

# ICR Treatment Study Summary Report

## Evaluation of GAC Using RSSCT Bench-Scale Studies for Compliance with the Information Collection Rule

Conducted during the period of May, 1998 through February, 1999

Prepared by:  
University of Nebraska  
Dept. of Civil Engineering  
Lincoln, NE 68588-0531

In July 1999

For: City of Lincoln Water System  
PWSID # NE3110926  
2021 N.27th Street  
Lincoln, NE 68503  
(402)441-7571  
(402) 441- 8493 (Fax)

Plant Names: LWS Ashland WTP-Aeration  
Plant ICR#: ICR761

LWS Ashland WTP-Ozone  
Plant ICR#: ICR455

Attachments: 4 diskettes containing the Data Collection Spreadsheets, Summary Spreadsheet,  
and the text of this report.



University of  
Nebraska  
Lincoln

Department of  
Civil Engineering  
W348 Nebraska Hall  
P.O. Box 880531  
Lincoln, NE 68588-0531

July 9, 1999

US EPA-OGWDW  
Technical Support Center, MS 140  
Steve Allgeier  
ICR Treatment Studies Coordinator  
26 West Martin Luther King Drive  
Cincinnati, Ohio 45268

Dear Steve,

Enclosed is a copy of the ICR Treatment Study Report for the Lincoln Water System's (LWS) plants (ICR#761 and #455). Enclosed are a text and disk copies of the report, summary spreadsheets and data collection spreadsheets.

Since I was unable to include comments in the Study Summary spreadsheet, I have included those comments below.

- The distribution system DBP data provided is from the quarterly samples of one site (ICR 17). This site represents an "average" residence time and DBP values.
- The population and water flow data provided are for the combination of LWS's two treatment plants. The two plants are physically within 100 yards of each other. Both plants receive their source water from the same well field, although some of the wells within the field are used only by one of the two plants. Since LWS varies the flow through each plant depending on a wide range of variables (demand, renovation and cleaning needs, etc.), they have a difficult time estimating a split of the population served by each plant and the flow from each plant.
- The calcium hardness data was not collected in the LWS's 18-month DBP/micro monitoring study and has not been included in the spreadsheet. I am sure that the LWS has this data from their regular operations and can obtain it if needed.
- Fortified matrix samples were not performed by the University of Nebraska (UNL) laboratory on UV<sub>254</sub> and TOC due to a misunderstanding of the procedures on UNL's part. We sincerely regret this omission.

Please feel free to contact me concerning any questions or requests for additional information. I would be happy to modify the format of any of the disk submissions.

Yours very truly,

Bruce Dvorak  
Assistant Professor

## **I. Conclusions and Recommendations**

1. The THM and HAA precursors in Lincoln's influent source water are sufficiently low that the Stage II MCL will not be an issue. The City of Lincoln will not need to treat its water to remove organic disinfection by-product (DBP) precursors.
2. In all cases, the DBP precursors passed through the Granular Activated Carbon (GAC) columns before the trace concentrations of herbicides. A GAC column designed to remove DBP precursors will also remove all herbicides.
3. The 10-minute Empty Bed Contact Time (EBCT) columns treated more bed volumes than the 20-minute EBCT columns in most cases. In other words, there was not an improvement in the fractional utilization of the GAC column as a larger column was utilized. Utilities designing GAC systems should carefully evaluate the relative economics of carbon column size and reactivation frequency before deciding on an EBCT.
4. The Norit GAC 1240 and Calgon F-400 GAC samples generally treated the most bed volumes of water a particular parameter of the four carbons considered. The bed volumes treated by the Calgon F-200 GAC sample were only 40 to 80% of the quantity treated by the F-400 and Norit GACs. The bed volumes treated by Pica carbon were only 15 to 30% of the quantity treated by the F-400 and Norit GACs.
5. Ozone treatment of the source water appears to have two implications on the use of GAC to remove DBP precursors. One implication is that ozonation changes the characteristics of the natural organic matter making it less reactive and possibly more adsorbable (GAC columns treated more bed volumes for THM and HAA precursors when the water was treated with ozone). The second implication is that changes in treatment before a GAC column can greatly affect the relative breakthrough time/volume relationships between parameters. In other words, empirical relationships between TOC,  $UV_{254}$ , THM and HAA concentrations are dependent on the source water and treatment processes.

## **II. Background Information**

The Lincoln Water System (LWS) is voluntarily participating in the ICR treatment study. The 12-month running annual average TOC for ICR#761 was 2.38 mg/L which would have triggered a treatability study for Lincoln's West Plant. LWS was granted an "out" because they baseload their production of water from ICR#455 (East Plant which was not required to perform a treatment study) and operate ICR #761 intermittently. The EPS's view was that #761 did not serve over 100,000 people. Note that the population and flow data provided in the Summary Spreadsheets are for a combination of the two plants.

Accordingly, LWS was not required to perform treatment studies, but decided to perform them in order to learn more about their source water and to obtain additional data for the US EPA. LWS supports all efforts to provide a sound technical and scientific basis for regulatory decisions. LWS also voluntarily decided to have two bench-scale treatability studies performed on its "surface water" treatment plant (East plant, ICR # 455) for comparison. This report discusses the results for both plants.

### **Treatment Plant Description**

The water used in the research was taken from the City of Lincoln's Drinking Water Treatment Plant located in Ashland, Nebraska. The treatment plant has two different treatment trains, the old (West) plant and the new (East) plant. The West plant takes its natural water from the well field west of the Platte River, while the East plant takes its natural water from a few wells in the well field and from the two Ranney collector wells located on an island in the middle of the Platte River. Currently, during winter (November through February) low demand periods the West plant will be taken out of service. The West plant raw water is considered a groundwater source, while the East plant raw water is considered a groundwater under the direct influence of surface water.

The treatment process train used for the West plant is illustrated in the two-page Figure II-1. The treatment train consists of the following: raw water is chlorinated and aerated before entering a contact basin, after the basin, water flows to the filters and then to clearwells where ammonia and fluoride are added before discharge into the distribution system.

The treatment process train used for the East plant is illustrated in the two-page Figure II-2. Raw water is ozonated then a filter aid polymer is added. The water proceeds to dual media (sand and anthracite) filters then goes into clearwells where chlorine is added. Fluoride is added as this water exits the clearwells with ammonia addition taking place as the water enters the influent channel of a finished water reservoir that discharges to the distribution system.

#### *Treatment Plant Schematic*

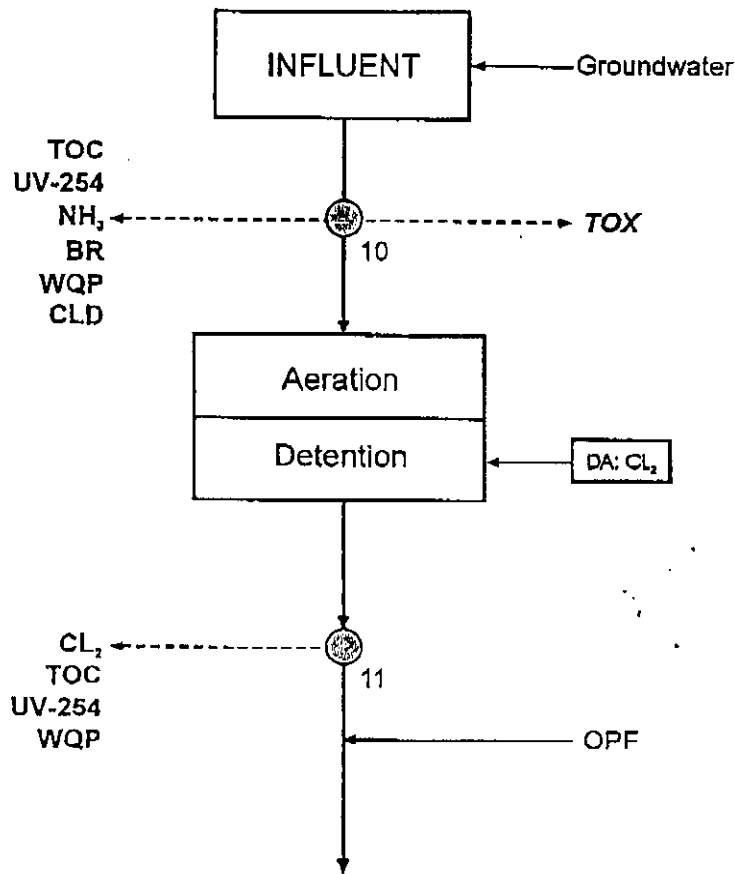
A schematic of the treatment plant is provided in Figure II-1 and Figure II-2 for each of the two plants, respectively. For the West plant, water samples were collected at ICR sample collection point #10. For the East plant, water samples were collected at ICR sample collection point #4.

#### *Treatment Plant Design Information*

The treatment plant design information is provided for the West Plant in Table II-1 (3 pages) and for the East in Table II-2 (4 pages). These tables were taken from Report A.2 from ICR Water Utility Database System.

