ICR Treatment Study Summary Report

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

Conducted during the period of April 16, 1998 through July 14, 1999

Prepared by:

Environmental Engineering & Technology, Inc.
712 Gum Rock Court
Newport News, VA 23606
(757) 873-1534 (phone)
(757) 873-2392 (fax)

July 1999

Prepared for:

City Utilities of Ft. Wayne, Indiana
PWSID #IN5202020
1100 Griswold Drive
Ft. Wayne, IN 46805
(219) 427-1254 (phone)
(219) 427-1354 (fax)

Three Rivers Filtration Plant ICR #368

July 9, 1999

Mr. Chet Shastri
City of Fort Wayne Public Utilities
Three Rivers Filtration Plant
1100 Griswold Drive
Ft. Wayne, IN 46805

Dear Chet:

Enclosed is the final report for the ICR Rapid Small Scale Column Test (RSSCT) for your review and submission to EPA. The report includes a hard copy summary report, data collection spreadsheets, and summary report spreadsheets. The 3½" diskette contains all of the files that are included in the unbound hard copy report.

EPA requires submission by Wednesday, July 14, 1999. The "help packet" provides information on final submission to EPA. You will send the same package to EPA as delivered to you, however, EPA does not require that you send hard copies of the data collection spreadsheets or summary report spreadsheets since they are included on the disk.

If you have any questions please give me a call at (757) 873-1534.

Sincerely,

ENVIRONMENTAL ENGINEERING & TECHNOLOGY, INC.

Michael J. MacPhee, Ph.D.
Process Manager

/wmm

Enclosure

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INTRODUCTION

The City of Ft. Wayne currently operates a 72-mgd water treatment facility in Ft. Wayne, Indiana. This facility is called the Three Rivers Filtration Plant. The plant treats raw water from the St. Joseph's River for use primarily as a municipal drinking water supply. The City of Ft. Wayne 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 City selected an RSSCT study to satisfy this ICR treatability requirement. The treatment study 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. The City of Ft. Wayne was required to perform a year-long DBP precursor removal treatment study because its historical average raw water TOC concentration exceeded 4.0 mg/L.

BACKGROUND INFORMATION

Treatment Plant Description

The Three Rivers Filtration Plant uses a softening treatment process for purification of drinking water, which includes primary and secondary treatment processes for chemical mixing, mechanical flocculation, and sedimentation followed by conventional filtration. A process schematic of the treatment facility is included in Figure 1. The process schematic shows the different unit processes, chemical feed injection locations, and the RSSCT sample collection location. The Three Rivers Filtration Plant currently uses ferric sulfate as the primary coagulant which is fed at both the primary and secondary mix basins. Chlorine dioxide is fed at the secondary rapid mixing basin while

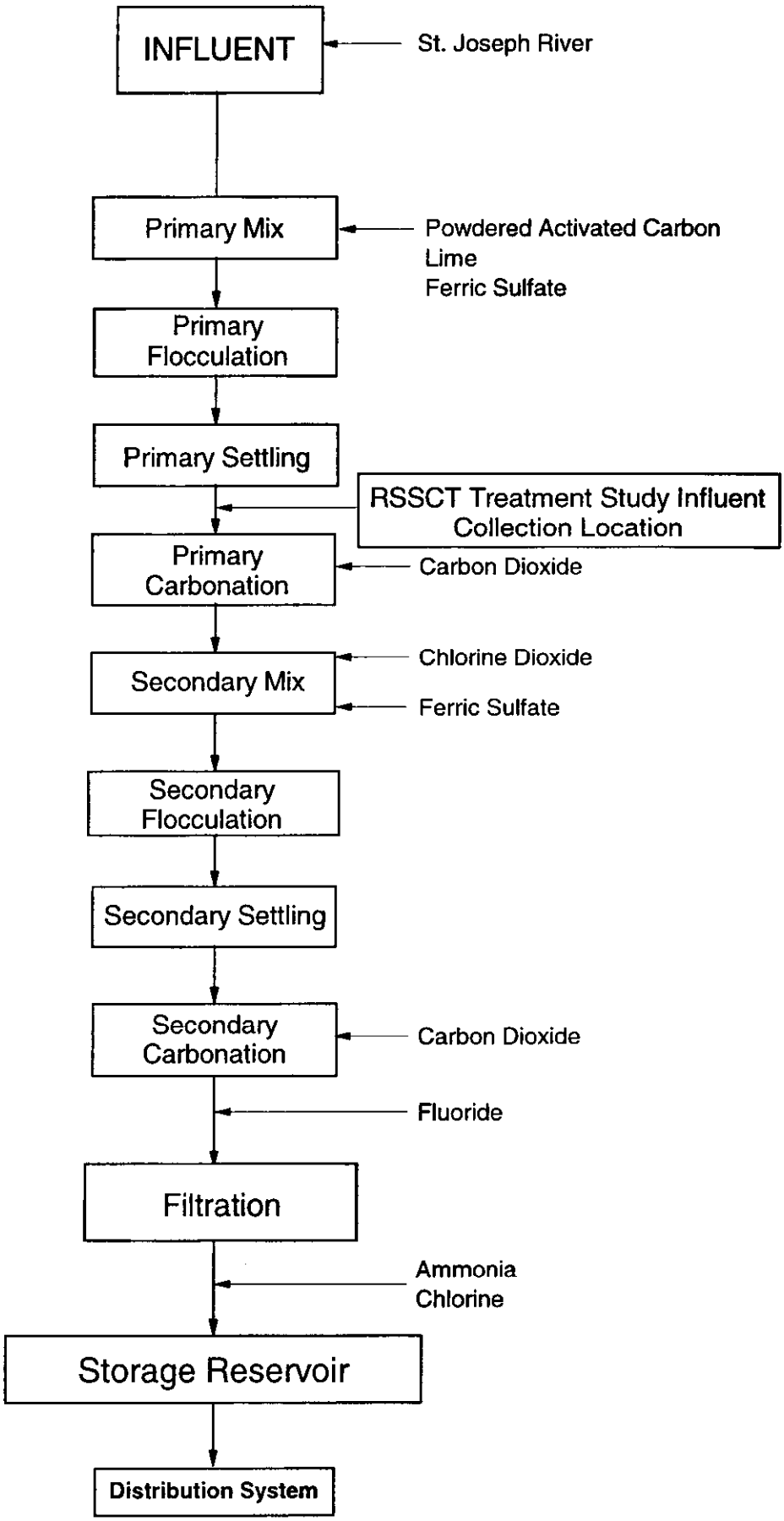

Figure 1 Three River Filtration Plant process schematic

chlorine and ammonia are fed post-filtration to generate chloramines for residual disinfection in the clearwells and pipe distribution system. Other treatment chemicals used are powdered activated carbon, lime, and fluoride.

Design information for each of the 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	
Primary mix	Type of mixer	None
	Surface area (ft^2)	750
	Liquid volume (gal)	33,660
	Chemical addition	Lime, Ferric, and PAC
Primary sedimentation	Surface area (ft^2)	11,100
	Liquid volume (gal)	1,203,300
Primary flocculation	Liquid volume (gal)	660,600
	Stage sequence number	1
	Stage mean velocity gradient (sec^{-1})	40
	State liquid volume (gal)	126,000
	Stage sequence number	2
	Stage mean velocity gradient (sec^{-1})	29
	State liquid volume (gal)	236,400
	Stage sequence number	3
	Stage mean velocity gradient (sec^{-1})	26
	State liquid volume (gal)	298,200
Primary carbonation	Surface area (ft^2)	876
	Liquid volume (gal)	64,776
	Detention time (min)	19
	Chemical feed	Carbon dioxide
Secondary mix	Liquid volume (gal)	5,386
	Detention time (min)	1
	Coagulant addition	Ferric sulfate
	Disinfectant	Chlorine dioxide
	Disinfectant dose rate (mg/L)	1.10

Unit process	Process description	
Secondary sedimentation	Surface area (ft^2)	11,400
	Liquid volume (gal)	1,236,300
	Detention time (min)	151
Secondary flocculation	Total liquid volume (gal)	658,200
	Detention time (min)	72
	Stage sequence number	1
	Stage mean velocity gradient (sec^{-1})	48
	State liquid volume (gal)	125,700
	Stage sequence number	2
	Stage mean velocity gradient (sec^{-1})	42
	State liquid volume (gal)	235,500
	Stage sequence number	3
	Stage mean velocity gradient (sec^{-1})	40
	State liquid volume (gal)	297,400
Secondary carbonation	Surface area (ft^2)	794
	Liquid volume (gal)	51,811
	Detention time (min)	6
	Chemical feed	Carbon dioxide
	Fluoride addition (mg/L)	1.20
Filtration	Surface area (ft^2)	4,900
	Liquid volume (gal)	293,216
	Detention time (min)	39
	Filter run time (hrs)	51
	Water flow into filter (mgd)	51
	Post-filter disinfection additions	Chlorine and Ammonia
	Dose rate (mg/L)	1.19 and 0.36
Clearwell	Surface area (ft^2)	159,696
	Liquid volume (gal)	20,000,000
	Detention time (min)	161
Finished	Water flow at time of sampling (mgd)	35.1
	Monthly average flow (mgd)	37.5

Historical Water Quality

Raw Water

The City of Ft. Wayne's raw water supply source is the St. Joseph's River. The raw water quality is dramatically affected by rainfall events that can produce raw water turbidities as high as 400 ntu. A summary of Ft. Wayne's historical raw water quality is provided in Table 2.

Table 2

Summary of raw water quality

Water quality parameter	Average yearly value	Minimum yearly value	Maximum yearly value
Temperature (°C)	10	0	28.9
pH	8.04	7.61	8.37
Turbidity (ntu)	60	12	401
Alkalinity (mg/L as $CaCO_3$)	183	82	270
Calcium hardness (mg/L as $CaCO_3$)	166	80	225
Total hardness (mg/L as $CaCO_3$)	236	111	311
TOC (mg/L)	7.6	6.0	9.2
UV_{254} (cm^{-1})	0.312	0.190	0.753
Bromide (mg/L)	0.036	<0.02	0.046

Raw water turbidity ranges from 12 to 400 ntu with a yearly average of 60 ntu. The historical yearly average total organic carbon (TOC) concentration is approximately 7.6 mg/L, with TOC spikes up to 9.2 mg/L. The pH of the raw water ranges between 7.6 and 8.4, with an average of 8.04. The river water treated has a very high average total hardness concentration of 236 mg/L that is reduced during the softening treatment process. The raw water alkalinity averages 183 mg/L as $CaCO_3$.

Finished Water

A summary of Ft. Wayne's finished water quality is provided in Table 3. The finished water turbidity ranges between 0.04 and 0.3 ntu with an average of approximately 0.09 ntu. The historical yearly average of the finished water is approximately 2.93 mg/L, and has been measured as high as 3.5 mg/L. Historical finished water DBPs monitored by Ft. Wayne include the average distribution system trihalomethane (THM) concentration. The historical running annual average THM concentration measured in the City's distribution system sample locations is very low at 1.76 µg/L. This THM concentration is significantly lower than both the Stage I D/DBP Rule limit and the proposed Stage II D/DBP Rule limit. The City's treatment process and use of chloramines for residual disinfection limits the formation of DBP's in their finished water.

Table 3

Summary of finished water quality

Water quality parameter	Average yearly value	Minimum yearly value	Maximum yearly value
Temperature (ºC)	10	0	28.9
pH	8.59	8.01	9.03
Turbidity (ntu)	0.09	0.04	0.30
TOC (mg/L)	2.93	2.70	3.50
Distribution system THM4 (µg/L)	1.76	<1.00	3.60

Treatment Challenges

One of the major challenges facing the Three Rivers Filtration plant is balancing the DBP regulatory requirements against microbiological disinfection requirements. Using current disinfection practices, the finished water chlorite concentration exceeds the regulatory maximum contaminant level (MCL) of 1.0 mg/L. The chlorite concentration increases during periods of warm, high turbidity water due to the application of higher applied doses of chlorine dioxide. Higher chlorine dioxide doses are necessary during these periods because of evaporation and UV destruction of the chlorine

dioxide residual. The utility is currently in the process of evaluating disinfection strategies and is considering moving the locations of disinfection chemical addition within the existing plant process to improve performance.

METHODS AND MATERIALS

Influent Pretreatment Process

Influent water used for the RSSCT study was collected from the Three Rivers Filtration Plant after primary sedimentation. The sampling was conducted by the plant operators and the sample was collected prior to any disinfectant addition so that no residual chlorine was present The same sampling location was used for each quarterly sampling event.

The influent water collected for the RSSCT study was unfiltered settled water, therefore, the water required filtration prior to RSSCT testing. The water was filtered at the EE&T test facility by passing the water through a 4-in. PVC pilot filter column that contained anthracite and sand media to remove turbidity from the feed water. The pilot filter system process schematic is shown in Figure 2.

