

ICR Treatment Study Summary Report

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

Conducted during the period of April 9, 1998 through March, 1999

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City of Odessa Water Treatment Plant, ICR # 702

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

1. Conclusions and Recommendations

A treatment study was conducted by Montgomery Watson for the City of Odessa 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 influent to the WTP. All full-scale processes removing DBP precursors were simulated at bench-scale. Full-scale chemical dosages and chemicals were utilized to pre-treat the raw water sample. Full-scale distribution system conditions (pH, temperature, free chlorine residual) were simulated during chlorination testing. An average 24-hour incubation period was used during SDS testing to mimic the most conservative DBP formation condition during each quarter.

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

The control of TTHMs was observed to be the critical issue for purposes of designing and estimating the costs of replacing GAC to meet upcoming regulations. Both the Stage 1 TTHM MCL and the “placeholder” Stage 2 TTHM MCL were exceeded during the four quarters. The Stage 2 HAA5 MCL was exceeded during the Spring quarter under the 10-min EBCT design.

In the 10-min EBCT contactor, the GAC replacement cost ranged from \$0.7/1000 gal of treated water during the Fall quarter to \$1.83/1000 gal during the Winter quarter. In the 20-min EBCT contactor, the GAC replacement cost ranged from \$0.70/1000 gal of treated water during the Fall quarter to \$1.07/1000 gal during the Winter quarter. The annual average GAC replacement cost was estimated at \$9,166,841 for a 10-min EBCT, and at \$6,998,223 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 \$1,447,440 for a 10-min EBCT, and at \$1,217,673 for a 20-min EBCT.

Annual capital and O&M costs for a conventional concrete gravity GAC adsorber were also calculated. These costs were based on an 18 mgd average flowrate. Annual amortized capital costs for a 10-min EBCT were estimated at \$346,699 and for a 20-min

EBCT at \$558,407. When including the annual GAC reactivation costs to the annual O&M costs, the total annual costs were estimated at \$1,893,144 for a 10-min EBCT, and at \$1,875,085 for a 20-min EBCT. Using either EBCT resulted in equivalent total annual costs.

2. Background Information

2.1 City of Odessa Water Treatment Plant Description

The City of Odessa owns and operates a water treatment plant (WTP). The plant overall design capacity is 55 MGD. The WTP draws its water supply year-round primarily from Lake Ivie. Well water from the Ward County field is delivered from about April through September to the clearwells. The well water receives disinfection and pH adjustment before its application in the clearwells. From October 1 1997 through September 30 1998, a total of 5,331,582 million gallons (MG) of surface water was received, along with 2,250.662 MG of well water. This translates into averages of 14.6 MGD surface water, and 6.2 MGD of well water. The treatment plant is conventional and consists of rapid mix, flocculation, sedimentation, filtration and clearwells. Chloramines are applied in the influent to the WTP and in the effluent of the settling basins.

2.1.1 Treatment plant schematic

Figure 1 illustrates a simplified schematic of the water treatment processes applied at the City of Odessa WTP, and also shows the sample locations and analytes covered under the 18-months of monthly ICR monitoring. In the full-scale WTP, the flow is diverted into either one of two parallel identical plants: plant 1 and plant 2. Flow is diverted into plant 1 during the cold season and into plant 2, during the warm season. Plant 1 is based on a 15 MGD design flow, while plant 2 is based on a 40 MGD design flow.

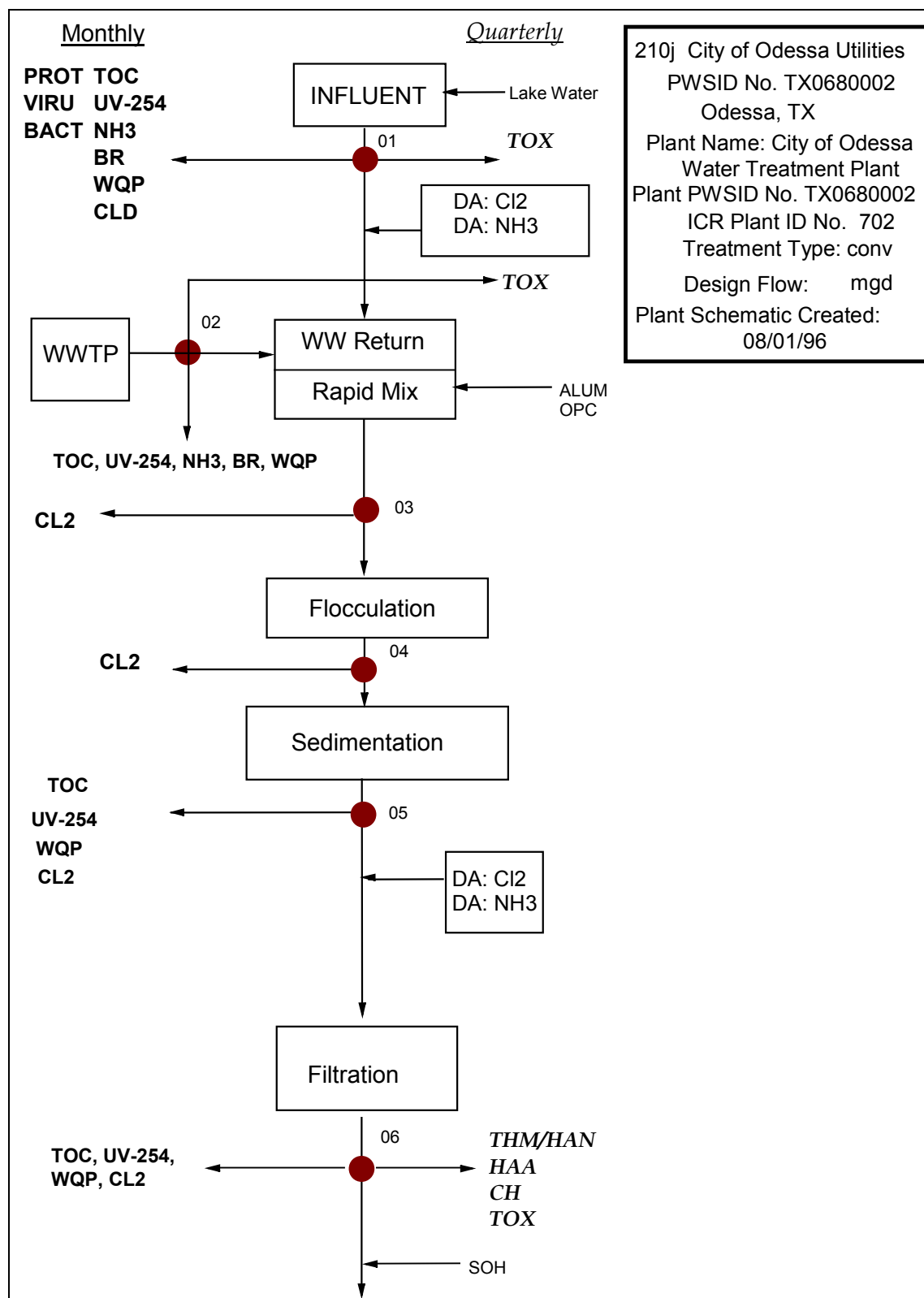


Figure 1. City Of Odessa WTP Schematic

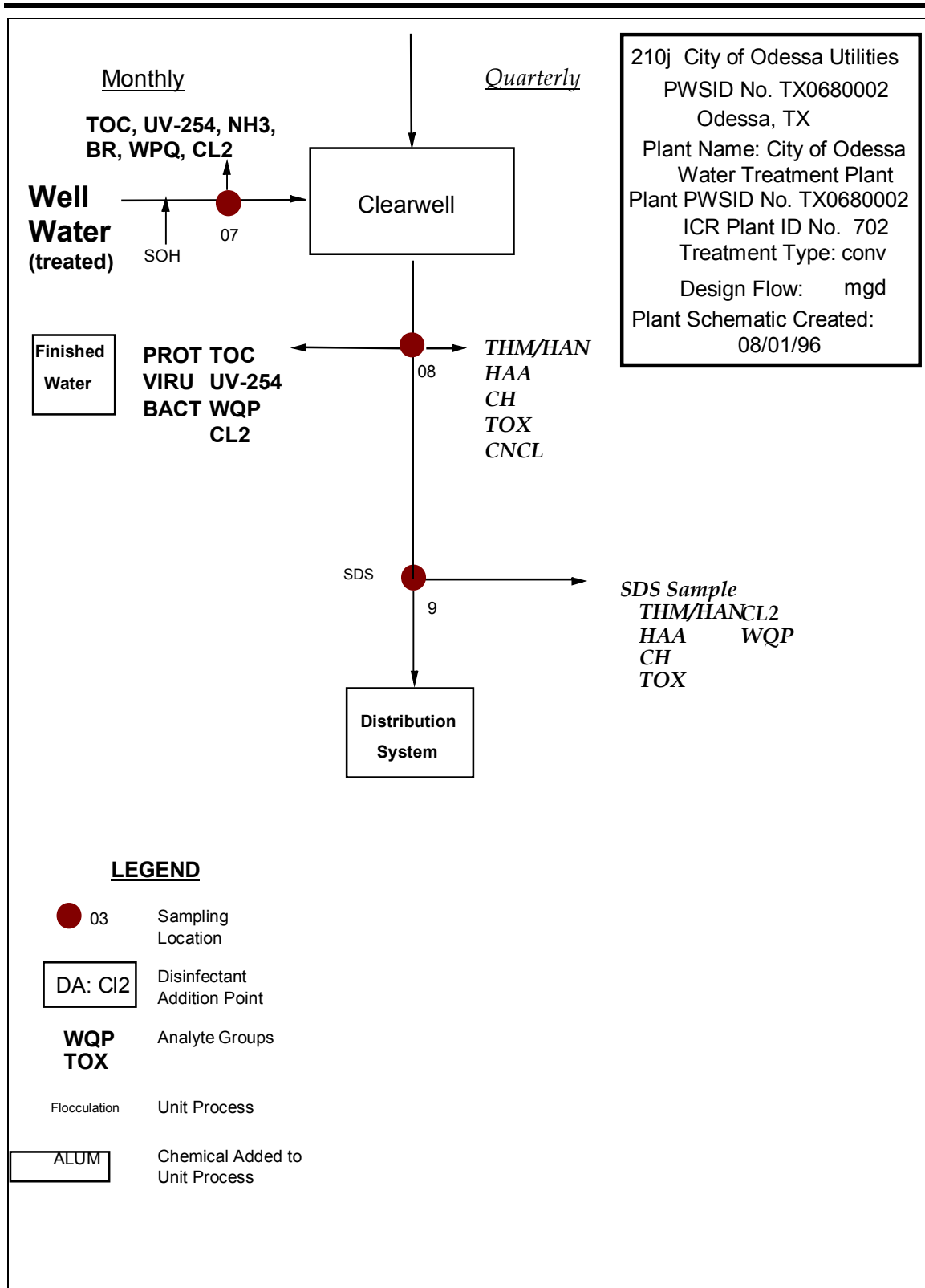


Figure 1 (continued).City of Odessa WTP Schematic

2.1.2 Treatment plant design information

The following Table 1 summarizes the City of Odessa WTP design data (plants 1 and 2).