Monthly

Quarterly



**223 Lincoln Water system**  
**PWSID No. NE3110926**  
**Lincoln, NE**

Plant Name: LWS Ashland WTP - Aeration  
Plant PWSID No. 55926001  
ICR Plant ID No. 761  
Treatment Type: other/gw  
Design Flow: 60 mgd  
Plant Schematic Created: 10/17/96  
Revised: 2/17/97

*Legend*






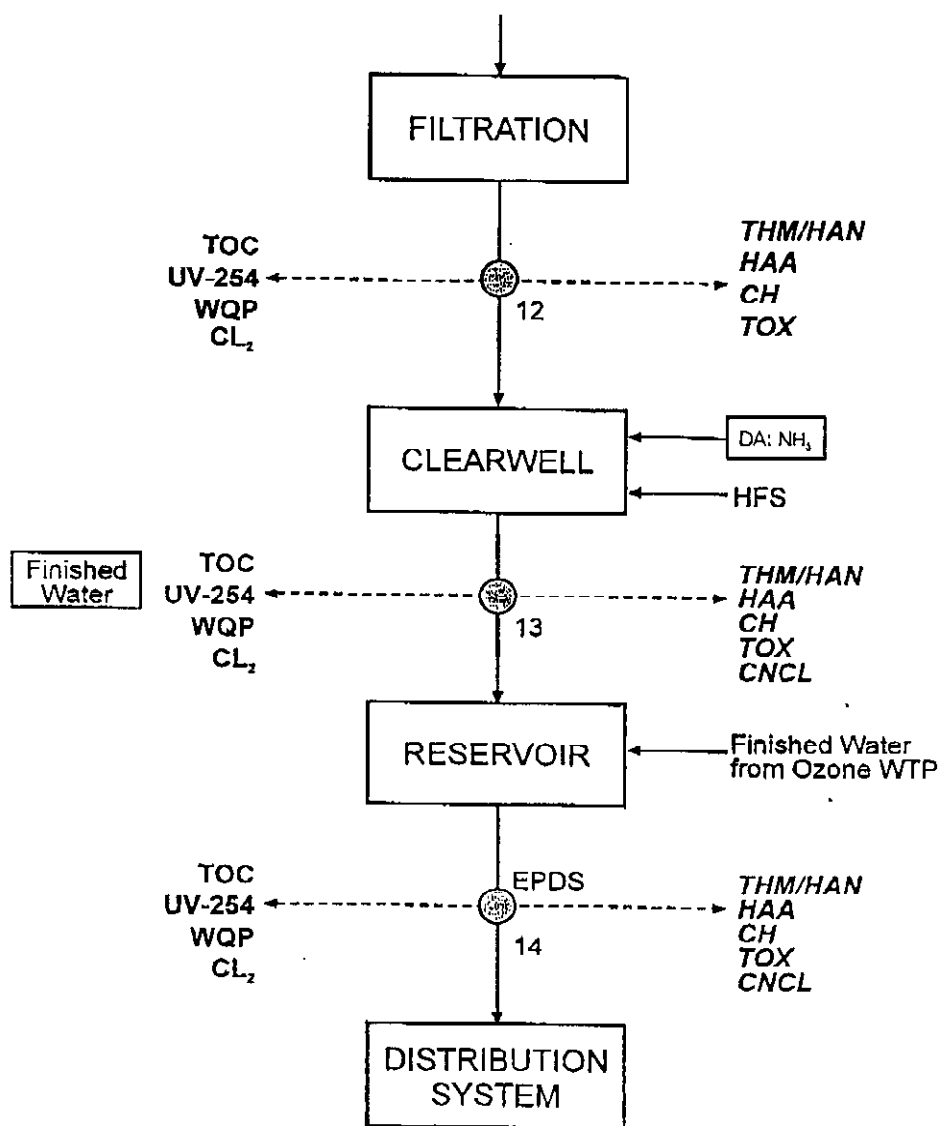
	Sampling Location
	Disinfection Addition Point
	Analyte groups
	Unit Process
	Chemical Added to Process

Figure II-1. West Plant Treatment Train.

Monthly

Quarterly



**223 Lincoln Water system**  
**PWSID No. NE3110926**  
**Lincoln, NE**

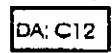
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Plant PWSID No. 55926001  
ICR Plant ID No. 761  
Treatment Type: other/gw  
Design Flow: 60 mgd  
Plant Schematic Created: 10/17/96  
Revised: 2/17/97

\* Finished water microbial sampling only  
if raw water-pathogens exceed allowable limits.

*Legend*



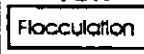
01 Sampling location



Disinfection Addition Point



Analyte groups



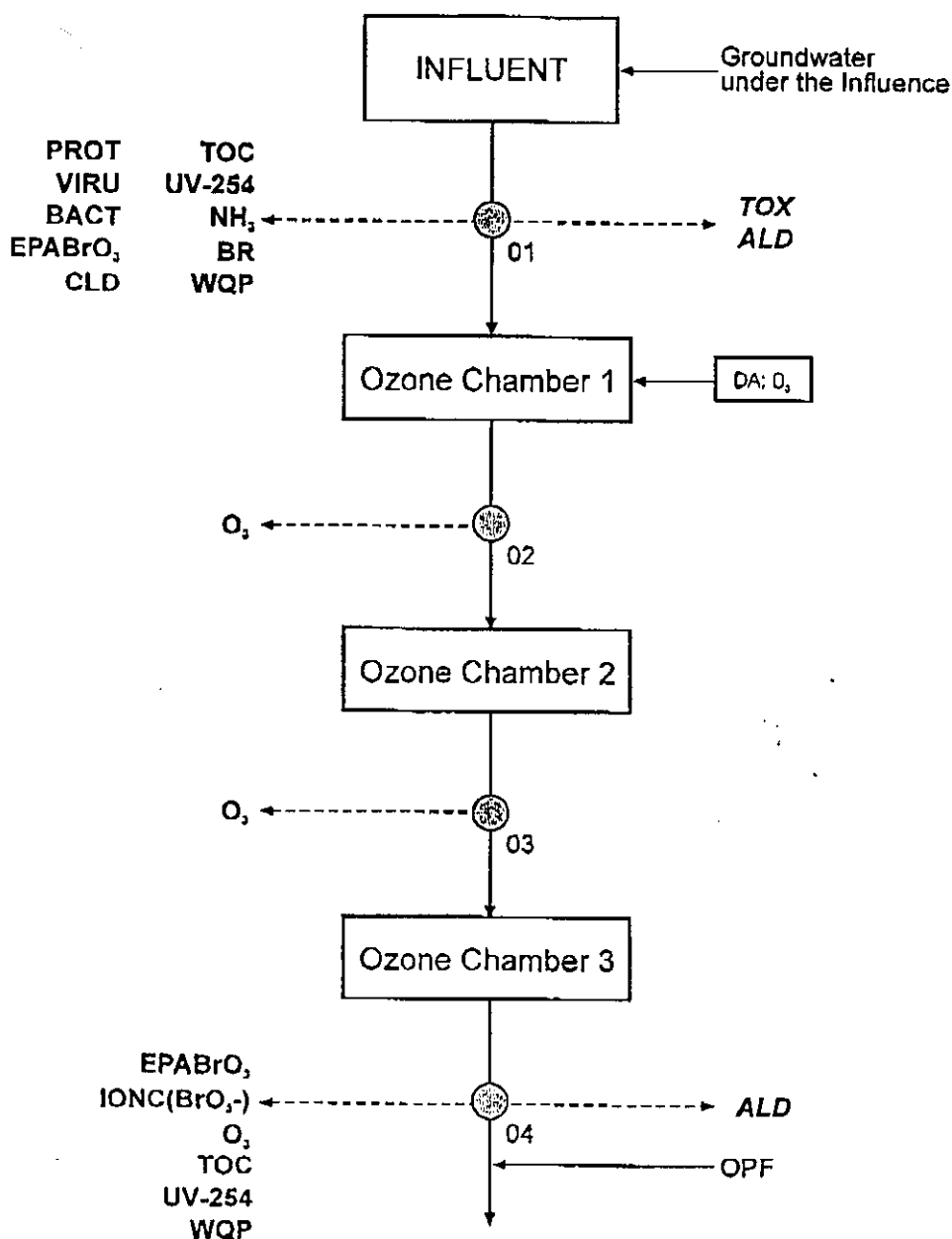
Unit Process



Chemical Added to Process

Monthly

Quarterly



**223 Lincoln Water system**  
**PWSID No. NE3110926**  
**Lincoln, NE**

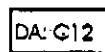
Plant Name: LWS Ashland WTP - Ozone  
Plant PWSID No. 55926001  
ICR Plant ID No. 455  
Treatment Type: df  
Design Flow: 50 mgd  
Plant Schematic Created: 10/17/96  
Revised: 2/17/97

Revised 2 Sheets: 6/27/97

*Legend*



01 Sampling Location



Disinfection Addition Point



Analyte groups



Unit Process

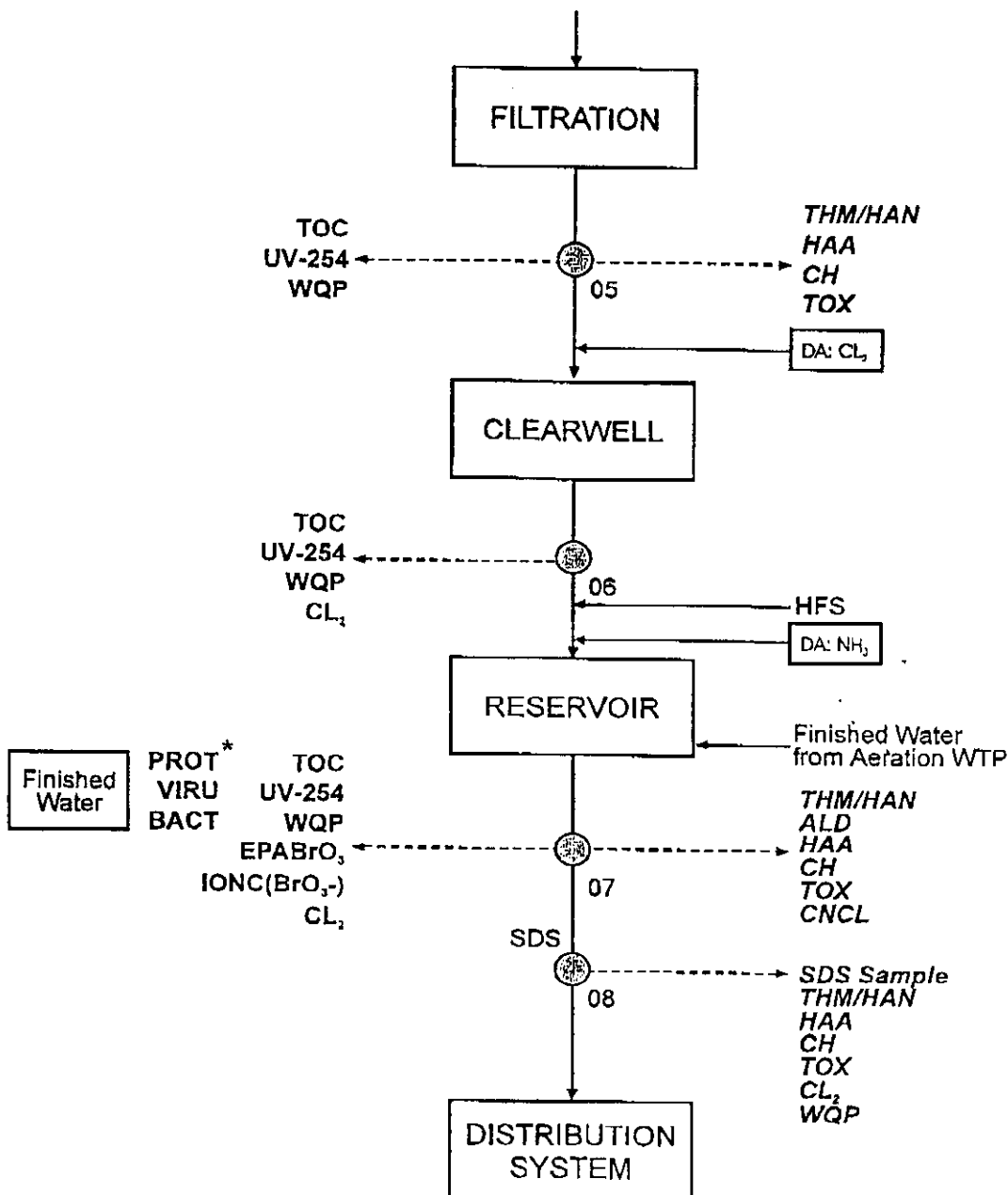
ALUM

Chemical Added to Process

Figure II-2. East Plant Treatment Train.

