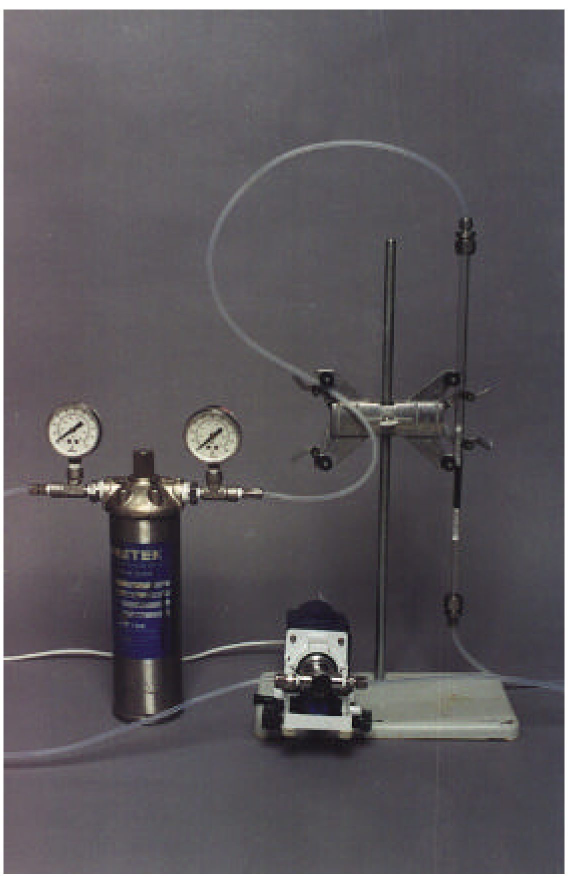
Final Report

ICR Treatment Study Summary Report

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

Conducted during the period of May 6, 1998 through March 24, 1999



Submitted: July 9, 1999

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Ann Arbor Water Treatment Plant
ICR # 411

Attachments: 1 CD-ROM containing the *Data Collection Spreadsheets* and *Treatment Study Summary Report Spreadsheets*

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Contents

1. Conclusions and Recommendations

Finished water quality data collected for the purposes of the ICR (Information Collection Rule) and submitted by the Ann Arbor Water Treatment Plant (WTP) indicate that the WTP was well within compliance with the Stage 1 MCLs (maximum contaminant levels) for total trihalomethanes (TTHMs, or THM4) and haloacetic acids (HAAs or HAA5). Annual average concentrations at distribution system monitoring points were 3.7 µg/L for THM4 and 4.3 µg/L for HAA5, compared to Stage 1 MCLs of 80 µg/L and 60 µg/L, respectively. The average annual concentrations of these compounds were also well within compliance with the proposed Stage 2 MCLs of 40 µg/L for THM4 and 30 µg/L for HAA5.

The treatment data indicate that THM precursors were more difficult to control than HAA precursors, and that simulated distribution system (SDS)-THM4 concentrations would control carbon usage rates. SDS-HAA5 levels in the influent water were less than the proposed Stage 2 MCLs, and therefore, no treatment was required for removal of HAA precursors. The data also show that GAC adsorbers sized to provide a 20-minute empty bed contact time (EBCT) would provide somewhat more efficient use of carbon than 10-minute EBCT adsorbers. Carbon usage, based on the test results, could be expected to be substantially higher in the summer months. Summer (July) carbon requirements were estimated to be 570 to 950 lbs/MG, whereas carbon usage rates in other quarters of testing ranged from zero (no breakthrough) to 300 lbs/MG.

While GAC adsorption is an effective method for controlling disinfection byproducts in finished drinking water, the Ann Arbor WTP already does an effective job of controlling DBPs by removing precursor material, using ozone for primary disinfection, and using chloramines for secondary disinfection. The generally excellent water quality of finished water from the Ann Arbor WTP (i.e., very low levels of THM4 and HAA5 measured in the distribution system) does not appear to warrant consideration of GAC adsorption treatment for DBP precursor removal.

2. Background Information

2.1 Treatment Plant Description

The City of Ann Arbor, Michigan, Water Treatment Plant has a capacity of 50 MGD and serves approximately 115,000 people. Figure 2-1 is a schematic of the Ann Arbor Water Treatment Plant (WTP). The WTP has two parallel treatment trains, designated Train #1 and Train #2. The unit processes are the same in each treatment train, although some vessel sizes differ. Treatment consists of lime softening, recarbonation, flocculation/sedimentation, primary disinfection, granular activated carbon (GAC) filtration/adsorption, and secondary disinfection. Treatment plant design data are summarized in Table 2-1.

The main treatment challenges at the WTP are:

- Hardness
- Turbidity and particulates
- Disinfection
- Disinfection byproducts

Hardness is reduced by lime softening and tubidity and particles are removed by flocculation with cationic polymer. Disinfection for the removal of potential pathogens is performed at two locations in the treatment sequence: before and after the GAC filters. Unfortunately, disinfection can and does produce unwanted byproducts. Byproduct formation is held in check at the plant by removing precursor material, using ozone for primary disinfection, and using chloramines for secondary disinfection.

2.2 Source/Finished Water Quality

Tables 2-2 and 2-3 summarize source and finished water quality characteristics for the Ann Arbor WTP. The finished water data show that distribution system (DS)-THM4 and DS-HAA5 concentrations are considerably lower than both the Stage 1 MCLs (80 and 60 µg/L, respectively) and the proposed Stage 2 MCLs (40 and 30 µg/L, respectively).