Table 1
Treatment Plant Design Data

Unit Process	Process Description
Pre-oxidation	Chemical type: Chlorine measured as: Cl_2 Dose rate (mg/L): 5.00
Pre-oxidation	Chemical type: Anhydrous Ammonia measured as: NH_3 Dose rate (mg/L): 1.00 mg/L
Rapid Mixing	Type of Mixer: ME Baffling Type: UN Liquid Volume (gal): 10,570 (plants 1 and 2) Mean Velocity Gradient (sec-1): 1,000.0
Coagulation	Coagulant addition in rapid mixer: $\text{Al}_2(\text{SO}_4)_3$ Alum dose (mg/L): 5.00-13.00 Organic Polymer addition in rapid mixer: OPC (coagulant aid) OPC dose (mg/L): 0.09-0.20
Flocculation	Type of Mixer: 1-stage Liquid Volume (gal): 1,554,400 (plants 1 and 2) Baffling Type: UN Stage Mean Velocity Gradient (sec-1): 50
Sedimentation	Surface Area (ft ²): 40,080 Liquid Volume (gal): 8,910,000 (plants 1 and 2) Baffling Type: PR
Disinfectant Addition (post sedimentation)	Chemical type: Chlorine Measured as: Cl_2 Dose rate (mg/L): 0.50– 1.50
Disinfectant Addition (post sedimentation)	Chemical type: anhydrous NH_3 Measured as: NH_3 Dose rate (mg/L): 0.13-0.30
Filtration	Surface Area (ft ²): 8,777 Liquid Volume (gal): 645,337 Total Media Depth (in): 27 (without gravel) Media type: DUAL Minimum Water Depth to Top of Media (ft): 45.7 Depth from Top of Media to Top of Backwash Trough (ft): 3.0
Ward County Well	Additional Water Source type: Treated Ground Water
Clearwell	Surface Area (ft ²): 103,309 (#2 out of service) Liquid Volume (gal): 13,720,609 Minimum Liquid Volume (gal): 2,318,976 @ 3 ft depth Baffling Type: UN
pH adjustment	Addition of sodium hydroxide NaOH Dose rate (mg/L): 12.00

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 City of Odessa WTP using data collected monthly between September 1997 and September 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 City of Odessa WTP
(September 1997 through September 1998)

Source Water Quality Parameter	Average Value	Standard Deviation	Maximum Value	Minimum Value
Temperature (°C)	19.7	6.2	28.8	11.4
pH	8.0	0.3	8.3	7.3
Turbidity (NTU)	1.74	1.09	4.20	0.45
Total Alkalinity (mg/L as CaCO ₃)	131	11.8	157	118
Total Hardness (mg/L as CaCO ₃)	485	56.6	608	412
Calcium Hardness (mg/L as CaCO ₃)	232	55.2	279	71
TOC (mg/L)	3.58	0.76	5.00	2.50
UV-254 (cm ⁻¹)	0.053	0.010	0.074	0.043
Bromide (mg/L)	1.11	0.62	2.23	0.45

Table 3 summarizes average finished water quality at the City of Odessa WTP.

Table 3
Summary of Finished Water Quality at the City of Odessa WTP
(September 1997 through September 1998)

Finished Water Quality Parameter	Average Value	Standard Deviation	Maximum Value	Minimum Value
Temperature (°C)	18.7	5.5	25.0	10.3
pH	8.1	0.2	8.3	7.7
Turbidity (NTU)	0.17	0.08	0.31	0.06
TOC (mg/L)	2.26	1.23	4.30	0.90
UV ₂₅₄ (cm ⁻¹)	0.052	0.016	0.077	0.031
TTHM (µg/L)*	34.43	16.13	55.40	20.50
HAA5 (µg/L)*	15.05	6.06	22.60	9.90
HAA6 (µg/L)*	18.45	7.35	27.10	12.20

* Based on four quarterly sampling campaigns (11/97; 02/98; 05/98; 08/98). Measured in the distribution system at the average residence time site (Fire Station #3)

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 City of Odessa WTP, since chloramines are added at the beginning of the treatment train, the feed water for the study was collected at the plant influent. Four quarterly samples were collected throughout the year to investigate seasonal variability. Table 3 presents the four sampling dates.

Table 3
Quarterly Sampling Dates

Quarter	Sampling Dates
Spring	April 9, 1998
Summer	August 20, 1998
Fall	November 5, 1998
Winter	January 28, 1999

A total of 200 gallons of water were collected during each quarter from the influent to the WTP. Two 100-gal polyethylene tanks were used for sample collection. Tanks were rinsed with tap water and deionized (DI) water prior to shipping. Upon arrival at the

laboratory, samples were shipped to Montgomery Watson's Applied Research Laboratory via FFE refrigerated trucks. Samples were immediately refrigerated at 4°C until the day of testing.

Upon receipt of the samples, the raw water was analyzed for general water quality parameters to verify sample representativeness. Table 4 presents general water quality of the four collected raw water samples.

Table 4
General Water Quality of Collected Raw Water Samples

Parameter	Unit	Spring	Summer	Fall	Winter
pH	---	8.3	8.0	8.1	8.2
TOC	mg/L	4.8*	4.7*	3.7*	5.0*
Turbidity	NTU	0.78 (1.63)	(1.5)	1.9 (0.59)	2.1 (0.76)
Alkalinity	mg/L as CaCO ₃	155 (134)	(135)	135 (129)	146 (132)
Total Hardness	mg/L as CaCO ₃	454 (480)	(544)	(416)	(488)
Apparent Color	Pt. Co. C.U.	13	8	14	15
True Color	Pt. Co. C.U.	6	5	4	4
Apparent UV-254	cm ⁻¹	0.068	0.055 (0.048)	0.066	0.075 (0.062)
Filtered UV-254	cm ⁻¹	0.067	0.052	0.062	0.068 (0.059)

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

Values in brackets were provided by the City at the time of sampling

3.2 Pretreatment Processes

3.2.1 Schematic of pretreatment processes

Figure 2 illustrates the general bench-scale processes that were applied to simulate full-scale pretreatment processes. Full-scale processes up to and including filtration were simulated. Chemical dosages and design parameters utilized at the day of sampling, were collected, and applied at bench-scale. Chemicals included aluminum sulfate (alum), and liquid cationic polymer (Applied Specialties, AS2140) during rapid mixing. Design parameters included flow-rate; contact times for rapid mixing, flocculation and sedimentation; G values for flocculation; and contact times of the flocculation and sedimentation processes. Table 5 presents chemical dosages and design parameters used during bench-scale pretreatment of the raw water.

During all quarters, all full-scale treatment processes and chemical dosages were simulated, including coagulation, flocculation, sedimentation, and sequential filtration through a 0.45- μ m cartridge filter and through on-line 0.2- μ m membranes.

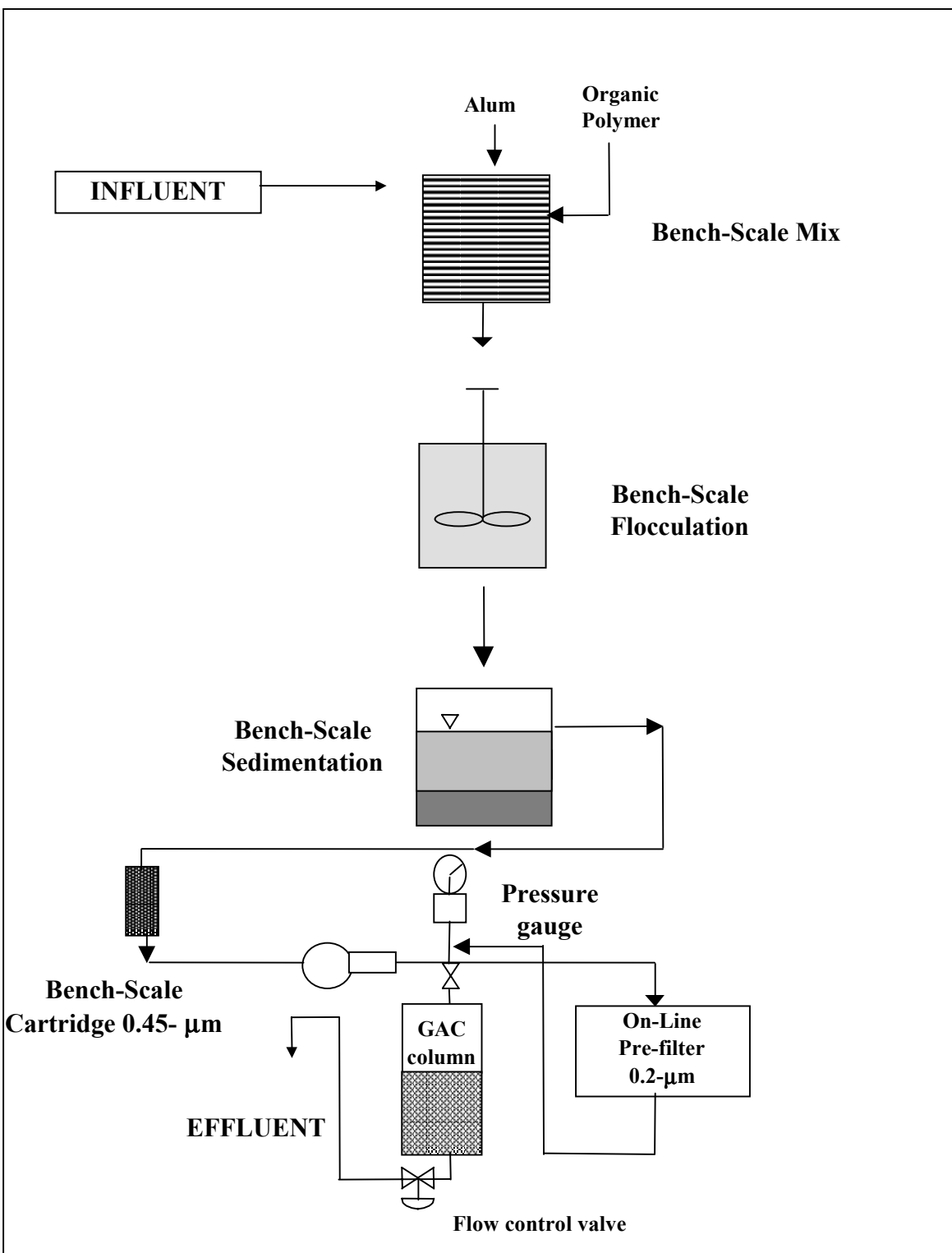


Figure 2. Schematics of Bench-Scale Processes Including GAC Columns

Table 5
Chemical dosages and Design Parameters Used during Pretreatment

	Spring	Summer	Fall	Winter
Cationic organic polymer, Applied Specialties AS2140, mg/L	0.2	0.5	0.5	0.3
Alum $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$ dose, mg/L	9.0	13.0	13.0	13.0
Potassium permanganate, mg/L	not used	0.3	not used	not used
Rapid mixing	30 sec @ 40 rpm	30 sec @ 40 rpm	30 sec @ 40 rpm	30 sec @ 40 rpm
Flocculation (in 80-gal drum, 1 paddle assembly, 10 vertical paddles, stage mean velocity gradient = 50 sec^{-1})	15/10/5 rpm for 10-min each	15/10/5rpm for 10-min each	15/10/5rpm for 10-min each	15/10/5 rpm for 10-min each
Sedimentation (in 80-gal-drum)	1-2 hours	1-2 hours	1-2 hours	1-2 hours
Filtration	0.45- 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

Table 6 compares the water quality of the pretreated sample (including filtration through the 0.45- μm cartridge) to the full-scale filtered water quality at the day of sampling.

Table 6. Comparison of Simulated Pre-treated to Full-scale Filtered Water For the Same Sampling Day

Quarter	Parameter	Simulated Pre-treated water	Full-scale Filtered Water
Spring	TOC, mg/L	4.78	2.7*
	Turbidity, NTU	0.38	0.31
	Hardness	449	488
	Alkalinity	127	124
	UV-254, cm^{-1}	0.067	0.044*
Summer	TOC, mg/L	4.25	4.15
	Turbidity, NTU	0.30	0.16
	Hardness	587	580
	Alkalinity	125	116
	UV-254, cm^{-1}	0.050	0.056
Fall	TOC, mg/L	3.97	n.a.
	Turbidity, NTU	0.20	0.08
	Hardness	459	488
	Alkalinity	133	123
	UV-254, cm^{-1}	0.051	n.a.
Winter	TOC, mg/L	4.97	4.00
	Turbidity, NTU	0.20	0.14
	Hardness		484
	Alkalinity		123
	UV-254, cm^{-1}	0.061	0.059

* Measured on April 22 1998. The sampling date for the Spring quarter was April 9 1998.

n.a: not analyzed

Small differences were observed between the water quality of the full-scale treated raw water and that of the bench-treated raw water. This is expected with bench-scale simulation. When available at full-scale, the differences in the TOC concentration in the simulated pretreated water and the full-scale treated water ranged from only 2% (Summer quarter) to 19% (Winter quarter). UV-254 absorbances measured in the two samples were not substantially different. The turbidity measured in the bench-treated sample was higher than that measured in the plant treated filtered water. Hardness was high during all four quarters, regardless of the pretreatment method.

