

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 September 16, 1997 through June 16, 1998

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O.N. Stevens Water Treatment Plant, ICR # 641

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 Corpus Christi's O.N. Stevens 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 were simulated during chlorination testing.

Seasonal variability had a big impact on control of DBP formation using GAC, and thus on the cost of the process. The fall quarter (September sampling) was observed to be the most critical for DBP precursor removal. During this month, the highest TOC concentration and UV-254 absorbance were recorded (5.83 mg/L and 0.137/cm, respectively), a high average distribution system temperature was measured (31°C), the highest chlorine demand was measured (6.12 mg/L) and the highest concentrations of TTHM, HAA5 and TOX were measured in the influent to the RSSCT (256 µg/L, 78 µg/L and 388 µg/L, respectively).

The control of TTHMs was observed to be the critical issue for purposes of designing and estimating the costs of replacing GAC. In most cases, Stage 2 HAA5 MCL was not exceeded during the course of the column runs.

GAC replacement and regeneration costs were calculated based on the carbon usage rates to reach a certain design target (e.g. Stage 2 MCL for TTHM). Seasonal variability was observed to have a strong impact on CURs. The Fall quarter was observed to be the most critical for control of DBP precursors, while the Summer quarter was the least critical.

Using a 10-min EBCT, the GAC replacement costs to meet 80% of the Stage 2 TTHM MCL ranged from \$2.30/1000 gal during the Fall to \$1.04/1000 gal during the Summer. Using a 20-min EBCT, the replacement costs to meet 80% of the Stage 2 MCL for TTHMs ranged from \$1.90/1000 gal during the Fall to \$0.79/1000 gal during the Summer. Using a 20-min EBCT over a 10-min EBCT resulted in a 17% to 24% reduction in GAC replacement cost. These costs however translate to average annual replacement costs of \$71,744,400 for a 10-min EBCT, and of \$55,943,550 for a 20-min EBCT, rendering GAC replacement an infeasible approach.

Based on the carbon utilization rates, on-site thermal regeneration of GAC was not shown to be a feasible or cost-effective technology. The most conservative CUR (to meet 80% Stage 2 TTHM MCL using a 10-min EBCT) was utilized for estimating the surface area

of a single reactivator. Although the \$13,751,130 and \$11,877,010 annual reactivation costs for respectively a 10-min and 20-min EBCTs were lower than those for GAC replacement, GAC reactivation remains a infeasible approach.

Total annual costs for a conventional concrete gravity adsorber (including GAC reactivation cost) were estimated at \$15,065,911 for a 10-min EBCT and at \$13,687,940 for a 20-min EBCT. Without reactivation, the total annual costs were estimated at \$1,314,781 and at \$1,810,930 for a 10-min and 20-min EBCTs, respectively. Annual capital costs were estimated at \$786,793 for a 10-min EBCT and at \$1,282,941 for a 20-min EBCT. These costs were estimated using an average flowrate of 177 mgd.

The removal of DBPs would be an expensive treatment technology to implement for the City of Corpus Christi. 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 O.N. Stevens Water Treatment Plant Description

The City of Corpus Christi owns and operates the O.N. Stevens Water Treatment Plant. The plant is located several miles west of the central business district and provides drinking water for the City of Corpus Christi and several nearby communities. The plant design capacity is 144 MGD. The raw water source is the Nueces River. However, since September 1998, Lake Texana has been supplying approximately 20 mgd raw water to the O.N. Stevens WTP. All of the testing conducted for the ICR used water from the Nueces River. The treatment plant is conventional and consists of rapid mix, primary flocculation and sedimentation, rapid mix, secondary flocculation and sedimentation, filtration and a clearwell. Pre-oxidation is accomplished using chlorine dioxide and potassium permanganate, followed by the application of chloramines.

2.1.1 Treatment plant schematic

Figure 1 illustrates a simplified schematic of the water treatment processes applied at the O.N. Stevens 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 two parallel trains: one incorporating GAC filtration, and the other including conventional anthracite/sand dual media filtration.

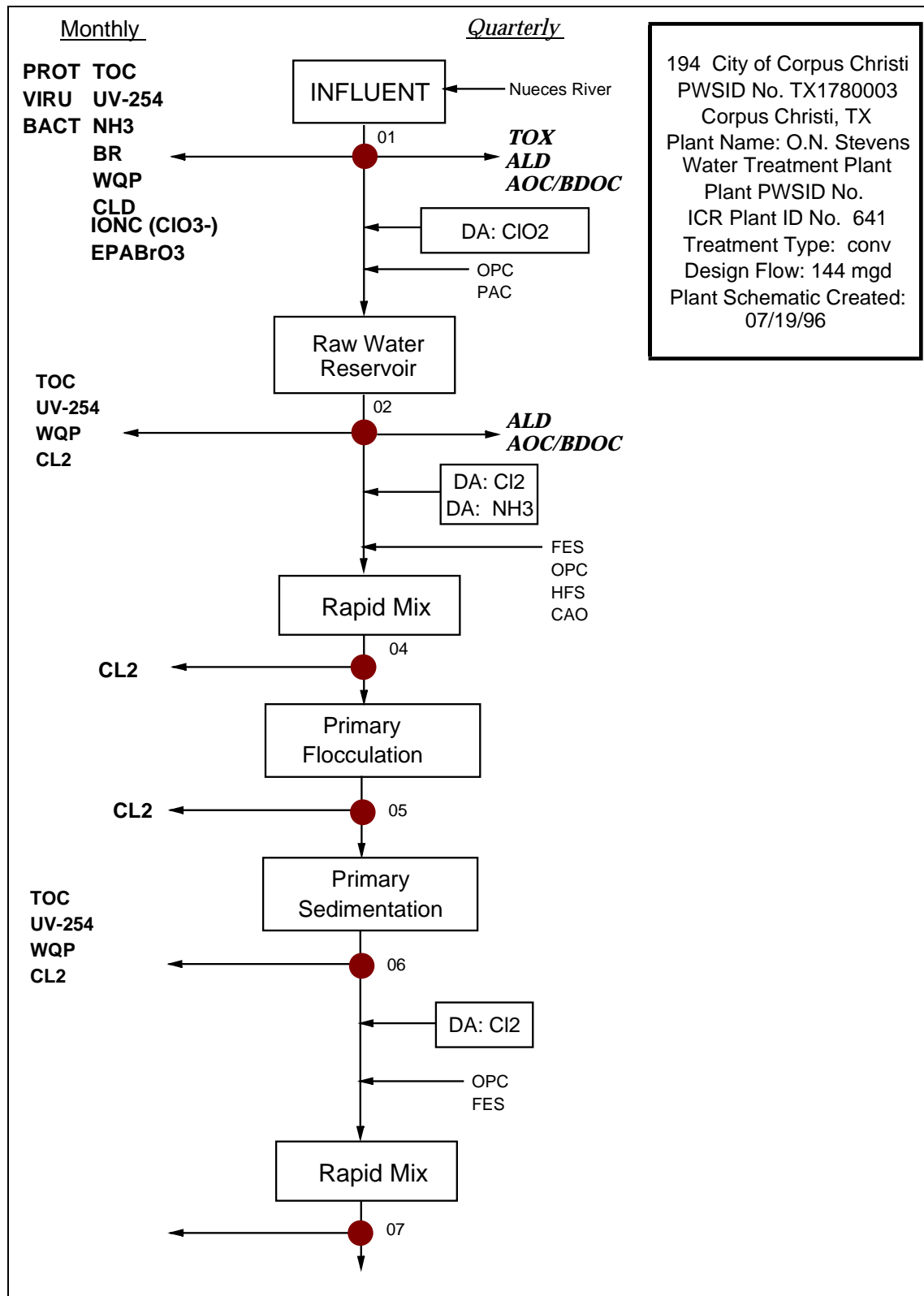


Figure 1. O.N. Stevens WTP Schematic

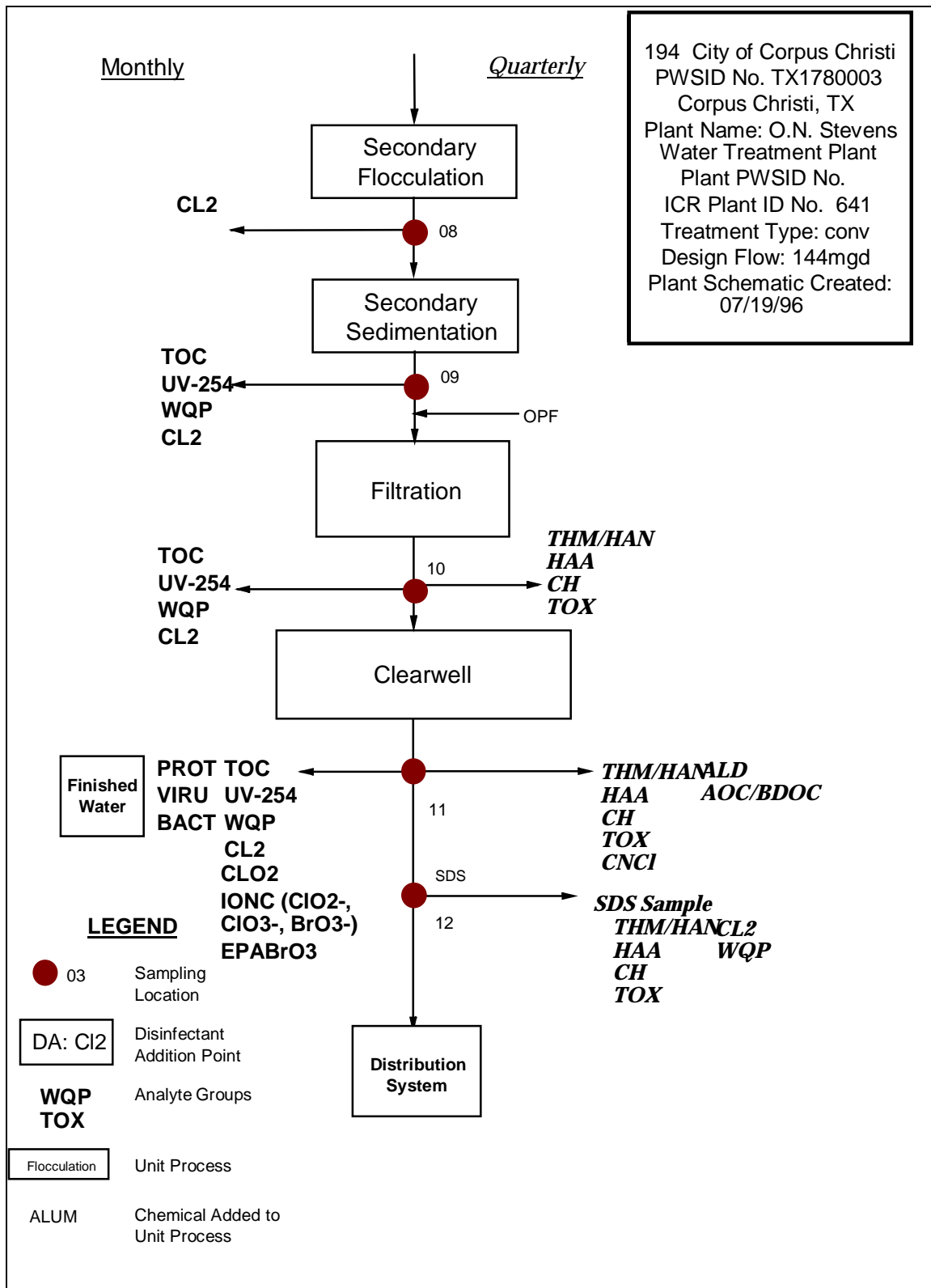


Figure 1 (continued).O.N. Stevens WTP Schematic

2.1.2 Treatment plant design information

The following Table 1 summarizes the O.N. Stevens WTP design data.

Table 1
Treatment Plant Design Data

Unit Process	Process Description		
	Common Train (up to raw water receiving unit)	Train 1 (with GAC)	Train 2 (without GAC)
Addition of polymer to raw water pumping station	Coagulant Aid: (C ₈ H ₁₆ NCl) ₁₁ (Cationic organic polymer) Coagulant Aid Dose (mg/L): 0.8		
Pre-oxidation	Chemical type: ClO ₂ measured as: Dose rate (mg/L): 1.0 mg/L		
Oxidation with KMnO ₄	Dose rate (mg/L): 1.0		
Pre-sedimentation	Liquid Volume (MG): 100 Surface Area (ft ²): 914,000 Retention time: 24 hrs		
Oxidation	Dose rate Cl ₂ (mg/L): 4 Dose rate NH ₃ (mg/L): 0		
Addition of ammonia		Measured as: NH ₃ Dose rate (mg/L): 1.0	Measured as: NH ₃ Dose rate (mg/L): 1.0
Coagulation and Rapid Mixing	Coagulant addition in raw water receiving unit: Al ₂ (SO ₄) ₃ ·14 H ₂ O Alum dose (mg/L): 45	pH Adjustment: in Rapid Mix Addition of CaO Dose (mg/L): 31.5 Q _{mixing} = 1400 CFM	pH Adjustment: in Rapid Mix Addition of CaO Dose (mg/L): 31.5 Q _{mixing} = 1400 CFM
Primary Flocculation		Type of Mixer: 3-stage Stage mean velocity gradient (sec ⁻¹): 12 Liquid Volume (MG): 1.62 Depth (ft): 14.5 Basins 3 & 4 Total Time = 55 min (Q=70 MGD)	Type of Mixer: 3-stage Stage mean velocity gradient (sec ⁻¹): 12 Liquid Volume (MG): 2.27 Depth (ft): 15.5 Basins 1 & 2 Total Time = 55 min (Q=70 MGD)