Monthly

Quarterly



**223 Lincoln Water system**  
**PWSID No. NE3110926**  
**Lincoln, NE**

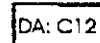
Plant Name: LWS Ashland WTP - Ozone  
Plant PWSID No. 55926001  
ICR Plant ID No. 455  
Treatment Type: df  
Design Flow: 50 mgd  
Plant Schematic Created: 10/17/96  
Revised: 2/17/97, 6/27/97

\* Finished water microbial sampling only  
If raw water-pathogens exceed allowable limits.

**Legend**



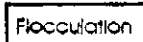
01 Sampling location



Disinfection Addition Point



Analyte groups



Unit Process



Chemical Added to Process



Table II-1. Treatment Plant Design Information For West Plant.

Treatment Plant Name: LWS Ashland WTP-Aeration		State Approved Plant Capacity (MGD): 60.0	
ICR Treatment Plant ID: 761		Historical Min. Water Temperature (deg C): 9.8	
Treatment Plant PWS ID: NE3110926		Installed Sludge Handling Capacity (DPD): 0.00	
Treatment Plant Category: OTHER/GW		Blending Indicator: Y	
Water Resource Name: P River Aquifer		Hydrologic Unit Code:	
Water Resource Type: Ground water		Latitude (degrees, minutes, seconds): +41°22'	
Intake Name: FCV501,502,503		Longitude (degrees, minutes, seconds): -96°22'5"	
Wellhead Protection: Y			
Seq. Sample No.	Sample Location Name	Sample Location Type	Sample Loc. No.
	Influent	INF	10
Process Train Name: Aeration			
Process Train Category: OTHER/GW			
1	Aeration	Other Treatment Process	
		Surface Area (ft <sup>2</sup> ):	
		Liquid Volume (gal):	
		Short Circuiting Factor:	
2	Chlorine gas	Disinfectant Addition	
		Chemical Code: CL2	
		Measurement Formula: CL2	
		Dose Rate (mg/L): 1.10	
3	W123	Disinfection Contact Basin	11
		Surface Area (ft <sup>2</sup> ): 8,517	
		Liquid Volume (gal): 4,059,475	
		Baffling Type: SP	

Seq. Sample No. Location Name	Sample Location Type	Sample Loc. No.		
4	OPF		Other Treatment Process	Short Circuiting Factor:
				Surface Area (ft <sup>2</sup> ):
				Liquid Volume (gal):
				Short Circuiting Factor:
5	West Filtration	12	Filtration	Surface Area (ft <sup>2</sup> ): 9,360
				Liquid Volume (gal): 385,070
				Total Media Depth (in): 20
				Depth of GAC (in):
				Media Type: SAND
				Type of Activated Carbon:
				Minimum Water Depth To Top of Media (ft): 5.0
				Depth From Top of Media to Top of Backwash Trough (ft): 2.8
6	Anhydrous ammon		Disinfectant Addition	Chemical Code: NH3A
				Measurement Formula: NH3
				Dose Rate (mg/L): 0.38
7	Clearwell	22	Clearwell	Surface Area (ft <sup>2</sup> ): 8,632
				Liquid Volume (gal): 774,800
				Minimum Liquid Volume (gal): 387,400
				Baffling Type: UN
				Short Circuiting Factor:
				Covered Indicator Code: Y

Seq. Sample No. Location Name	Sample Location Type	Sample Loc. No.	
8 HFS	Other Treatment Process		Surface Area (ft <sup>2</sup> ): Liquid Volume (gal): Short Circuiting Factor:
9 Reservoir	Clearwell		Surface Area (ft <sup>2</sup> ): 32,025 Liquid Volume (gal): 3,000,000 Minimum Liquid Volume (gal): 1,500,000 Baffling Type: UN Short Circuiting Factor: Covered Indicator Code: Y
10 Sample ID=455,07	Additional Water Source		Water Source Type: TGW
11 Blend	Additional Water Sample Point		
Finished Water	FIN	13	

End of Report A.2 -Design Plant Parameters

## A.2 -- Design Plant Parameters

Date: 6/29/99

PWS Name: Lincoln Water System

PWS ID: NE3110926

WIDB: 5592

ICR Contact Person: Mr. Jerry Obrist

Sampling Period: Design

Design Sampling Start Date: 7/8/97

Design Sampling End Date: 12/31/98

Treatment Plant Name: LWS Ashland WTP-Ozone

ICR Treatment Plant ID: 455

Treatment Plant PWS ID:

Treatment Plant Category: DF

State Approved Plant Capacity (MGD): 50.0

Historical Min. Water Temperature (deg C): 9.8

Installed Sludge Handling Capacity (DPD): 0.00

Blending Indicator: Y

Water Resource Name: Plate River Aquifer

Water Resource Type: Ground water under direct influence of surface water

Intake Name: FCV#504

Wellhead Protection: N

Hydrologic Unit Code:

Latitude (degrees, minutes, seconds): +41°22'

Longitude (degrees, minutes, seconds): -96°22'5"

Seq. Sample No. Location Name	Sample Location Type	Sample Loc. No.
Influent	INF	1

Influent

INF

1

Process Train Name: Ozone

Process Train Category: DF

1 Ozone

Disinfectant Addition

Chemical Code: O3

Measurement Formula: O3

Lincoln Water System

A.2 -- Design Plant Parameters 6/29/99

Table II-2. Treatment Plant Design Information For East Plant.

Seq. Sample No. Location Name	Sample Location Type	Sample Loc. No.	
2 O3oneB1C1	Ozone Chamber	2	Dose Rate (mg/L): 1.30  Type of Contactor: DI Ozone CT (mg/L x min): 1.0 Ozone Giardia Inactivation (log): 0.5 Ozone Virus Inactivation (log): 1.0 Ozone Concentration in Feed Gas (%): 1.0 Total Ozone Gas Flow Rate (SCFM): 240 Feed Gas Type: AI  Chamber Volume (ft3): 12,225 Chamber Surface Area (ft2): 540 Water/Ozone Flow Regime in Chamber: Counter Current Flow Ozone Gas Flow Split (%): 0.0
3 O3two	Ozone Chamber	3	Chamber Volume (ft3): 14,493 Chamber Surface Area (ft2): 540 Water/Ozone Flow Regime in Chamber: Counter Current Flow Ozone Gas Flow Split (%): 0.0
4 O3three	Ozone Chamber	4	Chamber Volume (ft3): 13,626 Chamber Surface Area (ft2): 540 Water/Ozone Flow Regime in Chamber: Counter Current Flow Ozone Gas Flow Split (%): 0.0
5 East Filtration	Filtration	5	Surface Area (ft2): 7,200

Seq. Sample No. Location Name	Sample Location Type	Sample Loc. No.	
			Liquid Volume (gal): 577,600 Total Media Depth (in): 42 Depth of GAC (in): Media Type: DUAL Type of Activated Carbon: Minimum Water Depth To Top of Media (ft): 7.5 Depth From Top of Media to Top of Backwash Trough (ft): 6.5
6 Chlorine gas	Disinfectant Addition		Chemical Code: CL2 Measurement Formula: Cl2 Dose Rate (mg/L): 2.15
7 Clearwell	Clearwell	6	Surface Area (ft2): 4,760 Liquid Volume (gal): 211,833 Minimum Liquid Volume (gal): 141,222 Baffling Type: UN Short Circuiting Factor: Covered Indicator Code: Y
8 HFS	Other Treatment Process		Surface Area (ft2): Liquid Volume (gal): Short Circuiting Factor:
9 Anhydrous ammon	Disinfectant Addition		Chemical Code: NH3A Measurement Formula: NH3A Dose Rate (mg/L): 0.38

Seq. Sample No. Location Name	Sample Location Type	Sample Loc. No.
10 Fin Water Res	Clearwell	Surface Area (ft2): 46,080 Liquid Volume (gal): 6,000,000 Minimum Liquid Volume (gal): 4,300,000 Baffling Type: SP Short Circuiting Factor: Covered Indicator Code: Y
11 SampleID=761,13	Additional Water Source	Water Source Type: TGW
12 Blend	Additional Water Sample Point	
Finished Water	FTN	7

### *Treatment Challenges facing Plants*

The source water for the plant is a high quality groundwater that has relatively little seasonal variation in quality. The biggest treatment challenges facing the plants at the moment are the D/DBP rule MCL for Bromate at 10 µg/L, the monitoring/reporting requirements of the IESWTR, and, some of the stringent turbidity standards (in particular dissolved manganese passing through the ozone treatment train and precipitating out over an extended time after contact with chlorine). The future arsenic MCL is a potential concern. If the arsenic MCL is set below 6-7 µg/L, the treatment plants will be forced to treat for arsenic because the finished water is consistently at 5-6 µg/L. A future radon MCL may also be a concern depending on how low the MCL is. Although the trace concentrations of herbicides during spring runoff have typically not surpassed any MCLs, they are an on-going concern. Last, the raw water contains high iron and manganese levels that require treatment for aesthetic reasons.

