

# **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 February, 1998 through March, 1999

Prepared by:  
Montgomery Watson Americas, Inc.  
Applied Research Department  
555 East Walnut Ave.  
Pasadena, CA 91101

June 1999

For:  
City of Sunrise, FL4061410  
14150 NW 8 ST  
Sunrise Florida, 33325  
Phone #: (954) 846-7425  
Fax #: (954) 846-7404

Springtree Water Treatment Plant, ICR # 710

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 Springtree 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 filters, 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, along with pH reduction had some impact on the control of DBP formation using GAC and thus on the cost of the process. This is expected since the Springtree WTP is served by a shallow groundwater aquifer that undergoes some changes in water quality. Nevertheless, the Winter quarter was observed to be the most critical for SDS-TTHM and SDS-HAA5 control. The high rates of breakthrough of SDS-DBPs were incurred by a high SDS-DBP concentration in the influent to the RSSCT rather than the influent 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. Both the Stage 1 and the “placeholder” Stage 2 TTHM MCL were exceeded, however, as a conservative measure, GAC reactivation costs were only based on meeting 80% of the Stage 2 TTHM MCL.

In the 10-min EBCT contactor, the GAC replacement cost to meet 80% of the Stage 2 TTHM MCL ranged from \$2.5/1000 gal of treated water during the Spring quarter to \$4.8/1000 gal during the Fall quarter. In the 20-min EBCT contactor, the GAC replacement cost to meet 80% of the Stage 2 TTHM MCL ranged from \$2.1/1000 gal of treated water during the Spring quarter to \$3.8/1000 gal during the Fall and Winter quarters. The annual average GAC replacement cost was estimated at \$27,471,360 for a 10-min EBCT, and at \$22,964,340 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 \$4,898,552 for a 10-min EBCT, and at \$4,844,293 for a 20-min EBCT. Although the reactivation costs are lower than GAC replacement costs, GAC reactivation remains an infeasible approach.

Total annual costs for a conventional concrete gravity adsorber (including GAC reactivation cost) were estimated at \$5,223,251 for a 10-min EBCT and at \$4,844,293 for a 20-min EBCT. Without reactivation, the total annual costs were estimated at \$324,699

---

and at \$463,825 for a 10-min and 20-min EBCTs, respectively. Annual capital costs for a concrete gravity adsorber were estimated at \$227,261 for a 10-min EBCT and at \$366,387 for a 20-min EBCT. These costs were estimated using an average flowrate of 19.6 mgd.

The removal of DBPs would be an expensive treatment technology to implement for the City of Sunrise. GAC performance can be improved by enhanced coagulation to remove TOC. Blending GAC contactor effluents (contactors in parallel or in-series) would also result in the extension of column runs and the reduction of O&M costs, including GAC replacement or reactivation costs.

## **2. Background Information**

### **2.1 Springtree Water Treatment Plant Description**

The City of Sunrise owns and operates the Springtree Water Treatment Plant. The plant overall design capacity is 28 mgd. The WTP draws its water supply year-round primarily from groundwater wells connected to the shallow Biscayne aquifer. The Springtree WTP is made up of three individual lime softening systems (trains A, B, and C), each having its own treatment units and filters. Train A, constructed in 1974, is an 8-mgd upflow lime softening plant and Train C, constructed in 1972, is an 8-mgd spiractors seeded lime softening plant. Train B was the newest addition to the WTP, built in 1990, consisting of a 12-mgd softening plant, which includes aerators, up-flow clarifiers, and dual media filters. Train C is put on a stand-by basis and used only for emergency and during maintenance of units. In this treatment study, the sample was collected from filter effluent of the new plant (Train B). The overall Springtree WTP ranks in the conventional filtration plant category and consists of aeration, softening with lime, coagulation and rapid mix, sedimentation, filtration, clearwell and a storage tank. Chloramines are added to the effluent of the filters. The current average daily flow through the WTP is 20 mgd.

#### **2.1.1 Treatment plant schematic**

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

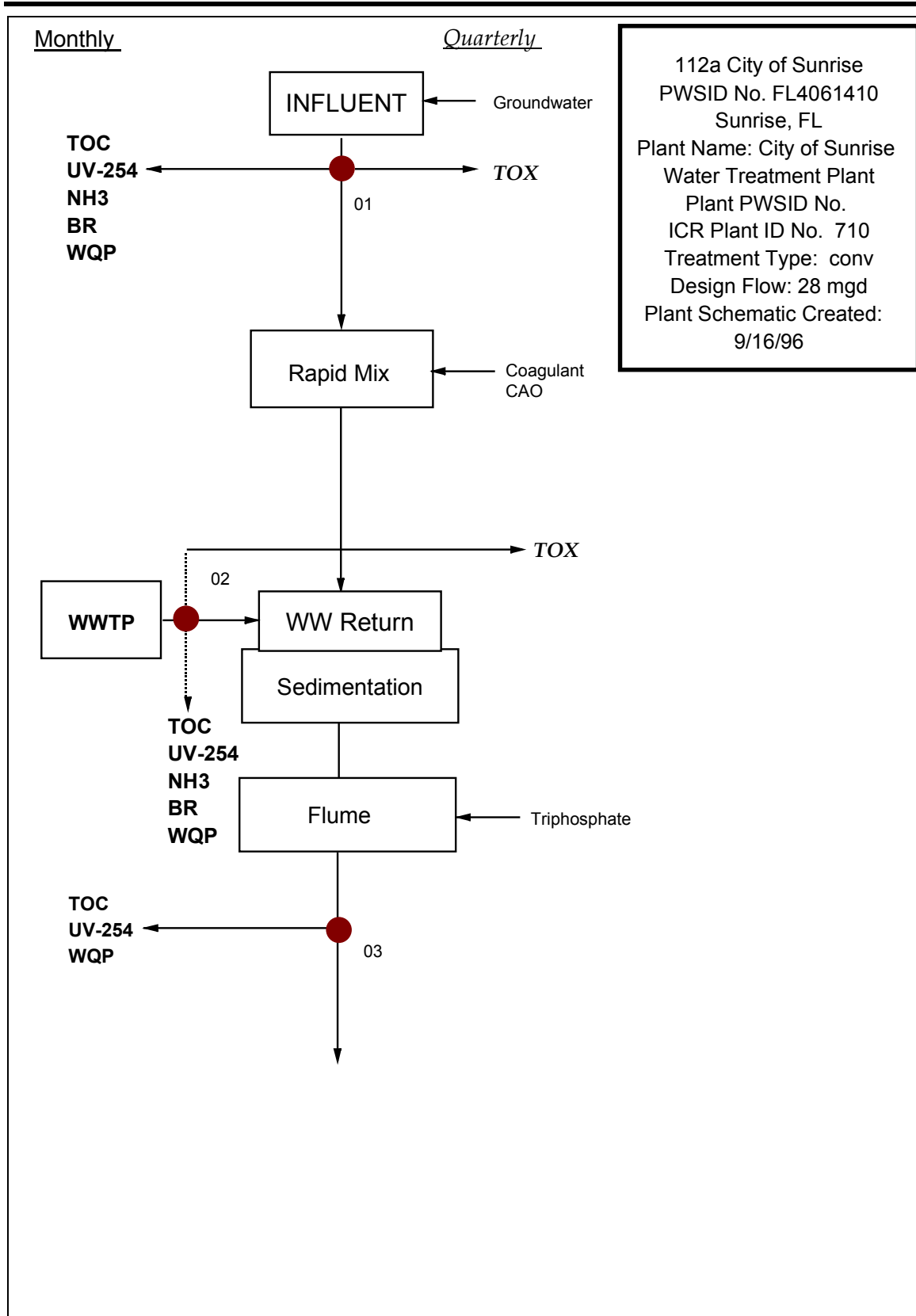


Figure 1. Springtree WTP Schematic

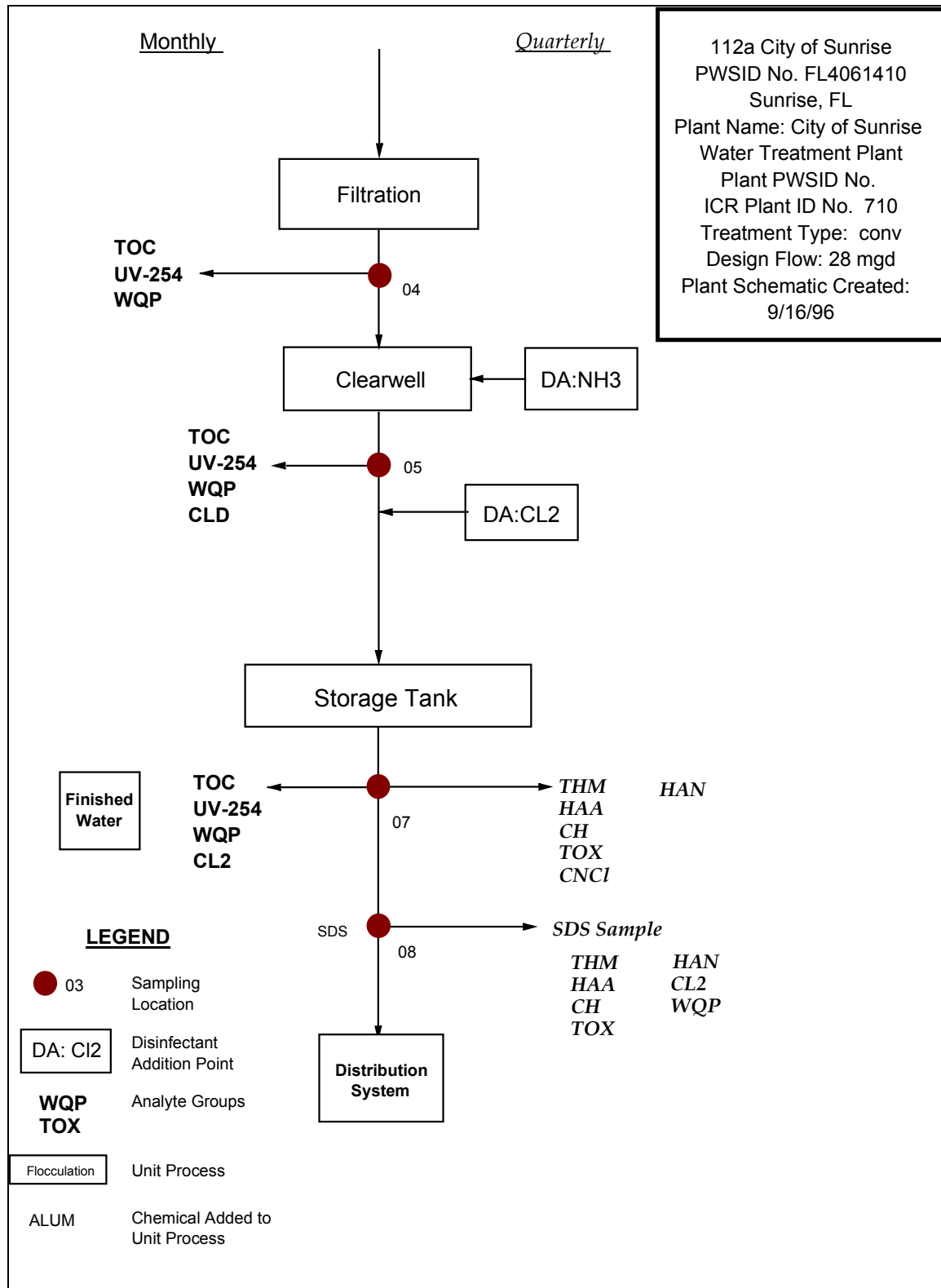


Figure 1 (continued).Springtree WTP Schematic

### 2.1.2 Treatment plant design information

The following Table 1 summarizes the Train B (new plant) design data.