Table 1 (continued)
Treatment Plant Design Data

Unit Process	Process Description	
	Train 1 (with GAC)	Train 2 (without GAC)
Primary Sedimentation	Surface Area (ft ²): 80,088 Liquid Volume (MG): 9.58 Depth (ft): 16 Basins 3 & 4 Retention time = 325 min (Q=70 MGD)	Surface Area (ft ²): 91,164 Liquid Volume (MG): 11.59 Depth (ft): 17 Basins 1 & 2 Retention time = 325 min (Q=70 MGD)
Chlorination	Chemical type: monochloramine measured as: NH ₂ Cl Dose rate (mg/L): 1.0	Chemical type: monochloramine measured as: NH ₂ Cl Dose rate (mg/L): 1.0
Rapid Mix	Q _{mixing} = 1400 CFM Coagulant Aid: (C ₈ H ₁₆ NCl) ₁₁ (Cationic organic polymer) Coagulant Aid dose (mg/L): 1.0	Q _{mixing} = 1400 CFM Coagulant Aid: (C ₈ H ₁₆ NCl) ₁₁ (Cationic organic polymer) Coagulant Aid dose (mg/L): 1.0
Secondary Flocculation	Type of Mixer: 3-stage Stage mean velocity gradient (sec ⁻¹): 12 Liquid Volume (MG): 1.67 Depth (ft): 15 Basins 3 & 4 Total time = 43 min (Q=70 MGD)	Type of Mixer: 3-stage Stage mean velocity gradient (sec ⁻¹): 12 Liquid Volume (MG): 1.67 Depth (ft): 15 Basins 1 & 2 Total time = 43 min (Q=70 MGD)
Secondary Sedimentation	Surface Area (ft ²): 96,844 Liquid Volume (MG): 11.59 Depth (ft): 16 Basins 3 & 4: Retention time = 290 min (Q=70 MGD)	Surface Area (ft ²): 81,508 Liquid Volume (MG): 10.36 Depth (ft): 17 Basins 1 & 2: Retention time = 290 min (Q=70 MGD)
Filtration	Surface Area (ft ²): 13,893.75 Liquid Volume (MG): 0.09 Depth (ft): 9 Total media depth (in): 48 Media type: Calgon 820 GAC Filter Run: 60 to 72 hours	Surface Area (ft ²): 13,860 Liquid Volume (MG): 0.11 Depth (ft): 10.8 Total media depth (in): 46 Media type: Anthracite: 18 in Sand: 10 in Gravel: 18 in Note: Some mixing of sand and anthracite Filter Run: 60 to 72 hours
Disinfection	Monochloramine NH ₂ Cl Dose rate (mg/L): 3.0 to 4.0	Monochloramine NH ₂ Cl Dose rate (mg/L): 3.0 to 4.0
Clearwell (MIN)	Surface Area (ft ²): 33,124 Liquid Volume (MG): 1.61 Depth (ft): 6.5	Surface Area (ft ²): 84,100 Liquid Volume (MG): 4.09 Depth (ft): 6.5
Clearwell (MAX)	Surface Area (ft ²): 33,124 Liquid volume (MG): 3.96 Depth (ft): 16	Surface Area (ft ²): 84,100 Liquid volume (MG): 10.07 Depth (ft): 16

2.1.3. Treatment challenges facing plant

Historically, the City of Corpus Christi has obtained its water from two reservoirs in the Nueces River watershed: Lake Corpus Christi on the Nueces River and Choke Canyon Reservoir on the Frio River, a tributary of the Nueces. Due to several years of record drought in the Nueces watershed, an additional water source, with very different water quality than the Nueces River, was recently implemented, through construction of a 104-mile pipeline from Lake Texana on the Navidad River to the O.N.Stevens WTP. This treatment study involved the collection of raw water from the Nueces River only since it was conducted before the additional water source was implemented. Pumping of the new surface water began in September 1998. The new water source will be introduced in the junction box at the WTP, and will flow through the pre-sedimentation basin. This will allow good blending of the water sources. Lake Texana water pumping rate can be based on a fixed blend percentage of Nueces River and Lake Texana water or a fixed pumping rate. Early pumping projections put the most likely blend percentages of Nueces River and Lake Texana between 80 percent Nueces River water and 20 percent Lake Texana water (80/20 blend), and 50 percent Nueces River water and 50 percent Lake Texana water (50/50 blend). The WTP must be able to treat both the individual source water and any blend combination. Several jar tests were conducted by an independent consultant to evaluate several factors, including chemical dosages required, range in chemical dosages required, settled and filtered water quality, and compliance with the proposed enhanced coagulation regulation. It was proposed that the optimal blend for Corpus Christi be identified by alkalinity, and achieved by targeting a range of alkalinity in the raw water.

Note: A pilot study was initiated in October 1998 to address more extensively the treatability requirements for the blended Lake Texana and Nueces River water and to address compliance issues anticipated with future regulations. The pilot will simulate the full-scale treatment processes, including a two-stage coagulation train and two filters. Each coagulation train consists of chemical addition, four stage flocculation and lamella type inclined plate rack settler. Pilot testing will be conducted over 6 months (not necessarily consecutive). The pilot testing will use different blends of the two water sources to address the issues stated above.

2.2 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 O.N. Stevens WTP using data collected monthly between July 1997 and July 1998. The water quality data can also be found in the Treatment Study Summary Report Spreadsheet attached at the end of this document as Appendix B.

Table 2
Summary of Raw Water Quality at the O.N. Stevens WTP
(July 1997 through July 1998)

Source Water Quality Parameter	Average Concentration	Standard Deviation	Maximum Value	Minimum Value
Temperature (° C)	22.6	4.5	28.1	15.5
pH	8.1	0.2	8.5	7.9
Turbidity (NTU)	26.62	11.12	58.00	15.00
Total Alkalinity (mg/L as CaCO ₃)	160.0	7.7	170.0	144.0
Total Hardness (mg/L as CaCO ₃)	212.8	23.4	256.0	182.0
TOC (mg/L)	4.78	0.73	6.20	4.00
UV-254 (cm ⁻¹)	0.136	0.063	0.332	0.095

Table 3 summarizes average finished water quality at the O.N. Stevens WTP data.

Table 3
Summary of Finished Water Quality at the O.N. Stevens WTP
(July 1997 through July 1998)

Finished Water Quality Parameter	Average Concentration	Standard Deviation	Maximum Value	Minimum Value
Temperature (° C)	NA	NA	NA	NA
pH	8.02	0.15	8.22	7.68
Turbidity (NTU)	0.15	0.15	0.66	0.05
TOC (mg/L)	3.64	0.61	5.10	3.00
UV ₂₅₄ (cm ⁻¹)	0.103	0.027	0.181	0.076
TTHM (µg/L)*	51.2	12.9	64.5	34.0

NA: Not Available

* Based on four quarterly sampling campaigns (09/97; 12/97; 03/98; 06/98). Measured in the distribution system at the point of estimated average residence time

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 O.N. Stevens WTP, since chlorine dioxide is 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 4 presents the four sampling dates.

Table 4
Quarterly Sampling Dates

Quarter	Sampling Dates
Fall	September 16, 1997
Winter	December 15, 1997
Spring	March 10, 1998
Summer	June 16, 1998

During the first quarter, a 100-gallon water sample was collected. Since this volume was not sufficient to capture the 70% TOC breakthrough criterion, sample volume was increased to 150 gallons during the second quarter of testing and to 200 gallons during quarters 3 and 4 of testing. 100-gal polyethylene tanks were used for sample collection. Tanks were rinsed with tap water and deionized (DI) water prior to shipping. Samples were shipped to Montgomery Watson's Applied Research Laboratory via Federal Express during the Fall and Winter quarters, and via FFE refrigerated trucks during the Spring and Summer quarters. Upon arrival at the laboratory, the 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 5 presents general water quality of the four collected raw water samples.

Table 5
General Water Quality of Collected Raw Water Samples

Parameter	Unit	Fall	Winter	Spring	Summer
pH	---	8.3	8.1	8.0	8.4
TOC	mg/L	7.0	5.6	4.0*	4.1**
Turbidity	NTU	27.0	27.0	30.0	29.3
Alkalinity	mg/L as CaCO ₃	165	165	220	180
Total Hardness	mg/L as CaCO ₃	120	160	232	n.a
Apparent Color	Pt. Co. C.U.	180	n.a	166	241
True Color	Pt. Co. C.U.	16	n.a	7	41
Apparent UV-254	cm ⁻¹	0.330	n.a	0.257	0.295
Filtered UV-254	cm ⁻¹	0.157	0.108	0.129	0.126

*After 1-μm cartridge filtration; ** After 0.45 -μm cartridge filtration; n.a: not available

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. A sample of the organic polymer (cationic Poly(DADMAC) polymer) utilized at the WTP was shipped to Montgomery Watson's Applied Research Laboratory for use. Chemicals added included permanganate, alum, organic polymer (at the influent receiving box and after primary sedimentation), lime, and hydro-fluosilicic acid. Design parameters included flow-rate; contact times for rapid mixing, flocculation and sedimentation; and G values for flocculation. Table 6 presents the chemical dosages and design parameters used during bench-scale pretreatment of the raw water.

During the Fall quarter, jar testing was conducted to optimize the water quality. Once that was achieved, bulk pretreatment was initiated on the water sample. During the remaining quarters, since water quality optimization was not part of the ICR treatment studies, bulk testing was conducted by using the chemical doses and design parameters applied at the O.N. Stevens WTP.

For the Fall quarter, bench-scale pretreatment included:

- Pre-sedimentation: addition of organic polymer and permanganate to the water sample followed by a 24-hour settling period,
- Coagulation: addition of alum, lime (and hydrofluosilicic acid) to the decanted water, and mixing at high speeds for 30 seconds,
- Primary flocculation and sedimentation: mixing at three intermediate speeds for 10 minutes per speed, to simulate a three-stage flocculation process, followed by a one to two-hour settling period.
- Filtration: sequential filtration through a 5- μm and a 1- μm filter papers was conducted to simulate full-scale filtration. To minimize headloss build-up in the columns, a 0.2- μm on-line membrane was put at the influent of each GAC column.

Note: Secondary pretreatment was found to be unnecessary since optimization of water quality at the plant was targeted, instead of simulation of plant conditions. It was found through jar testing that secondary pretreatment did not achieve any reduction in TOC, turbidity or UV-254 and was hence dropped. The organic polymer that is normally added in the secondary rapid mixing period was added in the primary rapid mix. Lime dosage was reduced from the 31.5 mg/L dose as CaO used at full-scale to 15 mg/L for pH control and optimization of the coagulation step.

During the Winter and Spring quarters, all full-scale treatment processes and chemical dosages were simulated, including pre-sedimentation, coagulation, primary flocculation and sedimentation, secondary flocculation and sedimentation and sequential filtration

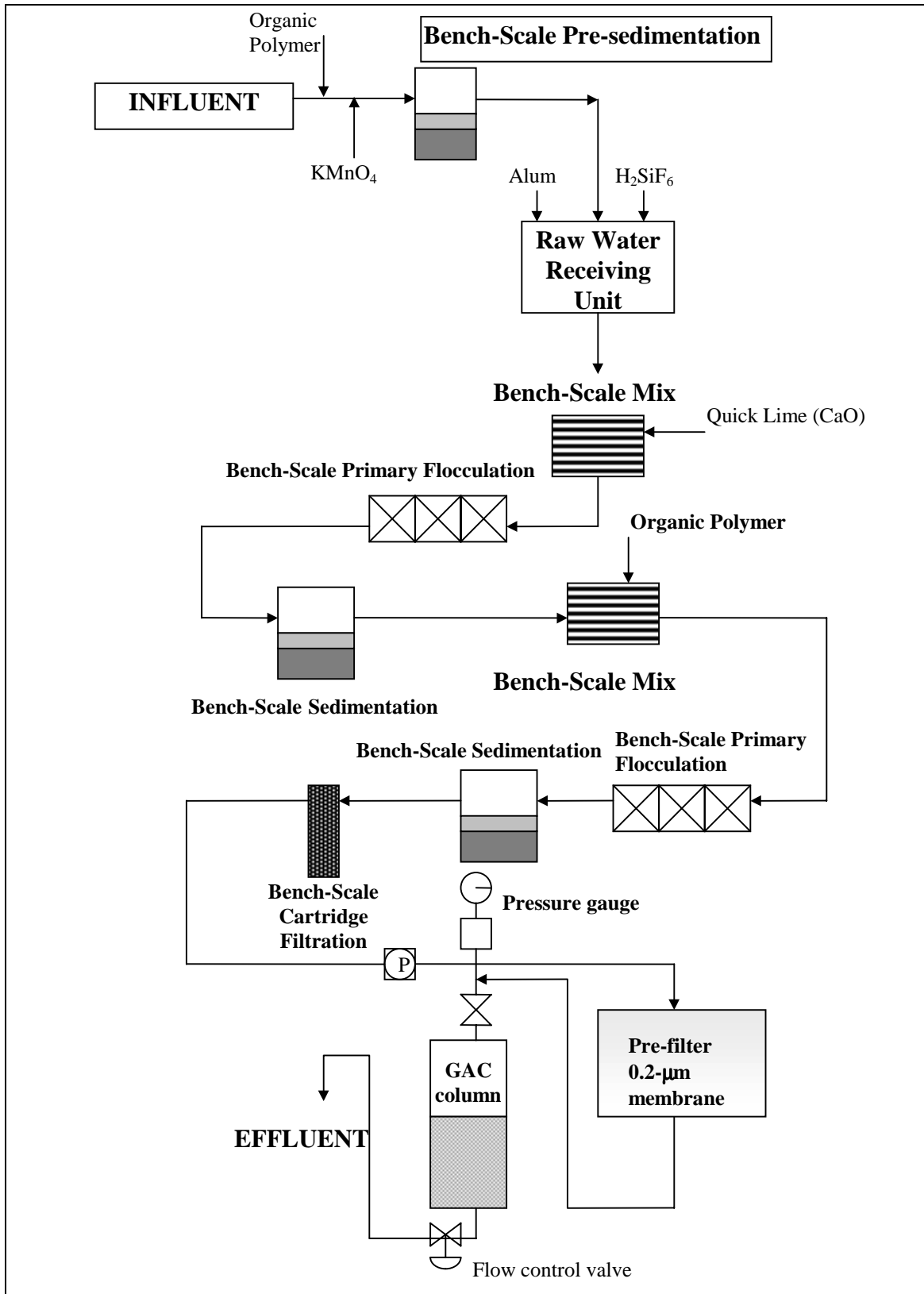


Figure 2. Schematics of Bench-Scale Processes Including GAC Columns

through 5- μ m and 1- μ m cartridge filters and through on-line 0.2- μ m membranes. During the Summer quarter, since no pre-sedimentation was applied at full-scale, it was also eliminated from the bench-scale test. In addition, since no lime was added at the O.N. Stevens WTP during the sampling day, the same was mimicked at bench-scale. The 5- μ m and 1- μ m cartridge filtration were replaced by one 0.45- μ m cartridge filtration, followed by on-line filtration through a 0.2- μ m membrane.