Table 4

Influent pre-treatment for RSSCT study

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

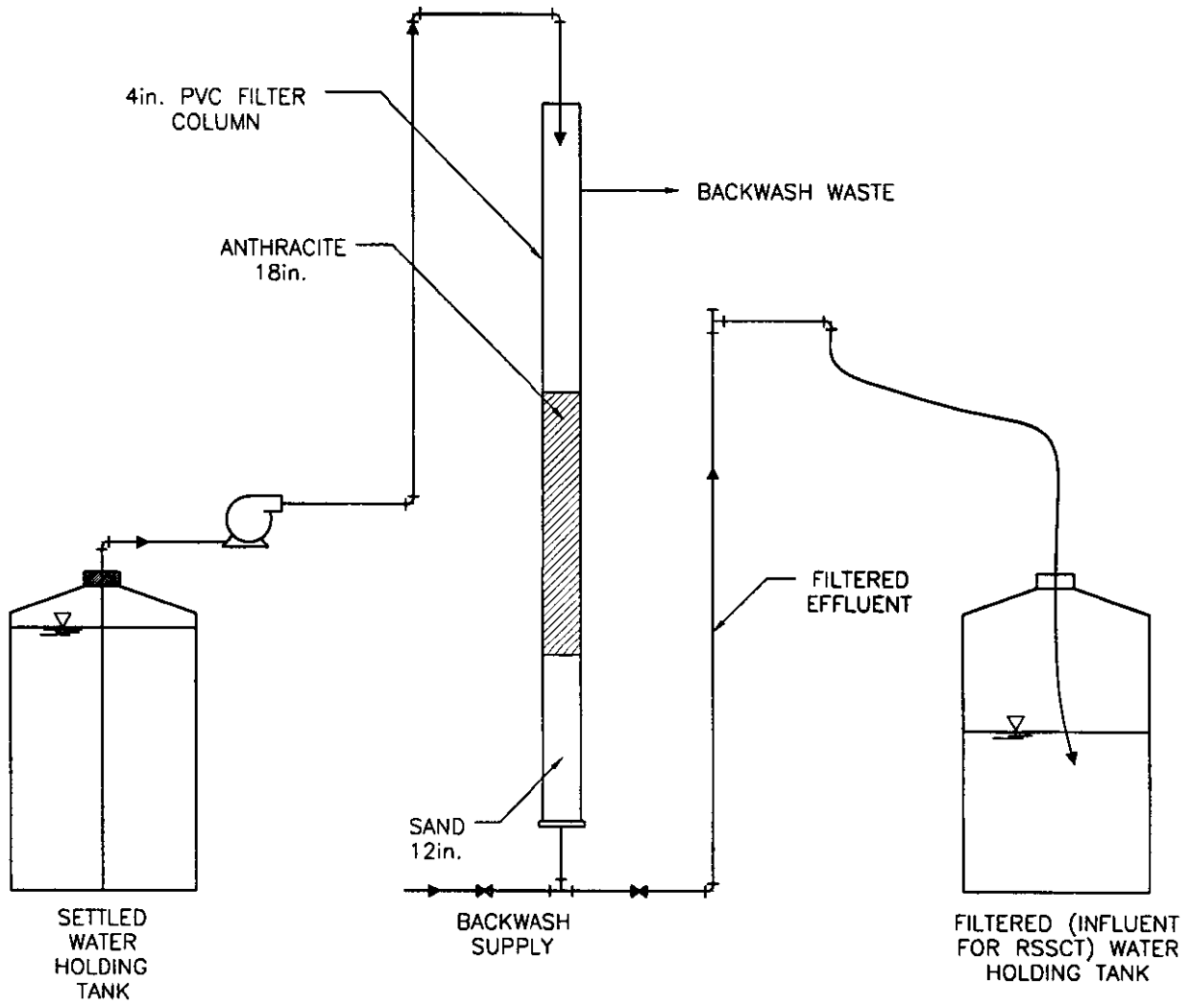

Figure 2. Pilot filter system used for filtering Ft. Wayne settled water

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Influent Water Analysis

Sample collection for the RSSCT study was only performed during periods when Ft. Wayne's raw water quality was stable and considered representative. In order to verify that the influent sample collected was typical, a series of five analytical tests were 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 to determine if the sample collected was truly representative. After confirming that the sample was representative, the water was delivered to the EE&T test facility to perform pilot filtration and then initiate 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 either a 1 to 2 µm, 5 to 6 µm, or 20 to 30 µm Teflon© filter disc), 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. Stainless steel screens were used to support the GAC media in the

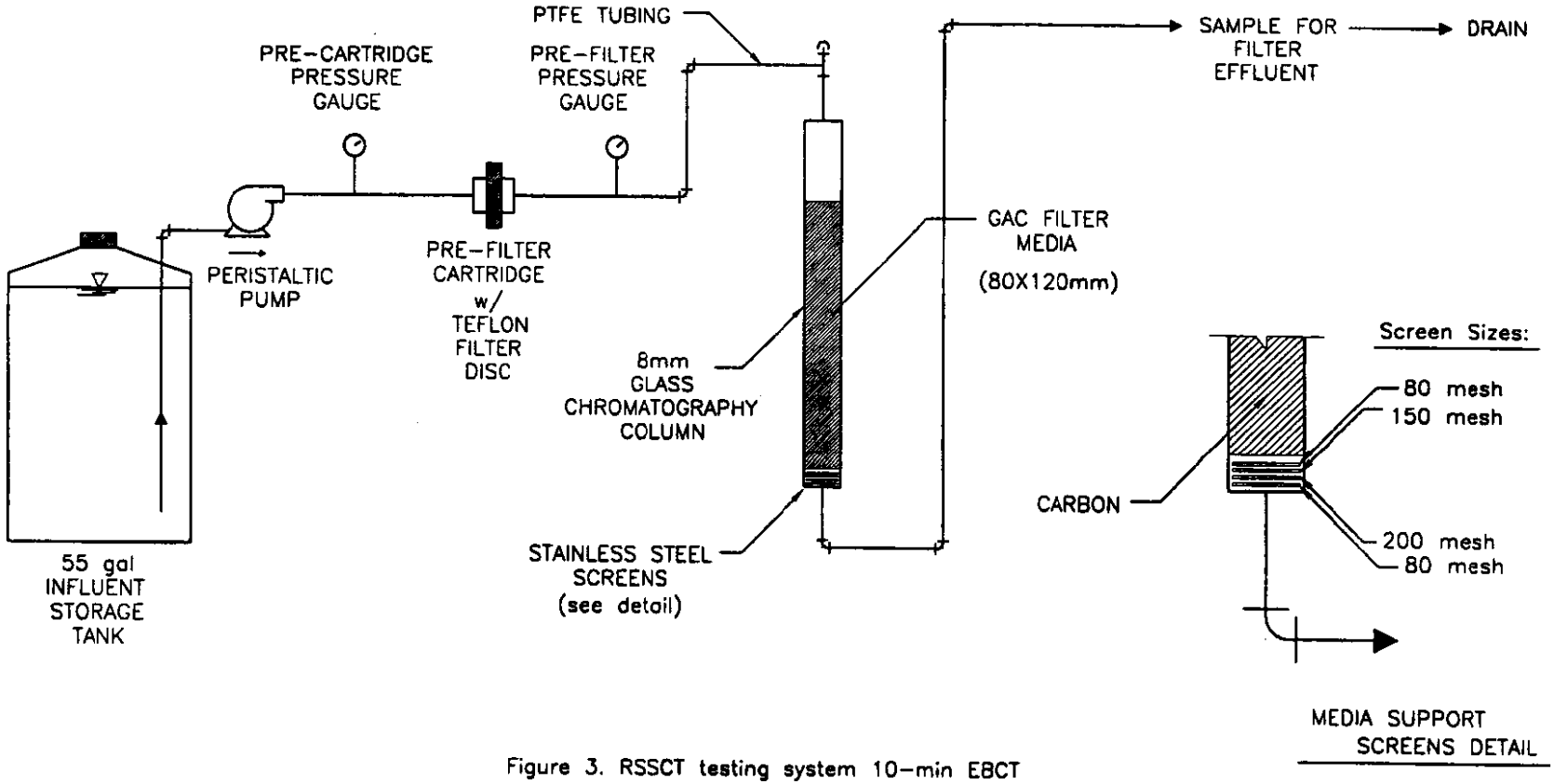

Figure 3. RSSCT testing system 10-min EBCT

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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 excessive 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 it 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(s) 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
	Column 2 media depth (cm) = 16.4

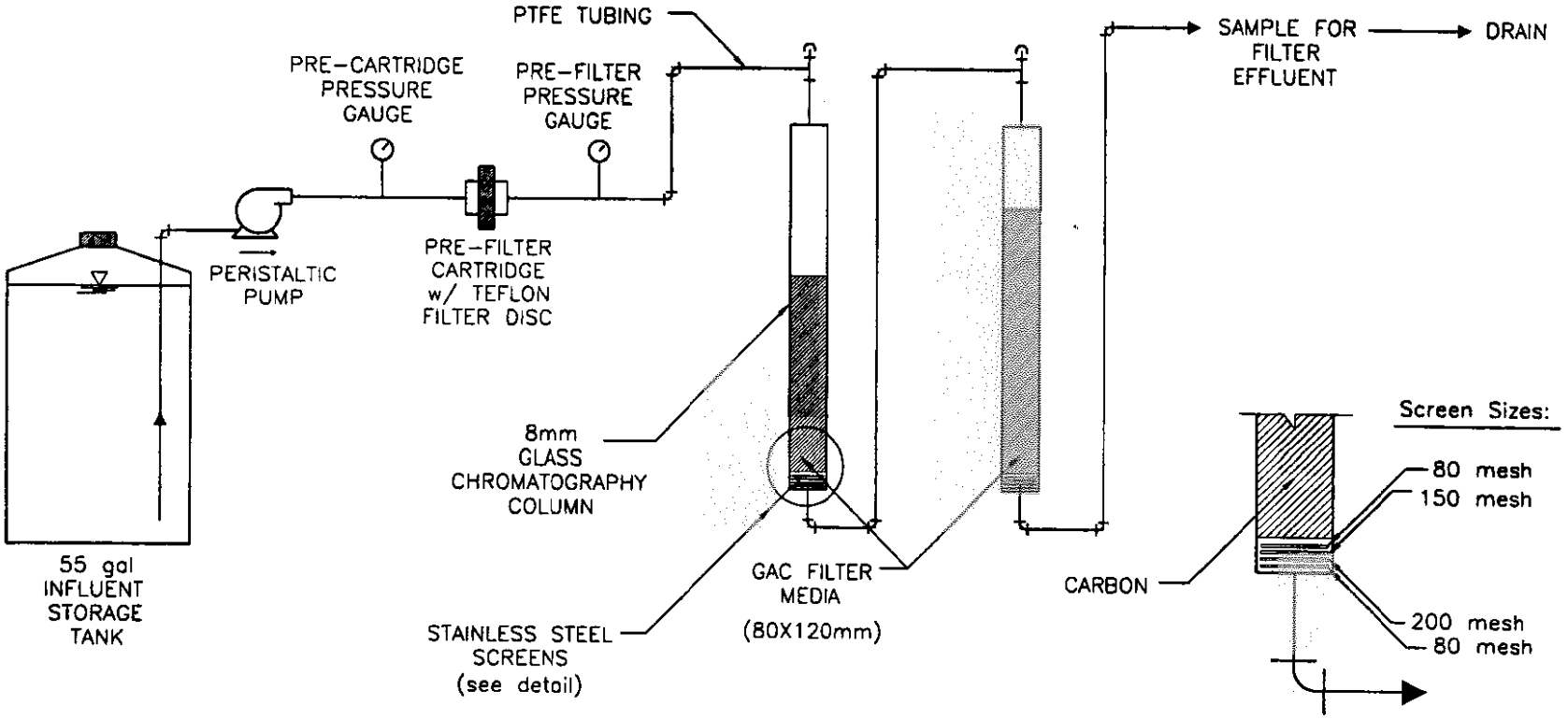

Figure 4. RSSCT testing system 20-min EBCT

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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

	RSSCT unit	
Parameter	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 analysis 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 sometimes 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	---	---
pH	SM 4500-H+ B	pH	---	---	---	---

Test	Method	Reporting units	MRL	MDL	Precision percent RSD*	Accuracy percent response*
Temperature	SM 2550 B	°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‡	≤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‡	≤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 2.80 to 4.26 mg/L during RSSCT testing. The influent water quality for each of the four test quarters was very similar for each of the parameters analyzed.

Table 8

Summary of RSSCT influent quality

Water quality parameter	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Temperature (ºC)	20.0	25.9	20.0	18.0
pH	7.06	7.27	7.01	6.57
Turbidity (ntu)	0.18	0.37	0.42	0.17
Alkalinity (mg/L as $CaCO_3$)	17.5	20.0	35.0	32.5
Calcium hardness (mg/L as $CaCO_3$)	65.3	64.8	98.0	87.0
Total hardness (mg/L as $CaCO_3$)	75.3	73.0	115.0	109.0

Water quality parameter	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Bromide (mg/L)	<0.02	0.04	0.04	0.22
TOC (mg/L)	3.50	2.80	4.26	3.28
UV_{254} (cm^{-1})	0.058	0.050	0.071	0.043
SDSTHM4 (µg/L)	47.1	56.6	77.8	55.3
SDSHAA6 (µg/L)	70.3	61.4	68.1	40.7
SDSTOX (µg/L)	175.5	196.5	255.0	144.6
SDS chlorine demand (mg/L)	2.81	2.48	4.97	2.45

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 quarterly influent SDSTHM4 concentrations shown in the table averaged 59 µg/L during the year-long study. This average SDSTHM4 concentration is, as expected, significantly higher than Ft. Wayne's historical average distribution system THM4 concentration of less than 2 µg/L. The full-scale THM4 concentration is lower than the SDSTHM average because the full-scale plant uses chlorine dioxide for primary disinfection and chloramines for residual maintenance in the distribution system. By comparison, the influent SDS determination for the RSSCT involved chlorination using free chlorine and an incubation period of three days.

Quarterly Test Results

Summary

The Ft. Wayne 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 none of the 20-min EBCT tests were terminated due to 70 percent TOC breakthrough. Data obtained from each of the four quarterly tests are presented in the following sections of this report. The key filter effluent quality parameters monitored 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

Ft. Wayne 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	4/16-5/25, 1998	3.50	2.45	276	70% TOC breakthrough
20-min	4/16-6/4, 1998	3.50	2.45	363	One full-scale year of run time
Quarter 2					
10-min	7/20-7/29, 1998	2.80	1.96	65	50% TOC breakthrough
20-min	7/20-8/6, 1998	2.80	1.96	131	70% TOC breakthrough
Quarter 3					
10-min	11/4-12/15, 1998	4.26	2.98	315	70% TOC breakthrough
20-min	11/4-12/16, 1998	4.26	2.98	323	One full-scale year of run time
Quarter 4					
10-min	3/15-4/6, 1999	3.28	2.30	322	One full-scale year of run time
20-min	3/15-4/30, 1999	3.28	2.30	345	One full-scale year of run time

Quarter 1 Results

TOC Data. The first quarter of RSSCT testing was initiated on April 16, 1998. During this test, the influent TOC concentration averaged 3.5 mg/L. The 10- and 20-min effluent TOC concentration versus time is shown in Figure 5. The figure shows that the 10-min EBCT effluent TOC concentration exceeded 70 percent breakthrough after approximately 260 full-scale operation days. The 20-min EBCT effluent TOC concentration never reached 70 percent breakthrough and the test was ended due to time after 360 full-scale days of operation.