**Table 1**  
**Treatment Plant Design Data**

<b>Unit Process</b>	<b>Process Description</b>
Rapid Mixing	Type of Mixer: ME Baffling Type: AV Liquid Volume (gal): 94,000 Mean Velocity Gradient (sec-1): 350.0
Lime Softening	Addition of calcium oxide CaO Dose rate (mg/L): 180.0
Coagulation-aid	Addition of Cytec Magnifloc 844-A Organic polymer dose (mg/L): 0.09
Sedimentation	Surface Area (ft <sup>2</sup> ): 9,775 Liquid Volume (gal): 691,000 Baffling Type: PR
Filtration	Surface Area (ft <sup>2</sup> ): 5,160 Liquid Volume (gal): 502,000 Total Media Depth (in): 36 Media type: DUAL Minimum Water Depth to Top of Media (ft): 6.0 Depth from Top of Media to Top of Backwash Trough (ft): 2.5
Ammonia addition	As NH <sub>3</sub> Dose rate (mg/L): 1.00
Clearwell	Surface Area (ft <sup>2</sup> ): 1,773 Liquid Volume (gal): 94,000 Minimum Liquid Volume (gal): 31,000 Baffling Type: SP
Chlorine gas addition	As Cl <sub>2</sub> Dose rate (mg/L): 5.50
Storage Tank	Surface Area (ft <sup>2</sup> ): 29,770 Liquid Volume (gal): 9,000,000

### 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 Springtree 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 Springtree WTP**  
*(January 1998 through December 1998)*

Source Water Quality Parameter	Average Value	Standard Deviation	Minimum Value	Maximum Value
Temperature (°C)	26.3	1.4	24.5	28.3
pH	7.1	0.2	6.9	7.3
Turbidity (NTU)	2.6	0.5	1.8	3.3
Total Alkalinity (mg/L as CaCO <sub>3</sub> )	210	18	160	226
Total Hardness (mg/L as CaCO <sub>3</sub> )	265	11	240	276
TOC (mg/L)	16.1	3.0	11.2	20.3
UV-254 (cm <sup>-1</sup> )	0.343	0.034	0.260	0.382
Bromide (mg/L)	0.17	0.03	0.14	0.22

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

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

Finished Water Quality Parameter	Average Value	Standard Deviation	Minimum Value	Maximum Value
Temperature (°C)	26.8	1.5	24.2	29.0
pH	8.9	0.3	8.1	9.3
Turbidity (NTU)	0.18	0.06	0.11	0.26
TOC (mg/L)	10.4	1.2	8.6	12.9
UV <sub>254</sub> (cm <sup>-1</sup> )	0.243	0.023	0.211	0.280
TTHM (µg/L)*	26.8	17.8	14.0	53.2
HAA5 (µg/L)*	16.6	9.1	9.1	29.8
HAA6 (µg/L)*	19.2	11.7	10.2	36.3

\* Based on four quarterly sampling campaigns (02/98; 05/98; 08/98; 11/98). Measured in the distribution system at the average residence time sites (14150 NW 8 St).

### 3. Materials and Methods

#### 3.1 Influent 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 Springtree WTP, since chlorine is first added in the clearwell, the feed water for the study was collected from the effluent of the filters. The only exception to this was for the first quarter (Winter), during which the water was collected from the influent to the WTP, and pretreated at bench-scale to simulate the full-scale treatment processes applied at the WTP that remove DBP precursors. Four quarterly samples were collected throughout the year to investigate seasonal variability. Table 4 presents the four sampling dates.

**Table 4**  
**Quarterly Sampling Dates**

<b>Quarter</b>	<b>Sampling Dates</b>
Winter	February 6, 1998
Spring	May 19, 1998
Summer	August 13, 1998
Fall	December 18, 1998

A total of 100 gallons of influent water was collected during the Winter quarter, and a total of 100 gallons of filtered water were collected the Spring, Summer, and Fall quarters. One 100-gal polyethylene tank was used for sample collection. The tank was 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 4°C until the day of testing.

Upon receipt of the samples, the influent and filtered waters were analyzed for general water quality parameters to verify sample representativeness. Table 5 presents general water quality of the four collected water samples.



**Table 5**  
**General Water Quality of Collected Raw and Filtered Water Samples**

Parameter	Unit	Winter Raw	Spring Filtered	Summer Filtered	Fall Filtered
pH	---	7.2	9.4	9.4	9.8
TOC	mg/L	12.0	10.5*	11.5*	9.7*
Turbidity	NTU	1.69	0.60	0.40	0.60
Alkalinity	mg/L as CaCO <sub>3</sub>	265	80	60	55
Total Hardness	mg/L as CaCO <sub>3</sub>	224	95	120	36
Apparent Color	Pt. Co. C.U.	50	18	N.A.	35
True Color	Pt. Co. C.U.	36	16	14	18
Apparent UV-254	cm <sup>-1</sup>	0.384	0.258	N.A	N.A.
Filtered UV-254	cm <sup>-1</sup>	0.344	0.254	0.277	0.251

\*After 0.45 -µm cartridge filtration; N.A.: not available

## 3.2 Pretreatment Processes

### 3.2.1 Description of pretreatment processes

During the Winter quarter, the sample was collected from the raw water, and all full-scale removing DBP precursors were simulated at bench-scale. This included rapid mix with addition of coagulant aid, lime addition, settling, and filtration. The bench-scale pre-treatment conditions are summarized in Table 6. During the Spring, Summer and Fall quarters, samples were collected from the filter effluent. Full-scale filtration was therefore the only TOC removing treatment process 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. pH was adjusted (pH reduced by 1.0 unit) during the Spring and Summer quarters to enhance TOC adsorption by the GAC. This was not done in the Fall quarter since influent TOC during the Fall quarter was lower than during the previous quarters. Discussion on this issue is presented in Section 4.1.2.

**Table 6**  
**Chemical dosages and Design Parameters Used during Pre-treatment**

	Winter	Spring	Summer	Fall
Superfloc A-130* dose, mg/L	0.12	N.A.	N.A.	N.A.
Lime CaOH dose, mg/L	186	N.A.	N.A.	N.A.
Rapid mixing	High speed, 30 sec	N.A.	N.A.	N.A.
Sedimentation (in 80-gal drum)	2 hours	N.A.	N.A.	N.A.
pH reduction by addition of H <sub>2</sub> SO <sub>4</sub>	N.A.	From 9.4 to 8.0	From 9.4 to 8.1	none
Filtration	5-, 1-µm, and 0.2-µm	0.45-µm and 0.2- µm	0.45-µm and 0.2- µm	0.45-µm and 0.2- µm

N.A.: Not Applicable

\*Cytex Industries

Table 7 compares the water quality of the pretreated sample (including filtration through the 1- $\mu$ m cartridge filter) collected on February 6<sup>th</sup> 1998, to the full-scale filtered water quality on February 4<sup>th</sup> 1998. Full-scale treatment included addition of 1.10 mg/L of filter aid (organic polymer Tripolyphosphate). This was not mimicked at bench-scale.

**Table 7**  
**Comparison of Simulated Pre-treated to Full-scale Filtered Water**  
**Winter Quarter**

Parameter	Simulated Pre-treated	Full-Scale Filtered Water*
	Water 02/06/98	02/04/98
pH	7.9	9.1
TOC, mg/L	10.0	11.3
Turbidity, NTU	0.61	0.16
Alkalinity, mg/L as CaCO <sub>3</sub>	123	28
Total Hardness, mg/L as CaCO <sub>3</sub>	132	70
Filtered UV-254, 1/cm	0.283	0.241
SUVA, L/(mg-m)	2.82	2.13

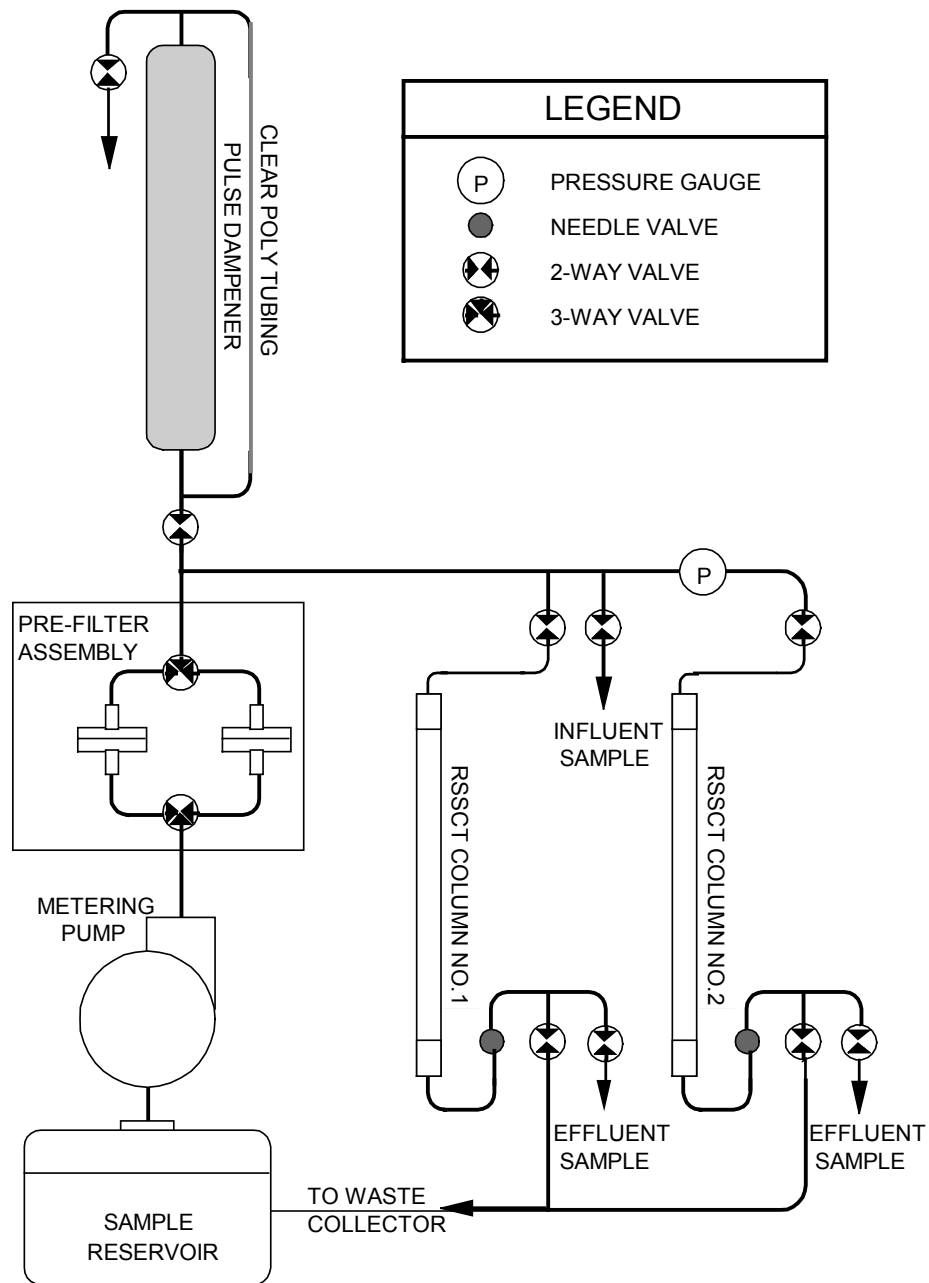
\* Full-scale data was only available for February 2<sup>nd</sup> 1998. It was taken from the 18-month ICR monitoring database.

The major difference between the bench-scale pre-treated water and the full-scale treated water lies in the alkalinity, hardness and pH parameters. Organic indicators represented by TOC concentration and UV-254 absorbance were more or less equivalent.

### 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) cubitainers. The influent water was pumped to each column using a single metering pump. A pre-filter (0.2  $\mu$ m) 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) during the Winter quarter, resulting in a scaling factor of 9.4. Due to early TOC breakthrough experienced during the Winter quarter, the carbon was ground to a 60×100 US Standard Mesh (particle diameter  $d_{SC}$ , of 0.2000 mm), resulting in a scaling factor of 5.3. The bigger bench-scale particle diameter extends the operation run time of the GAC columns. This makes it easier to collect the required number of samples from each column. A bituminous coal based GAC from Calgon Carbon Corp. (F-400) was used in this study. A minimum Reynolds number  $Re_{SCmin}$  of 0.5 was used as recommended by the ICR Guidance Manual. A 15-mm RSSCT column diameter was used in the two columns. An on-line pre-filter consisting of a 0.2- $\mu$ 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 8.

### 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) during the Winter quarter and to the 60×100 US Standard Mesh size (particle diameter of 0.2000 mm) during all other quarters 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 became 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 a 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.

