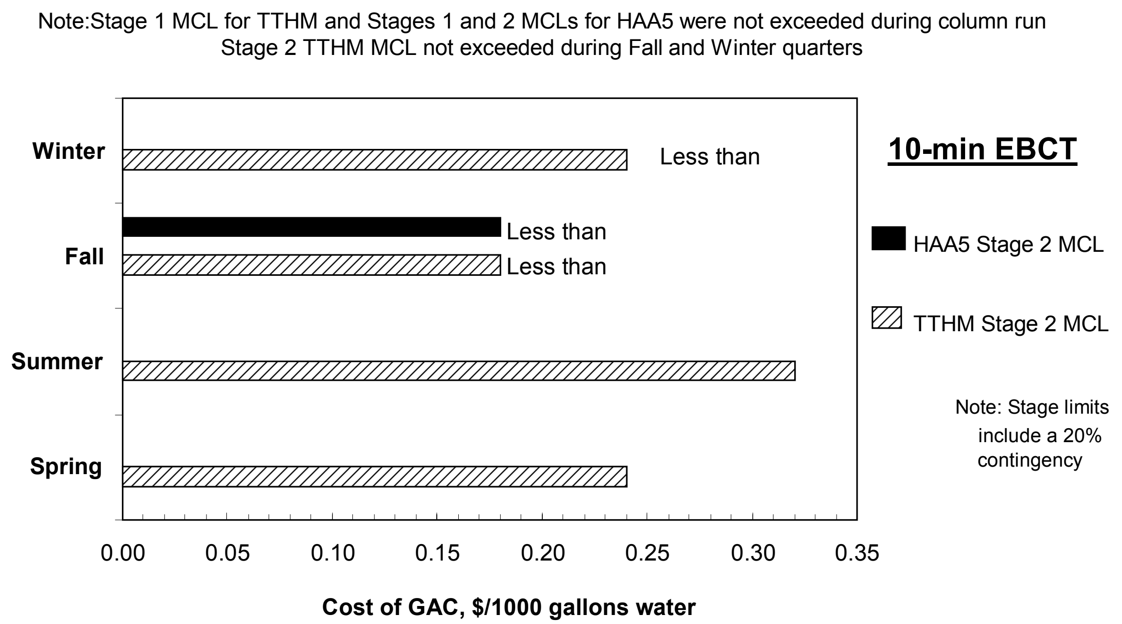

Figure 13. Cost of GAC Replacement from the 10-min EBCT Contactor to Meet Target DBP MCL Criteria