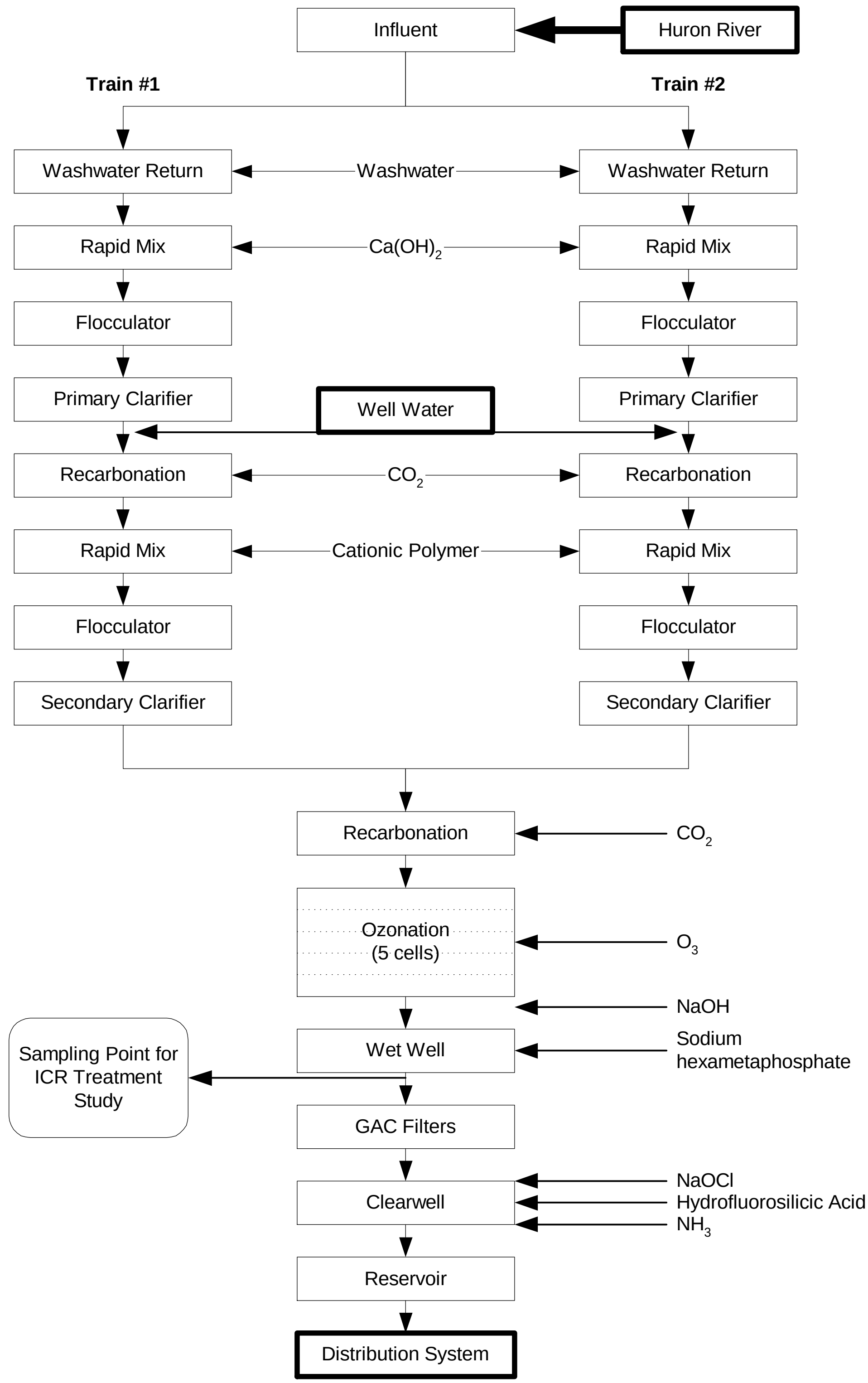

FIGURE 2-1
Ann Arbor Water Treatment Plant Schematic

TABLE 2-1
WTP Design Data

<table>
<tr><th rowspan="2">Unit Process</th><th colspan="6">Process Description</th></tr>
<tr><th colspan="3">Train #1</th><th colspan="3">Train #2</th></tr>
<tr><td>Rapid Mix</td><td colspan="3">Liquid volume (gal): 32,180
Chemical addition: Lime</td><td colspan="3">Liquid volume (gal): 9,965
Chemical addition: Lime</td></tr>
<tr><td>Flocculation</td><td colspan="3">Liquid volume (gal): 462,494
No. of Stages: 3
Liquid Volume per stage (gal): 154,284
Stage Mean Velocity (sec^{-1}): 44, 44, 41</td><td colspan="3">Liquid volume (gal): 327,444
No. of Stages: 3
Liquid Volume per stage (gal): 109,148
Stage Mean Velocity (sec^{-1}): 104, 104, 104</td></tr>
<tr><td>Sedimentation</td><td colspan="3">Surface area (ft^2): 13,970
Liquid volume (gal): 1,279,968</td><td colspan="3">Surface area (ft^2): 13,273
Liquid volume (gal): 1,812,065</td></tr>
<tr><td>Recarbonation</td><td colspan="3">Surface area (ft^2): 132
Liquid volume (gal): 11,848
Chemical Addition: CO_2
Additional Water Source: Well</td><td colspan="3">Surface area (ft^2): 750
Liquid volume (gal): 12,000
Chemical Addition: CO_2
Additional Water Source: Well</td></tr>
<tr><td>Rapid Mix</td><td colspan="3">Liquid volume (gal): 11,766
Chemical addition: Cationic polymer</td><td colspan="3">Liquid volume (gal): 9,965
Chemical addition: Cationic polymer</td></tr>
<tr><td>Flocculation</td><td colspan="3">Liquid volume (gal): 217,176
No. of Stages: 3
Liquid Volume per stage (gal): 72,392
Stage Mean Velocity (sec^{-1}): 80, 50, 25</td><td colspan="3">Liquid volume (gal): 327,444
No. of Stages: 3
Liquid Volume per stage (gal): 109,148
Stage Mean Velocity (sec^{-1}): 104, 104, 104</td></tr>
<tr><td>Sedimentation</td><td colspan="3">Surface area (ft^2): 12,272
Liquid volume (gal): 1,335,235</td><td colspan="3">Surface area (ft^2): 13,273
Liquid volume (gal): 1,996,153</td></tr>
<tr><td></td><th colspan="6">Combined Flow</th></tr>
<tr><td>Recarbonation</td><td colspan="6">Surface area (ft^2): 2,765
Liquid volume (gal): 258,531
Chemical addition: CO_2</td></tr>
<tr><td rowspan="4">Disinfection
(Ozone)</td><td></td><td>Cell #1</td><td>Cell #2</td><td>Cell #3</td><td>Cell #4</td><td>Cell #5</td></tr>
<tr><td>Volume (gal)</td><td>4,800</td><td>14,400</td><td>9,600</td><td>9,600</td><td>6,000</td></tr>
<tr><td>Surface Area (ft^2)</td><td>240</td><td>720</td><td>480</td><td>480</td><td>300</td></tr>
<tr><td>Dose Rate (mg/L as O_3)</td><td>0.0</td><td>1.16</td><td>0.0</td><td>0.0</td><td>0.0</td></tr>
<tr><td>Wet well</td><td colspan="6">Surface area (ft^2): 2,052
Liquid volume (gal): 30,160
Chemical addition: NaOH
Chemical addition: Sodium hexametaphosphate</td></tr>
<tr><td>Filtration
(GAC Filters)</td><td colspan="6">Surface area (ft^2): 11,934
Liquid volume (gal): 624,864</td></tr>
</table>

TABLE 2-1
WTP Design Data

Unit Process	Process Description
Clear Well / Disinfection	Surface area (ft^2): 1,853 Liquid volume (gal): 153,693 Chemical addition: NaOCl Chemical dosage: 3.27 mg/l as Cl_2 Chemical addition: Anhydrous ammonia Chemical dosage: 1.00 mg/l as NH_3 Chemical addition: Hydrofluorosilicic Acid Chemical dosage: 0.8 mg/L as F
Resevoir	Surface area (ft^2): 40,107 Liquid volume (gal): 6,000,000

TABLE 2-2

Source Water Quality

Water Quality Parameter	Units	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
Temperature	° C	16.1		23.5	6.8
pH	pH units	8.1		8.2	7.90
Turbidity	ntu	10.9	7.80	46	0.30
Alkalinity	mg/L as $CaCO_3$	208		212	195
Calcium Hardness	mg/L as $CaCO_3$	35	6.00	46	25
Total Hardness	mg/L as $CaCO_3$	277		309	263
TOC	mg/L	3.1	0.40	3.7	2.4
UV254	cm^{-1}	0.045	0.024	0.110	0.027
SUVA	L/(mg-m)	0.015		0.030	0.011
Bromide	µg/L	0.08	0.03	0.10	BMRL

SUVA = specific ultraviolet absorbance = UV254*100/TOC

BMRL = Below Minimum Reporting Level

TABLE 2-3

Finished Water Quality

Water Quality Parameter	Units	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
Temperature	° C	14.4	7.30	23.9	4.4
pH	pH units	9.3	0.0	9.3	9.3
Turbidity	ntu	0.053	0.02	0.27	0.02
TOC	mg/L	2.4	0.40	3.1	1.8
UV254	cm^{-1}	0.047	0.006	0.10	0.039
DS - THM4	µg/L	3.74	1.12	6.6	1.6
DS - HAA5	µg/L	4.30	2.70	13.4	2.20
DS - HAA6	µg/L	4.30	2.70	13.4	2.20

SUVA = specific ultraviolet absorbance = UV254*100/TOC

DS = distribution system; the DS values are averaged over four distribution system sampling locations.

3. Materials and Methods

3.1 Pretreatment

Water samples for ICR treatment testing were collected at the WTP after ozonation and before the GAC filters. Thus, most of the pretreatment occurred at the WTP. The GAC filtration process used at the WTP was not simulated in lab testing because it was felt that if GAC adsorbers were employed, the GAC caps on the filters would not be used. The only pretreatment performed in the lab was filtration to remove particles and reduce head loss across the carbon columns. During advanced treatment process testing, the feed water was filtered through an in-line Teflon cartridge filter (0.1- to 0.2-µm pore size) installed upstream from the bench-scale carbon columns.

3.2 Advanced Treatment Process

Granular activated carbon (GAC) treatment was simulated in the lab using rapid small-scale column tests (RSSCTs). These tests were performed in accordance with the *ICR Manual for Bench- and Pilot-Scale Treatment Studies* (EPA, 1996a). Figure 3-1 is a schematic of the RSSCT apparatus. The process equipment included a feed tank, feed pump, glass carbon column, glass effluent sampling vessel and plastic effluent tank, Teflon tubing, and stainless steel fittings. All surfaces in contact with the test water were made of inert materials such as Teflon, glass, and stainless steel. Table 3-1 lists RSSCT design data. TOC concentrations measured immediately after pretreatment (i.e., RSSCT Influent TOC in Table 3-1) were used in RSSCT design calculations.

Calgon F-300 carbon was prepared for use in the RSSCTs as follows. A representative sample of GAC was taken from the carbon stock and ground so that the entire amount passed through a 60-mesh sieve (the upper sieve mesh size). The ground carbon passing the 60-mesh sieve but retained on the 80-mesh sieve (the lower sieve mesh size) was reserved for RSSCT testing. After sieving, the ground carbon was washed with organic-free water using the step-wise decanting procedure described in the guidance manual (EPA, 1996a). For carbon:wash-vessel volume ratios of 0.1 or less, about 10 wash-vessel volumes of organic-free water were used for carbon washing. After washing, the ground carbon was dried overnight to a constant weight in a drying oven at 80-90°C. The washed and dried carbon was then transferred to a clean bottle and stored in a desiccator until used. The density of the ground carbon was determined by precisely weighing 2 g of dry carbon and measuring its volume in a 5-mL graduated cylinder.

The carbon columns were prepared for testing as follows:

- Weighing out the pre-determined amount of dry ground carbon required for the column test.

- Pre-wetting the carbon by placing it in an Erlenmeyer flask, covering it with organic-free water, and allowing it to sit overnight.
- De-aerating the carbon / water mixture by applying a vacuum to the flask for at least 15 minutes.
- Filling the column to about 25% of the planned GAC bed depth with de-aerated, organic-free water and ensure that the carbon remains entirely submerged throughout the loading process.
- Transferring the carbon / water slurry to the column, while gently tapping the column to promote packing of the GAC particles.
- Checking RSSCT system integrity for leaks, air pockets, immediate head loss build-up, etc., by operating the system with organic-free water for about 10 minutes.
- Purging the feed system and columns of air and organic-free water with the feed solution (test water).

Test start-up and operation involved filling the feed tank with test water, connecting the feed system, initiating feed delivery and setting the feed flow rate, maintaining the system during operation, and collecting samples at appropriate intervals for analysis. Flow rates were checked daily and maintained within 5% of the target value. Pressure was also checked daily to monitor head loss. An RSSCT was operated until the effluent TOC concentration was at least 70% of the average influent TOC concentration on two consecutive sample times.

3.3 Experimental Design

RSSCT testing was performed quarterly as shown in Table 3-2. The purpose of this experimental design was to evaluate seasonal variability and carbon treatment at two empty bed contact times (EBCT = 10 and 20 minutes). The two EBCT tests were run concurrently using a common feed tank.

