ICR Treatment Study Summary Report

Pilot-Scale Evaluation of Granular Activated Carbon Contactors for Compliance with the Information Collection Rule

Conducted from 4/28/98 to 1/26/99

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Wade G. Brown Water Treatment Plant
ICR #450

Attachment: 1 Compact Disk containing the Data Collection Spreadsheets

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1.0 Introduction

The Information Collection Rule (ICR) for Public Water Systems (Subpart M or the National Primary Drinking Water Regulations, 141.141(e)) requires public water systems that meet certain applicability criteria to conduct disinfection byproduct (DBP) precursor removal studies. Those utilities that were subject to the ICR study requirements could select to conduct either a granular activated carbon (GAC) study or membrane filtration study. Depending on the population served by the utility, the type of study may be either bench-scale or pilot scale. In order to meet ICR requirements, the City of Durham conducted a pilot-scale GAC precursor removal study from May 1998 to January 1999.

The City of Durham currently operates two conventional water treatment plants (WTPs) which provide the City with a production capacity of 52 MGD. Two reservoirs with very similar water quality, the Little River Reservoir and Lake Michie, provide sources of drinking water for the City. With the two plants, the City of Durham supplies an estimated 152,000 people with potable water. The Williams Water Treatment Plant, built in 1926 on Hillandale Road, has undergone several upgrades and is rated at 22 MGD capacity. The Brown Treatment Plant, located on Infinity Road, has a production capacity of 30 MGD. The plant was originally constructed in 1977 and expanded in 1991.

1.1 Purpose and Scope

This report presents the City of Durham ICR study and summarizes the results. The main objectives of this report are to:

- Introduce the Brown Water Treatment Plant and raw water quality;
- Describe the pilot plant used in the City of Durham GAC study;
- Discuss the analytical methods used in the GAC study;
- Examine the removal of organic matter by the GAC pilot study columns; and
- Examine the effectiveness of GAC to reduce DBPs.

- Fulfill the requirements of the Information Collection Rule

2.0 Background

The City of Durham is located in the Piedmont area of North Carolina, approximately three hours south of Richmond, Virginia. The City operates two conventional water treatment plants that serve over 152,000 people. The City chose to conduct the required ICR study at the Brown Water Treatment Plant, the newer of the two facilities. The City owns two surface-water reservoirs with similar water quality, and the Brown Plant can use either reservoir. During the ICR study, the Brown WTP was supplied exclusively from the Little River Reservoir.

2.1 Raw Water Quality

The Little River Reservoir became operational in 1988 to supplement the Lake Michie Reservoir as a source of potable water for the City of Durham. The reservoir has a watershed area of approximately 97 square miles and can hold approximately 4.9 billion gallons. The Reservoir undergoes stratification and experiences lake turnover in the fall. The safe yield of Little River is estimated at 20.6 MGD. The Little River Reservoir is typical of central North Carolina surface waters used as sources of potable water.

A list of Little River Reservoir water quality parameters is shown in Table 2-1. Data shown was collected during calendar year 1998.

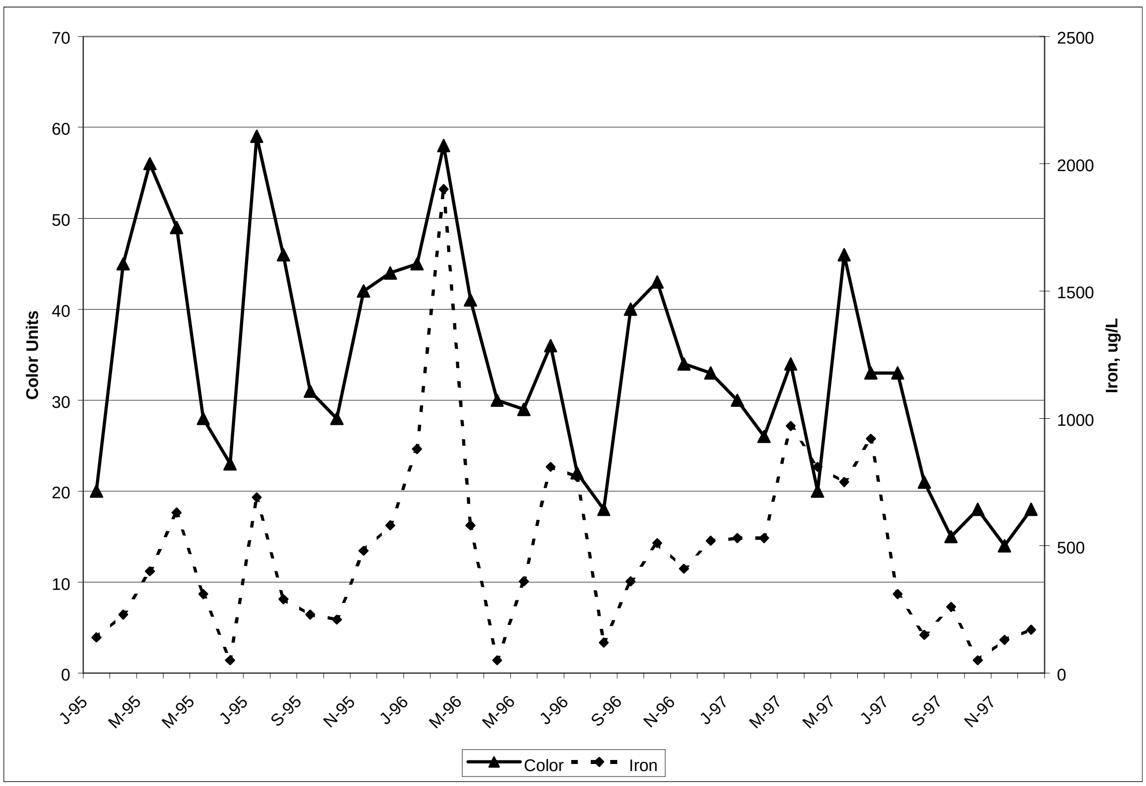
Table 2-1 Little River Reservoir Water Quality, 1998

