ICR Treatment Study Summary Report

Evaluation of Pilot-Scale GAC Technology for Compliance with the Information Collection Rule

Conducted during the period of October 1998 through June 1999

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Attachments: 2 diskettes containing the Data Collection Spreadsheets

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I. Conclusions And Recommendations

The granular activated carbon pilot shown ability to reduce disinfection byproduct species by adsorbing the precursor total organic carbon. The carbon was quickly exhausted, however, due to the large concentrations of organic carbon in the influent waters. Typical run times (60% breakthrough) were on the order of 150 hours in warm water and about 1250 hours in cold water. The disinfection by products began forming in significant quantities at 100 to 200 hours in the 20 EBCT column in warm water and about 500 hours in cold water. The 10 minute EBCT columns showed earlier accumulation of disinfection byproducts in warm water, and significant number at the beginning of the run for total trihalomethanes (TTHM's). The consistency of the data is somewhat altered by the change of carbon type between the warm and cold water runs.

The prevalent forms of disinfection by products formed were chloroform and dibromochloromethane which are consistent with the TTHM data collected in our treatment plant effluent water for the past two decades. Dichloroacetic acid and trichloroacetic acid were the dominant forms found in the pilot effluent and are also consistent with the limited treatment plant effluent data collected in the past year.

It appears from the pilot data that granular activated carbon would not be a cost effective alternative for use in limiting disinfection byproduct formation at the Saint Paul Water Utility Treatment Plant. The cost for operating and maintaining a full scale process would greatly exceed initial capital costs due to the need for frequent regeneration of the carbon media..

II. Background Information

The Saint Paul Water Utility (SPWU) water treatment process consists of a lime softening and alum-ferric chloride coagulation/flocculation scheme followed by clarification and rapid sand filtration. Quick lime is added to the raw water entering the plant along with aluminum sulfate in a rapid mix resulting in an increase in pH to a range between 10.8 and 11.2 for the warm water and cold water seasons, respectively. Potassium permanganate is fed to the rapid mixing chamber in the event of a taste and odor incidence. The lime-alum solution is then flocculated in three consecutive rectangular basins for approximately 15 to 30 minutes per reactor, depending on flow rates. The solids are separated by gravity settling in two radial and three rectangular clarifiers. The clear water overflows are collected and channeled into a rectangular recarbonation basin. The pH is lowered to an average of 8.7 with carbon dioxide and immediately followed by the disinfection processes.

The initial disinfection step occurs within the remainder of the recarbonation basin following pH reduction to 8.7. Free chlorine is added at either 26, 42.17, or 57.75 feet upstream of the basin effluent to provide ample time for virus inactivation. The different feed points are used in response to elevated THM levels that may occur, in which case the feed point would be moved closer to the exit of the basin to reduce the THM formation reaction time. Ammonia is fed at the effluent of the recarbonation basin to quench the chlorine and form monochloramines for the inactivation of *Giardia lamblia*; additional chlorine is fed along with the ammonia to boost the chloramine residual, (excess ammonia is added to accommodate a third chlorine dose). The water containing the chloramine residual flows into two, 3 million gallon secondary settling basins configured in a parallel flow arrangement. The water then passes to 12 dual media filters and 12 rapid sand filters arranged in four galleries of six filters each. The filtered water is collected in four small clearwells located immediately below each gallery. The water is again dosed with chlorine to raise the chloramine residual prior to entering the large 20 million gallon reservoir. Effluent water from the finished water reservoir is then dosed with sodium hydroxide to adjust the pH to 9.2 for corrosion control purposes. Finally, the water flows to the pumps where it is sent to the distribution system. Tables A.2 and A.3 from the ICR Database have been attached to this report with the details of the design plant parameters and the chemical parameters.

TREATMENT CHALLENGES FACING PLANT

Among the most pressing issues facing the St. Paul Water Utility, are the current rules and largely undefined future regulatory climate. These rules demand ever increasing water quality standards while providing little to no economic incentive or support. In addition, the various MCL's often create conflicting treatment strategies where optimized treatment for one contaminant is done at the expense of another. The most prevalent case is disinfection at the expense of disinfection byproducts.

Monitoring results from the ICR and the MN Department of Health suggest that we will easily meet the requirements of the Disinfectants and Disinfection Byproducts Rule. Our combined filter effluent turbidities indicate that we will also meet the requirements of the Interim Enhanced Surface Water Treatment Rule. We seem to be optimized given our current disinfection scheme and our influent TOC levels. However, meeting the future requirements of Stage 2 D/DBPs, (whatever they may be), may prove more difficult.

The Lead and Copper Rule is another regulation that has caused much concern and expense due to the single fact that we are directed to control contamination sources in household plumbing over which we have little control. The MCL's associated with this rule do not appear to be realistic in terms of public health concerns. The most effective control is phosphate addition, which creates and/or exacerbates further problems downstream at waste treatment facilities and natural aquatic systems. The cost vs. benefit of this strategy may not have been fully examined. Although we have reduced lead levels to very near the action level, currently, we are in a mandatory lead service line replacement program as a result of not meeting the "action level" for two consecutive semesters. This is causing great expense with little evidence of significantly reducing the problem; tier-1 copper services are statistically the same as tier-1 lead services.

The most urgent concern for our utility is the threat of privatization. We are forced to do "more for less" to meet the ever stringent EPA regulations and be competitive at the same time. The net result, even if stressful, is very positive, however. We as a work group have been forced to reexamine our work loads, attitudes, and ethics. As a result we have become more efficient and effective as water and service provider. Our understanding of the treatment process and goals have been enhanced by the combination of increased regulations coupled with competitive forces.

One of the major complaints voiced during the past decade was the setting of regulatory based on health risk assessment and laboratory simulations of treatment effectiveness. The information collection rule along with the treat ability studies are viewed as an effort by the EPA to base the next set of regulations on additional real world factors such as cost, need, and effectiveness across the wide set of water quality scenarios existing throughout North America. This step has been received with confidence within our utility as a method of optimizing cost and benefit for human health protection.

Table 1 Tabular Summary of Source/Finished Water Quality

Full-Scale Water Quality Data

Full-Scale Influent Water Quality Data

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	10.01	5.44	3	23	266
pH	Unit	8.15	0.23	7.7	8.9	269
Turbidity	ntu	1.33	0.8	0.35	3.6	269
Alkalinity	mg/L as $CaCO_3$	168.98	18.62	130	220	269
Total Hardness	mg/L as $CaCO_3$	181.7	18.41	140	234	269
Calcium Hardness	mg/L as $CaCO_3$	129.13	19.37	82	198	269
TOC	mg/L	8.69	0.91	7.1	10.1	7
UV_{254}	1/cm	0.19	0.01	0.172	0.207	7
Bromide	µg/L	<0.02				3
TSUVA*	L/(mg*m)	0.022	0.0025	0.0195	0.0255	7

*TSUVA = [UV_{254} (1/m)] / [TOC (mg/L)]. Summary information for TSUVA should only be calculated from TSUVA values with paired TOC and UV_{254} measurements

Full-Scale Finished Water Quality Data

Item	Units	Average	Std Dev	Min	Max	Count
Temperature	C	10.09	5.44	3	23	270
pH	unit	8.96	0.18	8.06	9.65	269
Turbidity	ntu	0.06	0.04	0.01	0.19	270
TOC	mg/L	4.3	0.57	3.2	5	7
UV_{254}	1/cm	0.07	0.01	0.044	0.081	7
DS-THM4	µg/L	26.67	6.74	21.8	36.2	3
DS-HAA5	µg/L	27.4	1.53	25.4	29.1	3
DS-HAA6	µg/L	30.17	1.49	28.2	31.8	3

III. Materials And Methods

PRETREATMENT PROCESSES TO THE ADVANCED TREATMENT PROCESS

Table 2 Tabular Summary of Pretreatment Design Data

UNIT PROCESS	PROCESS DESCRIPTION
Rapid Mix (Full Scale)	Type of Mixer: ME Baffling Type: AV Liquid Volume (gal): 59,000 Mean Velocity Gradient (sec-1): 100.0
Flocculation (Full Scale)	Type of Mixer: ME Liquid Volume (gal): 2,926,000 Baffling Type: SP Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec-1): 18 Stage Liquid Volume (gal): 981,000 Stage Sequence Number: 2 Stage Mean Velocity Gradient (sec-1): 18 Stage Liquid Volume (gal): 882,000 Stage Sequence Number: 3 Stage Mean Velocity Gradient (sec-1): 14 Stage Liquid Volume (gal): 1,063,000
Sedimentation (Full Scale)	Surface Area(ft^2): 83,150 Liquid Volume (gal): 13,390,000 Baffling Type: PR
PH Adjustment (Pilot Scale)	Chemical Type: Carbon Dioxide Adjusted pH: 7.0
Filtration (Pilot Scale)	Total Media Depth (in): 40 Media Type: DUAL Sand Depth (in): 4 Anthracite Depth (in): 36

ADVANCED TREATMENT PROCESS INFORMATION

List of equipment:

- 9-foot glass columns
- centrifugal pumps
- stainless steel tanks
- mixer with stainless steel rod
- pH meter
- solenoid valve
- pressure gages

- flow meter
- mass flow meter
- manual valves
- Teflon tubing
- Teflon gaskets

EXPERIMENTAL DESIGN

The SPWU historical database shows two distinctive seasonal periods based upon water temperature. The transitional periods are relatively short, therefore only two situations were evaluated: warm and cold water.

Table 3 Experimental Design Summary

SEASON	PRETREATMENT	EBCT, MIN
Warm Water	Recarbonation, Conventional Filtration	10 & 20
Cold Water	Recarbonation, Conventional Filtration	10 & 20

IV. Results And Discussion

PROBLEMS ENCOUNTERED

We had a difficult time starting up the columns. Due to breakage and replacement of the glass columns, we had to postpone our start-up date until September 1998. Then the breakthrough was occurring extremely fast, so we stopped and re-considered our possibilities. With the advice of Steve Allgeier, we adjusted the pH to an average of 7.0 before the GAC columns. The initial goal was to simulate the full-scale treatment pH of 8.5. Since the historical data suggested seasonality of the DBP formation and not of the influent TOC, we decided to incubate the SDS samples at 23°C to test the warm water conditions in the distribution system. October is typically a transition month in Minnesota and we couldn't keep the influent water temperature constant. We still had some trouble with the logistics of sending the samples on a timely manner to the laboratory due to the fast breakthrough. We failed to send 4 SDS samples from the first run.