3.3 Design Data for the Advanced Treatment Processes

3.3.1 RSSCT set-up information

Figure 3 illustrates the RSSCT column set-up.

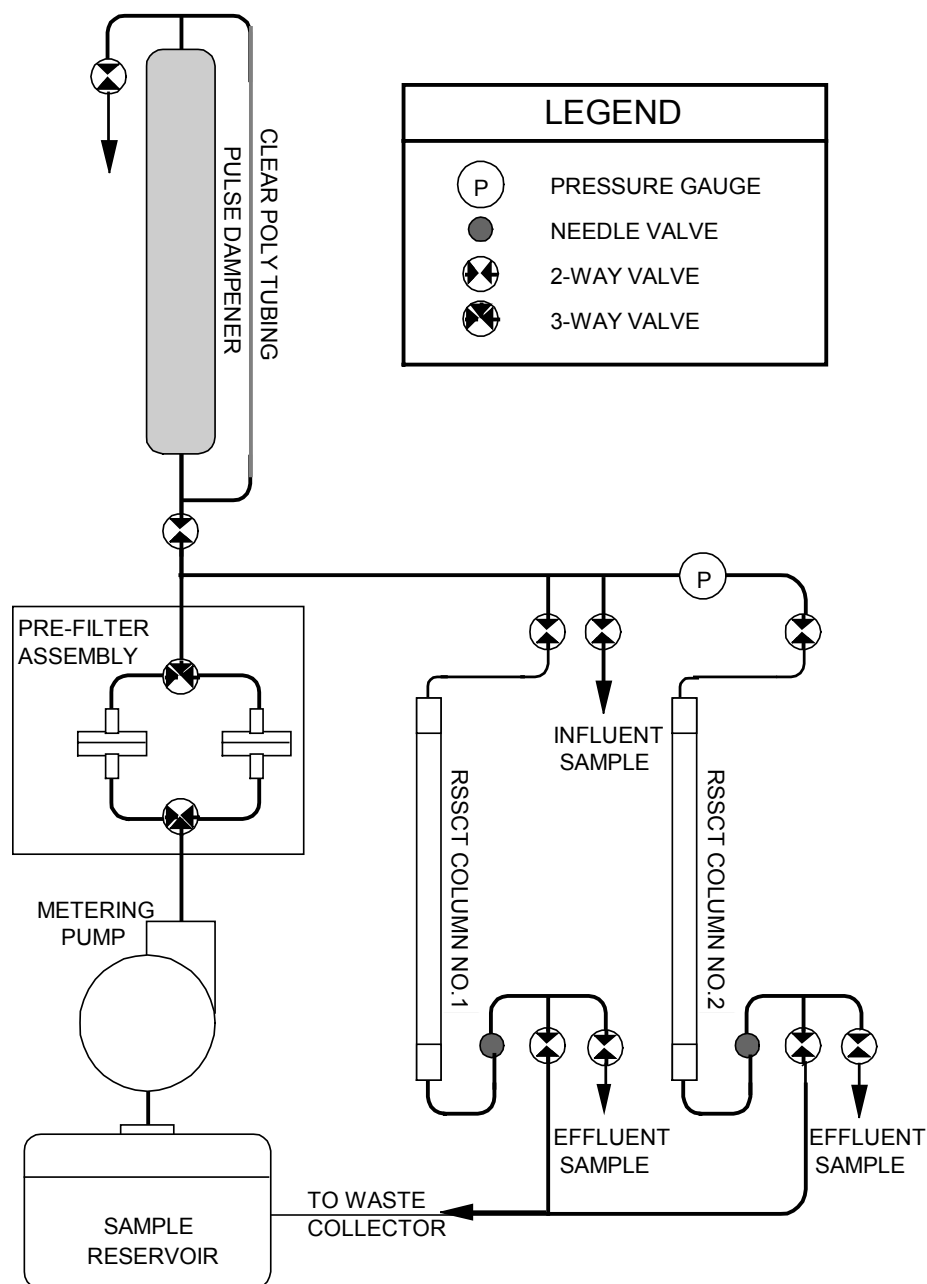


Figure 3. RSSCT Flow Diagram

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

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

3.3.2 Design data for the GAC process

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

Table 8
RSSCT Design Parameters

DESIGN PARAMETER	Quarter 1	Quarter 2	Quarter 3	Quarter 4
RSSCT influent TOC (mg/L)	4.8	4.7	3.7	5.0
Inner diameter of the RSSCT column, D_{SC} (mm)	11.0	11.0	11.0	11.0
Minimum RSSCT Reynolds number, $Re_{SC, min}$	0.5	0.5	0.5	0.5
Full-scale operating temperature, T (°C)	20.0	20.0	20.0	20.0
Full-scale bed porosity, ϵ_{LC}	0.45	0.45	0.45	0.45
Measured RSSCT dry bed density, ρ_{SC} (g/cm ³)	0.5	0.5	0.5	0.5
RSSCT GAC mesh size, upper (US standard mesh)	100	100	100	100
RSSCT GAC mesh size, lower (US standard mesh)	200	200	200	200
Estimated Run Length				
Bed volumes to 50% TOC breakthrough, BV_{50}	2824	2918	4032	2678
Estimated run length, BV_T (= 2 x BV_{50})	5648	5837	8063	5356
BV_T + 30% safety factor, $BV_{T+30\%}$ (= 2.6 x BV_{50})	7342	7588	10482	6963
General RSSCT Design Parameters				
Kinematic viscosity at $T^\circ C$, ν_{LC} (m ² /s)	1.027E-06	1.027E-06	1.027E-06	1.027E-06
RSSCT carbon particle diameter, d_{SC} (mm)	0.1125	0.1125	0.1125	0.1125
Scaling factor, SF	9.36	9.36	9.36	9.36
RSSCT hydraulic loading rate, v_{SC} (m/hr)	7.39	7.39	7.39	7.39
RSSCT flow rate, Q_{SC} (mL/min)	11.71	11.71	11.71	11.71
Estimated total influent volume required, V_{SC}^T (L)	276	285	394	261
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)	51	53	73	48
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	1.07	1.07	1.07	1.07
Estimated RSSCT run time, t_{SC}^T (days)	5.45	5.63	7.78	5.17
RSSCT bed length, l_{SC} (cm)	13.2	13.2	13.2	13.2
Estimated volume required for 10-minute EBCT, V_{SC} (L)	92	95	131	87
Mass GAC required, m_{SC} (g)	6.26	6.26	6.26	6.26
20-Minute EBCT Run				
Full-scale empty bed contact time, $EBCT_{LC}$ (min)	20	20	20	20
Estimated full-scale run time, t_{LC}^T (days)	102	105	146	97
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	2.14	2.14	2.14	2.14
Estimated RSSCT run time, t_{SC}^T (days)	10.90	11.26	15.56	10.34
RSSCT bed length, l_{SC} (cm)	26.3	26.3	26.3	26.3
Estimated volume required for 20-minute EBCT, V_{SC} (L)	184	190	262	174
Mass GAC required, m_{SC} (g)	12.51	12.51	12.51	12.51

3.3.3 Procedures Specific to the treatment study

3.3.3.1 Carbon Preparation

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

3.3.3.2 RSSCT monitoring

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

3.3.3.3 Headloss buildup

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

3.4 Experimental Design

The experimental design summary is presented in Table 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

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

3.5 Simulated Distribution System (SDS) Chlorination Testing

The distribution system conditions existing on the day of sampling were provided to Montgomery Watson each quarter by the City of Odessa 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	April 1998		August 1998		November 1998		January 1999	
	Value	Tolerance	Value	Tolerance	Value	Tolerance	Value	Tolerance
Incubation time, hrs	15.0	1.0	7	1.0	14	1.0	15	1.0
Incubation temp., °C	17.0	2.0	25.0	2.0	20.0	2.0	13.0	2.0
pH	8.2	0.4	8.0	0.4	7.9	0.4	8.0	0.4
Free Cl ₂ residual, mg/L	1.0	0.4	1.0	0.4	1.0	0.4	1.0	0.4

The incubation periods presented in Table 10 were roughly estimated from the average flows during the day of the sampling and a simplified estimation of the distribution system volume. The contact time within the WTP was not accounted for (chlorine is first added in the influent to the plant). In order to achieve the most conservative condition for SDS testing, a 24-hour incubation period was used during all quarters, with the exception of the Spring quarter, during which a 15-hour incubation period was used. Full-scale

incubation temperatures and pH values were however used, since these have a significant impact on DBP formation.

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 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 <i>CDBAA&MCAA</i> 4 µg/L for <i>TBAA</i>
pH	SM 4500-H ⁺	Not Applicable
Turbidity	SM 2130 B	0.05 NTU
Temperature	SM 2550 B	Not Applicable
All four THMs and THM4	EPA 502.2/551	0.5 µg/L for all analytes
TOC	SM 5310 C	0.5 mg/L
TOX	SM 5320	10 µg/L and 25 µg/L
UV ₂₅₄	SM 5910	0.009 cm ⁻¹

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

Table 12
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), Hardness*, Temperature, pH, UV ₂₅₄ , Chlorine residual, Ammonia
Montgomery Watson Labs	Quarters 1 through 4	THM4 (EPA 502.2 and 551) , HAA6 (SM 6251B), TOX (SM 5320), Bromide, Ca-hardness
Montgomery Watson Labs E.S. Babcock & Sons	Quarters 2 to 4 Quarter 1	Total hardness TOX (SM 5320B) HAA6 (SM 6251B) and THM (EPA 551.1)

*Hardness analysis conducted by ARD during only Quarter 1

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
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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 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). Alkalinity ranged from 125 in summer to 133 mg/L CaCO₃ in Winter. The influent pH did not vary significantly between each quarter. Total hardness was high throughout the quarters, ranging from 449 mg/L CaCO₃ in Spring to 587 mg/L CaCO₃ in Summer. Organic content was observed to be highest in Winter and lowest in Fall, as represented by the TOC concentration and UV-254 absorbance. TOC concentration ranged from 3.97 mg/L in Fall to 4.97 mg/L in Winter. The UV-254 absorbance ranged from 0.050/cm in Summer/Fall to 0.067/cm in Spring. Ammonia-nitrogen concentration was found to be significantly higher during the Fall quarter, relative to the other quarters. During the Fall quarter, ammonia-nitrogen concentration was measured at 0.80 mg/L. This created a high chlorine demand of 9 mg/L. The SDS TTHM concentration was lower during the Fall quarter. The HAA5 concentration was however higher, at 44.6 µg/L. The SDS temperature during the Fall session was 20°C. The SDS pH did not vary from season to season (Table 10).

Table 13
Water Quality of the Influent to the RSSCT

Water Quality Parameter	Spring Average (SD)*	Summer Average (SD)*	Fall Average (SD)*	Winter Average (SD)*
pH	7.93 (0.01)	7.97 (0.02)	7.97 (0.01)	8.00 (0.01)
Turbidity (ntu)	0.38 (0.05)	0.30 (0.33)	0.20 (0.00)	0.20 (0.00)
Alkalinity mg/L CaCO ₃	128	125	133	125
Calcium Hardness mg/L CaCO ₃	250	300	230	245
Total Hardness mg/L CaCO ₃	449	587	459	505
Bromide (µg/L)	1390	1810	1160	1450
Ammonia-N (mg/L)	0.20	<0.10	0.80	<0.10
TOC (mg/L)	4.8 (0.0)	4.3 (0.0)	4.0 (0.0)	5.0 (0.0)
UV ₂₅₄ (cm ⁻¹)	0.067 (0.008)	0.050 (0.011)	0.051 (0.006)	0.061 (0.009)
SUVA (L/mg-cm)	1.39 (0.02)	1.18 (0.01)	1.29 (0.02)	1.23 (0.01)
SDS-THM4 (µg/L)	207 (0.1)	208 (0)	134 (0)	192 (0)
SDS-HAA5 (µg/L)	39 (0.1)	33 (0)	45 (0)	33 (0)
SDS-HAA6 (µg/L)	46 (0.1)	36 (0)	54 (0)	38 (0)
SDS-TOX (µg Cl ⁻ /L)	217 (0.1)	238 (0.2)	175 (0.1)	368 (0)
SDS-chlorine demand (mg/L)	3.64 (0.00)	3.39 (0.00)	9.01 (0.01)	3.25 (0.00)

*SD: Standard Deviation

4.1 Impact of Seasonal Variability

4.3.1 Impact of Seasonal Variability on TOC Breakthrough

The impact of seasonal variability on the TOC breakthrough in the 10-min and 20-min EBCT columns is illustrated in Figures 4 and 5. Some seasonal variation between the four quarters was observed in the TOC breakthrough curves. In both 10-min and 20-min EBCT column, the fastest 70% TOC breakthrough was observed during the Winter quarter (January sampling). During this quarter, the highest influent TOC concentration was recorded at 5.0 mg/L. UV-254 absorbance was measured at 0.061 /cm, which was the second highest absorbance recorded. The rates of TOC breakthrough in both the 10-min and the 20-min EBCT columns were somewhat constant, at 0.8 percent per day and at 0.4 percent per day, respectively (Figures 4 and 5), with the exception of the breakthrough in the 10-min EBCT column during the Spring quarter. The order of the curves did not, however, appear to depend on the influent TOC concentration and UV-254 absorbance.