PARAMETER	AVERAGE	MIN	MAX	COUNT
pH	6.8	6.4	7.1	364
Temperature (°C)	19	8	29	364
Turbidity (NTU)	12	2	61	364
Total Hardness (mg/L)	22	12	30	72
Color (SCU)	32	10	110	52
Alkalinity (mg/L)	18	7	24	242
Bromide (ug/L)	30	<20	50	12
TOC (mg/L)	5.26	4.15	6.80	12
UV-254 (1/cm)	0.195	0.10	0.345	12
SUVA (L/(mg*m))	3.56	2.41	5.07	12

In general, Little River Reservoir is characterized by a neutral pH, low alkalinity, and moderate color. Total organic carbon content is in the range of 4 to 7 mg/L, with typical UV-254 values of 0.10 to 0.35 cm^{-1}. At times there are significant levels of iron and manganese in the reservoir, resulting in plant operational strategies designed to remove the dissolved metals. Most of the watershed around the reservoir is undeveloped, which helps to preserve the quality of the reservoir.

As with most surface water sources, water quality in the Little River Reservoir varies with season. Lake turnover, seasonal ground cover, and precipitation can influence water quality. Turbidity, solids and organic content peaks during January, presumably due to increased seasonal precipitation and increased runoff due to lack of seasonal vegetation. During the late summer, manganese and algae levels peak along with water demand, presenting a different treatment challenge. Color levels do not exhibit a clear seasonal trend, however, as shown in Figure 2-1, color does appear to peak with iron content. The coincident peaks of iron and color suggest that a significant portion of color may come from iron as well as natural organic matter.

Figure 2-1 Average Color and Iron Levels, Little River Reservoir, 1995-1997



2.2 Process Train

The Brown Water Treatment Plant is a conventional flocculation/sedimentation/filtration plant. Design information is shown on the next page, in Table 2-2. Originally built in 1977 with a capacity of 12 MGD, the plant was upgraded to 30 MGD in 1991. The upgrade consisted of new rapid mix, flocculation and sedimentation basins, and three additional 6-MGD filters (based on 4 gpm/sf).

Table 2-2 Brown WTP Design Data

Rating **Facility**	30 MGD **Brown Plant**	
Terminal Reservoir **(Volume)**	90 MG	
Rapid Mix		
Number of Trains	2	
Basins/Train	2	
Volume (total) (gal)	18,800	
Mixing Mechanism	Vertical shaft impeller-type variable speed	
Flocculation		
Number of Trains	3	
Stages	6	
Volume (total) (gal)	756,000	
Design Detention Time (min)	60	
Baffling	None-Inlet/outlet only	
Mixing Mechanism	Vertical shaft impeller-type variable speed	
Sedimentation Basins		
Number	3	
Volume (total) (gal)	3,070,000	
Surface Area (total) (sf)	34,200	
Design Detention Time (hr)	4	
Design Overflow Rate (gpm/sf)	0.37	
Horizontal Velocity (ft/min)	1.24	
Sludge Removal	Continuous	
Filters	**New Filters (1991)**	**Original Filters (1977)**
Number	3	4
Surface Area (sf)	3,150	2,016
Rate (gpm/sf)	4	4
Backwash Method	Air scour followed by water wash	Water backwash with surface wash
<u>Media Depth</u>		
Anthracite (in)	36	20
Sand (in)	12	27
Gravel (in)	12[a]	12
Finished Water Storage		
Type	Unbaffled, Covered Above-ground Tank	
Number	2	
Total Volume (MG)	10	
Detention Time at 30 MGD (hours)	8	
T_{10}/T	0.46	
C*T (Based on 2 mg/L Cl_2)	220 mg/L-min[b]	

[a]In two of the three filters a 1-inch IMS layer is substituted for gravel.
[b]At the design production rate of 30 MGD, with clearwells half-full

The upgrade resulted in a total plant rating of 30 MGD, based on a 4 gpm/sf filtration rate. A schematic of the plant is shown on the next page in Figure 2-2.

The City of Durham uses a typical alum dose of 35 mg/L as a primary coagulant at the Brown Plant. The alum dose is optimized through zeta-potential zeroing. Lime or caustic (NaOH) may be added pre-rapid mix if needed to provide alkalinity and meet the desired coagulation pH of 6.2. After flocculation and sedimentation, chlorine is added pre-filter to control iron and manganese, and polymer is added as a filter aid. After filtration, lime is added to adjust pH and fluoride and phosphate are also added. At the time of the ICR study, the Plant was adding enough prefilter chlorine (5 mg/L) to result in a 2 mg/L residual at the entrance of the distribution system. Therefore, additional chlorine was not added prior to or after the clearwells.

The City of Durham elected to test GAC contactors as opposed to membranes for the ICR study. Installing GAC contactors after the filters appeared to be the more feasible than membranes if the City needed advanced technology to meet impending regulations.

As shown in the Plant schematic, a sidestream was piped to the GAC pilot plant from the settled water channel prior to chemical addition. During the ICR test period, plant production generally ranged from 10 to 25 MGD, with an average flow of 15 MGD. Because chemicals were added pre-filter in the full-scale plant, a pilot filter was built prior to the GAC columns. The pilot filter and the GAC pilot unit are described in Section 3.