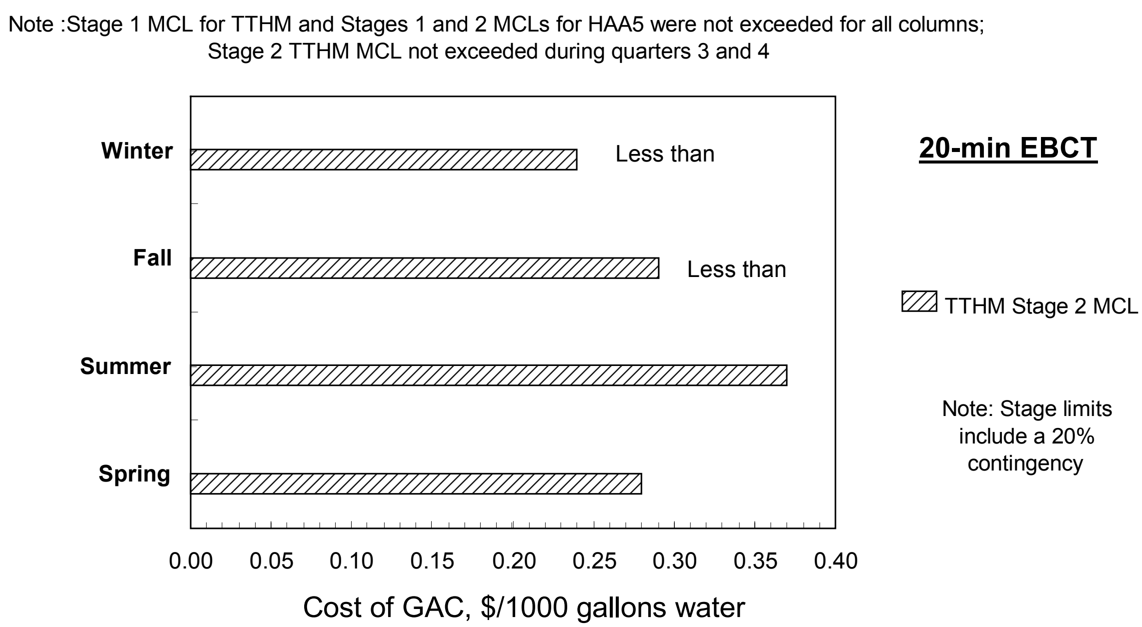

Figure 14. Cost of GAC Replacement from the 20-min EBCT Contactor to Meet Target DBP MCL Criteria

The average annual GAC replacement costs can be estimated from the average cost of GAC replacement per 1000 gal treated water (over the Spring and Summer quarters) to meet 80% of the Stage 2 TTHM MCL, and an average flowrate of 48 mgd. For a 10-min EBCT, the average annual GAC replacement cost was estimated at $4,905,600. The average annual GAC replacement cost for a 20-min EBCT was estimated at $5,694,000. These costs may seem high. It should be kept in mind however these costs were based on the Spring and Summer carbon use rates. The Fall and Winter carbon use rates are much lower than those of the other two quarters and integrating these CURs in the cost estimate would lower the average yearly GAC replacement costs. GAC replacement may 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 48 mgd, and were again based on numbers estimated during the Spring and Summer quarters. 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. Typical carbon usage rates vary from 1 to 10 million pounds per year. Based on the 10-min EBCT average CUR of 6.5 million lbs/yr (742 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 297 square feet. Based on the 20-min EBCT average CUR of 7.6 millions lbs/yr (867 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 347 square feet. Capital and O&M costs for thermal GAC reactivation and using a 10- and 20-min EBCTs are presented in Table 14.

In this analysis, the following parameters were assumed:

Parameter	Assumption
Single reactivator area, sq-ft (10-min EBCT)	297
Single reactivator area, sq-ft (20-min EBCT)	347
Capital amortization	I = 6 percent over N = 30 years
Capital recovery factor CRF	0.117
Labor and fringe rate	$19.61/hr
Electric rate	$ 0.05/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.

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

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.

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

where: PE = process energy requirement in kWh/year,
total filter area is in square feet.

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

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

where: BE = building energy requirements in kWh/year,
total filter area is in square feet.

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

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

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

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

Where: OL = O&M labor requirements in workhours per year,
total filter area is in square feet,

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

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

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		
lbs of GAC per hour (to meet 80% Stage 2 TTHM MCL) at 0.4 sq-ft required per lb/hr	742	867
Surface area per reactivator, sq-ft	297	347
CAPITAL COSTS		
CC, 1998 $	3,373,870	3,595,941
Annual capital costs, $/yr	**$245,108**	**$261,241**
O& M COSTS		
PE, kwh/yr	824741	**883344**
Annual PE costs, $/yr	**$65,979**	**$70,667**
BE, kwh/yr	24813	26148
Annual BE costs, $/yr	**$1,985**	**$2,092**
MM costs, 1998 $/yr	**$55,923**	**$59,523**
OL, workhours/yr	18097	19843
Annual OL costs, $/yr	**$452,419**	**$496,077**
NG requirement, scft/yr	48729058	55947562
Annual NG cost, $/yr	**$268,010**	**$307,712**
Total O&M Annual Costs, $/yr	**$844,316**	**$936,071**
TOTAL ANNUAL COSTS, $/yr	**$1,089,424**	**$1,197,313**

Since in-house thermal reactivation costs are lower than those for replacing the carbon, thermal GAC reactivation would be considered a more cost-effective approach.

