CITY OF TAMPA

HOWARD F CURREN AWTP

"TREATABILITY " STUDY-CONTROL OF THMs

September 27, 2005

MWH

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EXECUTIVE SUMMARY

The City of Tampa, as part of the National Pollutant Discharge Elimination System (NPDES) permitting process for the HFCAWTP, was given an administrative order (#AO-093-SW) by the Florida Department of Environmental Protection (FDEP) requiring a treatability study be conducted to investigate the formation and control of THMs in the plant effluent, particularly dichlorobromomethane and dibromochloromethane which are the THM compounds regulated in the NPDES permit. The results of the study and an evaluation of the feasible alternatives to consider at the HFCAWTP for THM control are summarized below.

The report addresses the investigation of the formation and control of THMs in the HFCAWTP effluent. In particular, this study addressed the chemistry of formation and etiology of THMs in the effluent, summarized the historical plant data and plant processes related to THM formation, treatment and control options, and a cost evaluation of alternative disinfection.

A number of alternatives were investigated to control the formation of dichlorobromomethane and dibromochloromethane in the HFCAWTP effluent. The treatment and THM control options investigated include the following:

- **Gravity Thickener** - The THM concentrations at the gravity thickener discharge make up approximately 5 percent of the final effluent THM concentrations and is not a significant contributor to the dichlorobromomethane exceedance.
- **pH control** - As the pH increases in the HFCAWTP effluent the THMs increase. Controlling the pH would require additional chemical treatment to lower the pH prior to disinfection and use of a caustic chemical to raise the pH prior to surface discharge (to above 6 pH units). This alternative has an estimated conceptual capital cost of $7,975,000 and an estimated conceptual O&M cost of $1,900,000 per year. Controlling the pH at the HFCAWTP to reduce THM concentrations does not appear to be a viable approach due to its significant costs.
- **Cooling Water Return Control** – Due to the amount of the cooling water return flow rate, there would be an increase of less than 10 percent in the formation of dichlorobromomethane and dibromochloromethane. While this is a source of additional DBP's, removal of this source would probably not significantly impact plant compliance with the DBP limits.
- **Bromide control** - Preventing or reducing saltwater intrusion in the wastewater collection system may reduce bromide concentrations and thus the levels of DBPs in the final effluent. While the average bromide level was relatively high in the late 1980's study, the variability in the wastewater does not indicate that bromide control could be a long-term viable DBP control strategy.
- **Methanol Reduction and TOC Control** - The methanol is less than the detection limit on the days when the THMs were analyzed at the HFCAWTP. There does not seem to be a relationship between methanol dosing and THM formation.

- **Cl_2 dose control** - The HFCAWTP staff lowered the Cl_2 dose after May 19, 2005. The reduction in the Cl_2 Dose after May 19, 2005, did not result in a reduction of the dichlorobromomethane and dibromochloromethane concentration.
- **UV Disinfection** – Utilizing a UV disinfection system to replace the chlorination system that is currently used at the HFCAWTP is generally more expensive than the other THM control alternatives, with an estimated conceptual total capital cost of $43,500,000 and an estimated conceptual O&M cost between $1,500,000 to $2,500,000. Conversion to a UV disinfection system would not be in the public interest.
- **Ozone Disinfection** - Due to the variability in the water quality in wastewater using ozone makes is difficult to achieve the required fecal coliform kill consistently. Also, the ozone demand would cause potentially high doses to be employed. Therefore, ozone is not recommended as an alternative disinfection system and the cost was not evaluated.
- **Aeration control** - The current operation at the HFCAWTP already employs a significant post-chlorination aeration step. Therefore, a reduction in THMs through the current operation is probably already occurring at the HFCAWTP after chlorination and additional aeration is not likely to improve or reduce THM formation.

The use of a mixing zone is a viable approach. A mixing zone would allow for the regulatory standard to be met, would provide for continuation of proven operational practices that achieve a high quality reclaimed water product, and is significantly less cost than the other alternatives that were analyzed. The initial data collected shows that there is approximately a 3 to 1 dilution of the THM concentrations occurring at the effluent boil within 29 feet of the end of the discharge pipe. Implementing a mixing zone will require an application to FDEP and coordination through the application review process. The City of Clearwater applied for a mixing zone for dichlorobromomethane and did ultimately receive a mixing zone consisting of a distance of two meters in circumference around the centerline of the outfall.

