ICR Treatment Study Summary Report

Evaluation of Rapid Small Scale Column Testing for Compliance with the Information Collection Rule

Conducted during the period of February 18, 1998 through July 14, 1999

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July 1999

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Appomattox River Water Authority ICR #680

June 30, 1999

Mr. Richard D. Hartman, P.E.
General Manager
Appomattox River Water Authority
21300 Chesdin Road
Petersburg, VA 23803

Dear Dee:

Please find enclosed one copy of the draft final report for the ICR RSSCT Treatability Study. The draft report includes printed copies of the summary report, data collection spreadsheets, and laboratory QA/QC summary report. This package contains all of the information required for submission to the EPA. Please review the report and provide comments as soon as possible so that we can edit the report and submit the final version to EPA by July 14, 1999.

Please contact us if there are any questions.

Sincerely,

ENVIRONMENTAL ENGINEERING & TECHNOLOGY, INC.

Michael J. MacPhee, Ph.D.
Process Manager

/wmm

Enclosure

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INTRODUCTION

The Appomattox River Water Authority (ARWA) currently operates a 46-mgd water treatment facility in Chesterfield County, Virginia. The facility treats raw water from a reservoir source for use primarily as a municipal drinking water supply. The ARWA was required by the EPA to conduct a bench-scale granular activated carbon (GAC) rapid small scale column test (RSSCT) or a rapid bench-scale membrane test (RBSMT) as directed by the Information Collection Rule (ICR) published in the May 14, 1996 Federal Register. The GAC Precursor Removal Studies guidelines are included in EPA's "ICR Manual for Bench- and Pilot-Scale Treatment Studies" (EPA 1996), and the EPA's "ICR Treatment Studies Data Collection Spreadsheets Users Guide" (EPA 1997).

The ICR is a regulatory agreement that is used to determine a course of action for controlling microbial contaminants and disinfection byproducts (DBPs). ICR treatment studies (i.e., the RSSCT) are used to obtain information on the potential options and costs for meeting the Stage I and proposed Stage II regulatory requirements.

ARWA was required to perform a year-long DBP precursor removal treatment study because its historical average distribution system DBPs exceeded 40 μg/L for THMs and 30 μg/L for HAAs, and its annual average raw water TOC concentration exceeded 4.0 mg/L. ARWA selected an RSSCT study to satisfy this ICR treatability requirement.

BACKGROUND INFORMATION

Treatment Plant Description

The ARWA treatment plant uses conventional treatment for purification of drinking water, which includes in-line static mixing for chemical dispersion, mechanical flocculation, sedimentation, and filtration. A process schematic of the ARWA facility is included in Figure 1. The process schematic shows different plant processes, the locations used for chemical feed injection, and the sampling location where influent water was collected for RSSCT testing. The

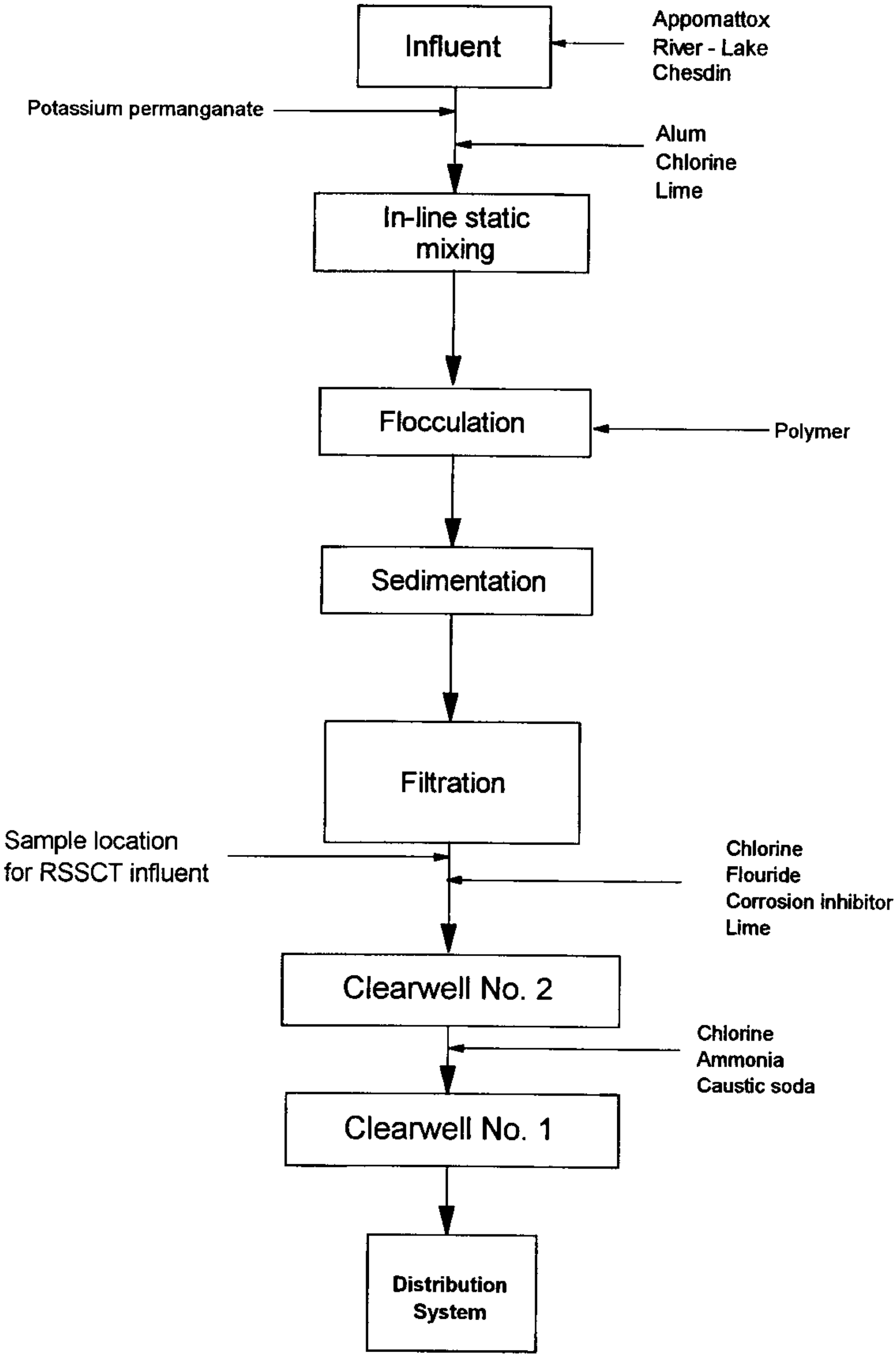

Figure 1 ARWA plant process schematic

ARWA plant currently uses aluminum sulfate (alum) as the primary coagulant. A nonionic polymer is fed during flocculation for use as a coagulant aid. Disinfection includes raw water chlorination, post-filter chlorination, and post-clearwell no. 2 chlorine and ammonia feed to generate chloramines for residual disinfection in the distribution system. Lime and caustic soda are used for pH adjustment.

Design information for each of ARWA's unit processes is included in Table 1. The table summarizes each of the plant processes by summarizing mechanical descriptions, basin volumes, media specifications, chemical feed information, etc.

Table 1

Design information

Unit process	Process description	
Pre-treatment	Chemical addition	Pre-chlorine, potassium permanganate
Rapid mix	Type of mixer Baffling type Liquid volume (gal) Mean velocity gradient (sec^{-1}) Coagulant addition Coagulant dose (mg/L) Oxidant addition Oxidant dose (mg/L) Base addition Base dose (mg/L)	Static in-line Unbaffled 888 800 Aluminum sulfate 34 Potassium permanganate 1.0 Calcium hydroxide 1.0
Flocculation	Type of mixer Baffling type (two types) Liquid volume (gal) Coagulant aid addition Coagulant aid dose (mg/L) Stage sequence number Stage mean velocity gradient (sec^{-1}) Stage liquid volume (gal)	Mechanical mixing Paddle over under step flocculation Turbine flocculation baffled 1,001,692 Calgon nonionic polymer 0.05 1 100 241,900
Sedimentation	Surface area (ft^2) Liquid volume (gal) Baffling type	67,760 7,110,000 Stilling wall
Filtration	Surface area (ft^2)	7,992

Unit process	Process description	
	Liquid volume (gal) Total media depth (in.) Media type Minimum water depth to top of media (in.) Depth from top of media to top of backwash trough (in.)	508,128 36 GAC (24 in.), sand (12 in.) 56.4 37.2
Post-filtration	Disinfection chemical Measured as Dose rate (mg/L) Other additions	Chlorine gas Free chlorine 1.5 Fluoride, corrosion inhibitor, lime
Clearwell no. 2	Surface area (ft^2) Liquid volume (gal) Covered contactor Post clearwell no. 2 additions	61,212 6,500,000 Yes Chlorine, ammonia, caustic soda

Historical Water Quality

Raw Water

The ARWA raw water supply source is Lake Chesdin, which is a small impoundment on the Appomattox River. The raw water quality is dramatically affected by rainfall events that can produce raw water turbidities as high as 85 ntu. A summary of ARWA's historical raw water quality is provided in Table 2.

Table 2

Summary of source water quality for ARWA

Water quality parameter	Average yearly value	Standard deviation	Minimum yearly value	Maximum yearly value
Temperature (ºC)	17.0	14.0	2.0	30.0
pH	7.0	0.92	6.2	7.5
Turbidity (ntu)	12.0	59.4	1.0	85.0
Alkalinity (mg/L as $CaCO_3$)	22.0	24.6	0.15	35.0
Calcium hardness (mg/L as $CaCO_3$)	40.0	14.1	35.0	55.0
Total hardness (mg/L as $CaCO_3$)	45.0	21.2	30.0	60.0
TOC (mg/L)	5.08	5.56	2.63	10.5
UV_{254} (cm^{-1})	0.228	0.51	0.014	0.739
Bromide (μg/L)	ND	ND	ND	ND

The historical yearly average total organic carbon (TOC) concentration is approximately 5 mg/L, with TOC spikes up to 10 mg/L. The typical TOC concentration range for ARWA raw water is 4 to 7 mg/L.

The pH of the raw water ranges between 6.0 and 7.5. The coagulation pH is adjusted to 6.5 to enhance chemical coagulation. The total hardness of the raw water is moderate averaging approximately 45 mg/L as $CaCO_3$, while the alkalinity averages 40 mg/L as $CaCO_3$.

Finished Water

A summary of ARWA finished water quality is provided in Table 3. The filtered water turbidity produced by ARWA ranges from 0.01 to 0.18 ntu. After final chemical feed for disinfection, pH adjustment and corrosion control, the finished water turbidity leaving the ARWA facility ranges between 0.2 and 0.35 ntu with an average of approximately 0.25 ntu. The finished water TOC concentration historical yearly average is approximately 2.9 mg/L, but has been measured as high as 7.8 mg/L. Historical finished water DBPs monitored by ARWA include only the distribution system trihalomethanes (THMs). The historical running annual average THM concentration measured in ARWA's distribution system sample locations was 81 μg/L. This THM concentration exceeds the Stage I D/DBP Rule limit of 80 μg/L. To reduce DBPs, in 1998 ARWA began using chloramines for residual disinfection. As a result of the use of chloramines, the distribution system THM concentration was reduced to below the Stage I D/DBP Rule limit. The THM data contained in Table 3 is historical finished water quality prior to the use of chloramines. ARWA began using chloramines in July 1998, therefore, one complete year of data is not yet available.

Table 3

Summary of finished water quality

Water quality parameter	Average yearly value	Standard deviation	Minimum yearly value	Maximum yearly value
Temperature (ºC)	17.0	19.8	2	30.0
pH	7.2	0.06	7.0	7.8
Turbidity (ntu)	0.25	0.11	0.2	0.35
TOC (mg/L)	2.85	4.38	1.67	7.83
Distribution system THM4 (μg/L)	81.0*	80.6	23*	137.0*

*Historical data based on years 1985-1998.

Treatment Challenges

The ARWA water treatment plant has recently undergone a number of process improvements and renovations. ARWA is beginning a Master Planning analysis to project future plant capacity upgrades and to determine how the proposed future water quality regulatory limits can be achieved. Currently, the ARWA WTP could not comply with the proposed Stage II D/DBP limits for THMs (40 μg/L) and HAAs (30 μg/L) using chloramines alone. The ARWA treatment facility may also need to be further modified and optimized to meet other future regulations, such as the Long Term 2 Enhanced Surface Water Treatment Rule.

In order to identify better treatment alternatives, ARWA plans on assessing other pre-oxidants, such as ozone and chlorine dioxide, for DBP reduction. Post-filter GAC contactors may also be evaluated for reduction of DBP precursors. Other challenges facing ARWA include manganese control and WTP and distribution system infrastructure improvements.

METHODS AND MATERIALS

Influent Pretreatment Process

Influent water used for the RSSCT study was collected from the ARWA WTP immediately after filtration. The sampling events were coordinated with the plant operators so that pre-chlorination would be stopped for a 24-hr period prior to sample collection. The same full-scale filter was used for each quarterly sampling event and the chlorine concentration was analyzed during sample collection to verify that no residual chlorine was present.

A process schematic showing the procedure used during sampling is included in Figure 2. During sampling, the filtered water was pumped directly from the filter effluent pipe through a 1 μm cartridge filter and into a storage tank. The post-filter sample tap was located upstream of any further chemical feed locations. The 1 μm cartridge filter was used to remove any large particulates that could potentially plug the GAC media during RSSCT operation. The filtered water was passed through the cartridge filter at a rate between 1 and 2 gpm. A pre-treatment summary for each quarterly RSSCT test is presented in Table 4.

Table 4

Sample collection pre-treatment for RSSCT study

Test quarter	Pre-treatment	EBCT (min)
Quarter 1	Cartridge filtration (1 μm)	10 and 20
Quarter 2	Cartridge filtration (1 μm)	10 and 20
Quarter 3	Cartridge filtration (1 μm)	10 and 20
Quarter 4	Cartridge filtration (1 μm)	10 and 20

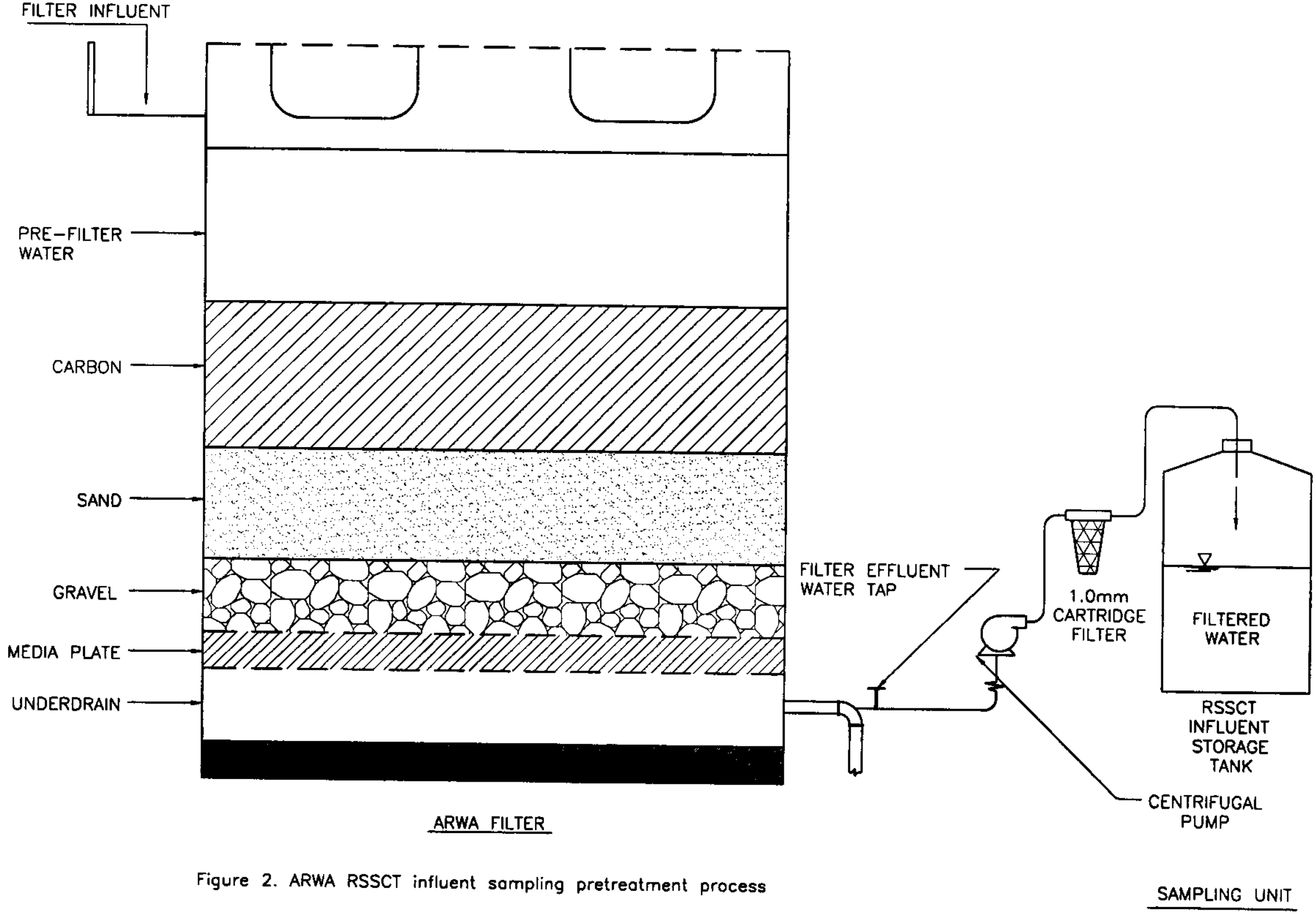

Figure 2. ARWA RSSCT influent sampling pretreatment process

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Influent Water Collection

Sample collection for the RSSCT study was performed during periods when ARWA's raw water quality was stable and considered representative based on historical seasonal data. In order to verify that the influent sample collected was typical, a series of five analytical tests was performed including:

- TOC
- pH
- Alkalinity (mg/L as $CaCO_3$)
- Total and calcium hardness (mg/L as $CaCO_3$)
- UV_{254}
- Turbidity

Results from these analyses were compared with historical plant filtered water quality data collected by ARWA to determine if the sample collected was truly representative. After confirming that the sample was representative, the water was quickly transported to the EE&T test facility to begin the study. At least 160 gal of filtered water were collected for each quarterly RSSCT study.