2.3 Finished Water Quality

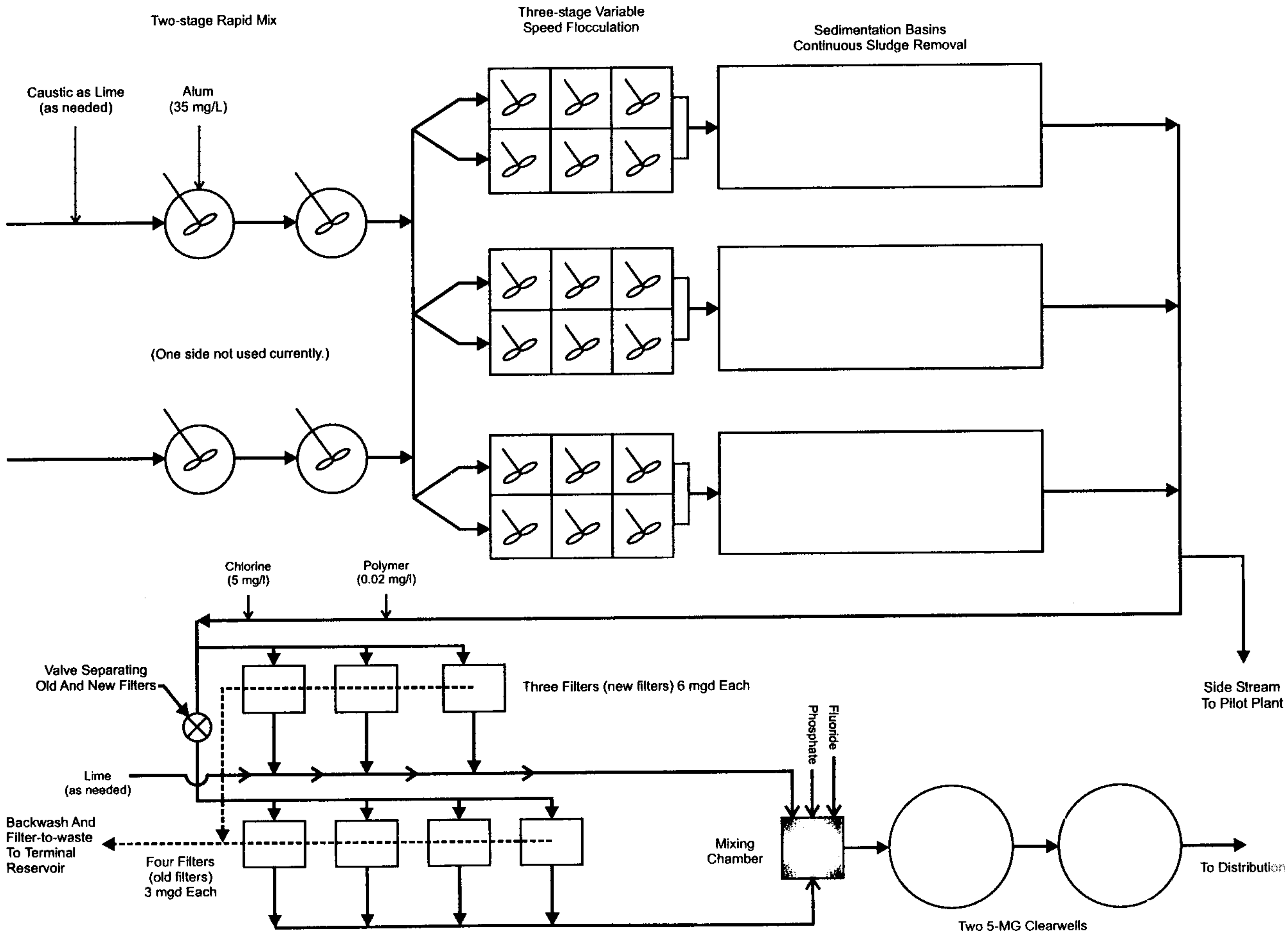
The Brown Plant has been producing high-quality water since its construction in 1977. A summary of 1998 finished water quality is shown in Table 2-3.

Table 2-3 Brown WTP Finished Water Quality

	AVERAGE	MIN	MAX	COUNT
pH	7.1	6.8	7.7	364
Temperature (°C)	19	8	29	364
Turbidity (NTU)	0.09	0.05	0.15	365
TOC (mg/L)	2.44	2.20	3.05	12
TOC (% Removal)	52%	34%	66%	12
UV-254 (1/cm)	0.028	0.018	0.035	12
SUVA (L/(mg*m))	1.15	0.65	1.43	12
Dist. System THM-4 (ug/L)	82.8	57.0	98.6	4
Dist. System HAA-6 (ug/L)	55.5	44.5	69.2	4