1.0 INTRODUCTION

This report represents the deliverable work product of Task 5 of the Howard F. Curren Advanced Wastewater Treatment Plant (HFCAWTP) Treatability Study – Control of Trihalomethanes (THMs) for the City of Tampa. This report summarizes the findings, conclusions, and recommendations of the Treatability Study.

1.1 Purpose

The City of Tampa, as part of the National Pollutant Discharge Elimination System (NPDES) permitting process for the HFCAWTP, was given an administrative order (#AO-093-SW) by the Florida Department of Environmental Protection (FDEP) requiring a treatability study be conducted to investigate the formation and control of THMs in the plant effluent, particularly dichlorobromomethane and dibromochloromethane which are the THM compounds regulated in the NPDES permit. The results of the study will be used to evaluate feasible alternatives to consider at the HFCAWTP for THM control.

The City of Tampa has requested MWH to perform this Treatability Study to evaluate the treatment and control of THM formation in the plant effluent. In particular, this study will address the following issues:

- Overview on the chemistry of formation and etiology of Trihalomethanes (THMs) in effluent wastewaters
- Summary of historical plant data and plant processes related to THM formation
- Techniques for control of dichlorobromomethane and dibromochloromethane formation
- Assessment of treatment approaches and options

2.0 TREATMENT SYSTEMS

2.1 Existing Treatment Systems

The Howard F. Curren Advanced Wastewater Treatment Plant (HFCAWTP) is a treatment facility with a annual average treatment capacity of 96 million gallons per day (mgd). The effluent water is discharged into Hillsborough Bay or used as reclaimed water for public access irrigation or industrial use. Wastewater enters the facility from sanitary sewer pipelines throughout the City of Tampa's service area and is subjected to preliminary and secondary treatment, nitrogen removal, post-aeration, chlorination, and dechlorination (see **Figure 2-1**).

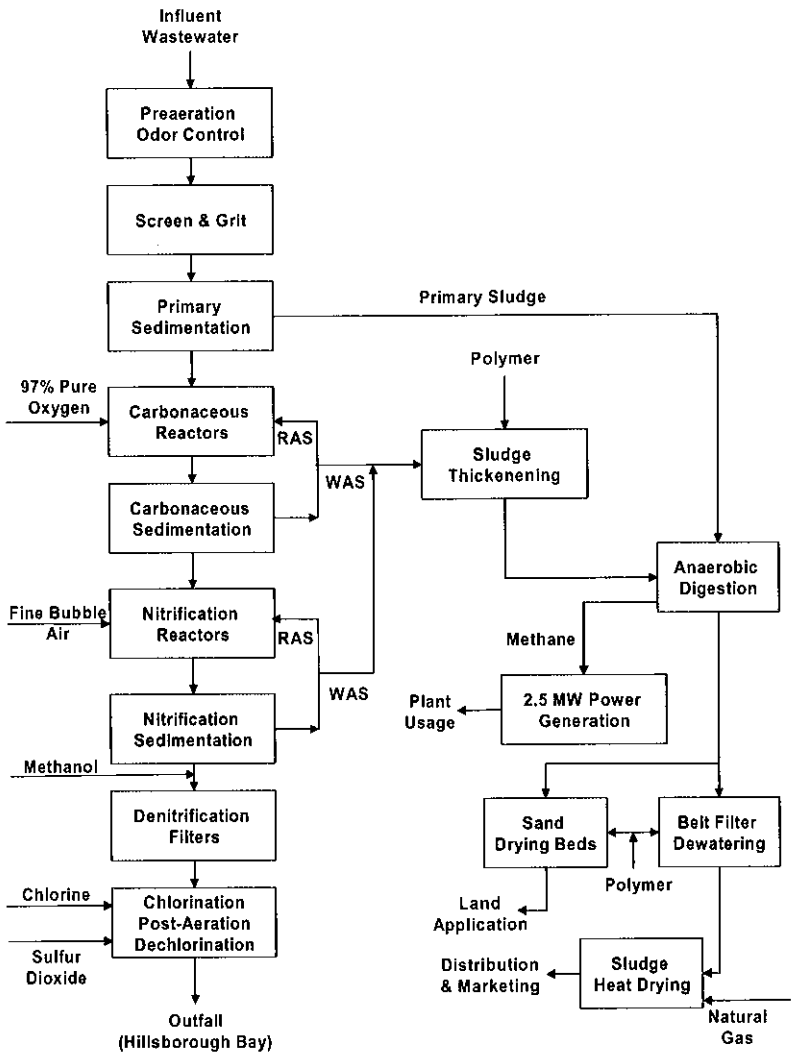

Figure 2-1
HFCAWTP Flow Schematic

2.1.1 Preliminary Treatment

The first treatment step is preliminary treatment, which includes aeration. Hydrogen sulfide is released and treated to reduce odor emissions. The raw wastewater is then filtered for solid material by mechanical bar screens with a 3/8-inch spacing. Next, grit is removed by decreasing the velocity of the wastewater to allow smaller particles to settle out for removal. Finally, gravity moves the water from the preliminary treatment on to eight primary sedimentation tanks with a total holding capacity of 5 million gallons and solids (primary sludge) settle to the base of the tanks during 1.2 hours of residence.