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 Saint Petersburg.

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

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 ≥ 7,000 square feet.
OL* labor rate (in $/hr) = labor costs

In this analysis, the following parameters were used:

Parameter	Assumption
GAC Contactor System Operation	70 percent of design capacity
Design capacity	68 MGD
Systems > 10 mgd	Use concrete gravity adsorbers
Capital amortization	I = 6 percent over N = 30 years
Capital recovery factor CRF	0.117
GAC price	$ 0.75/lb at 100,000 lb
Labor and fringe rate*	$19.61/hr
Electric rate*	$ 0.05/kwh
ENR Construction Cost Index (1983)	5064
ENR Construction Cost Index (1998)	6859
Producers Price Index (1983)	102
Producers Price Index (1998)	130.5

*Provided by the City

For the City of Saint-Petersburg, the following design parameters were assumed:
- Total plant capacity Q' =68 mgd; 70 % Q' = Q = 48 mgd = 33,055.5 gpm = 4,419.53 cu-ft/min;
- Hydraulic loading Q/A (provided by the City) = 2.6 gpm/sq ft = 0.348 cu-ft/min/sq ft;

Since the O&M cost equations were based on a hydraulic loading of 5 gpm/sq-ft, for cost-estimating purposes, the effective total area will be determined as if the rate were 5 gpm/sq-ft instead of 2.6 gpm/sq-ft.

- Ten GAC concrete gravity contactors.

Table 15 presents the capital and O&M costs for a conventional concrete gravity adsorber based on an average flowrate and hydraulic loading rate. These costs include the cost of GAC thermal reactivation costs.

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	4,419.5	8,839
Total GAC effective volume, cu-ft	44,195	88,391
CAPITAL COSTS	1	1
z (in CC equation)	5,772,120	9,374,176
CC, 1998 $	**677,991**	**1,101,088**
Annual capital costs, $/yr		
O& M COSTS	793,333	793,333
PE, kwh/yr	**$3,967**	**$3,967**
Annual PE costs, $/yr	1,120,347	1,120,347
BE, kwh/yr	**$56,017**	**$56,017**
Annual BE costs, $/yr	**$23,420**	**$23,420**
MM costs, 1998 $/yr	1	1
z (in OL equation)	7,315	7,315
OL, workhours/yr	**$104,234**	**$104,234**
Annual OL costs, $/yr		
	$187,642	**$187,642**
Total annual O&M costs		
	$1,089,424	**$1,197,313**
GAC annual reactivation costs		
	$1,955,057	**$2,486,042**
TOTAL ANNUAL COSTS		

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 9% higher when using a 20-min EBCT instead of a 10-min EBCT. Total annual costs (including GAC reactivation costs) were observed to be 21% higher when using a 20-min EBCT instead of a 10-min EBCT. Using a 10-min EBCT design would therefore be a favorable approach.

4.7 Summary of Significant Results

- No major seasonal variability was observed in the breakthrough curves of indicators of natural organic matter (TOC, UV-254) and precursors of TTHMs and HAA5 upon SDS chlorination. The TOC breakthrough rate was somewhat constant at 0.77 percent per day in the 10-min EBCT column, and at 0.44 percent per day in the 20-min EBCT column.

The breakthrough of SDS-DBPs was affected by the influent SDS-DBP concentration in the chlorinated influent water. The Stage 2 MCL for TTHMs was exceeded only during the Spring and Summer quarters, during which the highest influent TTHM concentration was recorded (53 and 55 μg/L, respectively). 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 low bromide influent concentration (range of 24 to 35 μg/L) shifted the speciation of DBPS towards chlorinated species rather than brominated. TTHMS were dominated by chloroform , whereas HAAs were dominated by dichloro- and trichloro- acetic acids.