**Table 8**  
**RSSCT Design Parameters**

<b>Design Parameters</b>	<b>Winter</b>	<b>Spring</b>	<b>Summer</b>	<b>Fall</b>
RSSCT influent TOC (mg/L)	<b>10.0</b>	<b>10.5</b>	<b>11.6</b>	<b>9.7</b>
Inner diameter of the RSSCT column, $D_{SC}$ (mm)	<b>15.0</b>	<b>15.0</b>	<b>15.0</b>	<b>15.0</b>
Minimum RSSCT Reynolds number, $Re_{SC, min}$	0.5	0.5	0.5	0.5
Full-scale operating temperature, $T^{\circ}C$ ( $^{\circ}C$ )	20.0	20.0	20.0	20.0
Full-scale bed porosity, $\epsilon_{LC}$	0.45	0.45	0.45	0.45
Measured RSSCT dry bed density, $\rho_{SC}$ (g/cm <sup>3</sup> )	<b>0.5</b>	<b>0.49</b>	<b>0.5</b>	<b>0.5</b>
RSSCT GAC mesh size, upper (US standard mesh)	100	60	60	60
RSSCT GAC mesh size, lower (US standard mesh)	200	100	100	100

<b>Estimated Run Length</b>				
Bed volumes to 50% TOC breakthrough, $BV_{50}$	1088	1021	897	1132
Estimated run length, $BV_T$ ( = 2 x $BV_{50}$ )	2175	2041	1793	2263
$BV_T$ + 30% safety factor, $BV_{T+30\%}$ ( = 2.6 x $BV_{50}$ )	2828	2654	2332	2942

<b>General RSSCT Design Parameters</b>				
Kinematic viscosity at $T^{\circ}C$ , $\nu_{LC}$ (m <sup>2</sup> /s)	1.027E-06	1.027E-06	1.027E-06	1.027E-06
RSSCT carbon particle diameter, $d_{SC}$ (mm)	0.1125	0.2000	0.2000	0.2000
Scaling factor, SF	9.36	5.26	5.26	5.26
RSSCT hydraulic loading rate, $v_{SC}$ (m/hr)	7.39	4.16	4.16	4.16
RSSCT flow rate, $Q_{SC}$ (mL/min)	21.77	12.25	12.25	12.25
Estimated total influent volume required, $V_{SC}^T$ (L)	197	185	163	205

<b>10-Minute EBCT Run</b>				
Full-scale empty bed contact time, $EBCT_{LC}$ (min)	10	10	10	10
Estimated full-scale run time, $t_{LC}^T$ (days)	20	18	16	20
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	1.07	1.90	1.90	1.90
Estimated RSSCT run time, $t_{SC}^T$ (days)	2.10	3.50	3.08	3.88
RSSCT bed length, $l_{SC}$ (cm)	13.2	13.2	13.2	13.2
Estimated volume required for 10-minute EBCT, $V_{SC}$ (L)	66	62	54	68
Mass GAC required, $m_{SC}$ (g)	11.63	11.40	11.63	11.63

<b>20-Minute EBCT Run</b>				
Full-scale empty bed contact time, $EBCT_{LC}$ (min)	20	20	20	20
Estimated full-scale run time, $t_{LC}^T$ (days)	39	37	32	41
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	2.14	3.80	3.80	3.80
Estimated RSSCT run time, $t_{SC}^T$ (days)	4.20	7.00	6.15	7.76
RSSCT bed length, $l_{SC}$ (cm)	26.3	26.3	26.3	26.3
Estimated volume required for 20-minute EBCT, $V_{SC}$ (L)	132	124	109	137
Mass GAC required, $m_{SC}$ (g)	23.27	22.80	23.27	23.27

### 3.3.3.3 Headloss buildup

Since a pre-filter set-up was connected to the influent of the columns, headloss was not generally a problem. During the Winter quarter, the water was filtered through a 1- $\mu$ m cartridge filter. Due to increasing headloss problems encountered during the Winter quarter which lead to frequent replacement of the 0.2- $\mu$ m on-line filter, the water was filtered through a 0.45- $\mu$ m cartridge filter during subsequent quarters to minimize potential headloss buildup in the column.

## 3.4 Experimental Design

The experimental design summary is presented in Table 9. 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 9**  
**Experimental Design Summary**

<b>Season</b>	<b>Pretreatment</b>	<b>EBCT, min</b>
Winter	Coagulation/ Flocculation and Sedimentation/Cartridge Filtration	10 & 20
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

## 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 Sunrise staff. These conditions included the average residence time, free chlorine residual, pH, and temperature at the average residence time. Table 10 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 10**  
**Target SDS Chlorination Testing Conditions**

Parameter	February 1998		May 1998		August 1998		December 1998	
	Value	Tolerance	Value	Tolerance	Value	Tolerance	Value	Tolerance
Incubation time, hrs	24	1.0	24	1.0	24	1.0	24	1.0
Incubation temp., °C	22	2.0	25	2.0	23	2.0	28	2.0
pH	8.1	0.4	8.8	0.4	8.1	0.4	8.6	0.4
Free Cl <sub>2</sub> 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 11.

**Table 11**  
**List of Analytical Methods and MRLs**

Analyte	Method	Minimum Reporting Level (MRL)
Alkalinity	SM 2320 B	5 mg/L CaCO <sub>3</sub>
Ammonia	SM 4500-NH <sub>3</sub> D	0.10 mg/L NH <sub>3</sub> -N
Bromide	EPA 300.0	40 µg/L
Calcium Hardness	SM 200.7	5 mg/L CaCO <sub>3</sub>
Total Hardness	SM 2340 B	7 mg/L CaCO <sub>3</sub>
Chlorine Residual/Dose	SM 4500-Cl D	0.2 mg/L as Cl <sub>2</sub>
All nine HAAs, HAA5 and HAA6	SM 6251B (MW lab) SM 552.2 (S&H Inc.)	1 µg/L for each analyte 2 µg/L for <i>CDBAA&amp;MCAA</i> 4 µg/L for <i>TBAA</i>
pH	SM 4500-H <sup>+</sup>	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 <sub>254</sub>	SM 5910	0.009 cm <sup>-1</sup>

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 12 is additional information on the location and contact person at each individual laboratory. More information is included in Appendix B.

**Table 12**  
**Listing of Laboratories involved in the Analytical Reporting**

<b>Laboratory</b>	<b>Dates of Service</b>	<b>Analyses Performed</b>
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 551.1) , HAA6 (SM 6251B), TOX (SM 5320), Bromide, Ca-hardness Total hardness
Summers and Hooper Inc.	Quarters 3 and 4	HAA9 (SM 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(s): Mr. Jim Hein/ Ms. Hillary Strayer  
Phone #: (626) 568-6489/ (626) 568-6412  
Fax #: (626) 568-6324

***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.

#### 4.1.2 Early TOC Breakthrough

During the first quarter (Winter), early TOC breakthrough was encountered due to the high influent TOC concentration. According to the Federal Register (page 24387) published May 14, 1996:

“If, after completion of the first quarter RSSCTs, the PWS finds that the effluent TOC reaches 70% of the average influent TOC within 20 full-scale equivalent days on the EBCT= 10 min test **and** within 30 full-scale equivalent days on the EBCT= 20 min test the last three quarterly tests shall be conducted using membrane bench-scale testing with only one membrane, as described in paragraph (b) (1) (ii) of this section.”

The results obtained on the TOC breakthrough during the first quarterly RSSCT run for the City of Sunrise, showed that the TOC breakthrough on 10-min EBCT column was reached before the 20 full-scale equivalent days criterion and that the breakthrough on the 20-min EBCT column was reached at exactly the 30 full-scale equivalent days criterion.

The issue of early TOC breakthrough had been already brought up on a general basis by MW staff to the EPA. We have been informed, that in the event that early breakthrough is reached within reasonable limits, the City could opt to stay with GAC bench-scale testing if different variables are investigated during the remaining three quarters. Factors that could be investigated include pre-treatment, such as enhanced coagulation or pH adjustment, carbon type, and EBCT.

Investigating different variables is also supported by the fact that the influent to the Sunrise WTP is of groundwater origin. According to the Federal Register language and the Bench- and Pilot-Scale Treatment Study Guidance Manual, “if seasonal variation is not an issue (as in the case for most groundwaters) and the water to be treated is not high-quality ground water, systems may wish to conduct studies under various pretreatment conditions and would be allowed to do so”.

In addition it is important to note, the water for the initial quarter was erroneously collected from the influent sampling point instead of the filter effluent point. Although

---

full-scale processes and conditions were simulated at bench-scale, the final simulated unchlorinated filtered water quality of the sample was probably not an exact match to the full-scale filtered water sample. This may have had an impact on the TOC breakthrough curve.

**The following recommendations were included in a previous memorandum to the EPA:**

1. That the City of Sunrise continue testing carbon during the second quarterly session (rather than test membranes during the second, third and fourth quarters).
2. For the subsequent quarters, the water sample will be collected from the WTP filter effluent (i.e., the correct sample location), and the RSSCT will be run with no pre-treatment other than the required filtration step.
3. pH will be adjusted (lowered) by 1.0 unit to improve TOC adsorption.
4. A larger particle diameter will be used in the RSSCT. This will increase the operation run time and ease the collection of the required number of samples.

## **4.2 Water Quality Data**

### **4.2.1 Water quality of pretreated influent to the RSSCT**

Table 13 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 Summer, as represented by the TOC concentration of 11.5 mg/L and UV-254 absorbance of 0.282/cm. Alkalinity was moderate to low and ranged from 123 during the Winter to 45 mg/L CaCO<sub>3</sub> during the Summer. The influent pH varied from 7.7 during the Summer to 9.0 during the Fall. Total hardness was moderate to low, ranging from 132 mg/L CaCO<sub>3</sub> during the Winter to 59 mg/L CaCO<sub>3</sub> during the Fall. Ammonia-nitrogen concentration was low throughout the quarters. Bromide concentration was moderate, and ranged from 140 to 190 µg/L. A higher proportion of chlorinated DBPs would therefore be expected. Chlorine demands were high throughout the quarters due to high organic content in the water, and ranged from 6.5 to 8.7 mg/L. The SDS-TTHM concentration in the chlorinated influent was high, and ranged from 187 µg/L during the Winter to 253 µg/L during the Fall. The SDS-HAA5 concentration was also high, and ranged from 84 µg/L during the Spring to 112 µg/L during the Winter. The SDS temperature varied somewhat (range of 22°C to 28°C). The SDS pH did not vary significantly and was measured highest at 8.8 during the Spring quarter (Table 10).

**Table 13**  
**Water Quality of the Influent to the RSSCT**

Water Quality Parameter	Winter Average (SD)*	Spring Average (SD)*	Summer Average (SD)*	Fall Average (SD)*
pH	7.90 (0.00)	7.97 (0.01)	7.73 (0.03)	9.03 (0.02)
Turbidity (ntu)	0.61 (0.04)	0.20 (0.00)	0.18 (0.00)	0.40 (0.00)
Alkalinity mg/L CaCO <sub>3</sub>	123	83	45	53
Calcium Hardness mg/L CaCO <sub>3</sub>	86	67	50	34
Total Hardness mg/L CaCO <sub>3</sub>	132	95	77	59
Bromide (µg/L)	140	180	190	170
Ammonia-N (mg/L)	0.10	0.10	0.10	<0.10
TOC (mg/L)	10.0 (0.0)	10.7 (0.0)	11.5 (0.0)	9.6 (0.0)
UV <sub>254</sub> (cm <sup>-1</sup> )	0.283 (0.006)	0.254 (0.009)	0.282 (0.003)	0.250 (0.004)
SUVA (L/mg-cm)	2.82 (0.00)	2.37 (0.02)	2.45 (0.01)	2.60 (0.00)
SDS-THM4 (µg/L)	187 (0.2)	247 (0)	208 (0)	253 (0)
SDS-HAA5 (µg/L)	112 (0)	84 (0)	100 (0)	89 (0)
SDS-HAA6 (µg/L)	126 (0)	99 (0)	115 (0)	105 (0)
SDS-TOX (µg Cl <sup>-</sup> /L)	757 (0)	710 (0)	730 (0.1)	655 (0)
SDS-chlorine demand (mg/L)	8.7 (0.0)	6.8 (0.0)	6.5 (0.0)	7.9 (0.00)

\* SD: Standard Deviation

## 4.1 Impact of Seasonal Variability

### 4.3.1 Impact of seasonal variability and pH 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. As illustrated, early TOC breakthrough was encountered during the Winter quarter. Sample pH was reduced by 1.0 unit during the Spring and Summer quarters only. Seasonal variation was not observed to impact significantly TOC breakthrough from either GAC column since each column exhibited different behavior with regards to TOC release. 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 (without exceeding the 70% TOC breakthrough criterion) during the Summer quarter (36 scaled days of operation), and shortest during the Winter quarter (15 scaled days of operation). For the 20-min EBCT design, the column ran longest during the Spring quarter (72 scaled days of operation), and shortest during the Winter quarter (30 scaled days of operation). Eventhough TOC concentrations during the Spring and Summer quarters were higher than those in the Winter quarter, column runs were extended. This is probably due to the decrease in the

pH of the influent sample. The rate of breakthrough (slope of curves) was observed to be somewhat constant for the 10-min EBCT design, estimated at approximately 3 percent/day. In the 20-min EBCT column, breakthrough rates varied from quarter to quarter.