Brown Water Treatment Plant

Figure 2-2



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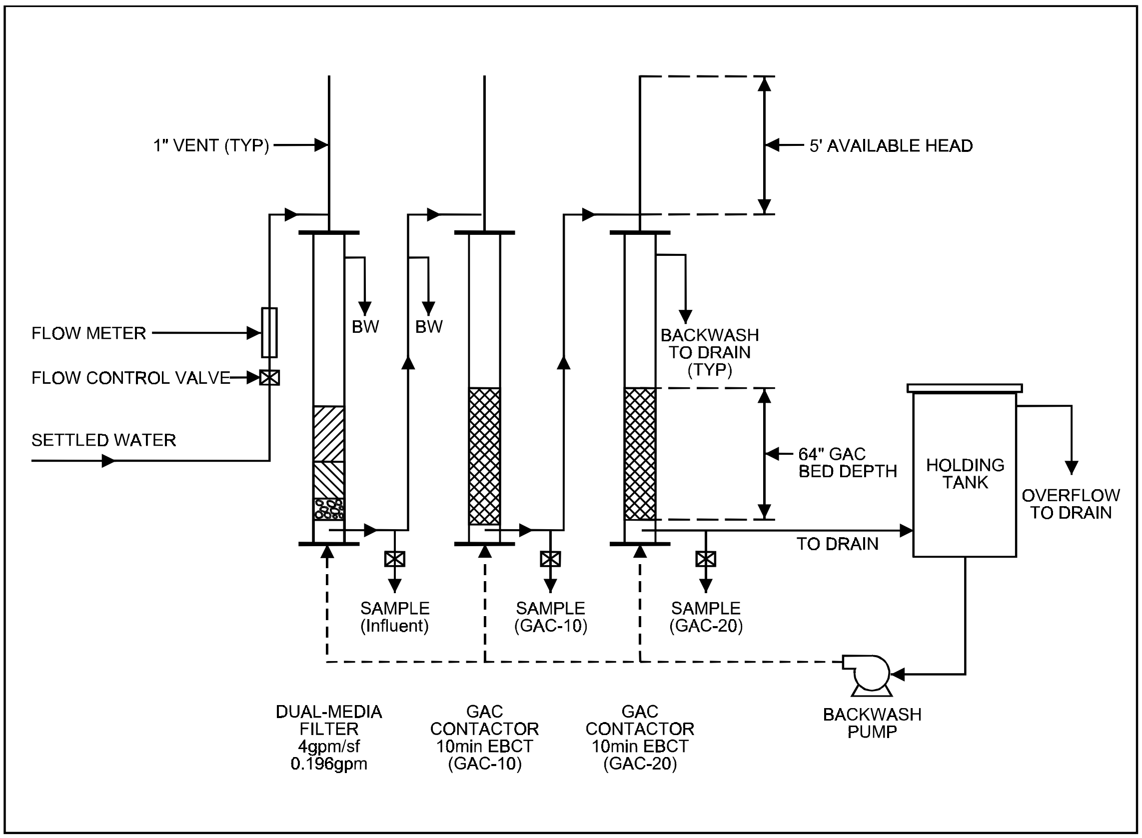
3.0 Materials and Methods

The pilot plant used in the City of Durham was constructed according to the guidelines in the EPA publication entitled ICR Manual for Bench- and Pilot-Scale Treatment Studies (EPA 814-B-96-003, April 1996). The design and the materials of construction were approved before the study was begun.

3.1 Pilot Plant Unit

A schematic of the pilot plant is shown below in Figure 3-1.

Figure 3-1 Schematic of Durham GAC Pilot Plant



Pilot filter and GAC columns were constructed of clear PVC, and tested for contaminant leaching as described in the ICR Guidance manual. As shown in Figure 3-1, a sample tap was located after the pilot filter, and will be referred to as the “influent” for the remainder of this report. Samples collected from taps located after the first and second contactor will be referred to as “GAC-10” and “GAC-20”, respectively, corresponding to the amount of GAC empty bed contact time.

The pilot filter was layered with 12 inches of anthracite and 24 inches of sand, to simulate the new filters at the Brown Plant. The pilot filter was operated at a loading rate of 4 gpm/sf, similar to the full-scale plant.

The pilot columns were filled with 3453 grams of coal-based Calgon Filtrasorb 100 carbon, with U.S. standard mesh size of 12x40. A bed depth of 64 inches in each column was used, corresponding to an EBCT of 10 minutes each.

3.2 Pilot Unit Operation

The pilot unit was operated in accordance with the ICR guidance manual. Effluent from the GAC-20 column was used as backwash water, because plant filtered/finished water was chlorinated. The pilot filter was backwashed every 24 hours, similar to the full-scale plant filters. The GAC columns were backwashed approximately once a month and after any unit shut-down. Head loss across the columns was checked regularly, and flow rate was checked once per day.

Samples were collected from sample points in accordance with the sampling schedule for a TOC of 3.0 mg/L as shown in Table 4-2 of the ICR guidance manual. After the length of the run exceeded the schedule, samples were collected on a 7 to 10 day schedule.

3.3 Sample Analysis

At the scheduled intervals, the City of Durham personnel collected two sample bottles of the column influent and effluent. Columns were not backwashed for the day until samples were collected. Both containers were put on ice, and one was transported to the City of Durham laboratory, while the other was sent to Environmental Engineering and Technology (EET). Table 3-1 shows the analyses for which each laboratory was responsible. A detailed list of laboratory QA/QC data can be found in the back of this report in Appendix I.

Table 3-1 Laboratories Responsible for ICR Analyses

LABORATORY	ANALYSES
Williams WTP Laboratory City of Durham, NC	Alkalinity, Ammonia, Calcium hardness, pH, Temperature, Total Hardness, Turbidity, UV-254
Environmental Engineering and Technology (EET) Newport News, VA	Bromide, HAA-6, THM4, TOC, THM, SDS Setup, including chlorine analyses

The SDS test was conducted at a pH of 7, temperature of 22 °C, and incubated for 24 hours. Initial influent samples were dosed with 2.5 mg/L chlorine, and contained a 0.2 to 1.0 mg/L free chlorine residual at the end of incubation. Halfway through the study, the dose was increased to 4.5 mg/L chlorine, which was closer to the actual plant dose. Residuals after the increase of chlorine generally ranged between 1 and 2 mg/L free chlorine. The GAC column samples were usually dosed with 2.5 mg/L chlorine throughout the study, and generally had a free chlorine residual of 0.5-1.0 mg/L free chlorine at the end of 24 hours. After incubation, the SDS samples were “quenched” with preservative and analyzed for trihalomethane (THM) and haloacetic acid (HAA-6) content. Each laboratory was pre-certified to conduct their respective analyses.

4.0 Results and Discussion

The GAC pilot test was conducted from April 5, 1998 to January 28, 1999. A total of 33 samples were collected from each sample point at regular intervals during the test. On three occasions, duplicate samples were collected from the sample points, in accordance with ICR guidelines. The pilot test was stopped when the GAC-20 column had a >70% TOC breakthrough on two successive sampling occasions. The pilot test did not break through until after 6500 hours of operation, so only one run was required, as stated in the ICR guidance manual. Results of the pilot test are discussed in this section.