RSSCT Design Information

A bench-scale filter apparatus was constructed that included all of the equipment required to perform the RSSCT study. The filter apparatus contained separate systems for both the 10-min empty bed contact time (EBCT) test and the 20-min EBCT test.

The process schematic for the 10-min EBCT test unit is presented in Figure 3. The 10-min EBCT setup included a positive displacement pump, a Teflon© cartridge filter housing (with 5 µm filter), pressure gauges, and one 8-mm glass chromatography column. The tubing connecting the equipment was ⅜-in. O.D. Teflon© and all fittings used were stainless steel.

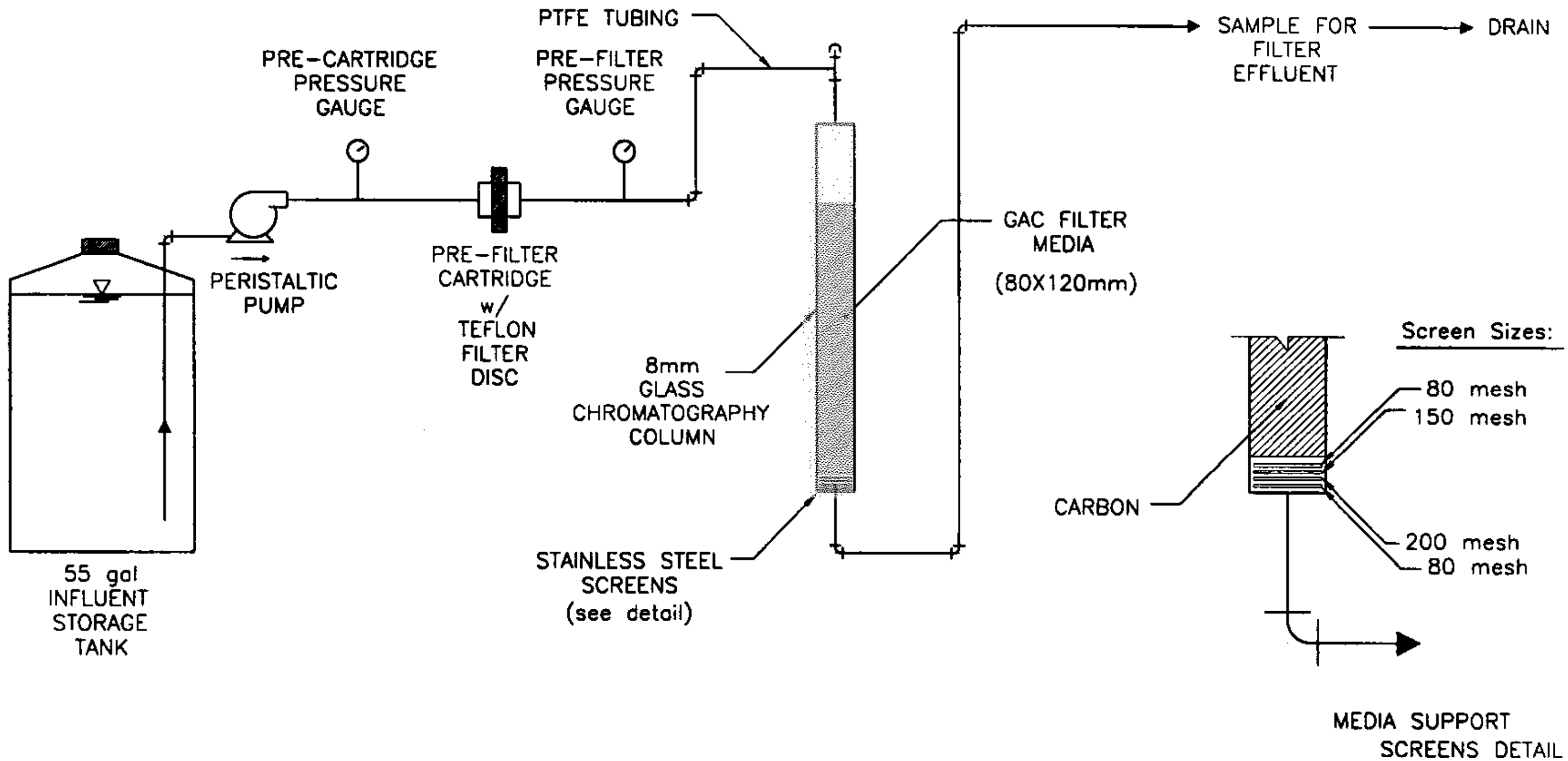

Figure 3. RSSCT testing system 10-min EBCT

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Stainless steel screens were used to support the GAC media in the glass column. The filter effluent was grab sampled downstream of the glass GAC column, and the influent feed water was sampled directly from the storage tank.

A process schematic for the 20-min EBCT test unit is included in Figure 4. The 20-min EBCT apparatus included the same equipment as the 10-min EBCT setup, however, to double the EBCT, two 8-mm glass columns were placed in series to house the additional GAC media.

GAC Media Preparation

A bituminous coal-based GAC media was selected for use in the RSSCT study. The product used was a Calgon F-400 GAC with a U.S. standard mesh size of 12x40. To reduce headloss in the media during testing, a GAC size range of 80x140 was selected for use in the 8-mm I.D. glass columns. To achieve the desired media size, the Calgon F-400 GAC was manually ground using a mortar and pestle and then sieved using 80 mm and 140 mm U.S. standard mesh screens. After sieving was complete, the GAC media was washed according to the procedure provided in Section 5.1 of the ICR Manual for Bench- and Pilot-Scale Treatment Studies (EPA 814-B-96-003).

Prior to loading the 80 mm x 140 mm GAC media into the glass columns, the media was re-sieved to verify the size and remove fines. It was discovered that drying the media after washing caused an excessive amount of GAC fines that significantly increased filter headloss during testing. Once the media preparation was completed and the GAC was added to the columns, the test was initiated using the pre-wetting procedure outlined in Section 5.2 of the ICR Treatment Studies Manual (EPA 814-B-96-003). The pre-wetted GAC slurry was added to the 10- and 20-min EBCT columns at depths determined by the RSSCT process projection spreadsheets. The media depths added to the 8-mm glass column to obtain a 10- and 20-min EBCT were as follows:

10-min EBCT:Column 1 media depth (cm) = 12.3

20-min EBCT:Column 1 media depth (cm) = 8.2

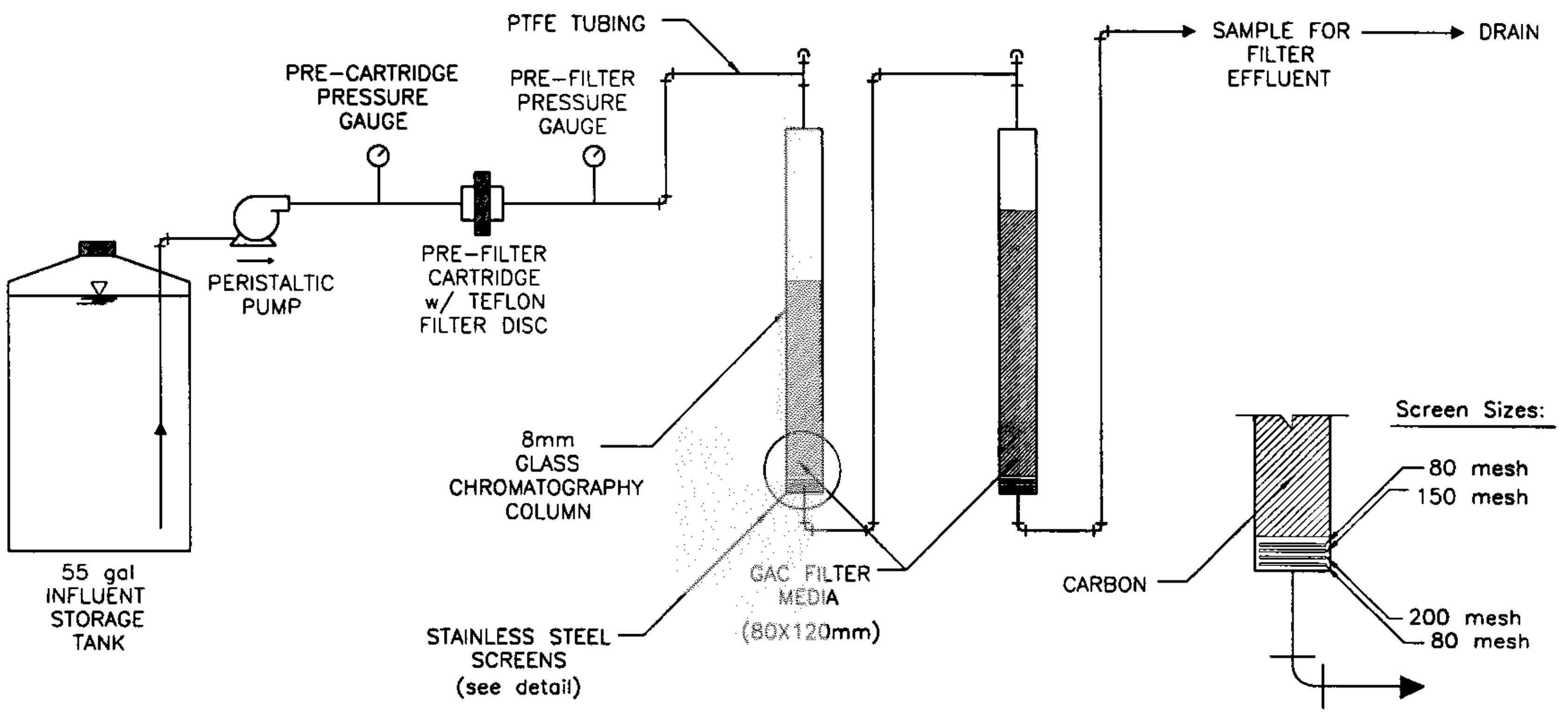

Figure 4. RSSCT testing system 20-min EBCT

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Column 2 media depth (cm) = 16.4

For the 20-min EBCT, one third of the total media volume was placed in column 1, while the balance of the media was placed in Column 2. This was done to reduce headloss build-up through the 20-min EBCT test unit. The media depths were identical for all four quarterly RSSCTs.

Operations Protocol

Process Projections

In order to determine the operational parameters for the RSSCTs, a computer process projection spreadsheet was developed using formulas provided by the ICR Treatment Studies Manual (EPA 814-B-96-003). The process projection was used to determine the mass of GAC media required to obtain a 10- and 20-min EBCT in the GAC columns. The mass of GAC required as well as other pertinent process parameters projected by the computer spreadsheet are shown in Table 5.

Table 5

RSSCT operational parameters

Parameter	RSSCT unit	
	10-min EBCT	20-min EBCT
Mass of GAC (g)	3.1	6.2
Total media depth (cm)	12.3	24.6
System flow rate (mL/min)	4.8	4.8
Scaling factor	7.69	7.69

The scaling factor is the ratio of the mean carbon particle diameter of the full-scale GAC media (1.1 mm) to the particle diameter (0.14 mm) of the crushed GAC used for the RSSCT study. The scaling factor is used to estimate the full-scale equivalent run time based on the measured bench-scale filter run lengths. To obtain the full-scale equivalent run time, the scaling factor is multiplied by the number of actual RSSCT operation days. For example, one day of RSSCT run time is equal to slightly longer than one full-scale equivalent week. After performing this adjustment, the RSSCT filter run time is referred to as the "scaled operation time".

The process projection provides an estimate of the TOC breakthrough time based on the influent TOC concentration and also is used to estimate the volume of influent water required to complete each test. A copy of the process projections calculated for each quarterly RSSCT are included in Appendix Tables A.1, A.2, A.3, and A.4.

RSSCT Influent Analysis

The influent water was sampled a total of four times for each quarterly RSSCT test. The first influent sample was analyzed prior to collection from the WTP. The remaining three influent samples were collected at the beginning, approximate middle, and end of each quarterly RSSCT. Influent analysis for these three samples included the following parameters:

TOC	Turbidity
pH	Bromide*
Alkalinity*	SDS chlorine demand
UV_{254}	SDSTHM4
Total hardness*	SDSHAA6
Calcium hardness*	SDSTOX
Ammonia*	

*Analyses were conducted for first and third influent samples only.

The influent TOC concentration was used to determine the 70 percent TOC breakthrough concentration. During each test, a running average of the beginning and end influent TOC concentrations was used to estimate the 50 and 70 percent breakthrough plateaus, which were used to determine test completion.

RSSCT Effluent Analysis

A total of 12 filter effluent compliance samples were collected during both the 10- and 20-min EBCT tests. Samples 4, 7, and 10 required a duplicate field sampling for each test. Effluent testing included analyses for the following parameters:

TOC	SDS chlorine demand
pH	SDSTHM4
Temperature	SDSHAA6
UV_{254}	SDSTOX

The first compliance sample was collected one hour after initiation of each quarterly test. The remaining 11 samples, however, did not have a specific time schedule for sampling but were collected based on the TOC breakthrough concentrations in the effluent water. The goal for each sampling event was to collect a filter effluent compliance sample at 5 to 8 percent TOC breakthrough increments. To accomplish this, a 10- and 20-min EBCT effluent sample had to be analyzed for TOC daily to determine when to collect each compliance sample. RSSCT study completion was based on at least one of the following ICR Rule 141.144(b)(l)(I) criteria:

a. An effluent TOC concentration $\geq$70 percent of the average influent TOC concentration on two consecutive sample dates that were two full-scale equivalent weeks part.

b. A 50 percent TOC breakthrough is reached and then the effluent concentration does not increase by more than 10 percent of the average influent TOC concentration for the next two full-scale equivalent months.

c. One full-scale equivalent year of testing and completion of sampling for all 12 required compliance samples.

Operational Monitoring

The 10- and 20-min EBCT RSSCT system operational parameters were checked and adjusted on a daily basis. The parameters monitored included the following:

- Pre-treatment cartridge filter pressure
- GAC media pressure
- System flow rate
- Media depth

The system flow rate was controlled by adjusting the rate of the peristaltic feed pump. The flow rate was confirmed daily to maintain the desired flow rate of 4.7 mL/min. Slight changes occurred due to increasing headloss in the pre-filter and GAC media.

Analytical Methods

The laboratory methods used for RSSCT sample analysis are summarized in Table 6. The table also includes the minimum reporting level (MRL), method detection level (MDL), and precision and accuracy criteria. All of the analytical methods used are approved by EPA for ICR testing.

Table 6

Analytical methods used for the RSSCT study

Test	Method	Reporting units	MRL	MDL	Precision percent RSD*	Accuracy percent response*
Inorganic analytes						
Alkalinity	SM 2320 B	mg/L	3	2	---	---
Bromide	EPA 300.0 B	μg/L	20	0.010	≤10	±10
Chlorine, free, total	SM 4500-Cl G	mg/L	0.1	---	---	---
Hardness, calcium	SM 3500-Ca D	mg/L	4.6	0.09	---	---
Hardness, total	SM 2340 C	mg/L	4.6	0.09	---	---

Test	Method	Reporting units	MRL	MDL	Precision percent RSD*	Accuracy percent response*
pH	SM 4500-H+ B	pH	---	---	---	---
Temperature	SM 2550 B	^{o}C	---	---	---	---
Total organic carbon (TOC)	SM 5310 C	mg/L	0.5	0.50	≤ 10	± 15
Total organic halide (TOX)	SM 5320 B	μg/L	20	25	---	---
Turbidity	SM 2130 B	ntu	0.05	0.015	---	---
UV absorbance at 254 nm	SM 5910 B	cm^{-1}	0.009	0.50 mg/L†	≤ 10	± 15
Organic analytes						
Haloacetic acids (except MCAA)	EPA 552.2 SM 6251 B	μg/L	1.0‡	$\leq$0.50‡	≤ 20	± 15
Monochloroacetic acid	EPA 552.2 SM 6251 B	μg/L	2.0	≤ 1.0	≤ 20	± 15
Trihalomethanes	EPA 551.1/551	μg/L	1.0‡	$\leq$0.50‡	≤ 20	± 20

*See QC criteria for frequency
†Potassium hydrogen phthalate (KHP) concentration (mg/L) is given as dissolved organic carbon (DOC)
‡Each analyte

The three laboratories used for RSSCT sample analysis are listed in Table 7. Most of the analyses were conducted by the EE&T laboratory. Only the SDSTOX and bromide samples were delivered to outside laboratories for analysis.

Table 7

Laboratory services summary

Laboratory	Dates of service	Analyses performed
EE&T Laboratories	1/98 to 7/99	Alkalinity, Ammonia, Calcium Hardness, Chlorine Residual, HAA6 (EPA 552.2), pH, Temperature, THM4 (EPA 551.1), Total Hardness, Turbidity, UV_{254}
James R. Reed & Associates	1/98 to 7/99	TOX (SM 5320 B)
Utah Department of Health Division of Epidemiology and Laboratory Services	1/98 to 7/99	Bromide (EPA 300.0)

RESULTS AND DISCUSSION

Influent Water Quality

RSSCT influent water was analyzed three separate times during each quarterly test. Samples were collected at the beginning, middle, and end of each test period. A summary of the water quality data obtained for each quarter of testing is shown in Table 8. The table shows that the influent TOC concentration ranged from 2.13 to 3.17 mg/L during RSSCT testing. The influent water quality for each of the four test quarters was very similar.

Table 8

Summary of RSSCT influent quality

Water quality parameter	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Temperature (ºC)	19.1	24.7	23.9	15.6
pH	6.48	7.20	7.08	7.07
Turbidity (ntu)	0.41	0.15	0.08	0.14
Alkalinity (mg/L as $CaCO_3$)	7.0	23.3	21.2	29
Calcium hardness (mg/L as $CaCO_3$)	27.3	16.3	21.5	25
Total hardness (mg/L as $CaCO_3$)	33.1	26.0	35	62
Bromide (µg/L)	<0.02	<0.02	<0.02	<0.02
TOC (mg/L)	3.17	2.69	2.57	2.13
UV_{254} (cm^{-1})	0.047	0.032	0.041	0.031
SDSTHM4 (µg/L)	24.7	69.6	57.1	59.5
SDSHAA6 (µg/L)	48.0	87.0	72.2	57.6
SDSTOX (µg/L)	141.0	200.1	176.1	154.6
SDS chlorine demand (mg/L)	2.35	2.64	2.92	2.11

Note: Averages are calculated using only three samples for each parameter except for hardness (total and calcium), bromide, and alkalinity. Each of these included results from only two different sample events.