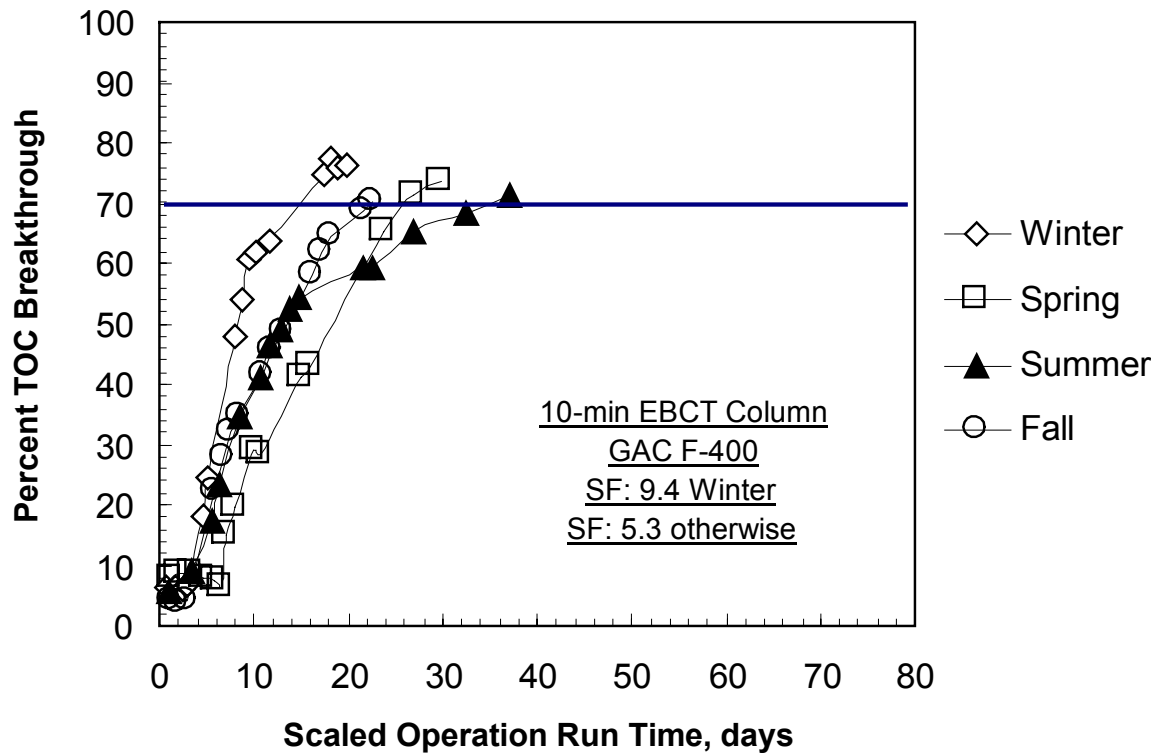
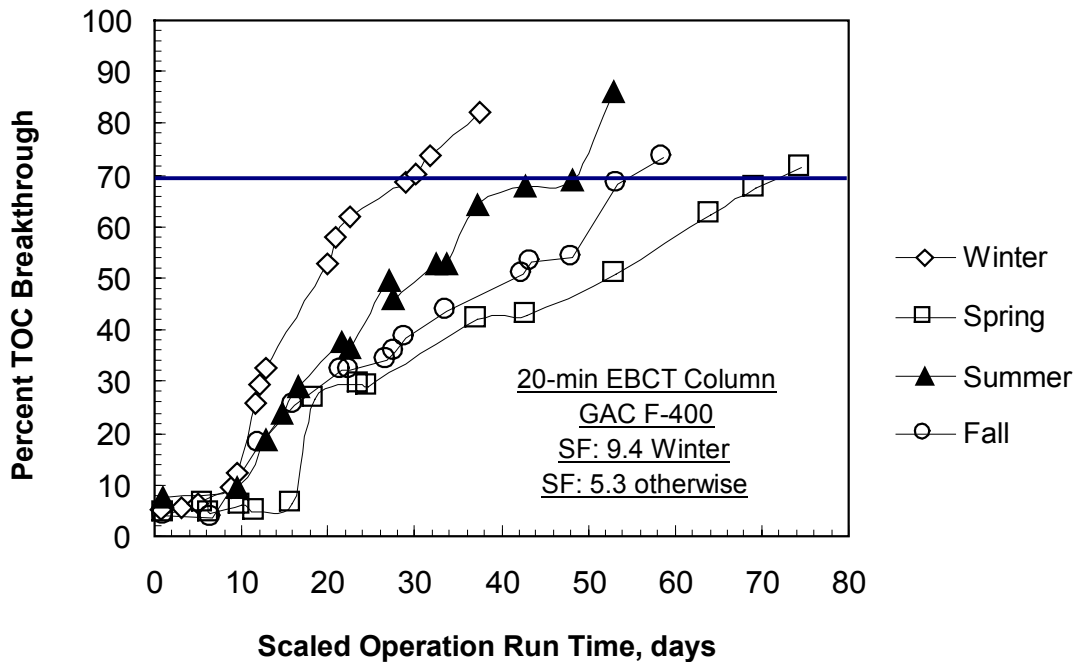


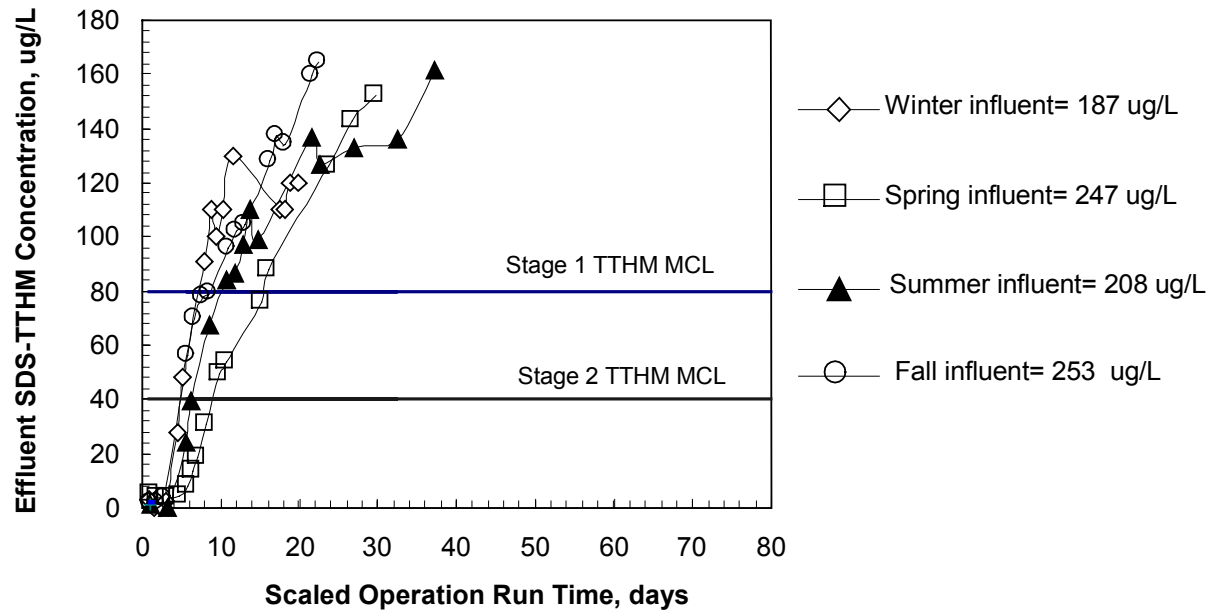
Figure 3. Impact of Seasonal Variability on Percent TOC Breakthrough in the 10-min EBCT Column



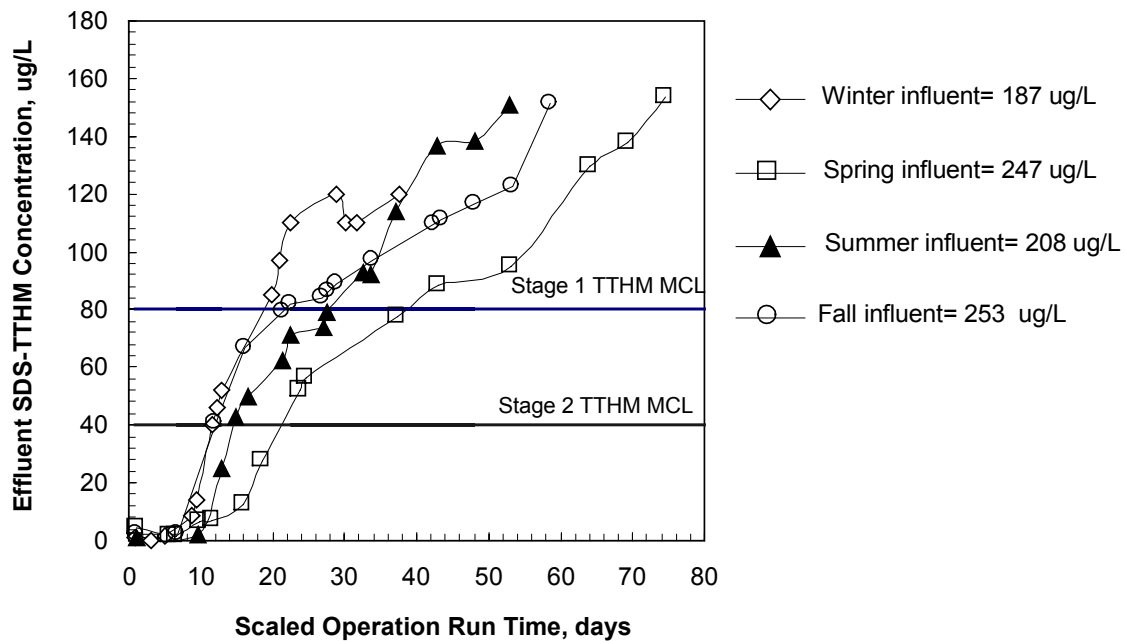
**Figure 4. Impact of Seasonal Variability on TOC Breakthrough in the 20-min EBCT Column**

#### 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 does not appear to be correlated with the influent SDS-TTHM concentration or the influent TOC concentration. For both EBCTs, the Stage 2 TTHM MCL was first exceeded during the Winter and Fall quarters, after 5 scaled days and after 12 scaled days for the 10- and 20-min EBCTs, respectively. The slowest breakthrough occurred during the Spring quarter. The Stage 2 TTHM MCL was exceeded after 9 scaled days for the 10-min EBCT column, and after 21 scaled days for the 20-min EBCT column. This may be due to the impact of pH reduction during the Spring and Summer quarters. Regardless, the rate of TTHM breakthrough was high during all four quarters and for both EBCTs, mainly due to a high SDS-TTHM concentrations in the chlorinated influent. The rates of SDS-TTHM breakthrough measured at approximately 5.3  $\mu\text{g/L/day}$  for the 10-min EBCT column and at 2.6  $\mu\text{g/L/day}$  for the 20-min EBCT column. The Stage 1 TTHM MCL was exceeded during all four quarters.