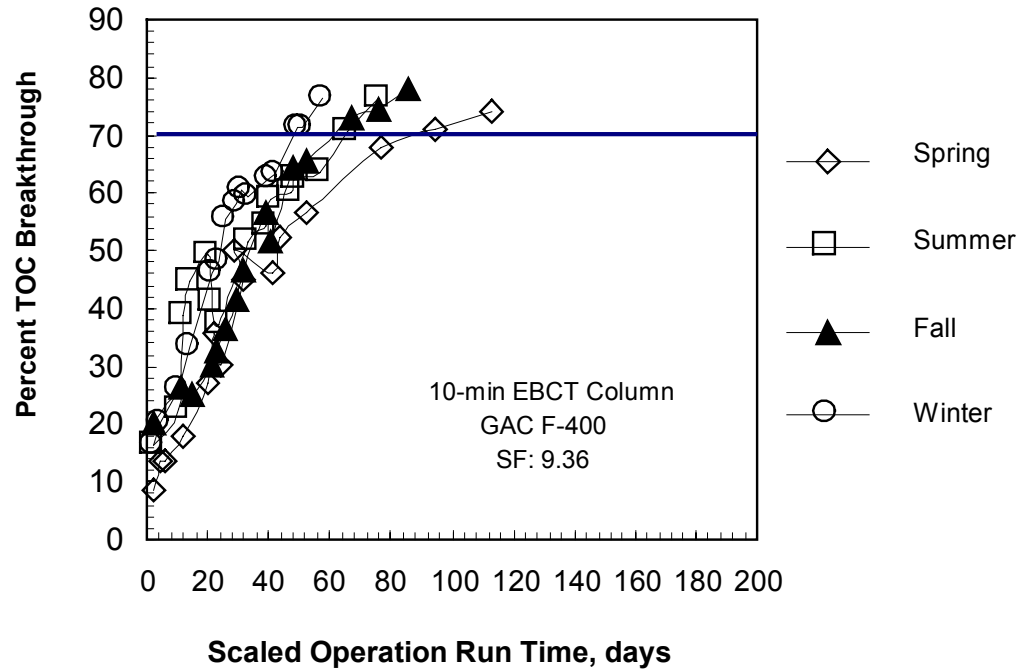


Figure 4. Impact of Seasonal Variability on Percent TOC Breakthrough in the 10-min EBCT Column

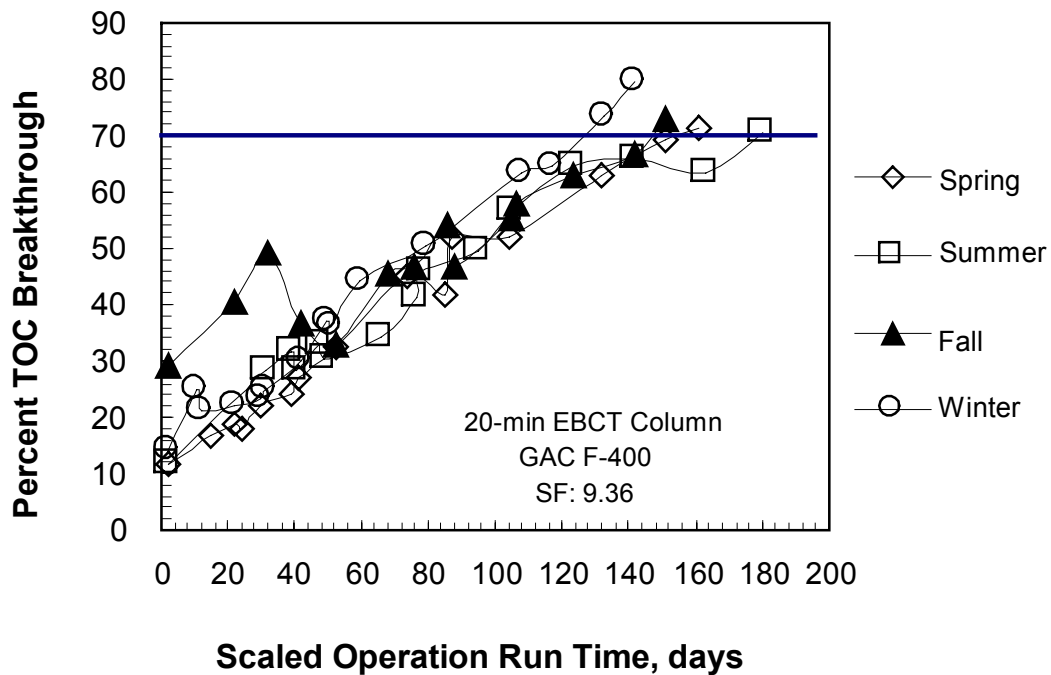


Figure 5. Impact of Seasonal Variability on TOC Breakthrough in the 20-min EBCT Column

4.3.2 Impact of Seasonal Variability on SDS-TTHM Breakthrough

Figures 6 and 7 illustrate the SDS-TTHM breakthrough versus run time in the 10-min and 20-min EBCT columns during the four quarters. The order of the SDS-TTHM breakthrough curves appears to be more correlated with the influent TOC concentration rather than the influent TTHM concentration. For both EBCTs, the fastest SDS-TTHM breakthrough occurred during the Summer and Winter quarters, while the slowest breakthrough occurred during the Fall quarter (low influent TOC concentration and low influent SDS-TTHM concentration). Influent SDS-TTHM concentrations were high, and ranged from a high of 208 $\mu\text{g/L}$ during the Spring and Summer quarters, to a low of 134 $\mu\text{g/L}$ during the Fall quarter. In the 10-min EBCT column, the Stage 2 TTHM MCL was exceeded first during the Winter quarter, after 13.4 scaled days of operation run time. During the first three quarters, the TTHM MCL was exceeded respectively after 20 days, 21 days and 34 days of full-scale operating time. In the 20-min column, the Stage 2 TTHM MCL was again exceeded first during the Winter quarter, after 45.8 days of operation, while the column was operated for 52 days, 58 days, and 75 days of full-scale operating times, before the Stage 2 TTHM MCL was exceeded during the Spring, Summer and Fall quarters, respectively

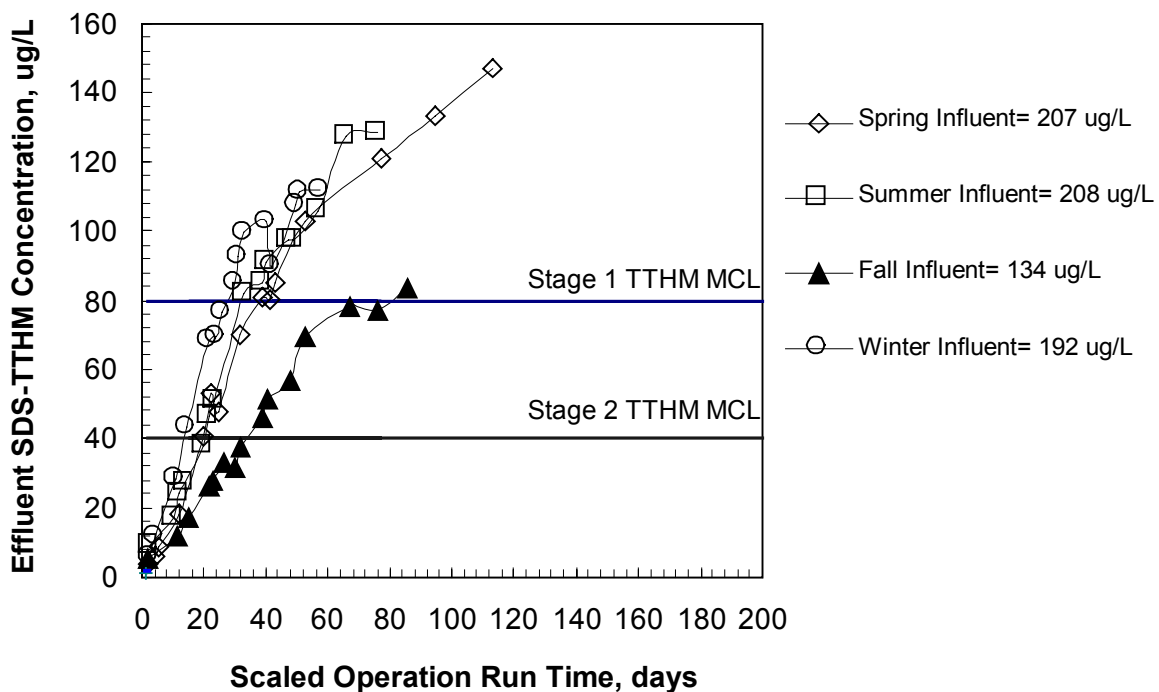


Figure 6. Impact of Seasonal Variability on SDS-TTHM Breakthrough in the 10-min EBCT Column

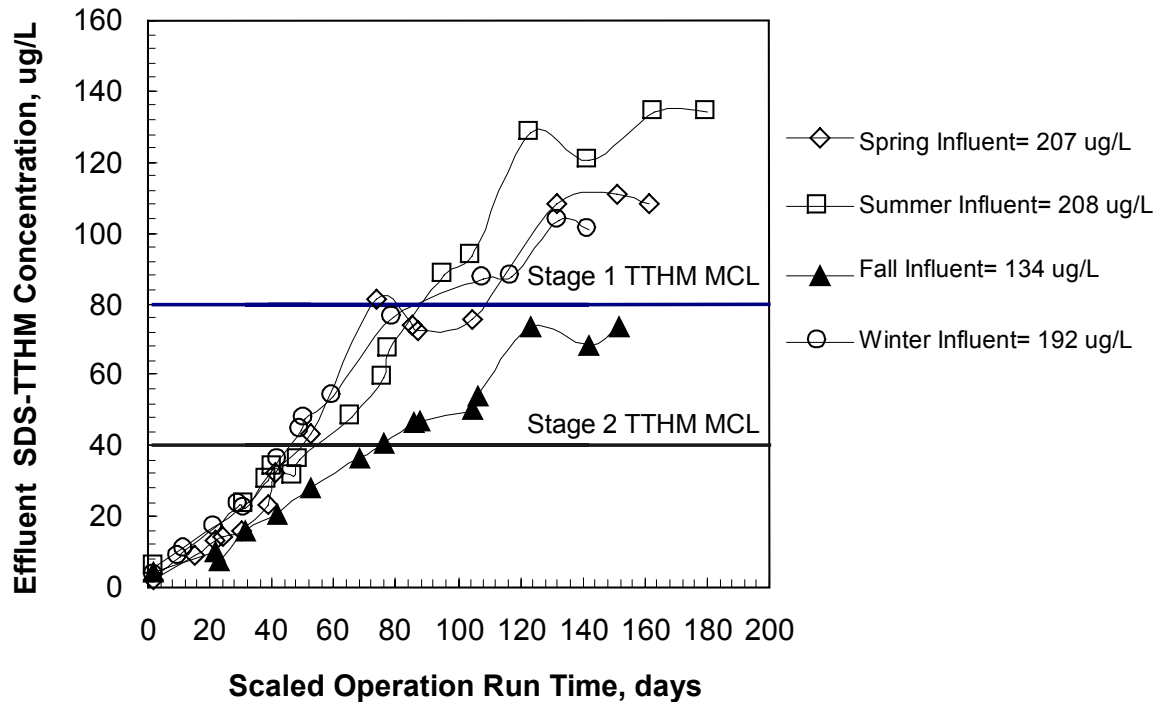


Figure 7. Impact of Seasonal Variability on SDS-TTHM Breakthrough in the 20-min EBCT Column

4.3.3 Impact of Seasonal Variability on SDS-HAA5 Breakthrough

The impact of seasonal variability on SDS-HAA5 breakthrough is illustrated in Figures 8 and 9. Due to the low influent SDS-HAA5 concentration neither the Stage 1 nor the Stage 2 HAA5 MCLs were exceeded in either column, with one exception: since the rate of TOC breakthrough in the 10-min EBCT was low during the Spring quarter (the column ran for 113 scaled days), the Stage 2 HAA5 MCL was exceeded after 95 scaled days. Nevertheless, the SDS-TTHM concentration in the GAC contactor effluent will be the limiting factor in contactor design, regeneration scenario, and costing.