3.4 Sampling and Analysis

Table 3-3 presents the RSSCT sampling plan. Table 3-4 records the analytical methods used during the treatment study, along with the minimum reporting levels. All analyses associated with this treatment study were performed on-site by CH2M HILL's Applied Science Laboratory in Corvallis, Oregon. Required laboratory information is given below:

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Applied Science Laboratory
2300 NW Walnut Blvd
Corvallis, Oregon 97330
ICR Lab ID No.: ICROR001

Lab contact: Kathy McKinley
Phone: 541 / 752-4271
Fax: 541 / 752-0276

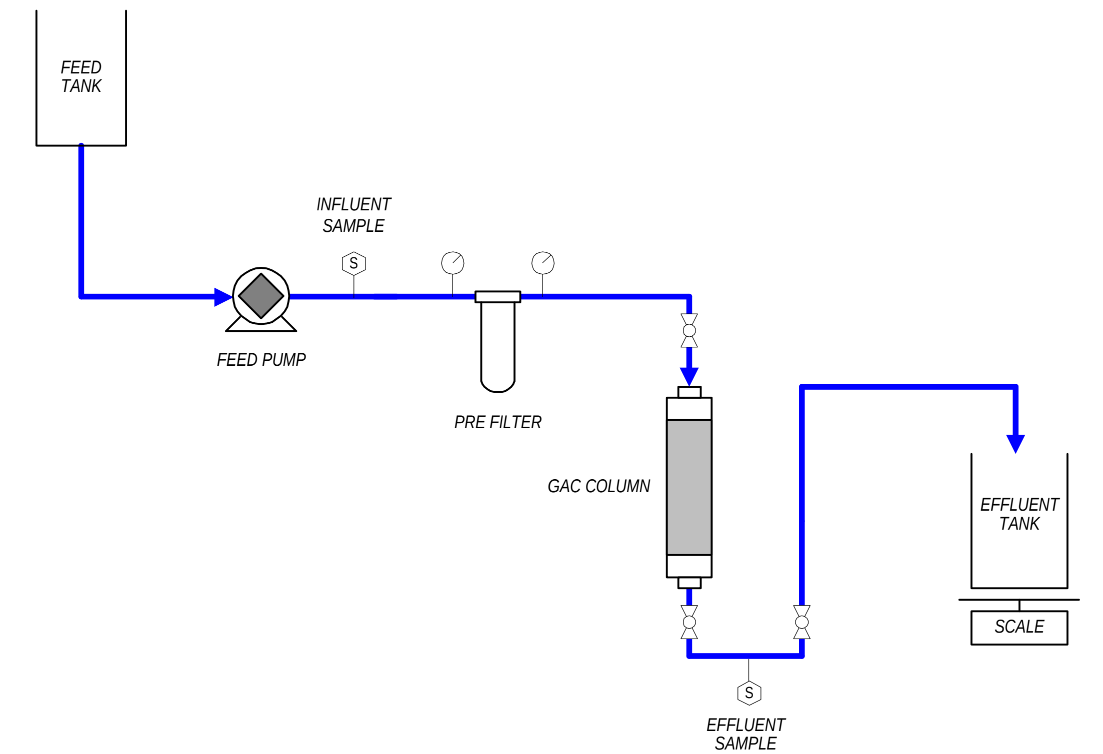


FIGURE 3-1
Schematic of RSSCT Apparatus

TABLE 3-1
RSSCT Design Data

Input Design Parameters	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
RSSCT influent TOC (mg/L)	2.6	2.6	2.5	2.5
Inner diameter of the RSSCT column, D_{SC} (mm)	8.0	8.0	8.0	8.0
Minimum RSSCT Reynolds number, $Re_{SC,\ min}$	0.500	0.500	0.501	0.501
Full-scale operating temperature, $T^{o}C$ (^{o}C)	14.0	23.0	15.0	7.0
Full-scale bed porosity, e_{LC}	0.42	0.42	0.42	0.42
Measured RSSCT dry bed density, r_{SC} (g/cm^3)	0.46	0.46	0.44	0.44
RSSCT GAC mesh size, upper (US standard mesh)	60	60	60	60
RSSCT GAC mesh size, lower (US standard mesh)	80	80	80	80
Estimated Run Length				
Bed volumes to 50% TOC breakthrough, BV_{50}	6426	6266	6628	6698
Estimated run length, BV_T (= 2 x BV_{50})	12852	12532	13257	13396
BV_T + 30% safety factor, $BV_{T+30\%}$ (= 2.6 x BV_{50})	16708	16292	17234	17415
General RSSCT Design Parameters				
Kinematic viscosity at $T^{o}C$, n_{LC} (m^2/s)	1.192E-06	9.548E-07	1.163E-06	1.431E-06
RSSCT carbon particle diameter, d_{SC} (mm)	0.2150	0.2150	0.2150	0.2150
Scaling factor, SF	6.88	6.88	6.88	6.88
RSSCT hydraulic loading rate, v_{SC} (m/hr)	4.19	3.36	4.10	5.04
RSSCT flow rate, Q_{SC} (mL/min)	3.51	2.81	3.43	4.23
Estimated total influent volume required, V_{SC}^{T} (L)	256	200	258	321
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)	116	113	120	121
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	1.45	1.45	1.45	1.45
Estimated RSSCT run time, t_{SC}^{T} (days)	16.86	16.44	17.39	17.57
RSSCT bed length, l_{SC} (cm)	10.2	8.1	9.9	12.2
Estimated volume required for 10-minute EBCT, V_{SC} (L)	85	67	86	107
Mass GAC required, m_{SC} (g)	2.35	1.88	2.19	2.70
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)	232	226	239	242
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	2.91	2.91	2.91	2.91
Estimated RSSCT run time, t_{SC}^{T} (days)	33.71	32.87	34.77	35.14
RSSCT bed length, l_{SC} (cm)	20.3	16.3	19.8	24.4
Estimated volume required for 20-minute EBCT, V_{SC} (L)	171	133	172	214
Mass GAC required, m_{SC} (g)	4.69	3.76	4.39	5.40

TABLE 3-2
RSSCT Experimental Design

Season	Pretreatment	EBCT [min]
1st Quarter (Spring)	Softening	10 & 20
2nd Quarter (Summer)	Softening	10 & 20
3rd Quarter (Autumn)	Softening	10 & 20
4th Quarter (Winter)	Softening	10 & 20

TABLE 3-3
RSSCT Sample Requirements

Parameter	Sample Location	No. of Samples/Test
pH	Influent	2
	10-min EBCT Effluent	15[b]
	20-min EBCT Effluent	15[b]
NH3-N	Influent	2
Calcium Hardness	Influent	2
Total Hardness	Influent	2
Bromide	Influent	2
Alkalinity	Influent	2
Temperature	Influent	3
Turbidity	Influent	3
	10-min EBCT Effluent	15[b]
	20-min EBCT Effluent	15[b]
TOC	Influent	3
	10-min EBCT Effluent	15[b]
	20-min EBCT Effluent	15[b]
UV254	Influent	3
	10-min EBCT Effluent	15[b]
	20-min EBCT Effluent	15[b]
SDS Test[a]	Influent	3
	10-min EBCT Effluent	15[b]
	20-min EBCT Effluent	15[b]

[a] SDS Test samples analyzed for THMs, HAAs, TOX, and Free Chlorine Residual
[b] Includes 3 duplicates

TABLE 3-4
RSSCT Analytical Methods and MRLs

Parameter	Analytical Method	Minimum Reporting Level
pH	SM 4500-H^+	Not Applicable
Ammonia	SM 4500-NH_3 D	0.10 mg/L as NH3-N
Calcium Hardness	EPA 200.7	5 mg/L as CaCO3
Total Hardness	SM 2340 D	5 mg/L as CaCO3
Bromide	EPA 300.0	10 µg/L
Alkalinity	SM 2320 B	5 mg/L as CaCO3
Temperature	Thermometer	Not Applicable
Turbidity	SM 2130 B	0.05 ntu
TOC	SM 5310 D	0.50 mg/L
TOX	SM 5320 B	25 µg/L as Cl
UV254	SM 5910	0.009 cm^{-1}
THMs: CHCl3, BDCM, DBCM, CHBr3	EPA 551.1	0.5 µg/L for each analyte
HAAs: BCAA, DBAA, DCAA, MBAA, MCAA, TCAA	SM 6251 B	1.0 µg/L for each analyte, except 2.0 µg/L for MCAA
Free Chlorine Residual	SM 4500-Cl G	0.05 mg/L

4. Results and Discussion

According to the *ICR Treatment Studies Data Collection Spreadsheets User's Guide* (EPA, 1997), the purpose of this section is **not** to report the detailed data included in the *Data Collection Spreadsheets* (submitted along with this *Treatment Study Summary Report*), but rather to provide information that is critical to the interpretation of the results reported in the spreadsheets and to succinctly report the key findings.

4.1 Problems Encountered

RSSCT operation was generally problem-free. The test systems were operated continuously each quarter without any shutdown periods.

4.2 Influent Water Quality

Table 4-1 presents the average water quality characteristics of the pretreated water (RSSCT influent before filtration). For a given season, influent water characteristics were identical for the 10- and 20-minute EBCT RSSCT systems because they used a common feed tank. Influent TOC concentrations were relatively consistent in all four quarters of testing. Simulated distribution system (SDS)-THM and SDS-HAA concentrations were highest in the 2nd Quarter (summer) than in the other three quarters. Elevated SDS-THM and SDS-HAA concentrations are important because higher levels of these parameters result in faster exhaustion of GAC.