2.1.2 Secondary Treatment

During secondary treatment, the partially treated wastewater enters a High Purity Oxygen (HPO) System, in a plug flow pattern, where it is mixed with activated sludge to form mixed liquor. The HPO System transfers high purity oxygen to the mixed liquor, and carbonaceous BOD5 is removed and settled by gravity from the mixed liquor. The settled carbonaceous BOD5 or activated sludge is returned to the start of the HPO System, or is wasted.

At this point, greater than 90 percent of carbonaceous BOD5 and suspended solids and between 15 and 20 percent of the nitrogen has been removed from the wastewater. The partially treated wastewater continues on to the nitrification reactors.

2.1.3 Nitrification

During this second stage of secondary treatment, the partially treated wastewater enters a Diffused Aeration Reactor (DAR), in a plug flow pattern, where it is mixed with activated sludge to form mixed liquor. In the DAR, nitrification occurs where ammonia (NH4-) is converted to nitrate (NO3-), the diffused air is provided to the mixed liquor, and solids are removed and settled by gravity from the mixed liquor. The solids or activated sludge are returned to the start of the DAR, or is wasted.

At this point, approximately 95 percent of the carbonaceous BOD5 and suspended solids have been removed from the wastewater. Furthermore, greater than 95 percent of the ammonia-nitrogen from the wastewater has been converted into nitrate-nitrogen. The partially treated wastewater continues on to the denitrification filters.

2.1.4 Denitrification

During this anaerobic stage of treatment, the nitrate-nitrogen is converted to nitrogen gas through deep bed, mono-media denitrification filters. The filters contain denitrifying cultures of facultative bacteria that live off of methanol and convert nitrate to nitrogen. Small nitrogen gas bubbles are formed within the filter, are released in a short backwash or are trapped in the filter.

2.1.5 Post Aeration and Chlorination

Effluent from denitrification is anerobic and aerated by diffused air to a residual of at least 5.0 milligrams per liter (mg/L). At this time, Cl_2 is also added to the wastewater to maintain a total chlorine residual of at least 1.0 mg/L.

At this point in the process, the wastewater has been fully treated and can be used as a resource. The treated wastewater can be used as reclaimed water or sulfur dioxide can be added to remove the total chlorine (to less than 0.01 mg/L total chlorine residual) and the treated wastewater can be discharged to Hillsborough Bay.

2.1.6 Sludge Treatment and Biosolids Production

Residuals are collected from each stage of treatment. The solids from the primary screens are removed and transported to a Refuse to Energy Facility. Grit is washed, dewatered and hauled to a landfill for disposal. Wasted solids are pumped to gravity thickening tanks and or the belt thickener for thickening. Sludge and scum from the primary sedimentation and scum from secondary treatment is pumped to the mixed sludge pumping station and onto anaerobic digestion. Solids removed from secondary treatment that are not returned to the HPO reactors or DAR system, respectively, are wasted. Thickened wasted solids are then sent to anaerobic digestion.

A number of useful products are created from the process of anaerobic digestion. Anaerobic digestion creates methane gas that is burned in methane fueled engine generators to produce electricity that is used to generate 20 percent of the HFCAWTP's electrical requirements. Anaerobic digestion also creates digested sludge that is dewatered and/or dried, creating biosolids. Sludge is belt pressed and dried in a heat drying plant, using natural gas, to produce a fertilizer biosolid product for distribution and marketing. Biosolids that are not heat dried are generally used for land applications as class B cake.

3.0 THM FORMATION

3.1 THM Formation Kinetics

THMs are formed by the reaction of dissolved organic matter (DOM) with disinfectants. Their control can be achieved in three ways: by removing the DOM, altering the disinfection scheme, or removing the THM after it is formed. The level of formation is a function of a number of variables, including character and concentration of the DOM, pH of the reaction, concentration of ions in the bulk water, concentration of the disinfectant, and temperature. The four THMs consist of chloroform, bromoform, dichlorobromomethane, and dibromochloromethane. For the purposes of this study we are particularly interested in dichlorobromomethane and dibromochloromethane since these are the two compounds regulated by the NPDES permit. The HFCAWTP operations staff provided historical data of analyses for dichlorobromomethane and dibromochloromethane.

