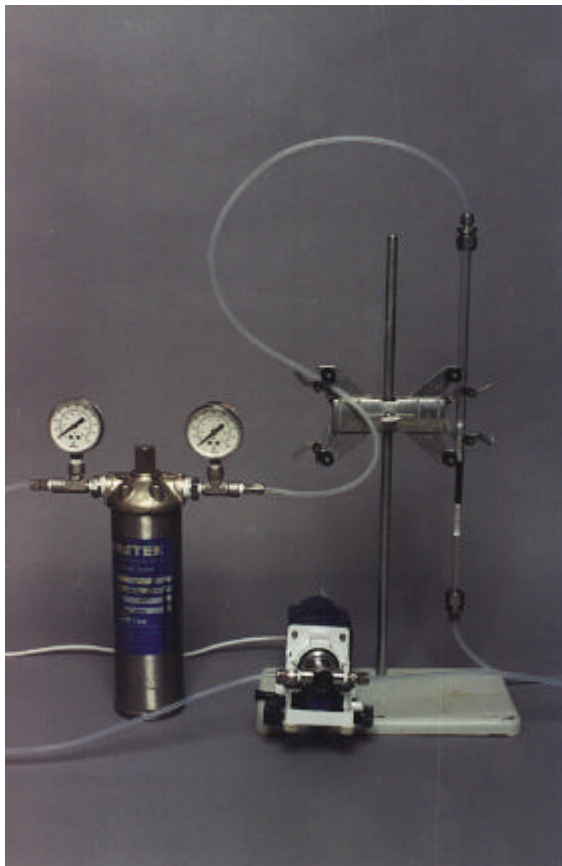

Final Report

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 February 16, and December 2, 1998



Submitted: July 9, 1999

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East St. Louis Water Treatment Plant,
ICR # 363

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

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1. Conclusions and Recommendations

Finished water quality data collected for the purposes of the ICR (Information Collection Rule) and submitted by the East St. Louis water treatment plant (WTP) would not always meet the maximum contaminant levels (MCLs) for total trihalomethanes (TTHMs, or THM4) or haloacetic acids (HAA5). Annual average concentrations at distribution system monitoring points were 72.9 µg/L for THM4 and 70.1 µg/L for HAA5, whereas the Stage 1 MCLs are 80 µg/L and 60 µg/L, respectively, and the proposed Stage 2 MCLs are 40 µg/L and 30 µg/L, respectively..

The results of this treatment study indicate that compliance with both the Stage 1 MCLs and the more stringent proposed Stage 2 MCLs could be achieved with a granular activated carbon (GAC) adsorption system at the WTP. Implementing GAC adsorption could also provide other water quality benefits, including: (a) removal of trace organics that might be present in the source water (such as atrazine); (b) control of tastes and odors; and (c) allowing the use of chlorine for disinfection rather than chloramines (as currently practiced). However, installing and operating a GAC adsorption process would be expensive and could require an additional operator.

The treatment data show that THM precursors tend to be more difficult to control than HAA precursors, and THMs largely would control carbon usage rates. The data also show that GAC adsorbers sized to provide a 20-minute empty bed contact time (EBCT) would provide more efficient use of carbon than 10-minute EBCT adsorbers. Carbon usage, based on the simulated distribution system (SDS) test results, could be expected to be substantially higher in the warmer months. Summer carbon requirements were estimated to be 720 to 1,200 lbs/MG, whereas winter requirements may be only 25% of those usage rates.

While GAC adsorption is an effective technology for controlling disinfection by-products (DBPs) in finished drinking water, alternate methods (e.g., alternative disinfectants and oxidants, membrane treatment) also exist. It is recommended that the public water supplier develop WTP-specific water quality goals, and then consider all practical options for achieving those goals before choosing a treatment strategy.

2. Background Information

2.1 Treatment Plant Description

The Illinois-American Water Company's East St. Louis Water Treatment Plant has a capacity of 57 MGD. Figure 2-1 is a schematic of the water treatment plant (WTP). The WTP has two parallel legs, designated the Main and Aldrich process trains. Treatment in each process train consists of coagulation, sedimentation, conventional filtration, and pre- and post-disinfection (the Aldrich Unit accomplishes coagulation and sedimentation). Treatment plant design data are summarized in Table 2-1.

The main treatment challenges at the WTP are:

- Turbidity and particulates
- Disinfection
- DBP precursors
- Atrazine

The removal of potential pathogens as indicated by turbidity and particle removal is a priority, along with disinfection at the East St. Louis Water Treatment Plant. Unfortunately, disinfection can and does produce unwanted byproducts. Byproduct formation is held in check at the plant by removing precursor material and carefully managing the contact time with free chlorine. Monochloramines are used to maintain a residual in the distribution system. Atrazine has been observed from time to time in the Mississippi River and activated carbon is used to remove the atrazine. The plant uses both powdered activated carbon and carbon filter/adsorbers.

2.2 Source/Finished Water Quality

Tables 2-2 and 2-3 summarize source and finished water quality characteristics for the East St. Louis WTP for the period of January through December 1998 (the last 12 months of the 18-month ICR data collection period).