Table 4-2 shows average simulated distribution system (SDS) test conditions for RSSCT influent water samples. The target free chlorine residual was 0.5 to 1.0 mg/L after the SDS test contact time. The EPA allows some latitude in meeting the target conditions and sets a goal of ±0.4 mg/L. If the target residual is taken as 0.75 mg/L, the EPA would allow a range of 0.35 to 1.15 mg/L. In 7 out of 12 cases (58%) this goal was met. Two 2nd Quarter samples were below this range and two 3rd Quarter and one 4th Quarter samples were above this range. EPA does not consider a residual outside the target range to constitute a failure of the SDS test.

The seasonal variation in THM and HAA formation in the feed water SDS tests appears to have been a function of the test water temperature. The Stage 1 MCLs for THM4 and HAA5 are 80 and 60 μg/L, respectively. The influent water SDS-THM4 concentration exceeded the Stage 1 MCL only in the 2nd Quarter, and the SDS-HAA5 concentration did not exceed the Stage 1 MCL in any quarter.

4.3 RSSCT Results

RSSCT breakthrough curves for TOC, THM4, and HAA5 are presented in Figures 4-1 through 4-4, for the four quarters of testing. The data are presented in two forms. On the left, measured effluent concentrations are plotted versus operation time of a full-scale carbon adsorber (the scaling factor determined as the ratio of the full-scale-to-RSSCT carbon particle diameter [d_{Lc} / d_{sc}] was 6.88). On the right, normalized effluent concentrations (effluent concentration/influent concentration) are plotted as a function of the number of bed volumes treated (operation time/EBCT). The latter data display provides a more practical comparison of the two different EBCTs. For a given flow, a 20-min EBCT adsorber would need to be twice as large as a 10-min EBCT adsorber, so operation times until breakthrough cannot be compared directly to evaluate carbon regeneration costs. The breakthrough curves exhibit a fairly typical pattern of a relatively rapid breakthrough phase followed by a relatively slow breakthrough phase.

GAC treatment is typically evaluated in terms of treatment objectives. For THMs and HAAs, the proposed Stage 2 regulatory limits (MCLs) of 40 µg/L for THM4 and 30 µg/L for HAA5 are good treatment objectives and will be used as breakthrough criteria. There is no regulatory limit for TOC so a breakthrough criterion of 30% removal will be used in this discussion. Table 4-3 summarizes the breakthrough thresholds for TOC, SDS-THM, and SDS-HAA5 in terms of operation time and throughput volume from the treatment study results.

The data show that THM precursors were consistently more difficult to control than HAA precursors. SDS-HAA5 concentrations in the RSSCT influent were less than the breakthrough criterion in all four quarters, so the time/bed volumes to HAA breakthrough were theoretically infinite. The influent SDS-THM4 concentration in the 4th Quarter was also less than the breakthrough criterion. In the 1st, 2nd and 3rd Quarters, THM precursors broke through the carbon, and, therefore, SDS-THM4 would dictate regeneration requirements (Figure 4-5).

The data also indicate that there is some benefit to using a 20-min EBCT GAC adsorber over a 10-min EBCT adsorber. The 20-min EBCT system treated more bed volumes before SDS-THM4 breakthrough than the 10-min system (Figure 4-6, note that the 3rd Quarter data shown in this figure are somewhat misleading because the bed volumes treated by the 20-minute EBCT system were actually greater than shown in the bar). Restated, the 20-min EBCT system provided more efficient use of the carbon.

Table 4-4 summarizes average SDS test conditions for GAC effluent water samples. The target free chlorine residual was 0.5 to 1.0 mg/L after the SDS test contact time. The EPA allows some latitude in meeting the target conditions and sets a goal of ±0.4 mg/L. If the target residual is taken as 0.75 mg/L, the EPA would allow a range of 0.35 to 1.15 mg/L. In 84 out of 125 cases (67%) this goal was met. EPA does not consider a residual outside the target range to constitute a failure of the SDS test.

4.4 Impact of Seasonal Variability

The GAC service life determined by RSSCT testing varied considerably over the four quarters of testing. Table 4-1 reveals that SDS-THM4 and SDS-HAA5 concentrations in RSSCT influent peaked in the 2nd Quarter (Summer). Variations in these parameters and TOC are shown in Figure 4-7.

Figures 4-5 and 4-6 illustrate the seasonal variability in the volume of water that could be treated before breakthrough occurred, indicating exhaustion of the GAC. Table 4-5 summarizes estimated carbon usage rates for each quarter based on the 20-min EBCT RSSCT results. These data indicate that carbon usage would be substantially higher in the 2nd Quarter (July) than in the other three quarters. Carbon usage rates and regeneration frequencies can be decreased by staggering regeneration so that there is always some fresher and some older GAC in use. The better water produced by the fresher carbon would be mixed with the poorer water produced by the older carbon to obtain blended water that would meet the treatment objectives. Through experience, regeneration can be timed to maintain a relatively constant blended water quality. Such an approach typically reduces carbon usage rates by 30-40%. For example, it may be possible to reduce the 2nd Quarter carbon requirement from 950 to 570 lbs/MG.

TABLE 4-1

RSSCT Influent Water Quality

Parameter	Units	1st Quarter (Apr-98) Average [CV %]	2nd Quarter (Jul-98) Average [CV %]	3rd Quarter (Oct-98) Average [CV %]	4th Quarter (Jan-99) Average [CV %]
Alkalinity*	mg/L as $CaCO_3$	45.5 [2.20]	33.3 [1.80]	58.3 [9.44]	71.5 [1.40]
Total hardness*	mg/L as $CaCO_3$	102 [16.7]	100 [3.29]	142 [8.45]	147 [2.72]
Calcium hardness*	mg/L as $CaCO_3$	59.1 [20.6]	72.3 [3.87]	75.6 [11.0]	69.9 [1.43]
Ammonia*	mg/L as N	0.1 [24.0]	0.2 [71.0]	BMRL	0.2 [48.6]
Bromide*	µg/L	89.9 [21.8]	95.9 [5.32]	87.5 [79.4]	101 [1.22]
pH	pH units	8.82 [4.15]	9.19 [2.54]	9.02 [1.38]	8.89 [1.20]
Turbidity	ntu	0.13 [5.66]	0.77 [87.7]	0.80 [102.9]	1.70 [80.5]
Temperature	^oC	20.0 [0.00]	20.0 [0.00]	20.0 [0.00]	22.0 [4.55]
Total organic carbon	mg/L	2.89 [1.80]	2.76 [37.5]	2.47 [1.76]	2.44 [5.29]
UV254	cm^{-1}	0.041 [1.42]	0.036 [5.56]	0.032 [7.14]	0.027 [2.11]
SUVA	L/(mg*m)	1.41 [2.81]	1.41 [31.1]	1.31 [6.20]	1.12 [5.98]
SDS-Cl2 demand	mg/L	1.93 [6.77]	2.72 [17.7]	1.59 [5.07]	1.80 [11.1]
SDS-TOX	µg/L as Cl^-	146 [9.47]	167 [8.25]	119 [9.40]	82.1 [8.08]
SDS-THM4	µg/L	55.2 [3.83]	88.0 [14.7]	52.0 [8.11]	32.3 [5.06]
SDS-HAA5	µg/L	9.02 [60.0]*	23.4 [12.300]*	11.0 [13.6]	8.87 [26.0]
SDS-HAA6	µg/L	13.0 [59.6]*	29.8 [11.200]*	14.8 [12.2]	11.8 [23.5]

BMRL = Below Minimum Reporting Level

SDS = Simulated distribution system

SUVA = Specific ultraviolet absorbance = UV254*100/TOC

CV = Coefficient of variation =(standard deviation/mean)(100%)

* For these parameters, values in brackets represent Relative Percent Difference(RPD). Defined as [(Sample 1 - Sample 2)/Sample Average] x 100%

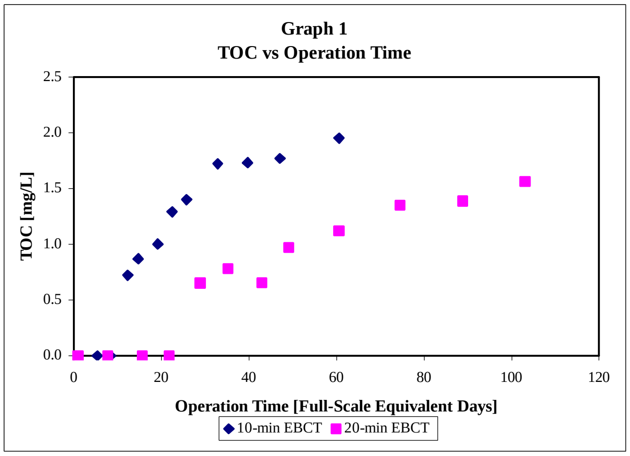
TABLE 4-2

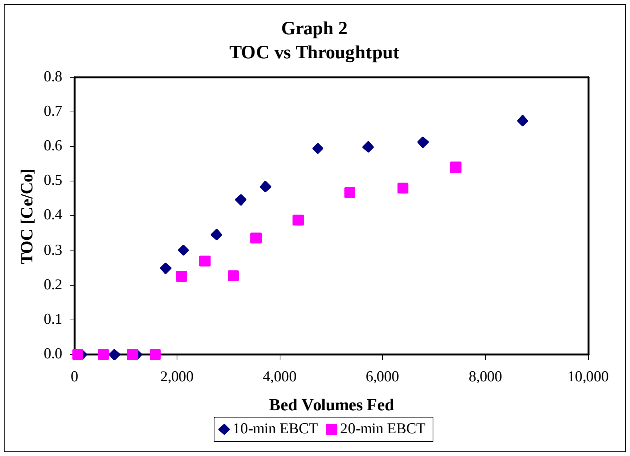
RSSCT Influent Water SDS Test Conditions