3.2 HFCAWTP THM Data

Dichlorobromomethane is one of the four THM's. The HFCAWTP currently is required by the Florida Department of Environmental Protection (FDEP) to meet an annual average concentration of 22 µg/L for dichlorobromomethane and report the average monthly values. The City of Tampa has exceeded this limit using chlorination disinfection of its reclaimed wastewater in the recent past. **Figure 3-1** shows the dichlorobromomethane annual average concentration from 1995 to 2004. The annual average dichlorobromomethane concentration has exceeded the 22 µg/L annual average limit in four of the past five years.

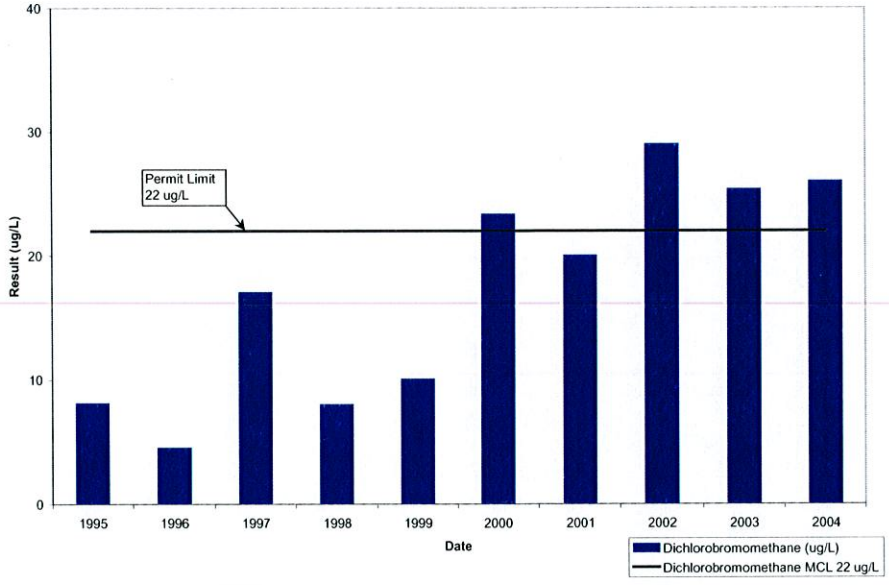

Figure 3-1
Dichlorobromomethane Annual Average Concentration

The other regulated THM is dibromochloromethane, which has an MCL set at 34 ug/L. The HFCAWTP is currently only required to report the maximum monthly values for dibromochloromethane. **Figure 3-2** shows the dibromochloromethane annual average concentration from 1995 to 2004. The annual average dibromochloromethane concentration does not exceed the 34 ug/L standard between 1995 and 2004.

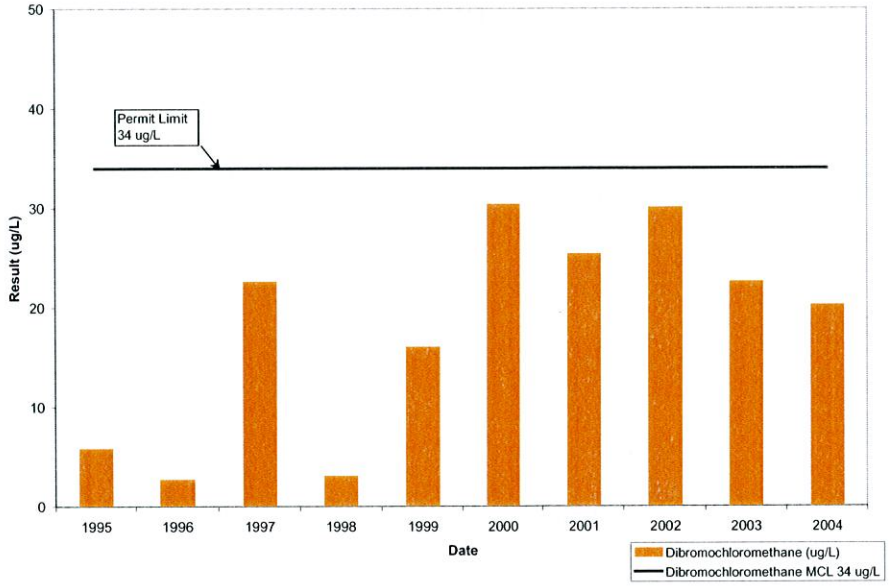

Figure 3-2
Dibromochloromethane Annual Average Concentration

The HFCAWTP operations staff provided the following daily historical data, which is analyzed to determine any potential trends that may exist with the THM values in the following section:

- Final Effluent Dichlorobromomethane,
- Final Effluent Dibromochloromethane,
- Effluent Boil Dichlorobromomethane,
- Effluent Boil Dibromochloromethane,
- Gravity Thickener Dichlorobromomethane,
- Gravity Thickener Dibromochloromethane,
- Cl_2 dose,
- Cl_2 residual,
- Gravity Thickener Bleach Dose,
- Final Effluent pH,
- Denitrification pH,
- Final Effluent Dissolved Oxygen (DO),
- Final Effluent Total Organic Carbon (TOC), and
- Denitrification Methanol

Various analyses were performed to determine if any of these treatment processes or parameters influenced the THM concentration.

3.2.1 Cl_2 Dose and THM

The dichlorobromomethane and dibromochloromethane are plotted below (see **Figures 3-3 to 3-8**) for analysis of potential trends with the average Cl_2 dose that was applied to the effluent. Figure 3-3 shows that the average Cl_2 dose increased since the year 2000 and there was also an increase in the dichlorobromomethane. Figure 3-4 also shows an increase in the same time period for the dibromochloromethane. However, Figures 3-5 and 3-6 show no apparent relationship between Cl_2 dose and dichlorobromomethane or dibromochloromethane. Figures 3-7 and 3-8 show no relationship between chlorine residual, dichlorobromomethane and dibromochloromethane. In summary, other than the relationship between the average increase in THMs and the average chlorine dose, there is no positive correlation between Cl_2 dose and THM concentration.