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

	Fall	Winter	Spring	Summer
Permanganate dose, mg/L	1.0	0.2	0.4	Not used
Cationic organic polymer dose, mg/L (in raw water)	0.8	0.97	0.3	Not used
Alum $\text{Al}_2(\text{SO}_4)_3 \cdot 14 \text{H}_2\text{O}$ dose, mg/L	50.0	63.2	75	34.8
Quick lime CaO dose, mg/L (pH-adjust.)	15.0	34.5	20.9	Not used
Hydrofluosilicic H_2SiF_6 acid dose mg/L	3.1	3.1	3.0	4.0
Secondary organic polymer dose, mg/L	1.0	0.9	0.8	0.8
Pre-sedimentation (in 80-gal drum)	24 hours	24 hours	24 hours	Not used
Rapid mixing	30 sec @ 40 rpm	30 sec @ 40 rpm	30 sec @ 40 rpm	30 sec @ 40 rpm
Primary flocculation (in 80-gal drum, 1 paddle assembly, 10 vertical paddles, stage mean velocity gradient = 20 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
Primary sedimentation (in 80-gal-drum)	1-2 hours	1-2 hours	1-2 hours	1-2 hours
Secondary flocculation/ Secondary sedimentation	None	Same as primary Same as primary		
Filtration	5-, 1- and 0.2- μ m	5-, 1- and 0.2- μ m	5-, 1- and 0.2- μ m	0.45- μ m and 0.2- μ m

Table 7 compares the water quality of the pretreated sample (including filtration through the 1- μ m cartridge filter) to the full-scale filtered water quality at the day of sampling.

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

Quarter	Parameter	Simulated Pre-treated water	Full-scale Filtered Water
Fall	TOC, mg/L	5.8	4.8
	Turbidity, NTU	0.10	0.10
	UV-254, cm ⁻¹	0.137	0.148
Winter	TOC, mg/L	3.9	3.4
	Turbidity, NTU	0.70 to 1.00	0.10
	UV-254, cm ⁻¹	0.095	0.103
Spring	TOC, mg/L	3.6	3.2
	Turbidity, NTU	0.19	0.10
	UV-254, cm ⁻¹	0.075	0.090
Summer	TOC, mg/L	4.3	3.9
	Turbidity, NTU	0.20	0.10
	UV-254, cm ⁻¹	0.090	0.108

Some 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. However, the difference in the TOC concentrations between the simulated pre-treated water and the full-scale treated water ranged only from 9% (Summer quarter) to 17% (Fall quarter). UV-254 absorbances measured in the two samples were not substantially different. The turbidity measured in the bench-treated sample was somewhat higher than that measured in the plant treated filtered water.

3.3 Design Data for the GAC Adsorption Process

3.3.1 RSSCT set-up information

Figure 3 illustrates the RSSCT column set-up.

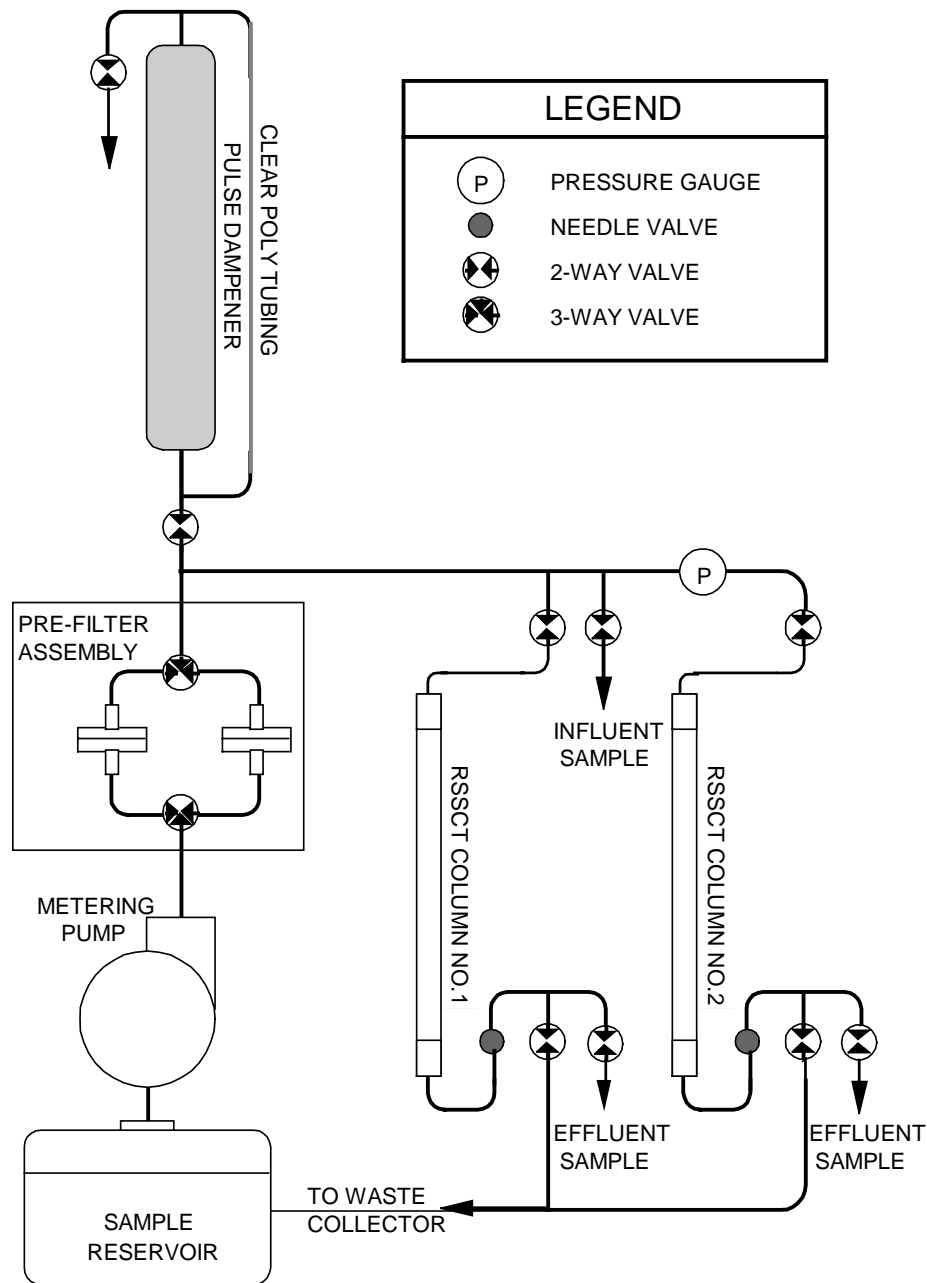


Figure 3. RSSCT Flow Diagram

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) cubitanors. The influent water was pumped to each column using a single metering pump. A pre-filter (0.2 μm) on-line assembly was set-up at the influent of the columns to minimize headloss build-up in the columns. The metering pump had a flowrate range of 0 to 51.8 mL/min and was operated at a range of

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

3.3.2 Design data for the GAC process

During the four quarters of testing, two columns were operated to simulate full-scale empty-bed contact times (EBCTs) of 10 and 20 minutes, as prescribed by the ICR. A sample of 12×40 US Standard Mesh GAC (apparent particle diameter, d_{LC} , of 1.053 mm) was ground to a 100×200 US Standard Mesh (particle diameter d_{SC} , of 0.1125 mm), resulting in a scaling factor of 9.4. 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. 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.

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 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 de-gassed by applying vacuum for 5 minutes to remove the air pockets from the carbon particles. The

Table 8
RSSCT Design Parameters

DESIGN PARAMETER	Sept.	Dec.	March	June
GAC manufacturer	Calgon	Calgon	Calgon	Calgon
GAC commercial name	F-400	F-400	F-400	F-400
GAC Type	Bituminous	Bituminous	Bituminous	Bituminous
GAC mesh size	12 x 40	12 x 40	12 x 40	12 x 40
Particle diameter d_{LC} (mm)	1.053	1.053	1.053	1.053
Input Design Parameters				
RSSCT influent TOC (mg/L)	5.6	3.9	4.0	4.1
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 ($^{\circ}C$)	20.0	20.0	20.0	20.0
Full-scale bed porosity, e_{LC}	0.45	0.45	0.45	0.45
Measured RSSCT dry bed density, r_{SC} (g/cm ³)	0.406	0.432	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}	2338	3699	3603	3522
Estimated run length, $BV_T (= 2 \times BV_{50})$	4676	7398	7205	7044
$BV_T + 30\%$ safety factor, $BV_{T+30\%} (= 2.6 \times BV_{50})$	6079	9617	9367	9157
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)	228	361	351	344
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)	42	67	65	64
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	1.07	1.07	1.07	1.07
Estimated RSSCT run time, t_{SC}^T (days)	4.51	7.14	6.95	6.79
RSSCT bed length, l_{SC} (cm)	13.2	13.2	13.2	13.2
Estimated volume required for 10-minute EBCT, V_{SC} (L)	76	120	117	115
Mass GAC required, m_{SC} (g)	5.08	5.40	6.25	6.25
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)	84	134	130	127
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	2.14	2.14	2.14	2.14
Estimated RSSCT run time, t_{SC}^T (days)	9.03	14.27	13.90	13.59
RSSCT bed length, l_{SC} (cm)	26.3	26.3	26.3	26.3
Estimated volume required for 20-minute EBCT, V_{SC} (L)	152	241	234	229
Mass GAC required, m_{SC} (g)	10.16	10.81	12.51	12.51

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. However, during the first 3 quarters, the two on-line filter membranes required frequent changing (due to clogging) to minimize pressure buildup. These membranes were preceded by a 5- μm and 1- μm cartridge filtration steps. During the final quarter, the sequential 5- and 1- μm filtration was replaced by a single 0.45- μm cartridge filtration. This allowed for a longer on-line membrane run life. Some headloss problems were encountered during the first quarter. The column run was stopped, and the carbon was removed and stirred slowly. The suspended fines were collected to determine the mass of carbon loss. Less than 5% loss of carbon was estimated. The columns were then repacked and put on-line.

NOTE: to isolate the source of the headloss, DI water was run through all the connections (including the in-line paper filters) except through the GAC column and the pressure was checked. Since the pressure was low and flow rates normal, the source of the problem was determined to be the actual GAC 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 treatability of the water.

Table 9
Experimental Design Summary

Season	Pretreatment	EBCT, min
Autumn	Coagulation/ Flocculation and Sedimentation/Cartridge Filtration	10 & 20
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

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 Corpus Christi 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	September 1997		December 1997		March 1998		June 1998	
	Value	Tolerance	Value	Tolerance	Value	Tolerance	Value	Tolerance
Incubation time, hrs	24.0	1.0	24.0	1.0	24.0	1.0	24.0	1.0
Incubation temp., °C	31.0	2.0	20.0	2.0	23.0	2.0	32.0	2.0
pH	8.0	0.4	8.5	0.4	8.2	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

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 524.2 and 502.2	0.5 µg/L for all analytes
TOC	SM 5310 C	0.5 mg/L
TOX	SM 5320	10 µg/L and 25 µg/L
UV ₂₅₄	SM 5910	0.009 cm ⁻¹

Table 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 on these laboratories is included in Appendix B (ICR Summary Spreadsheet).

Table 12
Listing of Laboratories involved in the Analytical Reporting

Laboratory	Dates of Service	Analyses Performed
RCFF (ARD Lab)	Quarters 1 through 4 *No hardness analysis by ARD in Quarter 4	Alkalinity, Turbidity, TOC (SM 5310 C), Hardness, Temperature, pH, UV ₂₅₄ , Chlorine residual, Ammonia
Montgomery Watson Labs	Quarters 1 through 4	THM4 (EPA 524.2), HAA6 (SM 6251B), TOX (SM 5320), Bromide, Ca-hardness Total hardness
Montgomery Watson Labs	Quarter 4	TOX (SM 5320B)
E.S. Babcock & Sons	Quarter 2	HAA6 (SM 6251B)
Weck Laboratories Inc	Quarter 3	HAAs (EPA 552.2) and TOX
Summers and Hooper Inc	Quarter 4	(SM 5320)

RCFF Laboratory

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

Montgomery Watson Laboratories

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

E.S. Babcock & Sons

6100 Quail Valley Court
Riverside, CA 92507
Contact Person: Mrs. Kathy Ljima
Phone #: (909) 653-3351
Fax #: (909) 653-1662
Environmental Laboratory Certification #1156

Weck Laboratories, Inc

14859 E. Clark Ave.
Industry, CA 91745-1396
Contact Person: Mrs. Jayna Kostura
Phone #: (818) 336-2139
Fax #: (818) 336-2634

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 Pre-treatment

- During the Fall quarter, the measured TOC in the influent raw water sample was higher than the average raw water TOC value recorded at the plant (7.0 mg/L versus an average of 5.5 mg/L at the plant). This high TOC value could be interpreted as a product of seasonal variability and could serve as a “worst case scenario” for design of a potential GAC filter unit at the plant.
- During all four quarters, the TOC in the water was difficult to remove with the pretreatment train. This is also illustrated in the TOC sampling results during the 12-month ICR monitoring period (September 1996 to August 1997). While primary sedimentation achieves a small TOC reduction (from negligible to 19 percent reduction), secondary pre-treatment, filtration and disinfection achieve no additional TOC removals. During the Fall quarter, although turbidity was reduced to 0.8 NTU in the pretreatment phase, versus 1.4 NTU in the plant, TOC was reduced to only 5.6 mg/L after filtration.
- High pH values (8.9 to 9.2) were recorded following the 31.5 mg/L lime addition. Since this high pH value would reduce the efficiency of coagulation, it was decided to add 15 mg/L of lime, which resulted in a pH value of 7.9, equivalent to the one measured at the plant.

4.1.2 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.

4.1.3 Head-loss Buildup

As mentioned in a previous section, some headloss problems were encountered during the first quarter. The columns were taken off-line for a period of 2 hours, during which the carbon was re-rinsed to get rid of some fines, and re-packed in the columns. A 0.45- μ m cartridge filtration followed by a 0.2- μ m on-line membrane filtration procedure was used in the remaining quarters to minimize headloss buildup and filter clogging.