### **Tabular Summary of Source / Finished Water Quality**

Tables II-3 through II-6 contain data concerning the source water and finished water quality from the City's two treatment trains. This data is from the 18 month long DBP/micro monitoring (July 1997 – December 1998). Bromide samples were only taken for the source water for each plant. Note that the distribution system DBP concentrations provided in the Summary spreadsheets are for Lincoln's site 17, which is considered an "average" site.

**Table II-2. Summary of Source Water Quality:  
East Plant – ICR Sampling Location 01.**

Water Quality Parameter	Average Concentration	Standard Deviation	Maximum Value	Minimum Value
Temperature (°C)	19.1	2.2	21.5	13.5
pH	7.5	0.2	7.8	7.3
Turbidity (NTU)	0.12	0.03	0.18	0.06
Alkalinity (mg/L as CaCO <sub>3</sub> )	161	10.0	180	148
Total Hardness (mg/L as CaCO <sub>3</sub> )	204	16.0	244	181
TOC (mg/L)	2.9	0.4	3.5	2.4
UV <sub>254</sub> (cm <sup>-1</sup> )	0.070	0.015	0.089	0.039
Bromide (µg/L)	0.131	0.023	0.181	0.100



**Table II-3. Summary of Finished Water Quality:  
East Plant – ICR Sampling Location 07.**

Water Quality Parameter	Average Concentration	Standard Deviation	Maximum Value	Minimum Value
Temperature (°C)	17.9	2.1	20.3	13.4
pH	7.6	0.2	7.8	7.3
Turbidity (NTU)	0.12	0.03	0.20	0.08
Alkalinity (mg/L as CaCO <sub>3</sub> )	162	9.0	174	150
Total Hardness (mg/L as CaCO <sub>3</sub> )	200	19.0	236	183
TOC (mg/L)	2.7	0.4	3.4	1.9
UV <sub>254</sub> (cm <sup>-1</sup> )	0.043	0.008	0.049	0.018

**Table II-4. Summary of Source Water Quality:  
West Plant – ICR Sampling Location 10.**

Water Quality Parameter	Average Concentration	Standard Deviation	Maximum Value	Minimum Value
Temperature (°C)	14.5	1.3	17.2	12.5
pH	7.4	0.1	7.6	7.2
Turbidity (NTU)	0.13	0.05	0.25	0.07
Alkalinity (mg/L as CaCO <sub>3</sub> )	166	7.0	176	154
Total Hardness (mg/L as CaCO <sub>3</sub> )	223	15.0	247	196
TOC (mg/L)	2.4	0.2	3.0	2.0
UV <sub>254</sub> (cm <sup>-1</sup> )	0.046	0.007	0.056	0.025
Bromide (µg/L)	0.134	0.017	0.165	0.108

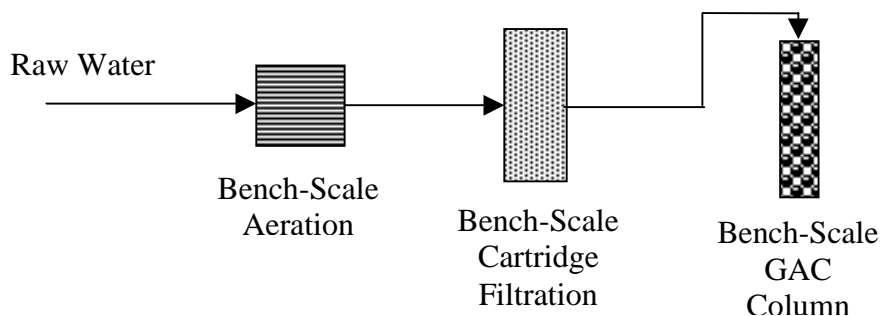
**Table II-5. Summary of Finished Water Quality:  
West Plant – ICR Sampling Location 13.**

Water Quality Parameter	Average Concentration	Standard Deviation	Maximum Value	Minimum Value
Temperature (°C)	16.1	2.2	20.6	12.8
pH	7.6	0.1	7.8	7.4
Turbidity (NTU)	0.12	0.04	0.20	0.06
Alkalinity (mg/L as CaCO <sub>3</sub> )	162	7.0	172	150
Total Hardness (mg/L as CaCO <sub>3</sub> )	219	13.0	244	192
TOC (mg/L)	2.4	0.4	4.0	2.0
UV <sub>254</sub> (cm <sup>-1</sup> )	0.044	0.006	0.054	0.023

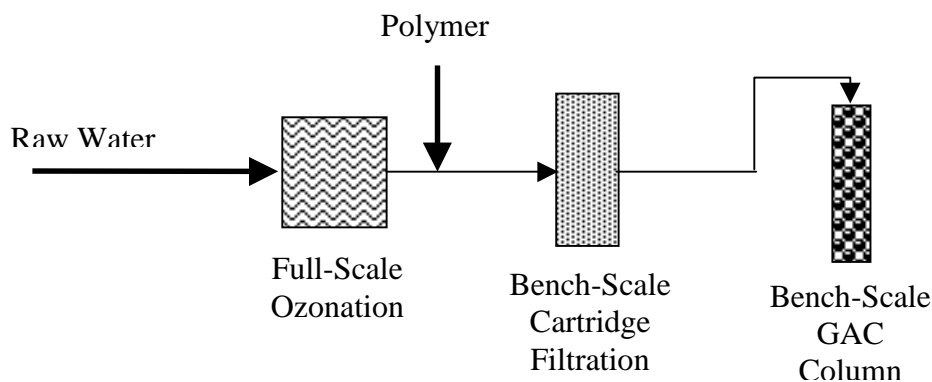
### III. Materials and Methods

#### Pretreatment Processes to the Advanced Treatment Process

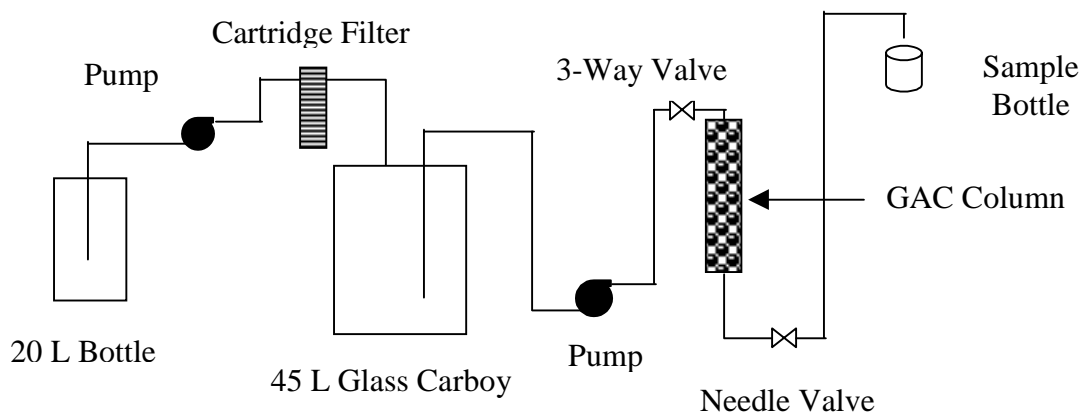
A schematic of the pretreatment processes for each plant is shown in Figures III-1 and III-2, respectively. Figure III-3 illustrates the schematic of the RSSCT design used for the treatability studies for both plants.



**Figure III-1. West Plant Pretreatment System.**



**Figure III-2. East Plant Pretreatment System.**



**Figure III-3. Schematic of RSSCT Design for Both Plants.**

## Advanced Treatment Process Information

### *Description of RSSCT*

Design information for all the pre-treatment processes used in the treatability study are listed in Tables III-1 and 2 for each plant, respectively. The raw water was taken from Lincoln's drinking water treatment plant in 20 liter glass carboys. The water samples were stored at 4°C at the University of Nebraska Food Stores until used. The influent water was allowed to warm overnight to room temperature before being passed through the RSSCT apparatus. The water was aerated, in the lab, with stone bubblers, in order to simulate the aeration to dissolved oxygen of approximately 9.5 mg/L at the plant. A minimum of a one-hour detention time was provided before the water was filtered to settle iron and manganese. A black film developed over the course of the study on the bottom of the glass bottles that contained the untreated water. The glass fiber filter removed most iron and manganese particulate. Water taken from the East plant was taken after ozonation, yet before filtration. Therefore, the water from the East plant was not aerated.

**Table III-1. West Plant Pretreatment Design Data.**

Unit Process	Process Description
Aeration (Bench-Scale)	Aeration using fish tank aerator for a minimum of 3 hours, raising the dissolved oxygen in the water to approximately 9.5 mg/L (similar to DO in West Plant aerators). The aeration occurred while the water was still in the glass carboys in which the water was originally collected. A glass air diffuser and Teflon tubing contacted the water.
Sedimentation (Bench-Scale)	Quiescent Settling for at least 1 hour in glass carboy.
(Cartridge) Filtration (Bench-Scale)	Surface Area (ft <sup>2</sup> ): 6.6 ft <sup>2</sup> Nominal Pore Size (µm): 1.0 µm Filter Material: Glass Fiber Filter Filter Life (gallons of processed water): Used for approximately 3,000 L.

**Table III-2. East Plant Pretreatment Design Data.**

Unit Process	Process Description
Ozonation (Full-Scale)	Ozone CT: 1.0 (mg/L min) Total Ozone Conc. in Feed Gas (%): 1.0 Chamber Volume (ft <sup>3</sup> ): 12,225 Chamber Surface Area (ft <sup>2</sup> ): 540 Water/Ozone Flow Regime: Counter Current
(Cartridge) Filtration (Bench-Scale)	Same technical data as listed in Table III-1.

After the aeration step, all of the water was pumped through a double-ended cartridge filter into a 45 liter glass carboy, to simulate the filtration process in the treatment plant. The water was pumped through a pulse dampner, to equalize the flow, and then through the GAC column. Once through the column, the water passed through a needle valve, used for flow restriction, and then out to the sampling collection point. Figure III-3 shows the RSSCT design.