SDSTHM Data. The SDSTHM data is plotted versus scaled operation days in Figure 6. The SDSTHM concentration measured in the influent samples averaged 47.1 µg/L during the study. The 10-min EBCT effluent SDSTHM concentration exceeded the proposed Stage II limit of 40 µg/L after 150 scaled operation days and reached as high as 70 µg/L after 250 scaled operation days. The 20-min EBCT effluent concentration exceeded the proposed Stage II limit after 230 scaled operation days. At no time did the 10-min or 20-min EBCT effluent SDSTHM concentrations ever reach the Stage I D/DBP Rule limit of 80 µg/L.

SDSHAA6 Data. Figure 7 shows the SDSHAA6 data for both the RSSCT influent and effluent analyses. The influent SDSHAA6 concentration averaged 70.3 µg/L during the study but

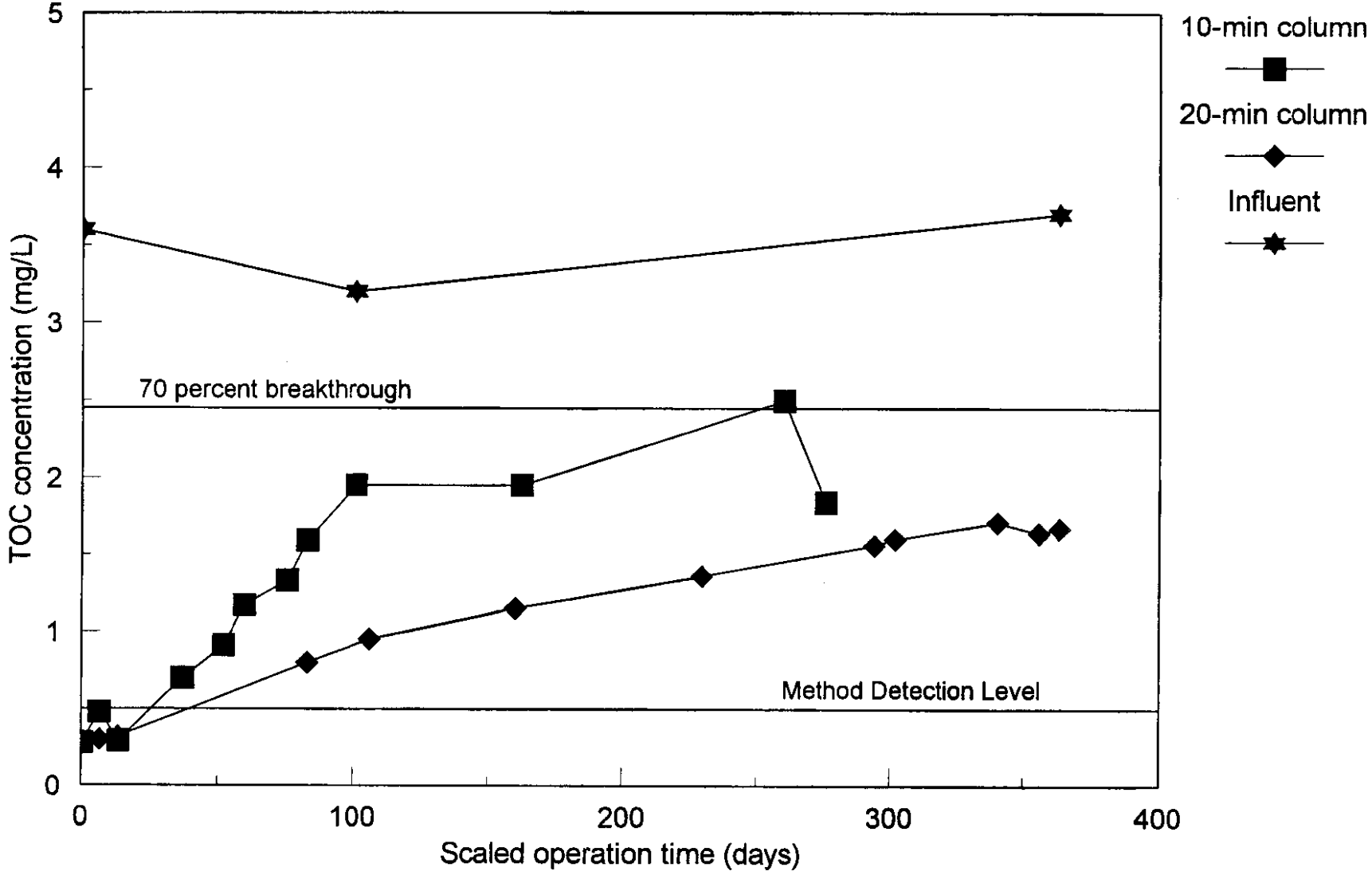

Figure 5 Ft. Wayne first quarter testing: TOC data

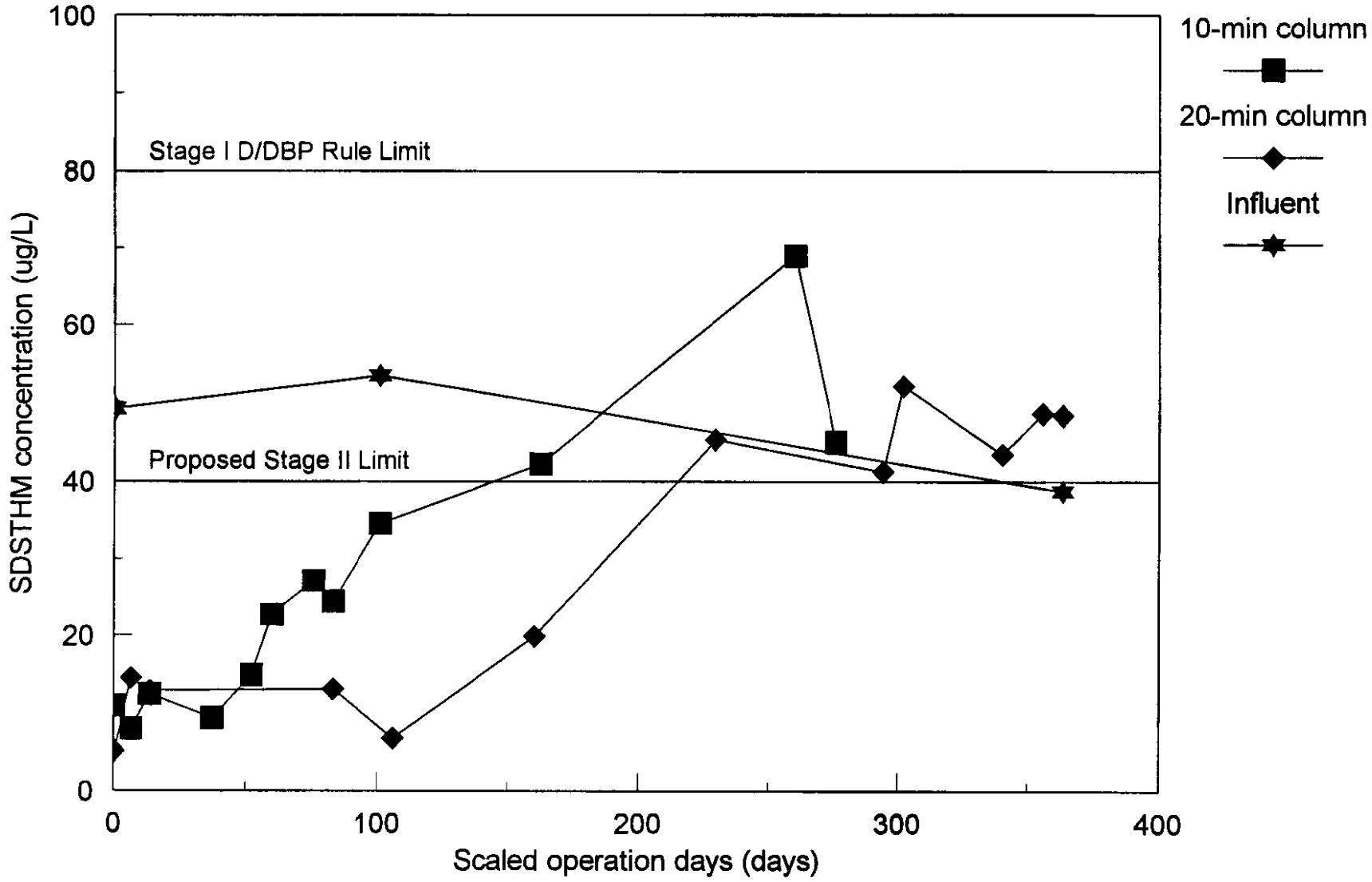

Figure 6 Ft. Wayne first quarter testing: SDSTHM data

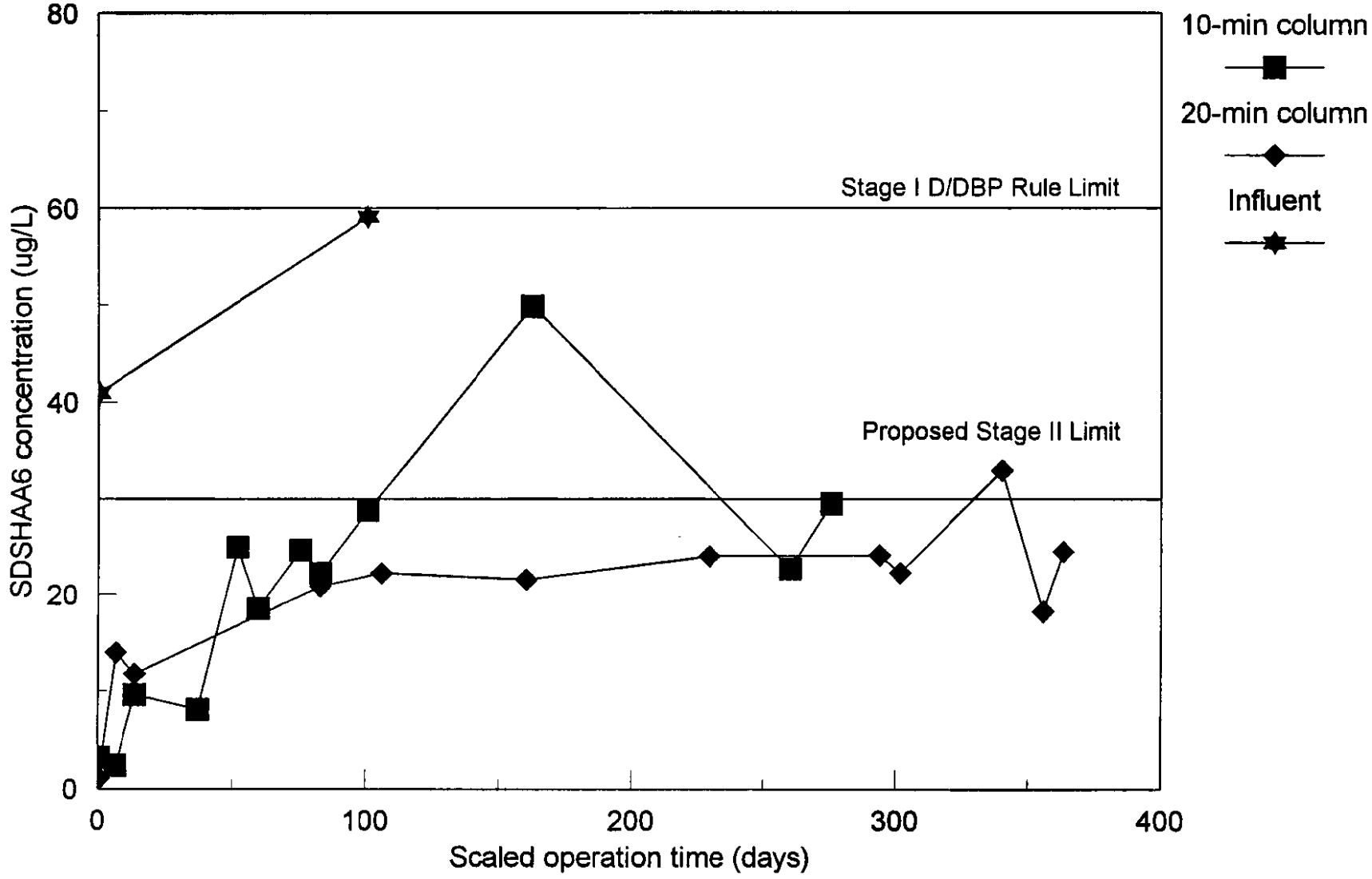

Figure 7 Ft. Wayne first quarter testing: SDSHAA6 data

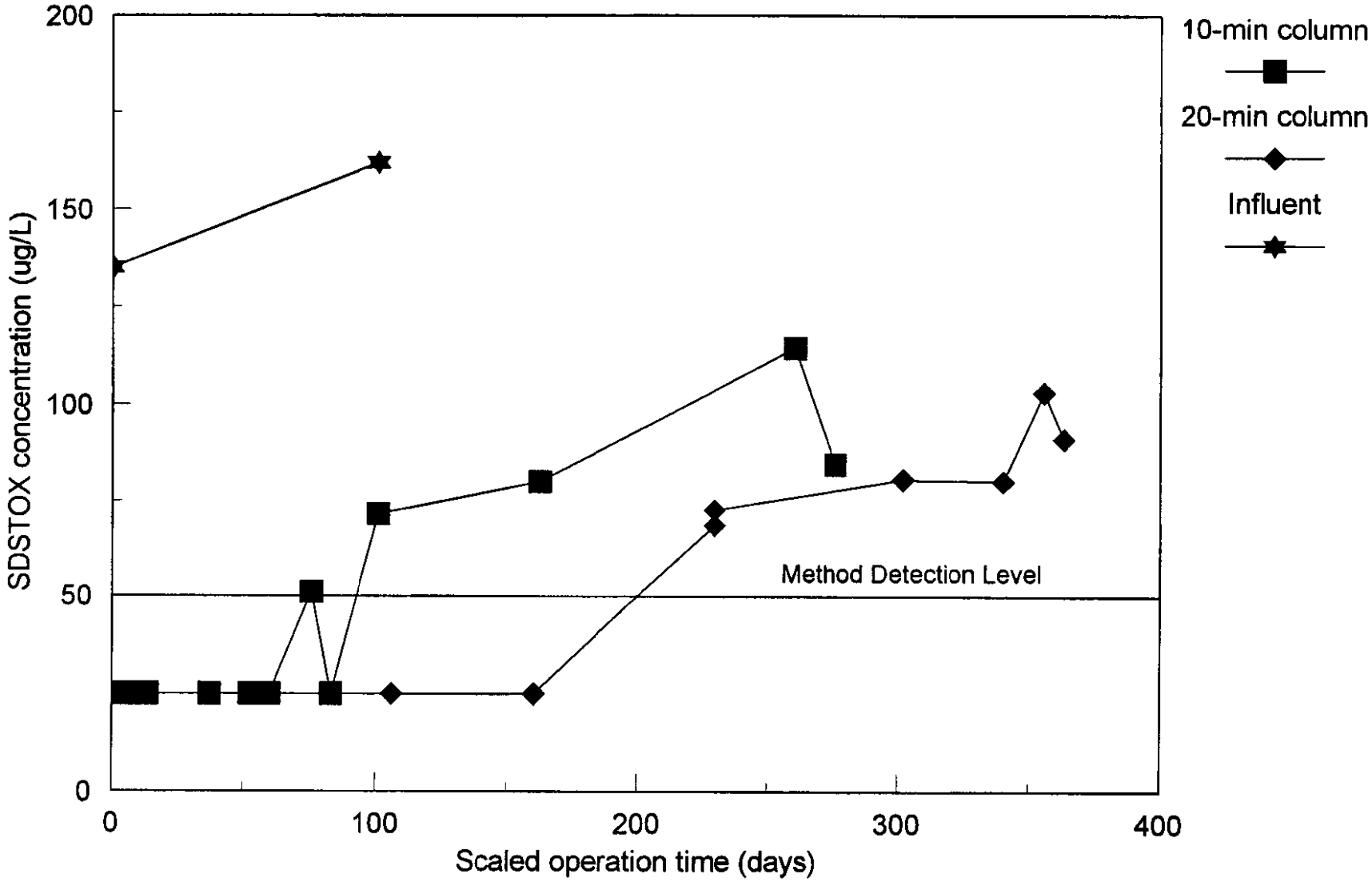

Figure 8 Ft. Wayne first quarter testing: SDSTOX data

was highly variable. The 10-min EBCT effluent concentration exceeded the proposed Stage II limit in only one of the 12 compliance samples. This sample was collected after 150 scaled operation days and had an SDSHAA6 concentration of 50 µg/L. The 20-min EBCT effluent exceeded the proposed Stage II limit but only after 340 scaled operation days. At no time did either of the column effluents exceed the Stage I D/DBP Rule limit of 60 µg/L.

SDSTOX Data. The SDSTOX data is presented in Figure 8. The average influent SDSTOX concentration was 175.5 µg/L. The 10-min EBCT effluent SDSTOX concentration was below the MDL through 100 scaled operation days and then ranged between 50 and 100 µg/L up to test completion at approximately 275 scaled operation days. The 20-min EBCT effluent SDSTOX exceeded the MDL after 200 scaled operation days and then averaged between 50 and 100 µg/L until the test was ended 360 scaled operation days.

Quarter 2 Results

TOC Data. The second quarter of RSSCT testing began on July 20, 1998. During testing the influent TOC concentration averaged 2.80 mg/L. A plot of the TOC concentration versus scaled operation time is shown in Figure 9. During this test the 10-min EBCT effluent concentration reached as high as 1.60 mg/L or 57 percent breakthrough. The test was ended after 65 scaled operation days after remaining at 50 percent breakthrough for two full-scale equivalent months. The 20-min EBCT effluent concentration reached 70 percent breakthrough after 85 scaled operation days and remained above 70 percent on two separate sampling events that were approximately two full-scale equivalent weeks apart. The test, however, was allowed to continue in order to collect the remaining three compliance samples.

SDSTHM Data. The SDSTHM data from second quarter testing are shown in Figure 10. The influent SDSTHM concentration averaged 56.6 µg/L. The figure shows that at no time did the 10-min or 20-min EBCT effluent SDSTHM concentration reach the proposed Stage II limit of 40 µg/L. All 10- and 20-min EBCT effluent SDSTHM concentrations were less than 30 µg/L.

SDSHAA6 Data. The SDSHAA6 data are shown in Figure 11. The influent SDSHAA6 data averaged 61.4 µg/L during testing. The 10- and 20-min EBCT effluent SDSHAA6 concentrations