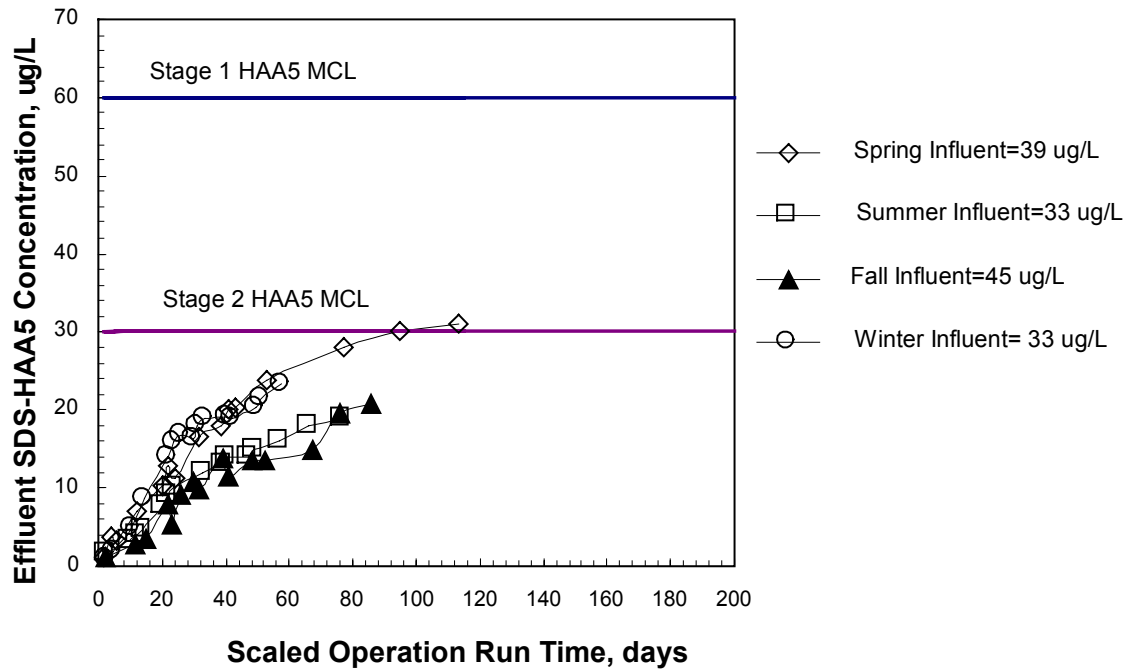


Figure 8. Impact of Seasonal Variability on SDS-HAA5 Breakthrough in the 10-min EBCT Column

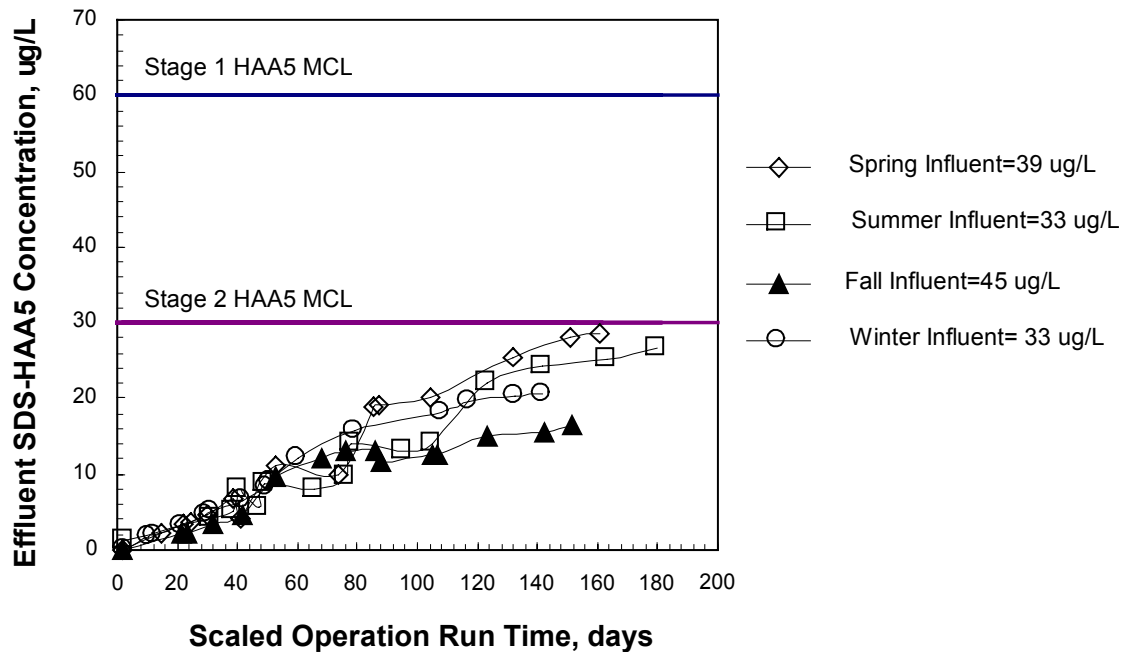


Figure 9. Impact of Seasonal Variability on SDS-HAA5 Breakthrough in the 20-min EBCT Column

4.3.4 Impact of Seasonal Variability on DBPs Speciation

The high concentration of bromide in the influent to the RSSCT was observed to impact the speciation of DBPs in the effluents of the GAC columns. Referring to Table 14, the highest bromide concentration was measured during the Summer quarter (1810 µg/L), and the lowest measured during Fall quarter (1160 µg/L). A higher proportion of brominated DBPs is expected during the Summer and Winter quarters as compared to quarters 1 and 3. Table 14 presents the range of SDS-THMs and SDS-HAAs formed in the effluent samples during the four quarterly RSSCTs. The SDS-TTHMs were dominated by bromoform and dibromochloromethane. Chloroform concentrations were always below minimum reporting levels for all quarters. The HAAs were dominated by dibromoacetic acid.

Table 14
Impact of Bromide Concentration on DPBs Speciation

		Spring	Summer	Fall	Winter
Influent to RSSCT	Bromide, µg/L	1390	1810	1160	1450
10-min EBCT	CHCl ₃ , µg/L	BMRL	BMRL	BMRL	BMRL
	BDCM, µg/L	BMRL to 3.1	BMRL	BMRL to 1.6	BMRL
	DBCM, µg/L	BMRL to 24.0	BMRL to 8.2	BMRL to 14.0	BMRL to 12.0
	CHBr ₃ , µg/L	4.0 to 120.0	9.0 to 120.0	5.4 to 68.0	6.0 to 99.0
	MCAA, µg/L	BMRL	BMRL	BMRL	BMRL
	DCAA, µg/L	BMRL	BMRL	BMRL to 3.1	BMRL
	TCAA, µg/L	BMRL	BMRL	BMRL	BMRL
	MBAA, µg/L	BMRL to 5.0	BMRL	BMRL to 3.6	BMRL to 3.3
	DBAA, µg/L	1.1 to 26.0	1.6 to 19.0	1.1 to 14.0	1.0 to 20.0
	BCAA, µg/L	BMRL to 4.0	BMRL	BMRL to 4.1	BMRL to 2.1
	TBAA, µg/L	NA	BMRL to 21.0	BMRL to 14.0	BMRL to 20.0
	CDBAA, µg/L	NA	BMRL to 2.7	BMRL to 3.4	BMRL to 3.9
	DCBAA, µg/L	NA	BMRL	BMRL	BMRL
20-min EBCT	CHCl ₃ , µg/L	BMRL	BMRL	BMRL	BMRL
	BDCM, µg/L	BMRL	BMRL	BMRL	BMRL
	DBCM, µg/L	BMRL to 13.0	BMRL to 13.0	BMRL to 11.0	BMRL to 11.0
	CHBr ₃ , µg/L	2.3 to 95.0	BMRL to 120.0	4.3 to 61.0	3.3 to 89.0
	MCAA, µg/L	BMRL	BMRL	BMRL	BMRL
	DCAA, µg/L	BMRL	BMRL	BMRL to 3.5	BMRL
	TCAA, µg/L	BMRL	BMRL	BMRL	BMRL
	MBAA, µg/L	BMRL to 4.7	BMRL	BMRL to 2.6	BMRL to 2.5
	DBAA, µg/L	BMRL to 24.0	BMRL to 3.7	BMRL to 14.0	BMRL to 18.0
	BCAA, µg/L	BMRL to 3.0	1.2 to 23.0	BMRL to 1.8	BMRL to 2.1
	TBAA, µg/L	NA	BMRL to 1.8	BMRL to 15.0	BMRL to 19.0
	CDBAA, µg/L	NA	NR	BMRL to 3.8	BMRL to 3.7
	DCBAA, µg/L	NA	BMRL to 3.8	BMRL	BMRL