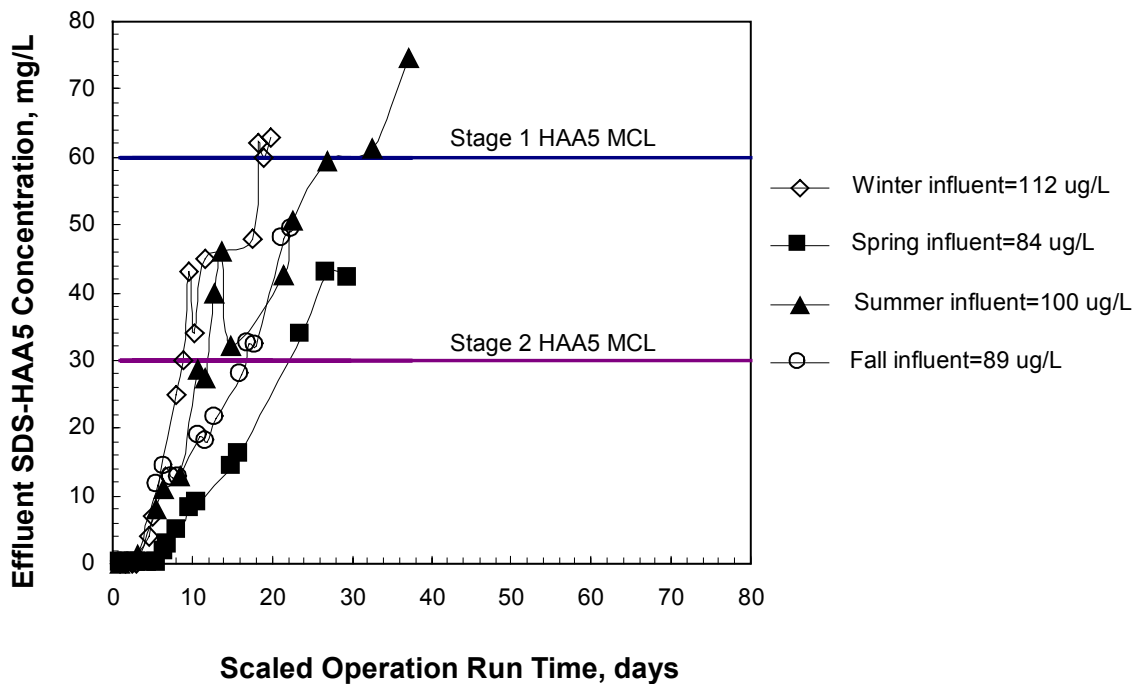
**Figure 5. Impact of Seasonal Variability on SDS-TTHM Breakthrough in the 10-min EBCT Column**



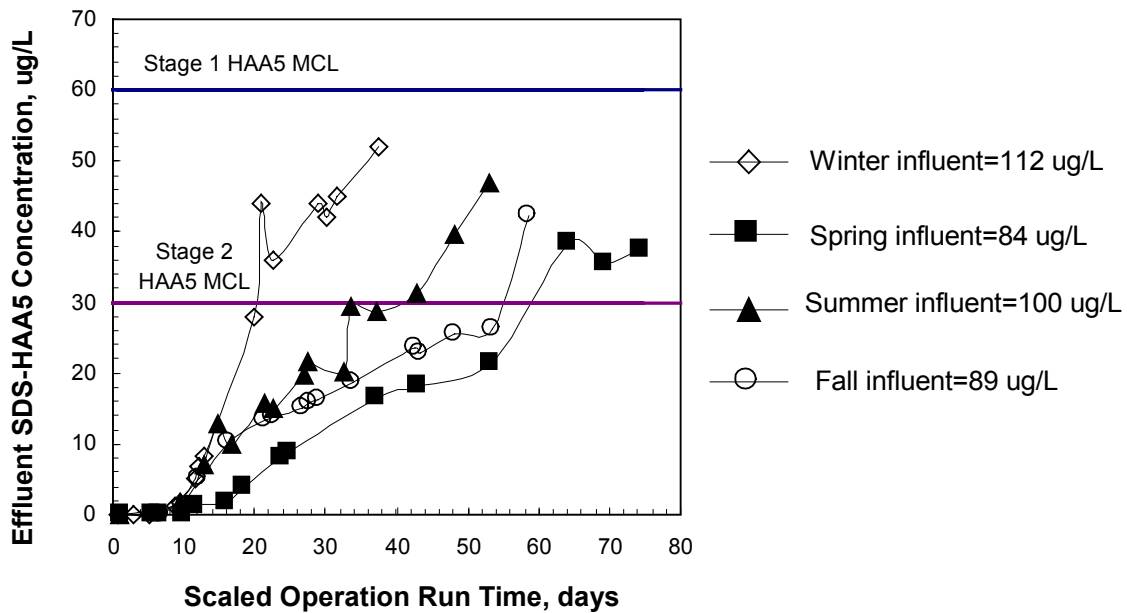
**Figure 6. Impact of Seasonal Variability on SDS-TTHM Breakthrough in the 20-min EBCT Column**

#### 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 high SDS-HAA5 concentration in the chlorinated influent, the Stage HAA5 MCL was exceeded during all four quarters. The Stage 2 HAA5 MCL was first exceeded during the Winter quarter after 9 scaled days in the 10-min EBCT column and after 20 scaled days in the 20-min EBCT column. The slowest breakthrough occurred during the Spring quarter and the Stage 2 HAA5 MCL was exceeded after 22 scaled days in the 10-min EBCT column and after 59 scaled days in the 20-min EBCT column and during the Winter and Summer quarters. 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 in the 10-min EBCT column and measured at approximately 2.2  $\mu\text{g/L/day}$ . The breakthrough rate in the 20-min EBCT varied from quarter to quarter.



**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 moderate 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 14 presents the range of SDS-THMs and SDS-HAAs formed in the effluent samples during the four quarterly RSSCTs. As observed in Table 14, the SDS-DBPs formed were highly chlorinated species, with most of the reported brominated species slightly higher than minimum levels. The dominant SDS-THM specie was observed to be chloroform, whereas the SDS-HAAs were dominated by dichloro- and trichloro- acetic acids.



**Table 14**  
**Impact of Low Influent Bromide Concentration on SDS-DPBs Speciation**

		Winter	Spring	Summer	Fall
Influent to RSSCT	Bromide, µg/L	140	180	190	170
10-min EBCT	CHCl <sub>3</sub> , µg/L	BMRL to 70.0	BMRL to 89.0	BMRL to 95.0	BMRL to 92.5
	BDCM, µg/L	BMRL to 39.0	BMRL to 41.0	BMRL to 46.0	BMRL to 43.5
	DBCM, µg/L	1.2 to 25.0	1.9 to 29.0	BMRL to 30.0	BMRL to 35.0
	CHBr <sub>3</sub> , µg/L	1.8 to 17.0	3.2 to 18.0	1.5 to 20.0	1.3 to 29.0
	MCAA, µg/L	BMRL to 3.5	BMRL to 2.6	BMRL to 4.2	BMRL to 4.8
	DCAA, µg/L	BMRL to 29.0	BMRL to 24	BMRL to 35.0	BMRL to 24.0
	TCAA, µg/L	BMRL to 26.0	BMRL to 12.0	BMRL to 31.0	BMRL to 15.5
	MBAA, µg/L	BMRL to 1.7	BMRL	BMRL to 1.2	BMRL
	DBAA, µg/L	BMRL to 6.1	BMRL to 7.7	BMRL to 11.0	BMRL to 8.4
	BCAA, µg/L	BMRL to 13.0	BMRL to 14.0	BMRL to 16.0	BMRL to 13.5
	TBAA, µg/L	BMRL	BMRL	BMRL	BMRL
	CDBAA, µg/L	BMRL to 6.6	BMRL to 3.7	BMRL to 8.7	BMRL to 5.4
	DCBAA, µg/L	BMRL to 13.0	BMRL to 7.4	BMRL to 17.0	BMRL to 8.1
20-min EBCT	CHCl <sub>3</sub> , µg/L	BMRL to 70.0	BMRL to 87.0	BMRL to 77.0	BMRL to 76.0
	BDCM, µg/L	BMRL to 35.0	BMRL to 42.0	BMRL to 46.0	BMRL to 44.0
	DBCM, µg/L	BMRL to 23.0	1.8 to 27.0	BMRL to 29.0	0.80 to 34.0
	CHBr <sub>3</sub> , µg/L	BMRL to 13.0	2.5 to 18.0	1.2 to 26.0	1.4 to 28.0
	MCAA, µg/L	BMRL to 3.3	BMRL	BMRL	BMRL to 2.9
	DCAA, µg/L	BMRL to 22.0	BMRL to 21.0	BMRL to 23.0	BMRL to 20.0
	TCAA, µg/L	BMRL to 21.0	BMRL to 11.0	BMRL to 18.0	BMRL to 12.0
	MBAA, µg/L	BMRL to 1.7	BMRL	BMRL	BMRL
	DBAA, µg/L	BMRL to 5.9	BMRL to 7.6	BMRL to 13.0	BMRL to 9.3
	BCAA, µg/L	BMRL to 11.0	BMRL to 12.0	BMRL to 13.0	BMRL to 12.0
	TBAA, µg/L	BMRL	BMRL	BMRL	BMRL
	CDBAA, µg/L	BMRL to 6.3	BMRL to 4.5	BMRL to 5.7	BMRL to 6.2
	DCBAA, µg/L	BMRL to 13.0	BMRL to 7.5	BMRL to 11.0	BMRL to 8.0

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. Despite 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 a small 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.