4.1 Pilot Plant Operation-Problems Encountered

The pilot unit was operated for 6536 hours with very few operational problems. The pilot filter was backwashed on a regular schedule, and headloss was not a problem across the pilot filter or the GAC columns. On one occasion during cold weather (12/14/99), the line from the settled water channel to the pilot unit froze, and unit operation was halted for the day until the hose was thawed and the cold weather was over. The unit was also shut down from 12/8/98 to 12/11/98 during annual maintenance of the sedimentation basins, during which the Plant cleaned the west settled water channel. The unit was put back into operation after 3 days, when maintenance of the channels was complete. Other than these two instances, the GAC pilot unit operated continuously.

In addition to the shut-downs detailed above, there was a slight problem with the flow meter on the unit. On 8/15, plant personnel noted that although the flow meter indicated a flow of 750 ml/minute, a volume/time measurement revealed that flow through the unit was only 250 ml/minute. There was a miscommunication between operators, and the unit flow was adjusted with the erroneous flowmeter until 9/1/98.

An examination of the flowmeter on 9/1/98 revealed that floc from the settled water had partially obstructed the orifice of the flowmeter. The flowmeter was jetted with clean water and put back into service. The meter became obstructed with floc soon after, and was cleaned with muriatic acid. To eliminate further erroneous flow monitoring, the operators monitored unit flow by the volume/time method for the remainder of the study.

After the problem was addressed on 9/1/98, flow was checked manually several times daily and adjusted as appropriate, so it is reasonable to assume that after that date, unit flows were close to the 750 ml/minute design flow. A 750 ml/minute flowrate for the length of this study (272 days) would yield a unit throughput of 77,700 gallons. If it is assumed that unit flow was at 250 ml/minute for the 16 days between 8/15 and 9/1, the total recorded throughput should be reduced by 3050 gallons, or 4 percent.

4.2 Sample Analysis-Problems Encountered

Sample analyses were split between the City of Durham laboratory and EET. During early September, 1998, recorded TOC levels rose significantly for all sample points.

Before September, column influent TOC content was on the order of 3 mg/L, and each column effluent had a TOC below 1 mg/L. During the time in question, influent TOC was measured around 8 mg/L, with column effluent TOC levels measured at 6 mg/L. In order to determine whether the numbers were erroneous, samples from each point were collected, split, and sent to different laboratories for analysis. The split sampling did reveal TOC discrepancies between different laboratories. To attempt to correct the problem, the EET laboratory made new TOC standards and recalibrated their instrument. The City of Durham operators properly cleaned sample bottles and reviewed proper collection techniques. At the end of September, TOC values returned to expected levels, and appeared consistent throughout the remainder of the pilot test. Several of the September TOC samples were not reported (recorded as NR), due to the sample analysis problems.

4.3 GAC column influent water quality

After filtration through the pilot filter, a sample was collected and analyzed for water quality parameters as directed by the ICR Manual. The influent water quality was relatively stable throughout the pilot-test period, with most parameters varying within a small range. Temperature varied with season and was significantly lower towards the end of the pilot run. Column influent TOC did not appear to significantly vary with season, however, influent UV-254 appeared to trend downward throughout the pilot test. Such a trend could be from better full-scale coagulation performance or due to a seasonal change in the nature of influent TOC. The average influent (settled) water turbidity before 11/3/98 was 0.16 NTU, while turbidity between 11/3 and 1/14/99 averaged 0.09 NTU, suggesting the full-scale plant was coagulating/clarifying more efficiently in the latter period. A slightly lower influent TOC during the latter period also supported the premise that pretreatment was improved. However, during the last three sampling events (1/99 samples), influent turbidities were 1.9, 8.8 and 2.5 NTU. Other influent water quality parameters, such as TOC, UV-254 and SDS-DBPs were also higher during that period. There was no significant rainfall on the sampling days, and plant records did not indicate any sort of treatment upset, so it was unknown why influent turbidities were elevated.

Column influent water quality is summarized in Table 4-1, on the next page.

Table 4-1 Influent Water Quality for the Pilot-scale GAC Columns

	AVERAGE	SD	COUNT

pH	6.06	0.20	30
Turbidity (NTU)	0.56	1.64	30
Alkalinity (mg/L, $CaCO_3$)	8.23	2.30	30
Temp. (deg. C.)	20.3	5.25	30
T-Hardness (mg/L, $CaCO_3$)	23.0	4.04	30
Ca-hardness (mg/L, $CaCO_3$)	14.3	6.53	17
Ammonia (mg NH_3-N/L)	BMRL	n/a	7
Bromide (ug/L)	13.9	16	27
TOC (mg/L)	2.65	0.49	31
UV254 (cm^{-1})	0.04	0.02	29
SUVA (L/(mg*m)	1.67	0.59	27
SDS-TOX (mg Cl-/L)	172	33	25
SDS-THM4 (mg/L)	29.3	5.15	25
SDS-HAA5 (mg/L)	50.2	23	25
SDS-HAA6 (mg/L)	51.9	23	25
Cl Demand (24 hr, mg/L)	2.29	0.79	25

One parameter that appeared questionable was the level of influent SDS-DBPs. In Table 4-2, a comparison of full-scale DBP results with pilot-generated SDS DBP content is shown. The numbers in Table 4-2 suggested that the influent to the GAC columns is less susceptible to DBP formation than full-scale finished water. Full-scale finished water in the distribution system experiences more chlorine contact time than 24 hours, however, separate experiments performed at the Brown Plant revealed that the majority of DBP formation took place within 24 hours.