4.1.4 Water Volume

During the Winter and Spring quarter testing, the GAC operation ran for longer than estimated in the RSSCT design. The water volume that had been collected from the raw water was not sufficient to meet the 70% breakthrough criterion. During the Fall quarter, 70 gallons of raw water were collected. The volume was increased during the Winter quarter to 120 gallons. During the Winter quarter, a 62% breakthrough plateau was reached in the 10-min EBCT column. In the 20-min EBCT column, a 62% TOC

breakthrough was reached instead of the 70% breakthrough criterion. The sample volume was increased to 200 gallons during the Spring and Summer quarters. However, even though the 70% breakthrough criterion was not reached, Stage 1 and 2 TTHM MCLs were exceeded in both Winter and Spring quarters.

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. Seasonal variability was observed in both inorganic and organic parameters. Alkalinity ranged from 140.0 in summer to 173 mg/L CaCO₃ in winter. The influent pH was observed to be lowest in spring and highest in winter. Total hardness ranged from 135 in autumn to 215 mg/L CaCO₃ in summer. Organic content was observed to be highest in autumn and lowest in spring, as represented by the TOC concentration and UV-254 absorbance. TOC concentration ranged from 5.83 mg/L in autumn to 3.60 mg/L in spring. The UV-254 absorbance ranged from 0.137/cm in autumn to 0.075/cm in spring. The formation potential of TTHMs was found to be more or less constant, at an average concentration of 235 µg/L. Some variability between the four quarters was observed in the HAAs concentrations. The highest HAA5 and HAA6 concentrations were measured during autumn and summer quarters, when the SDS test temperature was 31°C and 32°C, respectively (Table 10). Chlorine demand was also highest during these two quarters, probably due to both higher organic content and temperatures.

Table 13
Water Quality of the Influent to the RSSCT

Water Quality Parameter	Fall Average (SD)*	Winter Average (SD)*	Spring Average (SD)*	Summer Average (SD)*
pH	8.20 (0.00)	8.54 (0.00)	7.97 (0.01)	8.03 (0.01)
Turbidity (ntu)	0.10 (0.00)	0.70 (0.00)	0.19 (0.26)	0.20 (0.25)
Alkalinity mg/L CaCO ₃	160	173	163	140
Calcium Hardness mg/L CaCO ₃	156.0	192.0	199.5	170.0
Total Hardness mg/L CaCO ₃	NR	NR	213.0	215.0
Bromide (µg/L)	305	570	475	330
Ammonia-N (mg/L)	<0.10	<0.10	NR	<0.10
TOC (mg/L)	5.8 (0.0)	3.9 (0.0)	3.6 (0.0)	4.3 (0.0)
UV ₂₅₄ (cm ⁻¹)	0.137 (0.011)	0.095 (0.052)	0.075 (0.077)	0.090 (0.013)
SUVA (L/mg-cm)	2.34 (0.01)	2.47 (0.07)	2.09 (0.08)	2.07 (0.01)
SDS-THM4 (µg/L)	276 (0)	249 (0)	194 (0)	219 (0)
SDS-HAA5 (µg/L)	78 (0)	41 (0)	33 (0)	44 (0)
SDS-HAA6 (µg/L)	107 (0)	56 (0)	47 (0)	63 (0)
SDS-TOX (µg Cl ⁻ /L)	388 (0)	360 (0.2)	223 (0.1)	338 (0)
SDS-chlorine demand (mg/L)	6.12 (0.00)	3.71 (0.00)	3.13 (0.00)	4.25 (0.00)

*SD: Standard Deviation; NR: Not Reported

4.3 Impact of Seasonal Variability

4.3.1 Impact of Seasonal Variability on TOC Breakthrough

The impact of seasonal variability on the TOC breakthrough in the 10-min and 20-min EBCT columns is illustrated in Figures 4 and 5. As mentioned in a previous section, the Fall quarter, the TOC in the influent to the RSSCT was measured at 5.8 mg/L (Table 13). At this high TOC value, the estimated total influent volume required was 228 L (60 gallons). A sample size of 100 gallons was collected from the source water of the O.N. Stevens WTP, of which 30 gallons were used during pretreatment optimization. Reaching the 70% breakthrough criterion took longer than expected. During the Winter quarter, 120 gallons of water were collected from the raw water. A 361-L (95 gallons) required total influent volume was estimated based on the average plant 3.9 mg/L TOC concentration. In the 10-min EBCT column, a 62% TOC breakthrough plateau was obtained, over a period of 78 full-scale days, during which the effluent TOC concentration did not vary by more than 10% of the average influent concentration. In the 20-min EBCT column, a 62% TOC breakthrough plateau was obtained over a period of 127 full-scale days, during which the effluent TOC concentration ranged from 2.0 to 2.4 mg/L. Just as for the Fall quarter, reaching the 70% breakthrough criterion took longer than expected.

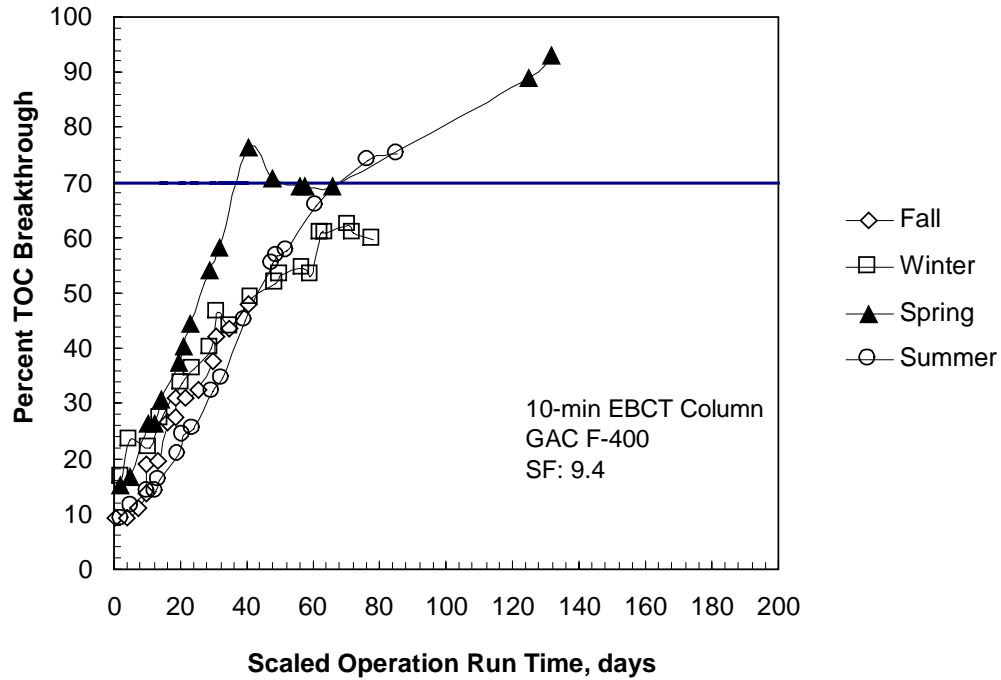


Figure 4. Impact of Seasonal Variability on Percent TOC Breakthrough in the 10-min EBCT Column

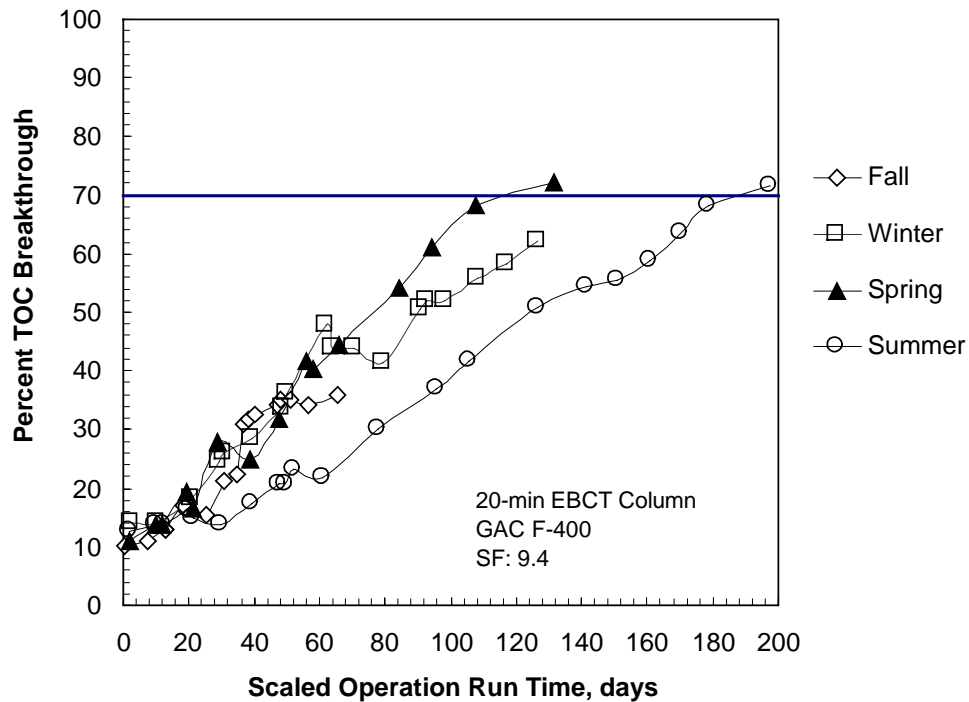


Figure 5. Impact of Seasonal Variability on TOC Breakthrough in the 20-min EBCT Column

Nevertheless, some seasonal variation between the four quarters was observed in the TOC breakthrough curves. In both 10-min and 20-min EBCT columns, the fastest TOC breakthrough was observed during the spring quarter (March sampling). This was observed despite the lowest recorded influent TOC concentration and UV-254 absorbance of 3.60 mg/L and 0.075 /cm, respectively. In the 20-min EBCT column (Figure 5), the rate of breakthrough (slope of curves) was observed to be somewhat constant, at 0.5 percent/day. The order of the curves did not, however, appear to depend on the influent TOC concentration and UV-254 absorbance.

4.3.2 Impact of Seasonal Variability on SDS-TTHM Breakthrough

Figures 6 and 7 illustrate the SDS-TTHM breakthrough versus run time in the 10-min and 20-min EBCT columns during the four quarters. The order of the SDS-TTHM breakthrough curves appears to be correlated with the influent SDS-TTHM concentration. Influent SDS-TTHM concentrations were high, and ranged from a high of 276 µg/L during the Fall quarter, to a low of 194 µg/L during the Spring quarter. In the 10-min EBCT column, even with a low TOC breakthrough of approximately 50% during the Fall quarter, Stage 2 TTHM MCL was exceeded first during the Fall quarter, after 10 scaled days of operation run time. During the other quarters, the TTHM MCL was exceeded respectively after 12 days, 19 days and 22 days of full-scale operating time. In the 20-min column, the Stage 2 TTHM MCL was again exceeded first during quarter 1, after 25 days of operation, while the column was operated for 29 days, 52 days, and 59 days, before the Stage 2 TTHM MCL was exceeded during the Winter, Spring, and Summer quarters, respectively.

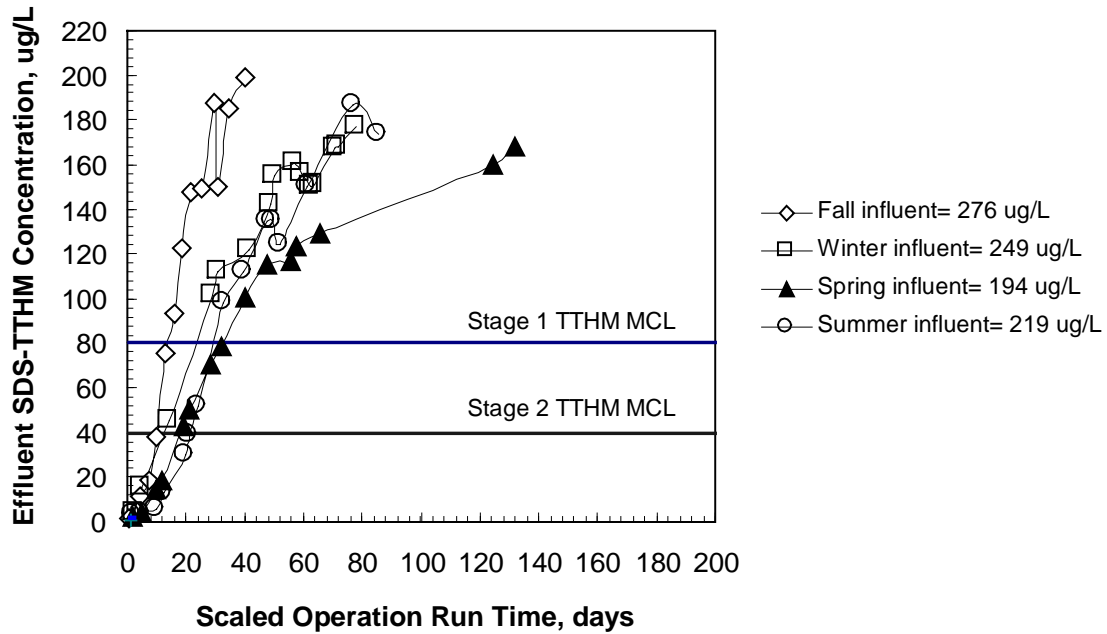


Figure 6. Impact of Seasonal Variability on SDS-TTHM Breakthrough in the 10-min EBCT Column

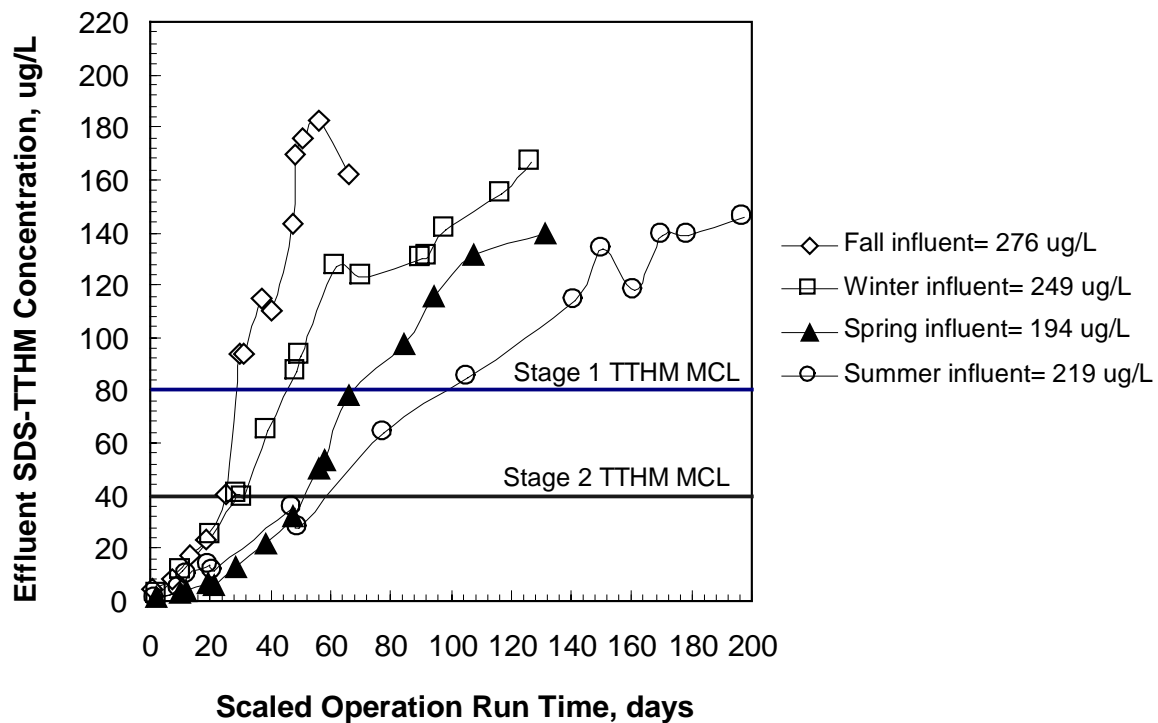


Figure 7. Impact of Seasonal Variability on SDS-TTHM Breakthrough in the 20-min EBCT Column

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. In the 10-min EBCT column, the Stage 2 HAA5 MCL was exceeded only during the Fall quarter, after 35 scaled days of operation. In the 20-min EBCT column, the Stage 2 HAA5 MCL was not exceeded in any quarter. The SDS-TTHM concentration in the GAC contactor effluent will therefore be the limiting factor in contactor design, regeneration scenario, and costing.