Figure 2-1
East St. Louis WTP Schematic

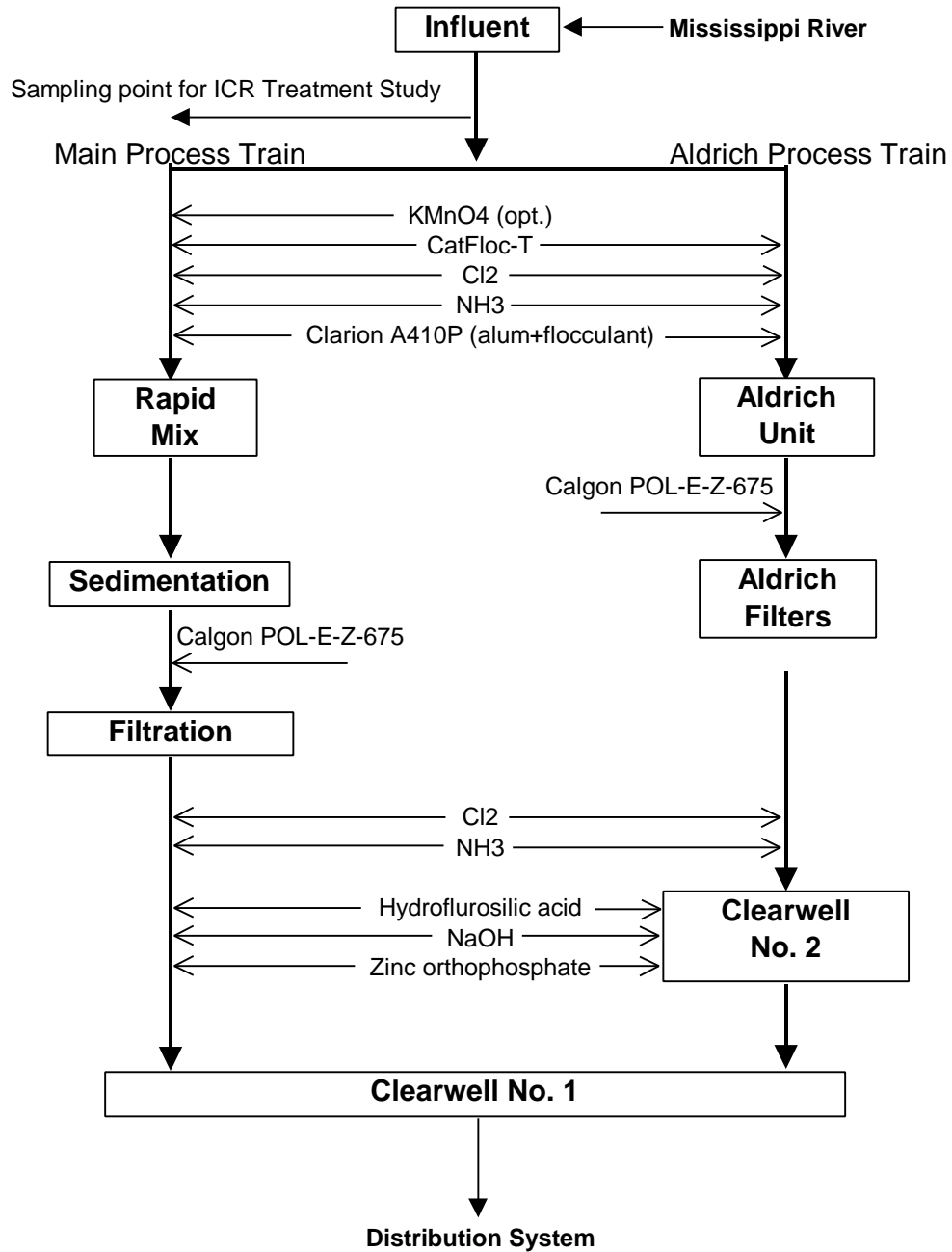


TABLE 2-1
WTP Design Data

Unit Process	Process Description	
	Main Process Train	Aldrich Process Train
Pre-Disinfection	Chemical type: chlorine gas Measurement formula: Cl ₂ Dose (mg/L): 5.10 Chemical type: anhydrous ammonia Measurement formula: NH ₃ Dose (mg/L): 1.60	Chemical type: chlorine gas Measurement formula: Cl ₂ Dose (mg/L): 5.30 Chemical type: anhydrous ammonia Measurement formula: NH ₃ Dose (mg/L): 1.40
Rapid Mix	Type of mixer: mechanical Baffling type: Unbaffled - mixed tank Liquid volume (gal): 121,000 Mean velocity gradient (s ⁻¹): 314 Coagulant addition: Al ₂ (SO ₄) ₃ -14H ₂ O + Floc agent [Clarion A410P] Coagulant dose (mg/L): 41 Polymer addition: Catfloc-T Polymer dose (mg/L): 1.90 Other chemical: KMnO ₄ (occasional) Chemical dose (mg/L): 1.50	No rapid mix tank – reagents fed in-line Coagulant addition: Al ₂ (SO ₄) ₃ -14H ₂ O + Floc agent [Clarion A410P] Coagulant dose (mg/L): 29 Polymer addition: Catfloc-T Polymer dose (mg/L): 2.00
Sedimentation	Surface area (ft ²): 98,800 Liquid volume (gal): 10,763,430 Baffling type: Poor – inlet/outlet only Short circuiting factor:	Surface area (ft ²): 31,732 Liquid volume (gal): 4,037,738 Baffling type: Poor – inlet/outlet only Short circuiting factor:
Filtration	Surface area (ft ²): 9,856 Liquid volume (gal): 294,910 Total media depth (in): 42 GAC depth (in): 18 Media type: GAC/Sand Type of GAC: Calgon F400 Minimum water depth to top of media (ft): 4.0 Depth from top of media to top of backwash trough (ft): 2.0 Polymer addition: Calgon POL-E-Z 675	Surface area (ft ²): 7,412 Liquid volume (gal): 665,345 Filter type: Aldrich filters Polymer addition: Calgon POL-E-Z 675 Polymer dose (mg/L): 0.03

TABLE 2-1
WTP Design Data

Unit Process	Process Description	
	Main Process Train	Aldrich Process Train
	Polymer dose (mg/L): 0.03	
Post-Disinfection	Chemical type: chlorine gas Measurement formula: Cl ₂ Dose (mg/L): 3.00 Chemical type: anhydrous ammonia Measurement formula: NH ₃ Dose (mg/L): 1.10	Chemical type: chlorine gas Measurement formula: Cl ₂ Dose (mg/L): 1.30 Chemical type: anhydrous ammonia Measurement formula: NH ₃ Dose (mg/L): 0.50
Clear Well	Clearwell No. 1 Surface area (ft ²): 12,786 Liquid volume (gal): 1,600,000 Minimum liquid volume (gal): 956,382 Baffling type: Average - serpentine Short circuiting factor: 0.7 Covered contactor: Yes Corrosion control chemical: zinc orthophosphate Corrosion inhibitor dose (mg/L): 1.90 as P pH adjustment chemical: NaOH Chemical dose (mg/L): 4.20 Fluoride addition: hydrofluorosilic acid Fluoride dose (mg/L): 0.80 as F	Clearwell No. 2 Surface area (ft ²): 28,369 Liquid volume (gal): 3,000,000 Minimum liquid volume (gal): 2,122,020 Baffling type: Poor – inlet/outlet only Short circuiting factor: 0.5 Covered contactor: Yes Corrosion control chemical: zinc orthophosphate Corrosion inhibitor dose (mg/L): 2.20 as P pH adjustment chemical: NaOH Chemical dose (mg/L): 3.20 Fluoride addition: hydrofluorosilic acid Fluoride dose (mg/L): 0.80 as F

TABLE 2-2
Source Water Quality

Parameter	Units	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
pH	pH units	7.9	0.07	8.0	7.8
Calcium Hardness	mg/L as CaCO ₃	133	19.3	160	102
Total Hardness	mg/L as CaCO ₃	218	26.3	258	174
Bromide	mg/L	0.05	0.01	0.06	0.03
Alkalinity	mg/L as CaCO ₃	166	15.5	190	140
Temperature	°C	15.4	9.67	28.5	3.2
Turbidity	ntu	144	269	990	19
TOC	mg/L	4.72	1.17	8.26	3.92
UV254	cm ⁻¹	0.149	0.034	0.218	0.104
SUVA	L/(mg-m)	3.22	0.746	2.28	4.67

SUVA = specific ultraviolet absorbance = UV254*100/TOC

TABLE 2-3
Finished Water Quality

Parameter	Units	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
pH	pH units	7.4	0.15	7.7	7.2
Temperature	°C	17.8	8.89	29.9	5.1
Turbidity	ntu	0.07	0.01	0.09	0.05
TOC	mg/L	3.43	0.48	4.20	2.64
UV254	cm ⁻¹	0.071	0.012	0.094	0.054
SUVA	L/(mg-m)	2.06	0.254	1.50	2.35
DS-THM4	µg/L	72.9	35.5	97.9	32.2
DS-HAA5	µg/L	70.1	32.1	101	36.7
DS-HAA6	µg/L	75.3	31.0	105	43.0

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

SUVA = specific ultraviolet absorbance = UV254*100/TOC

3. Materials and Methods

3.1 Pretreatment

The water was collected at the WTP inlet and pretreated in the lab to avoid the presence of chlorine in the test water sample. Pretreatment was designed to simulate DOC removal via coagulation and sedimentation at the WTP. Carbon adsorption processes used at the WTP (GAC filters and periodic PAC addition) were not simulated in lab testing. Pretreatment prior to advanced treatment process testing consisted of coagulation, flocculation, sedimentation, and filtration. Coagulation, flocculation, and sedimentation were performed in a single batch using a large (200-gal) cone-bottom polyethylene tank and a mechanical mixer. Figure 3-1 is a schematic of the first three pretreatment processes, and Table 3-1 gives pretreatment design information. Following sedimentation, the clarified water was decanted and transferred to the feed tanks for advanced treatment process testing. During advanced treatment process testing, this feed water was filtered through an in-line Teflon cartridge filter (0.1- to 0.2- μ m pore size) installed upstream from the bench-scale carbon columns.

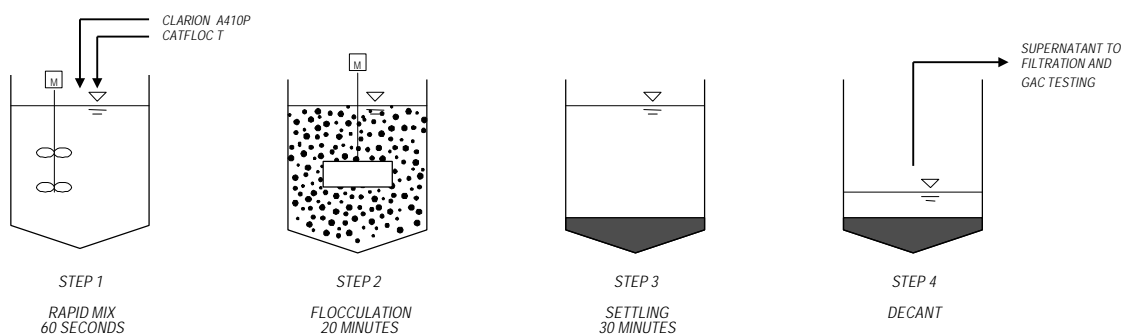


Figure 3-1. Schematic of bench-scale pretreatment processes

3.2 Advanced Treatment Process

Granular activated carbon (GAC) treatment was simulated 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 3-2 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 3-2 lists RSSCT design data. TOC concentrations measured immediately after pretreatment (i.e., RSSCT Influent TOC in Table 3-2) were used in RSSCT design calculations. In the 1st Quarter, the full-scale carbon particle diameter was determined experimentally as the 50%-passing size in a sieve analysis. In the subsequent three quarters, the average full-scale GAC particle diameter was calculated from the US Standard Mesh Sizes according to the computation in the *Data Collection Spreadsheets*.