The influent SDSTHM4 data during the year-long RSSCT study averaged 52.7 μg/L, which is less than the ARWA 1998 distribution system average of 81 μg/L. The difference is primarily attributed to the fact that raw water chlorination was discontinued for 24 or more hours prior to sample collection by EE&T. Filtered water was collected from one filter rather than a combined filter effluent (due to sampling constraints) which might also have contributed to the difference in SDSTHMs between the distribution system and the influent water to the RSSCT.

Quarterly Test Results

Summary

The RSSCT quarterly test findings are summarized in Table 9. The table provides the test dates and the reason why each test was terminated. The table shows that two of the four 10-min tests ended due to 70 percent TOC breakthrough, while only the first quarter of 20-min EBCT testing was terminated due to TOC breakthrough. Data obtained from each of the four quarterly tests are presented in the following sections. The key filter effluent quality parameters monitored for each test quarter include the simulated distribution system TOCs, THMs, HAAs, and TOXs. These water quality data are plotted versus the scaled operation time for both the 10- and 20-min EBCT tests.

Table 9

ARWA RSSCT quarterly test summary

Test ID	Test date	Average influent TOC (mg/L)	Average 70 percent breakthrough concentration (mg/L)	Scaled operation time (days)	Reason for ending test
Quarter 1					
10-min	2/18-3/11, 1998	3.17	2.22	162	70% TOC breakthrough
20-min	2/18-3/29, 1998	3.17	2.22	300	70% TOC breakthrough
Quarter 2					
10-min	6/12-7/29, 1998	2.46	1.72	361	One full-scale year of run time
20-min	6/12-7/29, 1998	2.46	1.72	361	One full-scale year of run time

Test ID	Test date	Average influent TOC (mg/L)	Average 70 percent breakthrough concentration (mg/L)	Scaled operation time (days)	Reason for ending test
Quarter 3					
10-min	9/1-10/8, 1998	2.57	1.80	284	70% TOC breakthrough
20-min	9/1-10/21, 1998	2.57	1.80	284	One full-scale year of run time
Quarter 4					
10-min	1/3-3/1, 1999	2.13	1.49	436	One full-scale year of run time
20-min	1/3-3/4, 1999	2.13	1.49	443	One full-scale year of run time

Quarter 1 Results

TOC Data. The first quarter of RSSCT testing was initiated on February 18, 1998. During this test, the influent TOC averaged 3.17 mg/L. The GAC effluent TOC concentration versus time is shown in Figure 5. The figure shows that the 10-min EBCT effluent concentration reached 70 percent breakthrough after approximately 150 scaled operation days. The 20-min EBCT test also ended due to 70 percent TOC breakthrough after approximately 290 scaled operation days.

SDSTHM Data. The SDSTHM data plotted versus scaled operation days in Figure 6. The SDSTHM concentrations measured in the influent and effluent samples were all less than 30 μg/L, which is 10 μg/L lower than the proposed Stage II D/DBP Rule limit.

SDSHAA6 Data. Figure 7 shows the SDSHAA6 data for both the RSSCT influent and effluent water. The 10-min EBCT SDSHAA6 concentration reached as high as 40 μg/L after approximately 125 scaled operation days, while the 20-min EBCT effluent concentration was only 46 μg/L after 300 scaled operation days. At no point did the influent or effluent SDSHAA6 concentrations exceed the Stage I D/DBP Rule limit of 60 μg/L.

SDSTOX Data. The SDSTOX data presented in Figure 8 shows that only six of the 24 compliance samples had SDSTOX concentrations that were measurable above the method detection limit (MDL) of 50 μg/L. The influent SDSTOX concentration averaged 141 μg/L during the quarterly test.