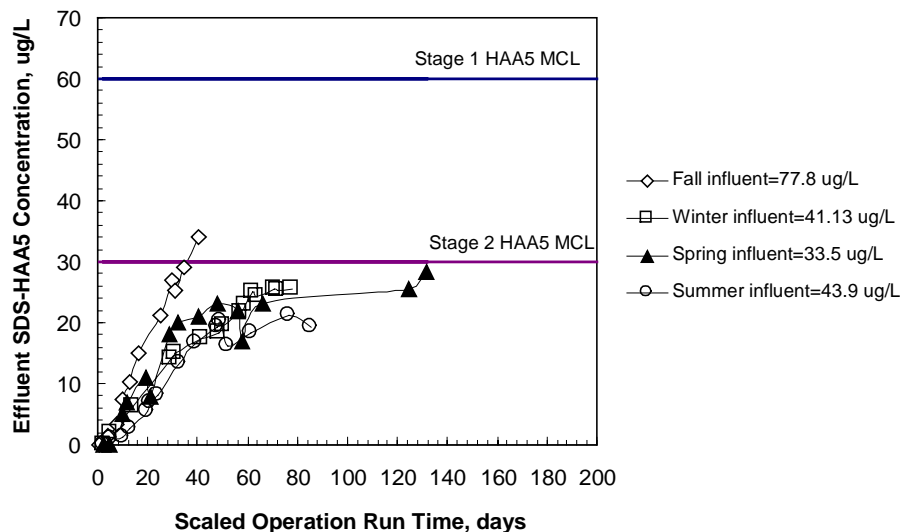


Figure 8. Impact of Seasonal Variability on SDS-HAA5 Breakthrough in the 10-min EBCT Column

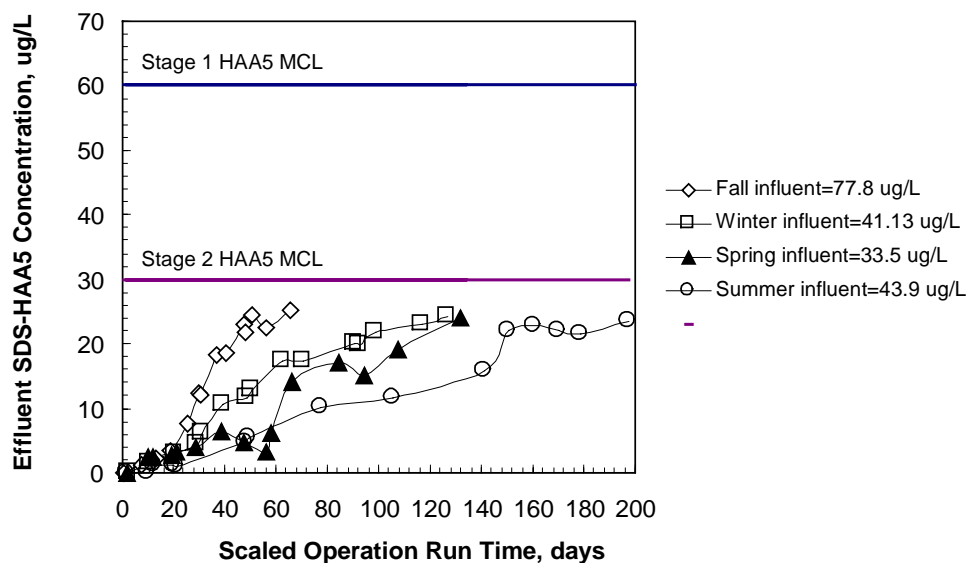


Figure 9. Impact of Seasonal Variability on SDS-HAA5 Breakthrough in the 20-min EBCT Column

4.3.4 Impact of Seasonal Variability on DBPs Speciation

The concentration of bromide in the influent to the RSSCT impacts the speciation of DBPs in the effluents of the GAC columns. Referring to Table 13, the highest bromide concentration was measured during the Winter quarter (570 µg/L), and the lowest measured during the Fall quarter (305 µg/L). A higher proportion of brominated DBPs is expected during the Winter and Spring quarters as compared to the Fall and Summer quarters. 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 low, especially during the Winter and Spring quarters. The SDS-HAAs were dominated by the formation of dibromoacetic acid, tribromoacetic acid, and chlorodibromo acetic acid. This trend was intensified during the Winter and Spring testing.

Table 14
Impact of Bromide Concentration on SDS-DBPs Speciation

		Fall	Winter	Spring	Summer
Influent to RSSCT	Bromide, µg/L	305	570	475	330
10-min EBCT	CHCl ₃ , µg/L	0 to 12	0 to 1.7	0 to 3.3	0 to 14
	BDCM, µg/L	0 to 39	0 to 11	0 to 18	0 to 45
	DBCM, µg/L	1.2 to 69	0 to 54	0 to 60	0 to 85
	CHBr ₃ , µg/L	2.1 to 54	4.2 to 110	2.3 to 87	0 to 85
	MCAA, µg/L	BMRL	BMRL	BMRL	BMRL
	DCAA, µg/L	0 to 5.1	0 to 1.5	0 to 2.8	0 to 7.6
	TCAA, µg/L	0 to 2.2	BMRL	BMRL	0 to 3.4
	MBAA, µg/L	0 to 2.3 to 0	0 to 2.9	0 to 3.6	0 to 3
	DBAA, µg/L	0 to 12	0 to 21	0 to 21	0 to 20
	BCAA, µg/L	0 to 9.8	0 to 6.7	0 to 10	0 to 15
	TBAA, µg/L	0 to 4.1	0 to 17	0 to 18	NR
	CDBAA, µg/L	0 to 6.5	0 to 8.1	0 to 13	NR
	DCBAA, µg/L	0 to 5.7	0 to 3.1	0 to 6.1	0 to 9.3
20-min EBCT	CHCl ₃ , µg/L	0 to 8	0 to 1.9	0 to 1.4	0 to 4.9
	BDCM, µg/L	0 to 28	0 to 11	0 to 8.2	0 to 22
	DBCM, µg/L	0 to 70	0 to 44	0 to 34	1.8 to 62
	CHBr ₃ , µg/L	0 to 40	2.5 to 110	1.3 to 96	2.5 to 73
	MCAA, µg/L	BMRL	BMRL	BMRL	BMRL
	DCAA, µg/L	0 to 5	0 to 1.5	BMRL	0 to 3.3
	TCAA, µg/L	0 to 2.5	BMRL	BMRL	0 to 1.5
	MBAA, µg/L	BMRL	0 to 2.7	BMRL	0 to 2.4
	DBAA, µg/L	0 to 16	0 to 20	0 to 24	0 to 18
	BCAA, µg/L	0 to 11	0 to 6.6	BMRL	0 to 9.6
	TBAA, µg/L	0 to 6	0 to 17	NA	NR
	CDBAA, µg/L	0 to 10	0 to 8.6	NA	0 to 9.9
	DCBAA, µg/L	0 to 7.8	0 to 3.6	NA	0 to 5.4

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 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 observed in Figures 10,11, and 12, eventhough the slope of the curves using a 20-min EBCT was equivalent to that using a 10-min EBCT, a small benefit for removing DBP precursors was observed when using a 20-min EBCT over a 10-min EBCT. This translates into somewhat lower costs for replacing or regenerating the GAC when using a 20-min EBCT. However capital costs of a 20-min EBCT GAC contactor are substantially higher than the capital costs of a 10-min contactor. More details on costing are presented in section 4.6.