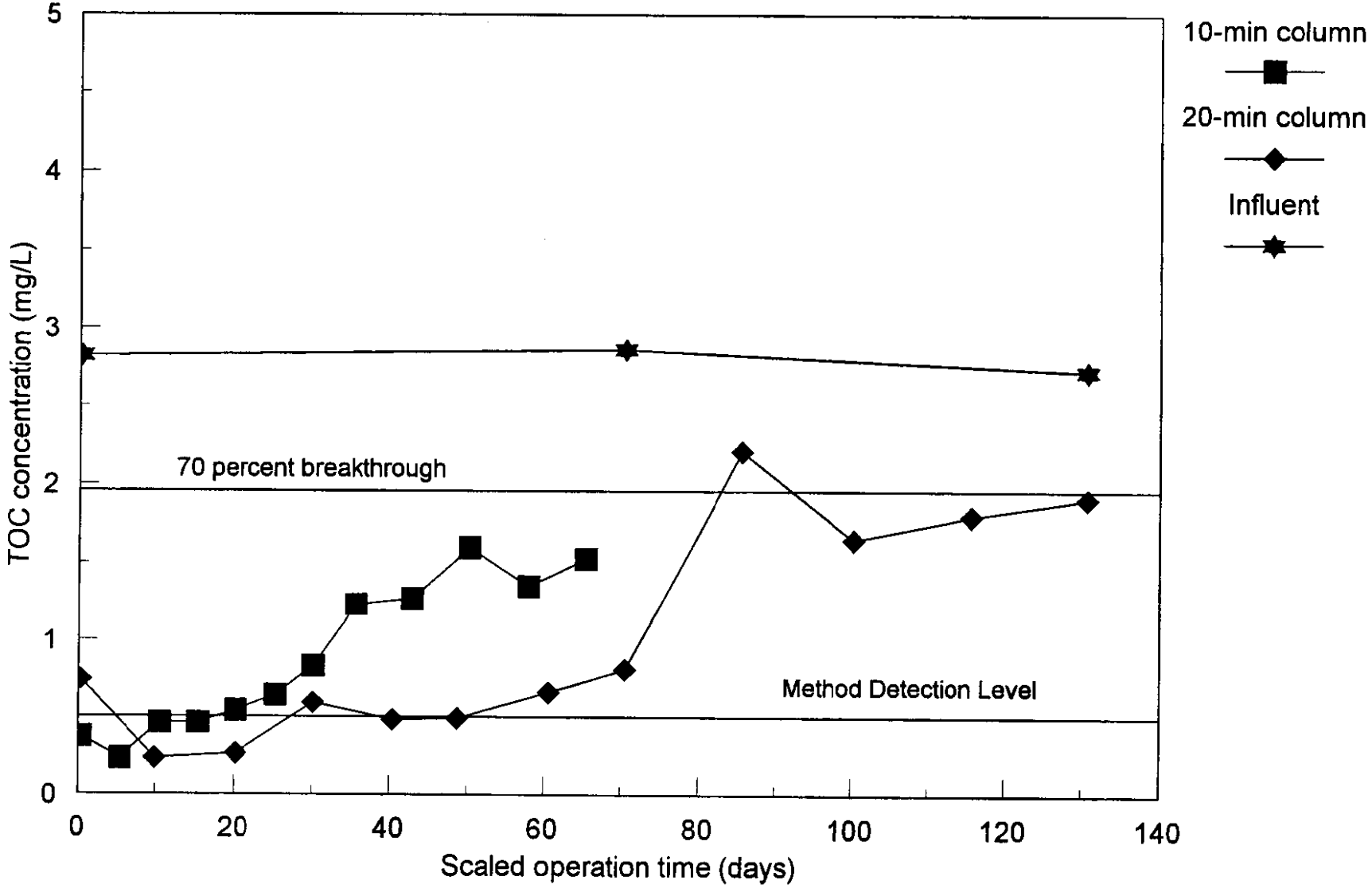

Figure 9 Ft. Wayne second quarter testing: TOC data

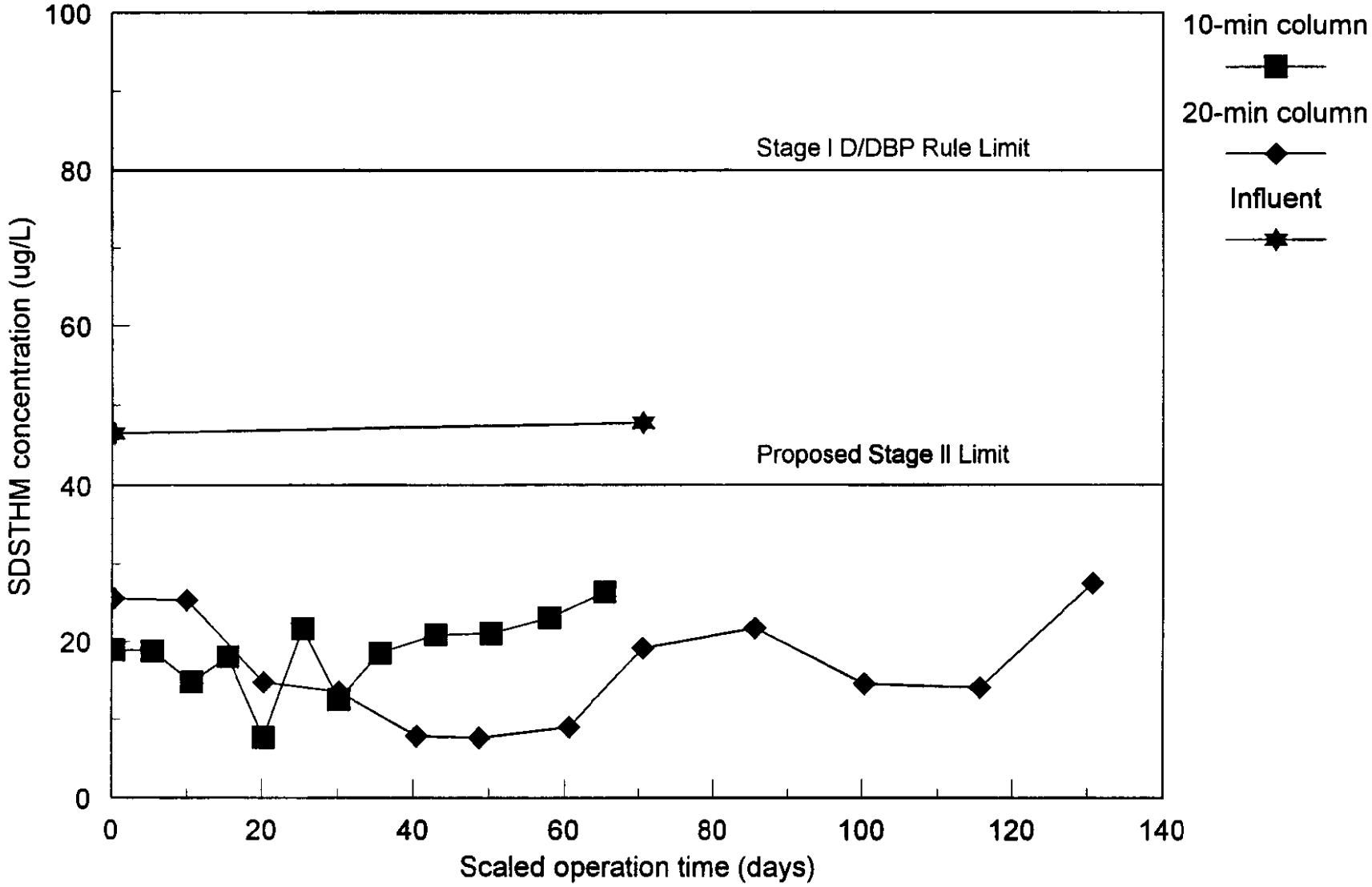

Figure 10 Ft. Wayne second quarter testing: SDSTHM data

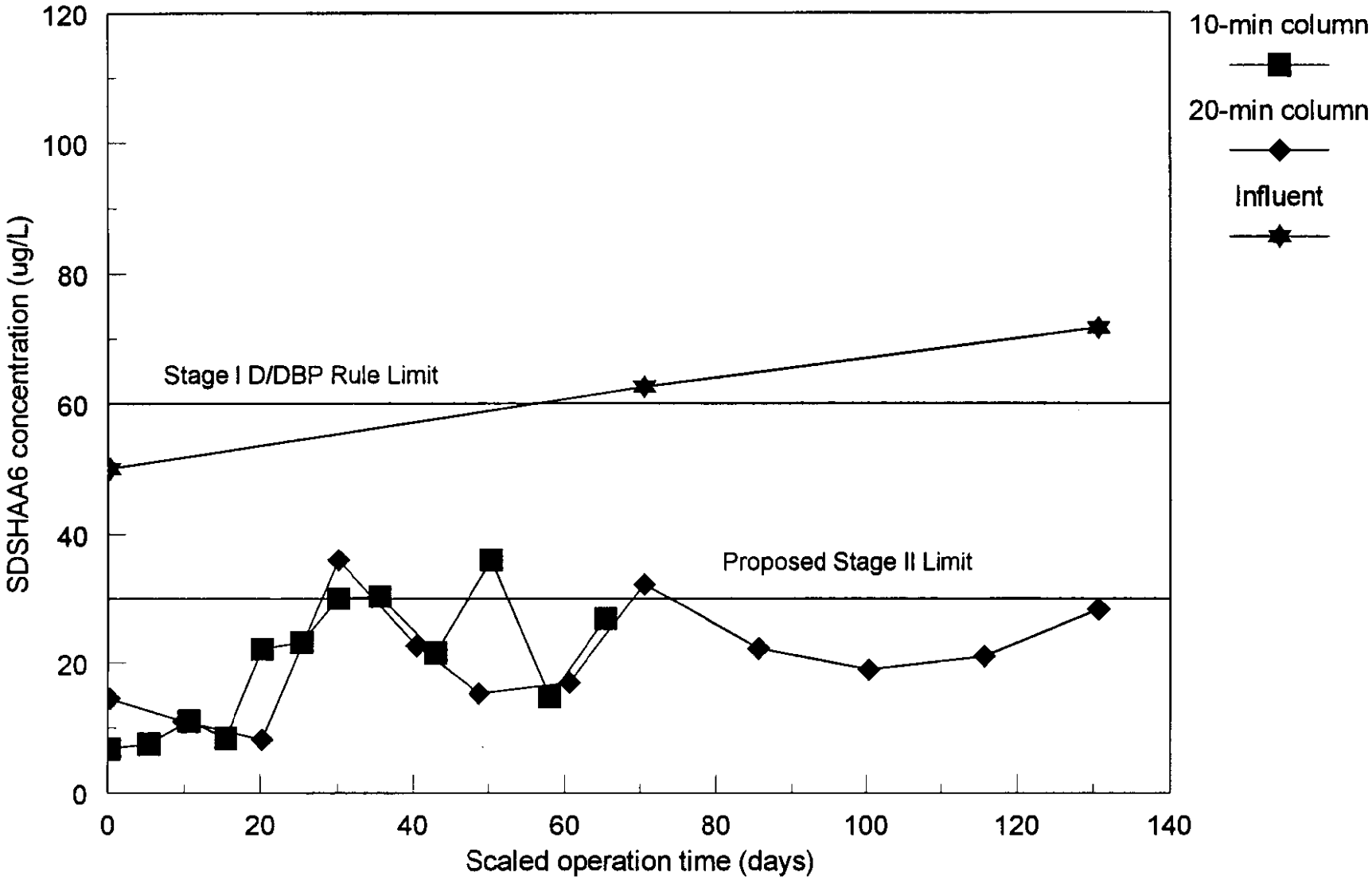

Figure 11 Ft. Wayne second quarter testing: SDSHAA6 data

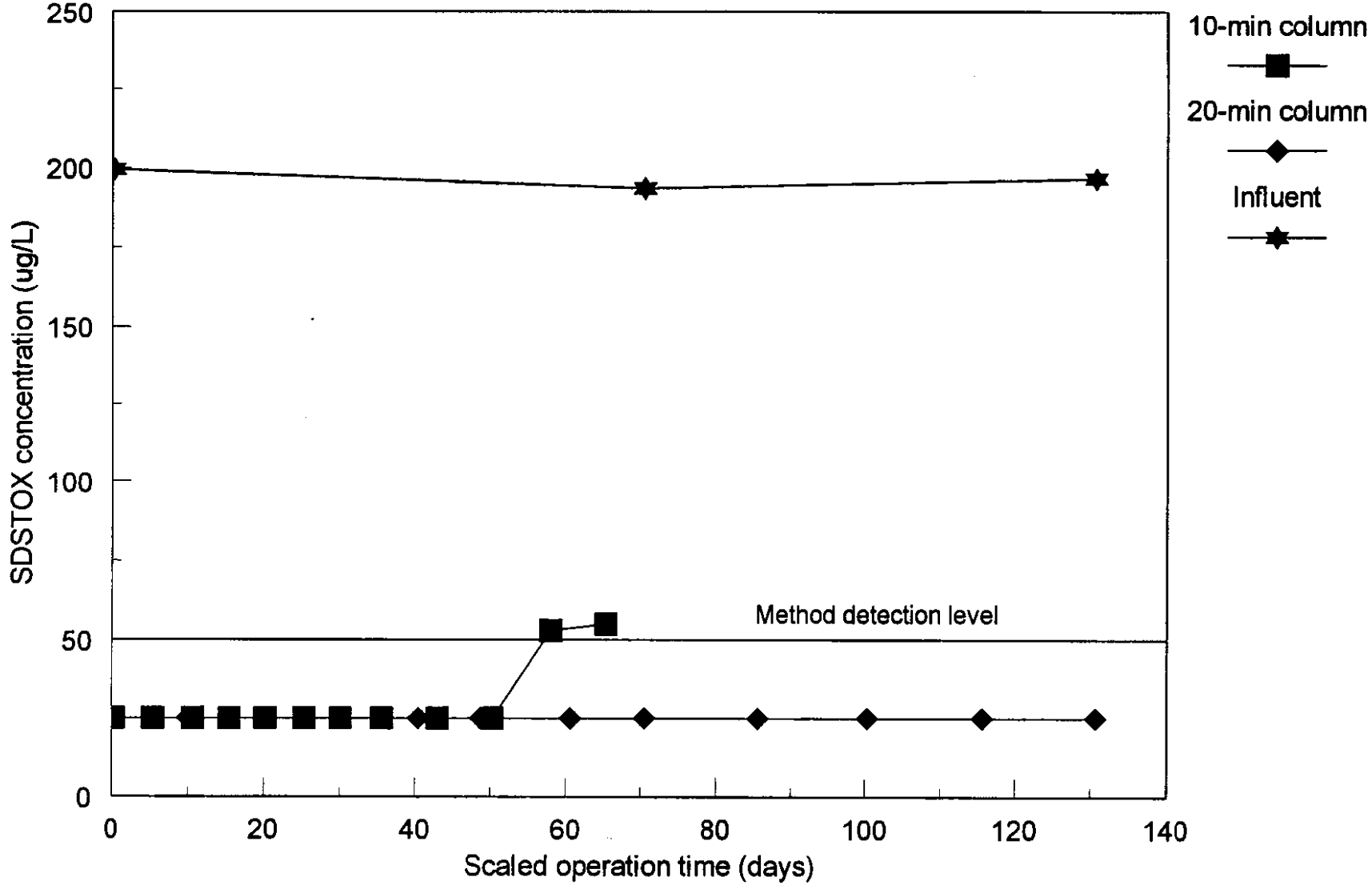

Figure 12 Ft. Wayne second quarter testing: SDSTOX data

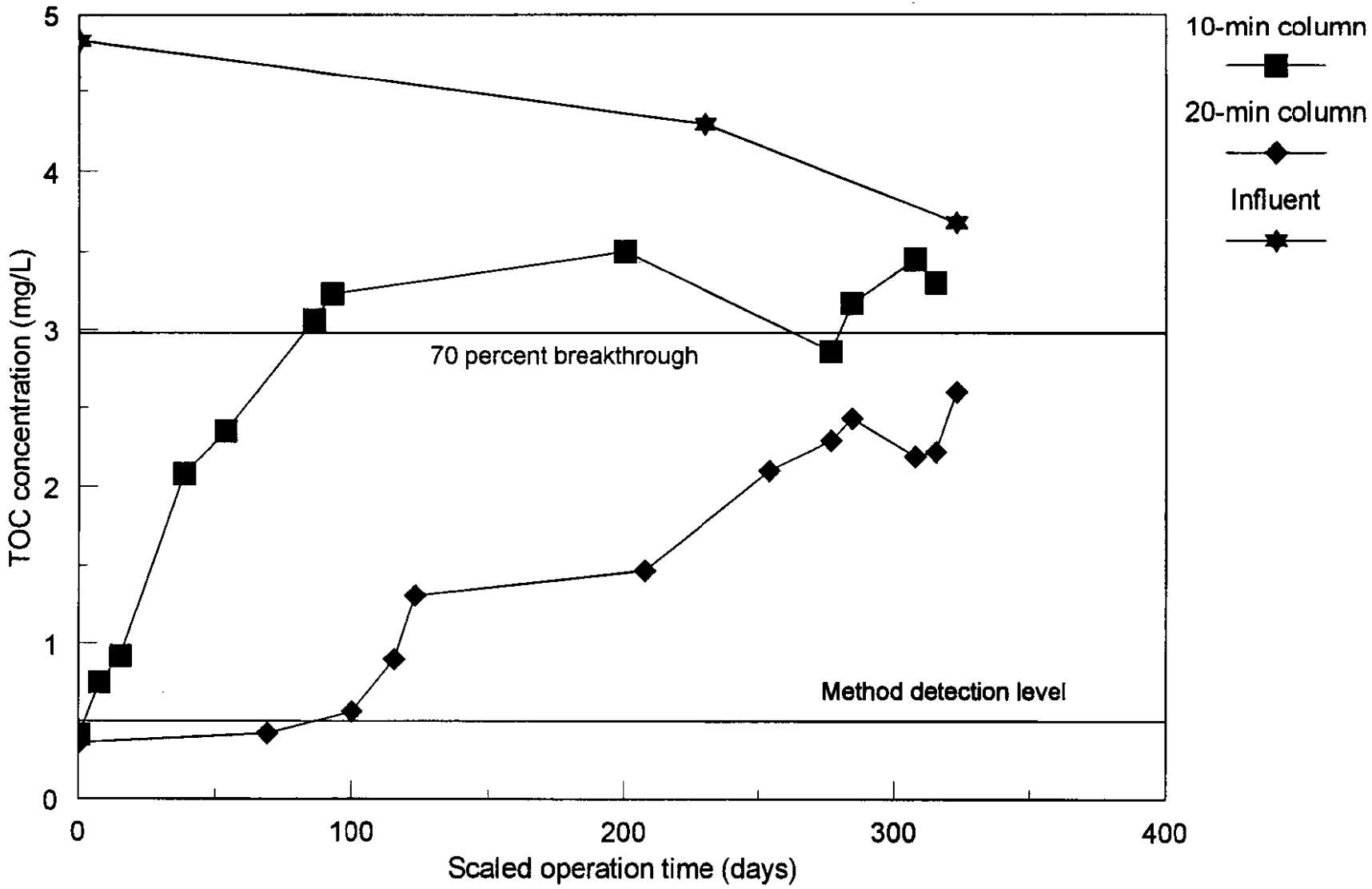

Figure 13 Ft. Wayne third quarter testing: TOC data

were below the proposed Stage II limit of 30 µg/L with the exception of five compliance samples which were slightly higher than 30 µg/L. At no time did the 10-min or 20-min EBCT effluent concentrations exceed 40 µg/L.

SDSTOX Data. The SDSTOX data are shown in Figure 12. The 10-min EBCT effluent SDSTOX concentration exceeded the MDL in the final two compliance samples after 55 scaled operation days. All of the 20-min EBCT effluent SDSTOX concentrations were below the MDL.

Quarter 3 Results

TOC Data. The third quarter of RSSCT testing began on November 4, 1998. During this quarter the influent TOC concentration averaged 4.26 mg/L. The TOC data are presented in Figure 13. Due to the increased influent TOC concentration, breakthrough in both the 10- and 20-min columns occurred more rapidly. The 10-min EBCT effluent TOC concentration reached 70 percent breakthrough after only 85 scaled