- When normalizing for EBCT, no benefit was observed for DBP control by using a 20-min EBCT versus a 10-min EBCT. At low SDS-DBP concentrations, the 20-min EBCT was observed to be beneficial. However at higher SDS-DBP concentrations (close to the Stage 2 MCLs), the 10-min EBCT was observed to provide a benefit in regards of longer bed volumes (and therefore lower GAC replacement or reactivation costs).

- TOC and UV-254 breakthroughs were observed to correlate well with those of SDS-TTHMs and SDS-HAA5. TOC concentration was a better indicator of DBP precursor breakthrough than UV-254 absorbance. Nevertheless, the low cost and simplicity of UV-254 absorbance measurement makes it a practical indicator of DBPs.

- The GAC replacement and regeneration costs were evaluated only for the Spring and Summer quarters, since the Stages 1 and 2 MCLs for DBPs were not exceeded during the Fall and Winter quarters. GAC replacement costs were limited by the SDS-TTHM concentration in the effluent of the columns. In both the 10-min EBCT and the 20-min EBCT contactors, only the costs to meet 80% of the Stage 2 TTHM MCL were reported, since the Stage 1 TTHM MCL and the Stages 1 and 2 HAA5 MCLs were not exceeded. In the 10-min EBCT contactor, the GAC replacement cost was estimated at $0.24/1000 gal of treated water during the Spring quarter, and at $0.32/1000 gal during the Summer quarter. In the 20-min EBCT contactor, the GAC replacement cost was estimated at $0.28/1000 gal of treated water during the Spring quarter, and at $0.37/1000 gal during the Summer quarter. The average GAC replacement annual cost was estimated at $4,905,600 for a 10-min EBCT, and at $5,694,000 for a 20-min EBCT. On-site GAC thermal reactivation costs were also estimated using the amount of GAC used to reach 80% of the Stage 2 TTHM MCL. Total annual costs (including capital costs for a reactivator) were estimated at $1,089,424 for a 10-min EBCT, and at $1,197,313 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 a 48 mgd average flowrate. Annual capital costs for a 10-min EBCT were estimated at $677,991, and for a 20-min EBCT at

$1,101,088. When including the annual GAC reactivation costs to the annual O&M costs, the total annual costs were estimated at $1,955,057 for a 10-min EBCT, and at $2,486,042 for a 20-min EBCT. Using a 10-min EBCT instead of a 20-min EBCT resulted in an overall cost saving of 21%.

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.

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	53	64	120	>3161	<0.32	<5.6
			32	60	3144	0.32	5.6
HAA5	μg/L	45	48	105	>3161	<0.32	<5.6
			24	53	>3161	<0.32	<5.6

* 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	55	64	116	>3708	<0.27	<4.7
			32	58	2360	0.42	7.4
HAA5	μg/L	27	48	178	>3708	<0.27	<4.7
			24	89	>3708	<0.27	<4.7

* 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	51	64	126	>4126	<0.24	<4.2
			32	63	>4126	<0.24	<4.2
HAA5	μg/L	36	48	132	>4126	<0.24	<4.2
			24	66	>4126	<0.24	<4.2

* 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	46.2	64	139	>3132	<0.24	<5.6
			32	69	>3132	<0.24	<5.6
HAA5	μg/L	34	48	143	>3132	<0.24	<5.6
			24	71	>3132	<0.24	<5.6

* 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	53	64	120	<0.34	<0.25	<5.9
			32	60	0.38	0.28	6.6
HAA5	μg/L	45	48	105	<0.34	<0.25	<5.9
			24	53	<0.34	<0.25	<5.9

* 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	55	64	116	<0.27	<0.2	<4.7
			32	58	0.49	0.37	8.6
HAA5	μg/L	27	48	178	<0.27	<0.2	<4.7
			24	89	<0.27	<0.2	<4.7

* 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	51	64	126	<0.38	<0.29	<6.7
			32	63	<0.38	<0.29	<6.7
HAA5	μg/L	36	48	132	<0.38	<0.29	<6.7
			24	66	<0.38	<0.29	<6.7