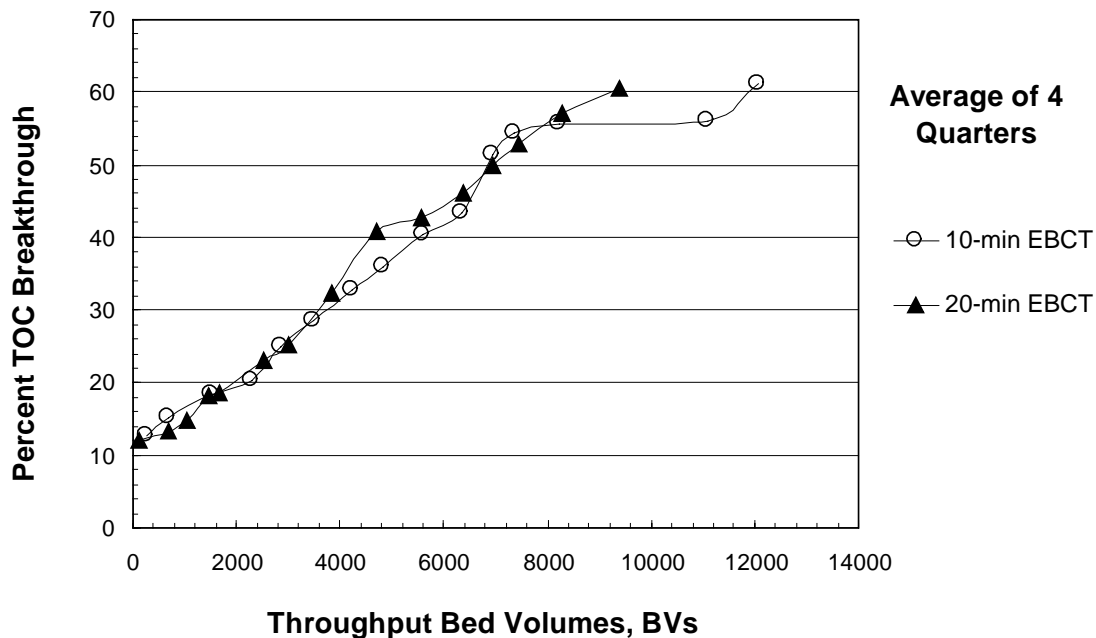


Figure 10. Impact of EBCT on Percent TOC Breakthrough

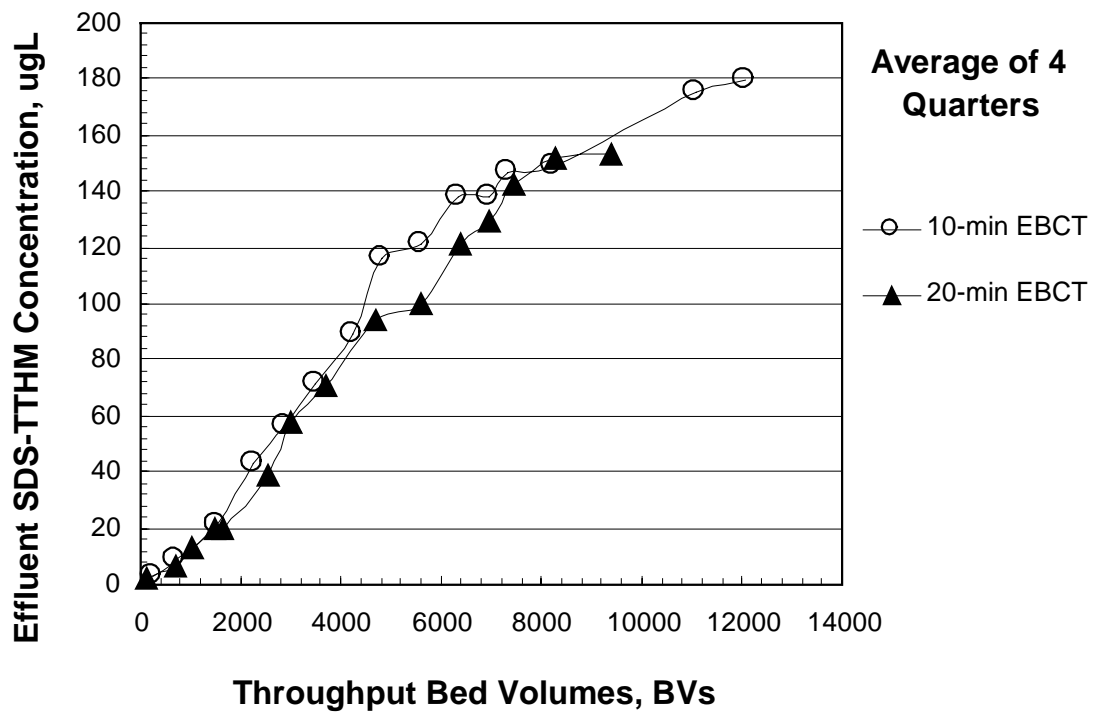


Figure 11. Impact of EBCT on SDS-TTHM Breakthrough

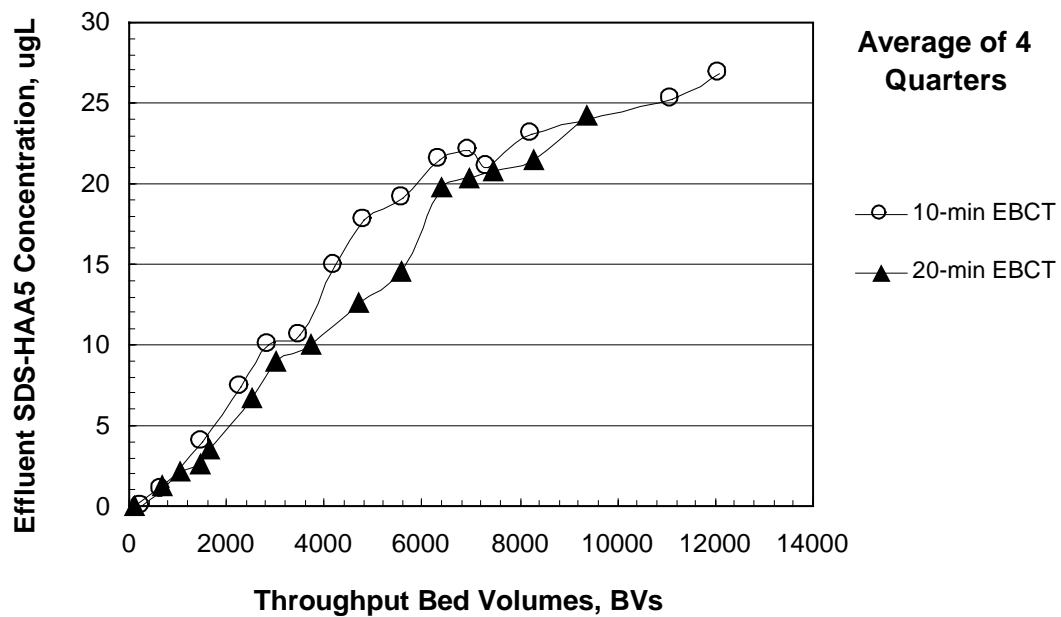


Figure 12. Impact of EBCT on SDS-HAA5 Breakthrough

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

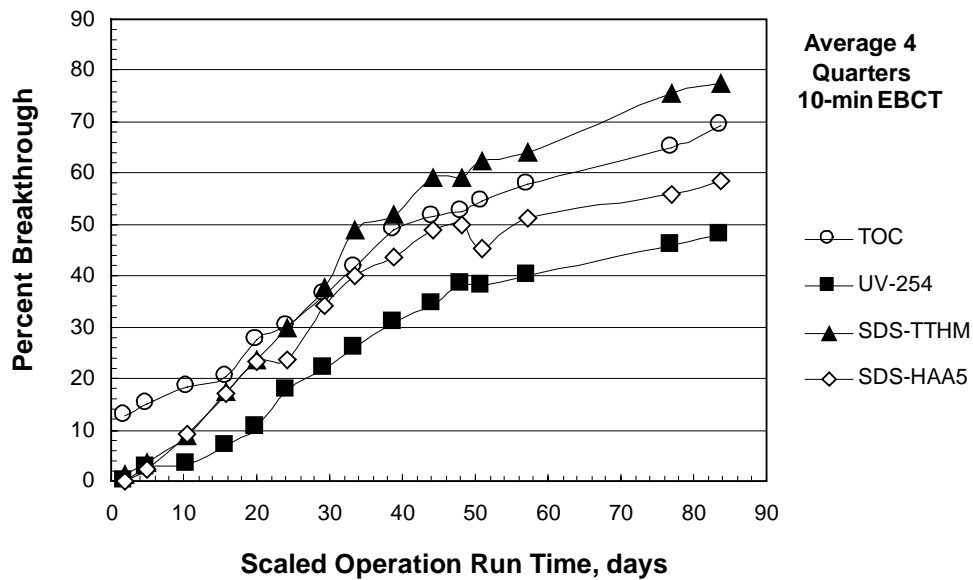


Figure 13. Breakthrough of TOC, UV-254 and SDS-DBPs from 10-min EBCT GAC Column

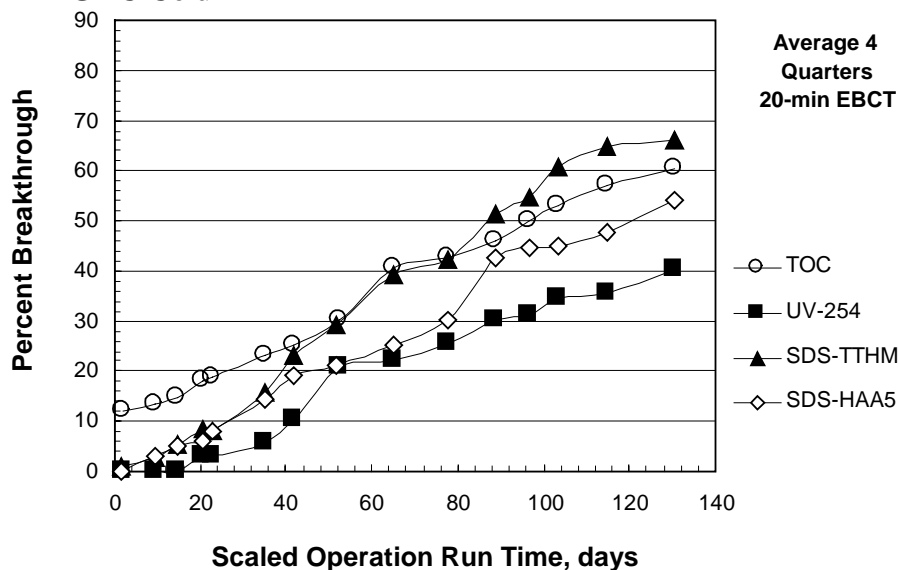


Figure 14. Breakthrough of TOC, UV-254 and SDS-DBPs from 20-min EBCT GAC Column

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. (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 of an indicator for DBP precursors, but remains a simple and cheap method to quantify percent SDS-DBP breakthrough curves. 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 rates (CURs) in lb GAC/1000 gal of processed water required to meet 80% of 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 117 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 Corpus Christi, 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	234	64	28	752	1.5	63
			32	14	496	2.2	95
HAA5	µg/L	49	48	108	>3015	<0.4	<17
			24	54	>2368	<0.5	<22

* 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	234	64	28	927	1.3	54
			32	14	662	1.8	75
HAA5	µg/L	49	48	108	>2347	<0.5	<21
			24	54	>2319	<0.5	<22

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

4.6.1.1 GAC Replacement Costs

Based on the CURs and a GAC price of \$0.75/lb, the GAC replacement costs were 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. In the 10-min EBCT contactor, the GAC replacement cost required to meet 80% of Stage 2 MCL of TTHMs ranged from \$2.30/1000 gal during the Fall to \$1.04/1000 gal during the Summer. The cost to meet Stage 2 MCL for HAA5 was lower, ranging from \$0.76/1000 gal during the Fall quarter to less than \$0.25/1000 gal during the Summer quarter. In the 20-min EBCT contactor, the cost to meet Stage 2 MCL for TTHMs ranged from \$1.90/1000 gal in the Fall quarter to \$0.79/1000 gal in the Summer quarter. In all cases, the Stage 2 MCL for HAA5 was not exceeded during the course of the column runs. Using a 20-min EBCT resulted in a cost reduction in GAC replacement costs of approximately 17% to 24%.

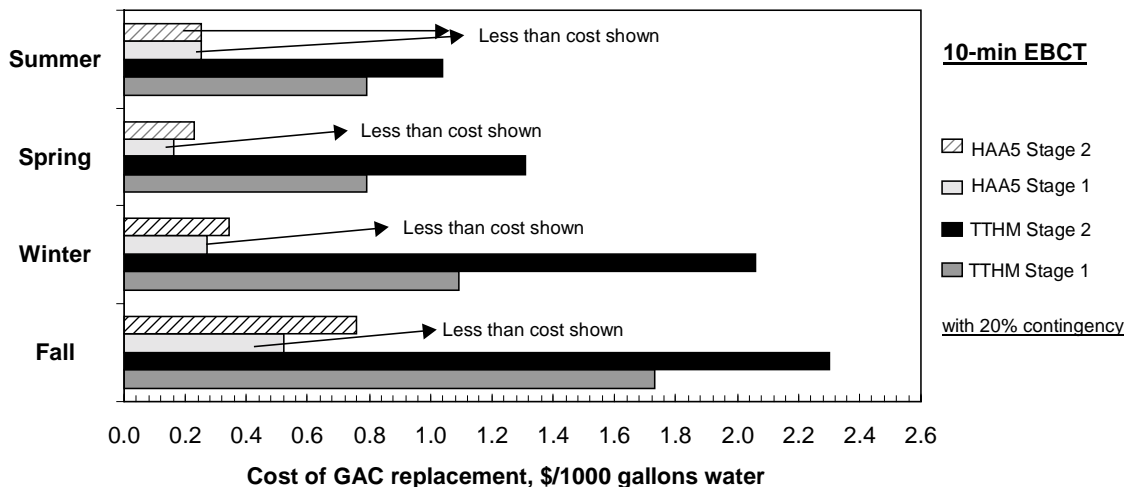


Figure 15. Cost of GAC Replacement from the 10-min EBCT Contactor to Meet Target DBP MCL Criteria

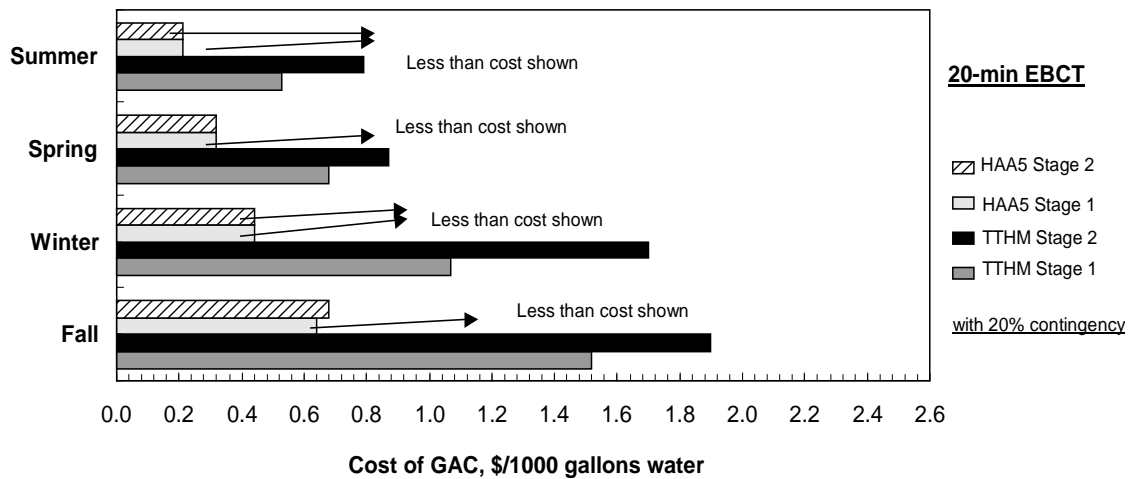


Figure 16. Cost of GAC Replacement from the 20-min EBCT Contactor to Meet Target DBP MCL Criteria

The average annual GAC replacement costs can be estimated from the average cost of GAC replacement per 1000 gal treated water (over the four quarters) to meet 80% of the Stage 2 TTHM MCL, and an average flowrate of 117 mgd. For a 10-min EBCT, the average annual GAC replacement cost was estimated at \$71,744,400. The average annual GAC replacement cost for a 20-min EBCT was estimated at \$55,943,550. These costs are extremely high, and GAC replacement is not considered to be a feasible option.

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 117 mgd, and are presented in Tables 16 and 17. Given that the Stage 2 MCL for HAA5 was not exceeded in all four quarters, GAC reactivation costs will be based on the Stage 2 MCL for TTHM. According to these high carbon usage rates, GAC reactivation would not be a practical technology, given that the costs incurred would be too high. Typical carbon usage rates vary from 1 to 10 million pounds per year. Based on the 10-min EBCT average CUR of 95 million lbs/yr (10844.7 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 4338 square feet. Based on the 20-min EBCT average CUR of 75 millions lbs/yr (8562 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 3424.6 square feet. Since these surface area falls out from the range of the developed existing cost equations presented in the next section, 10 reactivators will be assumed for the purpose of analysis, with the effective hearth area per reactivator at 433.8 square feet for

the 10-min EBCT and at 342.5 square feet for the 20-min EBCT. The capital and O&M costs will be estimated for one reactivator and multiplied thereafter by a factor of 10. Capital and O&M costs for thermal GAC reactivation and using a 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	433.79
Total reactivator are, sq-ft	4337.9
Capital amortization	$I = 6$ percent over $N = 30$ years
Capital recovery factor CRF	0.117
Labor and fringe rate	\$25/hr
Electric rate	\$ 0.08/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

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	10845	8562
Surface area per reactivator, sq-ft	433.79	342.46
CAPITAL COSTS		
CC, 1998 \$	3,941,924.64	3,576,558
Annual capital costs per reactivator, \$/yr	\$286,736	\$259,833
O& M COSTS		
PE, kwh/yr	980411	878113
Annual PE costs, \$/yr	\$78,433	\$70,249
BE, kwh/yr	28315	26030
Annual BE costs, \$/yr	\$2,265	\$2,082
MM costs, 1998 \$/yr	\$65,097	\$59,210
OL, workhours/yr	22705	19688
Annual OL costs, \$/yr	\$567,635	\$492,195
NG requirement, scft/yr	68237499	55296694
Annual NG cost, \$/yr	\$375,306	\$304,132
Total O&M Annual Costs per reactivator, \$/yr	\$1,088,736	\$927,868
TOTAL ANNUAL COSTS per reactivator, \$/yr	\$1,375,113	\$1,187,701

The costs incurred for the amount of GAC used would be ten times greater than those shown in Table 17. Although these costs are much lower than those for replacing the carbon, they remain too high 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 (Excluding GAC Replacement and Reactivation 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 Corpus Christi. The following analysis will include GAC reactivation cost.