The water contacted only with stainless steel, glass, and Teflon in all parts of the apparatus with the exception of a small portion (approximately 1-4 cm<sup>2</sup>) of the ceramic pump head for the piston pump. A piston pump was used instead of a diaphragm pump (containing all Teflon and stainless steel), because piston pumps can maintain a constant flow rate at high pressures for weeks. The flow rate from a diaphragm pump gradually declines, requiring frequent flow rate monitoring and pump readjusting. A full explanation of the relative advantages of piston pumps over diaphragm pumps was provided to the US EPA in a March 29, 1996 letter from Bruce Dvorak to James Westrick (Chief, Water Supply Technology Branch).

The apparatus consisted of the following items:

- Cole-Parmer Piston Pump. Catalog number: H-07104-02.

- Cole-Parmer Pump Head. Catalog number: H-07104-56.

- Cole-Parmer Pulse Dampener with pressure gauge. Catalog number: H-07115-50.

- Cole-Parmer Glass Fiber Filter, pore size 1.0 µm. Catalog number: H-06479-24.

- All tubing was either stainless steel or Teflon.

- All fittings and valves were made from stainless steel.

- Ace Glass Chromatographic Column (11 mm i.d.). Catalog number: 5820-04.

- A coarse Teflon screen and a fine stainless steel screen were used at the bottom of the GAC columns.

- Glass beads and glass wool were used to fill the void space in the columns.

For each study, approximately 20 grams of carbon was ground to the desired sieve size of 140 x 200 (following the procedures listed in the ICR Treatment Study Manual), and washed, the moisture content was determined. The carbon was allowed to equilibrate with the atmospheric moisture content. Three quantities of carbon weighing 1.5 grams each were placed into individual pre-weighed and pre-dried aluminum pans. The “wet” mass of both the pan and carbon were measured. Once measured and recorded, the three pans were placed in a 105 degree Celsius oven overnight. The following day, the pans were removed from the oven and placed in a desiccator and allowed to cool for about two hours. The three pans and the dried carbon were then measured again. The moisture content was then determined. Once the moisture content had been determined, the “moist” mass of carbon for each column was calculated, the carbon mass included the moisture content. The carbon was measured out and placed into a clean beaker with high purity water and degassed. Then the carbon was loaded into the columns as a slurry.

An RSSCT was used to model full-scale NOM adsorption to GAC beds. The scaling equations was developed based upon dimensional analysis to maintain similitude to the full-scale GAC column. The scaling relationship is a function of the carbon size used in the small column (RSSCT) and the large column (pilot or full-scale columns).

In general, to shorten the RSSCT length, the dominance of internal mass transfer over external mass transfer can be utilized. A minimum velocity can be used in the RSSCT, which still allows the internal mass transfer to dominate. According to the ICR Treatability Study Manual, this minimum velocity is defined using the minimum Reynolds number,  $Re_{SC,min}$ , which should range from 1.0 to 0.5, depending upon the molecular weight of the compound being removed. Using the  $Re_{SC,min}$  allows for the use of a lower  $v_{SC}$  in the RSSCT, which results in shorter column lengths and lower flow rates. Table III-3 shows the values needed for the RSSCT design for Calgon F-400 for this study.

**Table III-3 RSSCT Design Parameters and Calculations for Calgon F-400.**

Parameter	Description		Known Value	Units
$d_{LC}$	particle diameter in large column	-	1.053	mm
$d_{SC}$	particle diameter in small column	-	0.0905	mm
$EBCT_{LC}$	EBCT for large column	-	10	min
$v_{LC}$	velocity of large column	-	0.136	cm/sec
$Re_{LC}$	Reynolds No. for large column	-	3.45	
$Re_{SC}$	Reynolds No. for small column	-	0.5	
$\rho_{SC}$	dry density of carbon	-	0.45	g/cm <sup>3</sup>
$DC_{SC}$	diameter of small column	-	1.1	cm
Parameter	Description	Equation # from ICR Treatment Study Manual	Calculated Values	Units
SF	scaling factor	5.1	11.64	
$EBCT_{SC}$	EBCT for small column	5.3	0.86	min
$v_{SC}$	velocity of small column	5.8	13.76	cm/min
$l_{SC}$	length of small column	5.6	11.83	cm
$m_{SC}$	mass in small column	5.13	5.05	g

## RSSCT Experimental Design

The seasonal variability in water quality is relatively minor in the groundwater used as a source for Lincoln's treatment plants. The data provided to the US EPA on the Treatment Study Applicability Data Reporting Form shows that the influent TOC varies over the course of the year between 2.0 and 2.8 mg/L. A total of six sets of RSSCTs were performed to test four different carbon types as shown in Table III-4. The activated carbons tested were bituminous coal based carbons manufactured by Calgon, Norit, and Pica. All GAC samples were obtained from the manufacturer during May, 1998. The water samples were obtained and tested over the course of a seven-month period.

**Table III-4. Experimental Design for RSSCT Study.**

Plant	GAC Studied	Pre-treatment	EBCT Target = 10 min. <sup>1</sup>	EBCT Target = 20 min. <sup>1</sup>
West	Calgon F-400	Aeration followed by Direct Filtration	10.0	20.0
West	Calgon F-200	Aeration followed by Direct Filtration	8.4	16.7
West	Norit GAC 1240	Aeration followed by Direct Filtration	9.6	19.2
West	PicaCarb	Aeration followed by Direct Filtration	12.6	25.1
East	Calgon F-400	Ozonation followed by Direct Filtration	9.8	19.6
East	Calgon F-200	Ozonation followed by Direct Filtration	8.4	16.7

1- The EBCT of all columns is 10 and 20 minutes when an estimated dry GAC bed density was used. The calculated EBCTs given in this table are for when the measured dry density for each GAC sample was used.

## Analytical Methods

The bench-scale treatability study was performed by faculty and students from the Civil Engineering Department at the University of Nebraska-Lincoln. Dr. Bruce Dvorak was the lead investigator and Brian Hilts, graduate research assistant, performed much of the laboratory and data analysis work for the project. Table III-5 contains a summary of the analyses performed by each of the four laboratories involved in this study. A list of all analytical methods used in the study is provided in Table III-6.

**Table III-5. Summary of Laboratory Analyses for the RSSCT Treatment Studies.**

Testing Lab	Dates of Service	Analysis Performed
Lincoln Water System Attn. Eric Lee P.O. Box 144 Ashland, NE 68003 (402) 944-3306 (402) 944-3478 (Fax) ICR NE 002	7/2/98-2/28/99	Alkalinity, Total Hardness, & Calcium Hardness
Univ. of Nebraska Civil Engineering W348 Nebraska Hall Lincoln, NE 68588-0531 Contact: B. Dvorak (402) 472-3431 (402) 472-8934 (fax)	7/2/98-2/18/99	pH, Turbidity, Temperature, TOC, UV <sub>254</sub> , Chlorine Demand, and SDS Dosing Procedure
CH2M Hill 2300 NW Walnut Blvd Corvallis, OR 97330-3538 Contact: Kathy McKinley (541) 752-4271 (541) 752-0276 (fax) ICR LAB ID #: ICROR001	7/9/98-2/22/99	Ammonia & Bromide, THM4, HAA6, and TOX.
Chemistry Dept. Attn.: J. Carr 228 Hamilton Hall Univ. of Nebraska Lincoln, NE 68588 (402) 472-3514	8/10/98-4/15/99	Herbicide (atrazine, simazine, alachlor, methoxychlor, deethylatrazine, and deisopropylatrazine)

**Table III-6. Summary of Analytical Methods.**

Analyte	Method	Minimum Reporting Level
Alkalinity	SM 2320 B	5 mg/L CaCO <sub>3</sub>
Ammonia	SM 4500-NH <sub>3</sub> D	100 µg/L
Bromide	EPA 300	20 µg/L
Calcium Hardness	SM 3500-Ca D	5 mg/L CaCO <sub>3</sub>
Chlorine Residual	SM 4500-Cl D	0.2 mg/L
BCAA, DBAA, DCAA, MBAA, MCAA, & TCAA	SM 6251 B	1.0 µg/L 1.0 µg/L 1.0 µg/L 1.0 µg/L 2.0 µg/L 1.0 µg/L
pH	SM 4500-H <sup>+</sup>	Not Applicable
Temperature	SM 2550 B	Not Applicable
CHCl <sub>3</sub> , BDCM, DBCM, CHBr <sub>3</sub>	EPA 502.2	1.0 µg/L
Total Hardness	SM 2340 B	5 mg/L CaCO <sub>3</sub>
TOC	SM 5310 C	0.2 mg/L
TOX	SM 5320B	25 µg/L
Turbidity	SM 2130 B	0.05 NTU
UV <sub>254</sub>	SM 5910	0.003 cm <sup>-1</sup>
Herbicides (atrazine, simazine, alachlor, methoxychlor, deethylatrazine, and deisopropylatrazine)	Modified EPA 525.2	0.04 µg/L 0.02 µg/L 0.02 µg/L 0.03 µg/L 0.02 µg/L 0.04 µg/L

The SDS procedure was set up to help determine which DBPs were formed and in what quantity in Lincoln's drinking water distribution system. Each SDS sample had to be dosed with a certain amount of a standard prepared chlorine solution, stored in a incubator for exactly 16.5 hours at a temperature of 15°C (±0.5°C). After being removed from the incubator, the samples had to have a residual free chlorine level of 1.0 mg/L of Cl<sub>2</sub> +/- 0.4. If the samples had the necessary chlorine residual, then they were placed into bottles and shipped to a laboratory to determine the amounts of trihalomethanes, haloacetic acids, and TOX.



## **IV. Results and Discussion**

### **Problems Encountered**

During the course of the six different GAC bench-scale studies, the following problems did arise:

- The raw water source had a relatively high concentration of iron and manganese. Therefore a build up of these materials occurred on the glass wool, which was packed on both sides of the carbon in the column. This build-up caused a small increase in the column pressure throughout each individual column run.
- In the first column test (or run A), an insufficient volume of water was collected for the grab sample (7/13/98) since the TOC was unusually low. The 10-minute EBCT column reached its finishing criteria, but the column with the 20-minute EBCT had to be redone at a later date (11/21/98 to 12/18/98) using a different grab sample of the same raw water.
- In the third column test (run C), the 10-minute EBCT column (8/21/98) had to be rerun because the TOC breakthrough occurred too quickly, and not enough sample had been taken for the SDS. The study was redone on 9/1/98 using the same influent water grab sample as used in the 20-minute EBCT column.