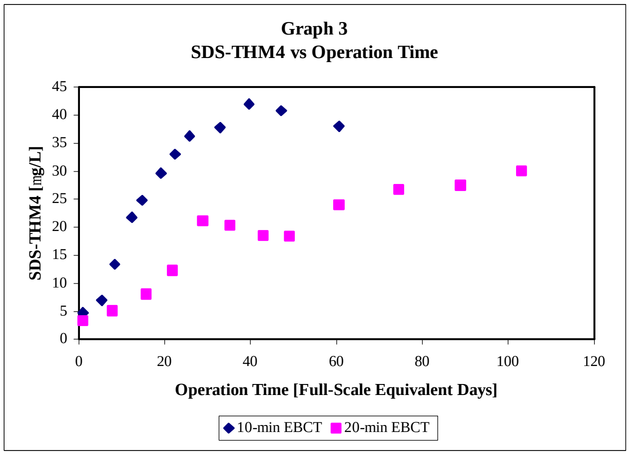
Parameter	1st Quarter (Apr-98)	2nd Quarter (Jul-98)	3rd Quarter (Oct-98)	4th Quarter (Jan-99)
Average pH	9.24	9.28	9.19	9.26
Average temperature [^{o}C]	13.3	24.5	14.7	7.3
Average contact time [hr]	20.2	20.3	20.6	20.3
Chlorine dose [mg/L]	2.63	3.16	2.80	2.86
Free chlorine residual [mg/L]	0.47 - 0.83 Average: 0.71	0.16 - 0.83 Average: 0.44	1.15 - 1.24 Average: 1.20	0.81 - 1.23 Average: 1.06

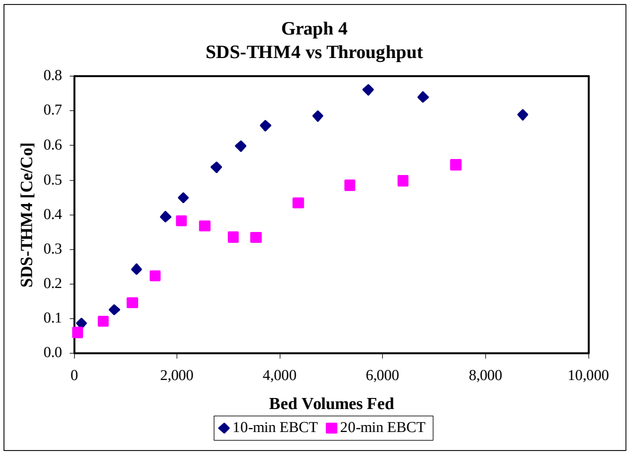
FIGURE 4-1

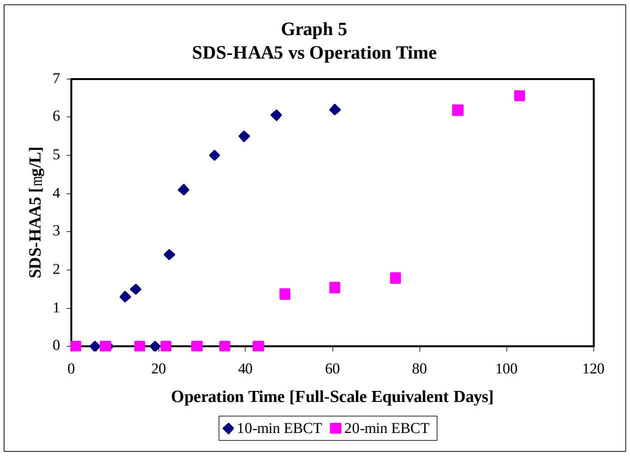
1st Quarter Breakthrough Curves











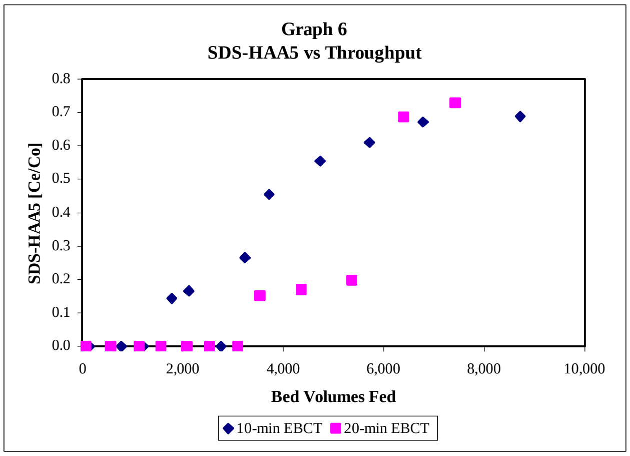
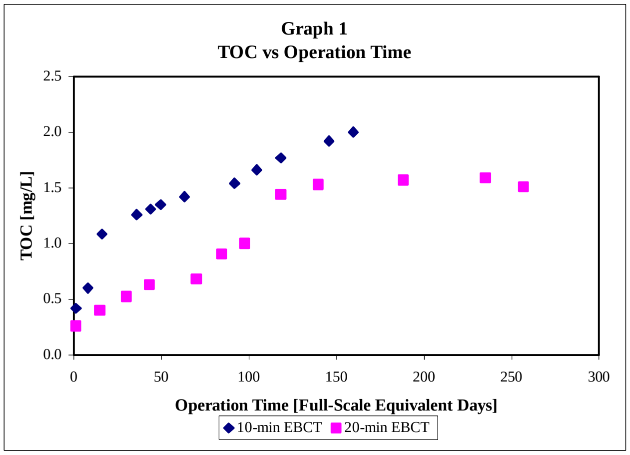
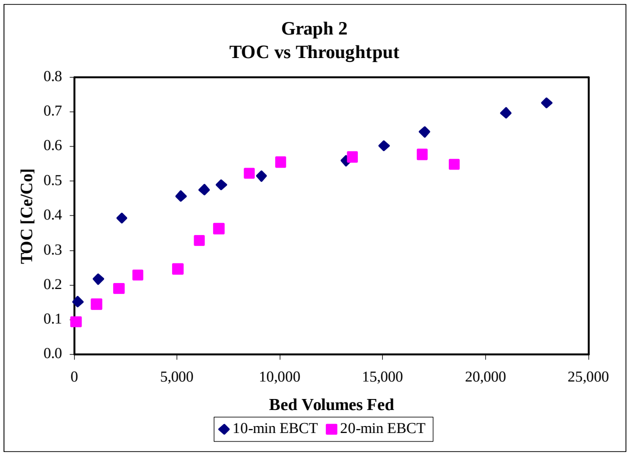
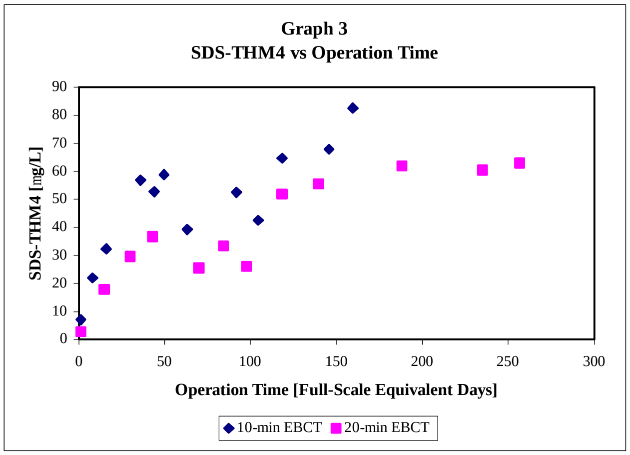
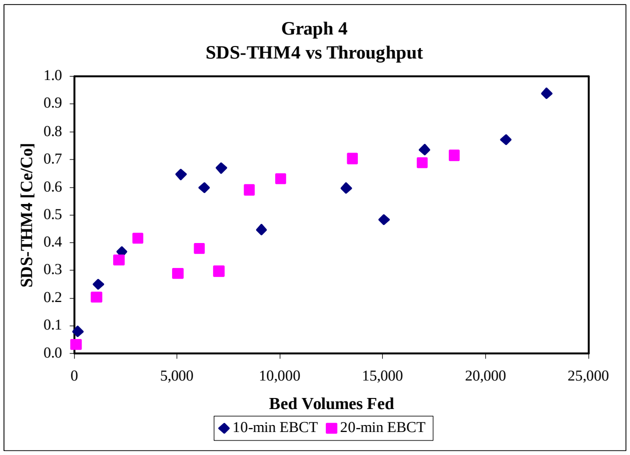


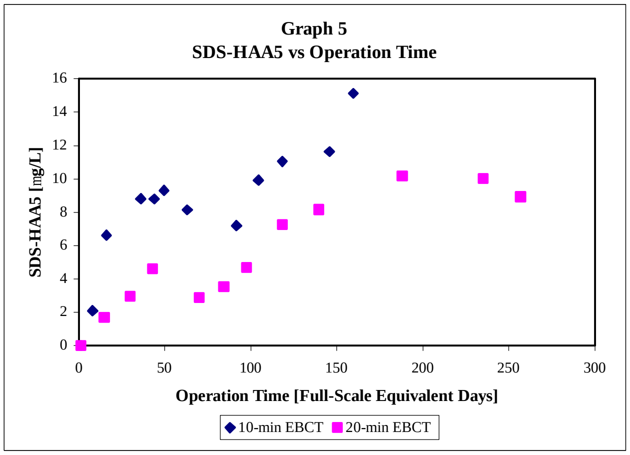
FIGURE 4-2
2nd Quarter Breakthrough Curves