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

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	$I = 6$ percent over $N = 30$ years
Capital recovery factor CRF	0.117
Labor and fringe rate	\$25/hr
Electric rate	\$ 0.08/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 Corpus Christi, the following design parameters were assumed:

- Total plant capacity $Q' = 167$ mgd; $70\% Q' = Q = 117$ mgd = 10854 cu-ft/min;
- Hydraulic loading $Q/A = 5$ gpm/sq ft = 0.6685 cu-ft/min/sq ft;
- 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 rates. These costs include the cost of GAC thermal reactivation costs.

Table 18
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	10,854	21,708
Total GAC effective volume, cu-ft	108,540	217,080
CAPITAL COSTS		
z (in CC equation)	1	1
CC, 1998 \$	10,830,073	17,659,475
Annual capital costs, \$/yr	786,793	1,282,941
O & M COSTS		
PE, kwh/yr	194,832	194,832
Annual PE costs, \$/yr	15,586	15,586
BE, kwh/yr	2,532,055	2,532,055
Annual BE costs, \$/yr	202,564	202,564
MM costs, 1983 \$/yr	35,486.4	35,486.4
MM costs, 1998 \$/yr	45,401	45,401
z (in OL equation)	0	0
OL, workhours/yr	10,577	10,577
Annual OL costs, \$/yr	264,430	264,430
Total O&M Annual Costs, \$/yr	527,988	527,988
Annual GAC reactivation cost, \$/yr	13,751,130	11,877,010
ANNUAL COSTS (excluding reactivation), \$/yr	1,314,781	1,810,930
TOTAL ANNUAL COSTS, \$/yr	15,065,911	13,687,940

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 (excluding GAC reactivation costs) are the same for either a 10-min EBCT or 20-min EBCT contactor, since both these costs are based on a 5 gpm/sq-ft hydraulic loading rate. Total annual costs (including GAC reactivation costs) were observed to be 9% lower when using a 20-min EBCT over a 10-min EBCT.

4.7 Summary of Significant Results

- The impact of seasonal variability was observed in the breakthrough curves of indicators of natural organic matter (TOC, UV-254) and precursors of TTHMs and HAA5 upon SDS chlorination. The Fall quarter (September sampling) was observed to be the most critical for DBP precursor removal. During this month, the highest TOC concentration and UV-254 absorbance were recorded (5.8 mg/L and 0.137/cm), a high average distribution system temperature was measured (31°C), the highest chlorine demand was measured (6.1 mg/L) and the highest concentrations of SDS- TTHM, HAA5 and TOX were measured (256 µg/L, 78 µg/L and 388 µg/L, respectively).
- The impact of seasonal variability was also observed in the DBP speciation. The concentration of bromide recorded in the influent to each RSSCT was observed to impact the speciation of TTHMs and HAAs formed in the RSSCT effluent samples. The highest bromide concentrations were recorded during the Winter and Spring quarters. A higher proportion of brominated DBPs was thus formed during these quarters in the effluent of the GAC samples.
- When normalizing for EBCT, a small benefit in carbon use was observed for DBP control by using a 20-min EBCT versus a 10-min EBCT.
- TOC breakthrough was 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.
- The impact of seasonal variability was also observed in the variation of the GAC replacement costs per quarter. GAC replacement costs were limited by the SDS-TTHM concentration in the effluent of the columns. In the 10-min EBCT contactor, the costs to meet 80% of the Stage 2 TTHM MCL ranged from \$2.30/1000 gal during the Fall to \$1.04/1000 gal during the Summer. In the 20-min EBCT contactor, the costs to meet 80% of the Stage 2 MCL for TTHMs ranged from \$1.90/1000 gal during the Fall to \$0.79/1000 gal during the Summer. Using a 20-min EBCT compared to a 10-min EBCT resulted in a 17% to 24% cost reduction. The average annual GAC replacement costs were estimated at \$71,744,400 for a 10-min EBCT and at \$55,943,550 for a 20-min EBCT. These costs are too high and GAC replacement would not a feasible approach. Based on the carbon utilization rates, total annual costs incurred by on-site thermal regeneration of GAC were estimated at \$15,065,911 for a 10-min EBCT, and at \$13,687,940, for a 20-min EBCT. Although much lower than GAC replacement costs, reactivation costs remain high, and GAC reactivation would not be a practical and feasible approach.
- The total annual cost (including reactivation cost) for a conventional concrete gravity GAC adsorber was 9% lower when using a 20-min EBCT design compared to a 10-min EBCT design. Annual capital costs of a 10-min EBCT contactor were estimated to be 38% lower than those for a 20-min EBCT contactor.

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. Quarterly laboratory data sheets are attached in a diskette. 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 attached in 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. 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. All other regulated analyses, including Br, TOX, THMs, and HAAs were performed by MW laboratories or by their sub-laboratories.

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

6. References

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

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Standard Methods for the Examination of Water and Wastewater (1996). 19th 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 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	276	64	23	434	2.3	98
			32	12	326	3.1	131
HAA5	µg/L	78	48	62	>1451	<0.69	<29
			24	31	991	1.0	43

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

Table A2
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	249	64	26	686	1.46	62
			32	13	364	2.75	117
HAA5	µg/L	41	48	117	>2806	<0.36	<15
			24	58	2194	0.46	19

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

Table A3
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	194	64	33	944	1.06	45
			32	16	573	1.74	74
HAA5	µg/L	33	48	143	>4739	<0.21	<9
			24	72	3220	0.31	13

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

Table A4
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	219	64	29	946	1.06	45
			32	15	722	1.38	59
HAA5	µg/L	44	48	109	>3068	<0.33	<14
			24	55	>3068	<0.33	<14

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

Table A5
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	276	64	23	492	2.03	87
			32	12	395	2.53	108
HAA5	µg/L	78	48	62	>1183	<0.85	<36
			24	31	1103	0.91	39

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

Table A6
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	249	64	26	702	1.42	61
			32	13	442	2.26	97
HAA5	µg/L	41	48	117	<2280	<0.44	<19
			24	58	2248	<0.44	19

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

Table A7
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	194	64	33	1103	0.91	39
			32	17	860	1.16	49
HAA5	µg/L	33	48	143	>2369	<0.42	<18
			24	72	2369	0.42	18

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

Table A8
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	219	64	29	1409	0.71	30
			32	15	951	1.05	45
HAA5	µg/L	44	48	109	>3556	<0.28	<12
			24	55	3556	<0.28	<12

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

APPENDIX B

Summary Report Spreadsheets

Miscellaneous Information

PWSID	TX1780003
Plant ICR #	641

Full-Scale Plant Information

Item	Result
Primary Disinfectant	CIO2 and chloramir (Pri Disinf, Free Cl2, Chloramines, Chlorine Dioxide, Ozone)
Residual Disinfectant	chloramines (Sec Disinf, Free Cl2, Chloramines, Chlorine Dioxide)
Source Type	River and Lake (River/Stream, Lake, Reservoir, Aquifer)
Source Name	Nueces & Texana

Laboratory Information

Item	ICR ID or Abbrev	Lab Name	Lab Type	Lab City	Lab State
Lab #1	MWL-CA013	Montgomery Watson	commercial	Los Angeles	CA
Lab #2	RCFF	MW Applied Research Departm	consultant	Los Angeles	CA
Lab #3	Babcock-CA009	E.S. Babcock & Sons	commercial	Riverside	CA
Lab #4	Weck-CA041	Weck Laboratories Inc	commercial	Industry	CA

(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	9/16/97	12/15/97	3/10/98	6/16/98

1998 Flow and Population Information

Source	Flow (mgd)	Population Served
Total Population Served		290247
Surface Water	82	82
Ground Water	0	0
Purchased Finished Water	0	0
Total	82	

Full-Scale Water Quality Data

Full-Scale Influent Water Quality Data

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	22.6	4.5	15.5	28.1	12
pH	Unit	8.1	0.2	7.9	8.5	12
Turbidity	ntu	26.62	11.2	15	58	12
Alkalinity	mg/L as CaCO ₃	160	7.7	144	170	12
Total Hardness	mg/L as CaCO ₃	213	23	182	256	12
Calcium Hardness	mg/L as CaCO ₃	NA	NA	NA	NA	NA
TOC	mg/L	4.78	0.73	4	6.2	12
UV ₂₅₄	1/cm	0.136	0.063	0.095	0.332	12
Bromide	µg/L	NA	NA	NA	NA	NA
TSUVA*	L/(mg*m)	2.84		2.37	5.35	12

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

Full-Scale Finished Water Quality Data

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	NA	NA	NA	NA	NA
pH	unit	8.02	0.15	7.68	8.22	12
Turbidity	ntu	0.15	0.15	0.05	0.66	12
TOC	mg/L	3.64	0.61	3	5.1	12
UV ₂₅₄	1/cm	0.103	0.027	0.076	0.181	12
DS-THM4	µg/L	51.2	12.9	34	64.5	4
DS-HAA5	µg/L	NA	NA	NA	NA	NA
DS-HAA6	µg/L	NA	NA	NA	NA	NA

QA/QC Data - Sheet 1													
Analyte Identification	Units	Laboratory Identification	Start Service Date	End Service Date	Method	MRL	Count	Average	Std Dev	Percentiles			
										25th	50th	75th	
pH	unit												
Temperature	C												
Alkalinity	mg/L as CaCO3												
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	9/4/98	9/9/98	SM 2340B	10							
Turbidity	ntu												
Bromide	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 300.0	20	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	192 392 5	2.7% 102% 100%	4.9% 7% 2%	0.0% 98% 99%	0.9% 101% 100%	3.9% 105% 100%
UV254	1/cm												
TOC	mg/L												
SDS-TOX	µg Cl-/L	ICR-CA013	9/1/97	5/1/99	SM5320B	25	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	865 883 5	4% 100% 88%	4% 20% 8%	1% 92% 85%	3% 98% 86%	6% 105% 88%
SDS-CHCl3	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 524.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	41 47 5	7% 105% 94%	5% 16% 10%	3% 3% 87%	7% 7% 90%	11% 11% 98%
SDS-BDCM	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 524.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	43 47 5	7% 108% 97%	6% 16% 6%	3% 3% 93%	6% 6% 95%	8% 8% 97%
SDS-DBCM	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 524.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	43 47 5	9% 108% 94%	9% 17% 7%	2% 2% 89%	6% 6% 96%	13% 13% 98%
SDS-CHBr3	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 524.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	38 47 4	10% 114% 88%	11% 15% 17%	2% 2% 77%	8% 8% 88%	11% 11% 98%
THM4	µg/L	ICR-CA013	9/1/97	5/1/99	EPA 524.2		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	45 47 4	9% 109% 94%	8% 13% 8%	5% 2% 91%	6% 8% 93%	11% 11% 96%
SDS-MCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	2	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	94 447 5	11% 107% 92%	12% 25% 5%	3% 97% 90%	6% 105% 91%	13% 115% 93%
SDS-DCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	367 444 5	4% 106% 90%	6% 41% 9%	0% 97% 85%	2% 100% 88%	6% 106% 88%
SDS-TCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	325 444 5	3% 108% 96%	6% 57% 12%	0% 97% 90%	2% 100% 92%	5% 110% 93%
SDS-MBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	48 448 5	10% 112% 89%	12% 27% 7%	0% 100% 84%	7% 105% 93%	16% 110% 94%
SDS-DBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	199 447 5	5% 105% 98%	6% 24% 15%	0% 97% 91%	3% 100% 94%	7% 106% 95%
SDS-BCAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	325 447 5	4% 103% 95%	6% 19% 12%	0% 97% 90%	3% 100% 91%	6% 105% 92%
SDS-TBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	4	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	11 320 0	3% 113% 113%	2% 24% 24%	1% 103% 104%	2% 115% 110%	4% 125% 120%
SDS-CDBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	2	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	133 407 0	4% 113% 113%	5% 24% 24%	0% 104% 104%	3% 110% 110%	5% 120% 120%
SDS-DCBAA	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	325 435 0	4% 113% 113%	6% 22% 22%	0% 103% 103%	3% 110% 110%	6% 120% 120%
HAA5	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	385 448 5	5% 108% 100%	5% 23% 8%	1% 99% 87%	4% 103% 93%	6% 109% 93%
HAA6	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:	385 448 5	5% 107% 100%	5% 20% 9%	2% 99% 87%	4% 103% 92%	6% 108% 93%
HAA9	µg/L	ICR-CA013	9/1/97	5/1/99	SM6251B		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:	387 448	5% 109%	4% 17%	2% 102%	4% 106%	6% 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 -WECK laboratory											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 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					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:							
SDS-CHCl ₃	µg/L	WECK	6/27/98	6/29/98	524.2	0.5	2	7.1	2.6	NA	5.2	8.9	
						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	3	103.6	1.2	102.8	103	105	
SDS-BDCM	µg/L	WECK	6/27/98	6/29/98	524.2	0.5	3	101.4	7.8	92.4	105.9	106	
						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	3	9.8	6.9	3.5	8.7	17.2	
SDS-DBCm	µg/L	WECK	6/27/98	6/29/98	524.2	0.5	3	103.5	4.8	99.9	101.6	109	
						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	3	99.1	4.4	94.4	100	103	
SDS-CHBr ₃	µg/L	WECK	6/27/98	6/29/98	524.2	0.5	3	8.6	5.1	2.8	11.3	11.8	
						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	3	95.6	4.7	92.3	93.5	101	
SDS-CHBr ₃	µg/L	WECK	6/27/98	6/29/98	524.2	0.5	3	95.2	4.1	91.6	94.3	99.7	
						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	3	11.2	8.4	3.6	10	20.2	
THM4	µg/L	WECK	6/27/98	6/29/98	524.2		3	85.3	4.3	81.3	84.8	89.8	
						Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	3	88.8	4.9	83.8	89	93.5	
							3	9	3.6	5	10	12	
							3	97	3.7	94.5	95.3	101.2	
							3	96.1	4.3	91.9	96	100.5	
SDS-MCAA	µg/L	WECK	5/15/98	5/28/98	SM6251B	2	2						
						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2	122.5					
SDS-DCAA	µg/L	WECK	5/15/98	5/28/98	SM6251B	1	2						
						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2	97.5					
SDS-TCAA	µg/L	WECK	5/15/98	5/28/98	SM6251B	1	2						
						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2	NA					
SDS-MBAA	µg/L	WECK	5/15/98	5/28/98	SM6251B	1	2						
						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2	120					
SDS-DBAA	µg/L	WECK	5/15/98	5/28/98	SM6251B	1	2	9.2					
						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2	130					
SDS-BCAA	µg/L	WECK	5/15/98	5/28/98	SM6251B	1	2						
						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	2	NA					
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	WECK	5/15/98	5/28/98	SM6251B		2						
						Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	2						
HAA6	µg/L	WECK	5/15/98	5/28/98	SM6251B		2						
						Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:	2						
HAA9	µg/L					Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:							