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 3-3. 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 3-4 presents the RSSCT sampling plan. Table 3-5 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

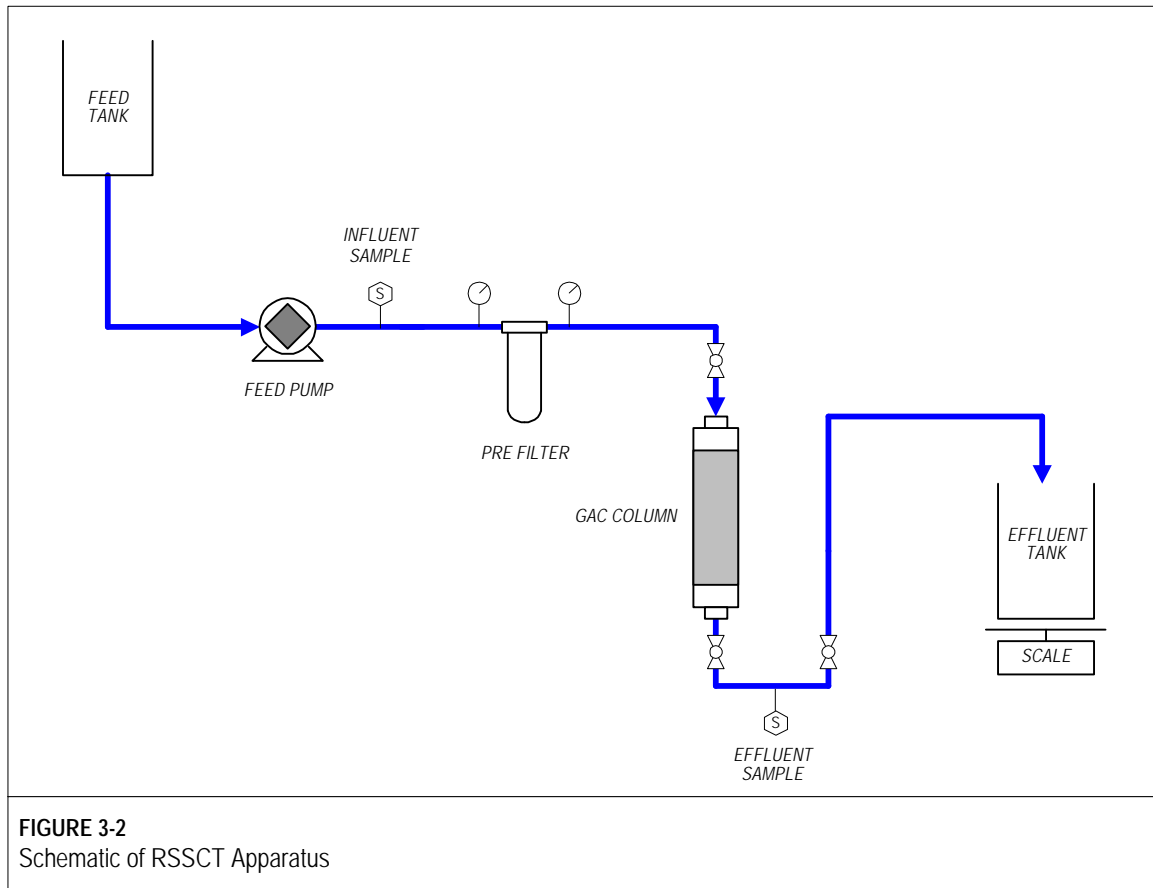


TABLE 3-1
Pretreatment Design Data

Unit Process	Process Description
Rapid Mix	Type of vessel: HDPE cone bottom tank Vessel volume (gal): 200 Type of mixer: mechanical Baffling type: none Rapid mix time (min): 1.0 Coagulant addition: Clarion A410P Coagulant dose (mg/L): 47
Flocculation	Vessel: same as above (batch operation) Stage 1: medium intensity flocculation for 10 min Stage 2: low intensity flocculation for 10 min
Sedimentation	Vessel: same as above (batch operation) Settling time (min): 30
Filtration	Filter type: Cartridge with 0.1 to 0.2- μ m Teflon filter

TABLE 3-2
RSSCT Design Data

Input Design Parameters	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
RSSCT influent TOC (mg/L)	4.00	3.51	3.77	4.10
Inner diameter of the RSSCT column, D_{SC} (mm)	8.0	8.0	8.0	8.0
Minimum RSSCT Reynolds number, $Re_{SC, min}$	0.501	0.500	0.500	0.500
Full-scale operating temperature, $T^{\circ}C$ ($^{\circ}C$)	17.0	13.0	29.0	18.0
Full-scale bed porosity, ϵ_{LC}	0.42	0.42	0.42	0.42
Measured RSSCT dry bed density, ρ_{SC} (g/cm ³)	0.41	0.56	0.445	0.443
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}	3579	4242	3866	3466
Estimated run length, BV_T ($= 2 \times BV_{50}$)	7158	8484	7731	6932
$BV_T + 30\%$ safety factor, $BV_{T+30\%}$ ($= 2.6 \times BV_{50}$)	9306	11029	10051	9012
General RSSCT Design Parameters				
Kinematic viscosity at $T^{\circ}C$, ν_{LC} (m ² /s)	1.106E-06	1.223E-06	8.294E-07	1.078E-06
RSSCT carbon particle diameter, d_{SC} (mm)	0.212	0.215	0.215	0.215
Scaling factor, SF	7.64	6.88	6.88	6.88
RSSCT hydraulic loading rate, ν_{SC} (m/hr)	3.95	4.30	2.92	3.79
RSSCT flow rate, Q_{SC} (mL/min)	3.31	3.60	2.44	3.18
Estimated total influent volume required, V_{SC}^T (L)	120.9	173.2	107.0	124.8
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)	64.62	76.59	69.80	62.58
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	1.31	1.45	1.45	1.45
Estimated RSSCT run time, t_{SC}^T (days)	8.46	11.13	10.14	9.09
RSSCT bed length, l_{SC} (cm)	8.62	10.41	7.06	9.18
Estimated volume required for 10-minute EBCT, V_{SC} (L)	40.30	57.73	35.67	41.59
Mass GAC required, m_{SC} (g)	1.78	2.93	1.58	2.04
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)	129.25	153.18	139.59	125.16
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	2.62	2.91	2.91	2.91
Estimated RSSCT run time, t_{SC}^T (days)	16.91	22.25	20.28	18.18
RSSCT bed length, l_{SC} (cm)	17.23	20.83	14.12	18.36
Estimated volume required for 20-minute EBCT, V_{SC} (L)	80.60	115.47	71.34	83.18

TABLE 3-3
RSSCT Experimental Design

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

TABLE 3-4
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
NH ₃ -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
UV ₂₅₄	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 3-5
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 NH ₃ -N
Calcium Hardness	EPA 200.7	5 mg/L as CaCO ₃
Total Hardness	SM 2340 D	5 mg/L as CaCO ₃
Bromide	EPA 300.0	10 µg/L
Alkalinity	SM 2320 B	5 mg/L as CaCO ₃
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: CHCl ₃ , BDCM, DBCM, CHBr ₃	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, except that the systems were temporarily shut down for maintenance on four occasions in the latter portion of the 1st Quarter tests:

RSSCT System	Shut-down	Start-up
10-min EBCT	Feb-23 16:39	Feb 28 16:45
	Mar-02 07:15	Mar-05 16:00
	Mar-05 22:15	Mar-07 11:42
20-min EBCT	Mar-03 14:00	Mar-08 07:30

System shut-down on those dates was necessitated by air bubbles in the GAC column. This problem was overcome in successive quarters by better degassing during column preparation. The operating time values in the *Data Collection Spreadsheets* have been corrected for these shut-down 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. TOC, SDS-THM, and SDS-HAA concentrations were higher in the 3rd quarter than in the other quarterly samples, and turbidity was relatively high in the 3rd and 4th quarters. Elevated TOC, SDS-THM, and SDS-HAA concentrations are important because higher levels of these parameters result in faster exhaustion of GAC. Turbidity normally does not affect the rate of GAC exhaustion. Elevated turbidity increases the rate of head loss build-up, but head loss was not a problem during RSSCT operation.