Although we had performed isotherm analysis to select the best carbon for our water, the warm water run showed a poor performance and we decided to change carbon brand . The carbon types used in each run are documented in the data collection spreadsheets. The second run started in February 1999 and ended in June 1999. The performance improved to some degree, but it is difficult to tell if it was due to the temperature or the carbon type.

Table 4 GAC Warm Water Run – Summary of DBP Breakthrough Scenarios

Breakthrough Criterion	**Value of Listed Parameter When Breakthrough Criterion is Met**													
	Run Time (days)		Throughput (Bed Vol.)		TOC (mg/L)		SDS-THM4 (µg/L)		SDS-HAA5 (µg/L)		SDS-HAA6 (µg/L)		SDS-TOX (µg Cl⁻/L)	
EBCT (minutes)	***10***	***20***	***10***	***20***	***10***	***20***	***10***	***20***	***10***	***20***	***10***	***20***	***10***	***20***
SDS-THM4 = 90 µg/L	7	14	1011	1006	1.9	1.6	92.10	94.8	17.10	27.3	20.10	31.20	160	145
SDS-THM4 = 72 µg/L		12		866		1.3		61		17.3		20.6		110
SDS-THM4 = 54 µg/L	5	10	755	719	1.2	0.9	54.25	45	11.60	7.2	14.45	9.50	94	63
SDS-THM4 = 36 µg/L	1	8	144	577	0.9	0.8	39.50	34.9	8.20	6.0	10.30	8.10	63	52
SDS-HAA5 = 54 µg/L	8	19	1154	1371	2.2	2	145	147	32.90	48.9	37.10	53.4	230	250
SDS-HAA5 = 27 µg/L	7	14	1011	1006	1.9	1.6	92.10	94.8	17.10	27.3	20.10	31.2	160	145
SDS-HAA6 = 54 µg/L	8	19	1154	1371	2.2	2	145	147	32.90	48.9	37.10	53.4	230	250
SDS-HAA6 = 27 µg/L	7	14	1011	1006	1.9	1.6	92.10	94.8	17.10	27.3	20.10	31.2	160	145

Table 5 GAC Cold Water Run – Summary of DBP Breakthrough Scenarios

Breakthrough Criterion	**Value of Listed Parameter When Breakthrough Criterion is Met**													
	Run Time (days)		Throughput (Bed Vol.)		TOC (mg/L)		SDS-THM4 (µg/L)		SDS-HAA5 (µg/L)		SDS-HAA6 (µg/L)		SDS-TOX (µg Cl⁻/L)	
EBCT (minutes)	***10***	***20***	***10***	***20***	***10***	***20***	***10***	***20***	***10***	***20***	***10***	***20***	***10***	***20***
SDS-THM4 = 90 µg/L	53	104	7611	7476	2.2	4	77.7	72.6	21.4	23.3	25.3	27.7	165	185
SDS-THM4 = 72 µg/L	34	104	4902	7476	1.8	4	58.5	72.6	12.9	23.3	16.6	27.7	115	185
SDS-THM4 = 54 µg/L	25	77	3600	5535	0.9	1.3	33.9	38.7	8.5	11.0	11.2	14.0	66	73
SDS-THM4 = 36 µg/L	25	61	3600	4379	0.9	1.3	33.9	36	8.5	9.65	11.2	12.4	66	70
SDS-HAA5 = 54 µg/L	61	104	8766	7476	NA	4	174.3	72.6	52.6	23.3	58.5	27.7	330	185
SDS-HAA5 = 27 µg/L	55	104	7902	7476	2.4	4	73.7	72.6	21.3	23.3	25.5	27.7	175	185
SDS-HAA6 = 54 µg/L	61	104	8766	7476	NA	4	174.3	72.6	52.6	23.3	58.5	27.7	330	185
SDS-HAA6 = 27 µg/L	55	104	7902	7476	2.4	4	73.7	72.6	21.3	23.3	25.5	27.7	175	185

V. QA/QC Summary

A hard copy of the QA/QC spreadsheets have been added to the Appendix. The file Tssumrpt.xls is attached to this report.

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Appendix

TABLE A.2 DESIGN PLANT PARAMETERS FROM *ICR DATABASE*

TABLE A.3 DESIGN PLANT CHEMICAL PARAMETERS FROM *ICR DATABASE*

WATER QUALITY SUMMARY

SIMULATED DISTRIBUTION SYSTEM CONDITIONS

SDS- DISINFECTION BY-PRODUCT SUMMARY

TREATMENT PLANT SCHEMATIC

PRETREATMENT SYSTEM SCHEMATIC

GAC PILOT PLANT DIAGRAM

GAC PILOT PLANT SCHEMATIC

TOC BREAKTHROUGH CURVE, WARM WATER RUN

DBP CONCENTRATION CURVES, WARM WATER RUN

TOC BREAKTHROUGH CURVE, COLD WATER RUN

DBP CONCENTRATION CURVES, COLD WATER RUN

COST ANALYSIS

HARD COPIES OF FIELDS 1 THROUGH 6 FROM THE *ICR TREATMENT STUDY DATA COLLECTION SPREADSHEETS*

HARD COPIES OF SPREADSHEETS FROM THE *ICR TREATMENT STUDY SUMMARY REPORT*

A.2 -- Design Plant Parameters

Date: 08/30/99

PWS Name: Saint Paul Water Utility
PWS ID: MN1620026
WIDB:
ICR Contact Person: Ms. Justine Roe

Sampling Period: Design
Design Sampling Start Date: 07/29/97
Design Sampling End Date: 01/06/99

Treatment Plant Name: McCarron's Filtration Plant
ICR Treatment Plant ID: 428
Treatment Plant PWS ID:
Treatment Plant Category: CS/SOFT

State Approved Plant Capacity (MGD): 144.0
Historical Min. Water Temperature (deg C): 2.0
Installed Sludge Handling Capacity (DPD): 250,000.00
Blending Indicator: N

Water Resource Name: Vadnais Lake
Water Resource Type: Reservoir/lake
Average Residence Time (Days): 69
Intake Name: Vadnais Lake Gatehouse
Watershed Control: Y

Hydrologic Unit Code:
River Reach:
Latitude (degrees, minutes, seconds): +45°2'56.1"
Longitude (degrees, minutes, seconds): -93°5'40.74"
River Reach Miles:

Water Resource Name: Well B
Water Resource Type: Ground water
Intake Name: Well B
Wellhead Protection: N

Hydrologic Unit Code:
Latitude (degrees, minutes, seconds): +45°2'48.12"
Longitude (degrees, minutes, seconds): -93°5'50.64"

Water Resource Name: Well C
Water Resource Type: Ground water
Intake Name: Well C
Wellhead Protection: N

Hydrologic Unit Code:
Latitude (degrees, minutes, seconds): +45°2'56.1"
Longitude (degrees, minutes, seconds): -93°5'40.74"

Water Resource Name: Well D
Water Resource Type: Ground water
Intake Name: Well D
Wellhead Protection: N

Hydrologic Unit Code:
Latitude (degrees, minutes, seconds): +45°2'50.34"
Longitude (degrees, minutes, seconds): -93°5'40.98"

Water Resource Name: Well E
Water Resource Type: Ground water
Intake Name: Well E
Wellhead Protection: N

Hydrologic Unit Code:
Latitude (degrees, minutes, seconds): +45°2'13.98"
Longitude (degrees, minutes, seconds): -93°6'5.58"

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

Process Train Name: Main
Process Train Category: CS/SOFT

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
1	Rapid Mix	Rapid Mix		Type of Mixer: ME Baffling Type: AV Liquid Volume (gal): 59,000 Short Circuiting Factor: Mean Velocity Gradient (sec-1): 100.0
2	Flocculator	Flocculation Basin		Type of Mixer: ME Liquid Volume (gal): 2,926,000 Short Circuiting Factor: Baffling Type: SP

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
				Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec-1): 18 Stage Liquid Volume (gal): 981,000
				Stage Sequence Number: 2 Stage Mean Velocity Gradient (sec-1): 18 Stage Liquid Volume (gal): 882,000
				Stage Sequence Number: 3 Stage Mean Velocity Gradient (sec-1): 14 Stage Liquid Volume (gal): 1,063,000
3	Clarifier	Sedimentation	2	Surface Area (ft2): 83,150 Liquid Volume (gal): 13,390,000 Baffling Type: PR Short Circuiting Factor: Plate Settler Surface Area (ft2): Plate Settler Brand Name: Tube Settler Surface Area (ft2): Tube Settler Brand Name:
4	Chlorine gas	Disinfectant Addition		Chemical Code: CL2 Measurement Formula: Cl2 Dose Rate (mg/L): 4.20
5	Anhydrous ammon	Disinfectant Addition		Chemical Code: NH3A

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
				Measurement Formula: NH3 Dose Rate (mg/L): 1.00
6	Recarb Chamber	Recarbonation Basin	3	Surface Area (ft2): 2,910 Liquid Volume (gal): 435,300 Baffling Type: PR Short Circuiting Factor: 0.7
7	Second Settling	Sedimentation	4	Surface Area (ft2): 49,164 Liquid Volume (gal): 6,150,000 Baffling Type: AV Short Circuiting Factor: 0.54 Plate Settler Surface Area (ft2): Plate Settler Brand Name: Tube Settler Surface Area (ft2): Tube Settler Brand Name:
8	Filtration	Filtration	5	Surface Area (ft2): 33,264 Liquid Volume (gal): 1,389,192 Total Media Depth (in): 42 Depth of GAC (in): Media Type: DUAL Type of Activated Carbon: Minimum Water Depth To Top of Media (ft): 3.0 Depth From Top of Media to Top of Backwash Trough (ft): 3.0