QA/QC Data - Babcock laboratory										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 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	2/19/98	7/7/98	SM5320B	25	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	62 30 3	6.4 109 93	5.4 19.7 8.5	3.1 97 83	6.1 107 96	8.2 112 99
SDS-CHCl ₃	µg/L	Babcock	6/18/98	7/7/98	EPA 551.1	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1 3 3	0 95 100	NA 13 4.9	0 80 97	0 98 98	0 107 106
SDS-BDCM	µg/L	Babcock	6/18/98	7/7/98	EPA 551.1	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1 3 3	2.3 103 108	NA 3.5 9.1	2.3 100 98	2.3 103 109	2.3 107 116
SDS-DBCM	µg/L	Babcock	6/18/98	7/7/98	EPA 551.1	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1 3 3	0 116 110	NA 8.5 3	0 108 107	0 116 110	0 125 113
SDS-CHBr ₃	µg/L	Babcock	6/18/98	7/7/98	EPA 551.1	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1 3 3	0 96 105	NA 46.8 12.7	0 42 90	0 120 111	0 126 113
THM4	µg/L	Babcock	6/18/98	7/7/98	EPA 551.1		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	1 3 3	0.6 103 106	1.2 17.7 6.7	0.6 82.5 98	0.6 109 9	0.6 116 110
SDS-MCAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	2	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	0 106 93	0 10.6 17.9	0 100 78	0 105 89	0 115 113
SDS-DCAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	1 97 82	2 7 15	0 95 67	0 95 83	1 105 97
SDS-TCAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	0.3 103 86	0.8 11 8.5	0 95 77	0 105 87	0 115 94
SDS-MBAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	0 102 82	0 12.8 11.3	0 95 69	0 100 88	0 120 89
SDS-DBAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	0.3 101 78	0.8 12.7 14.4	0 90 61	0 105 86	0 115 86
SDS-BCAA	µg/L	Babcock	6/18/98	7/7/98	SM6251 B	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	6 8 3	0.5 101 77	1.2 10.3 12.9	0 95 66	0 105 73	0 110 91
SDS-TBAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:							
SDS-CDBAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:							
SDS-DCBAA	µg/L					RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:							
HAA5	µg/L	Babcock	6/18/98	7/7/98	SM6251 B		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	6 8 3	0.5 102 83	0.4 8.9 11.6	0.3 94 70	0.5 103 88	1 113 91
HAA6	µg/L	Babcock	6/18/98	7/7/98	SM6251 B		Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:						
HAA9	µg/L					Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix:							

QA/QC Data - 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	OH033	8/25/98	8/26/98	SM 5320 B	25	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	12	3.4	5.2	0.7	2.0	2.4
SDS-CHCl3	µg/L						RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	5	90.3	4.5	90.9	91.3	93.1
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	8/27/98	8/27/98	EPA 552.2	2	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	111.3				
SDS-DCAA	µg/L	OH033	8/27/98	8/27/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	4	86.9	18.9	80.2	91.4	98.1
SDS-TCAA	µg/L	OH033	8/27/98	8/27/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	3.4				
SDS-MBAA	µg/L	OH033	8/27/98	8/27/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	98.8				
SDS-DBAA	µg/L	OH033	8/27/98	8/27/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	4	88.5	13.8	85.2	93.7	97.0
SDS-BCAA	µg/L	OH033	8/27/98	8/27/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	94.5				
SDS-TBAA	µg/L	OH033	8/27/98	8/27/98	EPA 552.2	4	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	4	81.8	8.2	75.3	81.1	87.5
SDS-CDBAA	µg/L	OH033	8/27/98	8/27/98	EPA 552.2	2	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	110.8				
SDS-DCBAA	µg/L	OH033	8/27/98	8/27/98	EPA 552.2	1	RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	4	82.2	16.0	80.7	88.2	89.7
HAA5	µg/L	OH033	8/27/98	8/27/98	EPA 552.2		RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	2.1				
HAA6	µg/L	OH033	8/27/98	8/27/98	EPA 552.2		RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	95.3				
HAA9	µg/L	OH033	8/27/98	8/27/98	EPA 552.2		RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	4	89.7	9.1	86.0	91.9	95.5
							RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	2.7				
							RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	96.0				
							RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	4	84.4	10.7	82.6	88.3	90.1
							RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	92.3				
							RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	95.5				
							RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	8.7				
							RPE of Analytical Duplicates: % Recovery for Lab Fortified Matrix: % Recovery for PE Samples:	1	99.0				
							Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	1	2.7				
							Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	1	102.1				
							Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	4	85.8	12.3	83.5	90.8	93.1
							Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	1	2.7				
							Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	1	101.1				
							Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	4	85.6	12.0	83.6	90.4	92.3
							Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	1	4.2				
							Avg RPE of Indiv Anal Dupl: Avg % Recov for Indiv Lab Fort Matrix: Avg % Recov for Indiv PE Samples:	1	99.3				

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	Sep-97	Jun-98	SM 4500-H+								
Temperature	C	RCFF	Sep-97	Jun-98	SM 2550 B								
Alkalinity	mg/L as CaCO ₃	RCFF	Sep-97	Jun-98	SM 2320 F	5 mg/L as CaCO ₃							
Ammonia	mg NH ₃ -N/L	RCFF	Sep-97	Jun-98	SM 4500-F	0.10 mg/L as N							
Calcium Hardness	mg/L as CaCO ₃												
SDS-Cl ₂ Residual	mg/L	RCFF	Sep-97	Jun-98	SM 4500-Cl	0.2 mg/L							
Total Hardness	mg/L as CaCO ₃	RCFF	Sep-97	Mar-98	SM 2340 F	7 mg/L as CaCO ₃							
Turbidity	ntu	RCFF	Sep-97	Jun-98	SM 2130 F	0.05 ntu							
Bromide	µg/L		Sep-97	Jun-98									
						RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
UV ₂₅₄	1/cm	RCFF	Sep-97	Jun-98	SM 5910	0.009 1/cm	32	2.77	3.59	0	1.53	6.35	
						RPE of Analytical Duplicates:	NA	NA	NA	NA	NA	NA	
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:	NA	NA	NA	NA	NA	NA	
TOC	mg/L	RCFF	Sep-97	Jun-98	SM 5310	0.5 mg/L	33	4.97	7.35	0	3.92	5.41	
						RPE of Analytical Duplicates:	34	101	10	97	103	105	
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:	NA	NA	NA	NA	NA	NA	
SDS-TOX	µg Cl ⁻ /L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-CHCl ₃	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-BDCM	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-DBCM	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-CHBr ₃	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
THM4	µg/L					Avg RPE of Indiv Anal Dupl:							
						Avg % Recov for Indiv Lab Fort Matrix:							
						Avg % Recov for Indiv PE Samples:							
SDS-MCAA	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-DCAA	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-TCAA	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-MBAA	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-DBAA	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-BCAA	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-TBAA	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-CDBAA	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
SDS-DCBAA	µg/L					RPE of Analytical Duplicates:							
						% Recovery for Lab Fortified Matrix:							
						% Recovery for PE Samples:							
HAA5	µg/L					Avg RPE of Indiv Anal Dupl:							
						Avg % Recov for Indiv Lab Fort Matrix:							
						Avg % Recov for Indiv PE Samples:							
HAA6	µg/L					Avg RPE of Indiv Anal Dupl:							
						Avg % Recov for Indiv Lab Fort Matrix:							
HAA9	µg/L					Avg RPE of Indiv Anal Dupl:							
						Avg % Recov for Indiv Lab Fort Matrix:							

July 12, 1999

Mr. Steve Allgeier
ICR Treatment Study Coordinator
U.S. Environmental Protection Agency
Technical Support Center (MS 140)
26 West Martin Luther King Drive
Cincinnati, OH 45268

Re: Response to Comments on Corpus Christi RSSCT: O.N. Stevens, ICR Plant # 641

Dear Mr. Allgeier,

The purpose of this letter is to respond to your comments and questions regarding the bench-scale GAC testing conducted for the City of Corpus Christi O.N. Stevens Water Treatment Plant (plant # 641).

All revisions were made to the *ICR Database* sheets and *Summary Spreadsheets*, and are being sent to you electronically along with this letter. General comments common to all quarters will first be addressed, followed by specific comments to each quarter.

General Comments

1. Please include historic average water temperature and current water process rate:

These will be included in the database for all quarters. Information is being gathered by the City.

2. Was the reported temperature measured?

The actual water temperature was not measured for all the 15 samples. However, the RSSCT setup was located throughout the four quarters in a temperature-controlled laboratory in which the temperature ranged between 22°C and 24°C which was confirmed by frequent measurements. As far as the analyses are concerned, the water, which is stored in a fridge at 4°C, allowed to warm up to room temperature before any analysis was conducted. In subsequent tests performed for other utilities, the water temperature was measured on all 15 samples. A footnote was added in the database regarding this issue

3. Are the values reported for the SDS conditions target values or measured values? The measured SDS conditions should be reported.

During the first and the fourth quarters, bottles were incubated at 31°C and 32°C, respectively. The incubator (Fisher Scientific, low temperature incubator, Model # 307) has an operational range of -10°C to +50°C, and a deviation of ± 0.5 -1°C. During the first quarter, the incubator temperature was recorded in the database sheet, however during the last quarter; the SDS temperatures were measured in all samples. As shown in the database sheet, the temperature fluctuation during this last quarter was minimal, with temperatures fluctuating between 32°C and 33°C. As for the second and third quarters, the samples were incubated at room temperature (target distribution system temperature of 23°C for both quarters). Again, the temperature was not measured for all samples, and some spot checks were performed. This was however rectified for subsequent studies conducted for other utilities.

As far as the SDS pH is concerned, the actual pH on all samples was measured during quarters 2, 3, and 4, however the target value was recorded in the database sheet for the first quarter. pH fluctuation during the last three quarters was however minimal, with a measured variability of ± 0.2 .

A footnote was included on this issue in the ICR database sheets.

4. Is the reported full-scale temperature the measured average temperature for this season?

The full-scale temperature used in the RSSCT design of all four quarters was recorded as 20°C. All four quarters RSSCTs were conducted at room temperature. A minimum Reynolds number value was assumed at 0.5 for the design. The actual water temperatures during the 18-month monitoring campaign are included in Table 1. The actual sampling dates for the water are September 1997, December 1997, March 1998 and finally, June 1998. The average temperature for the Fall season, Winter season, Spring season, and Summer season are the following: 24.3°C, 18.3°C, 23.3°C, and 32.0°C. We will modify the design sheets to include the actual temperatures, and modify the assumed minimum Reynolds number slightly (by 0.05 to 0.1) to obtain the initial operational design parameters (at 20°C) are obtained.

Table 1

**Actual Water Temperatures during the 18-month ICR Monitoring Campaign
-Raw Water-**

Month	Temperature (°C)
July 1997	30.8
August 1997	30
September 1997	31
October 1997	22
November 1997	20
December 1997	16
January 1998	19
February 1998	20
March 1998	17
April 1998	27
May 1998	26
June 1998	32
July 1998	32
August 1998	32
September 1998	29
October 1998	26
November 1998	22
December 1998	17

Specific Comments

Quarter 1

1. The first sentence of section 4.1.4 reads "During the Winter and Spring quarter testing...". Did you actually mean Fall and Winter?

Yes, we meant Fall and Winter.

2. The first sample collection date was 9/16 and the study did not commence until 11/3.
Describe what tests were conducted to ensure that the sample was stable during storage.

During the period running from sample collection and actual RSSCT run, the sample was undergoing pre-treatment. During this first quarter, reaching actual full-scale filtered water

quality was targeted. Since this approach took a long time and effort, it was decided that for the remaining quarters full-scale operational parameters (chemical type, dose and operation) will be targeted instead of full-scale water quality. During the pretreatment optimization testing, several water quality parameters were measured on various days. Table 2 summarizes these parameters and their values. The results show that the water quality did not undergo significant changes during storage. For example, the TOC concentration in the water varied from 5.5 mg/L to 6.5 mg/L, with an average of 5.9 mg/L and a standard deviation of 0.4 mg/L.

Table 2
Summary of Pre-treatment Results

Date/test	TOC, mg/L
10-16-97	5.5
10-17-97	5.7
10-20-97	
Jar 1	6.5
Jar 2	6.5
Jar 3	6.5
Jar 4	5.8
Jar 5	5.9
Jar 6	5.6
10-24-97	5.5
Week of 10-28-99	5.6

3. Please verify that no full-scale temperature, bromide, or HAA data is available.

These were added to the water quality spreadsheet.

4. Babcock QA/QC were verified and corrected.

Please refer to attached *Summary Spreadsheet*.

Quarter 2

1. Was any additional TOC monitoring conducted during the second half of the season

Yes. One last TOC measurement was conducted at the end of the 20-min column run. The concentration was 4.1 mg/L.

2. Please verify TOX spike in 10 minute column.

The high TOX spike was checked. This was the actual result measured by MW Laboratories.

Quarter 3

1. During the first two quarters, ammonia was reported to be BMRL. During this quarter, ammonia is reported as NR.

During quarter 3, ammonia was first measured in the collected raw water at 0.46 mg/L. Ammonia was then measured in the influent RSSCT samples; however the actual measurements were erroneous. This error was caught too late (after the samples were disposed off). We therefore reported the concentration as NR.

Quarter 4

TTHM results were checked. They are the measured values. Even though the RPD is high, these duplicate samples are field duplicates; collected at different times (one after the other). TTHM concentration in the column effluent may therefore vary between each duplicate.

I hope these responses are to your satisfaction. If you have additional comment, or question, please do not hesitate to contact me.

Sincerely,

Lina Boulos
Montgomery Watson

Attachment Enclosed

cc: Hubert Hall, City of Corpus Christi
Issam Najm, MW
Daniel Askenaizer, MW
Joseph Marcinko, MW