operation days, but the test was allowed to continue through 325 scaled operation days in order to collect all 12 compliance samples. The 20-min EBCT effluent TOC concentration showed a steady increase over the 320 scaled operation. After 323 days, the 20-min EBCT test was ended due to time. The final effluent TOC concentration was to 2.60 mg/L or 61 percent breakthrough.

SDSTHM Data. The third quarter influent and effluent SDSTHM data are shown in Figure 14. The influent SDSTHM concentration averaged 77.2 µg/L during testing. The 10-min EBCT effluent concentration increased to 63 µg/L after only 53 scaled operation days and then ranged between 40 µg/L and 60 µg/L for the remainder of the test. The 20-min EBCT effluent SDSTHM concentration gradually increased over the course of the test and exceeded the proposed Stage II limit in only one compliance sample collected after 300 scaled operation days.

SDSHAA6 Data. The SDSHAA6 data from third quarter testing are shown in Figure 15. The influent SDSHAA6 concentration averaged 68.1 µg/L during the test period. The figure shows the same trend as the TOC and SDSTHM curves for both the 10- and 20-min effluents. The 10-min EBCT effluent SDSHAA6 concentration increased to above the proposed Stage II limit of 30 µg/L after only 40 scaled operation days, and reached the Stage I limit after 200 scaled operation days.