Table 4-2 Distribution System and Pilot Unit SDS-DBP Levels

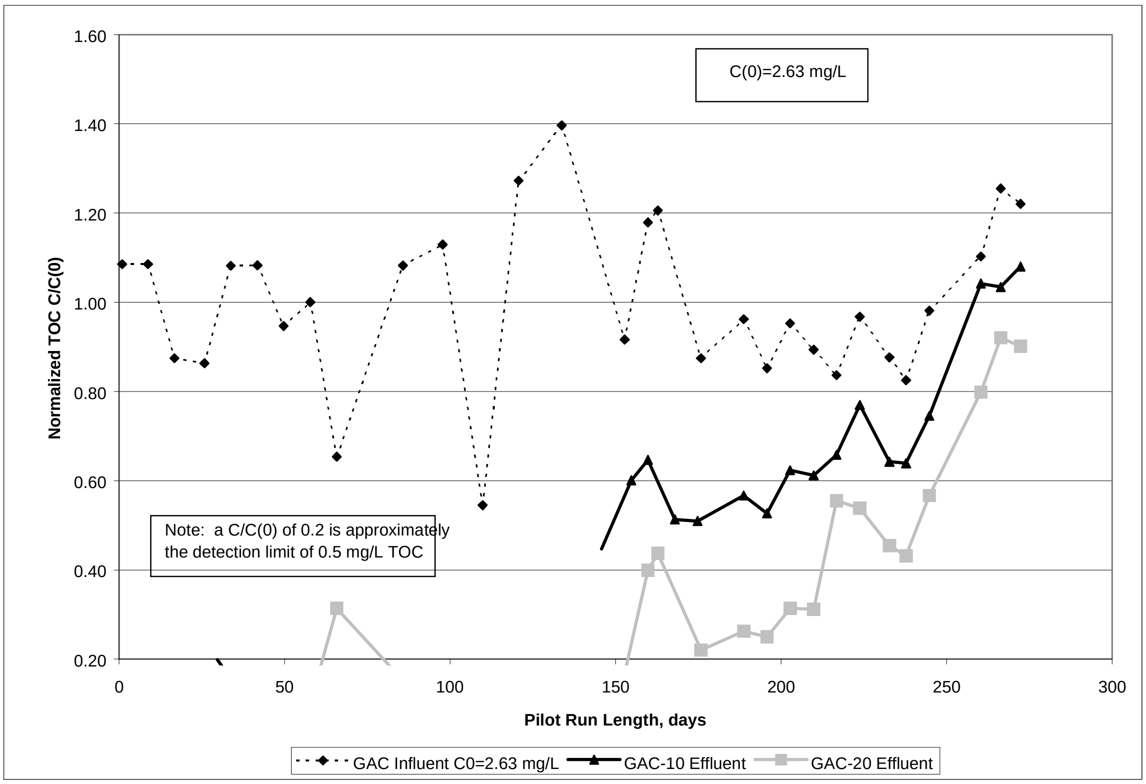
QUARTER 1998	DIST. SYS. THM-4 (DATE / UG/L)	PILOT INFL. THM-4 (DATE / UG/L)	DIST. SYS. HAA-6 (DATE / UG/L)	PILOT INFL. HAA-6 (DATE / UG/L)
Second	4/15/98 / 84.9	**4/29/98 / 28.6**	4/15/98 / 69.2	**4/29/98 / 13.4**
Third	9/17/98 / 98.6	**9/21/98 / 28.8**	9/17/98 / 44.5	**4/29/98 / 62.1**
Fourth	12/8/98 / 90.8	**12/8/98 / 29.8**	12/8/98 / 46.1	**12/8/98 / 44.2**

The factor most likely causing the discrepancy in DBPs was thought to be the pre-filter chlorination step practiced in the full-scale plant. The Brown Plant generally adds 4-5 mg/L chlorine on top of the filters. Possibly the pre-filter chlorine was oxidizing some of the organic matter trapped within the filter bed. Another possibility was that indigent microorganisms had colonized the unchlorinated pilot filter (i.e, biologically active anthracite), and were biologically removing DBP precursor material. The City is continuing to assess the effect of biologically active anthracite on DBP formation.

4.4 GAC Contactor Performance

Total organic carbon was a primary indicator of GAC contactor performance. Organics breakthrough was quantified by dividing the TOC content of the GAC contactor effluent by the running average influent TOC. A GAC contactor was assumed to be spent after TOC breakthrough was measured at 70% for two consecutive weeks. Figure 4-1 shows normalized TOC breakthrough curves of each GAC column over time.