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 48-hr contact time. Measured chlorine residual levels were within the target range, except for one

sample (low) in the 3rd Quarter and all three samples (high) in the 4th Quarter. 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 allows a range of 0.35 to 1.15 mg/L. In 11 out of 12 cases (92%) this goal was met. 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 was largely a function of the test water temperature (SDS test samples were incubated at the water temperature measured when each quarterly sample was collected). Feed water TOC levels may also have been a factor. The Stage 1 MCLs for THM4 and HAA5 are 80 and 60 $\mu\text{g/L}$, respectively. The influent water SDS concentrations exceeded these regulatory levels in the 3rd Quarter and were within 10% of these levels in the 2nd (for HAA5) and 4th Quarters (for THM4 and HAA5).

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 [$d_{\text{Lc}}/d_{\text{Sc}}$] was 7.64 for the 1st Quarter and 6.88 for the 2nd, 3rd, and 4th Quarters). 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 $\mu\text{g/L}$ for THM4 and 30 $\mu\text{g/L}$ 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 tended to be more difficult to control than HAA precursors. In the 1st, 3rd, and 4th Quarters, THM precursors broke through the carbon sooner than HAA precursors, and, therefore, SDS-THM4 would dictate regeneration requirements (Figure 4-5). In contrast, in the 2nd Quarter HAA precursors broke through before THM precursors in the 10-min EBCT column, and the two types of precursors broke through essentially simultaneously in the 20-min EBCT column.

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 breakthrough than the 10-min system in the 2nd, 3rd, and 4th Quarters (Figure 4-6). 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 48-hr 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 allows a range of 0.35 to 1.15 mg/L. In 64 out of 97 cases (66%) 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

Seasonal variations had a considerable effect on GAC treatment. Table 4-1 revealed that TOC, SDS-THM4, and SDS-HAA5 peaked in the 3rd Quarter (Summer). Variations in these parameters are shown in Figure 4-7. Figures 4-5 and 4-6 illustrated the seasonal variability in the volume of water that could be treated before breakthrough of DBP precursors 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 warmest months. 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 3rd Quarter carbon requirement from 1,200 to 720 lbs/MG.

4.5 Cost Opinions

This section presents the estimated costs of GAC treatment for controlling THMs and HAAs. These costs are intended for use in evaluating the feasibility of implementing GAC treatment, not as budget level estimates. The American Association of Cost Engineers divides estimates into three categories:

- Order of magnitude estimate -- This is an approximate estimate made without detailed engineering data. An example would be an estimate from cost capacity curves. It is normally expected that an estimate of this type would be accurate within +50% or -30%.
- Budget level estimate – Budget in this case applies to the owner’s budget and not to the budget as a project control document. A budget estimate is prepared with the use of flowsheets, layouts, and equipment details. It is normally expected that an estimate of this type would be accurate with +30% or -15%
- Definitive estimate – As the name implies, this is an estimate prepared from very defined engineering data. As a minimum, the data must include plans and elevations,

equipment data sheets and quotations, structural sketches, and a complete set of specifications. It is expected that a definitive estimate would be accurate with +15% and -5%.

The estimates provided in this report are from cost curves and should be considered order of magnitude cost estimates. The costs were developed from data published by the EPA (1989) and by Adams and Clark (1989). The costs were updated to the present by using an ENR 20 city average index of 6000. The design information in Table 4-6 was used as the basis for estimating order of magnitude capital and operation and maintenance (O&M) costs.

The estimated capital and O&M costs are summarized in Table 4-7. Two cases were considered, one with on-site carbon regeneration and one without. The capital cost with on-site regeneration was estimated to be \$20 million. This includes gravity carbon contactors, the carbon backwash pumping facilities, a regeneration facility, carbon storage, and carbon transport facilities. The cost does not include any special site work, a GAC contactor building, additional clearwell volume, or additional backwash storage. Without on-site regeneration facilities the capital cost is estimated to be \$17 million.

The O&M costs were based on the bed volumes fed until breakthrough that are summarized in Table 4-3. The following procedure was used to determine the carbon use rate (CUR), the amount of GAC that would need to be regenerated per unit volume of water treated.

- The DBP, THM4 or HAA5, that would drive the regeneration frequency was determined from Table 4-3 by identifying which compound reached its treatment objective first. In each case the treatment objective was the proposed Stage 2 DBP limits, 40 µg/L THM4 and 30 µg/L HAA5.
- The throughput in bed volumes associated with the limiting compound was identified for each quarter
- For the purposes of off-site regeneration, an average of the four values was calculated.
- For the purposes of on-site regeneration, the regeneration facility capacity was based on the next to the highest quarterly CUR (4th Quarter) rather than the highest quarterly CUR (3rd Quarter). The highest CUR was not used because it was so much greater than the other quarters that the regeneration facility would be substantially oversized for the other quarters. During the summer quarter the regeneration facility would be undersized. Either extra carbon would need to be stored on-site, or the extra carbon would need to be regenerated off-site.

The carbon usage rate, in pounds of carbon to be regenerated per million gallons of water treated (lb/MG), was calculated using the following formula:

$$\text{Carbon use rate (lbs/MG)} = [\text{carbon density (lbs/ft}^3\text{)}][133,690 \text{ ft}^3\text{/MG}] / [\text{bed volumes to breakthrough (water volume/carbon volume)}]$$

For the off-site regeneration scenario, the average number of bed volumes processed before breakthrough was calculated to be 7,950. This calculation results in an average carbon usage rate of 470 lbs of carbon to regenerate per million gallons treated.

For the on-site regeneration scenario, the assumed number of bed volumes processed to breakthrough is 6,400, which results in a CUR of 542 lb/MG.

If the estimated capital costs are annualized, by assuming an interest rate of 8 percent and a 20-year payback, it appears to more cost effective to regenerate the GAC on-site (Table 4-7). It is notable that the cost estimates do not include any additional administration costs that may be associated with the additional process, but they do include labor to operate the GAC system.

The regeneration costs can often be significantly decreased if the carbon is regenerated on a semi-continuous basis rather than all at once. For example, in a bank of contactors, some individual contactors would have freshly regenerated carbon and would produce water with low DBP formation potential. Other individual contactors would contain carbon that is close to exhaustion and would be less effective at removing DBP formation potential. However, these treated waters could be blended to produce finished water that complies with the DBP formation limits. It is possible to use the breakthrough profiles generated in this study to calculate the carbon usage rate under these conditions and estimate the costs for using a staggered regeneration approach. Careful analysis of the breakthrough profiles revealed that the carbon use can be decreased by about 50 percent when regeneration is staggered. The capital and O&M costs associated with this type of operation are summarized in Table 4-8. Again, it appears that on-site carbon regeneration would be more cost effective than off-site regeneration. It should be noted, however, that the costs shown in Table 4-8 are for a regeneration facility that was sized for the second highest quarterly CUR (4th Quarter) rather than the highest quarterly CUR (3rd Quarter). Either extra carbon would need to be stored on-site, or some carbon would need to be regenerated off-site during peak carbon usage periods.