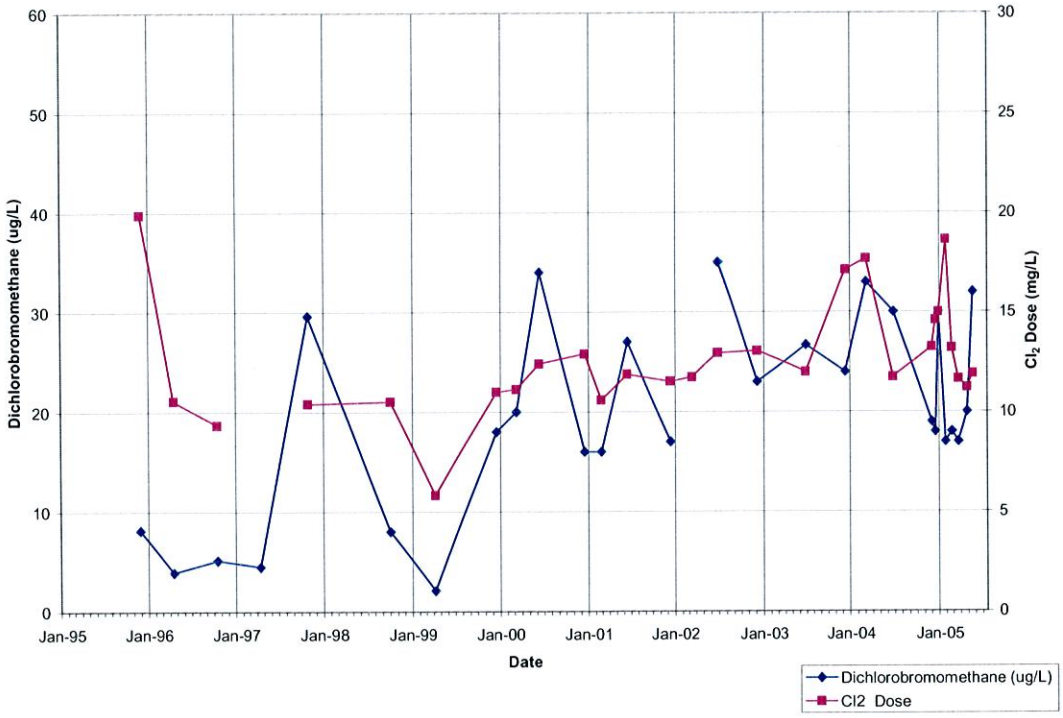

Figure 3-3
Dichlorobromomethane and Cl_2 Dose versus Time

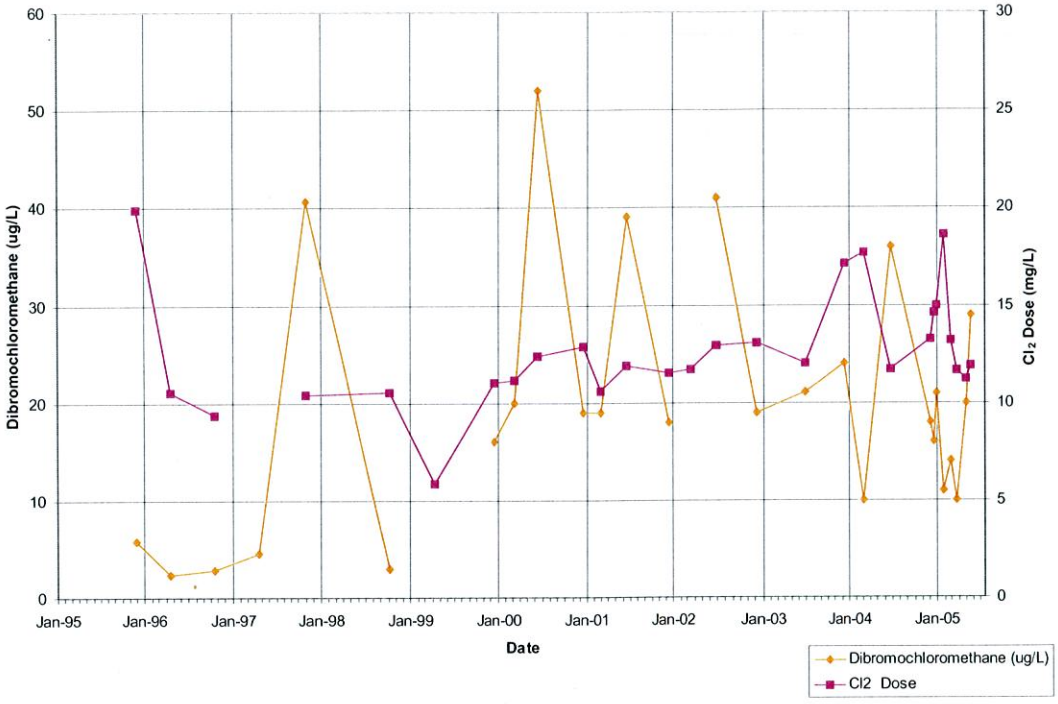

Figure 3-4
Dibromochloromethane and Cl_2 Dose versus Time

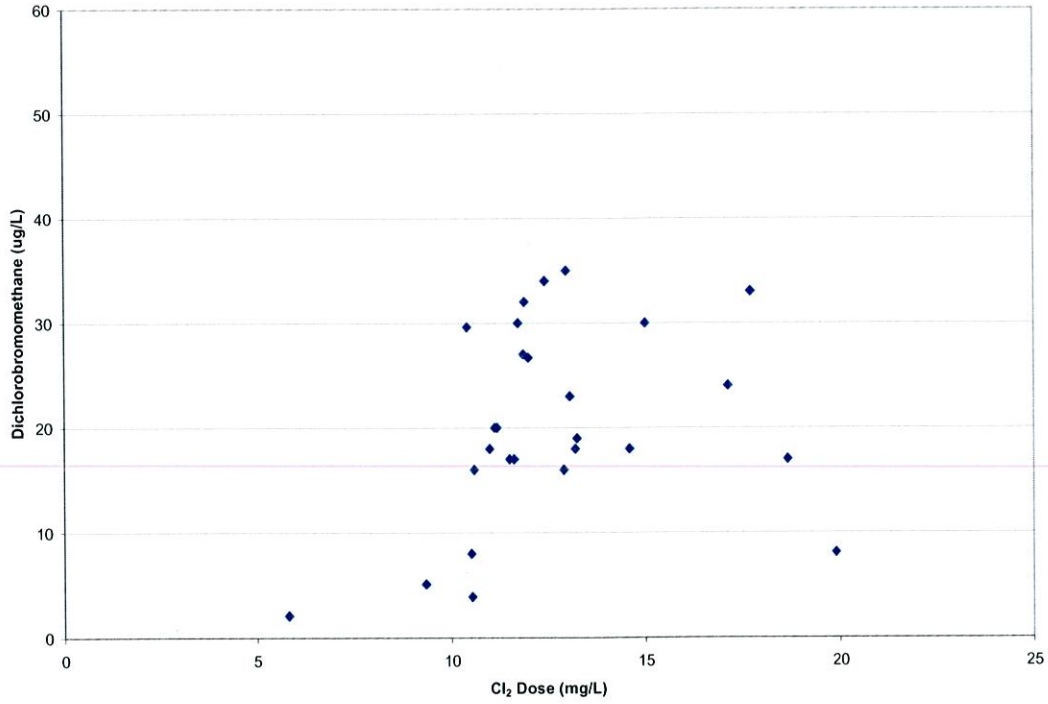

Figure 3-5
Dichlorobromomethane versus Cl_2 Dose

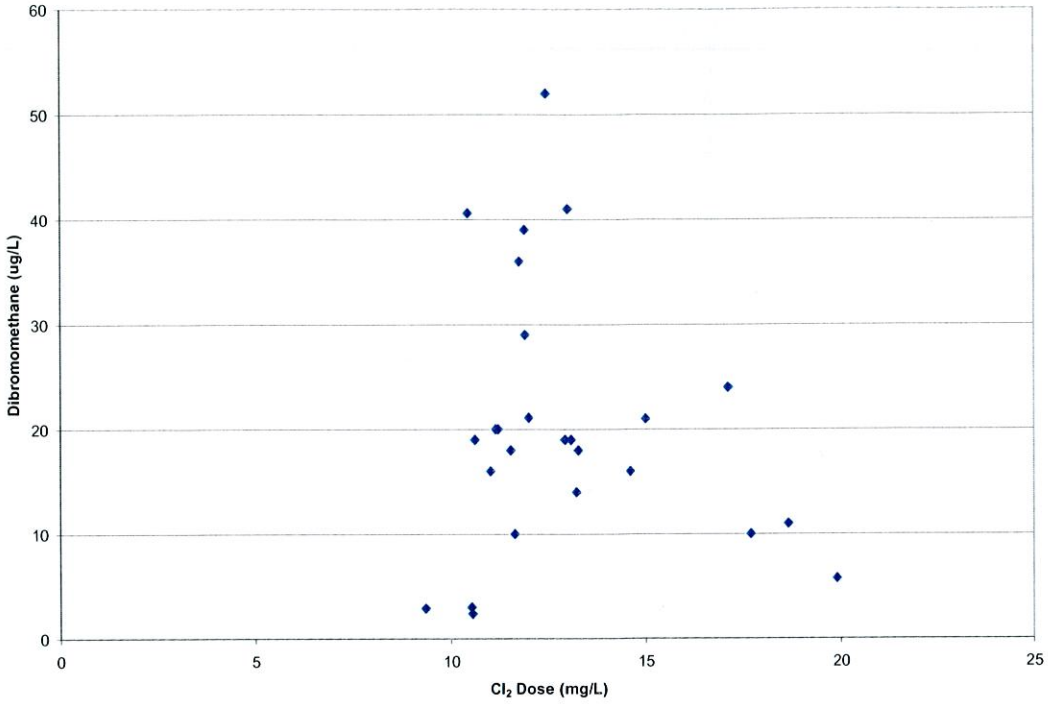

Figure 3-6
Dibromochloromethane versus Cl_2 Dose

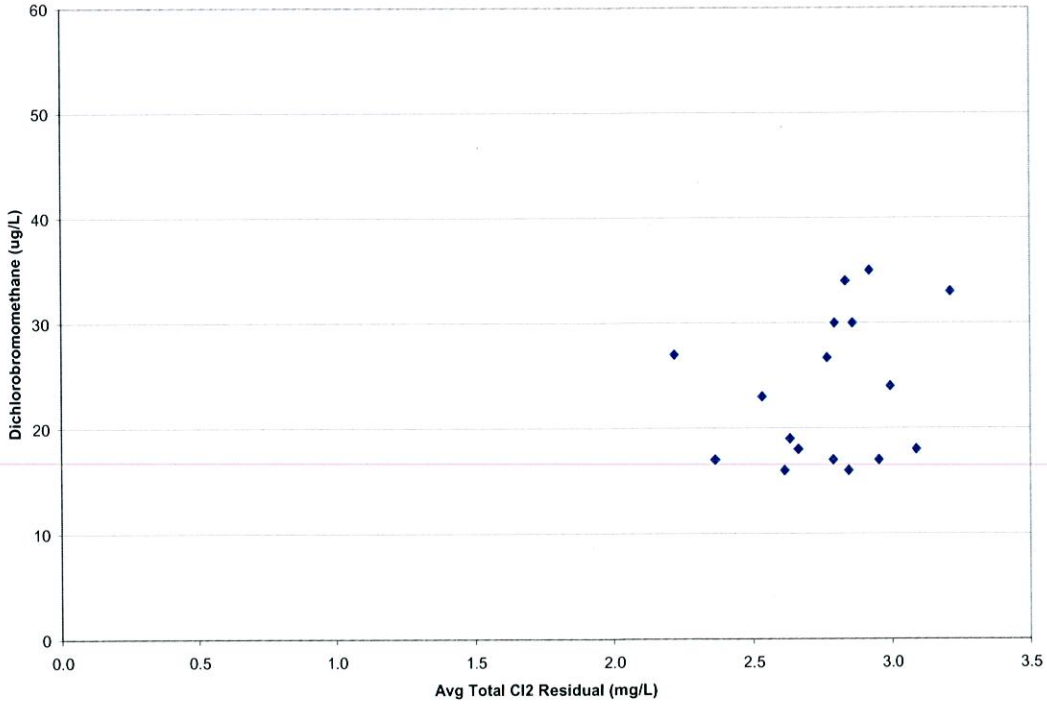

Figure 3-7