Figure 4-1 GAC Contactor Pilot-Test: TOC Breakthrough

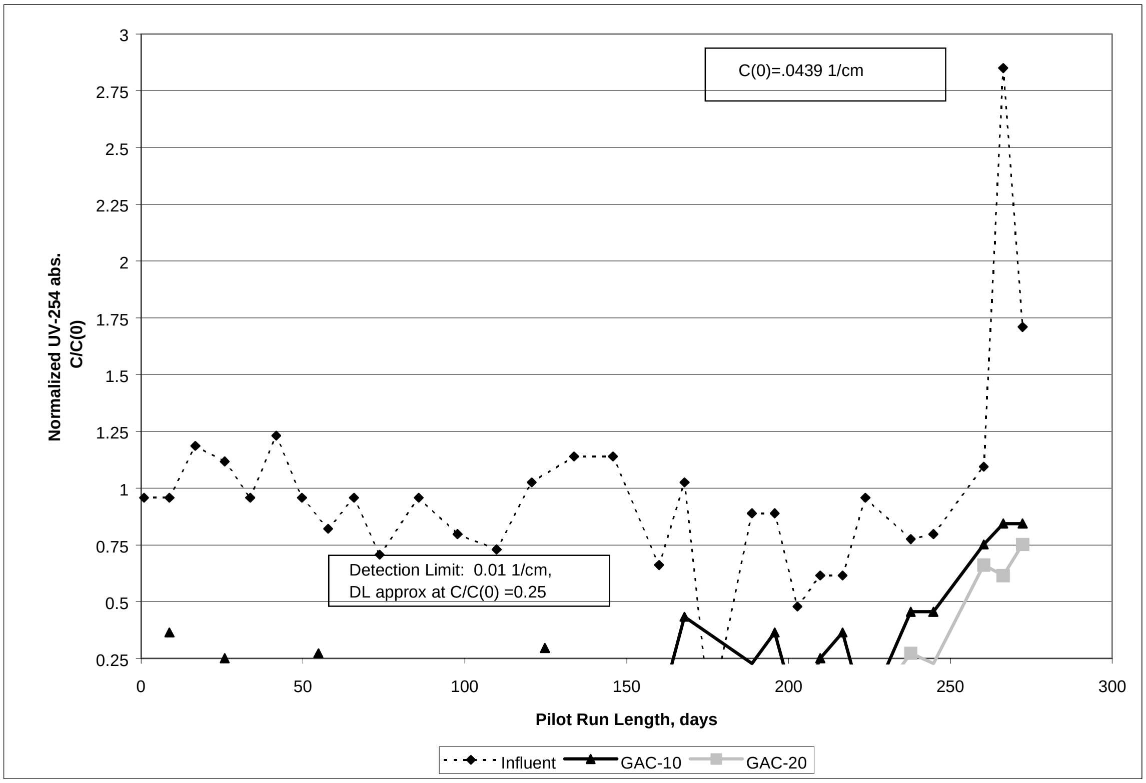


As shown in Figure 4-1, the carbon content of the contactor influent generally stayed within +/- 20% of the running average value, 2.63 mg/L. Neither column showed signs of significant TOC breakthrough until after the 154th day of operation (9/30/98). TOC breakthrough rose rapidly in GAC-10 and GAC-20 after 200 days of operation. The 10-minute GAC column first reached 70% breakthrough on Day 224 after 32220 (10-minute) bed volumes. The 20-minute GAC column reached a steady 70% breakthrough on Day 260 after 37488 (10-minute) bed volumes. The sharp breakthrough curve suggests that the naturally organic carbon in the Brown settled water is highly adsorbable.

A plot of UV-254 absorbance breakthrough is shown in Figure 4-2. The UV-254 levels in Figure 4-2 have been normalized, and a C/C(0) value of 0.25 corresponds to the method detection limit in this study. As apparent from the chart, significant UV breakthrough occurred after 150 days in the GAC-10 column, and after approximately 230 days in the GAC-20 column. The breakthrough observed in the GAC-10 column was similar to the

TOC breakthrough shown previously in Figure 4-1. As mentioned previously, influent UV-254 was slightly lower towards the end of the study.

Figure 4-2 GAC Contactor Pilot Test: UV-254 Breakthrough



Breakthrough charts are shown for THMs and HAAs in Figure 4-3 and 4-4, respectively. As discussed in Section 4.3, the DBPs in the influent SDS sample were lower than anticipated. At the start of the run, both columns produced very small to nondetectable amounts of THMs. The GAC-10 effluent began to produce 10 ug/L of each DBP starting on 10/13/98, shortly after significant rises in TOC and UV-254 were observed. At no time did either column effluent contain THM levels that exceeded the proposed Stage 2 MCL (40 ug/L). Each column produced HAA-5 levels that were less than the proposed Stage 2 MCL (30 ug/L) with the exception of one instance towards the end of the study.

The DBP data presented in this study should be analyzed with care. The full-scale plant currently uses prechlorination to control manganese, a process not reflected in this study. The results of this study would be more applicable to a full-scale application in which pre-filter chlorination was not used as a means of manganese control.