* 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	46.2	64	139	<0.32	<0.24	<5.6
			32	69	<0.32	<0.24	<5.6
HAA5	μg/L	34	48	143	<0.32	<0.24	<5.6
			24	71	<0.32	<0.24	<5.6

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

APPENDIX B

Summary Report Spreadsheets

Miscellaneous Information

PWSID	FL6521715
Plant ICR #	318

Full-Scale Plant Information

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

Laboratory Information

Item	ICR ID or Abbrev	Lab Name	Lab Type	Lab City	Lab State
Lab #1	MWL-CA013	Montgomery Watson	commercial	Los Angeles	CA
Lab #2	RCFF	MW Applied Research Departm	consultant	Los Angeles	CA
Lab #3					
Lab #4					

(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	3/27/98	7/2/98	9/17/98	11/19/98

1998 Flow and Population Information

Source	Flow (mgd)	Population Served
Total Population Served		317101
Surface Water	0	0
Ground Water	37	37
Purchased Finished Water	0	0
Total	37	

Full-Scale Water Quality Data

Full-Scale Influent Water Quality Data

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	24.5	0.7	23.4	25.4	12
pH	Unit	7.41	0.09	7.22	7.51	12
Turbidity	ntu	0.2	0.08	0.1	0.33	12
Alkalinity	mg/L as $CaCO_3$	200	27	117	213	12
Total Hardness	mg/L as $CaCO_3$	204	4	198	212	12
Calcium Hardness	mg/L as $CaCO_3$	NA	NA	NA	NA	
TOC	mg/L	2.45	0.28	1.9	2.8	12
UV_{254}	1/cm	0.107	0.011	0.09	0.124	12
Bromide	µg/L	NA	NA	NA	NA	
TSUVA*	L/(mg*m)	4.37	3.93	4.74	4.43	12

*TSUVA = [UV_{254} (1/m)] / [TOC (mg/L)]. Summary information for TSUVA should only be calculated from TSUVA values with paired TOC and UV_{254} measurements

Full-Scale Finished Water Quality Data

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	24.8	0.7	23.4	25.8	12
pH	unit	7.7	0.28	7.14	8.14	12
Turbidity	ntu	0.25	0.15	0.12	0.54	12
TOC	mg/L	2.2	0.28	1.6	2.6	12
UV_{254}	1/cm	0.064	0.006	0.054	0.076	12
DS-THM4	µg/L	86.35	16.91	58	107.3	8
DS-HAA5	µg/L	NA	NA	NA	NA	
DS-HAA6	µg/L	NA	NA	NA	NA	