### **Water Quality Data**

The water quality of the pretreated influent used in each of the GAC column studies is presented in Tables IV-1 and IV-2. The pretreated influent water quality generally was similar to that observed for the treatment plants during the 18-month DBP/micro monitoring study (as listed in Tables III-2 through III-5). For the West plant, the pH, temperature, and TOC concentrations found in the treatment study all showed differences as compared to the values found during the 18 month DBP/micro monitoring. The temperature and pH were higher for the treatment study, in part due to the time of year that the samples were taken and in part due to operating the RSSCT at room temperature. The average TOC in the treatment study typically was about 0.4 mg/L lower than the 18-month average.

For the East plant, the only parameter significantly different in the treatment study from the 18-month DBP/micro monitoring was the TOC concentration; the TOC in the treatment study typically was 0.8 mg/L lower than the 18- month average.

**Table IV-1. Water Quality of Pretreated Influent: West Plant**

Plant:	West	West	West	West	West
Carbon Studied:	Calgon	Calgon	Calgon	PicaCarb	Norit
Water Quality Parameter	F-400	F-400	F-200	830	GAC 1240
	Average	Average	Average	Average	Average
	(SD)	(SD)	(SD)	(SD)	(SD)
Grab Sample Collection	5/22/98 <sup>1</sup> (10-min. EBCT)	11/18/98 <sup>2</sup> (20-min. EBCT)	7/24/98 <sup>3</sup>	8/18/98 <sup>3</sup>	9/23/98 <sup>3</sup>
Temp. (°C)	21.1 (1.4)	21.0 (1.1)	19.2 (1.7)	19.1 (2.9)	19.7 (3.2)
pH	8.0 (.03)	7.9 (0.08)	7.95 (.23)	8.1 (.2)	8.0 (.1)
Turbidity (NTU)	0.143 (.04)	0.13 (0.02)	.145 (.06)	.075 (.01)	.38 (.23)
Alkalinity (mg/L as CaCO <sub>3</sub> )	165. (5.0)	162. (2.82)	166. (2.8)	178. (5.7)	173. (2.8)
Calcium Hardness (mg/L as CaCO <sub>3</sub> )	165.8 (15.4)	152.5 (0.707)	179 (8.5)	193.5 (5.0)	182.5 (5.0)
Total Hardness (mg/L as CaCO <sub>3</sub> )	214.8 (17.1)	200.0 (1.41)	219.5 (10.6)	242 (1.4)	233.5 (.71)
Bromide (µg/L)	148.3 (27.1)	150.0 (46.7)	139.7 (7.2)	244.5 (222.3)	135.5 (3.5)
TOC (mg/L)	2.0 (.3)	2.1 (0.12)	1.9 (.03)	2.0 (.06)	2.1 (.05)
UV <sub>254</sub> (cm <sup>-1</sup> )	.049 (.008)	0.053 (0.005)	.051 (0.0)	.050 (.001)	.055 (.008)
SDS-THM4 (µg/L)	43.9 (1.2)	44.7 (0.37)	40.7 (3.5)	41.4 (.75)	46.8 (2.8)
SDS-HAA5 (µg/L)	12.2 (1.3)	13.2 (0.94)	13.3 (.44)	10.4 (.7)	13.1 (.4)
SDS-HAA6 (µg/L)	17.5 (1.8)	18.9 (1.37)	18.9 (.38)	15.5 (.95)	19.0 (.76)
SDS-TOX (µg Cl <sup>-</sup> /L)	111 (26.6)	141.3 (25.4)	107 (7.9)	104 (4.0)	122 (6.0)
SDS-Chlorine Demand (mg/L)	1.10 (.4)	1.33 (0.02)	1.26 (.1)	1.13 (.1)	1.43 (.1)

1 – 10-minute EBCT

2 – 20-minute EBCT

3 – Target 10- and 20-minute EBCTs

**Table IV-2. Water Quality of Pretreated Influent: East Plant**

Plant:	East	East
Carbon Studied:	Calgon F-400	Calgon F-200
Water Quality Parameter	Average (SD)	Average (SD)
Grab Sample Collection	1/18/99	12/19/98
Temp. (°C)	20.9 (1.6)	19.5 (2.9)
pH	7.6 (.3)	7.7 (.1)
Turbidity (NTU)	.14 (.03)	.14 (.04)
Alkalinity (mg/L as CaCO <sub>3</sub> )	186 (11.3)	165 (7.1)
Calcium Hardness (mg/L as CaCO <sub>3</sub> )	225.5 (2.1)	166 (18.4)
Total Hardness (mg/L as CaCO <sub>3</sub> )	180 (11.3)	210.5 (13.4)
Bromide (µg/L)	116.5 (4.95)	75.5 (12.7)
TOC (mg/L)	2.1 (.04)	2.1 (.07)
UV <sub>254</sub> (cm <sup>-1</sup> )	.034 (.001)	.033 (.001)
SDS-THM4 (µg/L)	33.5 (.9)	39.6 (3.0)
SDS-HAA5 (µg/L)	8.1 (.51)	13.6 (3.9)
SDS-HAA6 (µg/L)	11.8 (.72)	18.9 (5.8)
SDS-TOX (µg Cl <sup>-</sup> /L)	80 (4.6)	122.2 (33.5)
SDS-Chlorine Demand (mg/L)	1.24 (.12)	1.04 (.1)

**DBP Data and Data Analysis**

The THM and HAA precursors in Lincoln's influent source water are sufficiently low that the Stage II MCL will not be an issue. The City of Lincoln will not need to treat its water to remove organic disinfection by-product (DBP) precursors. Thus this data is of limited value for analyzing the economics of GAC. Figures illustrating the breakthrough curves for each of the column runs are provided in Appendix A.

**Impact of Seasonal Variability**

The seasonal variability in water quality is relatively minor in the groundwater used as a source for Lincoln's treatment plants; accordingly, its impact was not studied. The data provided to the US EPA on the Treatment Study Applicability Data Reporting Form showed that the influent TOC varied over the course of the year between 2.0 and 2.8 mg/L. The data in Tables IV-1 and IV-2 also show that there was not a large seasonal variation in the water quality. Thus, the treatment study focused on the performance of four different carbon types as shown in Table III-4.

## Impact of Specific Variables on Performance

In this set of treatment studies, three variables were examined: carbon type, herbicide removal, and source water pretreatment. A total of four different carbon types were examined: Calgon F-400, Calgon F-200, Norit GAC 1240, and Pica 830. The influent and effluent herbicide concentrations were monitored for each RSSCT.

### *Herbicides*

The concentration of a range of herbicides was monitored in both the influent and selected effluent samples from five of the treatment studies. Table IV-3 lists the influent concentrations observed. The influent herbicide concentrations were quite low since the Lincoln Water System operates their well field in such a way as to avoid pulling in water from the Platte River during the herbicide spring flush. As expected for highly adsorbable trace organic compounds, none of the herbicides broke through the GAC columns before each was taken off-line due at 75% breakthrough of the initial TOC.

**Table IV-3. Influent Herbicide Concentrations<sup>1</sup>.**  
(All concentrations are in µg/L)

Run	Atrazine	Deethylatrazine	Deisopropylatrazine
West F-400	0.213	0.083	0.070
West F-200	NA	NA	NA
West Pica	0.243	0.100	< DL
West Norit	0.510	0.125	< DL
East F-200	0.125	0.105	0.06
East F-400	0.133	0.083	< DL
Limit of Detection	0.04	0.02	0.04

1 – All effluent herbicide concentrations were below the detection limits.

### *Bed Volume Analysis*

The comparison of the effectiveness of each carbon type and pretreatment was performed by determining the bed volumes treated until specific criteria were reached, such as concentration over the initial concentration ( $C/C_0 = 0.5$ ). These criteria were used since all THM4 and HAA5 concentrations in the pretreated influent water were below the Phase II levels. The results of this comparison are shown in Tables IV-4 and IV-5.

A comparison of the number of bed volumes to each breakthrough criteria in Tables IV-4 and IV-5 for the 10- and 20-minute EBCT columns showed that for a given breakthrough criteria, generally there was no improvement in the performance of the carbon columns when a larger EBCT was used. In fact, in the majority of cases, the 10-minute EBCT treated more bed volumes than the 20-minute EBCT to achieve a given breakthrough criteria.

Cases where a smaller EBCT actually is more efficient at bed utilization than a large EBCT has been reported previously by Owen *et al.* (1996) and Chowdhury *et al.* (1996). This trend could occur if the water contained a high-molecular weight fraction characterized by strong sorption and slow intraparticle transportation. A trend of an decreasing bed volumes treated with increasing EBCT was also reported previously by Arbuckle (1980) and Roberts and Summers (1982). Because the intraparticle transport is slow, the decreasing efficiency of bed utilization with increasing EBCT would be expected to be more pronounced when evaluating columns with long run times. Such time dependent reductions in GAC adsorption capacity have been observed in many cases where synthetic organic chemicals are removed from waters with background NOM (e.g., Summers *et al.*, 1989).

The objective of using RSSCTs is to significantly reduce the study time; unfortunately, the reduced study time may mean that the results will not yield a realistic activated carbon usage rate estimate because of the concerns about slow intraparticle transport discussed above. Accordingly, RSSCT results should be expected to more likely provide an underestimate than an overestimate of the activated carbon usage rate estimate for large EBCTs (columns with long run times). The estimates for smaller EBCTs may be closer to the actual usage rate. Accordingly, in this study the 10-minute EBCT appears to be the most efficient option.