Figure 4-3 GAC Contactor Pilot Test: Effluent SDS-THM Levels

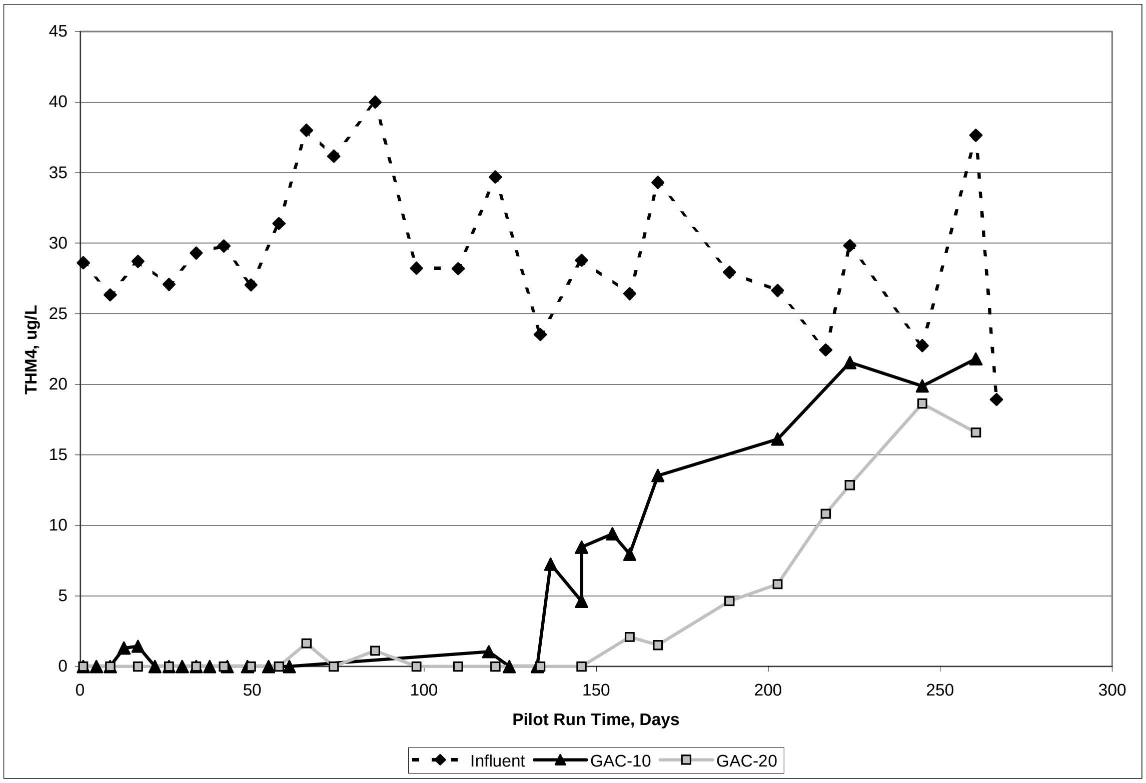
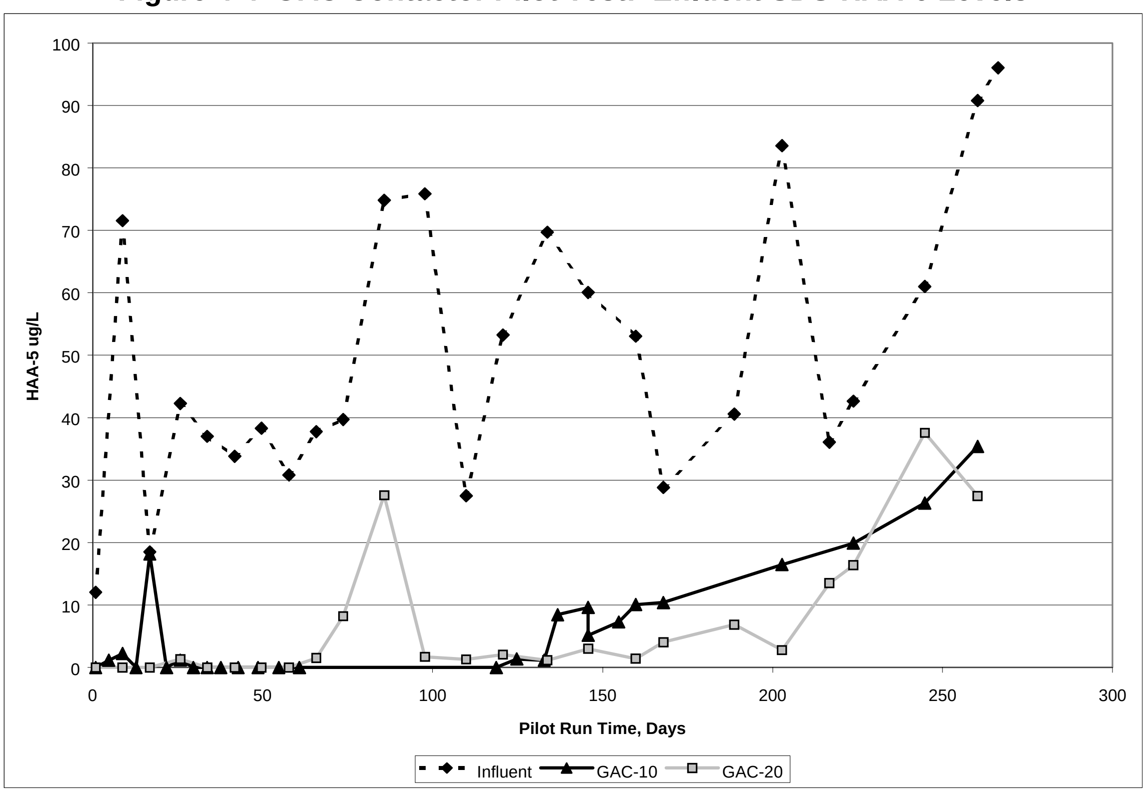


Figure 4-4 GAC Contactor Pilot Test: Effluent SDS-HAA-6 Levels



4.5 *Summary of Results*

In the GAC pilot test, significant TOC and UV-254 breakthrough occurred after approximately 22,300 bed volumes of a 10 minute EBCT GAC contactor. Once breakthrough was apparent, effluent TOC levels rose rapidly and 70% of influent TOC occurred after 32,200 bed volumes. Disinfection byproduct levels, as generated by a SDS test, rose concurrently with TOC breakthrough. Representative levels of organics and DBP breakthrough in each column effluent are shown in Table 4-3.

Table 4-3 Selected Results of GAC Pilot Study

Ten-minute Contactor (GAC-10)

RUN TIME (DAYS)	10-MIN BED VOLUMES	TOC (MG/L)	UV-254 (1/CM)	SDS-THM-4 (UG/L)	SDS-HAA-5 (UG/L)
49	7005	0.31	BMRL	BMRL	BMRL
125	17961	0.49	0.013	BMRL	1.4
155	22281	1.58	BMRL	9.41	7.13
203	29193	1.64	BMRL	16.1	16.5
245 (end)	35245	1.96	0.020	19.9	26.3

*BMRL = Below Minimum Reporting Levels

Twenty-minute Contactor (GAC-20)

RUN TIME (DAYS)	20-MIN BED VOLUMES	TOC (MG/L)	UV-254 (1/CM)	SDS-THM-4 (UG/L)	SDS-HAA-5 (UG/L)
50	3575	0.36	BMRL	BMRL	BMRL
125	8691	0.28	BMRL	BMRL	2.1
146	10492	0.28	BMRL	BMRL	3.0
217	15602	1.46	BMRL	10.8	13.5
272 (end)	19608	2.37	0.033	16.7	25.5

*BMRL = Below Minimum Reporting Levels

The results of this study suggest that even after 35,000 10-minute bed volumes, proposed Stage 2 Limits can be achievable with GAC contactors after filtration. The sharp TOC breakthrough curve suggests that the carbon present in Durham settled water is highly adsorbable. However, the GAC pilot study does not include provisions for iron and manganese removal. In order to realistically consider GAC contactors for DBP control at the Brown Plant, alternate manganese removal methods need to be evaluated. Durham has undertaken an extended pilot program to assess the best options for control of DBPs and has included manganese control in the overall program.

APPENDIX