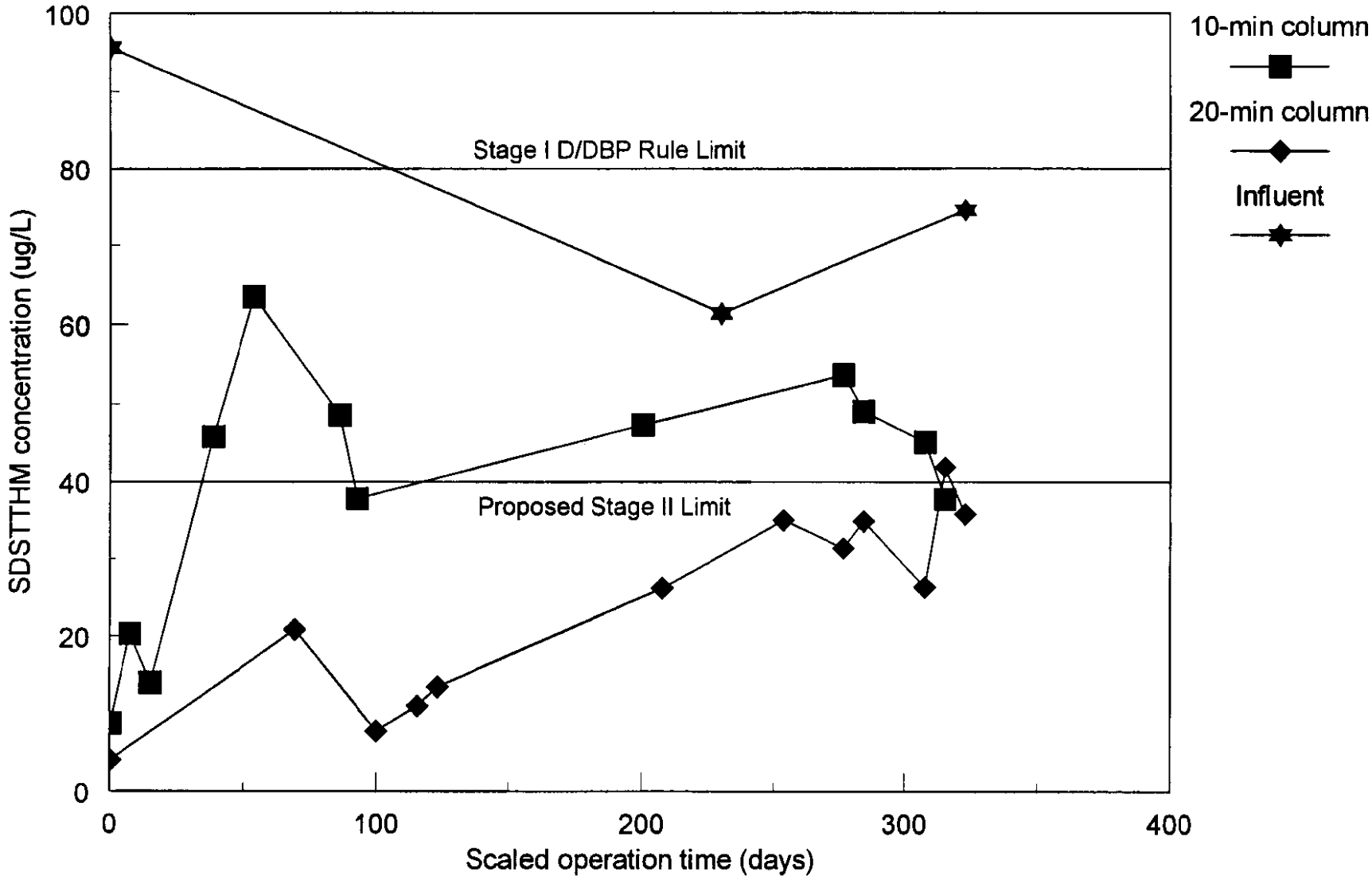

Figure 14 Ft. Wayne third quarter testing: SDSTHM data

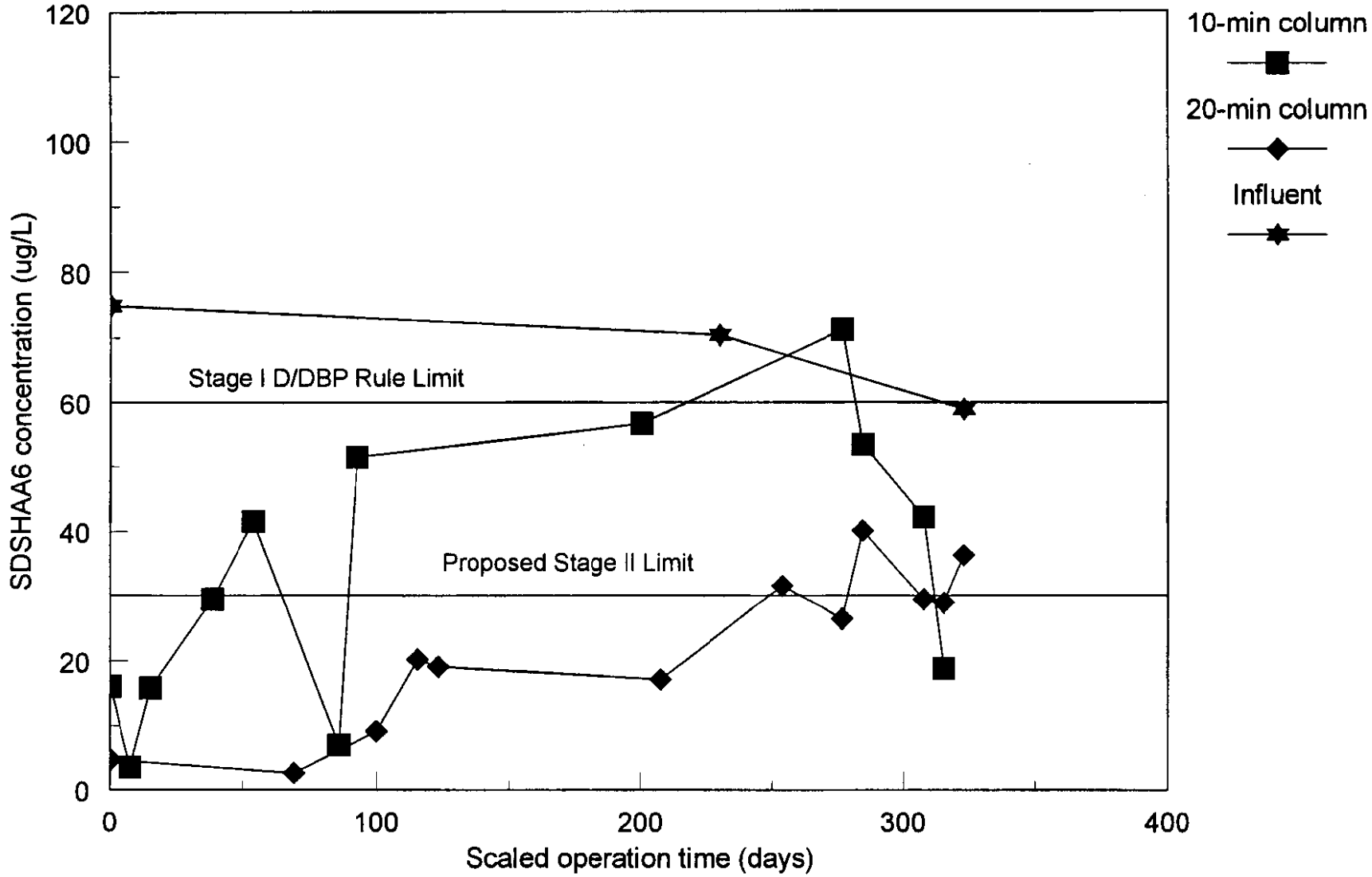

Figure 15 Ft. Wayne third quarter testing: SDSHAA6 data

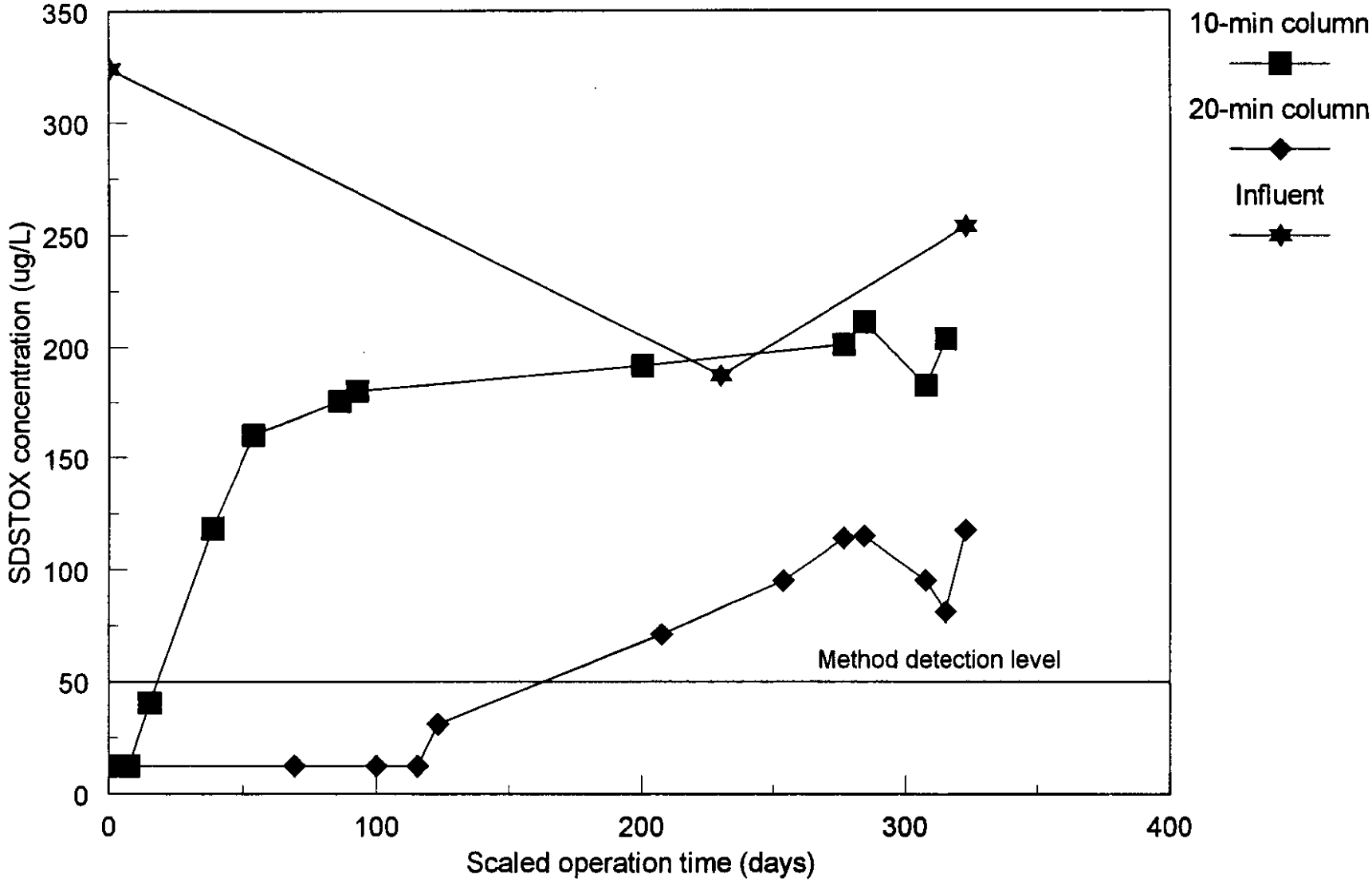

Figure 16 Ft. Wayne third quarter testing: SDSTOX data

The 20-min EBCT effluent exceeded the proposed Stage II limit after 250 scaled operation days but did not exceed the Stage I regulatory limit of 60 µg/L.

SDSTOX Data. The SDSTOX data from the third quarter are shown in Figure 16. The influent and effluent SDSTOX concentrations were higher during the third quarter than for the first and second quarters of the study. The influent SDSTOX concentration averaged 255 µg/L. The 10-min EBCT effluent SDSTOX concentration increased to 175 µg/L after only 100 scaled operation days and then ranged between 175 µg/L and 225 µg/L throughout the remainder of the test. The 20-min EBCT effluent SDSTOX concentration was at a measurable concentration of 75 µg/L after 200 scaled operation days and reached as high as 117 µg/L after 320 scaled operation days.

Quarter 4 Results

TOC Data. the fourth quarter of RSSCT testing began on March 15, 1999. During this quarter the influent TOC concentration averaged 3.28 mg/L. The influent and effluent TOC breakthrough curves are shown in Figure 17. Breakthrough in the 10-min EBCT effluent increased rapidly up to 100 scaled operation days and then remained slightly below the 70 percent breakthrough concentration of 2.30 mg/L through 300 scaled operation days. Only the final 10-min EBCT effluent sample concentration exceeded 70 percent breakthrough. The 20-min EBCT effluent TOC concentration steadily increased during the test to a maximum breakthrough level of 61 percent after approximately 315 scaled operation days. The 20-min EBCT test was ended due to time.

SDSTHM Data. The SDSTHM data from fourth quarter testing are shown in Figure 18. The influent concentration during this test averaged 55.3 µg/L. After 100 scaled operation days the 10-min EBCT effluent SDSTHM concentration was slightly higher than the proposed Stage II limit. With the exception of one compliance sample concentration of 64 µg/L, the 10-min EBCT effluent concentration averaged approximately 40 µg/L through 322 scaled operation days of testing. The 20-min EBCT SDSTHM concentration ranged between 10 µg/L and 30 µg/L during the test and did not exceed the proposed Stage II limit.