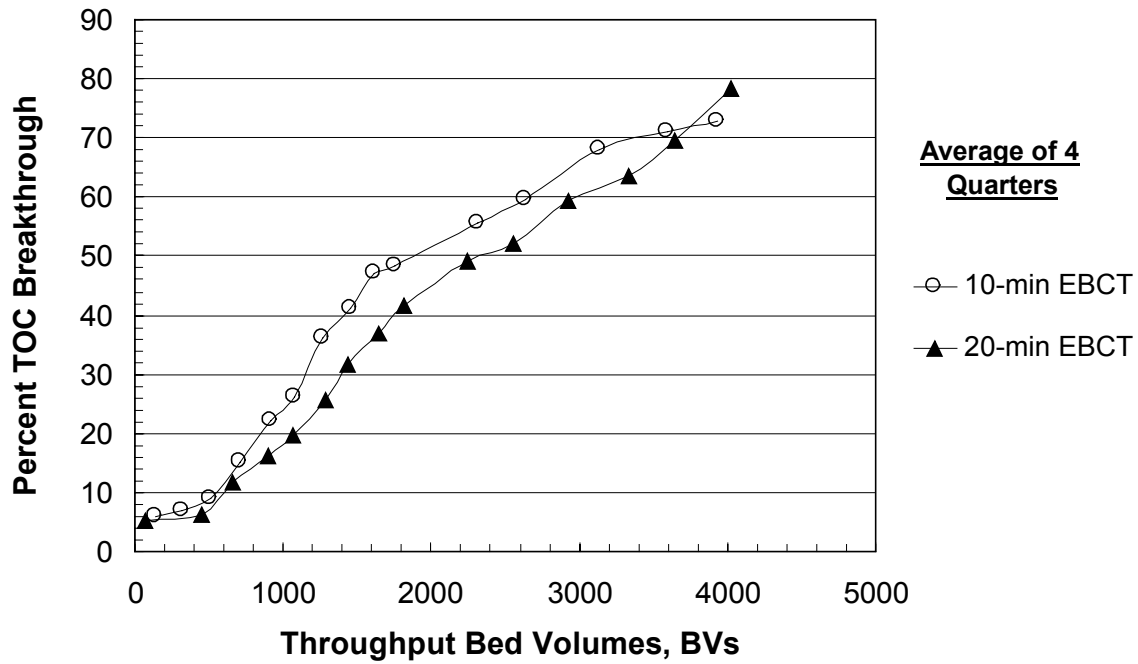


Figure 10. Impact of EBCT on Percent TOC Breakthrough

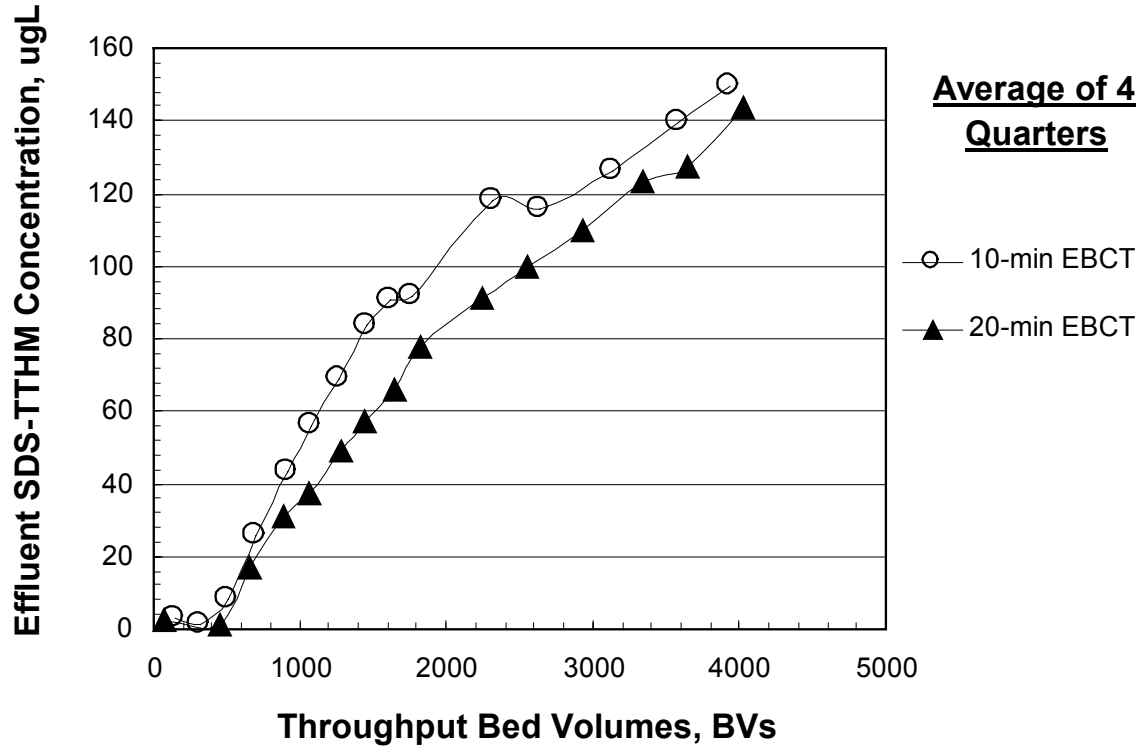


Figure 11. Impact of EBCT on SDS-TTHM Breakthrough

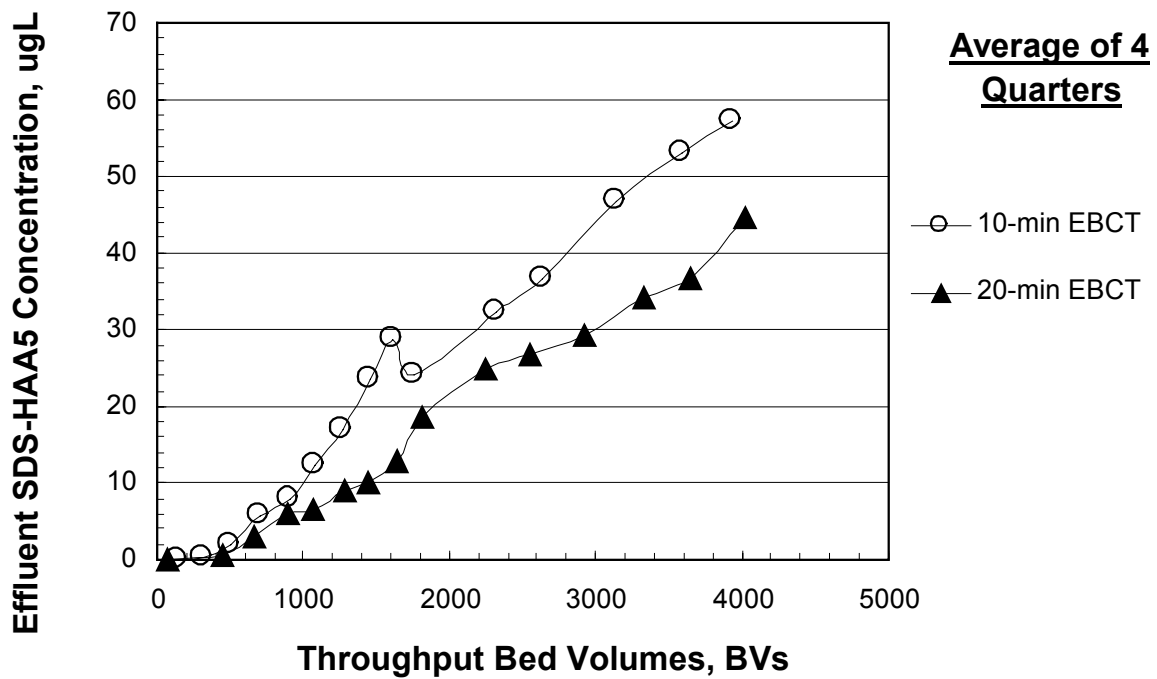


Figure 12. Impact of EBCT on SDS-HAA5 Breakthrough

#### 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 13 and 14 illustrate, respectively, the breakthrough of the above parameters from the 10-min and 20-min EBCT GAC contactors.

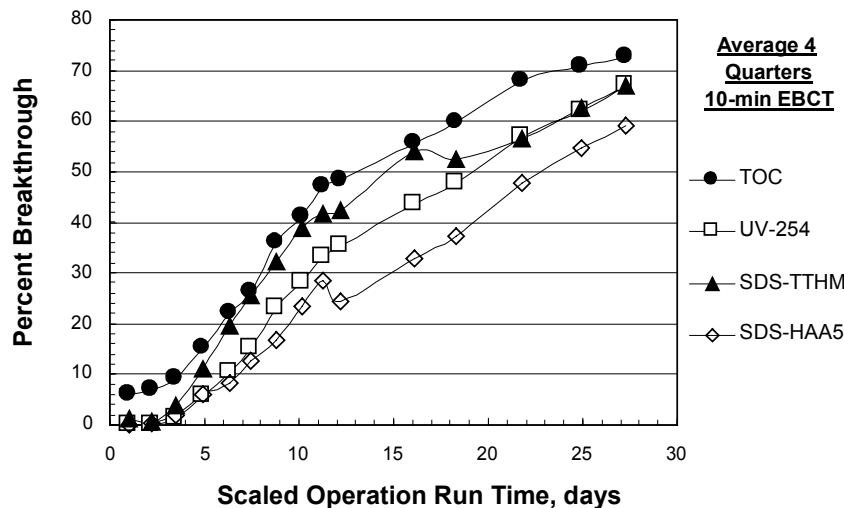


Figure 13. Breakthrough of TOC, UV-254 and SDS-DBPs from 10-min EBCT GAC Column

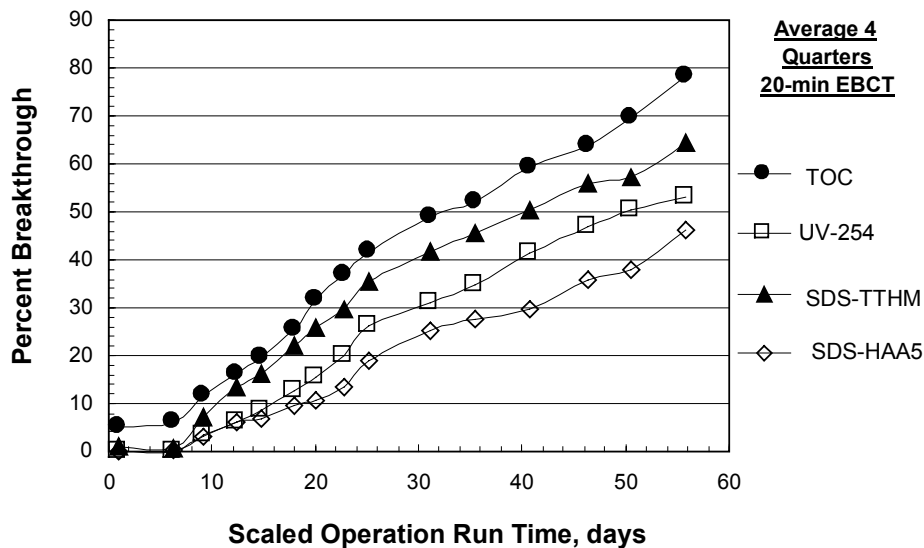


Figure 14. Breakthrough of TOC, UV-254 and SDS-DBPs from 20-min EBCT GAC Column

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 2.7 percent/day for the 10-min EBCT design, and at 1.0 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 to be 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 1 and 2 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 15 and 16. The amount of GAC (in million pounds per year) was estimated based on an average flowrate of 19.6 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 Sunrise, 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 15**  
**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	224	64	29	300	3.6	25.9
			32	14	208	5.1	36.6
HAA5	µg/L	96	48	50	>820	<1.3	<9.0
			24	25	466	2.4	17.3

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

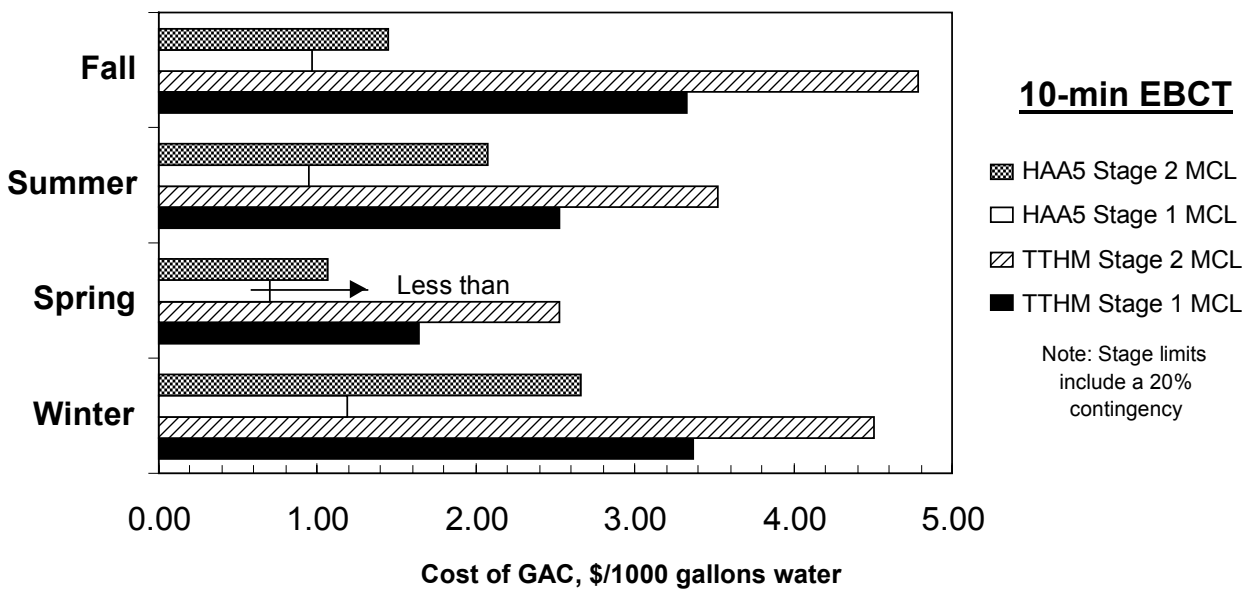
**Table 16**  
**Average CURs over Four Quarters for the 20-min EBCT Design**

Parameter	Units	Influent Concentration	Target Concentration*	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	224	64	29	369	2.9	20.7
			32	14	247	4.3	30.6
HAA5	µg/L	96	48	50	>991	<1.1	<7.8
			24	25	684	1.7	12.4

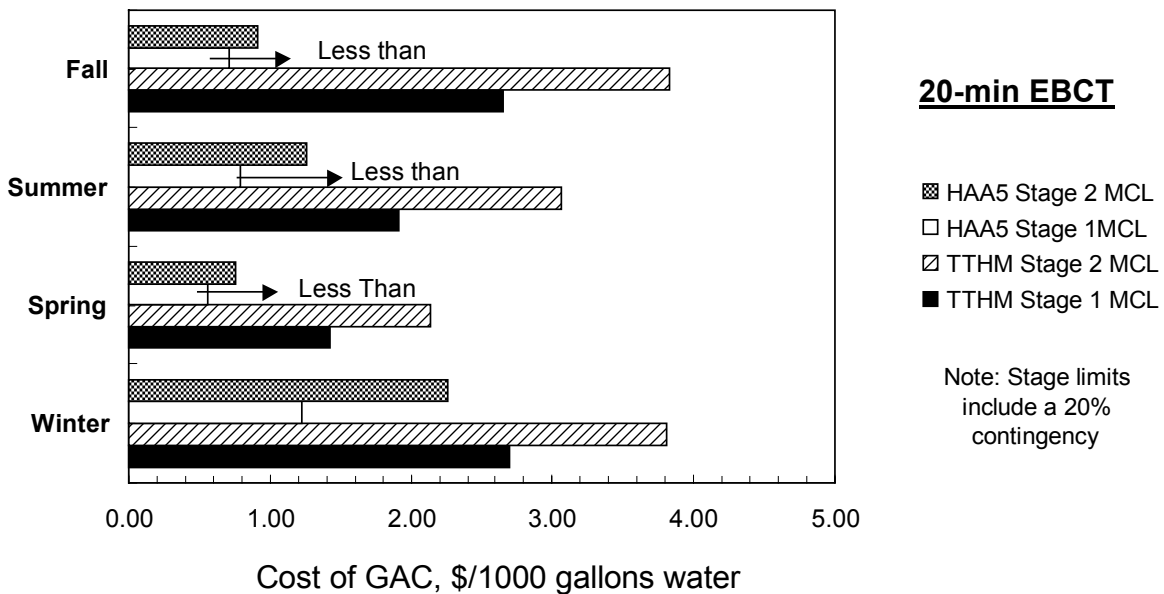
\* 80% of the Stage 1 and Stage 2 MCLs for each DBP

#### 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 15 and 16. These costs were estimated with a 20% contingency (i.e., 80% of the MCL). The Stage 2 TTHM MCL was exceeded during all four quarters, and for both EBCTs. In the 10-min EBCT column, the Stage 2 HAA5 MCL was exceeded in all quarters except for the Spring quarter. In the 20-min EBCT column, the Stage 2 HAA5 MCL was only exceeded in the Winter quarter. The cost analysis will therefore be based on the CURs to meet 80% of the Stage 2 TTHM MCL. In the 10-min EBCT contactor, the costs to meet the Stage 2 MCL for TTHMs ranged from \$2.5/1000 gal during the Spring quarter to \$4.8/1000 gal during the Fall quarter. During the Winter and Summer quarters, these costs were evaluated as being \$4.5/1000 gal, and \$3.5/1000 gal, respectively. In the 20-min EBCT contactor, the GAC replacement costs to meet 80% of Stage 2 MCL of TTHMs ranged from \$2.1/1000 gal during the Spring quarter to \$3.8/1000 gal during both the Winter and Fall quarters. 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. This statement is in agreement with the findings in Section 4.4.