QA/QC Data - Sheet 1

Analyte Identification	Units	Laboratory Identification	Start Service Date	End Service Date	Method	MRL		Count	Average	Std Dev	Percentiles 25th	50th	75th
pH	unit												
Temperature	C												
Alkalinity	mg/L as CaCO3	ICRCA013	9/1/97	5/1/99	SM2320B	10							
Ammonia	mg NH3-N/L	ICRCA013	9/1/97	5/1/99	EPA 350.1	0.05							
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:	192	2.7%	4.9%	0.0%	0.9%	3.9%
							% Recovery for Lab Fortified Matrix:	392	102%	7%	98%	101%	105%
							% Recovery for PE Samples:	5	100%	2%	99%	100%	100%
UV254	1/cm	ICR-CA013	2/1/98	12/31/98	SM5910B	0.009	RPE of Analytical Duplicates:	383	0.2%	0.5%	0.0%	0.0%	0.0%
							% Recovery for Lab Fortified Matrix:						
							% Recovery for PE Samples:	5	96%	3%	95%	95%	96%
TOC	mg/L	ICR-CA013	9/1/97	5/1/99	SM5310C	0.5	RPE of Analytical Duplicates:	758	1.2%	1.7%	0.0%	0.0%	2.3%
							% Recovery for Lab Fortified Matrix:	180	98%	6%	97%	99%	102%
							% Recovery for PE Samples:	5	96%	3%	94%	95%	98%
SDS-TOX	µg Cl-/L	ICR-CA013	9/1/97	5/1/99	SM5320B	25	RPE of Analytical Duplicates:	865	4%	4%	1%	3%	6%
							% Recovery for Lab Fortified Matrix:	883	100%	20%	92%	98%	105%
							% Recovery for PE Samples:	5	88%	8%	85%	86%	88%
SDS-CHCl3	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates:	254	5%	7%	0%	3%	6%
							% Recovery for Lab Fortified Matrix:	300	112%	74%	93%	100%	113%
							% Recovery for PE Samples:	5	93%	9%	86%	93%	99%
SDS-BDCM	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates:	250	4%	5%	0%	2%	5%
							% Recovery for Lab Fortified Matrix:	300	99%	30%	90%	98%	103%
							% Recovery for PE Samples:	5	96%	3%	95%	96%	98%
SDS-DBCM	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates:	203	4%	6%	0%	2%	6%
							% Recovery for Lab Fortified Matrix:	301	103%	36%	93%	100%	108%
							% Recovery for PE Samples:	5	102%	4%	99%	101%	103%
SDS-CHBr3	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates:	113	6%	9%	0%	4%	9%
							% Recovery for Lab Fortified Matrix:	301	99%	21%	95%	100%	103%
							% Recovery for PE Samples:	4	106%	4%	103%	106%	109%
THM4	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1		**Avg RPE of Indiv Anal Dupl:**	269	4%	5%	1%	3%	6%
							Avg % Recov for Indiv Lab Fort Matrix:	301	103%	29%	94%	100%	105%
							Avg % Recov for Indiv PE Samples:	4	100%	4%	97%	99%	100%
SDS-MCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	2	RPE of Analytical Duplicates:	94	11%	12%	3%	6%	13%
							% Recovery for Lab Fortified Matrix:	447	107%	25%	97%	105%	115%
							% Recovery for PE Samples:	5	92%	5%	90%	91%	93%
SDS-DCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	367	4%	6%	0%	2%	6%
							% Recovery for Lab Fortified Matrix:	444	106%	41%	97%	100%	106%
							% Recovery for PE Samples:	5	90%	9%	85%	88%	88%
SDS-TCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	325	3%	6%	0%	2%	5%
							% Recovery for Lab Fortified Matrix:	444	108%	57%	97%	100%	110%
							% Recovery for PE Samples:	5	96%	12%	90%	92%	93%
SDS-MBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	48	10%	12%	0%	7%	16%
							% Recovery for Lab Fortified Matrix:	448	112%	27%	100%	105%	110%
							% Recovery for PE Samples:	5	89%	7%	84%	93%	94%
SDS-DBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	199	5%	6%	0%	3%	7%
							% Recovery for Lab Fortified Matrix:	447	105%	24%	97%	100%	106%
							% Recovery for PE Samples:	5	98%	15%	91%	94%	95%
SDS-BCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	325	4%	6%	0%	3%	6%
							% Recovery for Lab Fortified Matrix:	447	103%	19%	97%	100%	105%
							% Recovery for PE Samples:	5	95%	12%	90%	91%	92%
SDS-TBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	4	RPE of Analytical Duplicates:	11	3%	2%	1%	2%	4%
							% Recovery for Lab Fortified Matrix:	320	113%	24%	103%	115%	125%
							% Recovery for PE Samples:	0					
SDS-CDBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	2	RPE of Analytical Duplicates:	133	4%	5%	0%	3%	5%
							% Recovery for Lab Fortified Matrix:	407	113%	24%	104%	110%	120%
							% Recovery for PE Samples:	0					
SDS-DCBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	325	4%	6%	0%	3%	6%
							% Recovery for Lab Fortified Matrix:	435	113%	22%	103%	110%	120%
							% Recovery for PE Samples:	0					
HAA5	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		**Avg RPE of Indiv Anal Dupl:**	385	5%	5%	1%	4%	6%
							Avg % Recov for Indiv Lab Fort Matrix:	448	108%	23%	99%	103%	109%
							Avg % Recov for Indiv PE Samples:	5	100%	8%	87%	93%	93%
HAA6	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		**Avg RPE of Indiv Anal Dupl:**	385	5%	5%	2%	4%	6%
							Avg % Recov for Indiv Lab Fort Matrix:	448	107%	20%	99%	103%	108%
								5	100%	9%	87%	92%	93%
HAA9	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		**Avg RPE of Indiv Anal Dupl:**	387	5%	4%	2%	4%	6%
							Avg % Recov for Indiv Lab Fort Matrix:	448	109%	17%	102%	106%	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:	109	4%	4%	0%	4%	7%
							% Recovery for Lab Fortified Matrix:	145	84%	40%	75%	85%	95%
							% Recovery for PE Samples:	5	102%	8%	97%	104%	108%
SDS-BDCM	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2	1	RPE of Analytical Duplicates:	117	3%	4%	0%	2%	5%
							% Recovery for Lab Fortified Matrix:	145	98%	129%	80%	90%	100%
							% Recovery for PE Samples:	5	100%	9%	94%	105%	105%
SDS-DBCM	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2	1	RPE of Analytical Duplicates:	117	3%	4%	0%	2%	4%
							% Recovery for Lab Fortified Matrix:	146	104%	54%	90%	96%	100%
							% Recovery for PE Samples:	5	100%	11%	94%	101%	105%
SDS-CHBr3	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2	1	RPE of Analytical Duplicates:	86	4%	5%	0%	2%	6%
							% Recovery for Lab Fortified Matrix:	146	122%	77%	98%	100%	120%
							% Recovery for PE Samples:	4	93%	13%	88%	90%	95%
THM4	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2		**Avg RPE of Indiv Anal Dupl:**	144	3%	3%	1%	3%	4%
							Avg % Recov for Indiv Lab Fort Matrix:	146	102%	47%	88%	95%	103%
							Avg % Recov for Indiv PE Samples:	5	100%	9%	97%	99%	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 - Applied Research Department RCFF