SDSHAA6 Data. The SDSHAA6 data from fourth quarter testing are shown in Figure 19. The influent SDSHAA6 concentration during the test averaged 40.7 µg/L. After 100 scaled

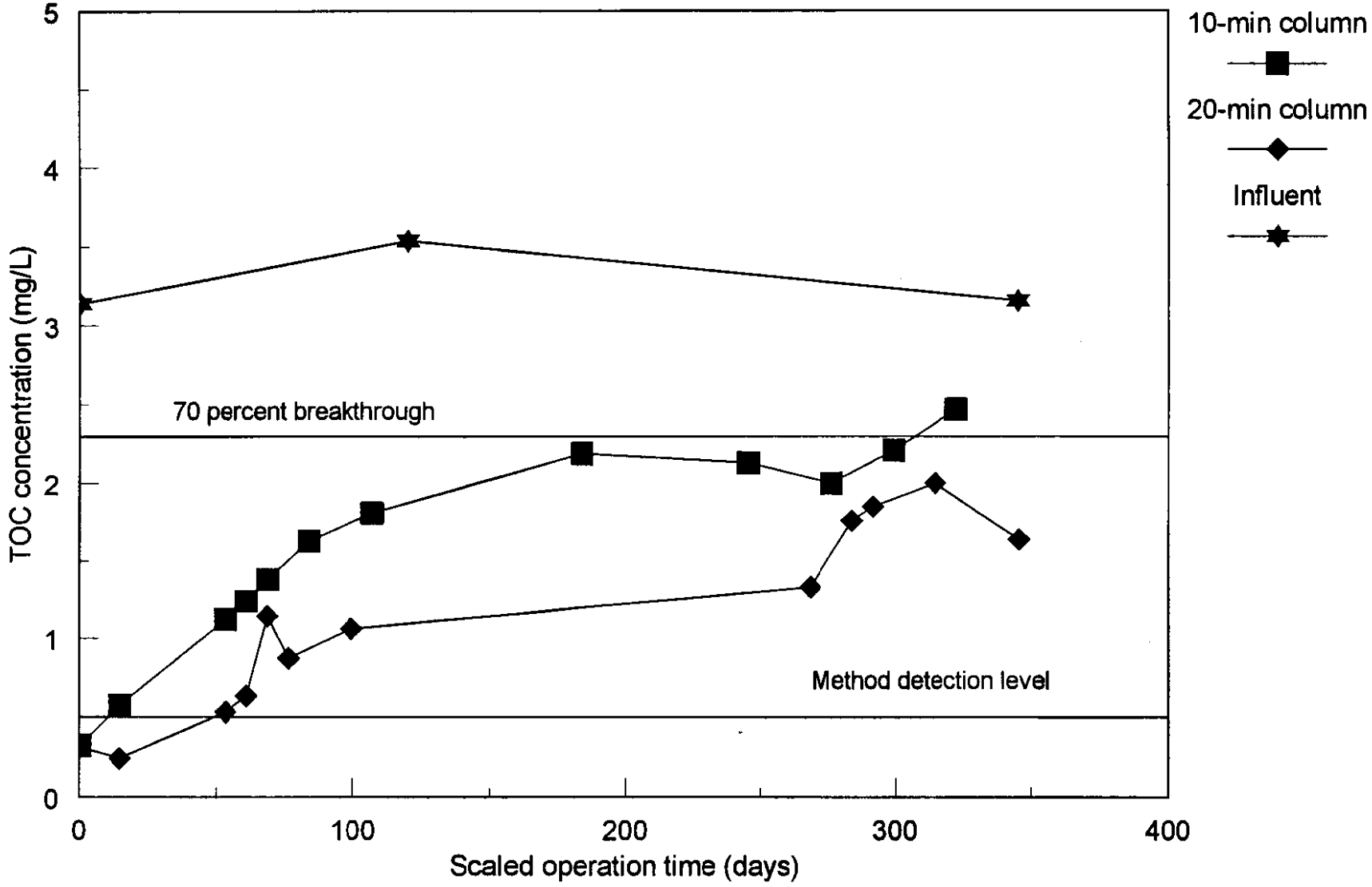

Figure 17 Ft. Wayne fourth quarter testing: TOC data

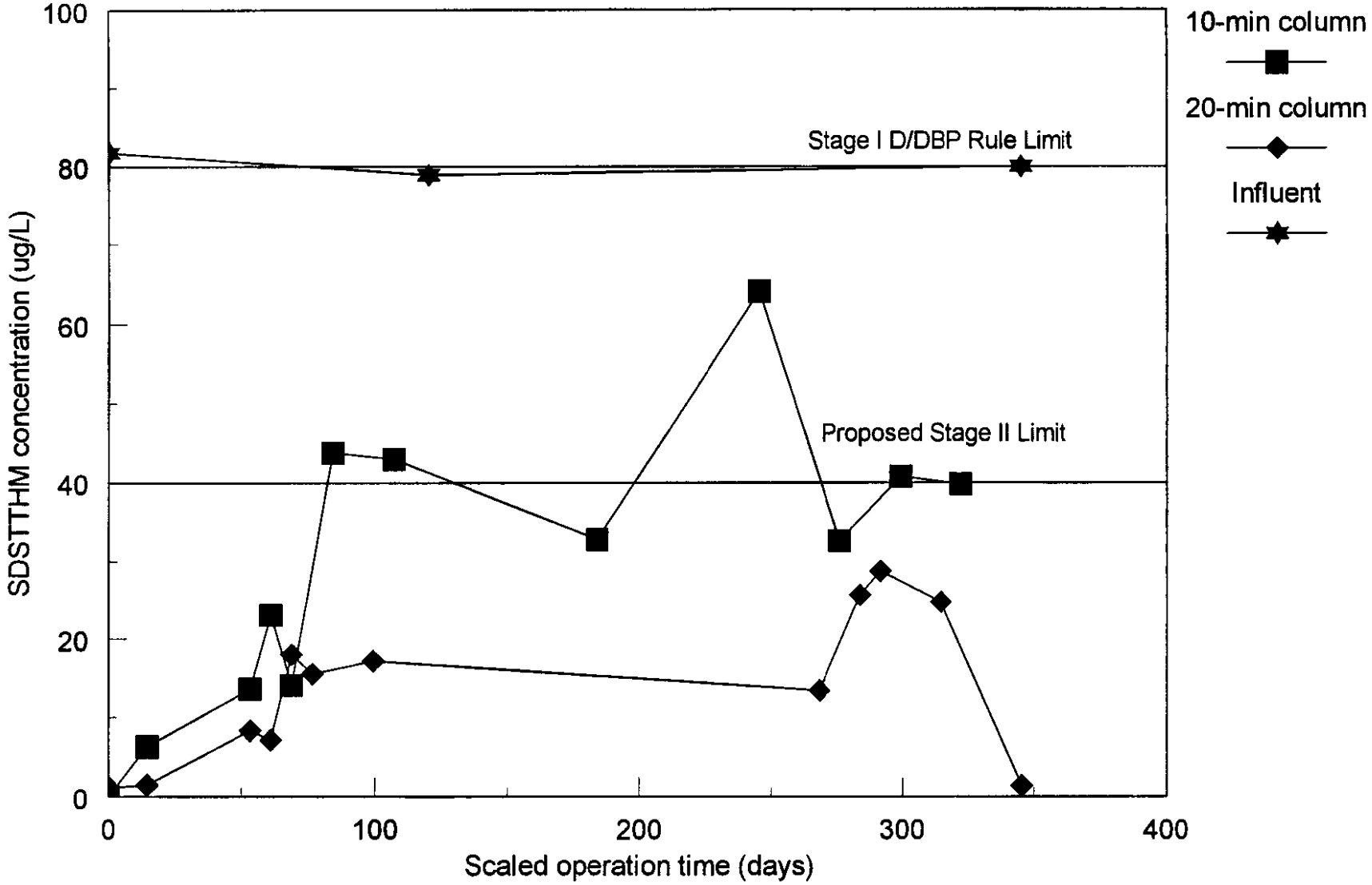

Figure 18 Ft. Wayne fourth quarter testing: SDSTHM data

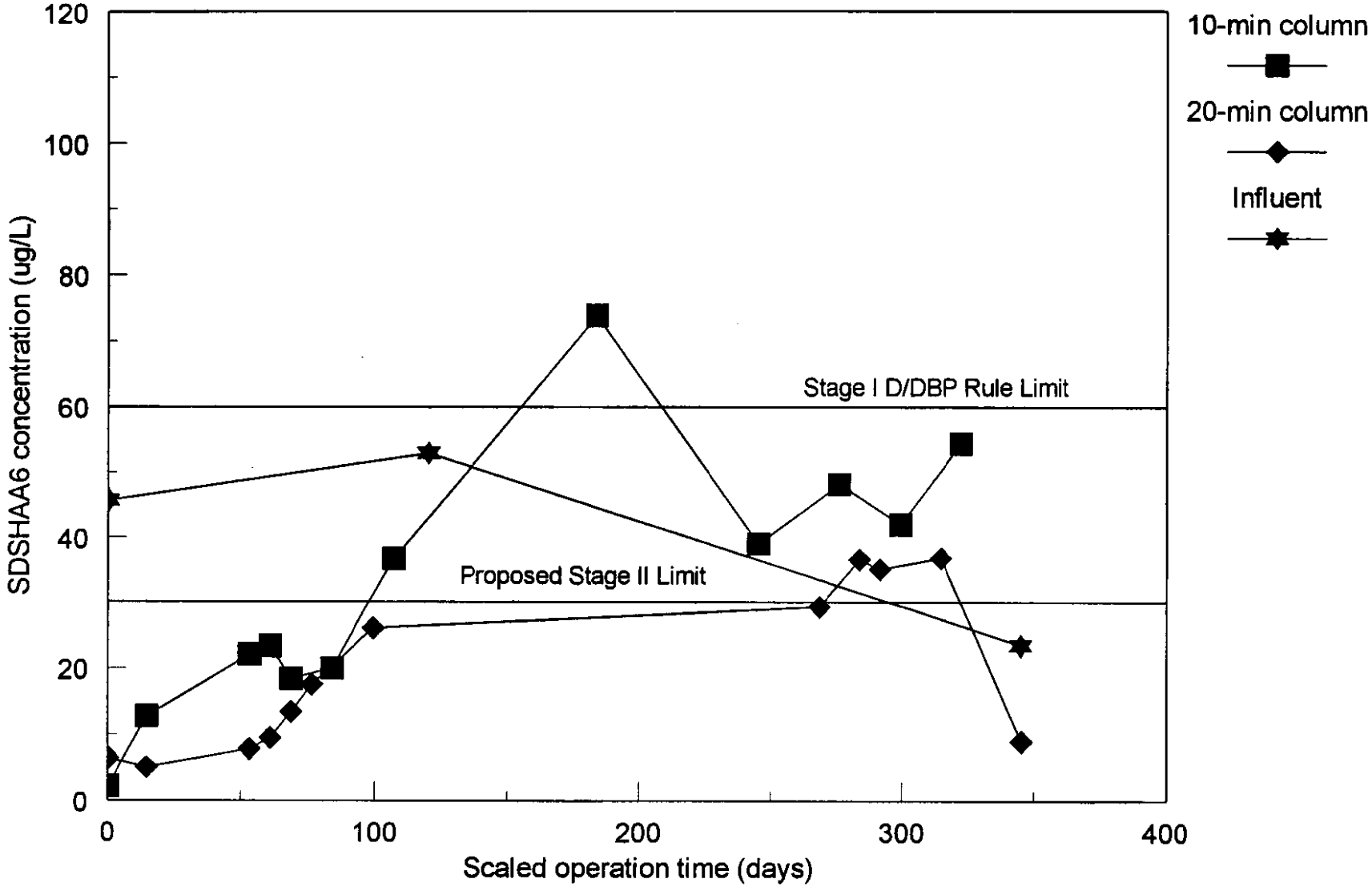

Figure 19 Ft. Wayne fourth quarter testing: SDSHAA6 data

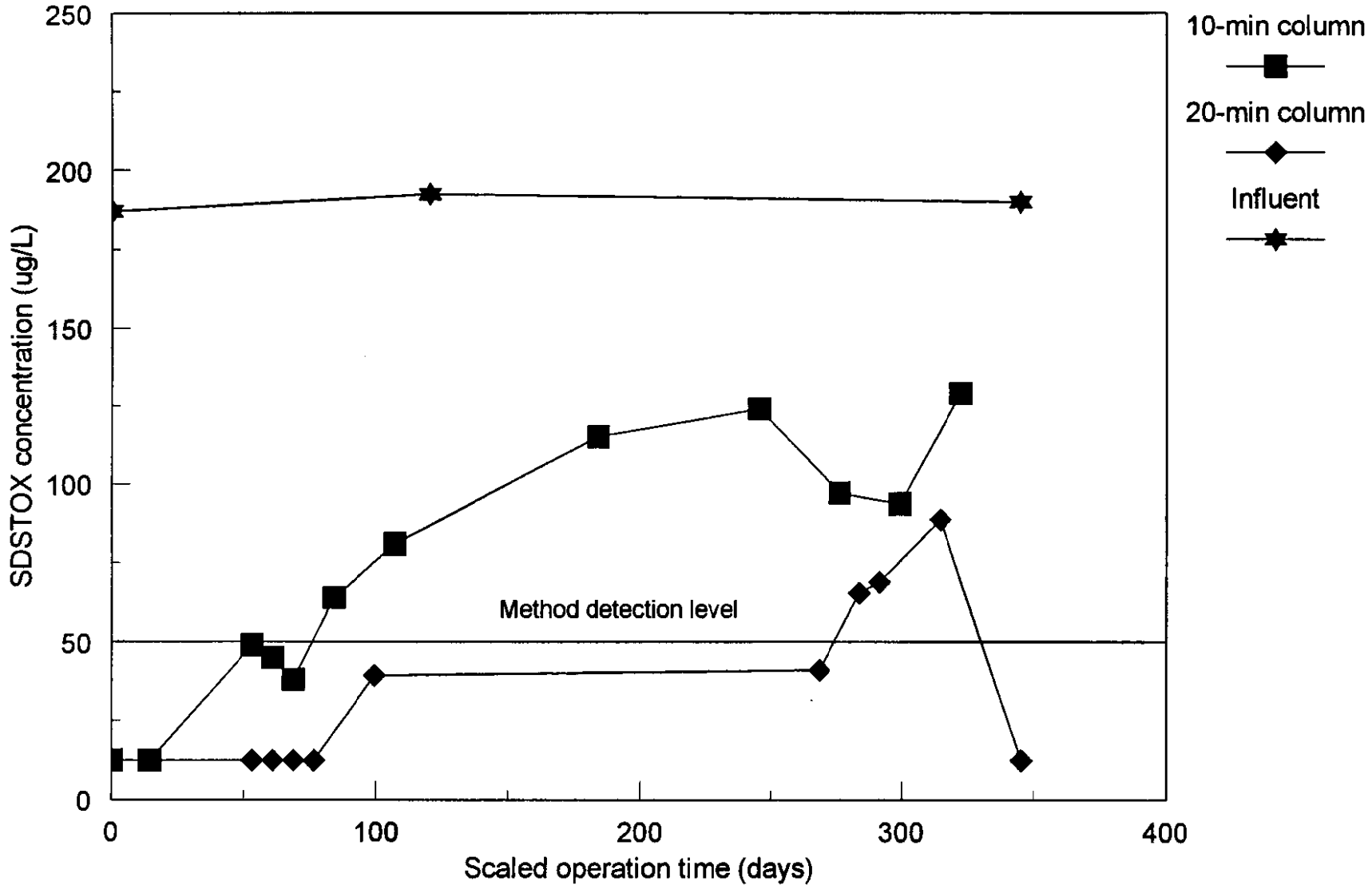

Figure 20 Ft. Wayne fourth quarter testing: SDSTOX data

operation days the 10-min EBCT effluent exceeded the proposed Stage II limit. Only one 10-min compliance sample, collected after 175 scaled operation days, exceeded the Stage I limit. The 20-min EBCT effluent SDSHAA6 concentration remained below the proposed Stage II limit of 30 µg/L through 275 scaled operation days and then increased to as high as 41 µg/L at the end of the test.