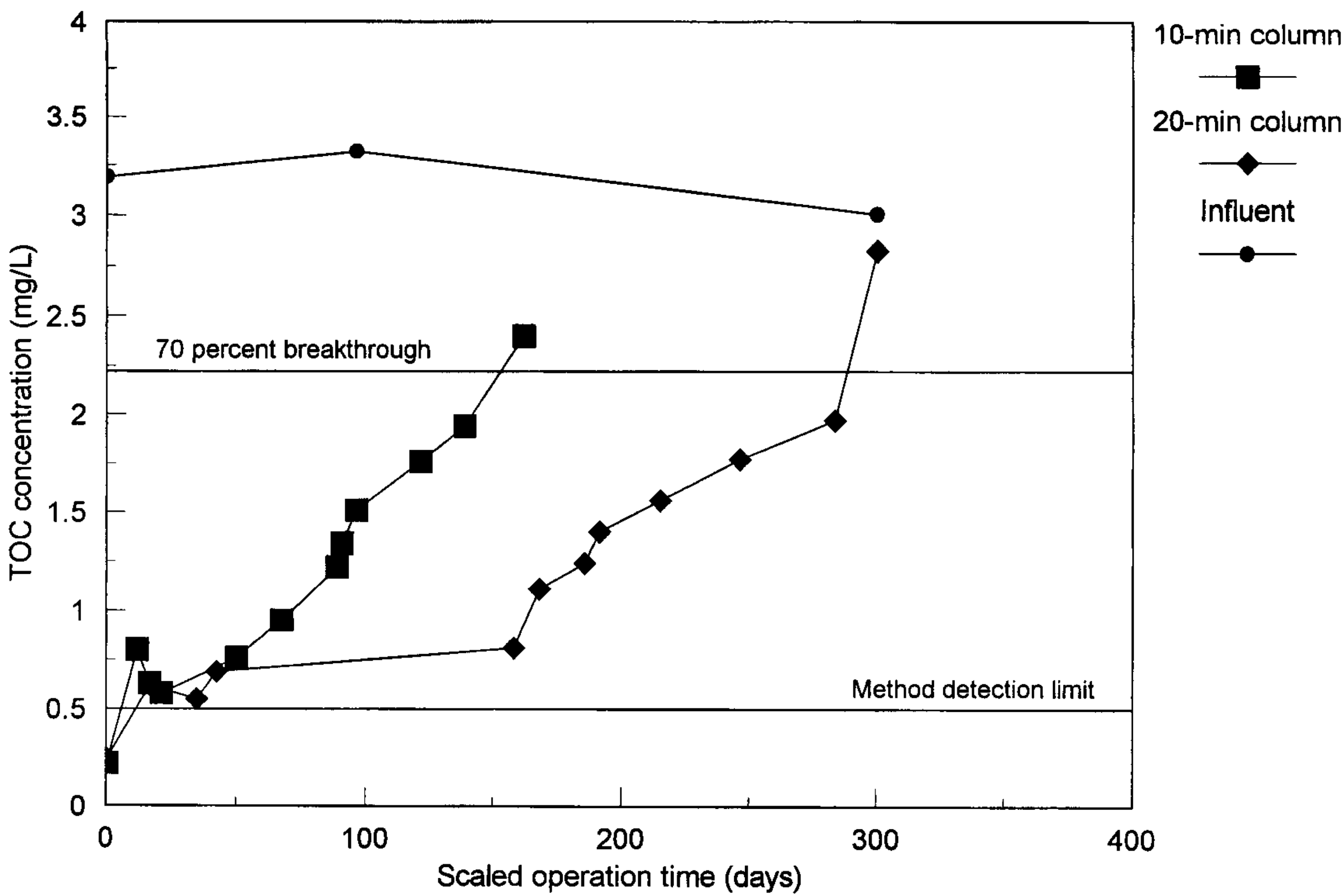

Figure 5 ARWA first quarter testing: TOC data

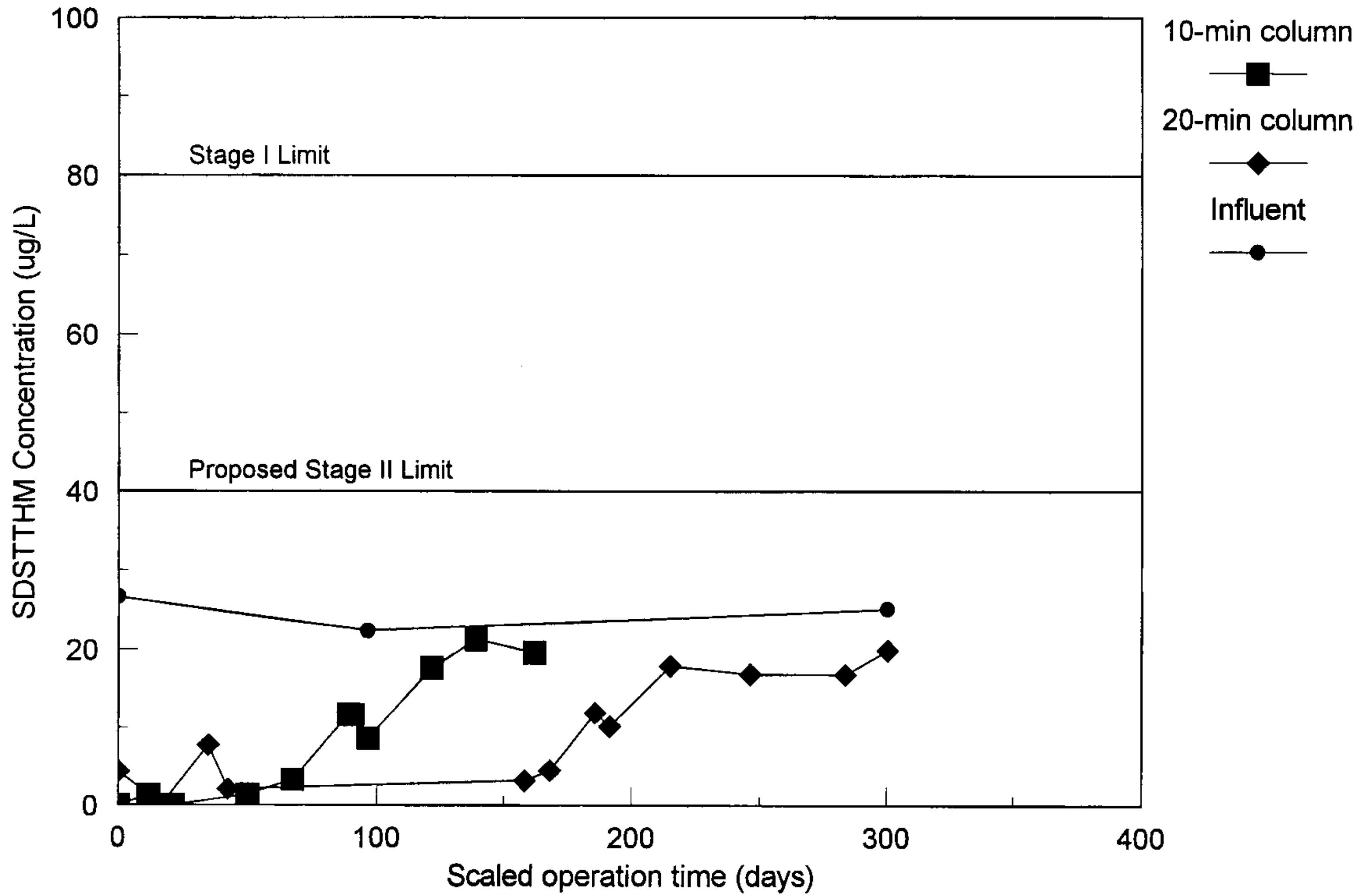

Figure 6 ARWA first quarter testing: SDSTTHM data

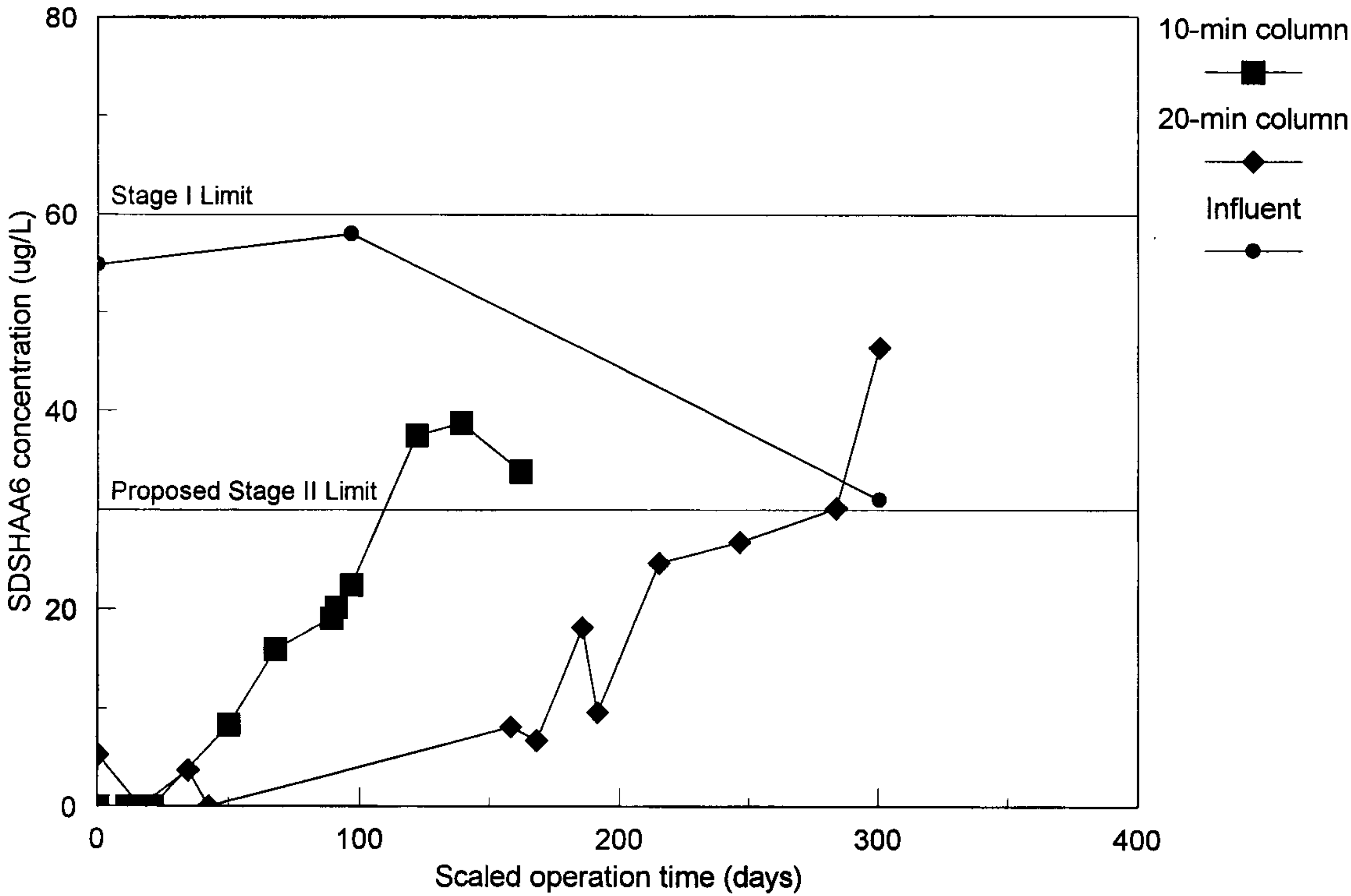

Figure 7 ARWA first quarter testing: SDSHAA6 data

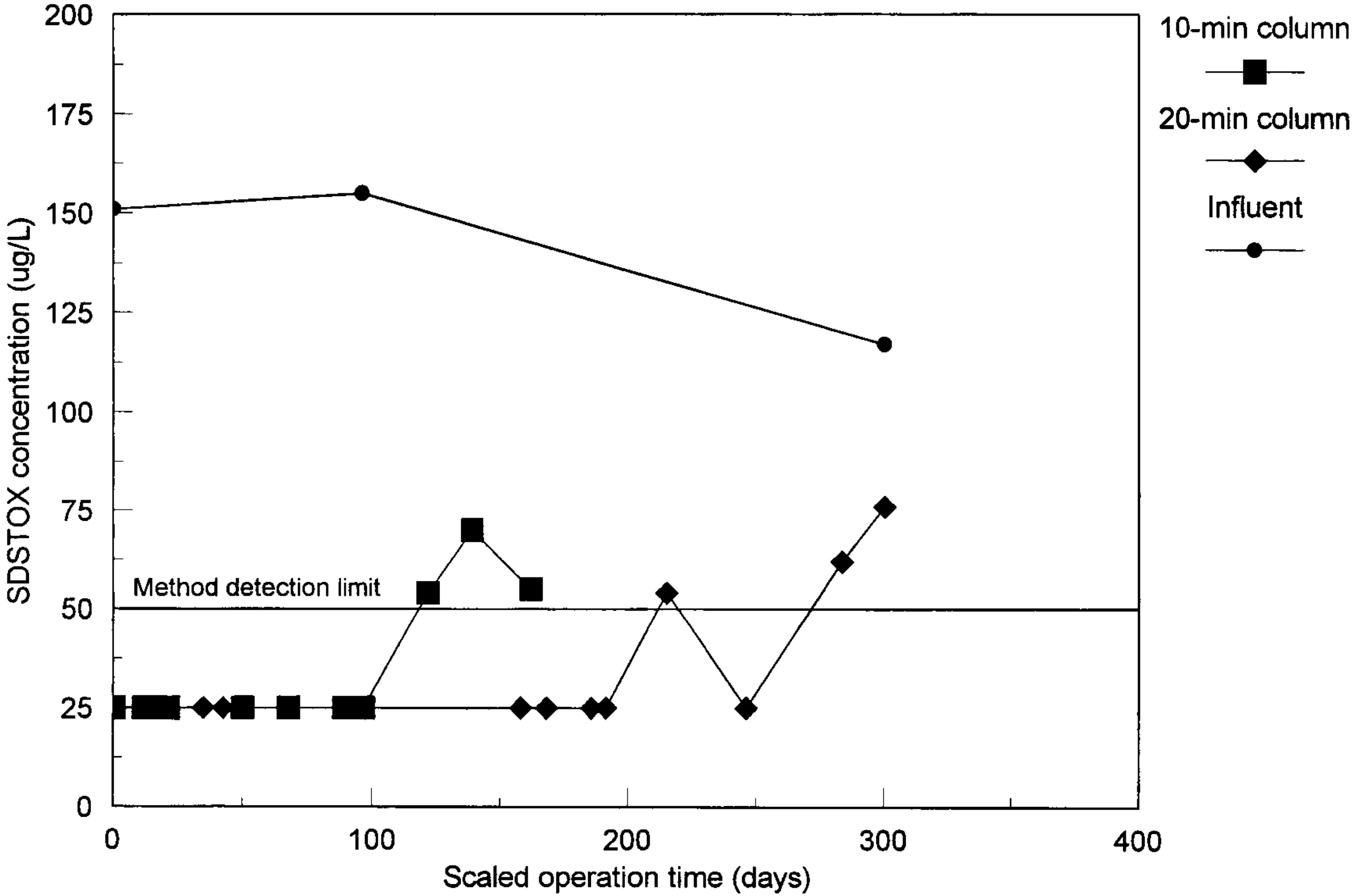

Figure 8 ARWA first quarter testing: SDSTOX data

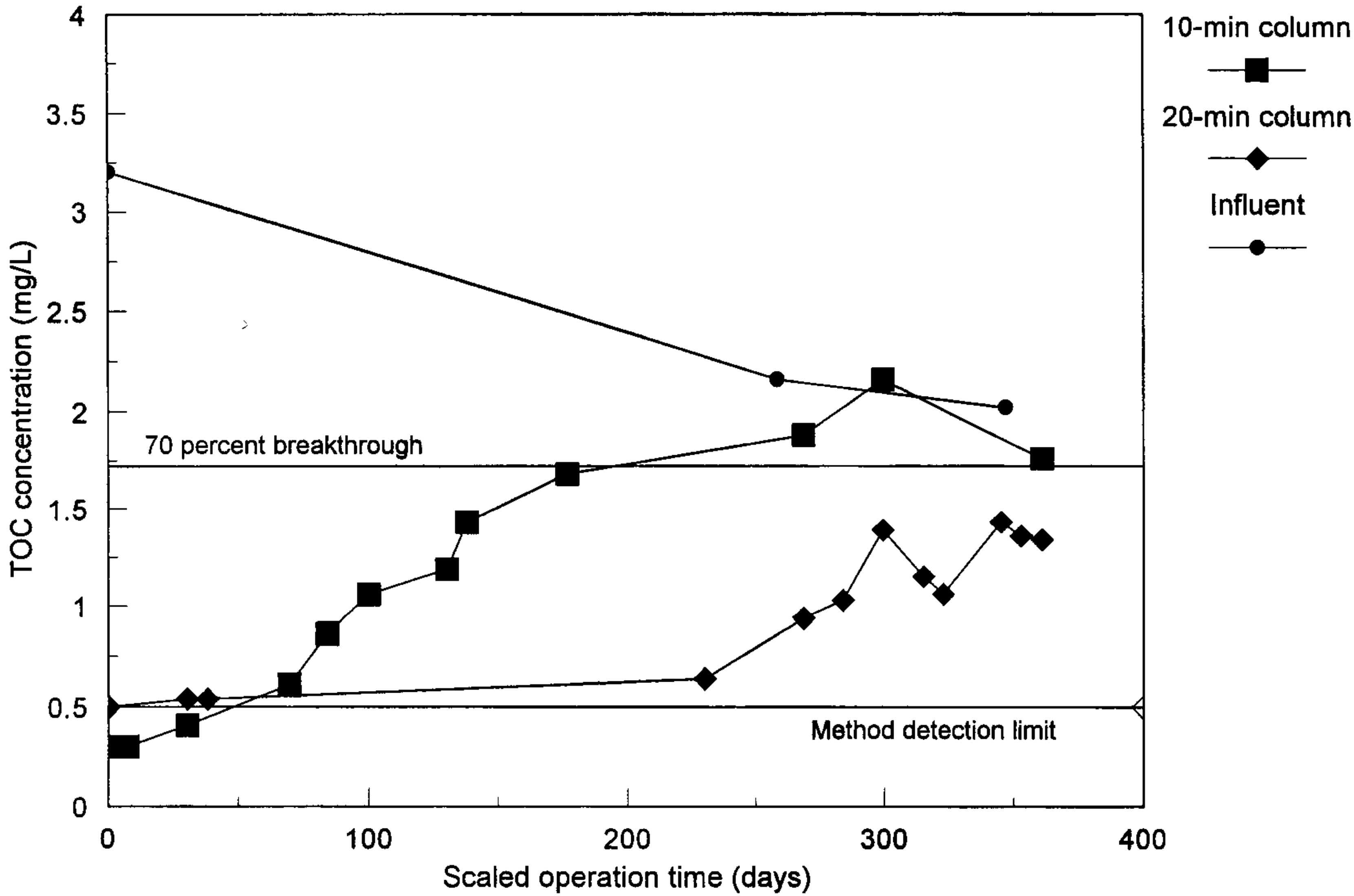

Figure 9 ARWA second quarter testing: TOC data

Quarter 2 Results

TOC Data. The second quarter of ARWA RSSCT testing began on June 12, 1998. During this quarter the influent TOC averaged 2.46 mg/L. The effluent TOC concentration versus run time for the 10- and 20-min tests are shown in Figure 9. The 10-min EBCT effluent TOC concentration reached 70 percent breakthrough at approximately 200 scaled operation days and then increased to 90 percent after 300 scaled operation days. The 10-min EBCT test was allowed to continue to one full-scale equivalent year, although the test could have been stopped based on the ICR criteria. The 20-min EBCT TOC concentration began to increase at approximately 225 scaled operation days and was measured at up to 1.5 mg/L (56 percent breakthrough) after approximately 350 scaled operation days. After 360 scaled operation days, the 20-min EBCT test was ended due to time.

SDSTHM Data. The SDSTHM concentrations for both the 10- and 20-min EBCT tests (Figure 10) were significantly higher than concentrations measured during Quarter 1. After 100 scaled operation days, the 10-min EBCT effluent SDSTHM concentration exceeded 40 μg/L (proposed Stage II limit) and after 275 scaled operation days exceeded the Stage I D/DBP Rule limit of 80 μg/L. The 20-min EBCT effluent SDSTHM concentration remained below 40 μg/L up to approximately 260 scaled operation days and then ranged between 35 and 50 μg/L for the remainder of the test. The influent SDSTHM concentration averaged slightly less than 70 μg/L.

SDSHAA6 Data. The SDSHAA6 concentrations measured from the 10- and 20-min EBCT (Figure 11) effluents were also higher than the concentrations measured during Quarter 1 testing. The 10-min EBCT effluent SDSHAA6 concentration was highly variable ranging from 20 μg/L to greater than 100 μg/L. The 20-min EBCT effluent concentrations exceeded the proposed Stage II limit for most of the test run and exceeded the Stage I D/DBP Rule limit after 300 scaled operation days. The 20-min SDSHAA concentration averaged 87 μg/L during Quarter 2 testing.

SDSTOX Data. The SDSTOX data are shown in Figure 12. The 10-min EBCT effluent concentration ranged between 50 and 150 μg/L. The first detected SDSTOX concentration was measured after 100 scaled operation days. The 20-min effluent SDSTOX concentration