TABLE 4-1
RSSCT Influent Water Quality

Parameter	Units	1 st Quarter (Jan-98) Average [CV%]	2 nd Quarter (Apr-98) Average [CV%]	3 rd Quarter (Aug-98) Average [CV%]	4 th Quarter (Oct-98) Average [CV%]
pH	pH units	7.88 [1.97]	7.97 [1.89]	8.10 [2.94]	8.01 [3.89]
Ammonia	mg/L as N	BMRL	BMRL	BMRL	BMRL
Calcium Hardness ^a	mg/L as CaCO ₃	132 [2.66]	120 [14.9]	124 [2.43]	128 [13.3]
Total Hardness ^a	mg/L as CaCO ₃	220 [2.95]	197 [16.6]	215 [3.72]	218 [14.3]
Bromide ^a	µg/L	51.4 [17.1]	33.1 [0.91]	53.2 [1.13]	80.0 [45.0]
Alkalinity ^a	mg/L as CaCO ₃	160 [6.25]	122 [0.82]	157 [0.64]	147 [1.36]
Temperature	°C	20.0 [0.00]	20.0 [0.00]	20.0 [0.00]	20.0 [0.00]
Turbidity	ntu	0.53 [59.5]	0.45 [79.5]	0.59 [44.3] ^b (0.74)	0.77 [52.1]
TOC	mg/L	3.70 [11.2]	3.44 [2.86]	4.26 [0.68]	3.76 [1.96]
UV254	cm ⁻¹	0.071 [3.87]	0.072 [0.70]	0.098 [0.39]	0.078 [4.10]
SUVA	L/(mg-m)	1.93 [7.17]	2.08 [3.42]	2.30 [1.01]	2.08 [4.20]
SDS-THM4	µg/L	50.1 [6.60]	67.7 [9.55]	136 [1.23]	79.8 [1.88]
SDS-HAA5	µg/L	31.6 [22.9]	59.0 [3.56]	81.3 [82.0] ^b (120)	54.5 [2.65]
SDS-HAA6	µg/L	35.4 [21.3]	62.9 [3.33]	89.8 [74.3] ^b (128)	58.7 [7.64]
SDS-TOX	µg/L as Cl	280 [15.5]	269 [4.20]	528 [5.37]	296 [2.83]
SDS-Chlorine Demand	mg/L	1.71 [5.00]	2.32 [5.81]	4.54 [3.31]	2.60 [0.97]

BMRL = below minimum reporting limit

SDS = simulated distribution system

SUVA = specific ultraviolet absorbance = (UV254)(100)/TOC

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

RPD = relative percent difference = ((C₁-C₂)/average)(100%)

^a These parameters were only measured twice, therefore RPD is reported in brackets rather than CV.

^b For these data, two of the three measurements were similar but the third differed considerably; the average of the two similar values is shown in parentheses.

TABLE 4-2
RSSCT Influent Water SDS Test Conditions

Parameter	1st Quarter (Jan-98)	2nd Quarter (Apr-98)	3rd Quarter (Aug-98)	4th Quarter (Oct-98)
Average pH	7.50	7.52	7.51	7.54
Average temperature [°C]	4.0	13.0	29.0	18.0
Average contact time [hr]	48.0	47.3	47.3	47.0
Chlorine dose [mg/L]	2.60	3.10	5.19	3.69
Free chlorine residual [mg/L]	Range: 0.80-0.97 Average: 0.89	Range: 0.64-0.91 Average: 0.78	Range: 0.41-0.80 Average: 0.66	Range: 1.04-1.17 Average: 1.09