**Figure 15. Cost of GAC Replacement from the 10-min EBCT Contactor to Meet Target DBP MCL Criteria**



**Figure 16. 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 all four quarters) to meet 80% of the Stage 2 TTHM MCL, and an average flowrate of 19.6 mgd. For a 10-min EBCT, the average annual GAC replacement cost was estimated at \$27,471,360. The average annual GAC replacement cost for a 20-min EBCT was estimated at \$22,964,340. These costs

are too cost prohibitive and 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 19.6 mgd, and were again based on numbers estimated during all four quarters. To be conservative, 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 36.6 million lbs/yr (4,178 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 1,671 square feet. Based on the 20-min EBCT average CUR of 30.6 millions lbs/yr (3,493 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 1397 square feet. Since these surface areas are beyond 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 418 square feet for the 10-min EBCT and at 349 square feet for the 20-min EBCT. To be conservative, the capital and O&M costs will be estimated for one reactivator and multiplied thereafter by a factor of four (4). Capital and O&M costs for thermal GAC reactivation using 10- and 20-min EBCTs are presented in Table 17.

In this analysis, the following parameters were assumed:

Parameter	Assumption
Single reactivator area, sq-ft (10-min EBCT)	418
Single reactivator area, sq-ft (20-min EBCT)	349
Total number of reactivators	4 for each EBCT design
Capital amortization	$I = 6$ percent over $N = 30$ years
Capital recovery factor CRF	0.117
Labor and fringe rate	\$21/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.

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



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 17**  
**Capital and O&M Costs for a GAC Reactivation using Multihearth Technology**

<b>Parameter</b>	<b>10-min EBCT</b>	<b>20-min EBCT</b>
<b>DESIGN PARAMETERS</b>		
lbs of GAC per hour (to meet 80% Stage 2 TTHM MCL) at 0.4 sq-ft required per lb/hr	4178	3493
Surface area per reactivator, sq-ft	418	349
<b>CAPITAL COSTS</b>		
CC, 1998 \$	3,881,345	3,605,706
<b>Annual capital costs, \$/yr</b>	<b>\$281,975</b>	<b>\$261,951</b>
<b>O&amp; M COSTS</b>		
PE, kwh/yr	962914	885988
Annual PE costs, \$/yr	<b>\$48,146</b>	<b>\$44,299</b>
BE, kwh/yr	27,928	26208
Annual BE costs, \$/yr	<b>\$1,396</b>	<b>\$1,310</b>
MM costs, 1998 \$/yr	<b>\$64,124</b>	<b>\$59,681</b>
OL, workhours/yr	22192	19,921
Annual OL costs, \$/yr	<b>\$466,032</b>	<b>\$418,352</b>
NG requirement, scft/yr	65993492	56276968
Annual NG cost, \$/yr	<b>\$362,964</b>	<b>\$309,523</b>
<b>Total O&amp;M Annual Costs, \$/yr</b>	<b>\$942,663</b>	<b>\$833,166</b>
<b>TOTAL ANNUAL COSTS, \$/yr</b>	<b>\$1,224,638</b>	<b>\$1,095,117</b>

The costs incurred for the amount of GAC used would be four times greater than those shown in Table 17. Although these costs are much lower than those for replacing the carbon, they too are cost prohibitive and on-site thermal GAC reactivation would 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 Sunrise.

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

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	28 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*	\$21.0/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 Sunrise, the following design parameters were provided:

- Total plant capacity  $Q' = 28$  mgd;  $70\% Q' = Q = 19.6$  mgd = 13,611.1 gpm = 1,819.8 cu-ft/min;
- Hydraulic loading  $Q/A$  (provided by the City) = 2.74-4.11 gpm/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 the above.

- Ten GAC concrete gravity contactors.

Table 18 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 18**  
**Capital and O&M Costs for a Concrete Gravity Adsorber**

<b>Parameter</b>	<b>10-min EBCT</b>	<b>20-min EBCT</b>
<b>DESIGN PARAMETERS</b>		
Bed volume per contactor, cu-ft	1,819.8	3,639.6
Total GAC effective volume, cu-ft	18,198	36,396
<b>CAPITAL COSTS</b>		
z (in CC equation)	1	1
CC, 1998 \$	2,309,557	3,723,437
Annual Capital Costs, \$/yr	<b>\$227,261</b>	<b>\$366,387</b>
<b>O&amp; M COSTS</b>		
PE, kwh/yr	32,666	32,666
Annual PE costs, \$/yr	<b>\$1,633</b>	<b>\$1,633</b>
BE, kwh/yr	505,444	505,444
Annual BE costs, \$/yr	<b>\$25,272</b>	<b>\$25,272</b>
MM costs, 1998 \$/yr	<b>\$12,343</b>	<b>\$12,343</b>
z (in OL equation)	1	1
OL, workhours/yr	2,771	2,771
Annual OL costs, \$/yr	<b>\$58,189</b>	<b>\$58,189</b>
	<b>\$97,438</b>	<b>\$97,438</b>
<b>Total annual O&amp;M costs</b>		
	<b>\$4,898,552</b>	<b>\$4,380,468</b>
GAC annual reactivation costs		
	<b>\$5,223,251</b>	<b>\$4,844,293</b>
<b>TOTAL ANNUAL COSTS</b>		

According to Table 18, 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 10% lower when using a 20-min EBCT instead of a 10-min EBCT. Total annual costs (including GAC reactivation costs) were observed to be 7% lower when using a 20-min EBCT instead of a 10-min EBCT.

#### **4.7 Summary of Significant Results**

- No major seasonal variability was observed for the 10-min EBCT design in the breakthrough curves of indicators of natural organic matter (TOC, UV-254) and precursors of TTHMs and HAA5 upon SDS chlorination. This is mainly due to a

---

constant natural organic matter (NOM) content in the influent water throughout the four quarters. However, some variation in the breakthrough curves were observed with the 20-min EBCT design. Column runs for Spring and Summer were extended, even though TOC concentrations during these two quarters were high. This was probably due to the impact of pH reduction during the Spring and Summer quarters. The TOC breakthrough rate was somewhat constant for both EBCTs, however some lag time was observed in the TOC breakthrough from the 20-min EBCT column. The TOC breakthrough rate was estimated at approximately 3.3 percent per day in the 10-min EBCT column and at approximately 1.4 percent per day in the 20-min EBCT column.

- The order of the SDS-DBPs breakthrough curves did not appear to be affected by either the influent SDS-DBP concentration in the chlorinated influent water or by the influent TOC concentration. Regardless, high SDS-DBP breakthrough rates were observed during all four quarters. This was probably due to high influent SDS-TTHM and SDS-HAA5 concentrations in the influent water. For both EBCT designs, the Stage 2 MCLs for TTHMs and HAA5 were first exceeded during the Winter quarter, while the slowest breakthrough for both contaminants occurred during the Spring quarter. This was probably a result of the pH reduction during the Spring quarter.
- The moderate bromide influent concentration (range of 140 to 190 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, a small benefit was observed for DBP control by using a 20-min EBCT versus a 10-min EBCT. This was illustrated on all three breakthrough curves of TOC, SDS-TTHM, and SDS-HAA5. Lower GAC replacement or reactivation costs are therefore expected when using a 20-min EBCT.
- TOC and UV-254 breakthroughs were observed to correlate well with those of SDS-TTHMs and SDS-HAA5. TOC concentration proved to be a conservative indicator of SDS-DBPs. 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 based on the average carbon usage rates from all four 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, the GAC replacement costs to meet 80% of the Stage 1 and the Stage 2 TTHM MCLs were reported, while the reactivation costs were based on meeting 80% of the Stage 2 TTHM MCL. In the 10-min EBCT contactor, the GAC replacement cost to meet 80% of the Stage 2 TTHM ranged from \$2.5/1000 gal of treated water during the Spring quarter to \$4.8/1000 gal during the Fall quarter. In the 20-min EBCT contactor, the GAC replacement cost to meet 80% of the Stage 2 TTHM MCL ranged from \$2.1/1000 gal of treated water during the Spring quarter, to

---

\$3.8/1000 gal during the Fall and Winter quarters. The average GAC replacement annual cost was estimated at \$27,471,360 for a 10-min EBCT, and at \$22,964,340 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 \$4,898,552 for a 10-min EBCT and at \$4,844,293 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 19.6 mgd average flowrate. Annual capital costs for a 10-min EBCT were estimated at \$227,261, and for a 20-min EBCT at \$366,387. When including the annual GAC reactivation costs to the annual O&M costs, the total annual costs were estimated at \$5,223,251 for a 10-min EBCT and at \$4,844,293 for a 20-min EBCT. Using either EBCT resulted in very high annual costs for the City of Sunrise.

## 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 “Standard Methods”. These data sheets describe the sampling date, the date of analysis, the method of analysis, the result, the minimum reporting level (MRL), and the QC batch identification label when appropriate. Quarterly QA/QC laboratory sheets are included separately on a 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. Also included are 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 and Summers and 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

Adams, J.Q. and Clark, R.M.(1991). *Evaluating the Costs of Packed-Tower Aeration and GAC for Controlling Selected Organics*. JAWWA, January issue.

Adams, J.Q. and Clark, R.M.(1988). *Development of Cost Equations for GAC Treatment Systems*. Jour. Envir. Engrg.-ASCE, 14:7:672.

Nieminski,E., Chaudhuri, S., Flint, T., Paxman, S., Reynolds, F., and Carman, J. (1996). *ICR Survival Guide*. JAWWA, August issue.

Standard Methods for the Examination of Water and Wastewater (1996). 19<sup>th</sup> Edition. Prepared and published by American Public Health Association, American Water Works Association, and Water Environment Federation.

USEPA (1996). *ICR Manual for Bench- and Pilot-Scale Treatment Studies*. Technical Support Division, Cincinnati OH.

USEPA (1996). *DBP/ICR Analytical Methods Manual*. Technical Support Division, Cincinnati OH.

USEPA (1997). *ICR Treatment Studies Data Collection Spreadsheets User's Guide*. Technical Support Division, Cincinnati OH.

USEPA (1997). *National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment Rule Notice of Data Availability; Proposed Rule*. Federal register Part III, Vol. 62, No.212.



---

**APPENDIX A**

---

**CURs for 10-min and 20-min EBCTs**

**Table A1**  
**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	187	64	34	222	4.5	32.2
			32	17	166	6.0	43.0
HAA5	µg/L	112	48	43	630	1.6	11.4
			24	21	282	3.5	25.4

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

**Table A2**  
**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	247	64	26	457	2.2	15.6
			32	13	296	3.4	24.2
HAA5	µg/L	84	48	57	>1070	<0.9	<6.7
			24	29	704	1.4	10.2

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

**Table A3**  
**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	208	64	31	297	3.4	24.1
			32	15	213	4.7	33.6
HAA5	µg/L	100	48	48	801	1.3	8.9
			24	24	362	2.8	19.8

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

**Table A4**  
**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	253	64	25	225	4.4	31.7
			32	13	157	6.4	45.6
HAA5	µg/L	89	48	54	779	1.3	9.2
			24	27	516	1.9	13.9

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

**Table A5**  
**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	187	64	34	278	3.6	25.7
			32	17	197	4.1	36.3
HAA5	µg/L	112	48	43	616	1.6	11.6
			24	21	332	3.0	21.5

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

**Table A6**  
**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	247	64	26	523	1.9	13.7
			32	13	351	2.9	20.4
HAA5	µg/L	84	48	57	>1341	<0.7	<5.3
			24	29	988	1.0	7.2

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

**Table A7**  
**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	208	64	31	391	2.5	18.3
			32	15	245	4.1	29.2
HAA5	µg/L	100	48	48	>952	<1.1	<7.5
			24	24	593	1.7	12.1

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

**Table A8**  
**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	253	64	25	283	3.5	25.2
			32	13	196	5.1	36.6
HAA5	µg/L	89	48	54	>1055	<0.9	<6.8
			24	27	821	1.2	8.7

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

---

**APPENDIX B**

***Summary Report Spreadsheets***

**Miscellaneous Information**

PWSID FL4061410  
Plant ICR # 710

**Full-Scale Plant Information**

Item	Result	
Primary Disinfectant	none	(Pri Disinf, Free Cl2, Chloramines, Chlorine Dioxide, Ozone)
Residual Disinfectant	chloramines	(Sec Disinf, Free Cl2, Chloramines, Chlorine Dioxide)
Source Type	Aquifer	(River/Stream, Lake, Reservoir, Aquifer)
Source Name	Biscayne	