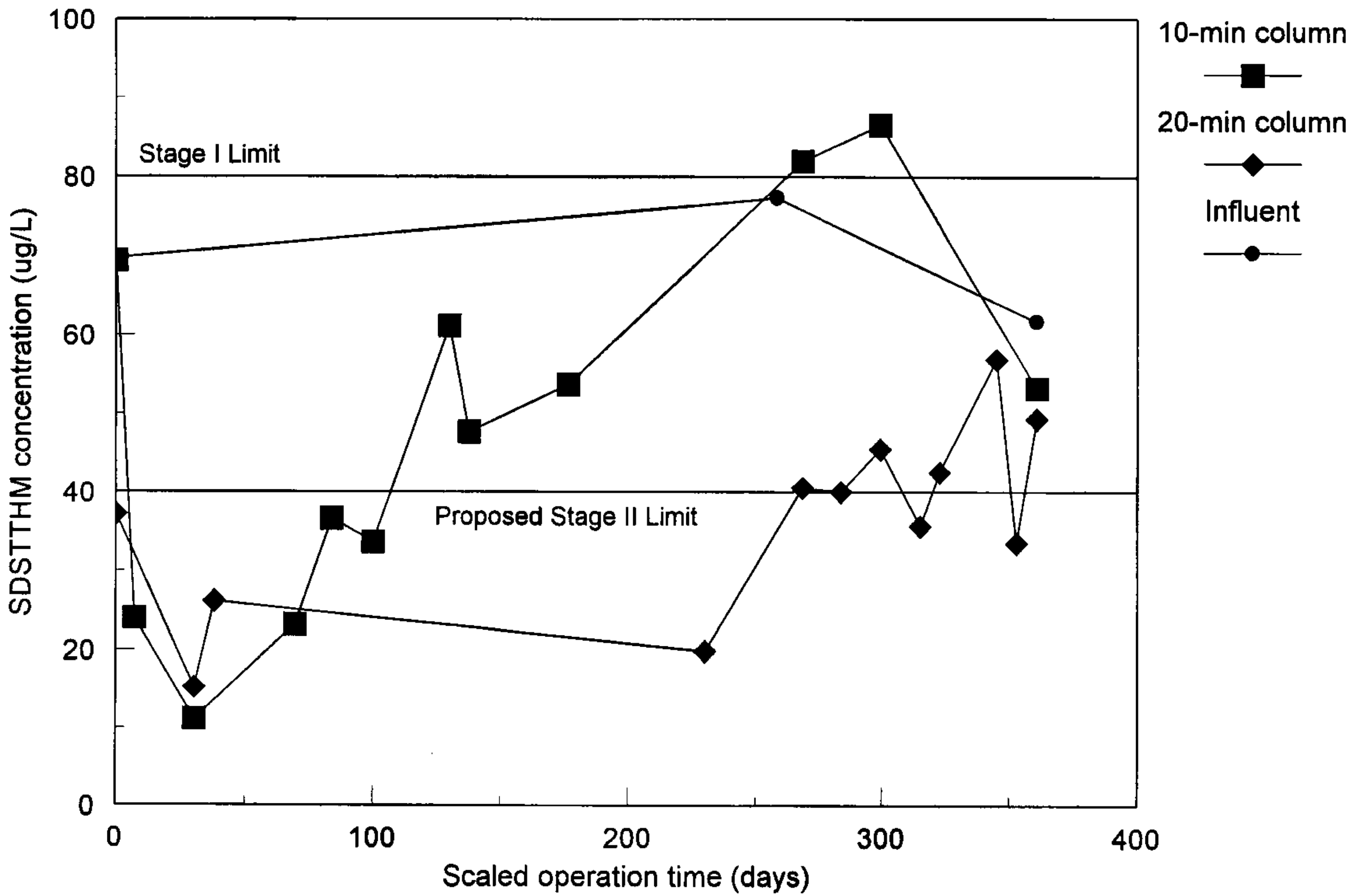

Figure 10 ARWA second quarter testing: SDSTTHM data

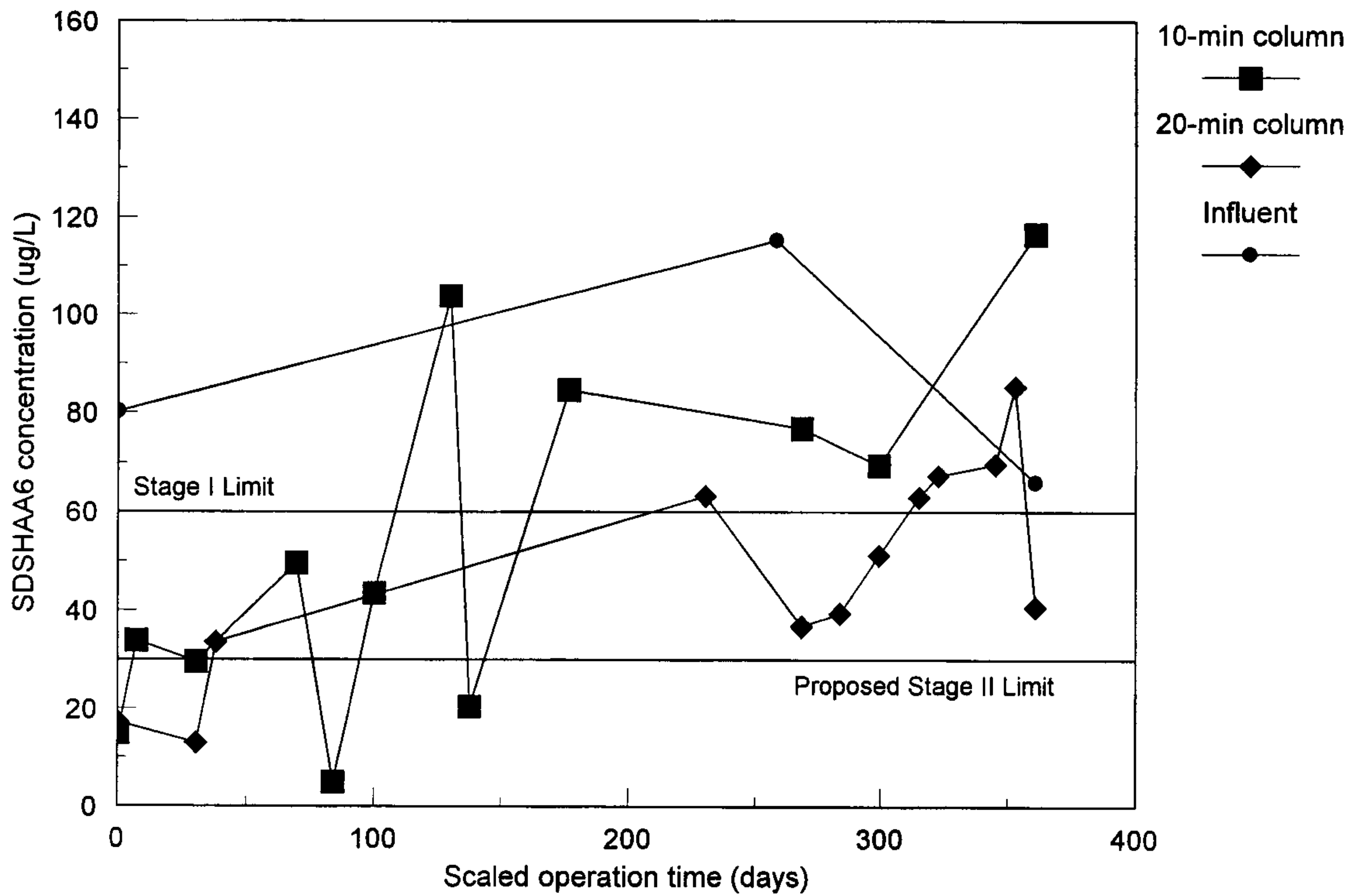

Figure 11 ARWA second quarter testing: SDSHAA6 data

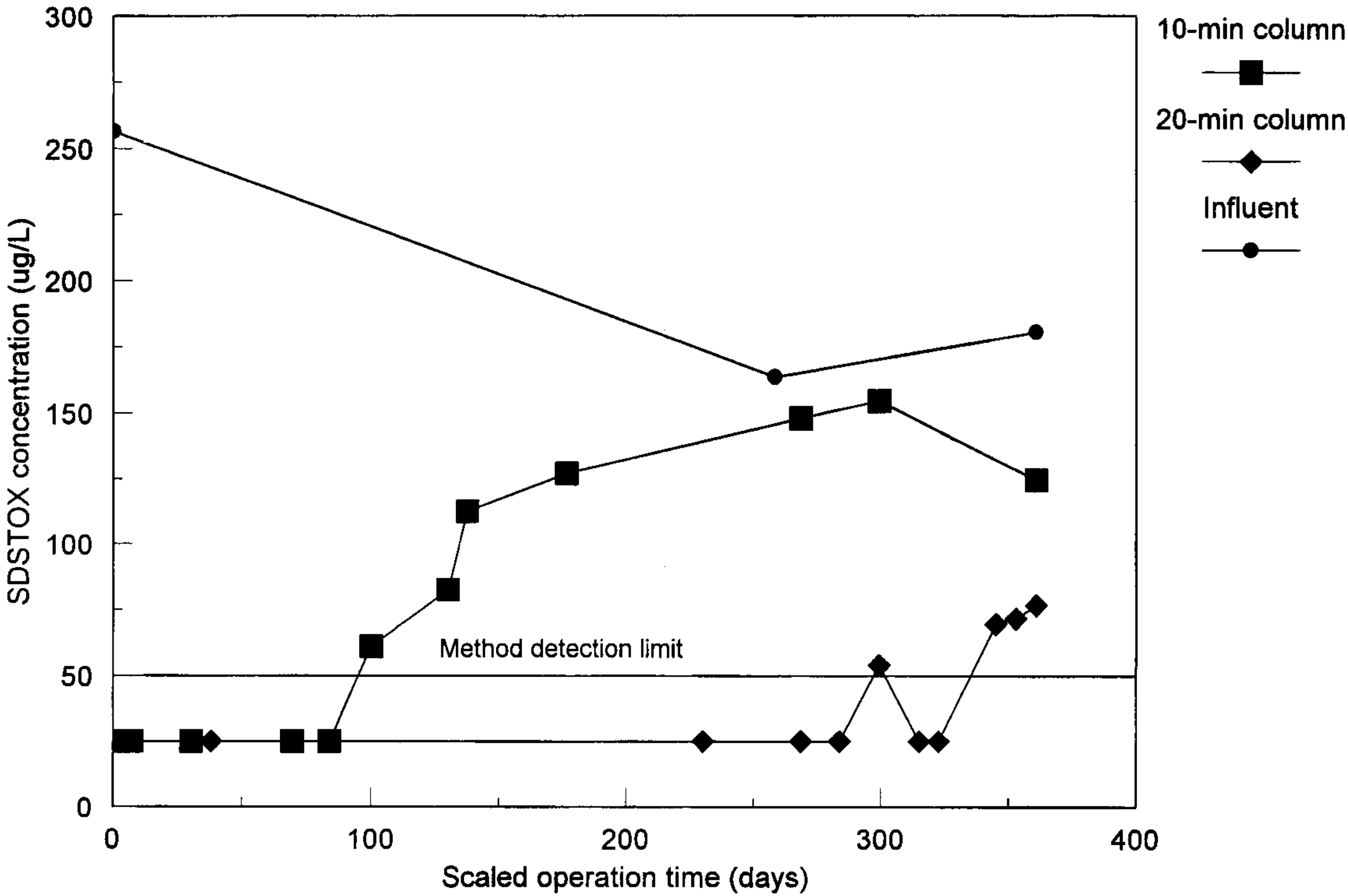

Figure 12 ARWA second quarter testing: SDSTOX data

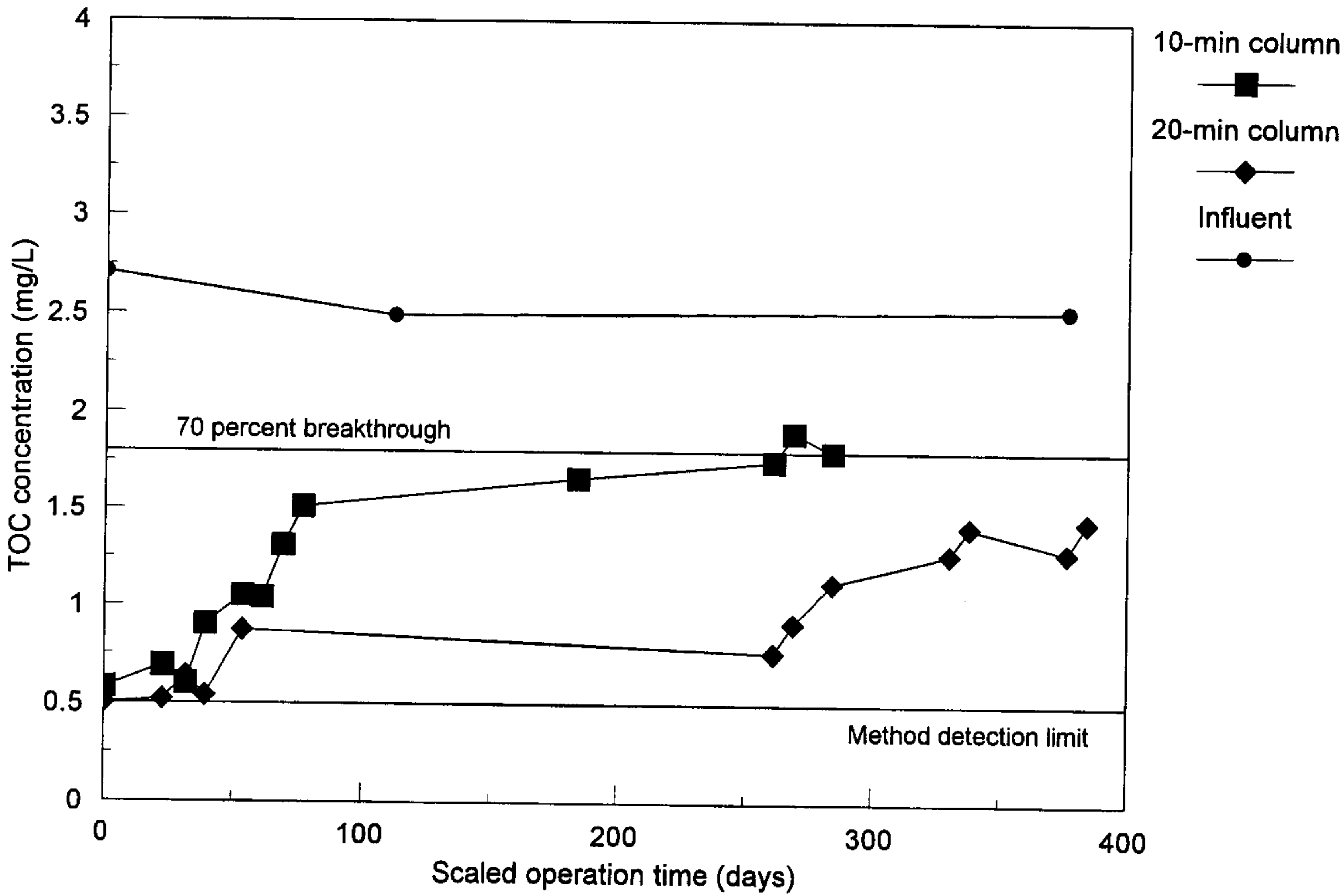

Figure 13 ARWA third quarter testing: TOC data

remained below the detection limit for almost 300 scaled operation days and did not exceed 75 μg/L at any time.

Quarter 3 Results

TOC Data. The third quarter of RSSCT testing began on September 1, 1998. During this quarter the influent TOC concentration averaged 2.57 mg/L. The 10- and 20-min EBCT effluent TOC concentration versus scaled operation time is shown in Figure 13. During Quarter 3 the 10-min EBCT TOC concentration reached 70 percent breakthrough after 250 scaled operation days, after which the test was ended. The 20-min EBCT TOC concentration did not reach 70 percent breakthrough and the test was ended after 384 scaled operation days which was slightly longer than one full-scale equivalent year. The maximum 20-min EBCT effluent TOC breakthrough concentration measured during the test was 58 percent.

SDSTHM Data. The influent and effluent SDSTHM data for Quarter 3 is shown in Figure 14. The influent SDSTHM concentration averaged 57 μg/L during the test. The 10-min EBCT effluent concentration exceeded the proposed Stage II D/DBP Rule limit after 50 scaled operation days and then remained slightly less than 40 μg/L through 250 scaled operation days. The final three 10-min EBCT effluent samples were also above 40 μg/L. The maximum SDSTHM concentration measured in the 10-min EBCT effluent was 61 μg/L, which is less than the Stage I D/DBP Rule limit.

The 20-min EBCT effluent remained below the Stage I D/DBP Rule limit for over 300 scaled operation days. After approximately 330 scaled operation days the SDSTHM concentration spiked to above 60 μg/L, however, the final compliance sample had a concentration below 40 μg/L.

SDSHAA6 Data. The SDSHAA6 results from Quarter 3 testing are shown in Figure 15. The influent SDSHAA6 concentration averaged approximately 72 μg/L. The 10-min EBCT effluent showed the same breakthrough trend as the SDSTHM data. The 10-min EBCT effluent spiked to 60 μg/L after 50 scaled operation days and then averaged approximately 40 μg/L for the remainder of the test run. The 20-min EBCT effluent had an initial spike up to 50 μg/L after 25

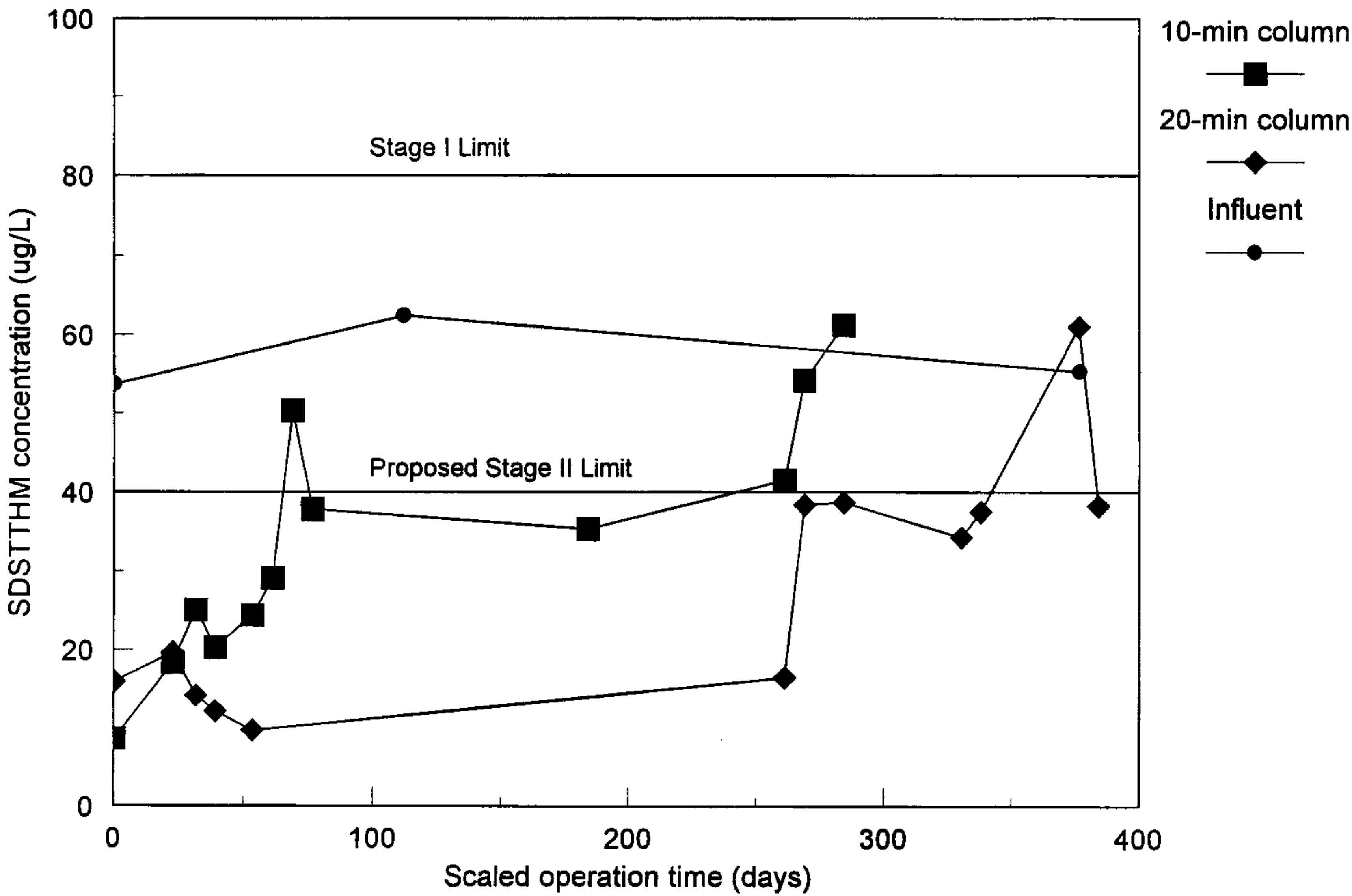

Figure 14 ARWA third quarter testing: SDSTTHM data

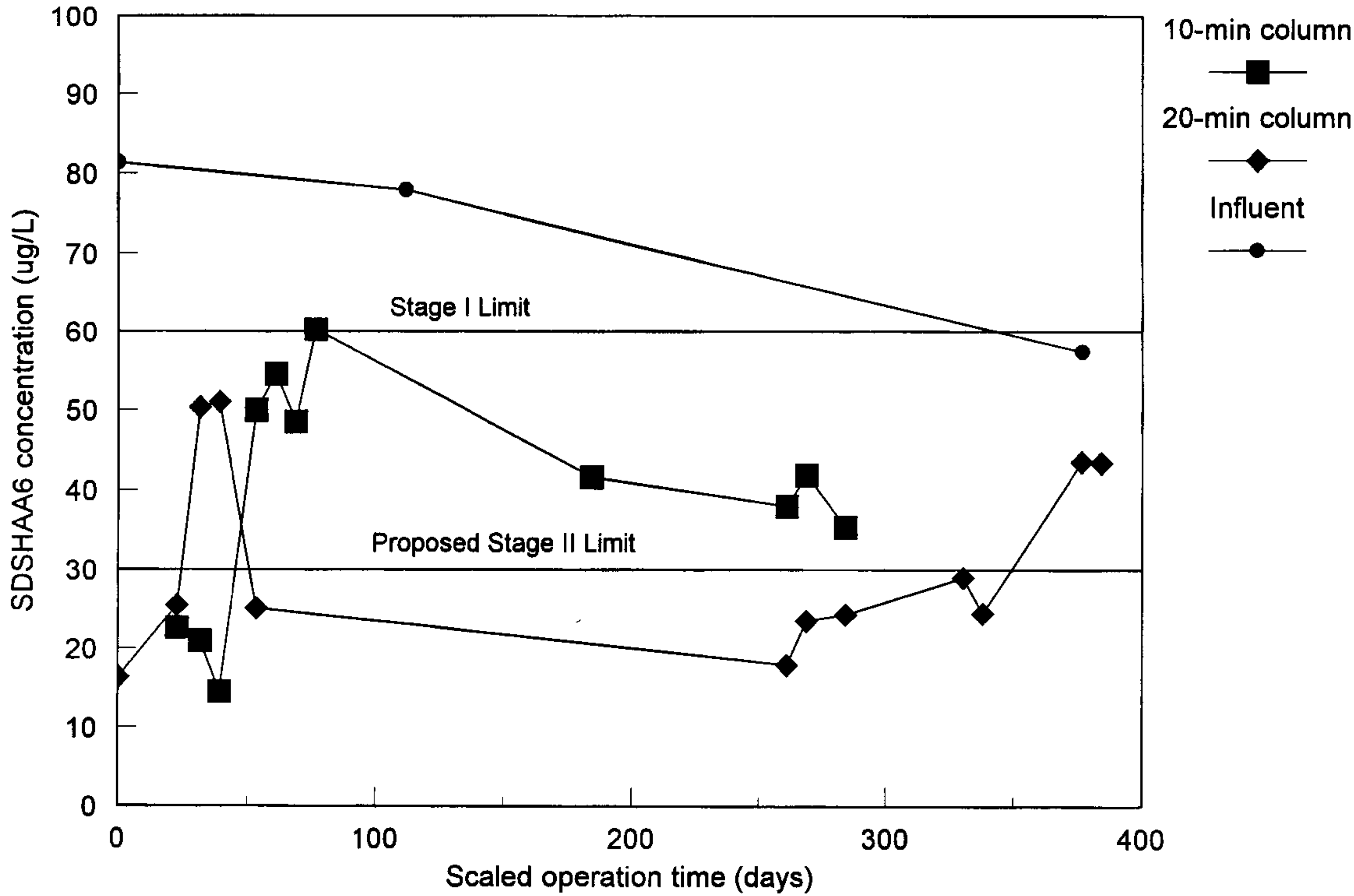

Figure 15 ARWA third quarter testing: SDSHAA6 data

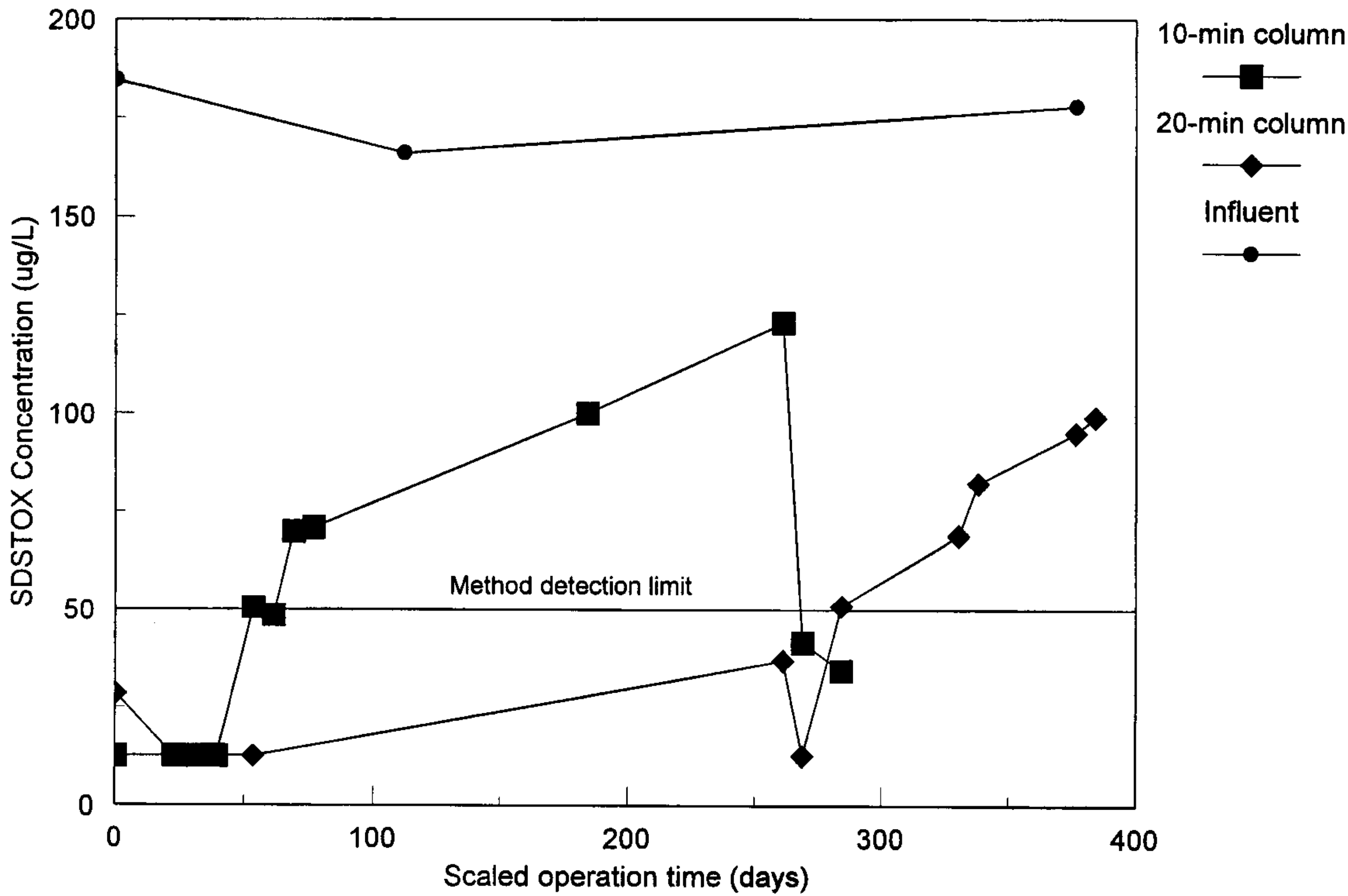

Figure 16 ARWA third quarter testing: SDSTOX data

scaled operation days but then remained below the proposed Stage II D/DBP Rule limit of 30 μg/L up to almost 350 scaled operation days. The final two 20-min samples had SDSHAA6 concentrations of 43 μg/L each.

SDSTOX Data. The Quarter 3 SDSTOX breakthrough curve is shown in Figure 16. The influent SDSTOX concentration averaged 176 μg/L for the test run. The 10-min EBCT SDSTOX began steadily increasing after 50 scaled operation days from 75 to almost 125 μg/L. The final two SDSTOX samples collected, however, were below the method detection limit. The 20-min EBCT SDSTOX concentration remained below the detection limit up to 275 scaled operation days before providing a measurable concentration. After 275 scaled operation days, the next five effluent SDSTOX concentrations increased linearly from 50 to almost 100 μg/L.

Quarter 4 Results

TOC Data. The fourth quarter of RSSCT testing began on January 3, 1999. During this quarter the influent TOC concentration averaged 2.13 mg/L. The effluent TOC breakthrough curves are presented in Figure 17. The 70 percent breakthrough level used during the test was 1.49 mg/L. Overall, the breakthrough curve shows that the 10-min EBCT effluent exceeded the 70 percent breakthrough level for only one sample at approximately 325 scaled operation days. After 100 scaled operation days, the 10-min EBCT TOC effluent increased to above 60 percent breakthrough and then remained at between 60 and 70 percent for the remainder of the test. The 20-min EBCT TOC effluent remained at or below the MDL up to 275 scaled operation days and then averaged approximately 65 percent TOC breakthrough for the final five samples. Both the 10-min and 20-min EBCT tests were ended due to time after more than 400 scaled operation days of run time.