BMRL: Below Minimum Reporting Level; NA: Not Analyzed

4.4 Impact of Empty Bed Contact Time

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

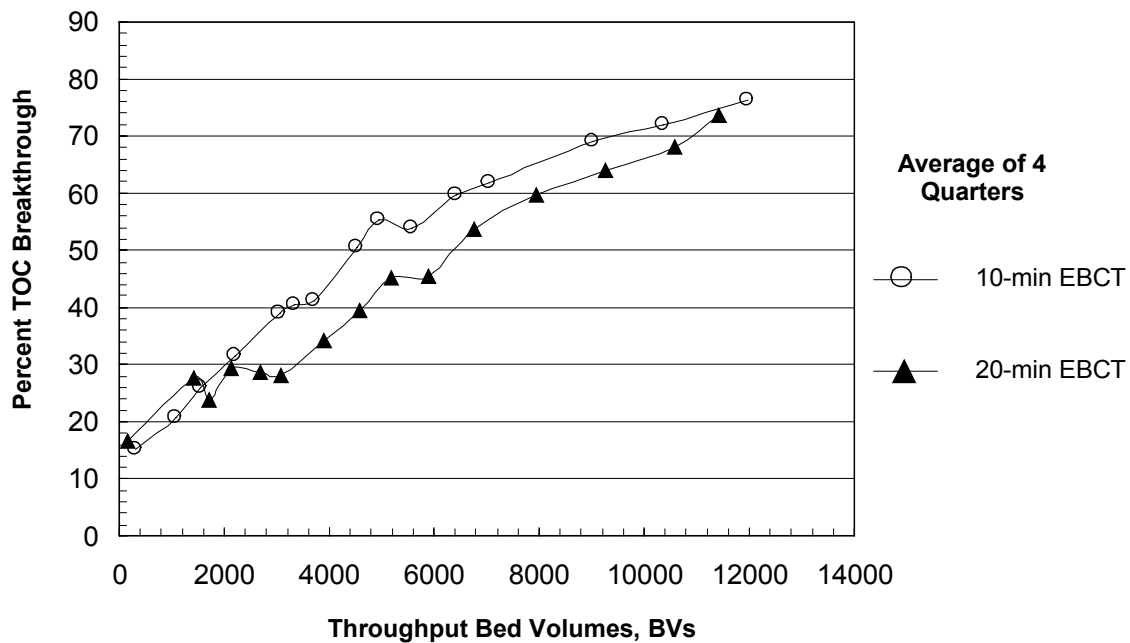


Figure 10. Impact of EBCT on Percent TOC Breakthrough

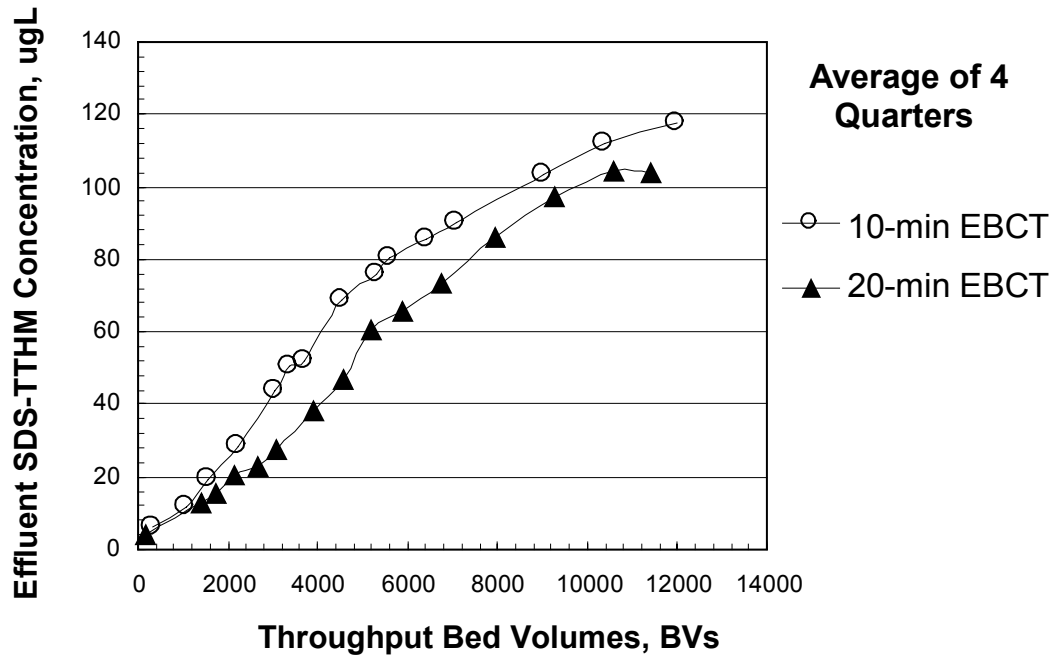


Figure 11. Impact of EBCT on SDS-TTHM Breakthrough

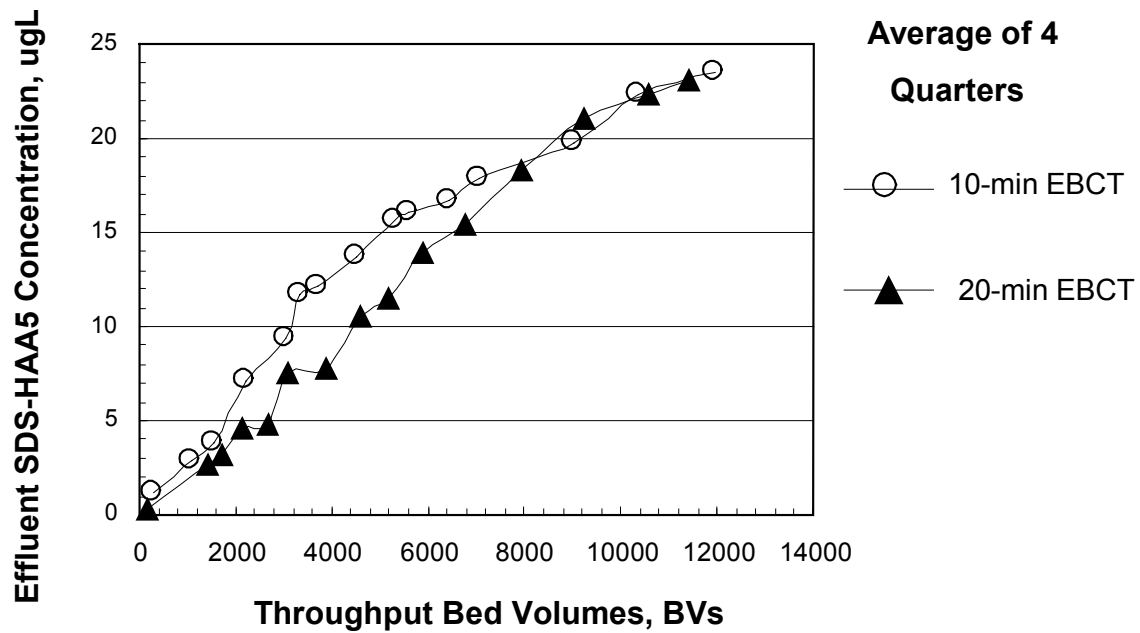


Figure 12. Impact of EBCT on SDS-HAA5 Breakthrough

4.5 Indicators of DBP Formation

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

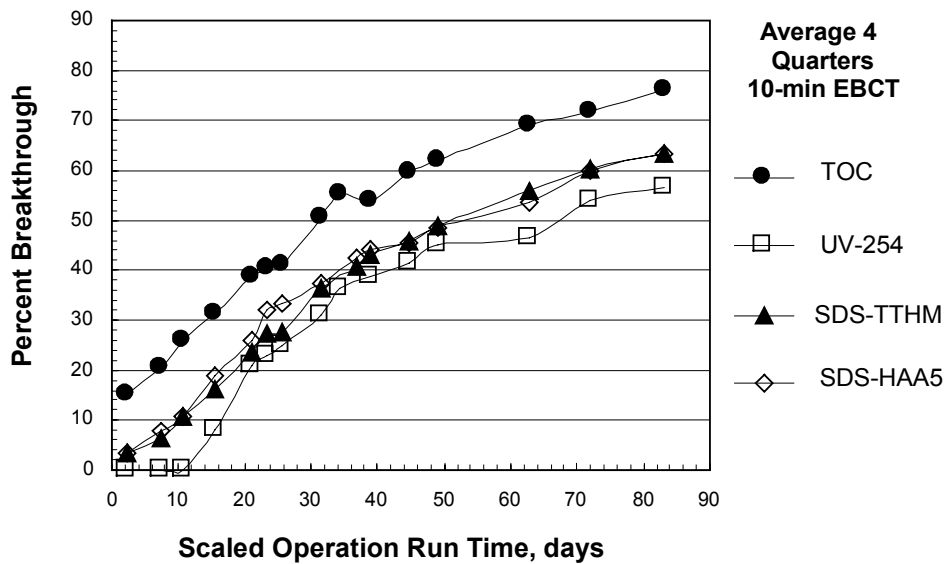


Figure 13. Breakthrough of TOC, UV-254 and SDS-DBPs from 10-min EBCT GAC Column

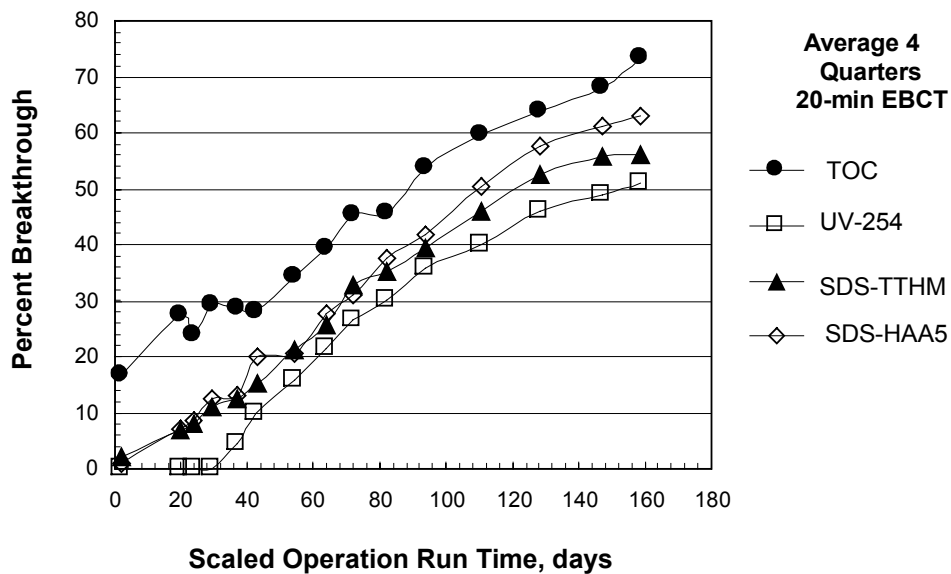


Figure 14. Breakthrough of TOC, UV-254 and SDS-DBPs from 20-min EBCT GAC Column

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

4.6 Cost Information and Analysis

4.6.1 GAC Replacement and Regeneration costs

The carbon usage rate (CUR) in lb GAC/1000 gal of processed water required to meet the Stages 1 and 2 MCLs for TTHMs and HAA5, have been estimated for the four quarters. The CURs for a 10-min EBCT and a 20-min EBCT, and for each quarter are presented in Tables A1 through A8 in Appendix A. The average CURs over four quarters for each EBCT are presented in Table 12 and 13. The amount of GAC (in million pounds per year) was estimated based on an average flowrate of 20 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 Odessa, 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	185	64	36	115	1.0	7.0
			32	18	671	1.7	12.2
HAA5	µg/L	37	48	130	>2992	<0.3	<2.6
			24	65	>2460	<0.4	<3.1

* 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	185	64	36	1464	0.7	5.2
			32	18	809	1.3	9.3
HAA5	µg/L	37	48	130	>2855	<0.3	<2.6
			24	65	>2509	<0.4	<2.9

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

4.6.1.1 GAC Replacement Costs

Based on the CUR and the GAC price of \$0.75/lb, the GAC replacement costs have been estimated for a 10-min EBCT and 20-min EBCT designs. The costs of GAC in \$/1000 gal to meet target DBP MCL criteria are plotted in Figures 13 and 14. These costs were estimated with a 20% contingency (i.e., 80% of the MCL). Due to the low concentration of SDS-HAA5 and the high SDS-TTHM in the chlorinated influent to the RSSCT, the Stages 1 and 2 TTHM MCL were the only limits to have been exceeded. The Stage 2 HAA5 MCL was only exceeded in the Spring quarter. In the 10-min EBCT contactor, the GAC replacement costs to meet 80% of Stage 2 MCL of TTHMs ranged from \$0.70/1000 gal during the Fall quarter to \$1.83/1000 gal during the Winter quarter. In the 20-min EBCT contactor, the costs to meet the Stage 2 MCL for TTHMs ranged from \$0.70/1000 gal during the Fall quarter to \$1.07/1000 gal during the Winter quarter. Although the 20-min EBCT GAC replacement costs to meet 80% of Stage 2 TTHM MCL were estimated to be 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.