**Table IV-4. Bed Volumes Treated Until Breakthrough Criteria is Achieved:  
West Plant.**

Carbon Type:	Calgon F-400	Calgon F-400	Calgon F-200	Calgon F-200	Pica 830	Pica 830	Norit 1240	Norit 1240
Actual EBCT (min):	10.18	20.38	8.00	16.00	12.6	25.15	9.55	19.15
Target EBCT (min):	10	20	10	20	10	20	10	20
Water Collection Date:	5/22/98	11/18/98	7/24/98	7/24/98	8/17/98	8/17/98	9/23/98	9/23/98
Bed Volumes Treated until:	Dimensionless							
TOC= 0.5 C/C <sub>o</sub>	9670	12900	5300	5270	2960	2680	11300	11500
UV <sub>254</sub> =0.5 C/C <sub>o</sub>	>18700	19000	8250	7750	3420	3510	14800	13400
THM4=0.5 C/C <sub>o</sub>	10100	13900	5100	4890	2950	2630	10600	11100
HAA5=0.5 C/C <sub>o</sub>	>18700	16000	7730	7550	3260	3160	9510	21800
TOX=0.5 C/C <sub>o</sub>	>18700	>21740	7730	7010	3320	3410	21300	17000
TOC= 1 mg/L	14400	10200	5800	5420	2990	2680	10200	10400
UV <sub>254</sub> = 0.015 cm <sup>-1</sup>	12700	10200	5000	4740	2830	2620	9050	6160
THM4= 20 mg/L	8900	12100	5100	4890	2930	2560	9230	8500
HAA5= 5 mg/L	>18000	14300	4460	4740	3320	3050	9180	17400

**Table IV-5. Bed Volumes Treated Until Breakthrough Criteria is Achieved:  
East Plant.**

Carbon	Calgon	Calgon	Calgon	Calgon
Type:	F-200	F-200	F-400	F-400
Actual EBCT (min):	8.33	16.63	9.62	19.6
Target EBCT (min):	10	20	10	20
Water Collection Date:	12/17/98	12/17/98	1/18/99	1/18/99
Bed Volumes Treated until:	Dimensionless			
TOC= 0.5 C/C <sub>o</sub>	4000	4060	10500	8670
UV <sub>254</sub> =0.5 C/C <sub>o</sub>	5840	10800	11200	12600
THM4=0.5 C/C <sub>o</sub>	> 10300	13300	16600	12600
HAA5=0.5 C/C <sub>o</sub>	> 10300	> 13300	21800	17300
TOX=0.5 C/C <sub>o</sub>	> 10300	Not Reached	16800	*
TOC= 1 mg/L	3580	3870	9470	8330
UV <sub>254</sub> = 0.015 cm <sup>-1</sup>	4260	9990	9470	9760
THM4= 20 mg/L	> 10300	> 13300	18300	16800
HAA5= 5 mg/L	8510	13200	> 22100	20500

\* - Interpolation not possible with given data

#### *Carbon Types*

The results in Tables IV-4 and IV-5 show that Norit GAC 1240 and Calgon F-400 generally provided the longest bed lives for a particular parameter, followed by Calgon F-200, then Pica carbon. A further examination of the data in Tables IV-4 and IV-5 shows that in every case TOC was the first or nearly the first parameter to reach C/C<sub>o</sub> = 0.50. The other parameters varied between carbons and pretreatment methods in how closely they followed the TOC front through each GAC column.

The relationship between the TOC breakthrough front and that for the other parameters is illustrated in Figure IV-1. In Figure IV-1, data for each study is displayed as a vertical column of abbreviations above the data denoting the EBCT, plant water source, and carbon type for each study; data from a total of twelve RSSCT columns is shown. The abbreviation for each parameter was placed in Figure IV-1 vertically above the description of each study at the ratio of the bed volumes required for that parameter to reach C/C<sub>o</sub>=0.5 over the bed volume for the first parameter to reach C/C<sub>o</sub> = 0.5. The first parameter to reach C/C<sub>o</sub>=0.5 for each study has a ratio of 1.0. A larger ratio means that a parameter requires more bed volumes to reach C/C<sub>o</sub> = 0.5. For example in the second column of data, UV is at a bed volume ratio of 1.47 for the 10-minute EBCT using Calgon F-400 with West plant water; this means that UV reaches C/C<sub>o</sub> = 0.5 at 1.47 times the bed volumes required for TOC to reach C/C<sub>o</sub> = 0.5.



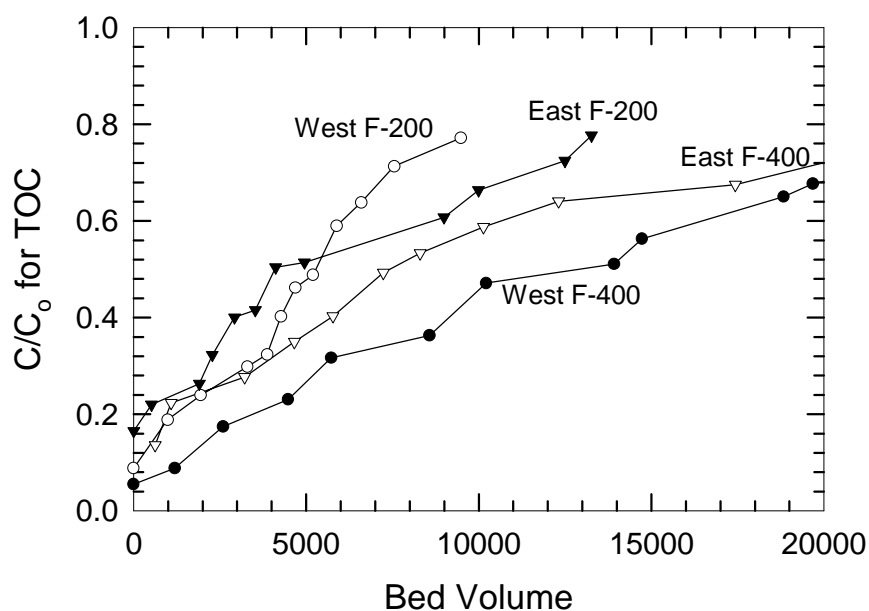
- UV<sub>254</sub>: The West plant has a higher concentration. The West Plant has an average of 0.051 cm<sup>-1</sup> (Std. Dev. = 0.0026) vs East Plant at an average of 0.033 cm<sup>-1</sup> (and Std. Dev. = 0.001), and
- SUVA: West Plant has an average of 2.56 (Std. Dev. = 0.10) vs East Plant at an average of 1.60 (Std. Dev. = 0.03).

Even though the grab samples for each of the pretreatment water samples were collected at different times, the differences were primarily attributed to differences in pretreatment of the water. Aeration (West Plant) would be expected to degas CO<sub>2</sub>, thus leading to a higher pH. Addition of a strong pre-oxidant (ozone) in the East plant would be expected to change the character of the natural organic matter, thus leading to changes in the UV<sub>254</sub>, SUVA, and even in the THM formation potential.

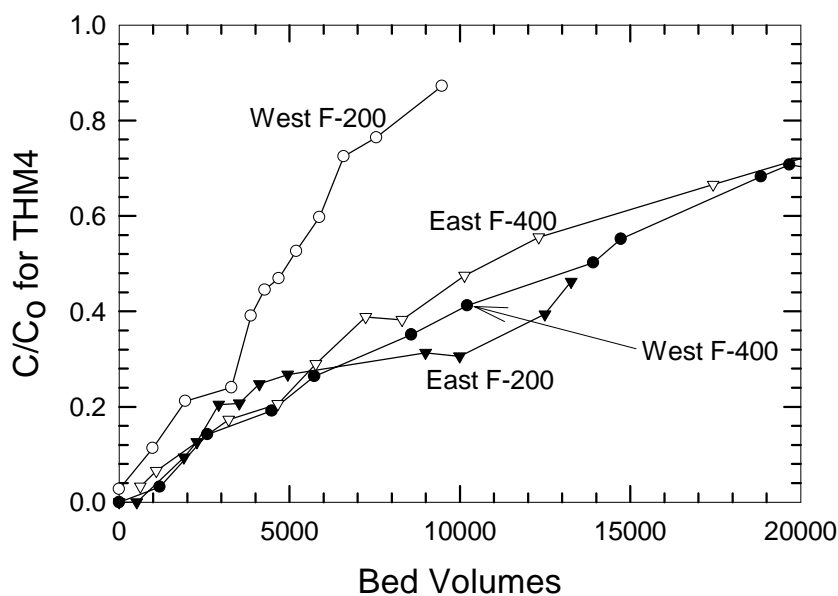
The only difference in the grab sample concentrations not potentially explained by the difference in pretreatment was the bromide concentration; the difference in the bromide concentration may have been due to differences between the wells used to obtain the source water for each grab sample. The East plant samples were obtained during the winter, when often much of the water is collected from wells near the Platte River; the water travel time is short for these wells, thus less bromide may have been picked up from the aquifer.

As noted previously, TOC was the first or nearly the first parameter to breakthrough each of the columns studied. The TOC breakthrough curves for four 20-minute EBCT columns are illustrated in Figure IV-2. For the two carbon types used on both East and West plant water (Calgon F-400 and F-200 GAC), the East Plant samples passed through the GAC before the West plant samples for  $C/C_o < 0.5$ . In contrast, for the same two carbon types, the West plant water passed through the columns faster than the East plant for THM4 formation potential as shown in Figure IV-3. The HAA formation potential breakthrough front also required more bed volumes to pass through the East than West plant columns. There are two implication of this finding. One is that ozonation of the East plant water changes the characteristics of the natural organic matter making it less reactive and possibly more adsorbable. The second implication is that changes in pretreatment can greatly affect the relative breakthrough time/volume relationships between parameters.