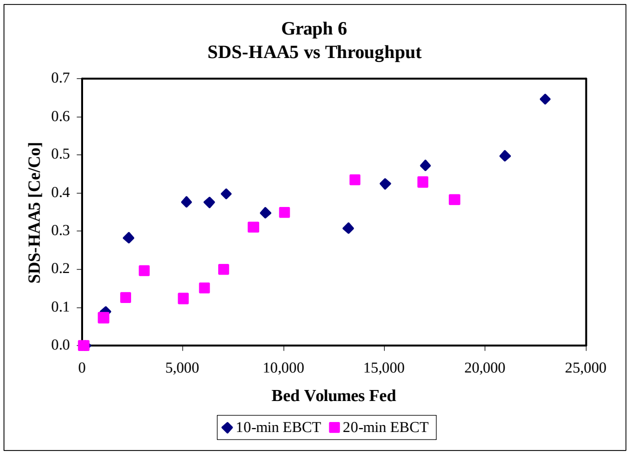
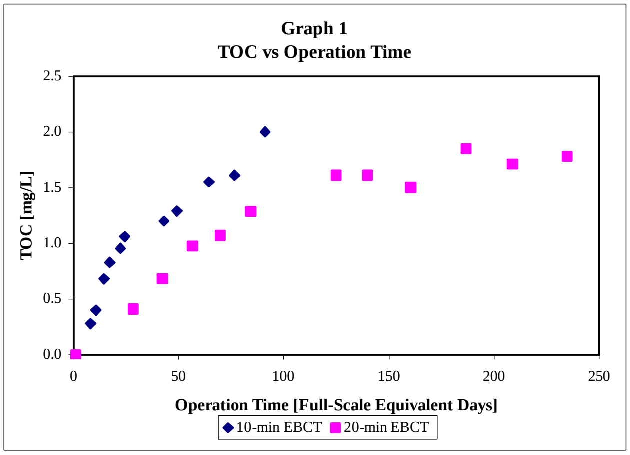
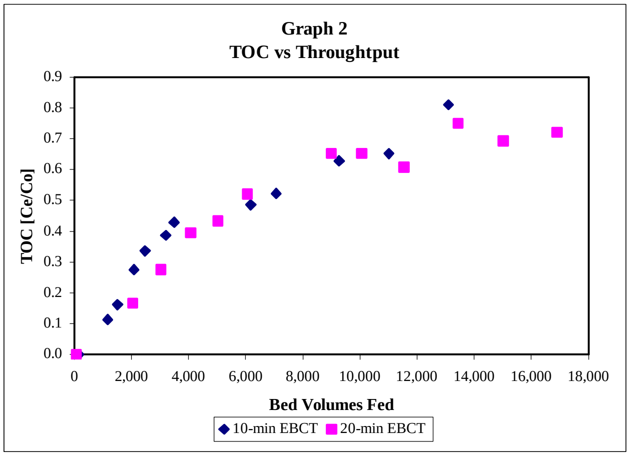
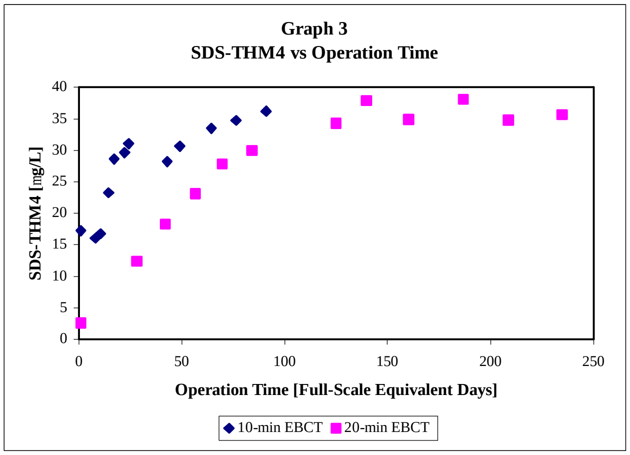
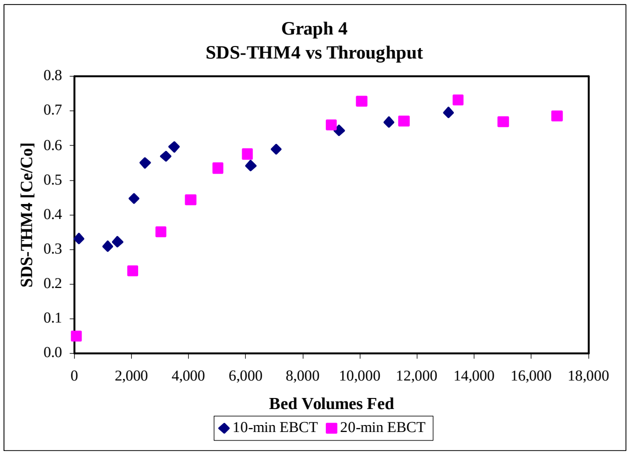


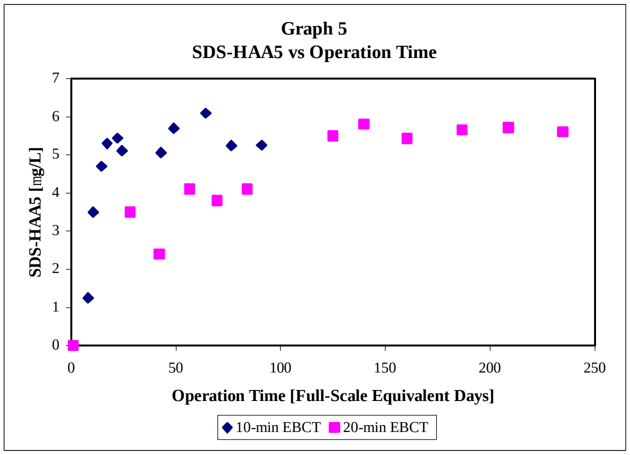
FIGURE 4-3
3rd Quarter Breakthrough Curves