SDSTHM Data. The SDSTHM results from Quarter 4 testing are presented in Figure 18. The influent concentration averaged 59 μg/L, and ranged between 30 μg/L to 88 μg/L. The 10-min EBCT effluent SDSTHM concentration remained below the proposed Stage II D/DBP Rule limit up through 300 scaled operation days. At this time the SDSTHM concentration spiked to almost 70 μg/L. The final two samples collected, however, averaged approximately 50 μg/L.

The 20-min EBCT SDSTHM concentration remained below the proposed Stage II D/DBP Rule limit for the entire study. The maximum SDSTHM concentration was measured in the final two samples and averaged slightly higher than 30 μg/L.

SDSHAA6 Data. The SDSHAA6 results from Quarter 4 testing are shown in Figure 19. The influent SDSHAA6 concentration averaged 57 μg/L during testing. The 10-min EBCT SDSHAA6 concentration increased almost linearly during the study. After 200 scaled operation days, the 10-min EBCT SDSHAA6 concentration exceeded 30 μg/L. The highest concentration measured was in the final sample at 56 μg/L.

The 20-min EBCT SDSHAA6 concentration ranged between 10 and 40 μg/L during the study. Only three of these samples collected had SDSHAA6 concentrations that exceeded the proposed Stage II D/DBP Rule limit of 30 μg/L.

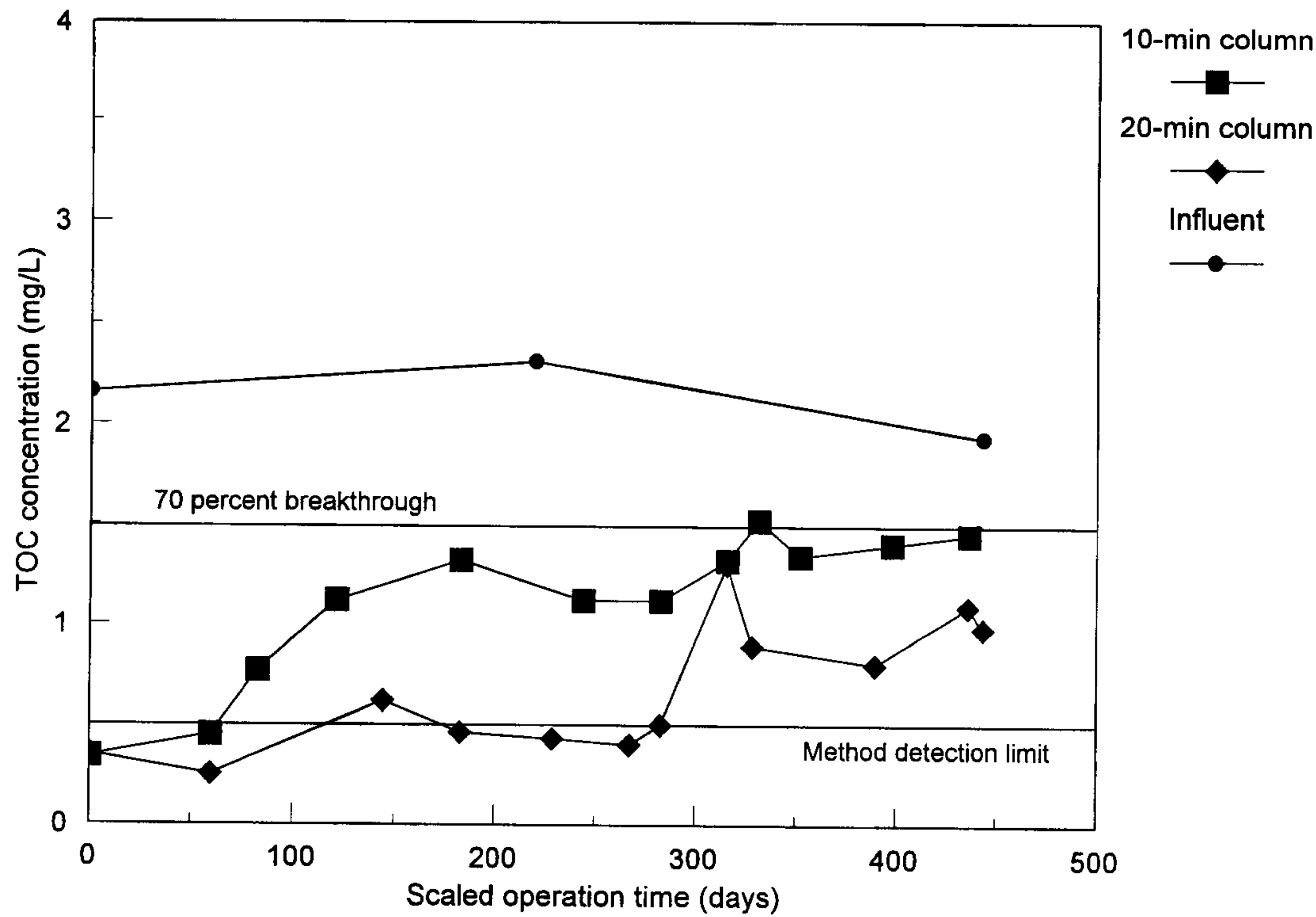

Figure 17 ARWA fourth quarter testing: TOC data

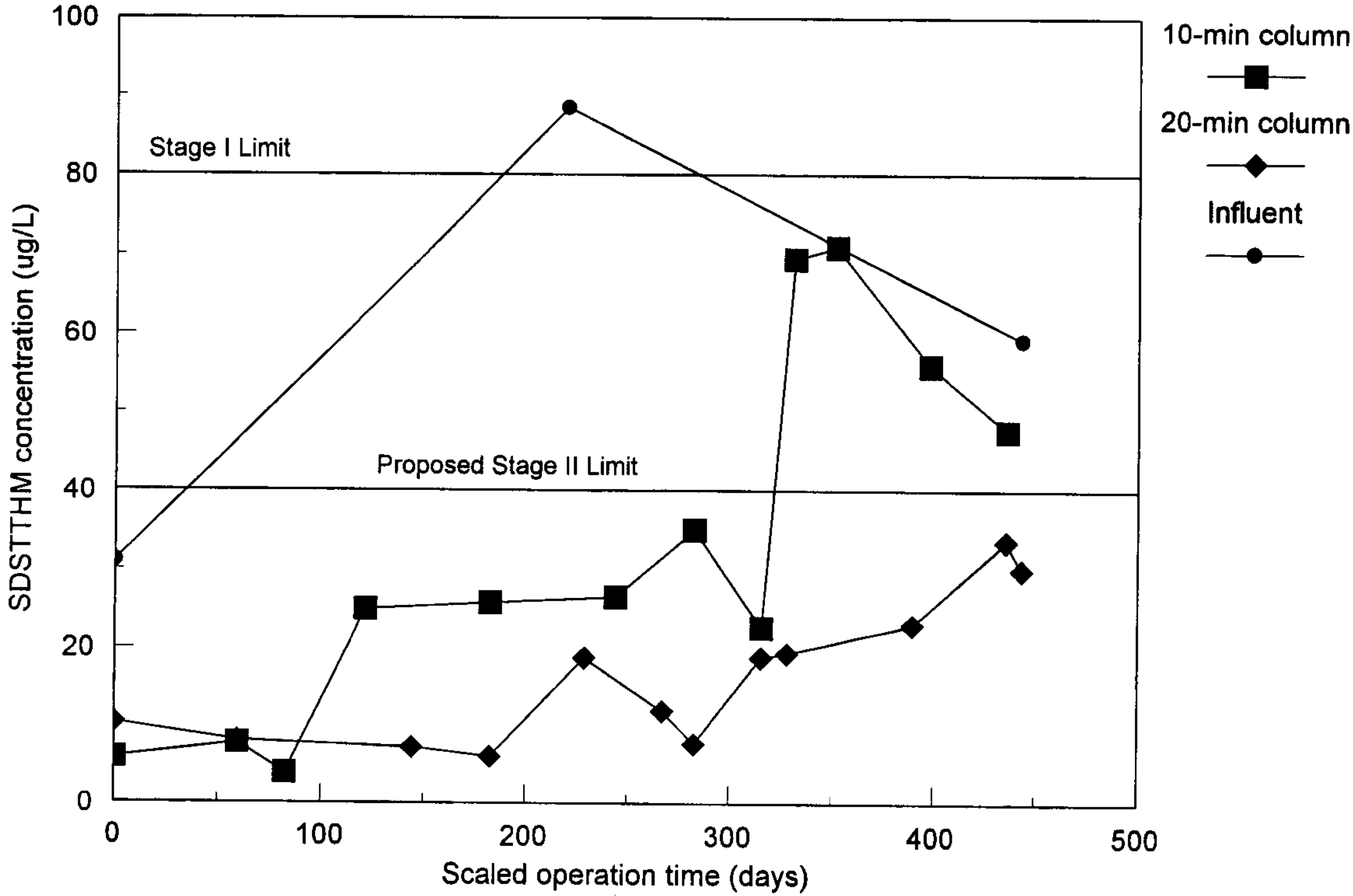

Figure 18 ARWA fourth quarter testing: SDSTTHM data

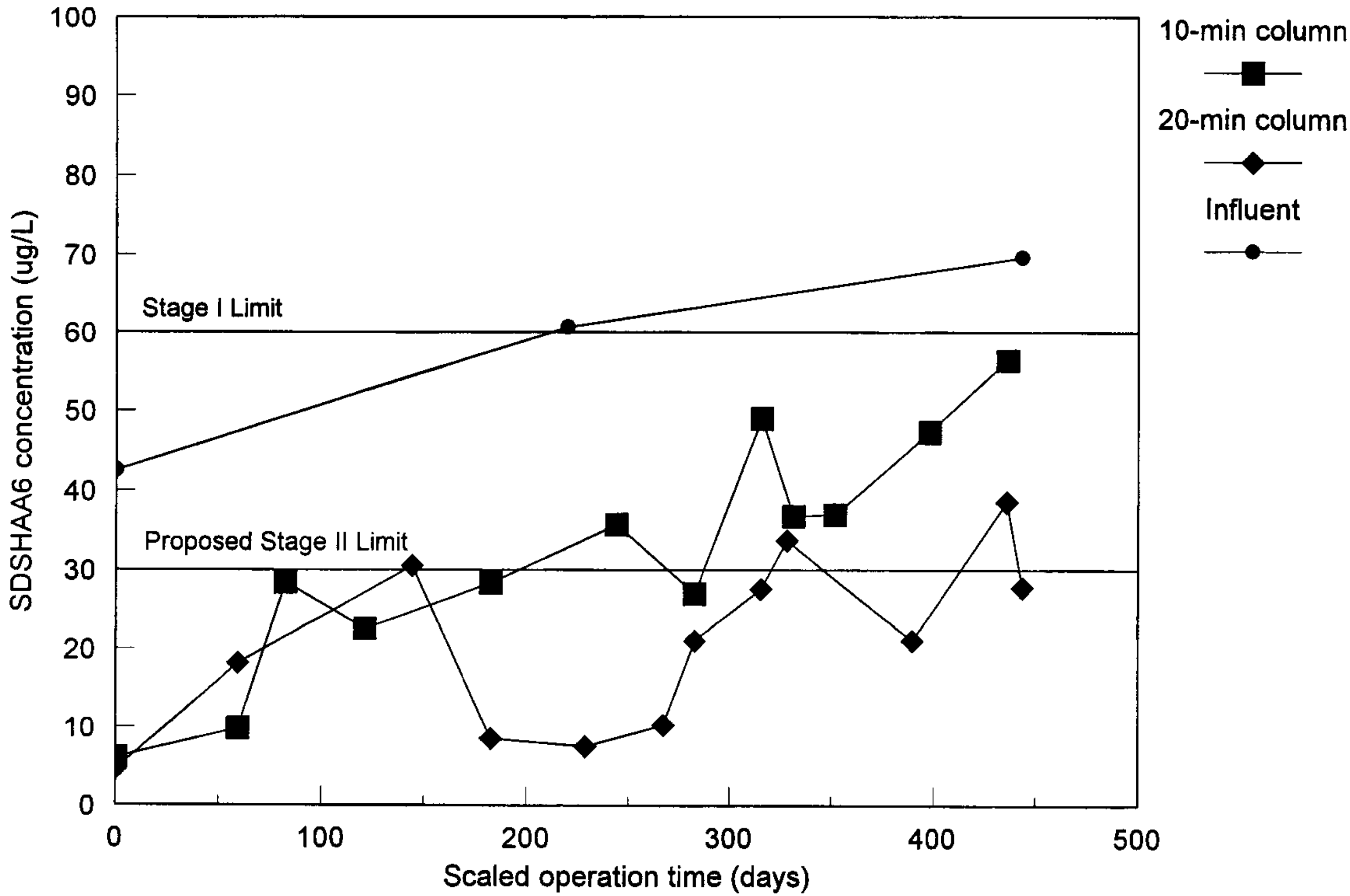

Figure 19 ARWA fourth quarter testing: SDSHAA6 data

SDSTOX Data. The SDSTOX data collected during Quarter 4 is presented in Figure 20. The influent SDSTOX concentration averaged 154 μg/L during the study. The 10-min EBCT effluent SDSTOX concentration reached a detectable level after 75 scaled operation days and increased almost linearly up to 100 μg/L after over 400 scaled operation days. The first ten 20-min EBCT effluent SDSTOX samples all had concentrations below detectable levels. The final two samples had measurable SDSTOX concentrations of slightly higher than 50 μg/L.

Summary of TOC Breakthrough

In order to compare the TOC breakthrough curves for the four quarterly tests, the 10-min and 20-min EBCT tests results were plotted together. The four quarterly 10-min TOC breakthrough curves are shown in Figure 21. This figure confirms that the TOC breakthrough was more rapid when filtering an influent water with a higher average TOC concentration. All four curves demonstrate a sharp increase in TOC breakthrough up to 100 scaled operation days. After 100 scaled operation days, the TOC breakthrough for the second, third, and fourth quarters remained stable or only slightly increased for the remainder of the tests. Quarter 1 had a higher TOC loading rate and, as a result, increased to above 70 percent breakthrough after which the test was terminated.

The 20-min EBCT quarterly breakthrough curves are shown in Figure 22. Similar to the 10-min breakthrough curve, the first quarter TOC breakthrough was much more rapid than the remaining three quarterly tests. Significant breakthrough in the first quarter began at approximately 150 hours and continued until the run was terminated after 70 percent breakthrough. The remaining quarterly tests all began to show a TOC breakthrough after 250 scaled operation days but never reached 70 percent. All three of these tests were ended after one full-scale equivalent year.