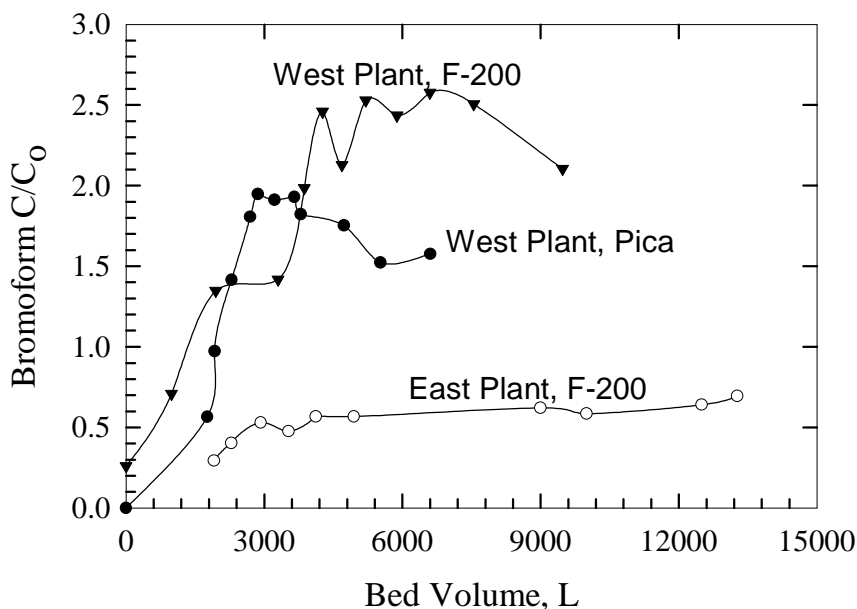
**Figure IV-2. Breakthrough Curve for TOC: Comparison of East and West Plants.**



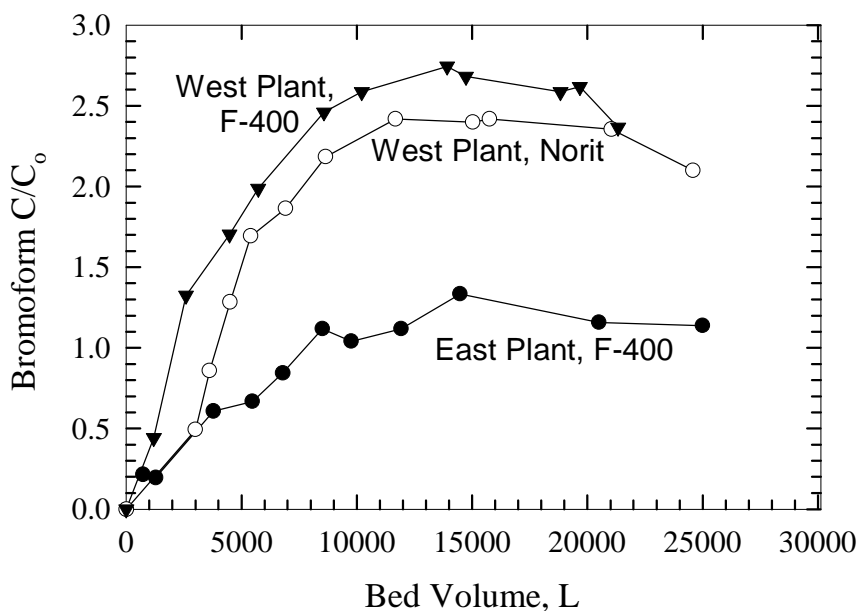
**Figure IV-3. Breakthrough Curve for THM4: Comparison of East and West Plants.**

Bromoform also shows some interesting trends. All runs, except the West (Calgon F-400) run, were within  $\pm 0.5 \mu\text{g/L}$  of the average influent Bromoform concentration of  $4.97 \mu\text{g/L}$ . For the West (F-400) run, the 10-minute EBCT column had an influent Bromoform concentration of  $8.97 \mu\text{g/L}$ , while the 20-minute EBCT column had an influent Bromoform concentration of  $3.17 \mu\text{g/L}$ . In Figures IV-4 and IV-5 Bromoform does not exhibit a chromatographic hump of an effluent concentration above  $C/C_0 = 1.0$  for the East plant studies unlike the West plant studies. The lack of a

chromatographic bromoform hump could be linked to the ozonation that takes place in the East Plant or it could be due to the small bromide concentrations in the East plant influent water during this study.



**Figure IV-4. Breakthrough Curve for Bromoform:**  
Comparison of East and West Plants. (Only Target 20-minute EBCT data shown)



**Figure IV-5. Breakthrough Curve for Bromoform:**  
Comparison of East and West Plants. (Only Target 20-minute EBCT data shown)

## Summary of Significant Results

A total of five results appear to have some degree of significance.

1. The THM and HAA precursors in Lincoln's influent source water are sufficiently low that the Stage II MCL will not be an issue. The City of Lincoln will not need to treat its water to remove organic disinfection by-product (DBP) precursors.
2. In all cases, the DBP precursors passed through the GAC columns before the trace concentrations of herbicides.
3. The 10-minute EBCT columns treated more bed volumes than the 20-minute EBCT columns in most cases. In other words, there was not an improvement in the fractional utilization of the GAC column as a larger column was utilized. Utilities designing GAC systems should carefully evaluate the relative economics of carbon column size and reactivation frequency before settling on an EBCT.
4. Norit GAC 1240 and Calgon F-400 generally provided the longest bed lives for a particular parameter, followed by Calgon F-200, then Pica carbon.
5. Ozone treatment of the source water appears to have two implications on the use of GAC to remove DBP precursors. One implication is that ozonation changes the characteristics of the natural organic matter making it less reactive and possibly more adsorbable (GAC columns treated more bed volumes for THM and HAA precursors when the water was treated with ozone). The second implication is that changes in treatment before a GAC column can greatly affect the relative breakthrough time/volume relationships between parameters. In other words, empirical relationships between TOC,  $UV_{254}$ , THM and HAA concentrations are dependent on the source water and treatment processes.

## V. QA/QC Summary

### Summary of Laboratory Duplicate and Fortified Matrix Sample Analyses Results

Participation in this study by the Lincoln Water System was voluntary. Duplicates samples were performed for sample batches. Fortified Matrix Samples were performed for all samples, except for TOC and UV<sub>254</sub>. A summary of all duplicate results from the treatment studies is listed in Table V-1. A summary of all fortified matrix sample analysis results is shown in Table V-2. As an external check, three TOC samples during the studies were sent to the Water Sciences laboratory on the University of Nebraska Campus; the results of the three samples had an average RPD of 2.9%.

**Table V-1. Summary of Duplicate Results: Combination of All Six-Treatment Studies.**

Analyte	Count	Average		Percentiles		
		RPD (%)	Std Dev	25th	50th	75th
Bromide	12	1.88	1.99	0	1.45	3.77
TOC	34	1.61	1.50	0.52	1.16	2.56
UV <sub>254</sub>	41	1.64	2.25	0.45	0.69	2.38
SDS-TOX	153	5.31	7.39	0	2.60	8.30
SDS-CHCl <sub>3</sub>	23	0.89	1.23	0	0.20	1.00
SDS-BDCM	23	1.99	1.41	0.80	2.00	2.90
SDS-DBCM	23	1.48	1.52	0	1.10	2.15
SDS-CHBr <sub>3</sub>	23	1.41	1.50	0	1.30	2.05
THM4	92	1.42	1.45	0	1.00	2.20
SDS-MCAA	32	0.51	2.47	0	0	0.0
SDS-DCAA	32	5.43	8.36	0	2.05	8.07
SDS-TCAA	32	6.76	17.0	0	0.30	6.27
SDS-MBAA	32	5.18	11.8	0	0.05	4.77
SDS-DBAA	32	2.53	3.62	0	0.10	4.25
SDS-BCAA	32	2.51	8.28	0	0	0.0
HAA5	160	3.47	9.59	0	0	2.72
HAA6	188	3.75	10.1	0	0	3.30

**Table V-2. Summary of Fortified Matrix Sample Results:  
Combination of All Treatment Studies.**

Analyte	Count	Average %		Percentiles		
		Recovery	Std Dev	25th	50th	75th
Bromide	12	104.1	39.9	97.5	106.5	118.75
SDS-TOX	40	105.6	19.8	97.75	106.5	117.25
SDS-CHCl <sub>3</sub>	23	101.0	5.3	97.5	101	104
SDS-BDCM	23	106.1	10.3	101	104	107
SDS-DBCM	23	103.4	11.0	100	102	104.5
SDS-CHBr <sub>3</sub>	23	103.7	11.3	100	103	105
THM4	92	103.6	9.8	100	103	105
SDS-MCAA	31	104.6	28.5	94	104	115.5
SDS-DCAA	31	99.1	35.7	93.5	99	103.5
SDS-TCAA	31	94.6	22.5	90	96	103.5
SDS-MBAA	31	95.6	22.3	89	97	102.5
SDS-DBAA	31	95.1	22.7	85.5	96	103
SDS-BCAA	31	100.5	24.2	98.5	102	109
HAA5	155	99.0	27.0	91.5	99	106.5
HAA6	182	98.5	26.6	91	99	106

### **Summary of Calibration Procedures for DBP, Bromide and TOC analyses.**

#### **TOC Calibration**

In order to determine the Total Organic Carbon (TOC) in the samples, a Dohrmann DC-180 TOC Analyzer was used. This machine uses persulfate-ultraviolet oxidation method for the measurement of non-purgable organic carbon (NPOC). The procedure for TOC operation and calibration was taken from Standard Methods 5310-C (Persulfate-Ultraviolet Oxidation Method). According to Standard Methods 5310-C, the standard curve preparation isn't necessary for instruments like the DC-180. Standard Methods recommends that the manufacture's instructions for testing, calibration and operation be followed, as they were.

In order to calibrate the DC-180, standard solutions were prepared. A 2% persulfate solution was used as a feed solution during the instruments operation. A 2000-ppm phthalate solution was diluted to a 4.0-ppm solution. Once the instrument had been turned on, and a baseline established, a 4.0-ppm standard was run to check the machine calibration. If the instrument had a reading that was between 3.8 and 4.2-ppm CO<sub>2</sub>, then samples were run immediately. However, if the standard didn't fall in that range, the calibration numbers in the instrument were readjusted, and a 4.0-ppm standard was run again. The process was repeated until the standard fell in the desired range. If the instrument was run for more than 2-hours, an additional standard calibration was run.

#### **DBP and Bromide Calibration**

See letter on next page from CH2M Hill.



CH2M HILL  
Applied Sciences Group  
2300 NW Walnut Blvd  
Corvallis, OR  
97330-3538  
P.O. Box 428  
Corvallis, OR  
97339-0428  
Tel 541.752.4271  
Fax 541.766.2852

**To:** Bruce Dvorak

**From:** Kathy McKinley

**Company:** Univ. of Nebraska

**Date:** July 8, 1999

**Fax No.:** 402/472-8934

**Voice No.:**

**Message:**

Bruce,

CH2M HILL Applied Sciences Laboratory was EPA Information Collection Rule Approved during the ICR for general monitoring and followed DBP/ICR protocol for the treatability analyses we performed for City of Lincoln.

We followed the QA requirements for all parameters in the EBP/ICR Analytical Methods Manual (EPA 814-B-96-002 April 1996).

Performance Evaluation Results are attached for your review and to include in your report to the EPA.

## **Appendix A.**

### **Breakthrough Profiles for TOC, UV<sub>254</sub>, THM4 and HAA5 Data for All Treatment Studies**