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
9	Clearwell	Clearwell	6	Surface Area (ft2): 34,272 Liquid Volume (gal): 3,000,000 Minimum Liquid Volume (gal): 700,000 Baffling Type: PR Short Circuiting Factor: 0.42 Covered Indicator Code: Y
10	Chlorine gas	Disinfectant Addition		Chemical Code: CL2 Measurement Formula: Cl2 Dose Rate (mg/L): 0.80
11	Fin Water Res	Clearwell		Surface Area (ft2): 137,000 Liquid Volume (gal): 20,000,000 Minimum Liquid Volume (gal): 7,600,000 Baffling Type: PR Short Circuiting Factor: Covered Indicator Code: Y
12	Chemical Feed	Other Treatment Process		Surface Area (ft2): Liquid Volume (gal): Short Circuiting Factor:
	Finished Water	FIN	7	

End of Report A.2 -Design Plant Parameters

A.3 -- Design Plant Chemical Parameters

Date: 08/30/99

PWS Name: Saint Paul Water Utility
PWS ID: MN1620026
WIDB:
ICR Contact Person: Ms. Justine Roe

Sampling Period: Design
Sampling Start Date: 07/29/97
Sampling End Date: 01/06/99

Sep. No.	Sample Location Name	Sample Location Type	Sample Location Number	Chemical Name	Measurement Formula	Dose (mg/L)

Treatment Plant Name: McCarron's Filtration Plant
ICR Treatment Plant ID No: 428
Treatment Plant Category: CS/SOFT

Process Train Name: Main
Process Train Category: CS/SOFT

Sep. No.	Sample Location Name	Sample Location Type	Sample Location Number	Chemical Name	Measurement Formula	Dose (mg/L)
1	Rapid Mix	Rapid Mix				
				Calcium hydroxide	CaO	150.00
				Potassium permanganate	KMnO4	1.00
				Aluminum sulfate (Alum)	Al2(SO4)3.18H2O	15.00
2	Flocculator	Flocculation Basin				
				Powdered activated carbon	C	1.00
				Ferric chloride	FeCl3.6H2O	4.00
3	Clarifier	Sedimentation	2			
4	Chlorine gas	Disinfectant Addition				
				Chlorine gas	Cl2	4.20

Sep. No.	Sample Location Name	Sample Location Type	Sample Location Number	Chemical Name	Measurement Formula	Dose (mg/L)
5	Anhydrous ammon	Disinfectant Addition				
				Anhydrous ammonia	NH3	1.00
6	Recarb Chamber	Recarbonation Basin	3			
				Hydrofluorosilic acid	F	1.00
				Carbon dioxide	CO2	28.00
7	Second Settling	Sedimentation	4			
8	Filtration	Filtration	5			
				Ferric chloride	FeCl3.6H2O	0.25
9	Clearwell	Clearwell	6			
10	Chlorine gas	Disinfectant Addition				
				Chlorine gas	Cl2	0.80
11	Fin Water Res	Clearwell				
12	Chemical Feed	Other Treatment Process				
				Sodium hydroxide	NaOH	5.00

<u>End of Report A.3 --Design Plant Chemical Parameters</u>

Saint Paul Water Utility

GAC Pilot Study - Water Quality Summary

First Run: Warm Water

		pH	Turbidity	Alkalinity	Temp.	Total Hardness	Calcium Hardness	Ammonia	Bromide	TOC	UV254	SUVA
		---	ntu	mg/L as CaCO3	oC	mg/L as CaCO3	mg/L as CaCO3	mg NH3-N / L	mg/L	mg/L	cm-1	L/(mg*m)
Influent	Avg	6.84	0.13	65.95	19.11	85.68	60.55	0.10	BMRL*	4.26	0.077	1.81
	Std	0.17	0.04	14.87	2.78	2.70	4.94	0.00		0.38	0.02	0.40
	Count	19	19	19	19	11	11	9		19	19	19
	Min	6.51	0.05	58	11	81	53	0.1		3.7	0.01	0.27
	Max	7.27	0.19	128	22.5	91	69	0.1		4.92	0.096	2.34
10 min EBCT	Avg	6.94	0.09	Not Analized	19.53	Not Analized	Not Analized	0.11	Not Analized	2.81	0.045	1.55
	Std	0.16	0.02		2.92			0.03		0.98	0.02	0.18
	Count	19	19		19			11		19	19	19
	Min	6.71	0.06		11			0.1		0.9	0.01	1.11
	Max	7.36	0.14		24			0.2		4.08	0.07	1.92
20 min EBCT	Avg	6.98	0.09	Not Analized	19.45	Not Analized	Not Analized	0.10	Not Analized	2.14	0.037	1.83
	Std	0.47	0.04		2.79			0.00		0.85	0.01	1.54
	Count	19	19		19			6		17	15	15
	Min	6.61	0.06		11			0.1		0.6	0.017	1.24
	Max	8.85	0.22		23			0.1		3.3	0.068	7.56

Second Run: Cold Water

		pH	Turbidity	Alkalinity	Temp.	Total Hardness	Calcium Hardness	Ammonia	Bromide	TOC	UV254	SUVA
		---	ntu	mg/L as CaCO3	oC	mg/L as CaCO3	mg/L as CaCO3	mg NH3-N / L	mg/L	mg/L	cm-1	L/(mg*m)
Influent	Avg	7.31	0.05	53.53	11.18	89.62	57.76	0.21	0.00	3.54	0.061	1.74
	Std	0.90	0.03	5.60	2.57	22.25	23.01	0.16	0.00	0.37	0.01	0.16
	Count	17	17	17	17	17	17	14	2	17	17	17
	Min	6.48	0.02	43	9	72.5	44	0.1	0	2.9	0.05	1.48
	Max	10.83	0.12	65	18	175	148	0.5	0	4.1	0.075	2
10 min EBCT	Avg	7.18	0.05	Not Analized	12.26	Not Analized	Not Analized	0.20	Not Analized	1.96	0.028	1.19
	Std	0.40	0.02		1.62			0.20		1.16	0.02	0.26
	Count	19	19		19			14		16	13	13
	Min	5.98	0.01		10			0.1		0.6	0.009	0.75
	Max	8.31	0.12		16			0.8		5.5	0.081	1.6
20 min EBCT	Avg	7.26	0.04	Not Analized	13.18	Not Analized	Not Analized	0.16	Not Analized	1.38	0.026	1.34
	Std	0.70	0.02		2.18			0.08		0.99	0.02	0.52
	Count	17	17		17			10		9	5	5
	Min	5.95	0		11			0.1		0.5	0.013	1
	Max	9.67	0.08		18			0.3		4	0.054	2.33

* Below Minimum Reporting Level

Saint Paul Water Utility

GAC Pilot Study - Simulated Distribution System Conditions

First Run: Warm Water

		SDS Cl2 dose mg/L	SDS Free Cl2 residual mg/L	SDS Cl2 demand mg/L	SDS Chlorination temp. oC	SDS Chlorination pH ---	SDS Incubation time hours
Influent	Avg	10	0.74	8.83	23	9.04	233
	Std	2.07	0.94	1.56	0.00	0.11	93.37
	Count	13	13	13	13	13	13
	Min	7.12	0.05	5.72	23	8.83	168
	Max	15	3.6	11.4	23	9.21	432
10 min EBCT	Avg	5.29	0.30	4.99	23	8.99	245
	Std	1.83	0.19	1.91	0.00	0.17	100.38
	Count	15	15	15	15	15	15
	Min	3.05	0.1	2.25	23	8.71	168
	Max	6.8	0.8	6.7	23	9.2	456
20 min EBCT	Avg	3.60	0.63	2.97	23	9.05	224
	Std	1.39	0.56	1.17	0.00	0.11	72.62
	Count	15	15	15	15	15	15
	Min	2.54	0	1.44	23	8.83	168
	Max	8.47	2.2	6.27	23	9.2	384

Second Run: Cold Water

		SDS Cl2 dose mg/L	SDS Free Cl2 residual mg/L	SDS Cl2 demand mg/L	SDS Chlorination temp. oC	SDS Chlorination pH ---	SDS Incubation time hours
Influent	Avg	5.00	1.88	3.12	9.65	9.21	176.47
	Std	0.00	0.41	0.41	0.76	0.11	27.23
	Count	17	17	17	17	17	17
	Min	5	1.1	2.5	8	8.92	144
	Max	5	2.5	3.9	10	9.38	240
10 min EBCT	Avg	3.11	2.07	1.04	9.79	9.11	193.26
	Std	0.31	0.30	0.31	0.61	0.35	31.60
	Count	19	19	19	19	19	19
	Min	3	1.5	0.7	8	7.67	144
	Max	4	2.5	1.5	10	9.3	264
20 min EBCT	Avg	3.00	2.50	0.50	9.65	9.11	176.47
	Std	0.00	0.32	0.32	0.76	0.46	27.23
	Count	17	17	17	17	17	17
	Min	3	1.7	0.1	8	7.31	144
	Max	3	2.9	1.3	10	9.37	240

Saint Paul Water Utility

GAC Pilot Study - Simulated Distribution System - Disinfection By-Product Summary