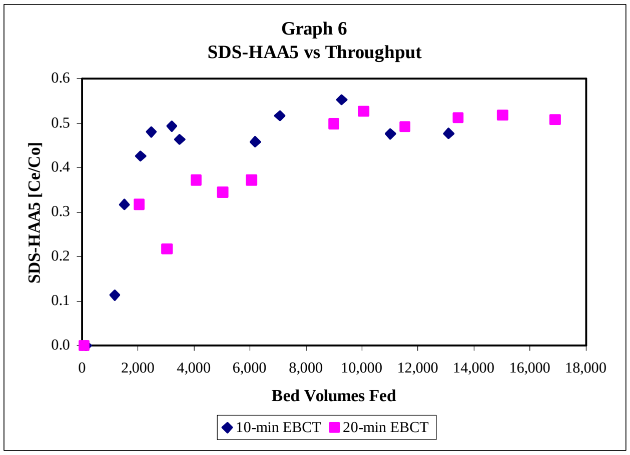


FIGURE 4-4
4th Quarter Breakthrough Curves

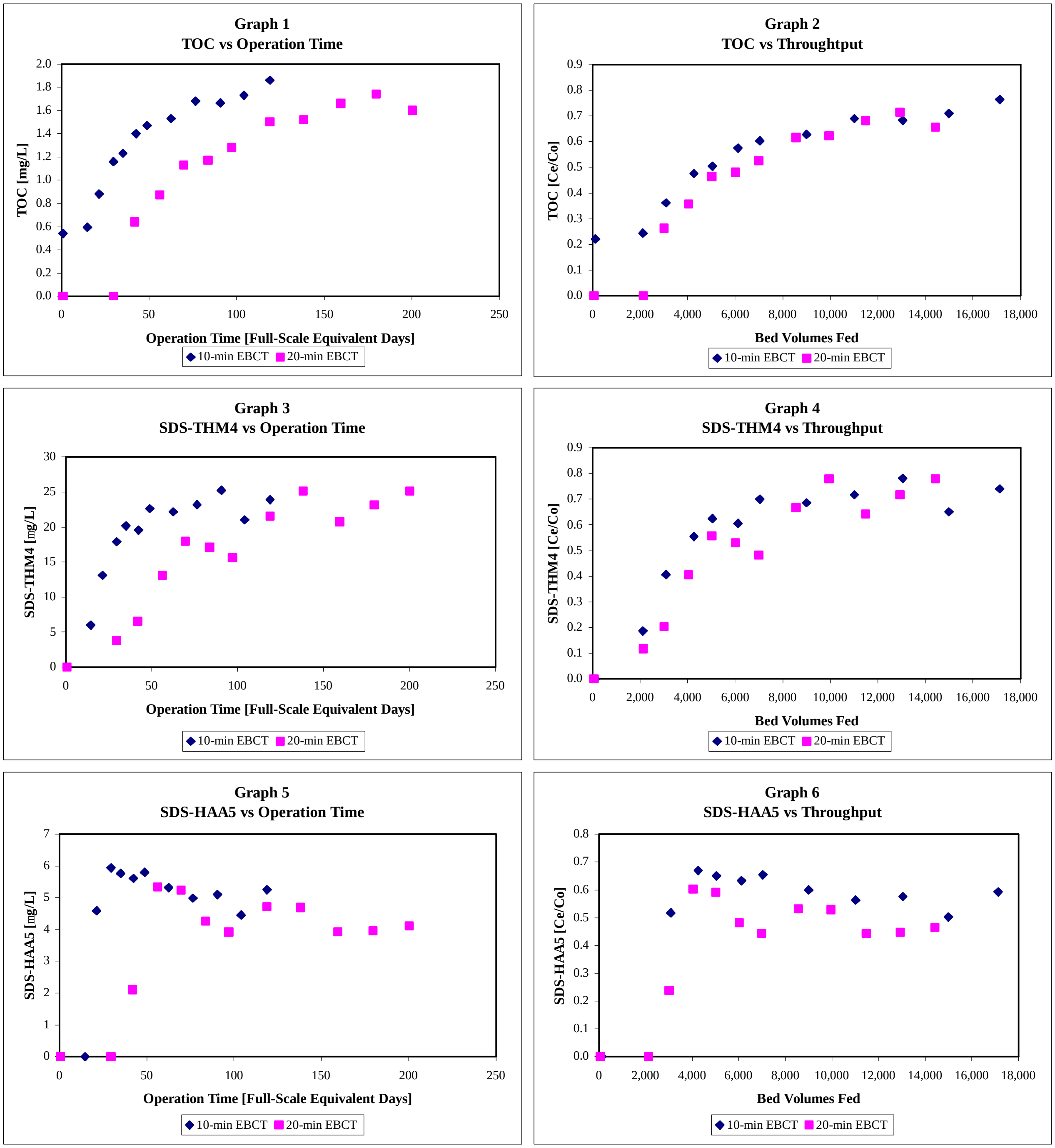


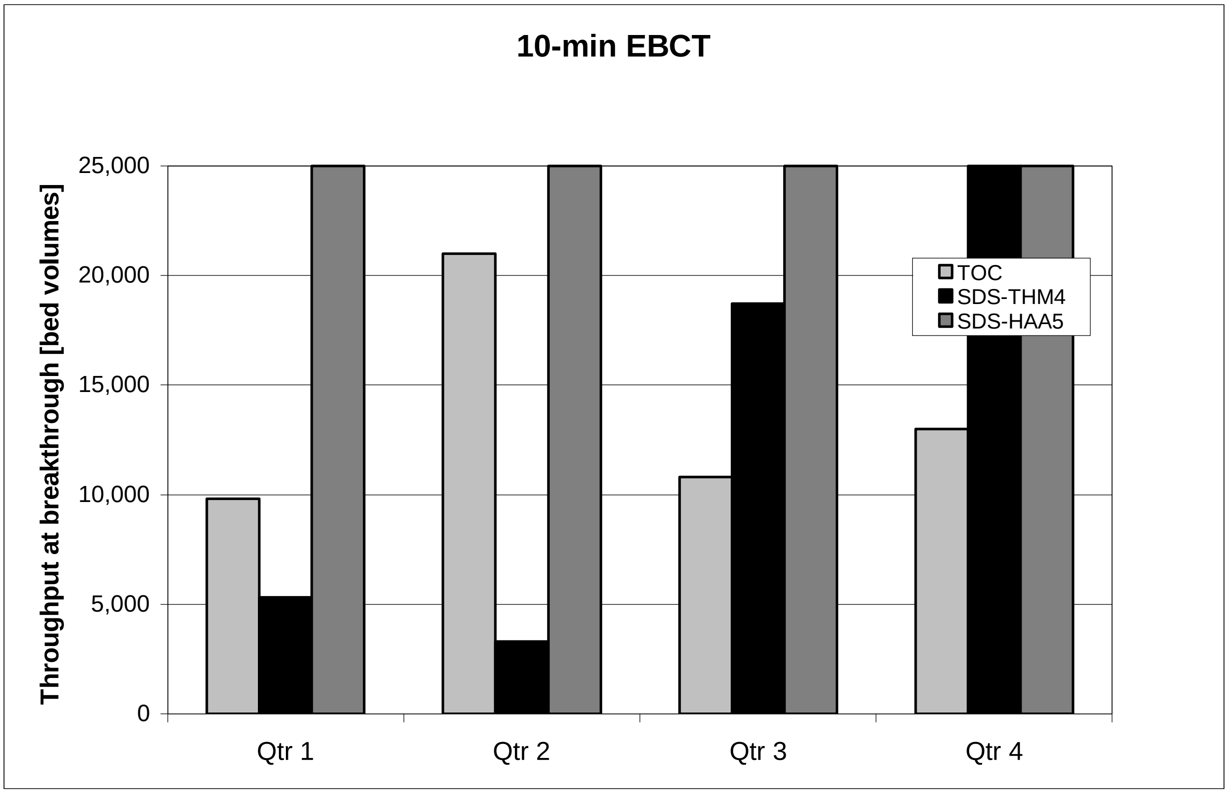
TABLE 4-3
RSSCT Breakthrough Times and Bed Volumes

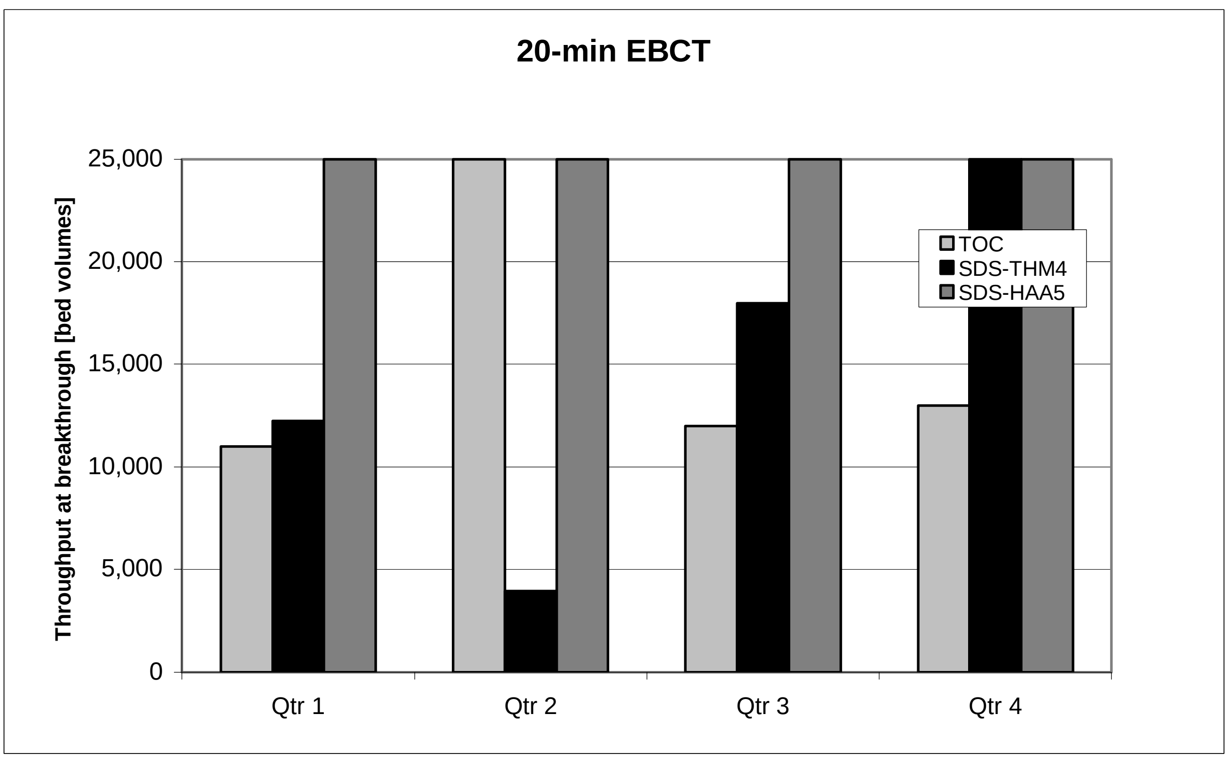
Parameter	Breakthrough Criterion	10-Minute EBCT		20-Minute EBCT	
		Operation Time [full-scale equiv. days]	Throughput [bed volumes]	Operation Time [full-scale equiv. days]	Throughput [bed volumes]
1st Quarter					
TOC	2.02 mg/L[a]	68	9,800	>153	>11000
SDS-THM4	40 µg/L	37	5,330	170	12,240
SDS-HAA5	30 µg/L	Infinite[b]	Infinite[b]	Infinite[b]	Infinite[b]
2nd Quarter					
TOC	1.93 mg/L[a]	146	21,000	>>347	>> 25,000[c]
SDS-THM4	40 µg/L	23	3,310	55	3,960
SDS-HAA5	30 µg/L	Infinite[b]	Infinite[b]	Infinite[b]	Infinite[b]
3rd Quarter					
TOC	1.73 mg/L[a]	75	10,800	167	12,000
SDS-THM4	40 µg/L	130	18,720	>250	>18,000
SDS-HAA5	30 µg/L	Infinite[b]	Infinite[b]	Infinite[b]	Infinite[b]
4th Quarter					
TOC	1.71 mg/L[a]	90	13,000	181	13,000
SDS-THM4	40 µg/L	Infinite[b]	Infinite[b]	Infinite[b]	Infinite[b]
SDS-HAA5	30 µg/L	Infinite[b]	Infinite[b]	Infinite[b]	Infinite[b]

[a] 70% of influent TOC (i.e., 30% removal)
[b] Influent concentration was less than the breakthrough criterion, so breakthrough would never occur.
[c] Reached plateau at <60% of influent concentration and test ended.
>> = much greater than