SDSTOX Data. the SDSTOX data are shown in Figure 20. The influent SDSTOX concentration averaged 144.6 µg/L during the test. The 10-min EBCT effluent SDSTOX concentration reached a concentration of 129 µg/L after 322 scaled operation days. The 20-min EBCT effluent SDSTOX concentration did not increase above the MDL until after 275 scaled operation days. The maximum 20-min EBCT SDSTOX concentration measured was 88.5 µg/L after over 300 scaled operation days.

Summary of TOC Breakthrough

In order to compare the TOC breakthrough curves for the four quarterly tests, the 10-min and 20-min EBCT test results were plotted together. The four quarterly 10-min EBCT effluent TOC breakthrough curves are shown in Figure 21. 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 all four quarters of testing remained stable or only slightly increased during the remainder of each test. The third quarter influent TOC concentration was significantly higher than the other three quarters and, therefore, TOC breakthrough concentrations were higher.

The 20-min EBCT effluent TOC breakthrough concentrations are shown in Figure 22. The 20-min EBCT quarterly TOC breakthrough each demonstrate a gradual increase in TOC breakthrough over time. The curves show that a 25 to 35 percent TOC breakthrough occurred after approximately 100 scaled operation days. A TOC breakthrough of 50 to 70 percent occurred after 300 scaled operation days.

Problems Encountered

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 to 2 µm, 5 to 6 µm, and 20 to 30 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 testing, only two of the 10-min EBCT tests and none of the 20-min EBCT tests were 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

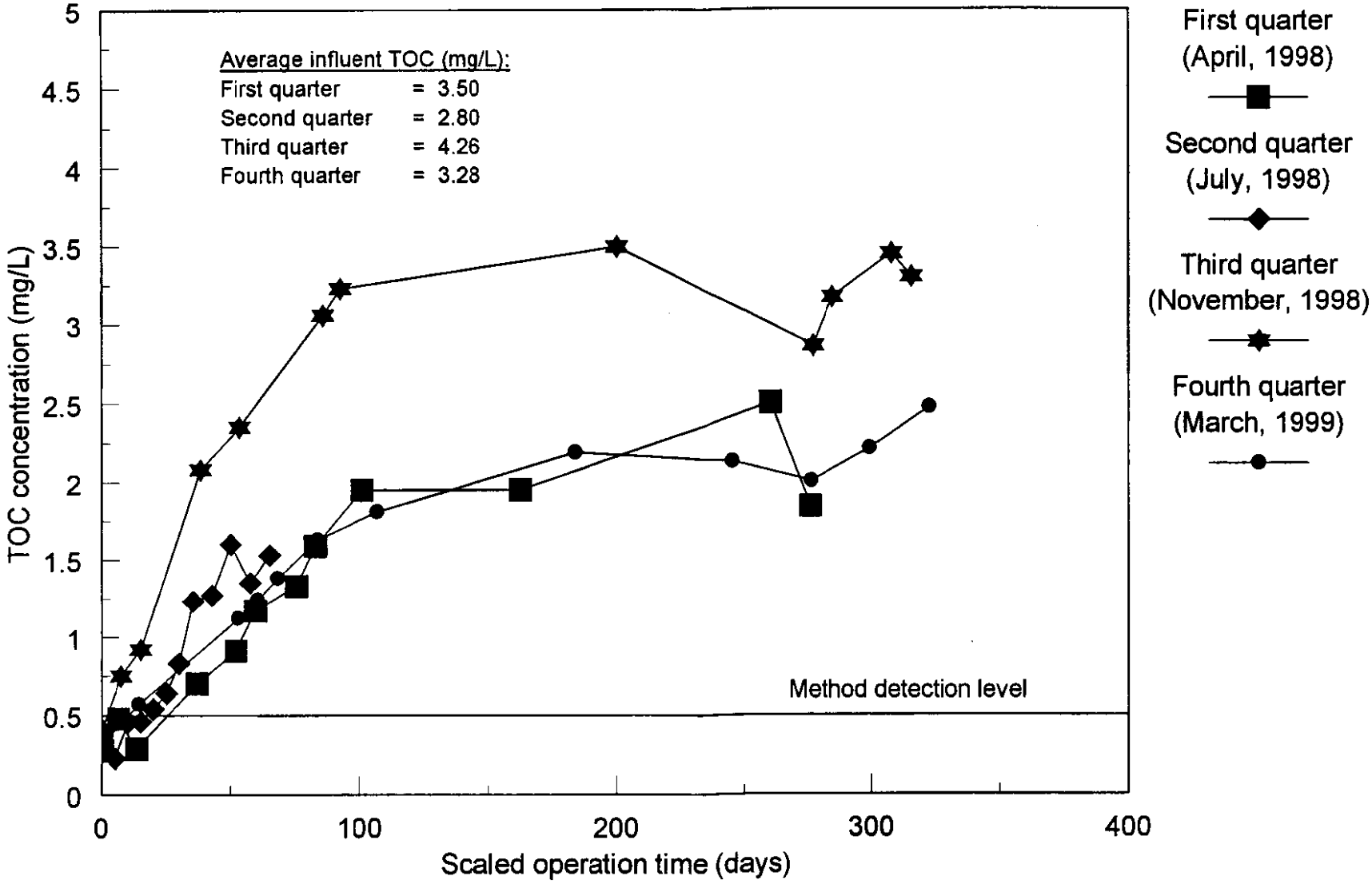

Figure 21 Ft. Wayne RSSCT testing: TOC data (10-min EBCT)

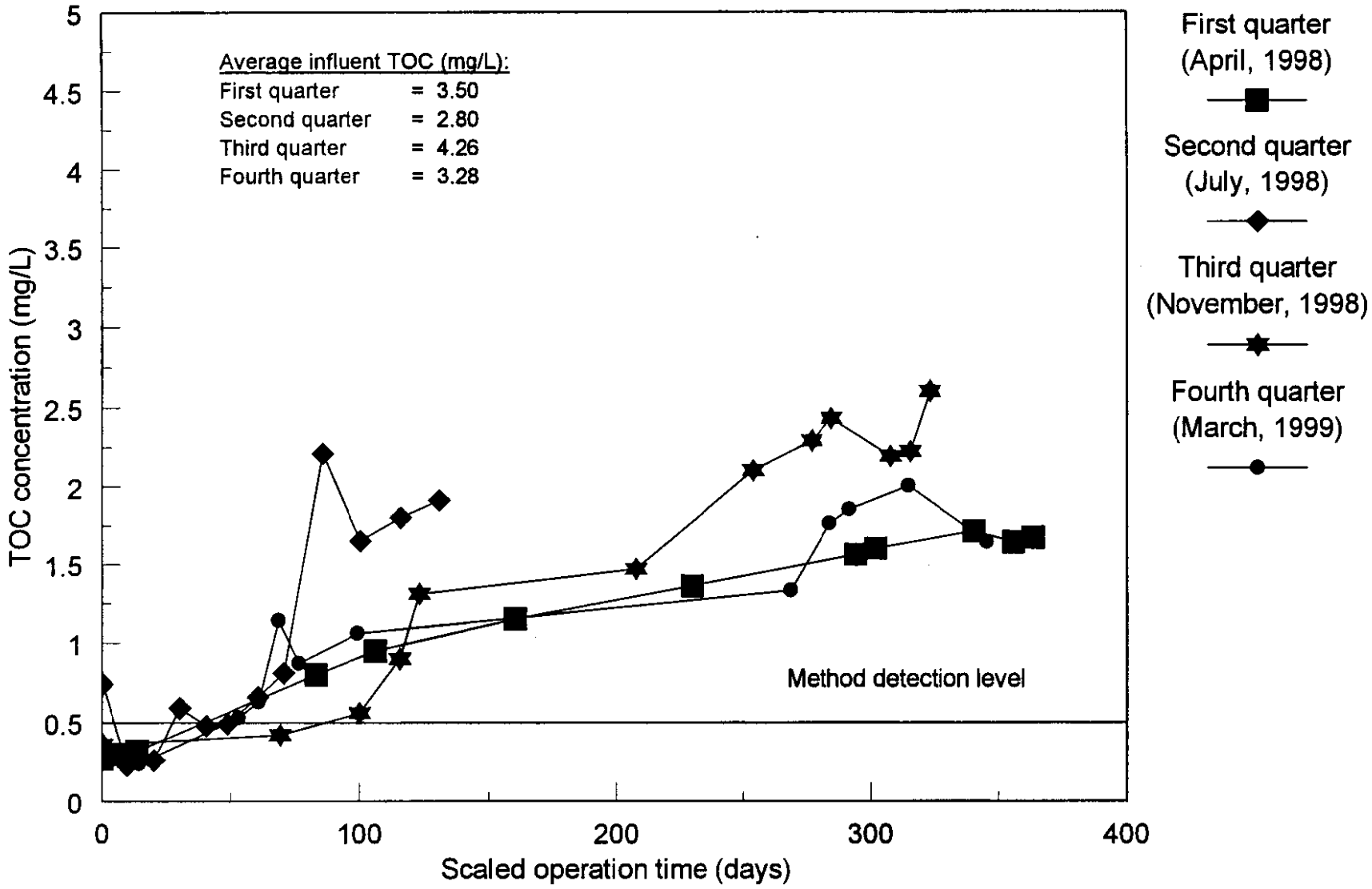

Figure 22 Ft. Wayne RSSCT testing: TOC data (20-min EBCT)

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. None of the RSSCT tests, however, 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 10^{th} 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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Table A.1

ICR RSSCT process projections

	Utility Name:	Ft. Wayne, Indiana	
	Quarter number:	1	
	Test date (start):	04/16/98	
	Test date (end):	06/04/98	
Parameter	Variables	10-min EBCT	20-min EBCT
Diameter (large column GAC media)	d lc	1.1	1.1
Diameter (small column GAC media)	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)	3.5	3.5
Bed volumes to 50% breakthrough	BV 50	4,258	4,258
Time to 50% breakthrough	t 50 (days)	29.6	59.1
	t int (days	4.2	8.4
Full-scale breakthrough	t lc (days)	59.1	11.83
Bench-scale breakthrough	t sc (days)	7.7	15.4
Volume of water	V sc (L)	52.61	105.27
Excess volume	Total GAC volume (L)	68.4	136.85

Table A.2

ICR RSSCT process projections

	Utility Name:	Ft. Wayne, Indiana	
	Quarter number:	2	
	Test date (start):	07/20/98	
	Test date (end):	08/06/98	
Parameter	Variables	10-min EBCT	20-min EBCT
Diameter (large column GAC media)	d lc	1.1	1.1
Diameter (small column GAC media)	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)	2.8	2.8
Bed volumes to 50% breakthrough	BV 50	5,691	5,691
Time to 50% breakthrough	t 50 (days)	39.5	79.0
	t int (days	5.6	11.3
Full-scale breakthrough	t lc (days)	79.0	158.10
Bench-scale breakthrough	t sc (days)	10.3	20.5
Volume of water	V sc (L)	70.32	140.70
Excess volume	Total GAC volume (L)	91.42	182.91

Table A.3

ICR RSSCT process projections

Utility Name:	Ft. Wayne, Indiana		
Quarter number:	3		
Test date (start):	11/04/98		
Test date (end):	12/16/98		
Parameter	Variables	10-min EBCT	20-min EBCT
Diameter (large column GAC media)	d lc	1.1	1.1
Diameter (small column GAC media)	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)	4.26	4.26
Bed volumes to 50% breakthrough	BV 50	3,298	3,298
Time to 50% breakthrough	t 50 (days)	22.9	45.8
	t int (days	3.3	6.5
Full-scale breakthrough	t lc (days)	45.8	91.6
Bench-scale breakthrough	t sc (days)	6.0	11.9
Volume of water	V sc (L)	40.75	81.54
Excess volume	Total GAC volume (L)	52.98	106

Table A.4

ICR RSSCT process projections

	Utility Name:	Ft. Wayne, Indiana	
	Quarter number:	4	
	Test date (start):	03/15/99	
	Test date (end):	04/30/99	
Parameter	Variables	10-min EBCT	20-min EBCT
Diameter (large column GAC media)	d lc	1.1	1.1
Diameter (small column GAC media)	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)	3.28	3.28
Bed volumes to 50% breakthrough	BV 50	4,633	4,633
Time to 50% breakthrough	t 50 (days)	32.2	64.3
	t int (days	4.6	9.2
Full-scale breakthrough	t lc (days)	64.3	128.7
Bench-scale breakthrough	t sc (days)	8.4	16.7
Volume of water	V sc (L)	57.25	114.54
Excess volume	Total GAC volume (L)	74.42	148.90