FIGURE 4-1
1st Quarter Breakthrough Curves

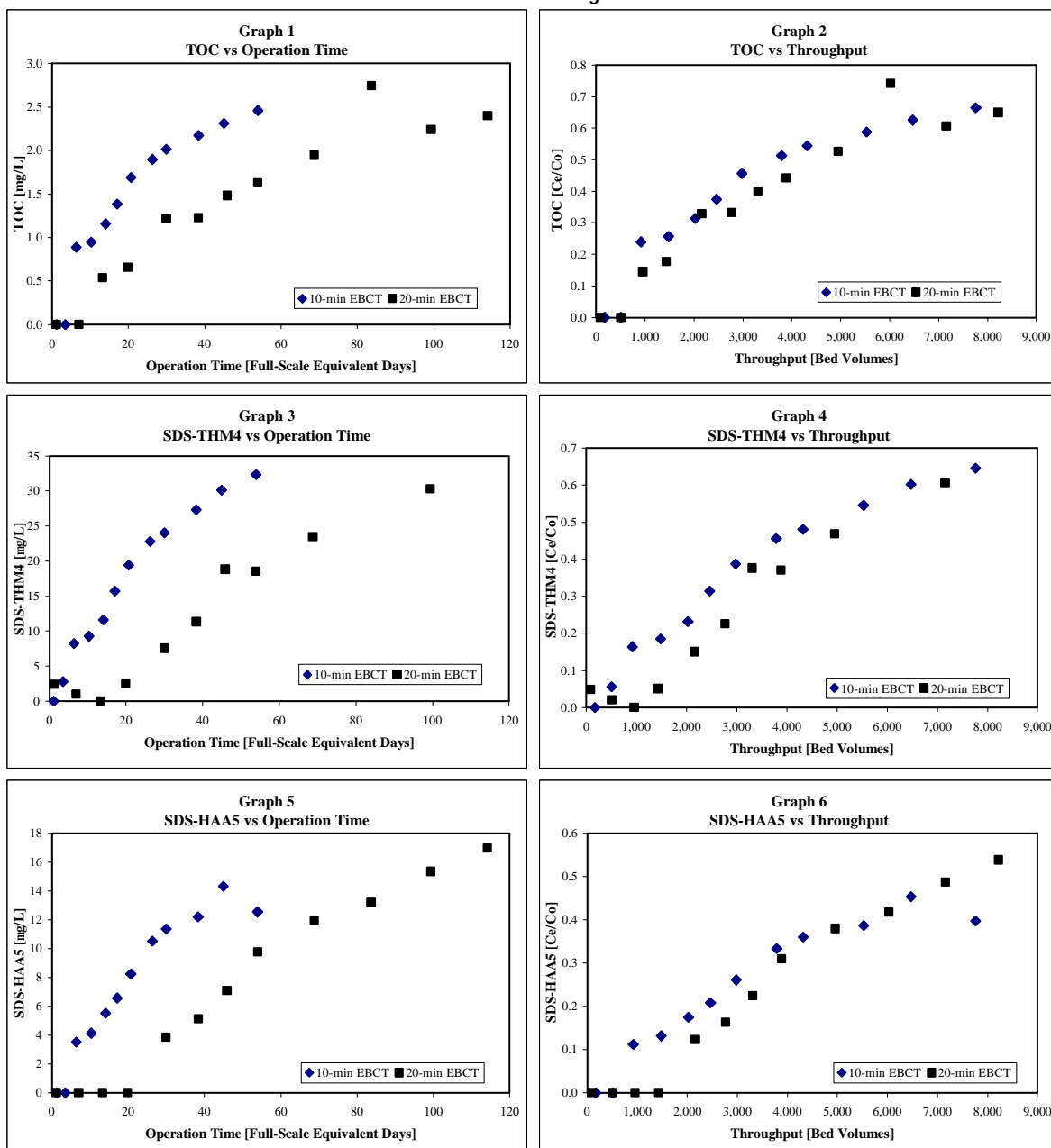


FIGURE 4-2
2nd Quarter Breakthrough Curves

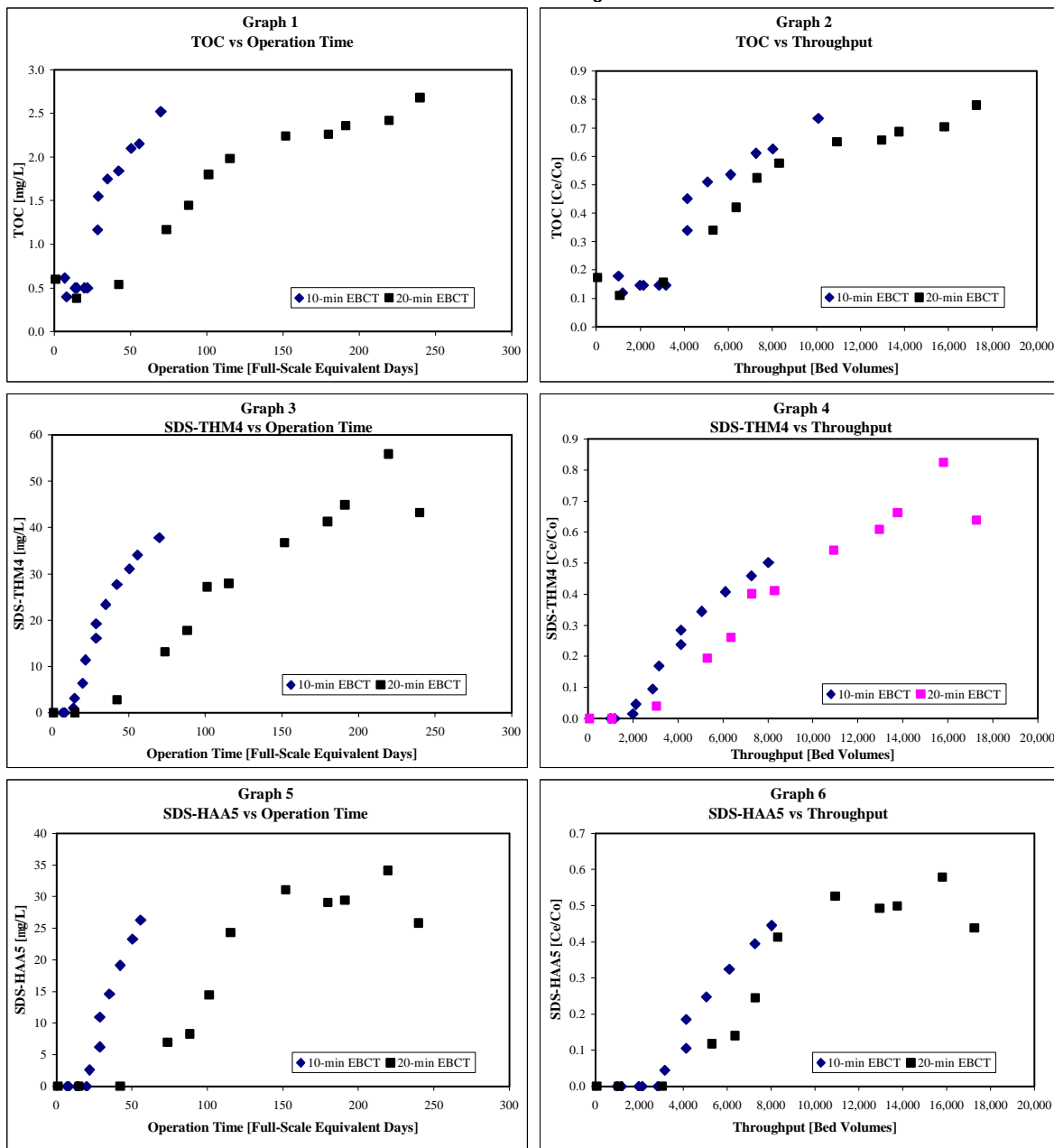


FIGURE 4-3
3rd Quarter Breakthrough Curves

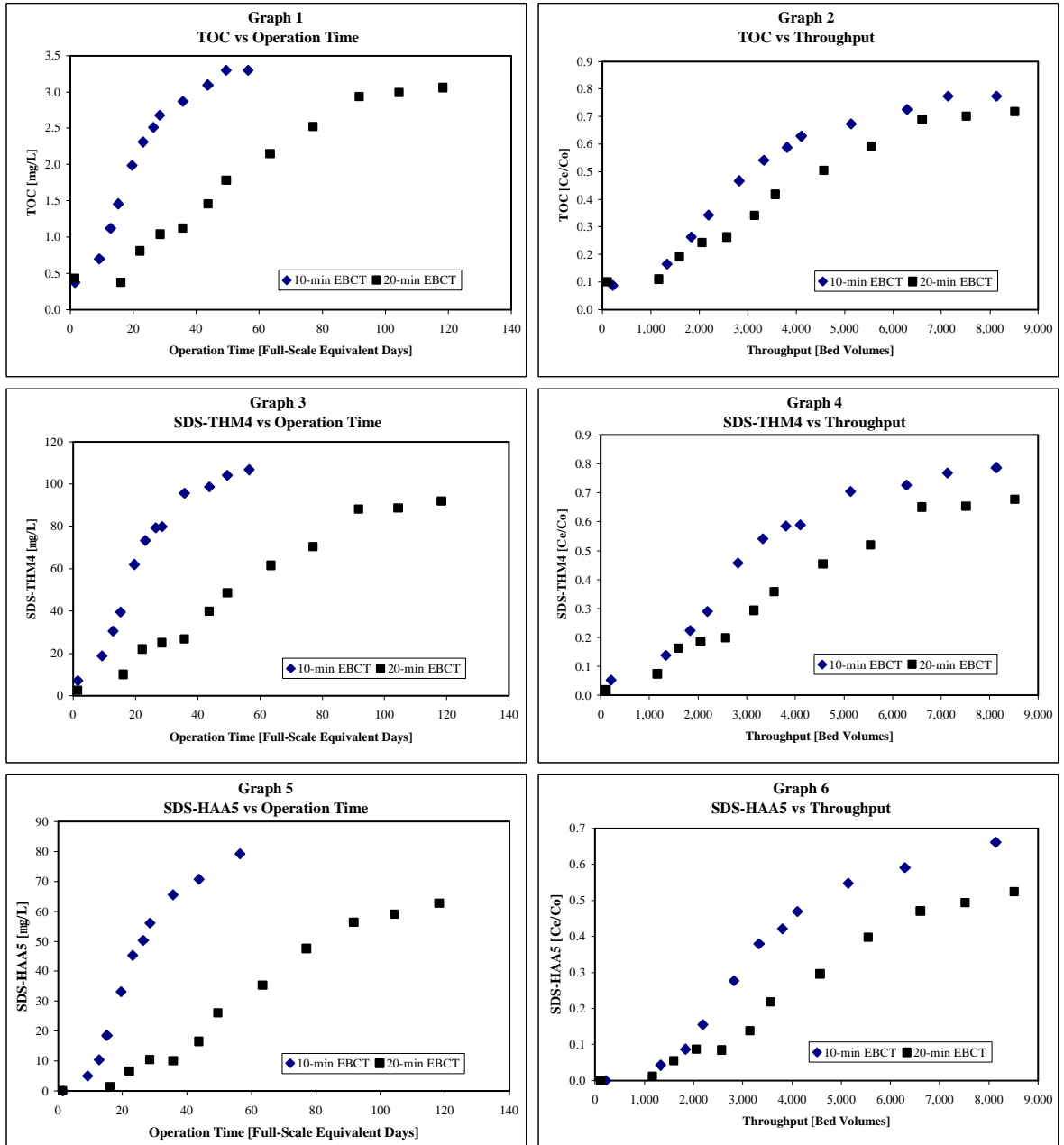


FIGURE 4-4
4th Quarter Breakthrough Curves

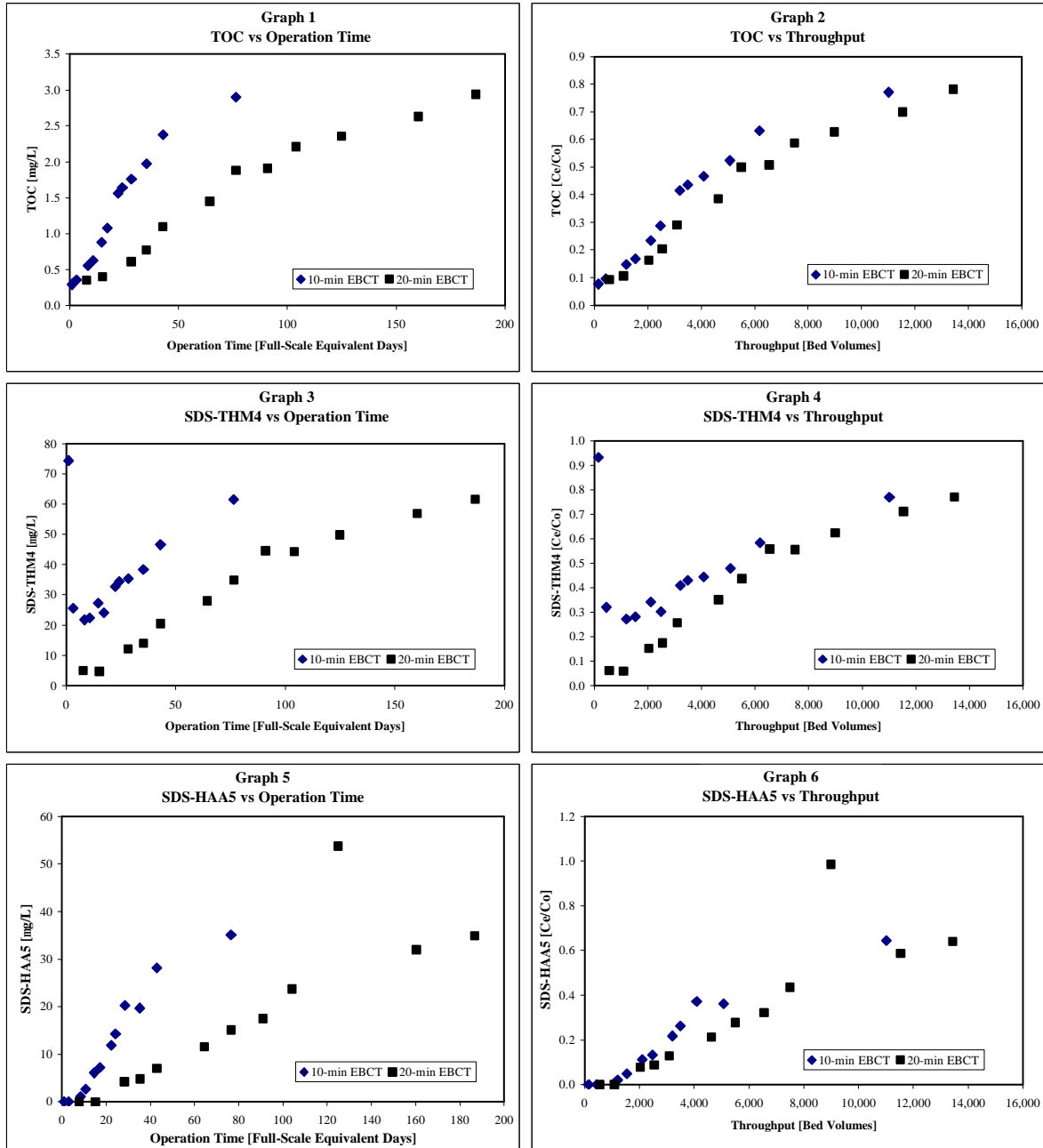


TABLE 4-3
RSSCT Breakthrough Times and Bed Volumes

Parameter	Breakthrough	10-Minute EBCT		20-Minute EBCT	
	Criterion	Operation Time [full-scale equiv. days]	Throughput [bed volumes]	Operation Time [full-scale equiv. days]	Throughput [bed volumes]
1st Quarter					
TOC	2.59 mg/L ^a	63	9,100	140 (est.)	10,100 (est.)
SDS-THM4	40 µg/L	84 (est.)	12,100 (est.)	144 (est.)	10,400 (est.)
SDS-HAA5	30 µg/L	169 (est.)	24,300 (est.)	227 (est.)	16,300 (est.)
2nd Quarter					
TOC	2.41 mg/L ^a	63	9,100	195	14,000
SDS-THM4	40 µg/L	82	11,800	165	11,900
SDS-HAA5	30 µg/L	67	9,600	164	11,800
3rd Quarter					
TOC	2.98 mg/L ^a	38	5,500	104	7,500
SDS-THM4	40 µg/L	15	2,200	45	3,200
SDS-HAA5	30 µg/L	18	2,600	55	4,000
4th Quarter					
TOC	2.63 mg/L ^a	58	8,400	153	11,000
SDS-THM4	40 µg/L	35	5,000	89	6,400
SDS-HAA5	30 µg/L	50	7,200	140	10,100

^a 70% of influent TOC (i.e., 30% removal)