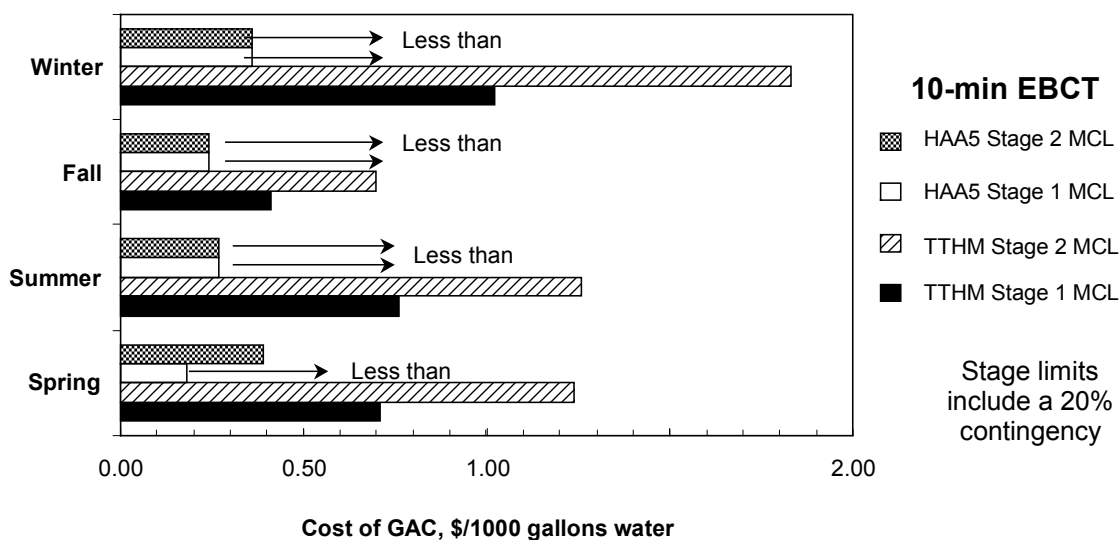


Figure 13. Cost of GAC Replacement from the 10-min EBCT Contactor to Meet Target DBP MCL Criteria

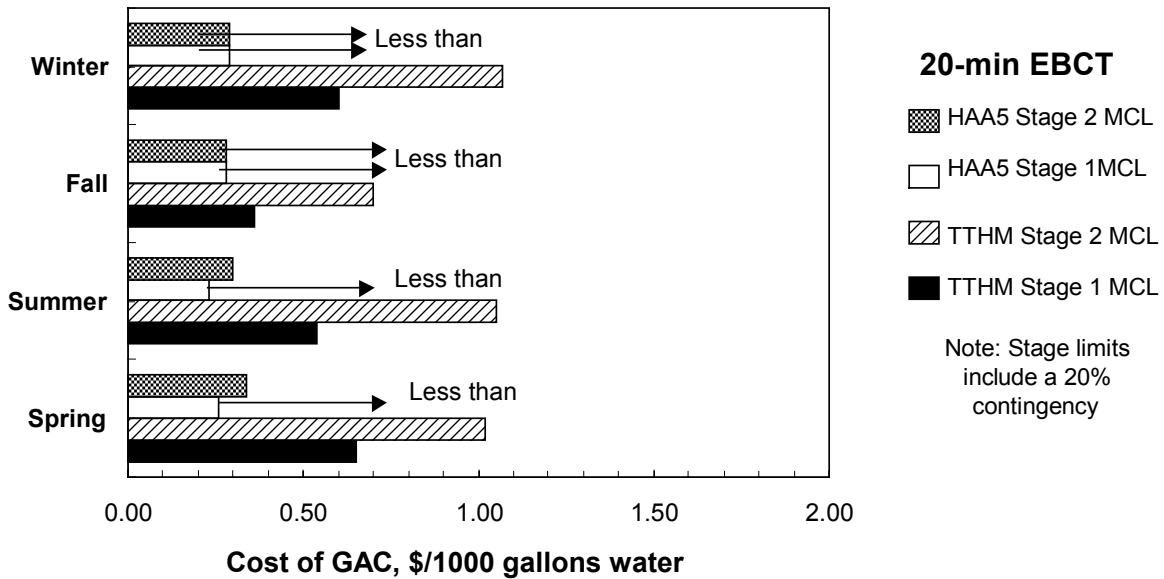


Figure 14. Cost of GAC Replacement from the 20-min EBCT Contactor to Meet Target DBP MCL Criteria

The average annual GAC replacement costs can be estimated from the average cost of GAC replacement per 1000 gal treated water (over the four quarters) to meet 80% of the Stage 2 TTHM MCL, and an average flowrate of 20 mgd. For a 10-min EBCT, the average annual GAC replacement cost was estimated at \$9,166,841. The average annual GAC replacement cost for a 20-min EBCT was estimated at \$6,998,223. These costs may seem high. It should be kept in mind however these costs were based meeting the “placeholder” Stage 2 TTHM MCL with a 20% contingency. 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 20 mgd. 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 12.2 million lbs/yr (1393 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 557 square feet. Based on the 20-min EBCT average CUR of 9.3 millions lbs/yr (1062 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 425 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)	557
Single reactivator area, sq-ft (20-min EBCT)	425
Capital amortization	$I = 6$ percent over $N = 30$ years
Capital recovery factor CRF	0.117
Labor and fringe rate	\$19/hr
Electric rate	\$ 0.075/kwh
Natural gas rate	\$0.0055/scf
ENR Construction Cost Index (1983)	5064
ENR Construction Cost Index (1998)	6859
Producers Price Index (1983)	102
Producers Price Index (1998)	130.5

According to Adams and Clark (1988), the following equations can be used to estimate construction costs (CC), cost estimates for electrical energy requirement (Process Energy (PE), and Building Energy (BE)), maintenance-materials MM costs, and O&M labor requirements (OL) costs for a multihearth reactivator.

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

where: CC = construction costs in 1983 dollars,

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

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

Annual capital costs = CC *CRF

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

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

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

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

total filter area is in square feet.

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

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

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

total filter area is in square feet.

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

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

where: MM = maintenance-materials costs in 1983 dollars per year,
total filter area is in square feet.

MM in current dollars = MM * current PPI / 287.1
Where PPI = producers price index for finished goods

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

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

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

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

Where: NG = natural gas requirement in standard cubic-feet per year,

NG* gas rate (\$/standard cubic-feet) = annual gas cost

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

Parameter	10-min EBCT	20-min EBCT
DESIGN PARAMETERS		
lbs of GAC per hour (to meet 80% Stage 2 TTHM MCL) at 0.4 sq-ft required per lb/hr	1393	1062
Surface area per reactivator, sq-ft	557	425
CAPITAL COSTS		
CC, 1998 \$	4,371,344	3,908,024
Annual capital costs, \$/yr	\$317,573	\$283,914
O&M COSTS		
PE, kWh/yr	1110418	970594
Annual PE costs, \$/yr	\$83,281	\$72,794
BE, kWh/yr	31145	28098
Annual BE costs, \$/yr	\$2,336	\$2,107
MM costs, 1998 \$/yr	\$71,962	\$64,553
OL, workhours/yr	26,489	22417
Annual OL costs, \$/yr	\$503,298	\$425,932
NG requirement, scft/yr	85270963	66976908
Annual NG cost, \$/yr	\$468,990	\$368,373
Total O&M Annual Costs, \$/yr	\$1,129,867	\$933,760
TOTAL ANNUAL COSTS, \$/yr	\$1,447,440	\$1,217,673

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 Odessa.

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

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 assumed:

Parameter	Assumption
GAC Contactor System Operation	70 percent of design capacity
Systems > 10 mgd	Use concrete gravity adsorbers
Capital amortization	$I = 10$ percent over $N = 20$ years
Capital recovery factor CRF	0.117
Labor and fringe rate	\$19/hr
Electric rate	\$ 0.075/kwh
ENR Construction Cost Index (1983)	5064
ENR Construction Cost Index (1998)	6859
Producers Price Index (1983)	102
Producers Price Index (1998)	130.5

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

- Total plant capacity $Q' = 20$ mgd; $70\% Q' = Q = 18$ mgd = 12500 gpm = 1671.25 cu-ft/min;
- Hydraulic loading $Q/A = 5$ gpm/sq ft = 0.6685 cu-ft/min/sq ft;
- Ten GAC concrete gravity contactors.

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

Parameter	10-min EBCT	20-min EBCT
DESIGN PARAMETERS		
Bed volume per contactor, cu-ft	1,671	3,343
Total GAC effective volume, cu-ft	16,713	33,425
CAPITAL COSTS		
z (in CC equation)	1	1
CC, 1998 \$	2,951,647	4,754,035
Annual capital costs, \$/yr	\$346,699	\$558,407
O&M COSTS		
PE, kwh/yr	30,000	30,000
Annual PE costs, \$/yr	\$2,250	\$2,250
BE, kwh/yr	468654	468654
Annual BE costs, \$/yr	\$35,1494	\$35,1494
MM costs, 1998 \$/yr	\$11,620	\$11,620
z (in OL equation)	1	1
OL, workhours/yr	2,631	2,631
Annual OL costs, \$/yr	\$49,987	\$49,987
Total annual O&M costs	\$99,005	\$99,005
GAC annual reactivation costs	\$1,447,440	\$1,217,673
TOTAL ANNUAL COSTS	\$1,893,144	\$1,875,085

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 14% higher when using a 10-min EBCT instead of a 20-min EBCT. Total annual costs (including GAC reactivation costs) were observed to be less than 1% higher when using a 10-min EBCT instead of a 20-min EBCT. Using either EBCT design (10 or 20 minutes) would result in equivalent total annual costs.

4.7 Summary of Significant Results

- Some seasonal variability was observed in the breakthrough curves of indicators of natural organic matter (TOC) and precursors of TTHMs and HAA5 upon SDS chlorination. The TOC breakthrough rate was somewhat constant at 0.8 percent per day in the 10-min EBCT column, and at 0.4 percent per day in the 20-min EBCT column.
- The breakthrough of SDS-DBPs was affected by the influent TOC concentration rather than the influent SDS-DBP concentration. The Stage 2 MCL for TTHMs was exceeded first for both EBCTs during the Summer and Winter quarters. The slowest SDS-TTHM breakthrough occurred during the Fall (low influent TOC concentration and low influent SDS-TTHM concentration). Since the influent SDS-HAA5 concentration was low, neither the Stage 1 nor the Stage 2 MCLs for HAA5 were exceeded during the column runs, with only one exception: the Stage 2 HAA5 MCL was exceeded after 95 scaled days during the Spring quarter.
- The high bromide influent concentration (range of 1160 to 1810 µg/L) shifted the speciation of DBPs towards brominated species rather than chlorinated. SDS-TTHMs were dominated by bromoform and dibromochloromethane, whereas HAAs were dominated by dibromoacetic acid.
- When normalizing for EBCT, a small benefit was observed for DBP control by using a 20-min EBCT versus a 10-min EBCT. The 20-min EBCT column was observed to run for longer bed volumes before exceeding a specific target level. Lower GAC replacement or reactivation costs are therefore expected with the use of a 20-min EBCT.
- TOC and UV-254 breakthroughs were observed to correlate well with those of SDS-TTHMs and SDS-HAA5. 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 for all quarters using 80% of the Stage 2 MCL for TTHMs criterion. GAC replacement costs were limited by the SDS-TTHM concentration in the effluent of the columns since the Stage 2 HAA5 MCL was not exceeded. In the 10-min EBCT contactor, the GAC replacement costs ranged from \$0.70/1000 gal during the Fall quarter to \$1.83/1000 gal during the Winter quarter. In the 20-min EBCT contactor, the GAC replacement costs ranged from \$0.70/1000 gal

of treated water during the Fall quarter, to \$1.07/1000 gal during the Winter quarter. The average GAC replacement annual cost was estimated at \$9,166,841 for a 10-min EBCT, and at \$6,998,223 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 \$1,447,440 for a 10-min EBCT, and at \$1,217,673 for a 20-min EBCT.

- Annual capital and O&M costs for a conventional concrete gravity GAC adsorber were also calculated. These costs were based on an 18 mgd average flowrate. Annual capital costs for a 10-min EBCT were estimated at \$346,699, and for a 20-min EBCT at \$558,407. When including the annual GAC reactivation costs to the annual O&M costs, the total annual costs were estimated at \$1,893,144 for a 10-min EBCT, and at \$1,875,085 for a 20-min EBCT. Using either EBCT would result in equivalent total annual costs.

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 results, the minimum reporting level (MRL), and the QC batch identification label when appropriate. Quarterly QA/QC laboratory sheets are included in a separate diskette. These sheets describe for each type of analysis (TOC, UV-254, Br, THM, HAA, and TOX): the QC batch labels, standard calibration results, method blank results, and matrix spike results. These results include spikes and recoveries, yield coefficients and relative percent difference (RPD) coefficients for duplicate samples.