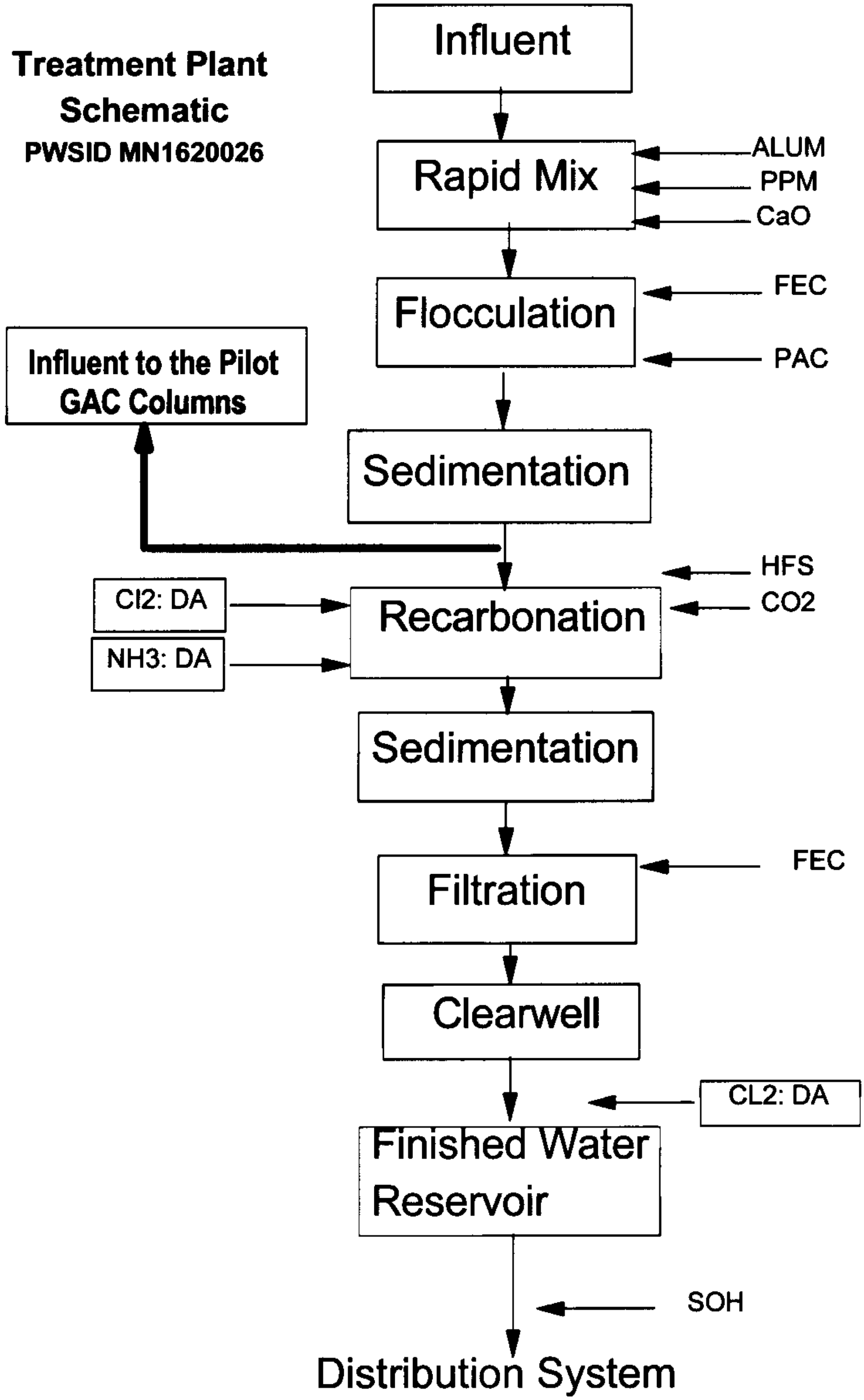
First Run: Warm Water

		SDS TOX mg Cl- /L	SDS CHCl3 mg/L	SDS BDCM mg/L	SDS DBCM mg/L	SDS CHBr3 mg/L	SDS THM4 mg/L	SDS MCAA* mg/L	SDS DCAA* mg/L	SDS TCAA* mg/L	SDS MBAA* mg/L	SDS DBAA* mg/L	SDS BCAA* mg/L	SDS TBAA mg/L	SDS CDBAA mg/L	SDS DCBAA mg/L	SDS HAA5 mg/L	SDS HAA6 mg/L
Influent	Avg	480	256	19	2	BMRL*	175	8	54	24	BMRL*	BMRL*	6	BMRL*	2	3	54	58
	Std	77.36	43.33	1.21	0.17		138.04	2.02	14.55	5.24			0.73		0.00	0.84	44.45	47.12
	Count	12	12	12	12		19	12	12	12			12		1	12	19	19
	Min	315	169.5	16.5	1.5		0	4	31	13.05			4.4		2.4	2.1	0	0
	Max	570	320	21	2.1		342.7	11	75.5	30			6.8		2.4	4.8	112.6	118.4
10 min EBCT	Avg	258.77	135.90	13.93	2.18	BMRL*	120.01	4.98	31.05	10.64	BMRL*	1.00	4.35	BMRL*	2.10	1.70	35.84	39.28
	Std	118.95	61.30	3.11	0.33		84.21	1.55	16.62	5.73		0.00	1.21		0.00	0.35	28.40	30.33
	Count	15	15	15	15		19	11	15	15		1	15		1	14	19	19
	Min	63	30	7.4	1.8		0	2.7	6.3	1.9		1	2.1		2.1	1	0	0
	Max	405	190	17	3.25		209.3	7.7	50	17		1	6.2		2.1	2.25	70.6	75.7
20 min EBCT	Avg	153.96	67.24	9.68	2.57	BMRL*	58.44	3.38	17.82	5.17	BMRL*	BMRL*	3.50	BMRL*	BMRL*	1.34	15.94	18.15
	Std	73.78	43.52	3.82	0.48		53.46	1.02	9.62	2.98			0.97			0.15	16.43	18.16
	Count	12	14	14	13		19	8	12	12			12			10	19	19
	Min	37.5	4.3	1.7	1.8		0	2.3	2.6	1			1.6			1.1	0	0
	Max	250	130	14	3.4		146.5	5.2	34	12			4.6			1.5	48.9	53.4

Second Run: Cold Water

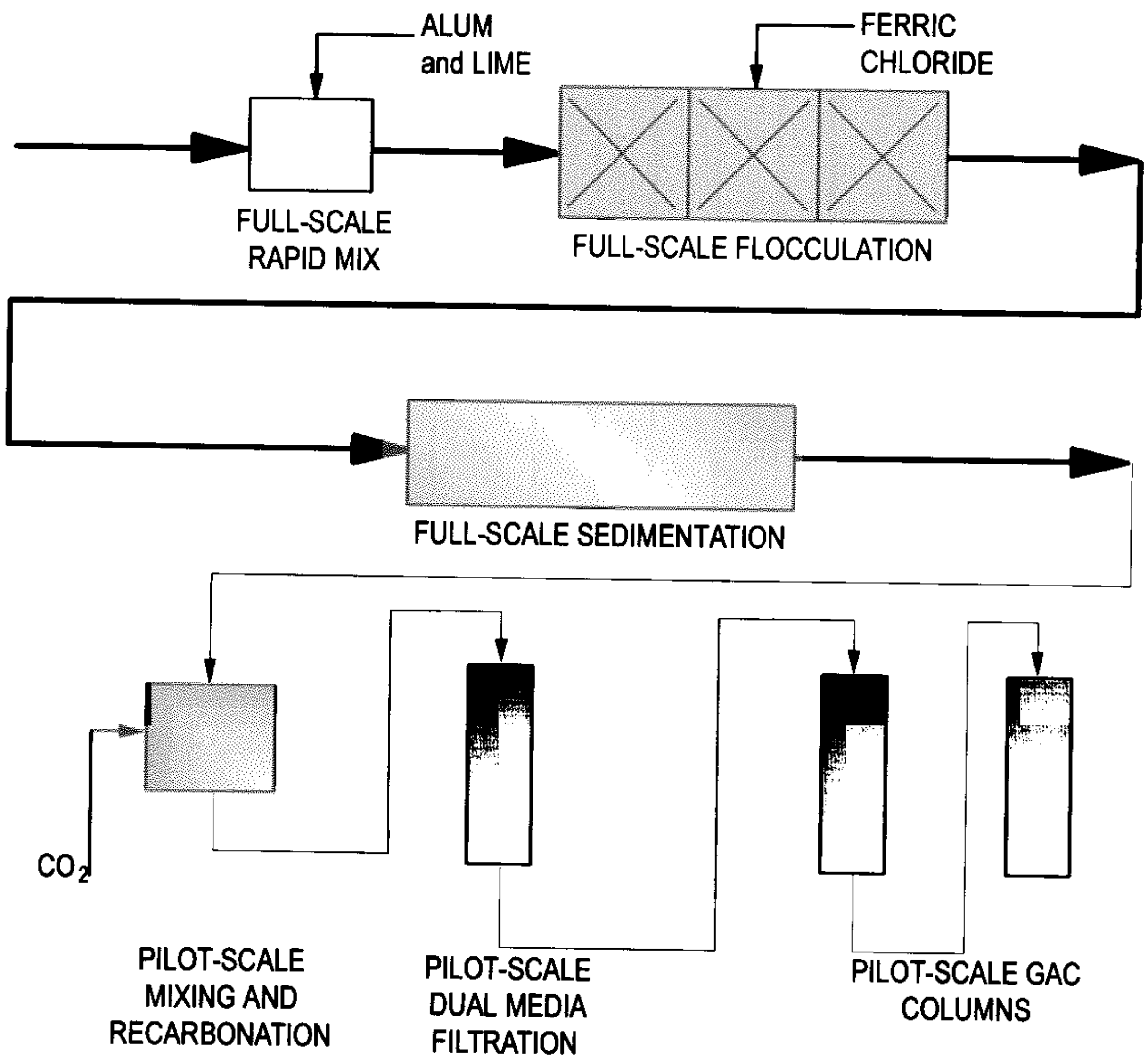
		SDS TOX mg Cl- /L	SDS CHCl3 mg/L	SDS BDCM mg/L	SDS DBCM mg/L	SDS CHBr3 mg/L	SDS THM4 mg/L	SDS MCAA* mg/L	SDS DCAA* mg/L	SDS TCAA* mg/L	SDS MBAA* mg/L	SDS DBAA* mg/L	SDS BCAA* mg/L	SDS TBAA mg/L	SDS CDBAA mg/L	SDS DCBAA mg/L	SDS HAA5 mg/L	SDS HAA6 mg/L
Influent	Avg	361	128	16	2	BMRL*	145	4	28	17	BMRL*	BMRL*	5	BMRL*	2	3	47	52
	Std	148.09	25.44	1.90	0.39		26.73	0.62	3.09	2.36			0.61		0.20	0.53	5.74	6.09
	Count	17	17	17	17		17	9	17	17			17		2	17	17	17
	Min	77	84	12	1.5		97.5	2.4	22	14			4		2	2.15	36	40
	Max	670	165	19	2.8		185.15	4.5	35	23			5.9		2.4	4.4	55.5	60.9
10 min EBCT	Avg	135.13	38.58	9.13	3.13	0.55	48.22	3.70	11.63	6.58	BMRL*	1.58	3.53	BMRL*	2.80	2.18	14.92	17.89
	Std	78.27	36.31	4.72	1.19	0.05	41.37	0.10	7.33	3.54		0.40	1.21		0.10	0.71	12.77	14.33
	Count	16	18	18	18	2	19	2	15	14		6	16		2	16	19	19
	Min	35	0.8	0.6	0.5	0.5	0	3.6	2.4	2.4		1.2	1		2.7	1	0	0
	Max	330	150	21	5.2	0.6	174.3	3.8	33	16		2.4	5.9		2.9	3.7	52.6	58.5
20 min EBCT	Avg	82.14	9.00	4.12	2.57	0.50	15.09	2.10	6.33	3.28	BMRL*	1.15	2.81	BMRL*	2.00	1.59	3.86	4.85
	Std	42.43	14.15	3.54	1.49	0.00	18.37	0.00	4.52	1.82		0.13	0.85		0.00	0.31	6.23	7.61
	Count	7	17	16	14	3	17	1	6	6		5	6		2	7	17	17
	Min	54	0.6	0.5	0.6	0.5	1.1	2.1	1.6	2		1	1.5		2	1.2	0	0
	Max	185	58	12	5.2	0.5	72.6	2.1	16	7.3		1.3	4.4		2	2.2	23.3	27.7