Figure 4-5
Breakthrough Comparison by Parameter

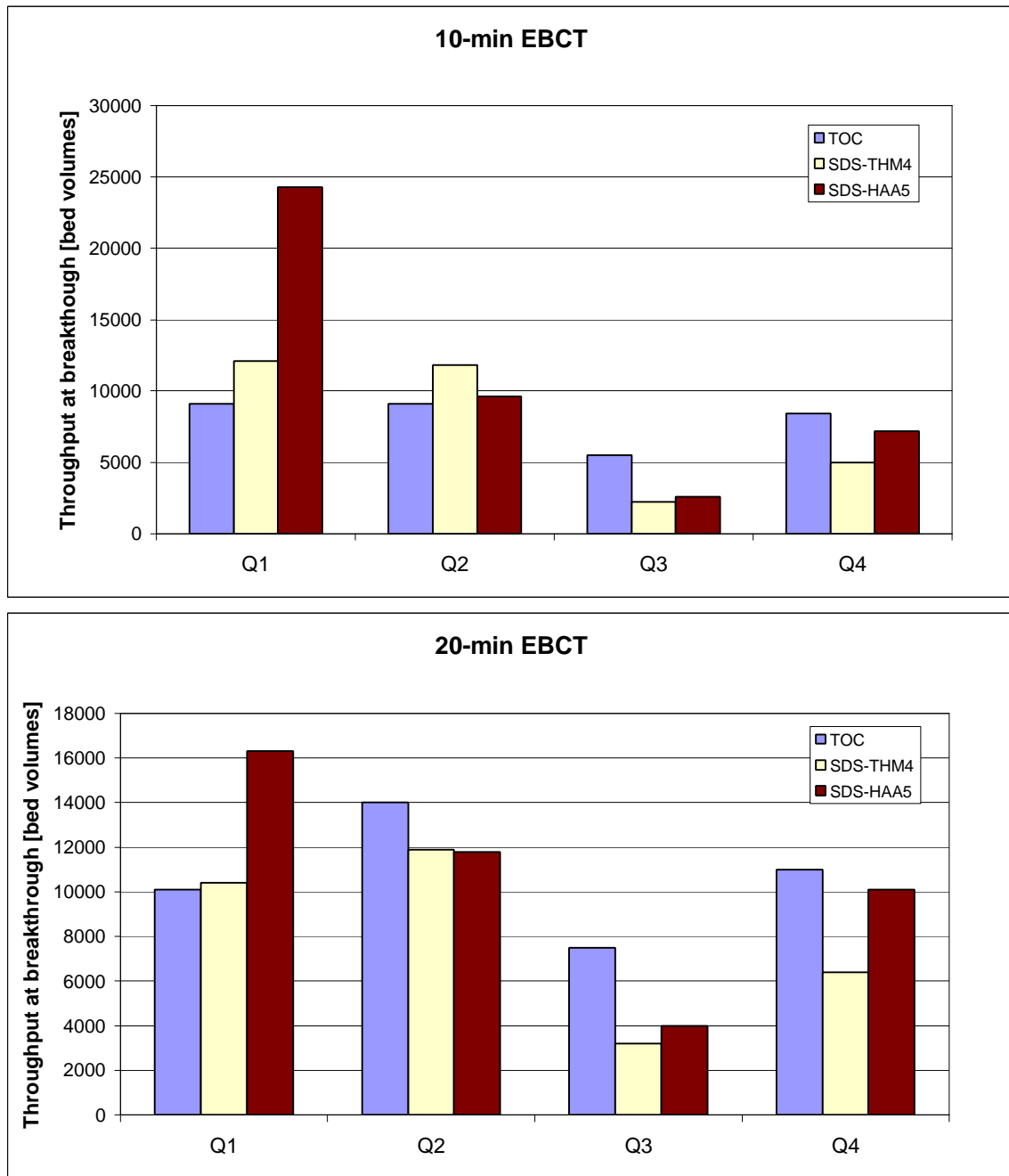


Figure 4-6
Breakthrough Comparison by EBCT

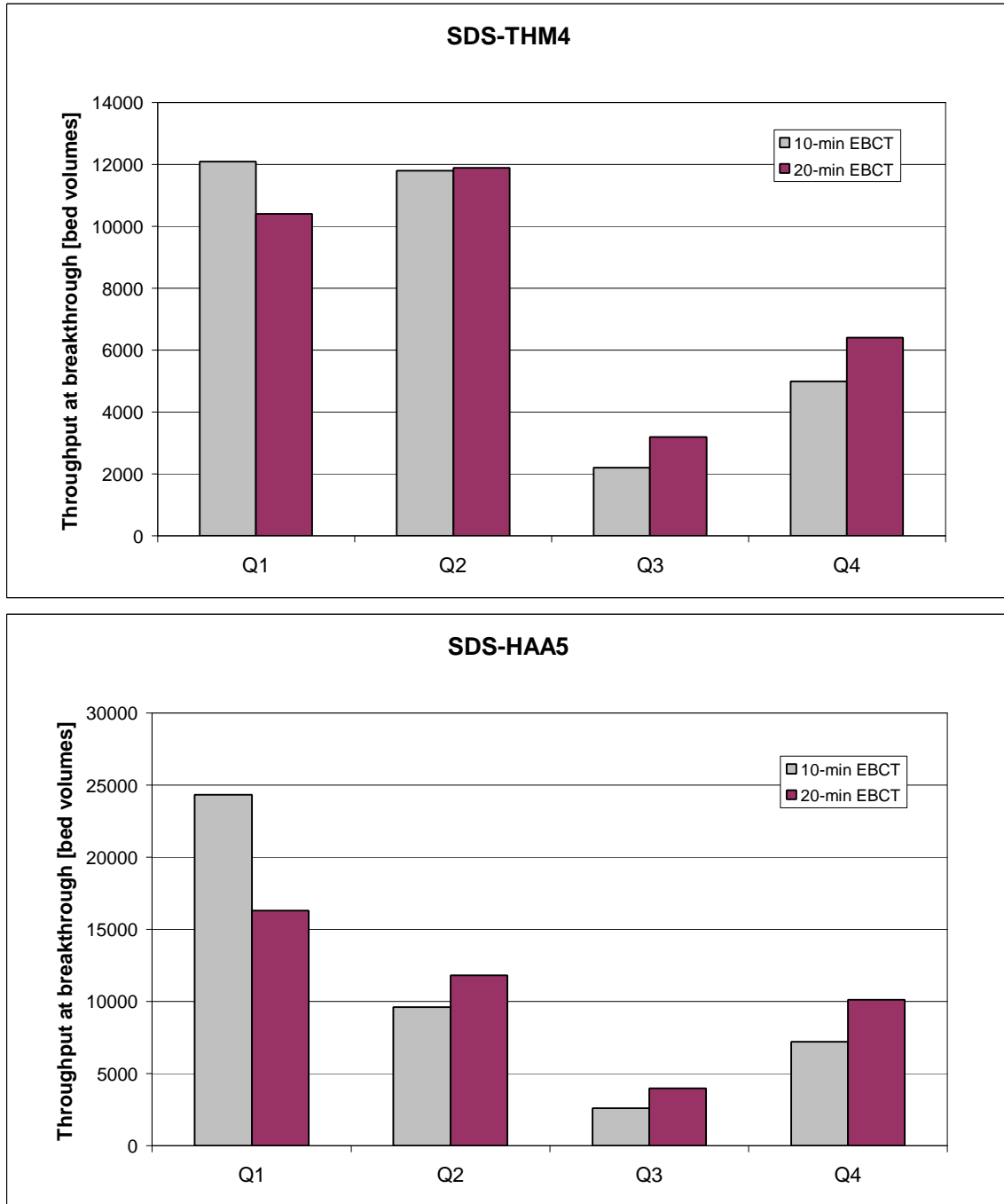


TABLE 4-4
RSSCT Effluent Water SDS Test Conditions

Parameter	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
10-min EBCT				
Average pH	7.50	7.51	7.53	7.53
Average temperature [°C]	4.0	13.0	29.0	18.0
Average contact time [hr]	49.1	48.4	47.8	46.7
Chlorine dose [mg/L]	Range: 1.0-2.0 Average: 1.53	Range: 1.5-2.6 Average: 1.91	Range: 1.10-4.12 Average: 2.92	Range: 1.20-3.10 Average: 2.01
Free chlorine residual [mg/L]	Range: 0.63-1.46 Average: 0.89	Range: 0.77-1.17 Average: 0.99	Range: 0.76-1.16 Average: 1.02	Range: 1.02-1.85 Average: 1.22
20-min EBCT				
Average pH	7.50	7.52	7.51	7.55
Average temperature [°C]	4.0	13.0	29.0	18.0
Average contact time [hr]	48.0	47.0	47.3	46.9
Chlorine dose [mg/L]	Range: 1.0-2.1 Average: 1.49	Range: 1.5-4.1 Average: 2.25	Range: 1.17-3.90 Average: 2.51	Range: 1.23-2.92 Average: 2.12
Free chlorine residual [mg/L]	Range: 0.55-1.46 Average: 0.97	Range: 1.0-2.74 Average: 1.32	Range: 0.81-1.34 Average: 1.11	Range: 0.95-1.30 Average: 1.17

Figure 4-7
RSSCT Influent TOC and DBP Precursors

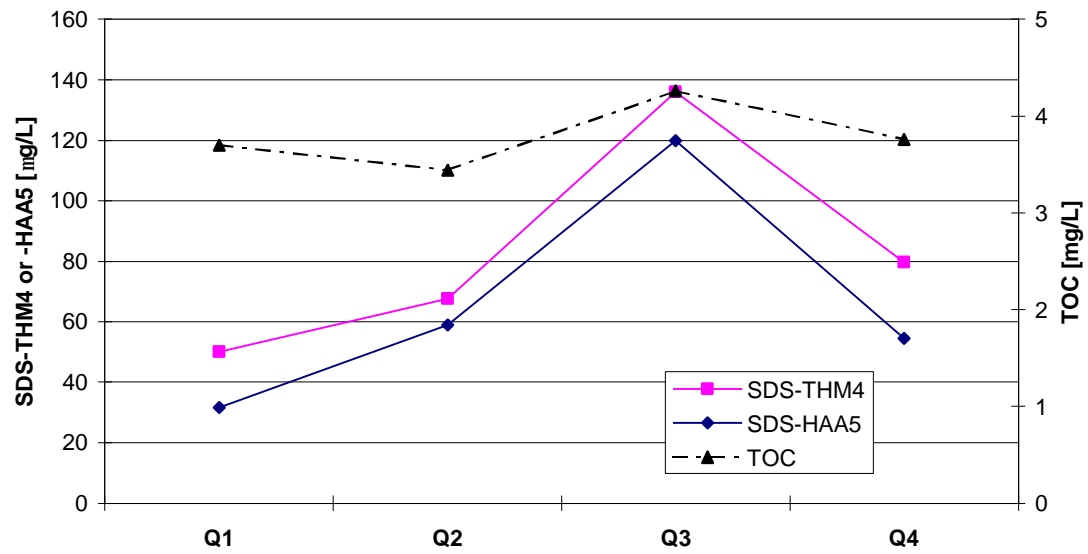


TABLE 4-5
Seasonal Variation in Carbon Usage Rates

Quarter (sampling date)	Est. Carbon Usage Rate for 20-min EBCT Bed [lb/MG]	Temperature [°C]	First Compounds to Break Through
1 st Quarter (Jan-98)	300	4	THM precursors
2 nd Quarter (Apr-98)	300	13	THM and HAA precursors simultaneously
3 rd Quarter (Aug-98)	1,200	29	THM precursors
4 th Quarter (Oct-98)	600	18	THM precursors

TABLE 4-6
Design Criteria Used For Order of Magnitude Cost Estimate

Criteria	Value
Maximum Flow	57 MGD
Average Flow	35 MGD
Empty Bed Contact Time	20-min
Hydraulic Loading Rate	6 gpm/ft ²
GAC density	28 lbs/ft ³

TABLE 4-7
GAC System Order Of Magnitude Cost Estimates

Cost element	Cost with on-site regeneration	Cost with off-site regeneration
Capital (\$) ^a	21,000,000	17,000,000
O&M (\$/yr)	1,400,000	4,200,000
Total Annual (\$/yr) ^b	3,500,000	5,900,000

^a Does not include contingency, engineering, or administration costs. Costs are expressed in 1999 dollars and have not been updated to the midpoint of construction.

^b Capital Recovery Factor (A/P, I = 8, n=20) = 0.1019, costs are rounded to nearest \$100,000 to avoid implying a false accuracy

TABLE 4-8
GAC System Order Of Magnitude Cost Estimates When Carbon Regeneration is Staggered

Cost element	Cost with on-site regeneration	Cost with off-site regeneration
Capital (\$) ^a	20,000,000	17,000,000
O&M (\$/yr)	640,000	2,000,000
Total Annual (\$/yr) ^b	2,700,000	3,700,000

^a Does not include contingency, engineering, or administration costs. Costs are expressed in 1999 dollars and have not been updated to the midpoint of construction.

^b Capital Recovery Factor (A/P, I = 8, n=20) = 0.1019, costs are rounded to nearest \$100,000 to avoid implying a false accuracy

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: CHCl ₃ , DBCM, CHBr ₃	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

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