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

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	207	64	31	1062	0.9	6.9
			32	15	606	1.6	12.0
HAA5	µg/L	39	48	122	>4066	<0.2	<1.8
			24	61	1938	0.5	3.8

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

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

Parameter	Units	Influent Concentration	Target Concentration *	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	208	64	31	991	0.8	7.4
			32	15	597	1.3	12.2
HAA5	µg/L	33	48	144	>2746	<0.3	<2.7
			24	72	>2746	<0.3	<2.7

* 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	134	64	48	1820	0.5	4.0
			32	24	1070	0.9	6.8
HAA5	µg/L	45	48	108	>3090	<0.3	<2.4
			24	54	>3090	<0.3	<2.4

* 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	192	64	33	732	1.4	10.0
			32	17	410	2.4	17.8
HAA5	µg/L	33	48	145	>2066	<0.5	<3.5
			24	73	>2066	<0.5	<3.5

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

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

Parameter	Units	Influent Concentration	Target Concentration *	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	207	64	31	1155	0.9	6.3
			32	15	738	1.3	9.9
HAA5	µg/L	39	48	122	>2898	<0.3	<2.5
			24	61	2233	0.4	3.3

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

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

Parameter	Units	Influent Concentration	Target Concentration *	% Breakthrough Criterion	Gallons water/lb GAC	CUR lbs/ 1000 gal	CUR Million lbs/yr
TTHM	µg/L	208	64	31	1389	0.7	5.3
			32	15	714	1.4	10.2
HAA5	µg/L	33	48	144	>3240	<0.3	<2.2
			24	72	2521	0.4	2.9

* 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	134	64	48	2071	0.5	3.5
			32	24	1068	0.9	6.8
HAA5	µg/L	45	48	108	>2725	<0.4	<2.7
			24	54	>2725	<0.4	<2.7

* 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	192	64	33	1240	0.8	5.9
			32	17	703	1.4	10.4
HAA5	µg/L	33	48	145	>2556	<0.4	<2.9
			24	73	>2556	<0.4	<2.9

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

APPENDIX B

Summary Report Spreadsheets

Miscellaneous Information

PWSID TX0680002
Plant ICR # 702

Full-Scale Plant Information

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

Laboratory Information

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

(Commercial, Consultant, State, University, Utility)

Batch Sampling Dates for Quarterly Bench-Scale Testing

Item	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Sample Collection Date	4/9/98	8/20/98	11/5/98	1/28/99

1998 Flow and Population Information

Source	Flow (mgd)	Population Served
Total Population Served		114424
Surface Water	15	10
Ground Water	6	2
Purchased Finished Water	0	0
Total	21	

Full-Scale Water Quality Data**Full-Scale Influent Water Quality Data**

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	19.7	6.2	11.4	28.8	12
pH	Unit	8	0.3	7.3	8.3	12
Turbidity	ntu	1.74	1.09	0.45	4.2	12
Alkalinity	mg/L as CaCO ₃	131	12	118	157	12
Total Hardness	mg/L as CaCO ₃	485.2	56.6	412	608	12
Calcium Hardness	mg/L as CaCO ₃	231.6	55.2	71	279	12
TOC	mg/L	3.58	0.76	2.5	5	10
UV ₂₅₄	1/cm	0.053	0.01	0.043	0.074	12
Bromide	µg/L	1.11	0.62	0.45	2.23	12
TSUVA*	L/(mg*m)	1.5	0.3	1.2	2	10

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

Full-Scale Finished Water Quality Data

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	18.7	5.5	10.3	25	12
pH	unit	8.07	0.15	7.74	8.3	12
Turbidity	ntu	0.174	0.077	0.06	0.31	11
TOC	mg/L	2.26	1.23	0.9	4.3	12
UV ₂₅₄	1/cm	0.052	0.016	0.031	0.077	12
DS-THM4	µg/L	34.43	16.13	20.5	55.4	4
DS-HAA5	µg/L	15.05	6.06	9.9	22.6	4
DS-HAA6	µg/L	18.45	7.35	12.2	27.1	4

QA/QC Data - Sheet 1

											Percentiles		
Analyte Identification	Units	Laboratory Identification	Start Service Date	End Service Date	Method	MRL		Count	Average	Std Dev	25th	50th	75th
pH	unit												
Temperature	C												
Alkalinity	mg/L as CaCO3												
Ammonia	mg NH3-N/L												
Calcium Hardness	mg/L as CaCO3	ICRCA013	9/1/97	5/1/99	EPA 200.7	5							
SDS-Cl2 Residual	mg/L												
Total Hardness	mg/L as CaCO3	ICRCA013	9/1/97	5/1/99	SM 2340B	10							
Turbidity	ntu												
Bromide	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 300.0	20	RPE of Analytical Duplicates:	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												
TOC	mg/L												
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%
							% Recovery for PE Samples:	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: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	109 145 5	4% 84% 102%	4% 40% 8%	0% 75% 97%	4% 85% 104%	7% 95% 108%
SDS-BDCM	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	117 145 5	3% 98% 100%	4% 129% 9%	0% 80% 94%	2% 90% 105%	5% 100% 105%
SDS-DBCM	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	117 146 5	3% 104% 100%	4% 54% 11%	0% 90% 94%	2% 96% 101%	4% 100% 105%
SDS-CHBr3	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	86 146 4	4% 122% 93%	5% 77% 13%	0% 98% 88%	2% 100% 90%	6% 120% 95%
THM4	µg/L	ICR-CA013	1/1/98	5/1/99	EPA 502.2		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	144 146 5	3% 102% 100%	3% 47% 9%	1% 88% 97%	3% 95% 99%	4% 103% 106%
SDS-MCAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-DCAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-TCAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-MBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-DBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-BCAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-TBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-CDBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
SDS-DCBAA	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:						
HAA5	µg/L						Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:						
HAA6	µg/L						Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:						
HAA9	µg/L						Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:						

QA/QC Data - Babcock laboratory													
										Percentiles			
Analyte		Laboratory	Start	End									
Identification	Units	Identification	Service Date	Date	Method	MRL		Count	Average	Std Dev	25th	50th	75th
pH	unit												
Temperature	C												
Alkalinity	mg/L as CaCO ₃												
Ammonia	mg NH ₃ -N/L												
Calcium Hardness	mg/L as CaCO ₃												
SDS-Cl ₂ Residual	mg/L												
Total Hardness	mg/L as CaCO ₃												
Turbidity	ntu												
Bromide	µg/L						RPE of Analytical Duplicates:						
							% Recovery for Lab Fortified Matrix:						
							% Recovery for PE Samples:						
UV ₂₅₄	1/cm						RPE of Analytical Duplicates:						
							% Recovery for Lab Fortified Matrix:						
							% Recovery for PE Samples:						
TOC	mg/L						RPE of Analytical Duplicates:						
							% Recovery for Lab Fortified Matrix:						
							% Recovery for PE Samples:						
SDS-TOX	µg Cl-/L	Babcock	6/18/98	7/7/98	SM5320B	25	RPE of Analytical Duplicates:	62	6.4	5.4	3.1	6.1	8.2
							% Recovery for Lab Fortified Matrix:	30	109	19.7	97	107	112
							% Recovery for PE Samples:	3	93	8.5	83	96	99
SDS-CHCl ₃	µg/L	Babcock	6/18/98	7/7/98	EPA 551.1	1	RPE of Analytical Duplicates:	1	0	NA	0	0	0
							% Recovery for Lab Fortified Matrix:	3	95	13	80	98	107
							% Recovery for PE Samples:	3	100	4.9	97	98	106
SDS-BDCM	µg/L	Babcock	6/18/98	7/7/98	EPA 551.1	1	RPE of Analytical Duplicates:	1	2.3	NA	2.3	2.3	2.3
							% Recovery for Lab Fortified Matrix:	3	103	3.5	100	103	107
							% Recovery for PE Samples:	3	108	9.1	98	109	116
SDS-DBCM	µg/L	Babcock	6/18/98	7/7/98	EPA 551.1	1	RPE of Analytical Duplicates:	1	0	NA	0	0	0
							% Recovery for Lab Fortified Matrix:	3	116	8.5	108	116	125
							% Recovery for PE Samples:	3	110	3	107	110	113
SDS-CHBr ₃	µg/L	Babcock	6/18/98	7/7/98	EPA 551.1	1	RPE of Analytical Duplicates:	1	0	NA	0	0	0
							% Recovery for Lab Fortified Matrix:	3	96	46.8	42	120	126
							% Recovery for PE Samples:	3	105	12.7	90	111	113
THM4	µg/L	Babcock	6/18/98	7/7/98	EPA 551.1		Avg RPE of Indiv Anal Dupl:	1	0.6	1.2	0.6	0.6	0.6
							Avg % Recov for Indiv Lab Fort Matrix:	3	103	17.7	82.5	109	116
							Avg % Recov for Indiv PE Samples:	3	106	6.7	98	9	110
SDS-MCAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	2	RPE of Analytical Duplicates:	6	0	0	0	0	0
							% Recovery for Lab Fortified Matrix:	8	106	10.6	100	105	115
							% Recovery for PE Samples:	3	93	17.9	78	89	113
SDS-DCAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	1	RPE of Analytical Duplicates:	6	1	2	0	0	1
							% Recovery for Lab Fortified Matrix:	8	97	7	95	95	105
							% Recovery for PE Samples:	3	82	15	67	83	97
SDS-TCAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	1	RPE of Analytical Duplicates:	6	0.3	0.8	0	0	0
							% Recovery for Lab Fortified Matrix:	8	103	11	95	105	115
							% Recovery for PE Samples:	3	86	8.5	77	87	94
SDS-MBAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	1	RPE of Analytical Duplicates:	6	0	0	0	0	0
							% Recovery for Lab Fortified Matrix:	8	102	12.8	95	100	120
							% Recovery for PE Samples:	3	82	11.3	69	88	89
SDS-DBAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	1	RPE of Analytical Duplicates:	6	0.3	0.8	0	0	0
							% Recovery for Lab Fortified Matrix:	8	101	12.7	90	105	115
							% Recovery for PE Samples:	3	78	14.4	61	86	86
SDS-BCAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	1	RPE of Analytical Duplicates:	6	0.5	1.2	0	0	0
							% Recovery for Lab Fortified Matrix:	8	101	10.3	95	105	110
							% Recovery for PE Samples:	3	77	12.9	66	73	91
SDS-TBAA	µg/L						RPE of Analytical Duplicates:						
							% Recovery for Lab Fortified Matrix:						
							% Recovery for PE Samples:						
SDS-CDBAA	µg/L						RPE of Analytical Duplicates:						
							% Recovery for Lab Fortified Matrix:						
							% Recovery for PE Samples:						
SDS-DCBAA	µg/L						RPE of Analytical Duplicates:						
							% Recovery for Lab Fortified Matrix:						
							% Recovery for PE Samples:						
HAA5	µg/L	Babcock	6/18/98	7/7/98	SM6251 B		Avg RPE of Indiv Anal Dupl:	6	0.5	0.4	0.3	0.5	1
							Avg % Recov for Indiv Lab Fort Matrix:	8	102	8.9	94	103	113
							Avg % Recov for Indiv PE Samples:	3	83	11.6	70	88	91
HAA6	µg/L	Babcock	6/18/98	7/7/98	SM6251 B		Avg RPE of Indiv Anal Dupl:						
							Avg % Recov for Indiv Lab Fort Matrix:						
HAA9	µg/L						Avg RPE of Indiv Anal Dupl:						
							Avg % Recov for Indiv Lab Fort Matrix:						

QA/QC Data - Applied Research Department RCFF											Percentiles		
Analyte Identification	Units	Laboratory Identification	Start Service Date	End Service Date	Method	MRL	Count	Average	Std Dev		25th	50th	75th
pH	unit	RCFF	Apr-98	Mar-99	SM 4500-H+								
Temperature	C	RCFF	Apr-98	Mar-99	SM 2550 B								
Alkalinity	mg/L as CaCO ₃	RCFF	Apr-98	Mar-99	SM 2320 E5 mg/L as CaCO ₃								
Ammonia	mg NH ₃ -N/L	RCFF	Apr-98	Mar-99	SM 4500-10.10 mg/L as N								
Calcium Hardness	mg/L as CaCO ₃												
SDS-Cl ₂ Residual	mg/L	RCFF	Apr-98	Mar-99	SM 4500-10.2 mg/L								
Total Hardness	mg/L as CaCO ₃	RCFF	Apr-98	May-98	SM 2340 E7 mg/L as CaCO ₃								
Turbidity	ntu	RCFF	Apr-98	Mar-99	SM 2130 E0.05 ntu								
Bromide	µg/L		Apr-98	Mar-99		RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:							
UV ₂₅₄	1/cm	RCFF	Apr-98	Mar-99	SM 5910 0.009 1/cm	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	46	0.84	1.99	0	0.08	0.67	
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 32	5.52 100.94	7.78 7.6	1.32 96.15	3.64 101.14	7.16 108.64	
SDS-TOX	µg Cl ⁻ /L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	NA	NA	NA	NA	NA	NA	
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:							