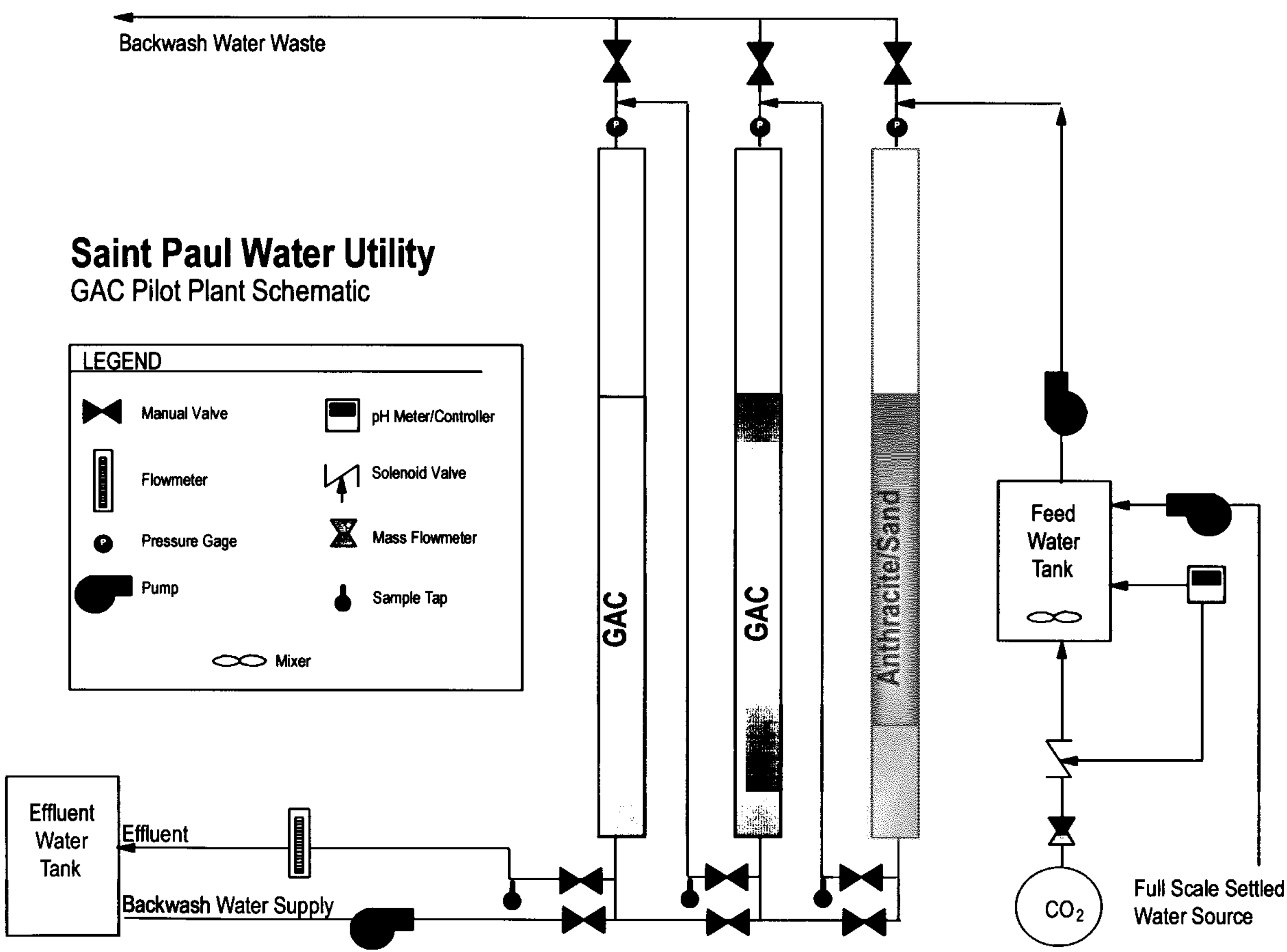
* Below Minimum Reporting Level


Treatment Plant
Schematic
PWSID MN1620026
Influent
Rapid Mix
ALUM
PPM
CaO
Flocculation
FEC
PAC
Influent to the Pilot
GAC Columns
Sedimentation
HFS
CO2
Cl2: DA
NH3: DA
Recarbonation
Sedimentation
Filtration
FEC
Clearwell
CL2: DA
Finished Water
Reservoir
SOH
Distribution System

Saint Paul Water Utility

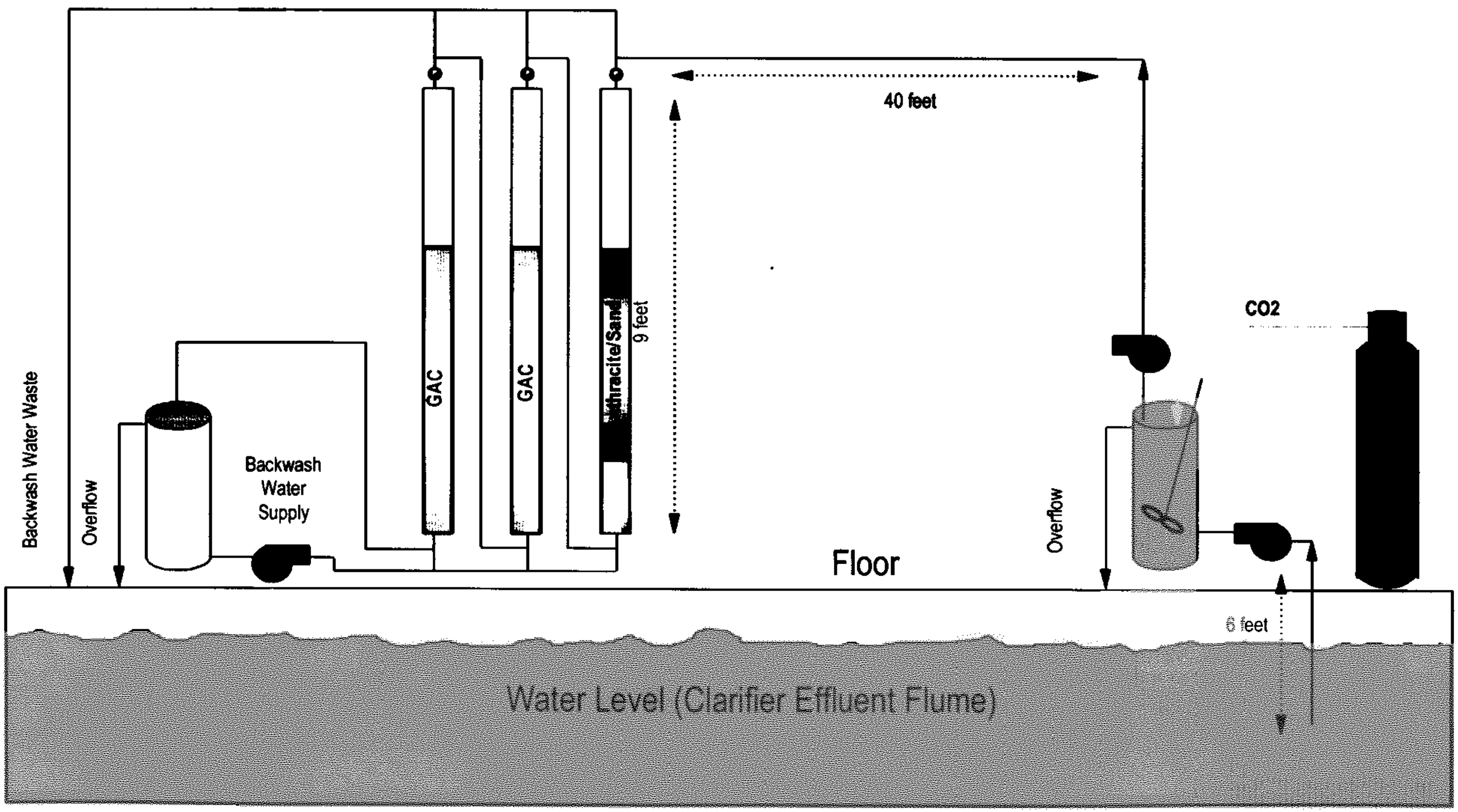
Pretreatment System Schematic of GAC Study