FIGURE 4-5

Breakthrough Comparison by Parameter

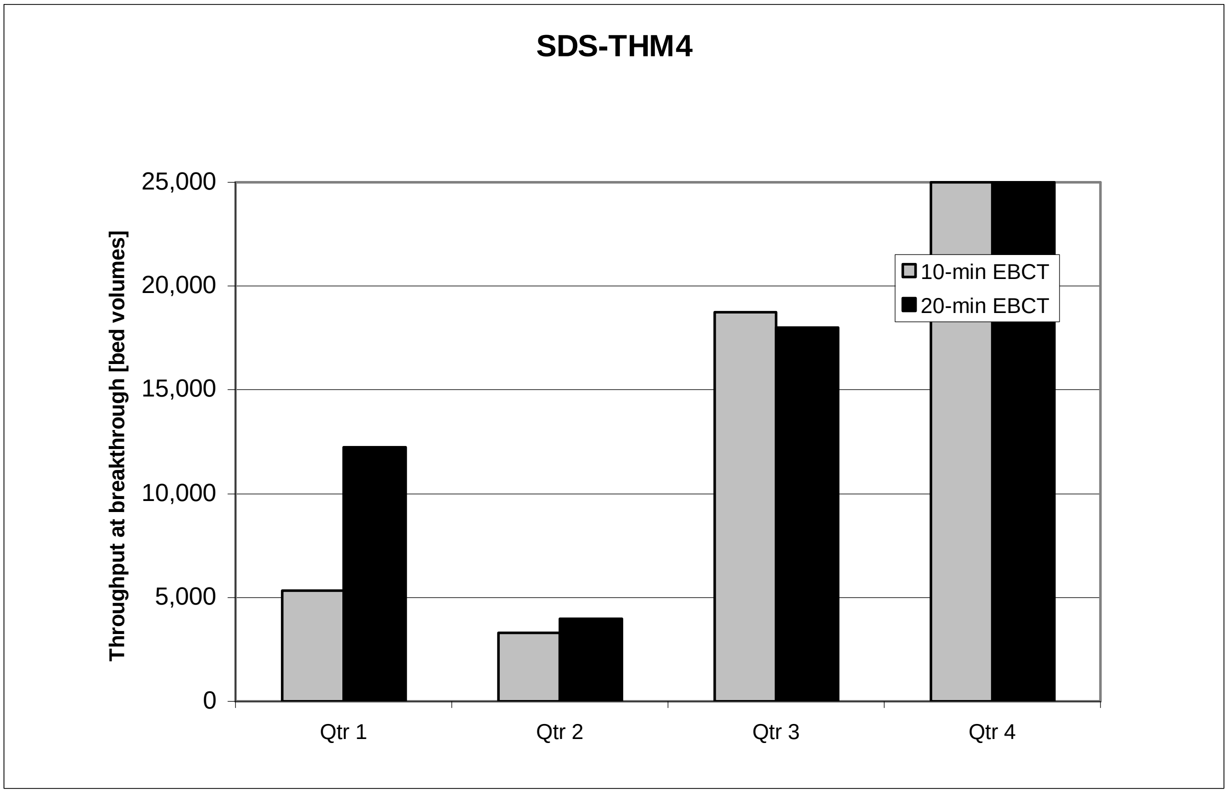




* Bars shown to 25,000 bed volumes are included for illustrative purposes
and indicate that breakthrough would not occur.

FIGURE 4-6

Breakthrough Comparison by EBCT



* Bars shown to 25,000 bed volumes are included for illustrative purposes and indicate that breakthrough would not occur.

TABLE 4-4
RSSCT Effluent Water SDS Test Conditions

Parameter	1st Quarter (Apr-98)	2nd Quarter (Jul-98)	3rd Quarter (Oct-98)	4th Quarter (Jan-99)
10-min EBCT				
Average pH	9.25	9.08	9.21	9.24
Average temperature [^oC]	13.9	24.0	14.2	7.4
Average contact time [hr]	20.42	20.33	20.58	20.51
Chlorine dose [mg/L]	1.90 - 2.30 Average: 2.09	1.58 - 2.51 Average: 2.21	1.72 - 2.60 Average: 2.10	2.08 - 2.60 Average: 2.40
Free chlorine residual [mg/L]	0.77 - 1.21 Average: 0.97	0.42 - 1.32 Average: 0.88	1.07 - 1.37 Average: 1.14	0.67 - 1.26 Average: 0.91
20-min EBCT				
Average pH	9.28	9.19	9.16	9.25
Average temperature [^oC]	13.6	24.3	14.7	7.2
Average contact time [hr]	20.66	20.04	20.26	20.33
Chlorine dose [mg/L]	1.90 - 2.80 Average: 2.08	1.24 - 2.35 Average: 2.00	1.72 - 2.48 Average: 2.22	2.04 - 2.68 Average: 2.38
Free chlorine residual [mg/L]	0.69 - 1.75 Average: 1.05	0.59 - 1.60 Average: 1.06	1.06 - 1.72 Average: 1.33	0.63 - 1.87 Average: 1.10

FIGURE 4-7
RSSCT Influent TOC and DBP Precursors

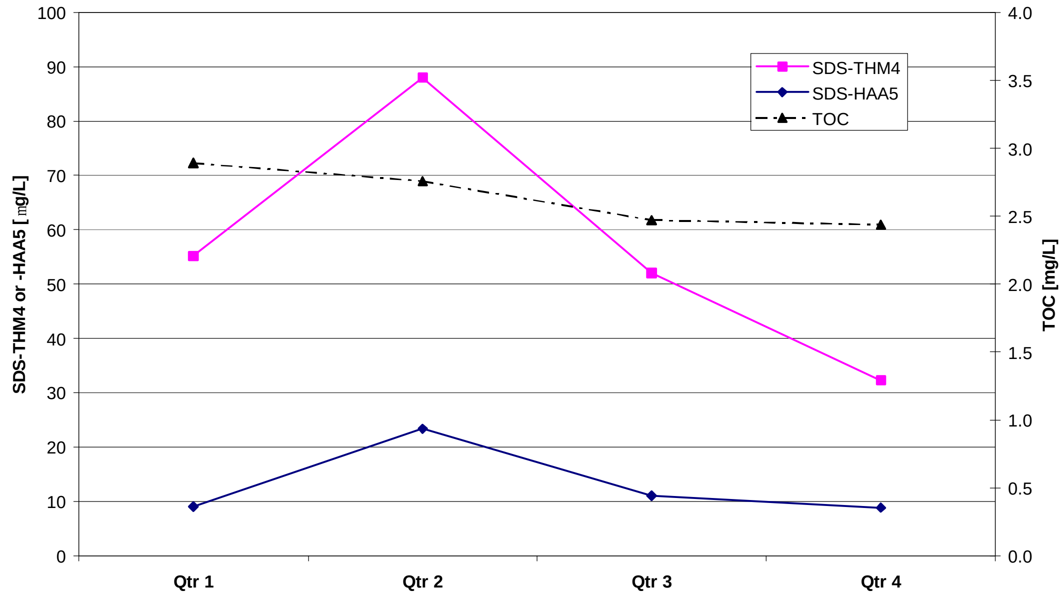


TABLE 4-5
Seasonal Variation in Carbon Usage Rates

Quarter (sampling date)	Est. Carbon Usage Rate for 20-min EBCT Bed [lb/MG]	Temperature [°C]	First Compounds to Break Through
1st Quarter (Apr-98)	300	14	THM precursors
2nd Quarter (Jul-98)	950	24	THM precursors
3rd Quarter (Oct-98)	<200	15	THM precursors
4th Quarter (Jan-99)	N/A[a]	7.2	None

[a] N/A = not applicable. Influent concentrations of THM and HAA precursors were less than the breakthrough criteria, so breakthrough would not occur

5. QA/QC Summary

The QA/QC data for laboratory duplicates, laboratory fortified matrix samples, and independent QC checks (Performance Evaluation, or PE samples) are summarized in the *Treatment Study Summary Report Spreadsheets*, submitted in conjunction with this report. The calibration procedures used for bromide, TOC, TOX, UV254, THMs, and HAAs are summarized in Table 5-1. Calibration frequencies, calibration check standard concentrations, and calibration acceptance criteria specified in the *DPB/ICR Analytical Methods Manual* (EPA, 1996b) were followed.

TABLE 5-1
Calibration Procedures Summary

Parameter	Analytical Method	Initial Calibration	Continuing Calibration
Bromide	EPA 300.0	4-point calibration with point-to-point interpolation	Low-, mid-, and high-level calibration checks each analysis day; LCS
TOC	SM 5310 D	5-point calibration with linear fit	Low-, mid-, and high-level calibration checks each analysis day; LCS
TOX	SM 5320 B	Test titrations; cell checks within 3% of injected mass	Low-, mid-, and high-level calibration checks each analysis day
UV254	SM 5910	Blank; LCS	Low-, mid-, and high-level calibration checks each analysis day
THMs: CHCl3, BDCM, DBCM, CHBr3	EPA 551.1	8-point calibration with point-to-point interpolation	Low-, mid-, and high-level calibration checks each analysis day; LCS
HAAs: BCAA, DBAA, DCAA, MBAA, MCAA, TCAA	SM 6251 B	5-point calibration with point-to-point interpolation	Low-, mid-, and high-level calibration checks each analysis day; LCS

LCS = lab control sample (secondary source standard)

6. References

EPA. 1996. ICR Manual for Bench- and Pilot-Scale Treatment Studies. EPA 814-B-96-003, April 1996a.

EPA. 1996. DBP/ICR Analytical Methods Manual. EPA 814-B-96-002, April 1996b.

EPA. 1997. ICR Treatment Studies Data Collection Spreadsheet User's Guide. EPA 815-B-97-002, April 1997.