Analyte Identification	Units	Laboratory Identification	Start Service Date	End Service Date	Method	MRL		Count	Average	Std Dev	Percentiles 25th	50th	75th
pH	unit	RCFF	Mar-98	Mar-99	SM 4500-H+								
Temperature	C	RCFF	Mar-98	Mar-99	SM 2550 B								
Alkalinity	mg/L as $CaCO_3$	RCFF	Mar-98	Mar-99	SM 2320 B	5 mg/L as CaCO3							
Ammonia	mg NH_3-N/L	RCFF	Mar-98	Mar-99	SM 4500-N	0.10 mg/L as N							
Calcium Hardness	mg/L as $CaCO_3$												
SDS-Cl_2 Residual	mg/L	RCFF	Mar-98	Mar-99	SM 4500-C	0.2 mg/L							
Total Hardness	mg/L as $CaCO_3$	RCFF	Mar-98	Mar-99	SM 2340 B	7 mg/L as CaCO3							
Turbidity	ntu	RCFF	Mar-98	Mar-99	SM 2130 B	0.05 ntu							
Bromide	µg/L		Mar-98	Mar-99			RPE of Analytical Duplicates:						
							% Recovery for Lab Fortified Matrix:						
							% Recovery for PE Samples:						
UV_{254}	1/cm	RCFF	Mar-98	Mar-99	SM 5910	0.009 1/cm	RPE of Analytical Duplicates:	65	1.33	2.35	0.05	0.1	1.8
							% Recovery for Lab Fortified Matrix:	NA	NA	NA	NA	NA	NA
							% Recovery for PE Samples:	NA	NA	NA	NA	NA	NA
TOC	mg/L	RCFF	Mar-98	Mar-99	SM 5310 C	0.5 mg/L	RPE of Analytical Duplicates:	65	4.66	6.29	0.83	3.39	6.45
							% Recovery for Lab Fortified Matrix:	32	103	12	98.5	101	107
							% Recovery for PE Samples:	NA	NA	NA	NA	NA	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:						