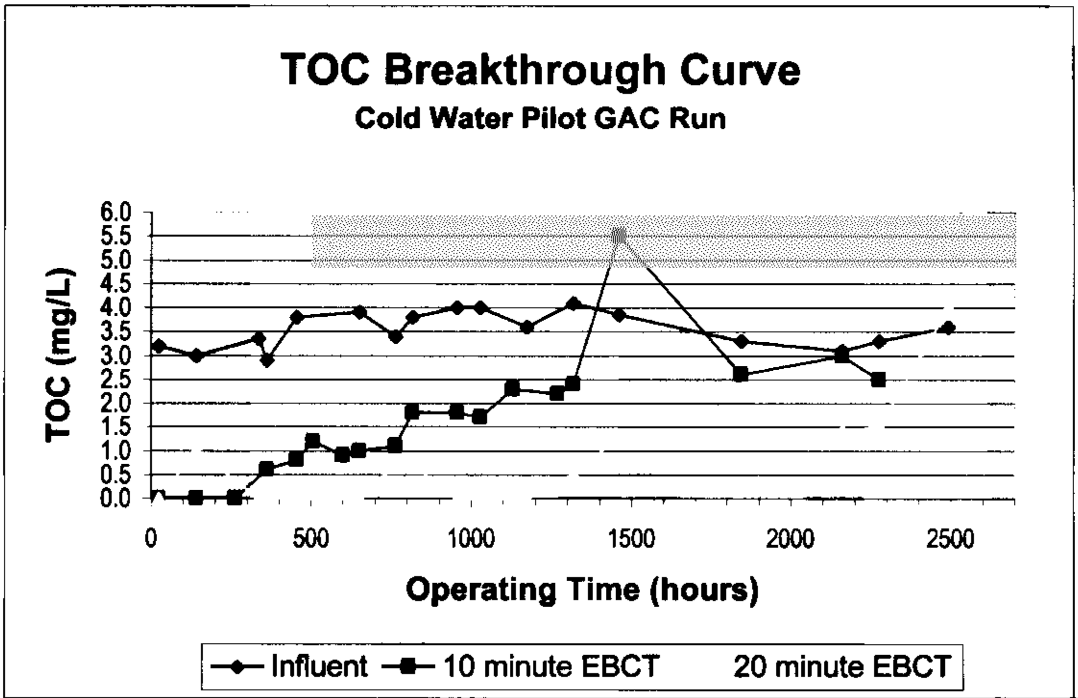


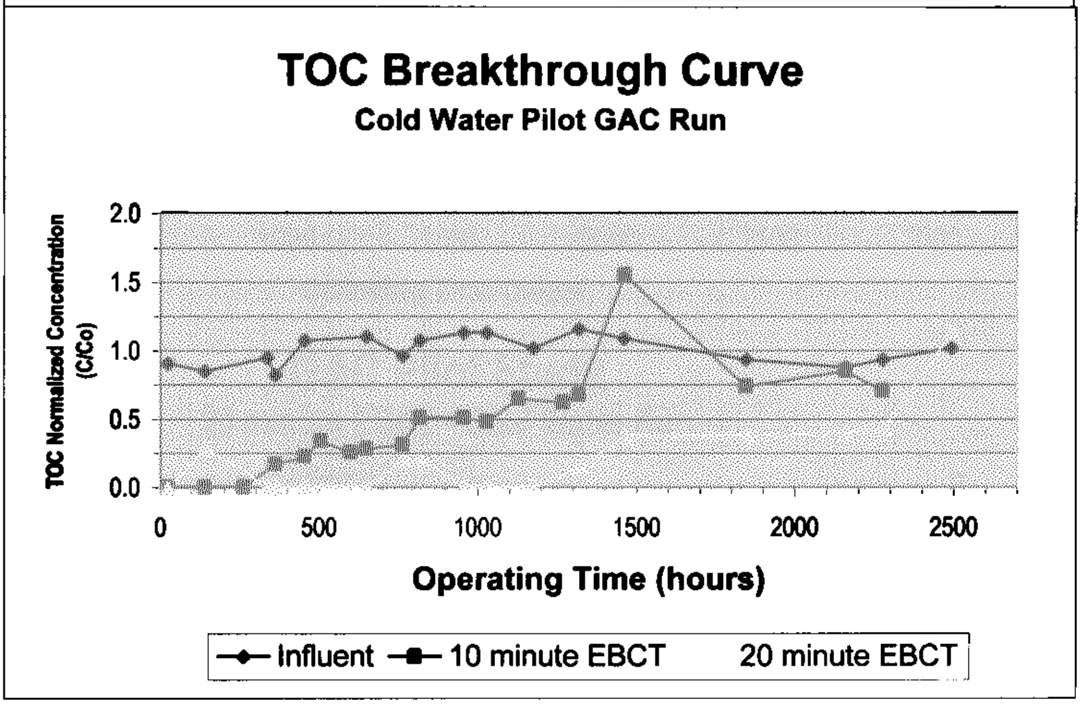

Backwash Water Waste
Saint Paul Water Utility
GAC Pilot Plant Schematic
LEGEND
Manual Valve
Flowmeter
Pressure Gage
Pump
pH Meter/Controller
Solenoid Valve
Mass Flowmeter
Sample Tap
Mixer
GAC
GAC
Anthracite/Sand
Feed Water Tank
Effluent Water Tank
Effluent
Backwash Water Supply
CO_2
Full Scale Settled Water Source