Problems Encountered

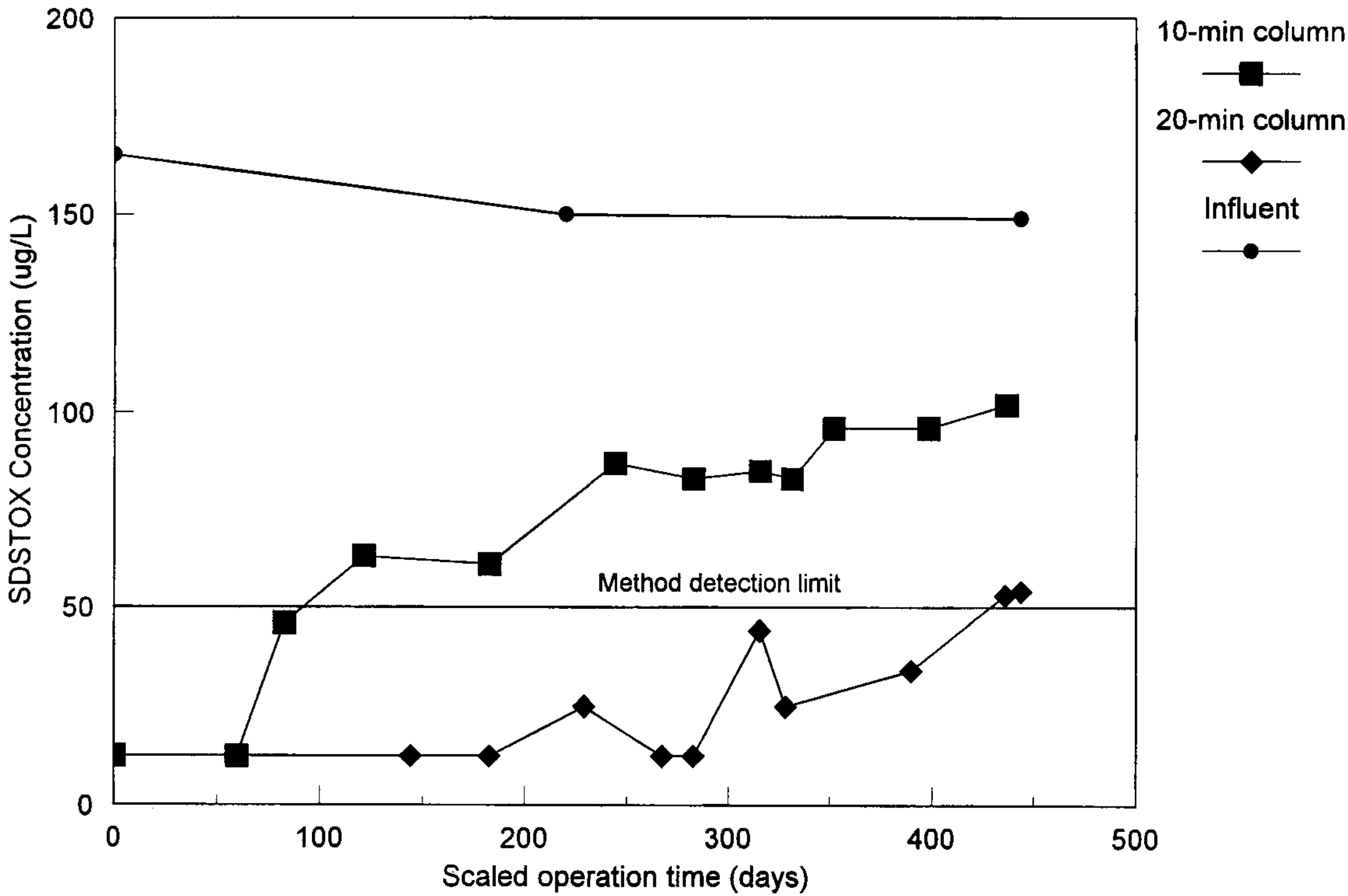

Figure 20 ARWA fourth quarter testing: SDSTOX data

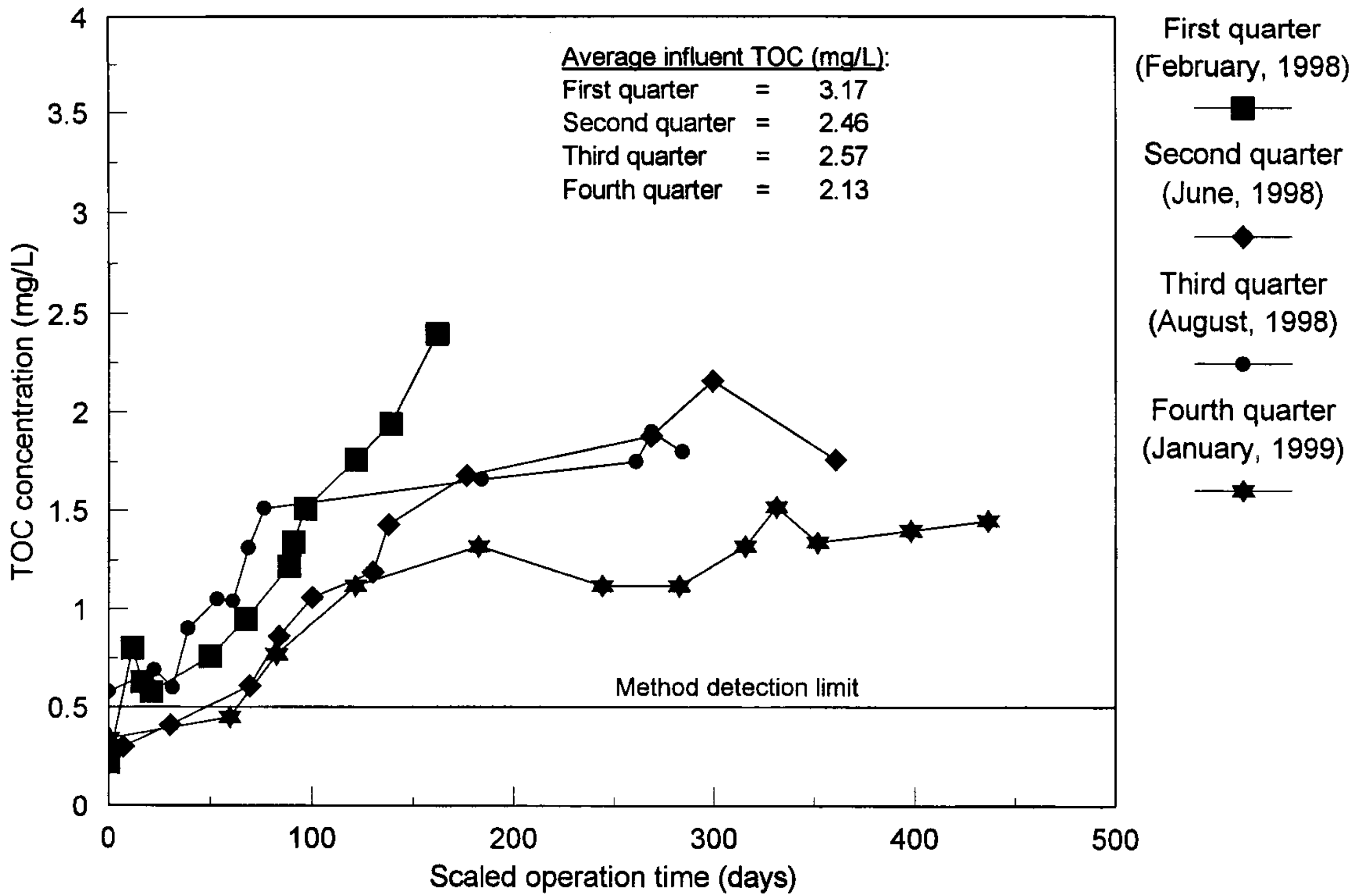

Figure 21 ARWA RSSCT testing: TOC data (10-min EBCT)

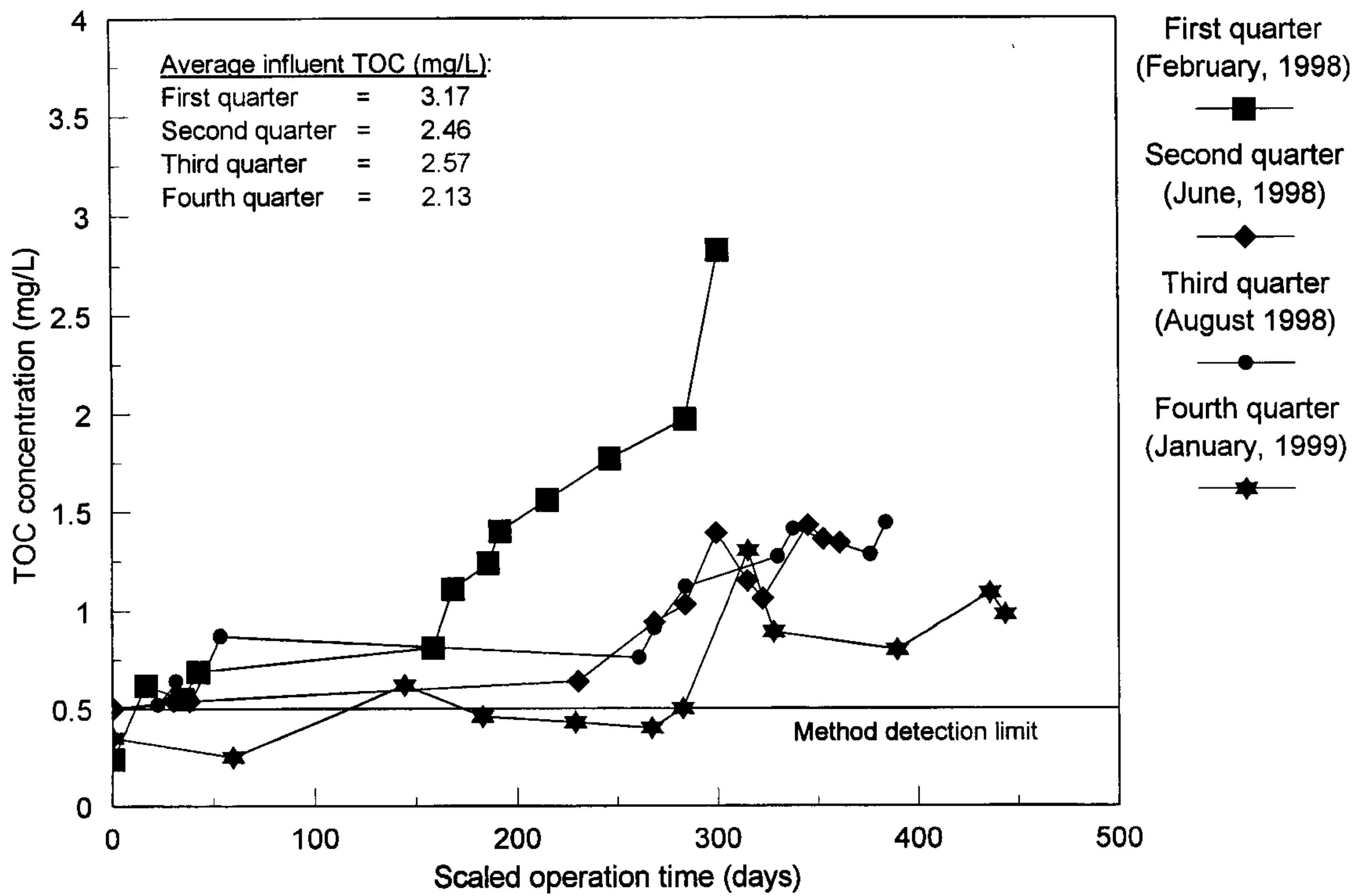

Figure 22 ARWA RSSCT testing: TOC data (20-min EBCT)

There were a number of problems encountered during the year-long RSSCT study, however, most were easily resolved. The most significant difficulties encountered were as follows:

- Rapid headloss development caused by both the pre-treatment cartridge filter and GAC media headloss.
- Long run time for each quarterly RSSCT study and the extensive amount of sampling required.
- Determination of when to collect compliance samples.
- Minor leaks and equipment failures.

The most significant problem encountered was the rapid rate of headloss accumulation caused by the pre-treatment filters. Teflon© filter disks were used to remove suspended solids from the feed water prior to entering the GAC columns. Teflon© filter sizes used were 1 μm, 5 μm , and 10 μm. These filter disks needed to be replaced at least two times per week due to plugging. Replacement of the disks was a simple process and involved very little operational downtime.

GAC media plugging was not a significant problem initially during a filter run, however, due to the very long run times needed for most of the quarterly tests, media headloss became a problem towards the end of a run. This problem was overcome by gently scraping the GAC media surfaces to break-up the plugged GAC as necessary.

During ARWA testing, only two of the 10-min EBCT tests and one 20-min EBCT test was completed prior to one full-scale equivalent year of testing. The tests that were not stopped due to TOC breakthrough had filter runs that lasted for at least 48 real time tests days. TOC sampling for each test had to be performed daily to determine the breakthrough concentrations.

Daily TOC sampling was necessary to determine when a compliance sample should be collected. It was difficult to collect the compliance samples at 5 to 8 percent TOC increments as required by RSSCT guidelines. Many of the quarterly tests did not show significant breakthrough during one full-scale equivalent year, therefore, compliance samples had to be collected at evenly spaced time intervals during the last few weeks of testing. These samples did not always have TOC concentrations that met the 5 to 8 percent TOC increment criteria for sampling.

As usual, with any pilot- or bench-scale test system, there were minor leaks and equipment failures. Only one of the RSSCT tests had to be terminated and restarted due to equipment failure. Most of the equipment problems were easily corrected.

QA/QC SUMMARY

Most of the EPA required QA/QC data is included in the treatment summary spreadsheets, however, the calibration procedure for the following parameters are included in Table 10. These parameters are as follows:

- THMs
- HAAs
- TOC
- UV_{254}
- Bromide
- TOX

The table provides the method used and a description of the percent recovery calibration check, method blank, field/laboratory duplicates, lab fortified sample, and internal and surrogate standards.

Table 10

QC criteria for ICR samples

Method	Percent recovery calibration check	Method blank	Field/laboratory duplicate	Laboratory fortified sample	Internal std.	Surrogate std.
SM-6251 B EPA 552.2 Non-MCAA	1,20,40 µg/L 1 µg/L Response +/- 50% 20,40 µg/L Response +/- 20%	1/batch [8-10 hours] <0.5 µg/L per analyte	1 laboratory/batch of each extraction set	1/batch of samples	Within 30% of mean for all samples processed with same batch of diazomethane	Within 30% of mean for all samples processed with same batch of diazomethane
SM 6251 B EPA 552.2 MCAA	2 µg/L Response +/- 50% 20, 40 µg/L Response +/- 20%	<1.0 µg/L per analyte				
EPA-551.1 THMs	1 µg/L Response +/- 50% 20, 40 µg/L Response +/- 20%	1/batch [8-10 hours] <0.5 µg/L per analyte	1 field/batch of samples	1/batch of samples	Within 30% of daily calibration std.	Within 30% of mean for all samples within the same extraction set
SM-5910 UV_{254}	0.5 cm^{-1}* Response +/- 25% 6, 60 cm^{-1} Response +/-15%	Initial zero, with organic free water every 10th sample	Laboratory dup. All samples ≤20% RSD ≤0.045 ≤10% RSD >0.045	No Requirement	No Requirement	No Requirement
300.0 Br^-	0.02 µg/L Response +/- 50% 0.1, 0.3 Response +/- 10%	1/batch [8-10 hours] <10 µg/L per analyte	Laboratory dup 5%/batch of samples	5% of sample in each batch	No requirement	No requirement
SM-5320-B TOX	50 µg/L Response +/- 25% 250, 500 µg/L Cl^- /L Response +/- 15%	<0.8 µg/L Cl^-/40 mg of activated carbon	All samples laboratory dup.	5% all samples analyzed each quarter	No requirement	No requirement
SM-5310 C TOC†	0.5 mg/L Response +/- 50% 4, 10 Response +/- 10%	1/batch [8-10 hours] <0.25 mg/L	Laboratory dup. (all samples) ≤10% RSD >2.0 mg/L ≤20% RSD ≤2.0 mg/L	5% of sample in each batch	No Requirement	No Requirement

*Potassium hydrogen phthalate (KHP) concentration (mg/L) is given as dissolved organic carbon (DOC)

†QC criteria during ICR treatment studies

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CONCEPTUAL GAC FACILITY DESIGN

Introduction

A conceptual full-scale GAC facility design for ARWA was generated based on results obtained from the RSSCT study. The design includes an equipment summary, a conceptual site plan, and a facility cost estimate. The equipment summary includes the design parameters for the following GAC facility processes:

- GAC contactors
- GAC media
- Storage tanks, basins, and pumps
- Fluid bed regeneration furnace

The site plan shows a proposed location for the GAC facility and how it could be incorporated into ARWA's existing process. The cost estimate provides a total capital cost as well as yearly operation and maintenance (O&M) costs.

GAC Contactor Design Summary

Data obtained from the year-long RSSCT study provided the information necessary for designing full-scale contactors is suitable for ARWA. Analysis of the RSSCT data demonstrated that using a 20-min EBCT the contactor effluent TOC concentration reached 1.0 mg/L after approximately 150 full-scale days. A maximum TOC breakthrough concentration of 1.0 mg/L was used for design purposes so that ARWA would be able to meet the proposed Stage II D/DBP Rule limits for HAAs and THMs. A summary of the full-scale GAC contactor design parameters is included in Table 11.

Table 11

GAC contactors design summary

Item	Size
Filter surface area	400 ft^2
GAC bed depth	10.75 ft
Filter EBCT	20 min
Design filtration rate	4 gpm/ft^2
Breakthrough time to 1.0 mg/L TOC	150 days
Number of filters	20
Design capacity	46 mgd

The contactor design includes a total of 20 square concrete, fixed bed gravity filters. At the maximum plant design capacity of 46 mgd, a filtration rate of 4.0 gpm/ft^2 would provide a 20-min EBCT. The GAC bed depth required to achieve a 20-min EBCT is 10.75 ft. The estimated TOC breakthrough time to 1.0 mg/L TOC is approximately 150 days—meaning that the GAC media would have to be regenerated at least two times per year. The GAC contactors would also require equipment for periodic backwashing and surface washing of the media.

GAC Media Depth Specifications

The design of the full-scale GAC facility is based on using the same media, Calgon Filtrasorb F-400, as used in the RSSCT study. The Calgon F-400 GAC is bituminous-based coal and is frequently used in post-filter adsorption contactors for removal of DBP precursors in drinking water. Media specifications for the Calgon F-400 GAC are included in Table 12.

Table 12

Design summary for Calgon Filtrasorb F-400 GAC

Item	Size
GAC size	12 mm x 40 mm
Total GAC mass (for 20 filters)	2,135,000 lbs
Washed density	25 lb/ft^3
Effective size (ES)	0.8 to 0.9 mm
Uniformity coefficient	$\leq$1.9
Pore volume	1.108 cm^3/g
GAC loss	10 percent/year

In order to achieve a 20-min EBCT, approximately 2,136,000 lbs of GAC media would be required to fill all 20 contactors. The media is projected to be exhausted after 150 days of operation after which it would have to be regenerated. It is estimated that approximately 5 percent of GAC media will be lost during regeneration.

Design Summary for Storage Tanks and Pumps

The GAC contactor facility would require a number of additional tanks and pumps to complete the system. A list of the necessary tanks and pumps are listed in Table 13.

Table 13

Design summary for storage tanks and pumps

Item	Size
Low lift wet well basin	21,000 gal
Spent GAC storage tank	35,000 gal

Regenerated GAC storage tank	35,000 gal
GAC quench tank	200 gal
Low lift contactor supply pumps	4 at 15 mgd each
GAC contactor slurry pumps	2

The low lift wet well is necessary to collect filtered water from the existing plant filters and provide suction supply water to the low lift pumps for transfer to the GAC contactors.

The Spent GAC Storage Tank (SGST) is used to store the exhausted GAC media pumped from the contactors prior to regeneration. This tank was designed to store the entire volume of GAC media from one contactor. Due to the aggressiveness of GAC, this tank would need to be made of plastic or stainless steel.

The Regenerated GAC Storage Tank (RGST) is identical to the spent GAC storage tank. This tank, however, is used to store the GAC that has been reactivated and is waiting to be returned to the contactors. The RGST is proceeded by a quench tank in the process after regeneration. The GAC quench tank is a small tank used to blend GAC with water to form slurry prior to entering the RGST.

The GAC facility would also require a number of additional pumps. A total of four 15-mgd low lift pumps would be required to transfer filtered water from the wet well to the GAC contactors. At least two GAC slurry transfer pumps would be required to remove exhausted GAC from the contactors and supply regenerated media back to the contactors.

Design for Fluid Bed Reactivation System

Fluid bed reactivation is commonly used to regenerate spent GAC media used for treating municipal drinking water. The fluid bed furnace functions by suspending carbon particulates in a furnace chamber by an upflow gas stream and heating the GAC to temperatures of 982ºC. The high temperature effectively burns the organic compounds off the surface of the GAC media. The design parameter summary for the fluid bed furnace is included in Table 14.