**Laboratory Information**

Item	ICR ID or Abbrev	Lab Name	Lab Type	Lab City	Lab State
Lab #1	CA013	Montgomery Watson	commercial	Pasadena	CA
Lab #2	RCFF	MW Applied Research Departm	consultant	Monrovia	CA
Lab #3	OH033	Summers & Hooper	consultant	Cincinnati	OH
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	2/6/98	5/19/98	8/13/98	12/18/98

**1998 Flow and Population Information**

Source	Flow (mgd)	Population Served
Total Population Served		152000
Surface Water	0	0
Ground Water	18	18
Purchased Finished Water	0	0
Total	18	

## Full-Scale Water Quality Data

### Full-Scale Influent Water Quality Data

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	26.3	1.4	24.5	28.3	12
pH	Unit	7.1	0.2	6.9	7.3	12
Turbidity	ntu	2.6	0.5	1.8	3.3	12
Alkalinity	mg/L as CaCO <sub>3</sub>	210	18	160	226	12
Total Hardness	mg/L as CaCO <sub>3</sub>	265	11	240	276	12
Calcium Hardness	mg/L as CaCO <sub>3</sub>	241	13	224	270	12
TOC	mg/L	16.1	3.1	11.2	20.3	12
UV <sub>254</sub>	1/cm	0.343	0.034	0.26	0.382	12
Bromide	µg/L	170	30	140	220	12
TSUVA*	L/(mg*m)	2.2	0.5	1.6	3.2	12

\*TSUVA = [UV<sub>254</sub> (1/m)] / [TOC (mg/L)]. Summary information for TSUVA should only be calculated from TSUVA values with paired TOC and UV<sub>254</sub> measurements

### Full-Scale Finished Water Quality Data

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	26.8	1.5	24.2	29	12
pH	unit	8.9	0.34	8.1	9.3	12
Turbidity	ntu	0.18	0.06	0.11	0.26	12
TOC	mg/L	10.4	1.2	8.6	12.9	12
UV <sub>254</sub>	1/cm	0.243	0.023	0.211	0.28	12
DS-THM4	µg/L	26.8	17.83	14	53.2	4
DS-HAA5	µg/L	16.6	9.1	9.1	29.8	4
DS-HAA6	µg/L	19.2	11.7	10.2	36.3	4

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											
Ammonia	mg NH3-N/L											
Calcium Hardness	mg/L as CaCO3	ICRCA013	9/1/97	5/1/99	EPA 200.7	5						
SDS-Ci2 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%
							% Recovery for Lab Fortified Matrix:	392	102%	7%	98%	101%
							% Recovery for PE Samples:	5	100%	2%	99%	100%
UV254	1/cm											
TOC	mg/L						RPE of Analytical Duplicates:	5	96%	3%	94%	95%
							% Recovery for Lab Fortified Matrix:	865	4%	4%	1%	3%
							% Recovery for PE Samples:	5	88%	8%	85%	86%
SDS-TOX	µg Cl-/L	ICR-CA013	9/1/97	5/1/99	SM5320B	25	RPE of Analytical Duplicates:	883	100%	20%	92%	98%
							% Recovery for Lab Fortified Matrix:	5	88%	8%	85%	86%
							% Recovery for PE Samples:	254	5%	7%	0%	3%
SDS-CHCl3	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates:	300	112%	74%	93%	100%
							% Recovery for Lab Fortified Matrix:	5	93%	9%	86%	93%
							% Recovery for PE Samples:	250	4%	5%	0%	2%
SDS-BDCM	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates:	300	99%	30%	90%	98%
							% Recovery for Lab Fortified Matrix:	5	96%	3%	95%	96%
							% Recovery for PE Samples:	203	4%	6%	0%	2%
SDS-DBCM	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates:	301	103%	36%	93%	100%
							% Recovery for Lab Fortified Matrix:	5	102%	4%	99%	101%
							% Recovery for PE Samples:	113	6%	9%	0%	4%
SDS-CHBr3	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1	1	RPE of Analytical Duplicates:	301	99%	21%	95%	100%
							% Recovery for Lab Fortified Matrix:	4	106%	4%	103%	106%
							% Recovery for PE Samples:	269	4%	5%	1%	3%
THM4	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 551.1		Avg RPE of Indiv Anal Dupl:	301	103%	29%	94%	100%
							Avg % Recov for Indiv Lab Fort Matrix:	4	100%	4%	97%	99%
							Avg % Recov for Indiv PE Samples:	94	11%	12%	3%	6%
SDS-MCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	2	RPE of Analytical Duplicates:	447	107%	25%	97%	105%
							% Recovery for Lab Fortified Matrix:	5	92%	5%	90%	91%
							% Recovery for PE Samples:	367	4%	6%	0%	2%
SDS-DCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	444	106%	41%	97%	100%
							% Recovery for Lab Fortified Matrix:	5	90%	9%	85%	88%
							% Recovery for PE Samples:	325	3%	6%	0%	2%
SDS-TCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	444	108%	57%	97%	100%
							% Recovery for Lab Fortified Matrix:	5	96%	12%	90%	92%
							% Recovery for PE Samples:	48	10%	12%	0%	7%
SDS-MBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	448	112%	27%	100%	105%
							% Recovery for Lab Fortified Matrix:	5	89%	7%	84%	93%
							% Recovery for PE Samples:	199	5%	6%	0%	3%
SDS-DBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	447	105%	24%	97%	100%
							% Recovery for Lab Fortified Matrix:	5	98%	15%	91%	94%
							% Recovery for PE Samples:	325	4%	6%	0%	3%
SDS-BCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	447	103%	19%	97%	100%
							% Recovery for Lab Fortified Matrix:	5	95%	12%	90%	91%
							% Recovery for PE Samples:	11	3%	2%	1%	2%
SDS-TBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	4	RPE of Analytical Duplicates:	320	113%	24%	103%	115%
							% Recovery for Lab Fortified Matrix:	0				
							% Recovery for PE Samples:	133	4%	5%	0%	3%
SDS-CDBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	2	RPE of Analytical Duplicates:	407	113%	24%	104%	110%
							% Recovery for Lab Fortified Matrix:	0				
							% Recovery for PE Samples:	325	4%	6%	0%	3%
SDS-DCBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates:	435	113%	22%	103%	110%
							% Recovery for Lab Fortified Matrix:	0				
							% Recovery for PE Samples:	385	5%	5%	1%	4%
HAA5	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		Avg RPE of Indiv Anal Dupl:	448	108%	23%	99%	103%
							Avg % Recov for Indiv Lab Fort Matrix:	5	100%	8%	87%	93%
							Avg % Recov for Indiv PE Samples:	385	5%	5%	2%	4%
HAA6	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		Avg RPE of Indiv Anal Dupl:	448	107%	20%	99%	103%
							Avg % Recov for Indiv Lab Fort Matrix:	5	100%	9%	87%	93%
							Avg % Recov for Indiv PE Samples:	387	5%	4%	2%	4%
HAA9	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		Avg RPE of Indiv Anal Dupl:	448	109%	17%	102%	106%
							Avg % Recov for Indiv Lab Fort Matrix:					
							Avg % Recov for Indiv PE Samples:					

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 CaCO <sub>3</sub>												
Ammonia	mg NH <sub>3</sub> -N/L												
Calcium Hardness	mg/L as CaCO <sub>3</sub>												
SDS-CI2 Residual	mg/L												
Total Hardness	mg/L as CaCO <sub>3</sub>												
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-CHCl <sub>3</sub>	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-CHBr <sub>3</sub>	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 - 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-C12 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	10/5/98	10/7/98	EPA 552.2	2	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2 4	97.4 86.9	7.8 18.9	95.4 80.2	97.4 91.4	99.3 98.1
SDS-DCAA	µg/L	OH033	10/5/98	10/7/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2 2 4	4.0 96.0 88.5	8.0 1.0 13.8	2.0 95.8 85.2	4.0 96.0 93.7	6.0 96.3 97.0
SDS-TCAA	µg/L	OH033	10/5/98	10/7/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1 2 4	9.5 109.1 81.8		19.3 104.3 75.3		113.9 109.1 87.5
SDS-MBAA	µg/L	OH033	10/5/98	10/7/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2 4	95.0 82.2	6.5 16.0	93.4 80.7	95.0 88.2	96.6 89.7
SDS-DBAA	µg/L	OH033	10/5/98	10/7/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2 2 4	2.7 103.9 89.7	5.4 12.8 9.1	1.4 100.7 86.0	2.7 103.9 91.9	4.1 107.1 95.5
SDS-BCAA	µg/L	OH033	10/5/98	10/7/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2 2 4	2.7 101.1 84.4	5.4 7.3 10.7	1.4 99.3 82.6	2.7 101.1 88.3	4.1 102.9 90.1
SDS-TBAA	µg/L	OH033	10/5/98	10/7/98	EPA 552.2	4	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2	109.5	10.5	106.9	109.5	112.1
SDS-CDBAA	µg/L	OH033	10/5/98	10/7/98	EPA 552.2	2	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2	110.8	14.0	107.3	110.8	114.3
SDS-DCBAA	µg/L	OH033	10/5/98	10/7/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1 2	7.8 110.1		6.8	108.4	110.1 111.8
HAA5	µg/L	OH033	10/5/98	10/7/98	EPA 552.2		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	2 2 4	4.3 100.3 85.8	3.1 3.8 12.3	3.5 99.3 83.5	4.3 100.3 90.8	5.1 101.2 93.1
HAA6	µg/L	OH033	10/5/98	10/7/98	EPA 552.2		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:	2 2 4	3.8 100.4 85.6	3.9 4.3 12.0	2.8 99.3 83.6	3.8 100.4 90.4	4.7 101.5 92.3
HAA9	µg/L	OH033	10/5/98	10/7/98	EPA 552.2		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:	2 2	4.0 103.7	4.3 6.4	2.9 102.1	4.0 103.7	5.1 105.2

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												
UV254	1/cm												
TOC	mg/L												
SDS-TOX	µg Cl-/L												
SDS-CHCl3	µg/L												
SDS-BDCM	µg/L												
SDS-DBCM	µg/L												
SDS-CHBr3	µg/L												
THM4	µg/L												
SDS-MCAA	µg/L	OH033	2/15/99	2/16/99	EPA 552.2	2							
SDS-DCAA	µg/L	OH033	2/15/99	2/16/99	EPA 552.2	1							
SDS-TCAA	µg/L	OH033	2/15/99	2/16/99	EPA 552.2	1							
SDS-MBAA	µg/L	OH033	2/15/99	2/16/99	EPA 552.2	1							
SDS-DBAA	µg/L	OH033	2/15/99	2/16/99	EPA 552.2	1							
SDS-BCAA	µg/L	OH033	2/15/99	2/16/99	EPA 552.2	1							
SDS-TBAA	µg/L	OH033	2/15/99	2/16/99	EPA 552.2	4							
SDS-CDBAA	µg/L	OH033	2/15/99	2/16/99	EPA 552.2	2							
SDS-DCBAA	µg/L	OH033	2/15/99	2/16/99	EPA 552.2	1							
HAA5	µg/L	OH033	2/15/99	2/16/99	EPA 552.2								
HAA6	µg/L	OH033	2/15/99	2/16/99	EPA 552.2								
HAA9	µg/L	OH033	2/15/99	2/16/99	EPA 552.2								

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 <sub>3</sub>	RCFF	Apr-98	Mar-99	SM 2320 E5 mg/L as CaCO3								
Ammonia	mg NH <sub>3</sub> -N/L	RCFF	Apr-98	Mar-99	SM 4500-10.10 mg/L as N								
Calcium Hardness	mg/L as CaCO <sub>3</sub>												
SDS-Cl <sub>2</sub> Residual	mg/L	RCFF	Apr-98	Mar-99	SM 4500-0.2 mg/L								
Total Hardness	mg/L as CaCO <sub>3</sub>	RCFF	Apr-98	Mar-99	SM 2340 E7 mg/L as CaCO3								
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 <sub>254</sub>	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	0.81 NA NA	1.51 NA NA	0.05 NA NA	0.1 NA NA	1.065 NA NA	
TOC	mg/L	RCFF	Apr-98	Mar-99	SM 5310 0.5 mg/L	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	65 33 NA	3.89 98.82 NA	5.53 8.14 NA	0.74 95.5 NA	1.83 100.5 NA	4.37 104 NA	
SDS-TOX	µg Cl-/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:							
SDS-CHCl <sub>3</sub>	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 <sub>3</sub>	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:							