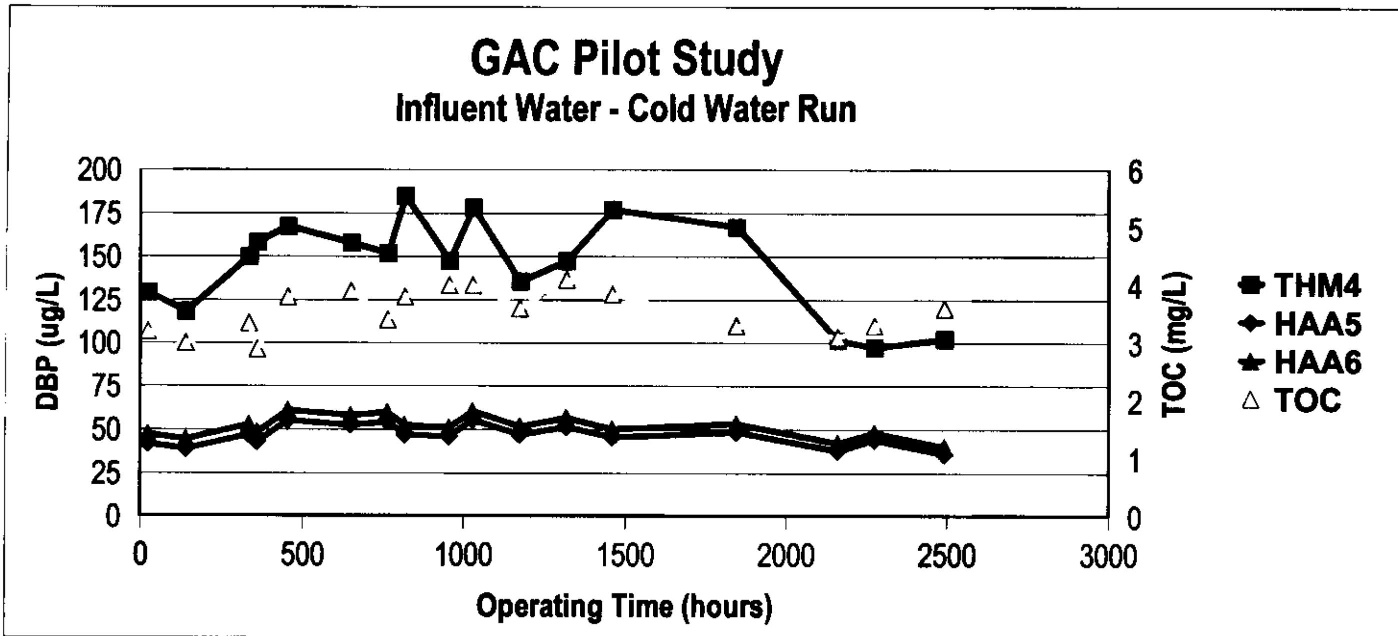
Saint Paul Water Utility

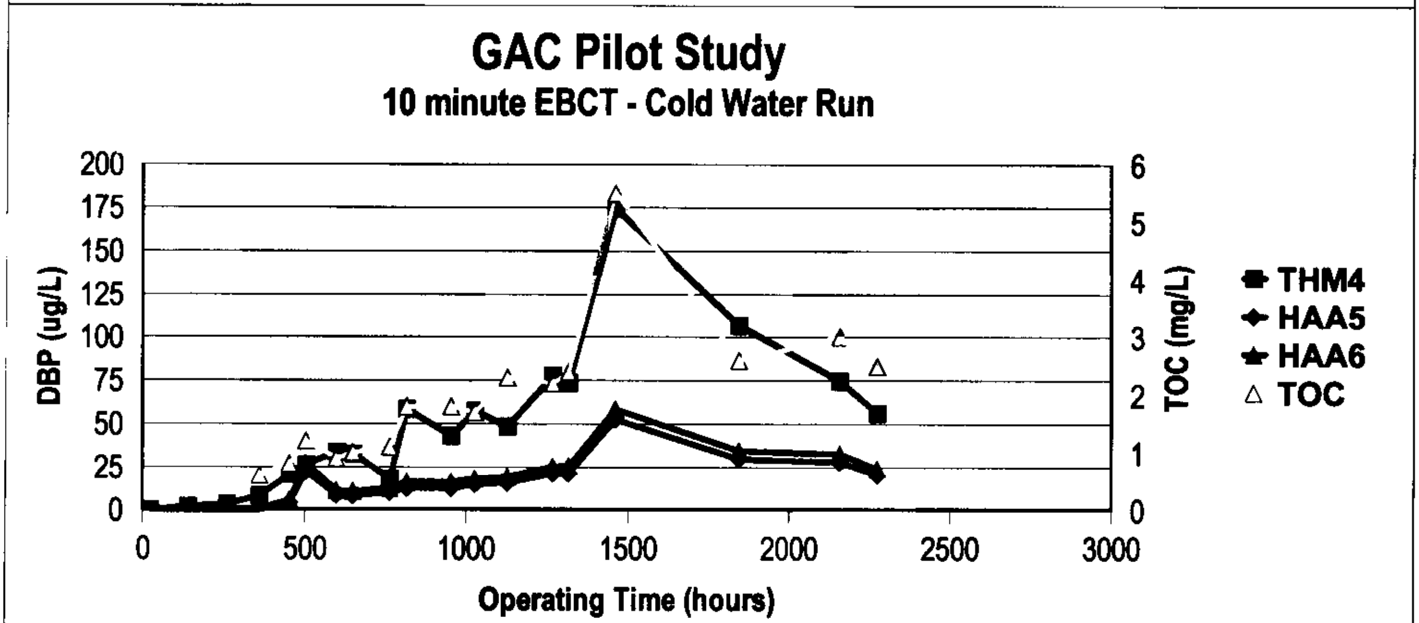
GAC Pilot Plant Diagram

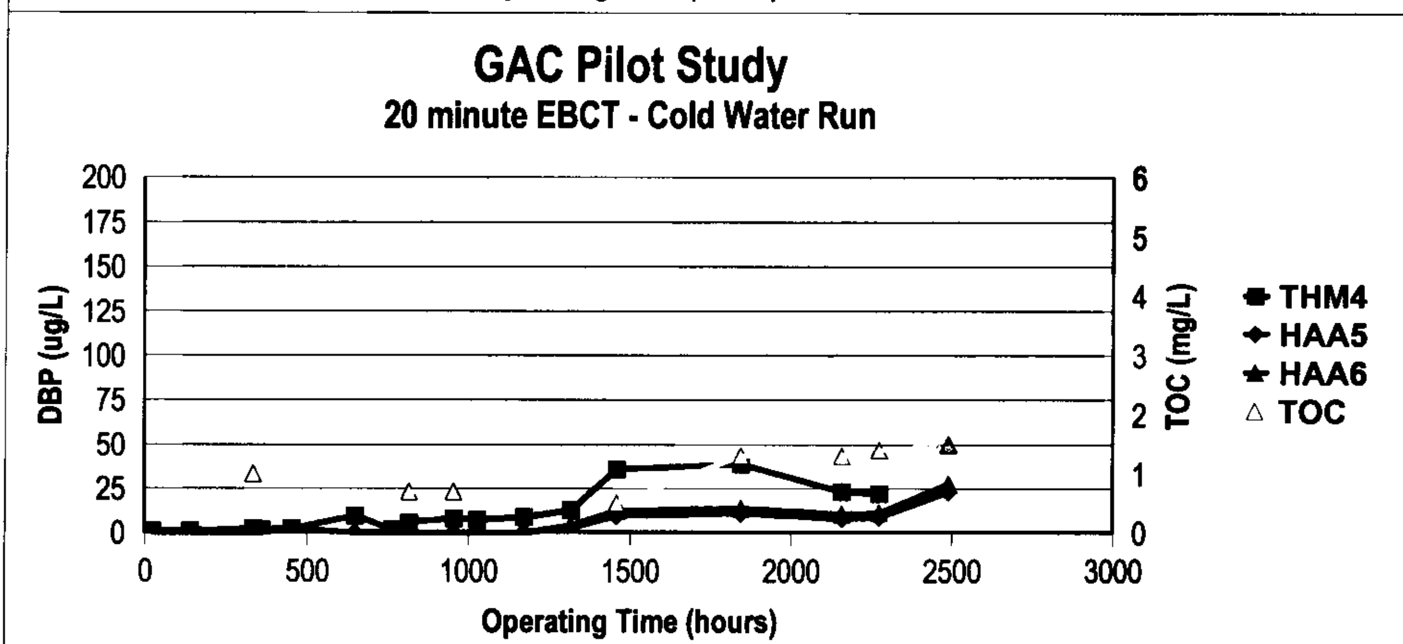


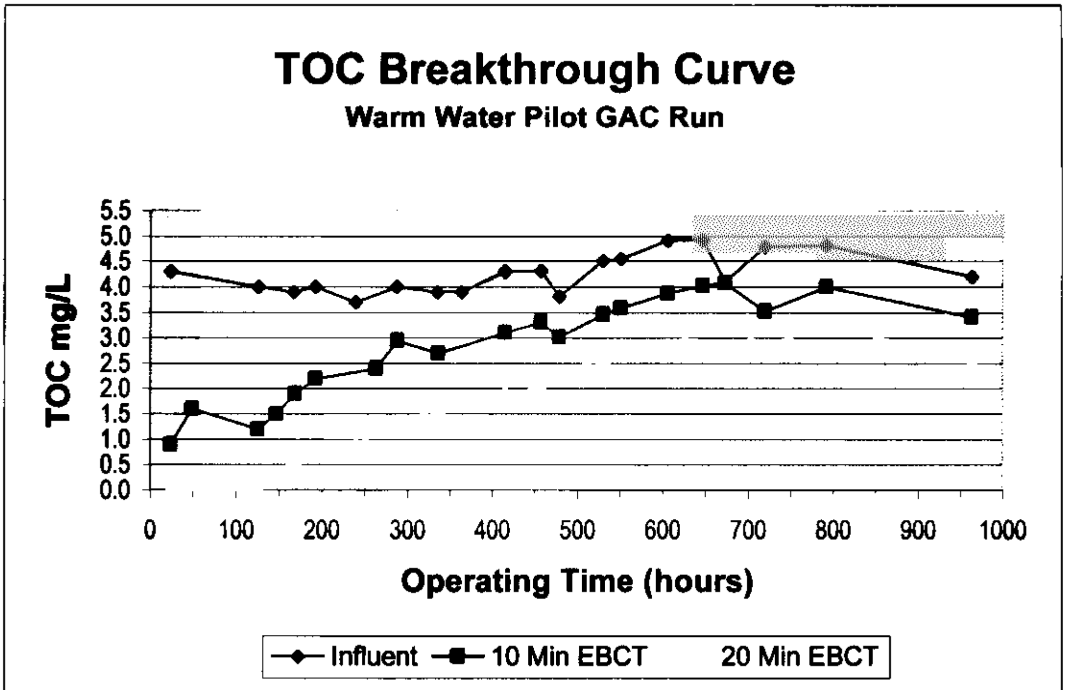

TOC Breakthrough Curve
Cold Water Pilot GAC Run
TOC (mg/L)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
500
1000
1500
2000
2500
Operating Time (hours)
Influent
10 minute EBCT
20 minute EBCT


TOC Breakthrough Curve
Cold Water Pilot GAC Run
TOC Normalized Concentration (C/Co)
2.0
1.5
1.0
0.5
0.0
0
500
1000
1500
2000
2500
Operating Time (hours)
Influent
10 minute EBCT
20 minute EBCT

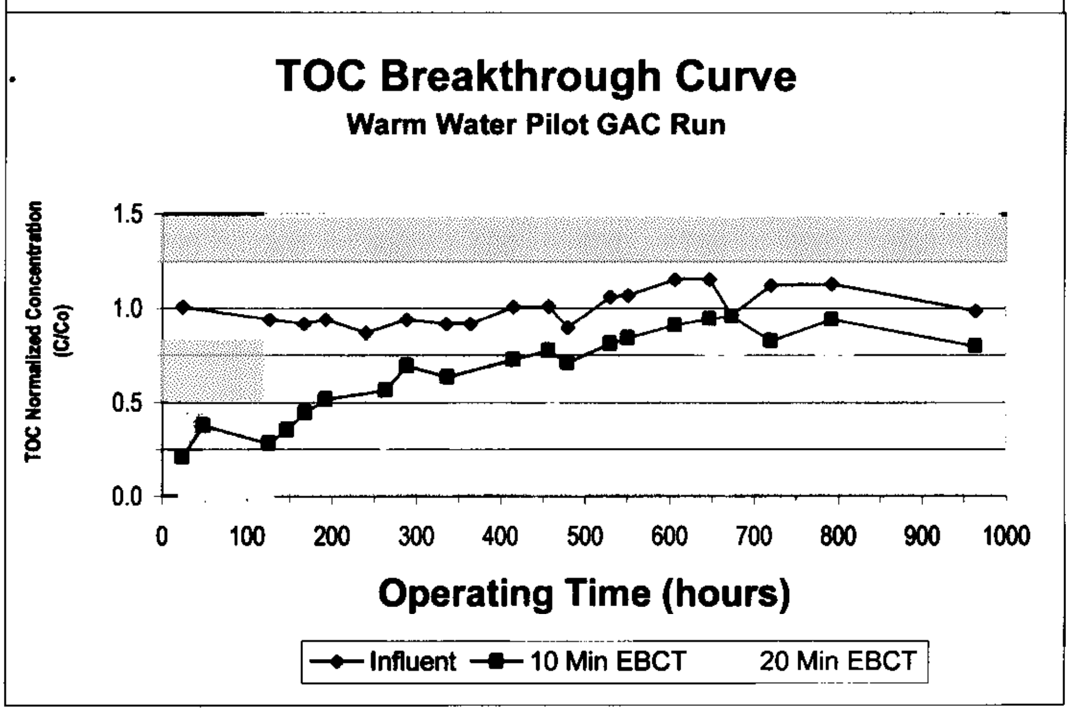

GAC Pilot Study
Influent Water - Cold Water Run
DBP (ug/L)
TOC (mg/L)
Operating Time (hours)
THM4
HAA5
HAA6
TOC


GAC Pilot Study
10 minute EBCT - Cold Water Run
DBP (ug/L)
TOC (mg/L)
Operating Time (hours)
THM4
HAA5
HAA6
TOC