Table 14

Design summary for fluidized bed regeneration system

Item	Size/Number
GAC regeneration rate	12,000 lbs/day
furnace regeneration rate	1,600 lb/ft^2/day
Furnace area	7.5 ft^2
Regeneration time per filter	9 days

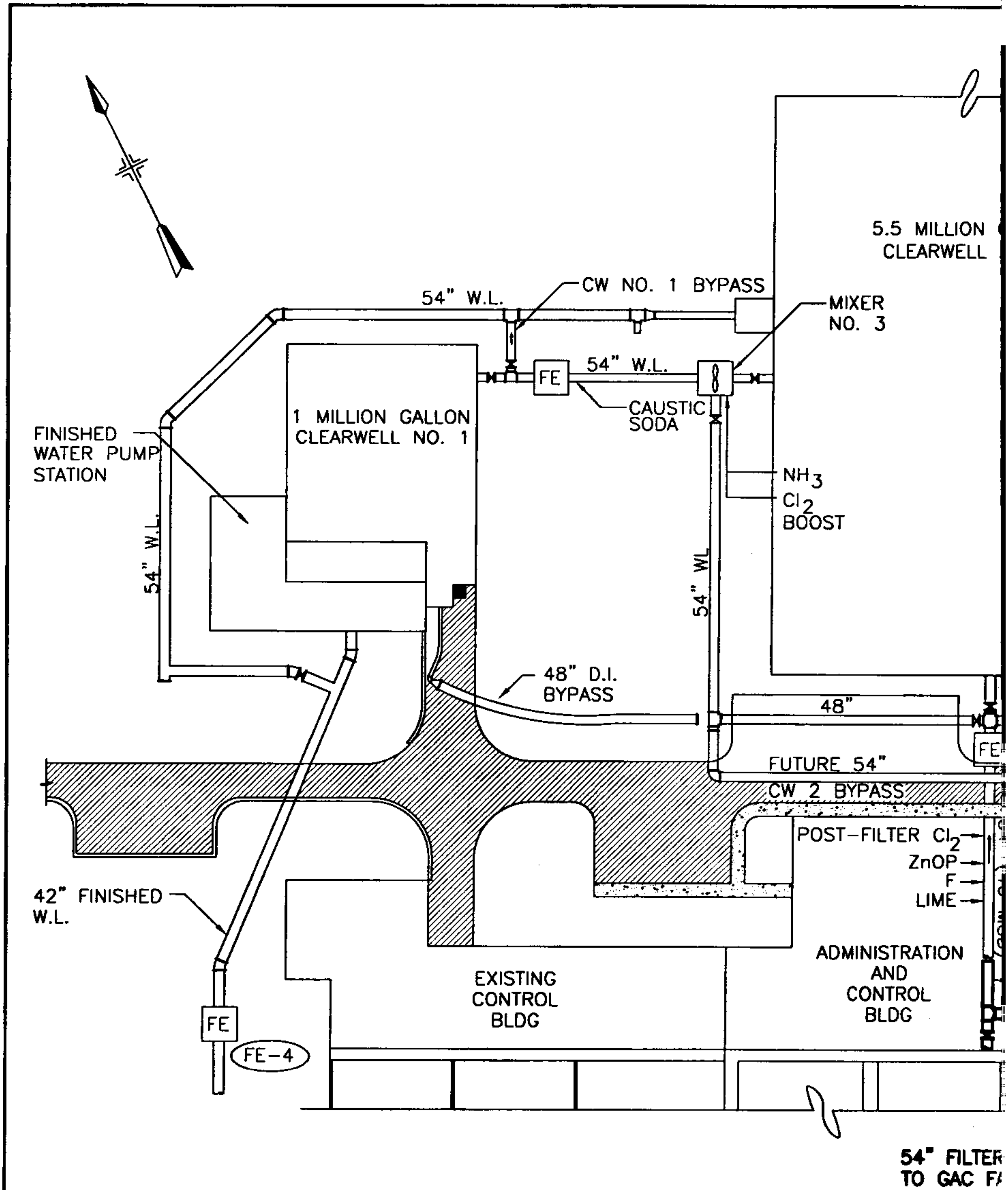
In order to meet GAC regeneration demand at the maximum plant capacity of 46 mgd, the furnace must be able to process 12,000 lbs/day of GAC. To achieve this, a furnace with a regeneration rate of 1,600 lb/ft^2/day with a cross sectional area of 7.5 ft^2 would be required.

Conceptual Site Layout

The proposed location of the GAC facility at the ARWA site is shown in Figure 23. This location was selected due to close proximity to the filter building in order to minimize yard piping. The GAC building includes a 1,500 ft^2 control room attached to a 24,700 ft^2 building that houses the contactors, contactor supply pumping station, and the regeneration facility. The site plan shows that filtered water will be detoured from its current location prior to chemical feed and then returned after GAC adsorption to the same approximate location.

Full-Scale Cost Estimate

The full-scale facility cost estimate was conducted using a series of cost equations that allow for a close estimation of the total GAC facility cost based on the design sizes of its unit processes (Clark and Lykins 1989). Cost considerations included capital costs and O&M costs for the following items:



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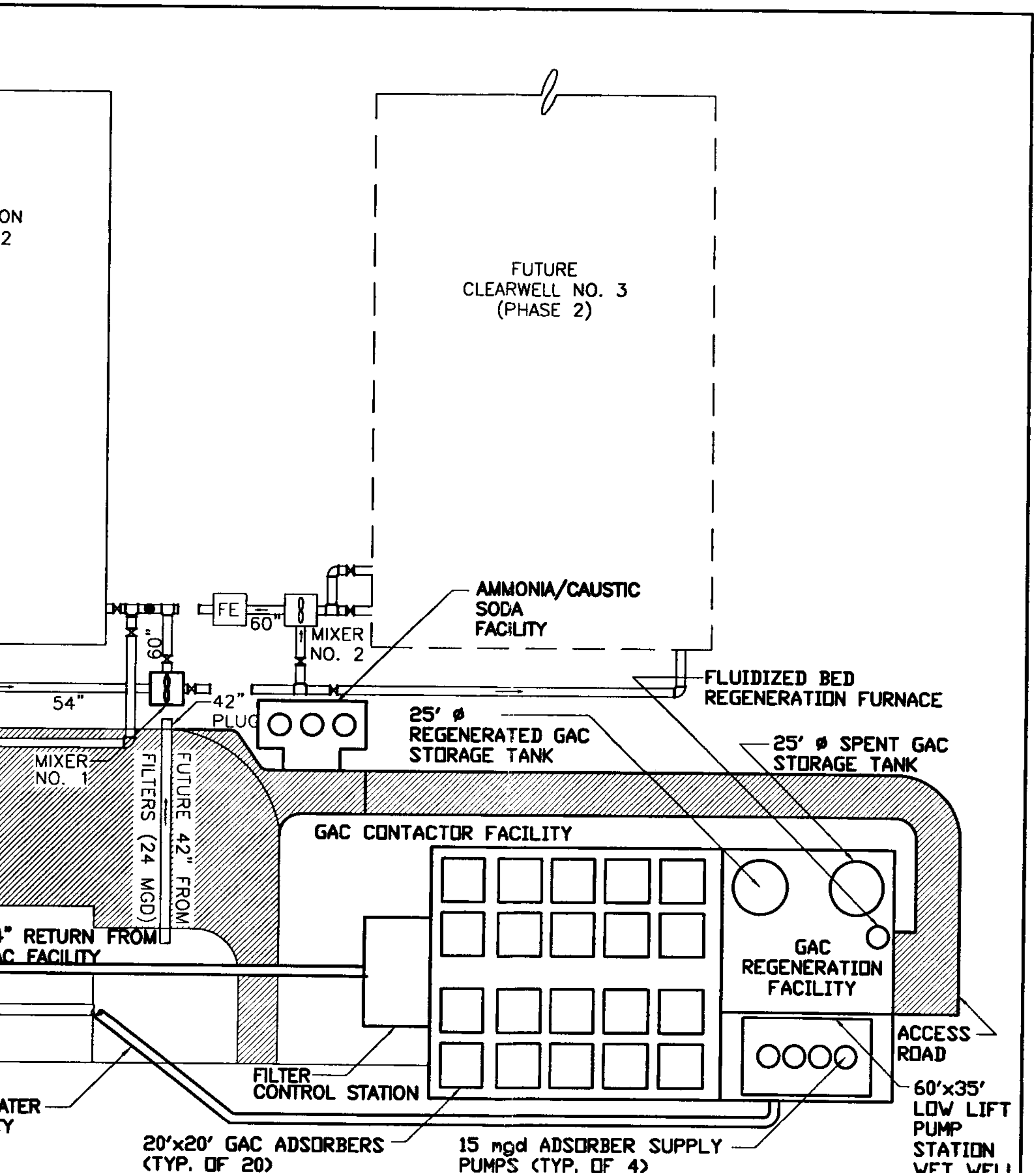

WATER AUTHORITY
PROJECT

CONCEPTUAL
POST-FILTER GAC FACILITY

FIGURE 23

- GAC contactors
- In-plant pumping
- On-site GAC storage
- Initial and make-up GAC costs
- Fluid bed reactivation

Design values for each of these units was applied to the cost equations to generate a total capital cost and a yearly O&M cost (Clark and Lykins 1989). Results from the cost equations are shown in Table 15. The capital and O&M cost variables used are shown in the table as well.

The table shows that the estimated cost for a 46-mgd GAC absorption facility is approximately $28.4 million with a yearly O&M cost of $1.5 million. The amortized capital cost would be $2.9 million per year.

Table 15

Cost estimate for ARWA GAC absorption facility

Parameter	Symbol	GAC contactor construction	In-plant pumping	On-site GAC storage	Initial cost for GAC (GAC make-up)	Fluid bed reactivation	Total system cost
Capital Cost							
Contactor cost	CT	$13,930,993	$492,135	$348,369	$2,082,255	$2,283,940	$19,137,692
O-head, int., eng. fee (40 %)	OH	$5,572,397	$196,854	$139,348	$832,902	$913,576	$7,655,077
Total building cost ($150/ft^2)	BC	$1,605,000					$1,605,000
Total capital cost	**CC**	**$21,108,391**	**$688,988**	**$487,717**	**$2,915,156**	**$3,197,516**	**$28,397,768**
Amortized capital cost	**AC**	**$2,149,936**	**$70,175**	**$49,675**	**$296,915**	**$325,674**	**$2,892,375**
O&M Costs							
Process electrical ($/yr)	PE	$3,091	$193,071	$0	$0	$42,048	$238,210
Pump electrical ($/yr)	PEI	$3,533	$220,653	$0	$0	$48,055	$272,240
Building electrical ($/yr)	BE	$105,721	$0	$0	$0	$0	$105,721
Onsite system maint. materials ($/yr)	MAINT	$10,032	$5,657	$0	$0	$12,319	$28,008
Process O&M labor ($/yr)	LABOR	$101,457	$20,105	$0	$0	$311,703	$433,266
Process natural gas ($/yr)	FUELG	$0	$0	$0	$0	$122,800	$122,800
Fuel oil cost ($/yr)	FUELO	$0	$0	$0	$0	$107,978	$107,978
Carbon makeup cost ($/yr)	MAKE	$0	$0	$0	$193,500	$0	$193,500
Total O&M Cost ($/yr)		**$223,834**	**$439,487**	**$0**	**$193,500**	**$644,903**	**$1,501,724**
Design factors							
Filter volume (ft^3 per filter)	USRT1	4,300	4,300	4,300	4,300	4,300	
Plant capacity (mgd)	USRT2	46	46	46	46	46	

Parameter	Symbol	GAC contactor construction	In-plant pumping	On-site GAC storage	Initial cost for GAC (GAC make-up)	Fluid bed reactivation	Total system cost
Total filter area (ft^2)	USRT2A	8,000	8,000	8,000	8,000	8,000	
GAC storage basin vol (ft^3)	USRT3	4,500	4,500	4,500	4,500	4,500	
No. of storage basins	NB	2	2	2	2	2	
No. of filters	NU	20	20	20	20	20	
Add. GAC (assume 10 % loss)	CLBS	10,750	10,750	10,750	10,750	10,750	
Total mass of GAC (lbs per filter)	USRT4	107,500	107,500	107,500	107,500	107,500	
Reactivation rate - 1 Fl. Bd (lb/day)	USRT5	12,000	12,000	12,000	12,000	12,000	
Reactivation rate - 1 M. Hrt (lb/day)	USRT6	105	105	105	105	105	
GAC loss (lb/yr) assume 10%	USRT7	215,000	215,000	215,000	215,000	215,000	
GAC facility building (ft^2)	BA	10,700	10,700	10,700	10,700	10,700	
Capital cost variables							
Capital cost coefficient	a	0	50163	14106	0	599030	
Capital cost coefficient	b	16418.64	2390.25	6.69		4694.8	
Capital cost coefficient	c	0.359	1.134	1.098	0.933	0.494	
Construction cost index ('99)	CCI	6000	6000	6000	6000	6000	
Prod price index ('99)	PPI	137.9	137.9	137.9	137.9	137.9	
Interest	I	0.08	0.08	0.08	0.08	0.08	
Payback period (yrs)	N	20	20	20	20	20	
O&M cost variables							
Electric cost ($/kWh)	EC	$0.08	$0.08	$0.08	$0.08	$0.08	
Natural gas fuel ($/$ft^3$)	NG	$0.009	$0.01	$0.01	$0.01	$0.01	
Fuel oil ($/gal)	FC	$1.10	$1.10	$1.10	$1.10	$1.10	
Diesel cost ($/gal)	DC	$1.20	$1.20	$1.20	$1.20	$1.20	
Tot dynamic head (ft)	TDH	40	40	40	40	40	
GAC cost ($/lb)	GAC	$0.90	$0.90	$0.90	$0.90	$0.90	

Parameter	Symbol	GAC contactor construction	In-plant pumping	On-site GAC storage	Initial cost for GAC (GAC make-up)	Fluid bed reactivation	Total system cost
Labor rate ($/hr)	LR	$15	$15	$15	$15	$15	

Source: Cost equations provided by “Granular Activated Carbon: Design, Operation and Cost.” Clark and Lykins, 1989.

Table A.1

ICR RSSCT process projections

Utility Name:	Appomattox River Water Authority
Quarter number:	1
Test date (start):	02/18/98
Test date (end):	04/06/98

Parameter	Variables	10-min EBCT	20-min EBCT
Diameter (large column)	d lc	1.1	1.1
Diameter (small column)	d sc	0.143	0.143
Scaling factor	SF	7.69	7.69
Empty bed contact time (small column)	EBCT sc	1.30	2.60
Reynolds number	Re sc	0.5	0.5
	bed porosity	0.45	0.45
	kinematic viscosity	1.002E-06	1.002E-06
Superficial velocity (small column)	v sc (m/h)	5.68	5.68
Media height (small column)	1 sc (cm)	12.3	24.6
Diameter (small column)	DC sc (cm)	0.8	0.8
Flow	Q sc (mL/min)	4.75	4.75
Mass of GAC	m sc (g)	3.1	6.2
Total organic carbon	TOC (mg/L)	3.19	3.19
Bed volumes to 50% breakthrough	BV 50	4,803	4,803
Time to 50% breakthrough	t 50 (days)	33.4	66.7
	t int (days	4.8	9.5
Full-scale breakthrough	t lc (days)	66.7	133.4
Bench-scale breakthrough	t sc (days)	8.7	17.3
Volume of water	V sc (L)	59.36	118.76
Excess volume	Total GAC volume (L)	77.16	154.39

Table A.2

ICR RSSCT process projections

Utility Name:	Appomattox River Water Authority		
Quarter number:	2		
Test date (start):	06/12/98		
Test date (end):	07/29/98		

Parameter	Variables	10-min EBCT	20-min EBCT
Diameter (large column)	d lc	1.1	1.1
Diameter (small column)	d sc	0.143	0.143
Scaling factor	SF	7.69	7.69
Empty bed contact time (small column)	EBCT sc	1.30	2.60
Reynolds number	Re sc	0.5	0.5
	bed porosity	0.45	0.45
	kinematic viscosity	1.002E-06	1.002E-06
Superficial velocity (small column)	v sc (m/h)	5.68	5.68
Media height (small column)	1 sc (cm)	12.3	24.6
Diameter (small column)	DC sc (cm)	0.8	0.8
Flow	Q sc (mL/min)	4.75	4.75
Mass of GAC	m sc (g)	3.1	6.2
Total organic carbon	TOC (mg/L)	3.2	3.2
Bed volumes to 50% breakthrough	BV 50	4,784	4,784
Time to 50% breakthrough	t 50 (days)	33.2	66.4
	t int (days	4.7	9.5
Full-scale breakthrough	t lc (days)	66.4	132.9
Bench-scale breakthrough	t sc (days)	8.6	17.3
Volume of water	V sc (L)	59.12	118.28
Excess volume	Total GAC volume (L)	77.85	153.76

Table A.3

ICR RSSCT process projections

Utility Name:	Appomattox River Water Authority
Quarter number:	3
Test date (start):	09/01/98
Test date (end):	10/21/98

Parameter	Variables	10-min EBCT	20-min EBCT
Diameter (large column)	d lc	1.1	1.1
Diameter (small column)	d sc	0.143	0.143
Scaling factor	SF	7.69	7.69
Empty bed contact time (small column)	EBCT sc	1.30	2.60
Reynolds number	Re sc	0.5	0.5
	bed porosity	0.45	0.45
	kinematic viscosity	1.002E-06	1.002E-06
Superficial velocity (small column)	v sc (m/h)	5.68	5.68
Media height (small column)	1 sc (cm)	12.3	24.6
Diameter (small column)	DC sc (cm)	0.8	0.8
Flow	Q sc (mL/min)	4.75	4.75
Mass of GAC	m sc (g)	3.1	6.2
Total organic carbon	TOC (mg/L)	2.58	2.58
Bed volumes to 50% breakthrough	BV 50	6,329	6,329
Time to 50% breakthrough	t 50 (days)	44.0	87.9
	t int (days	6.3	12.6
Full-scale breakthrough	t lc (days)	87.9	175.8
Bench-scale breakthrough	t sc (days)	11.4	22.9
Volume of water	V sc (L)	78.21	156.49
Excess volume	Total GAC volume (L)	101.68	203.44

Table A.4

ICR RSSCT process projections

Utility Name:	Appomattox River Water Authority
Quarter number:	4
Test date (start):	01/03/99
Test date (end):	03/04/99

Parameter	Variables	10-min EBCT	20-min EBCT
Diameter (large column)	d lc	1.1	1.1
Diameter (small column)	d sc	0.143	0.143
Scaling factor	SF	7.69	7.69
Empty bed contact time (small column)	EBCT sc	1.30	2.60
Reynolds number	Re sc	0.5	0.5
	bed porosity	0.45	0.45
	kinematic viscosity	1.002E-06	1.002E-06
Superficial velocity (small column)	v sc (m/h)	5.68	5.68
Media height (small column)	1 sc (cm)	12.3	24.6
Diameter (small column)	DC sc (cm)	0.8	0.8
Flow	Q sc (mL/min)	4.75	4.75
Mass of GAC	m sc (g)	3.1	6.2
Total organic carbon	TOC (mg/L)	1.71	1.71
Bed volumes to 50% breakthrough	BV 50	10,804	10,804
Time to 50% breakthrough	t 50 (days)	75.0	150.0
	t int (days	10.7	21.4
Full-scale breakthrough	t lc (days)	150.0	300.1
Bench-scale breakthrough	t sc (days)	19.5	39.0
Volume of water	V sc (L)	133.51	267.12
Excess volume	Total GAC volume (L)	173.56	347.25

APPENDIX

DATA COLLECTION SPREADSHEETS

SUMMARY REPORT SPREADSHEETS