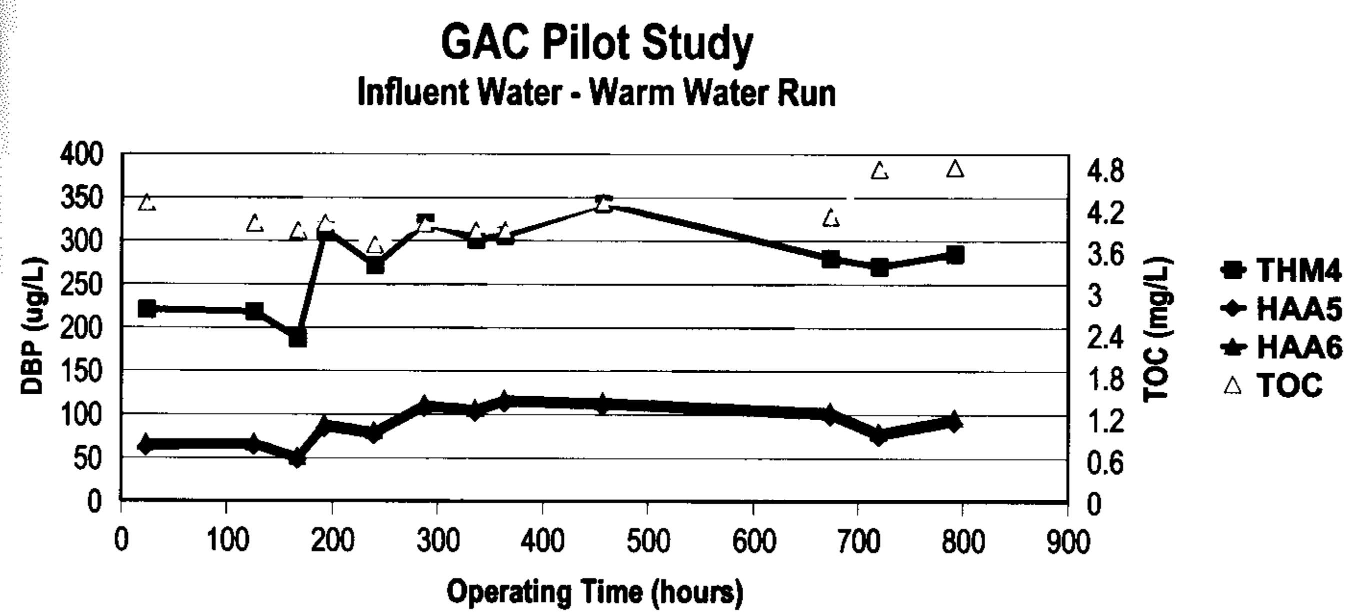

GAC Pilot Study
20 minute EBCT - Cold Water Run
DBP (ug/L)
TOC (mg/L)
Operating Time (hours)
THM4
HAA5
HAA6
TOC

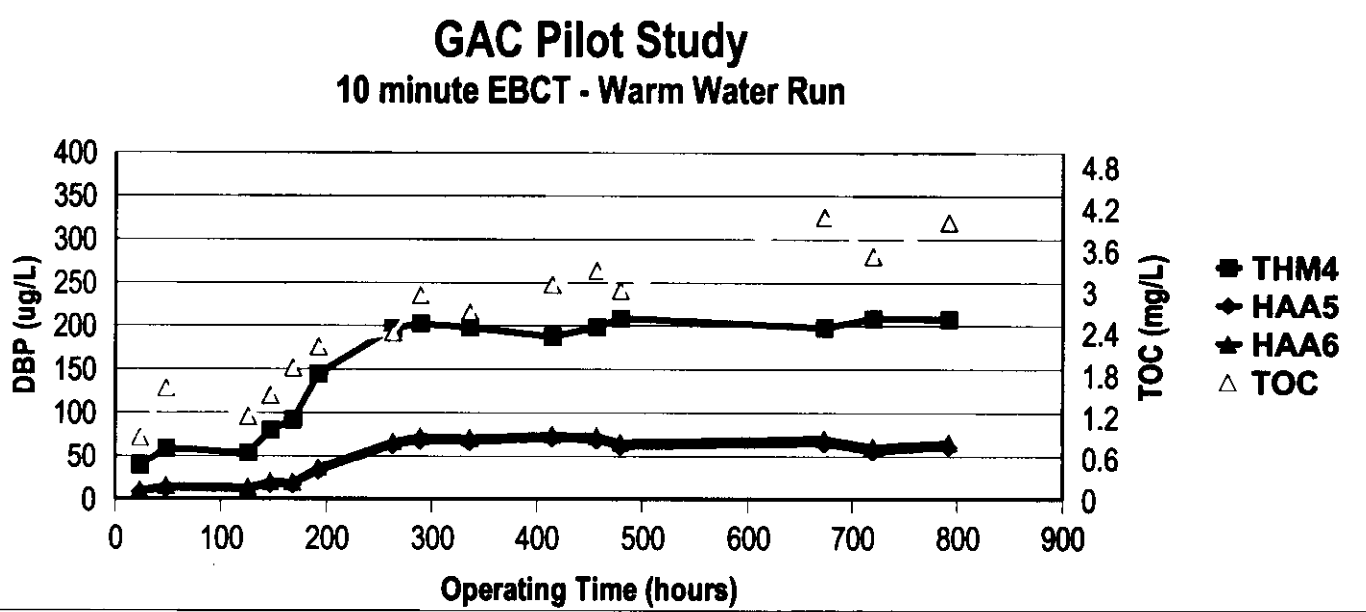


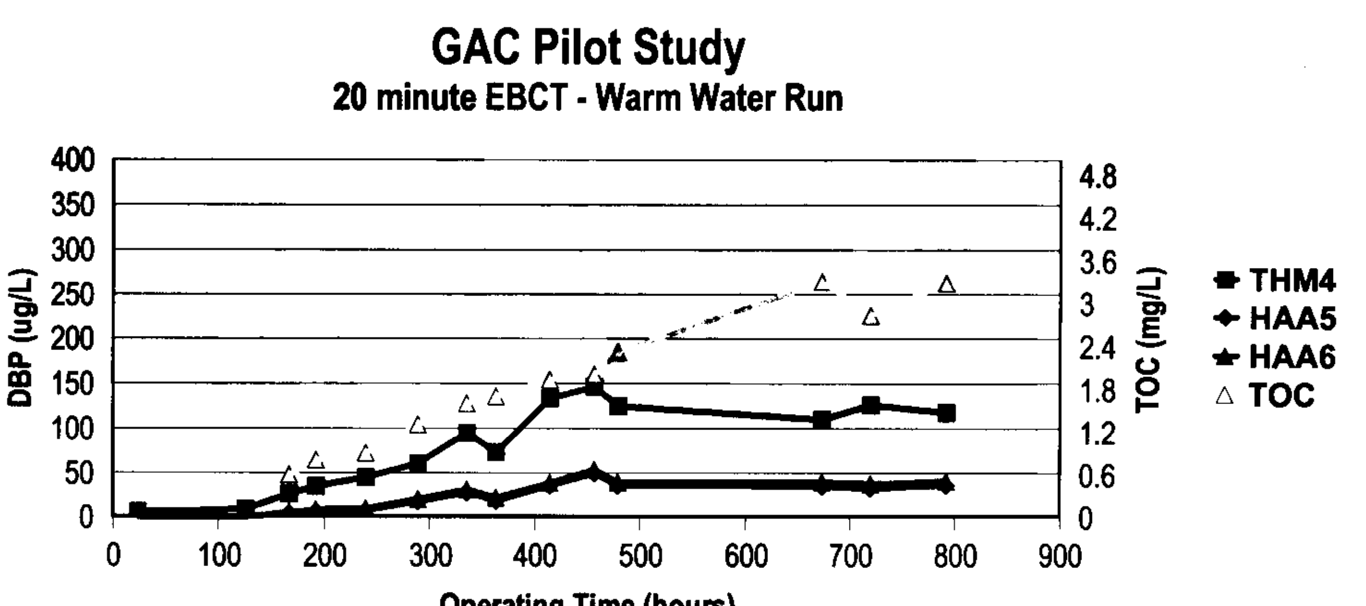
TOC Breakthrough Curve
Warm Water Pilot GAC Run
TOC mg/L
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
700
800
900
1000
Operating Time (hours)
Influent
10 Min EBCT
20 Min EBCT



TOC Breakthrough Curve
Warm Water Pilot GAC Run
TOC Normalized Concentration (C/Co)
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
700
800
900
1000
Operating Time (hours)
Influent
10 Min EBCT
20 Min EBCT


GAC Pilot Study
Influent Water - Warm Water Run
DBP (ug/L)
TOC (mg/L)
Operating Time (hours)
THM4
HAA5
HAA6
TOC
0
50
100
150
200
250
300
350
400
0
0.6
1.2
1.8
2.4
3
3.6
4.2
4.8
0
100
200
300
400
500
600
700
800
900


GAC Pilot Study
10 minute EBCT - Warm Water Run
DBP (ug/L)
TOC (mg/L)
Operating Time (hours)
THM4
HAA5
HAA6
TOC
0
50
100
150
200
250
300
350
400
0
0.6
1.2
1.8
2.4
3
3.6
4.2
4.8
0
100
200
300
400
500
600
700
800
900


GAC Pilot Study
20 minute EBCT - Warm Water Run
DBP (ug/L)
TOC (mg/L)
Operating Time (hours)
THM4
HAA5
HAA6
TOC
0
50
100
150
200
250
300
350
400
0
0.6
1.2
1.8
2.4
3
3.6
4.2
4.8
0
100
200
300
400
500
600
700
800
900

Saint Paul Water Utility

GAC Pilot Study - Cost Analysis

Alternative Number 2: Chloramine-GAC/Sand Filtration-Chloramine

Item No.	Description	Size	Units	Quantity (NO.)	Unit Cost ($)	Total Cost ($)
1	GAC Filter Media		tons	680	2,000	1,360,000
2	Flow Meter		each	3	25,000	75,000
3	Valves		each	3	30,000	90,000
4	Chlorine Feed System Modifications		LS	1	30,000	30,000
5	Ammonia Feed System Modifications		LS	1	30,000	30,000
	Sub-Total					1,585,000
	Design Contingency (30%)					475,500
	Overhead & Profit (12%)					190,200
	General Conditions (25%)					396,250
	Bonds & Insurance (2%)					31,700
	Sub-Total					2,678,650
	Final Design & Construction Management (15%)					401,798
	Total - 1996 Dollars					3,080,448
	Escalation 4%/yr, 2001 (22%)					677,698
	Total - 2001 Dollars					3,758,146

Cost Parameter	Parameter Value
Capital Recovery Interest Rate (%)	6%
Capital Recovery Period (years)	unknown
Overhead & Profit Factor (% of construction costs)	12%
Special Site Work Factor (% of construction costs)	15%
Construction Contingencies (% of construction costs)	15%
Engineering Fee Factor (% of construction costs)	10%-15%
1998 ENR Construction Cost Index (CCI base year 1913)	unknown
1998 Producers Price Index (PPI base year 1967 =100)	unknown
Labor Rate + Fringe ($/work-hour)	$22 + $8
Labor Overhead Factor (% of labor)	15%
Electric Rate ($/kW-h)	$0.035
Fuel Oil Rate ($/gal)	None
Natural Gas Rate ($/ft3)	$0.60
Current Process Water Rate ($/1000 gallons)	$2.00
Modifications to Exisiting Plant (% of construction costs)	100%