Dichlorobromomethane versus Average Total Cl_2 Residual

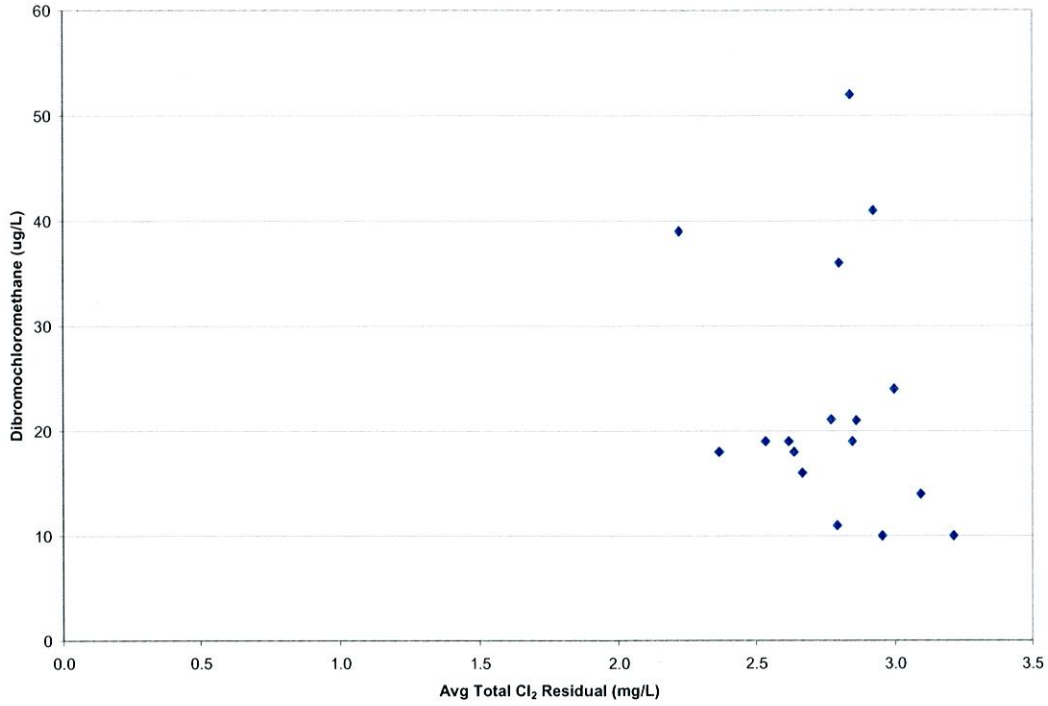

Figure 3-8
Dibromochloromethane versus Average Total Cl_2 Residual

Figure 3-9 depicts the minimum, maximum, and average Cl_2 doses on the same days when the THM concentrations were sampled. Figure 3-9 also shows that the average Cl_2 dose increases after 2000. Discussions with the HFCAWTP operations staff indicated that after 2000, the HFCAWTP increased the Cl_2 dose and went to breakpoint chlorination to maintain a total chlorine residual of 1.0 mg/L. Comparing the breakpoint curves in **Figure 3-10** and **Appendix B** between 1998, 1999, and 2005, the breakpoint chlorination curves are similar in that the breakpoint occurs at a Cl_2 dose close to 8 mg/L. The breakpoint chlorination curve for June 22, 2005, shows that the breakpoint was at approximately 7 mg/L on that particular day.

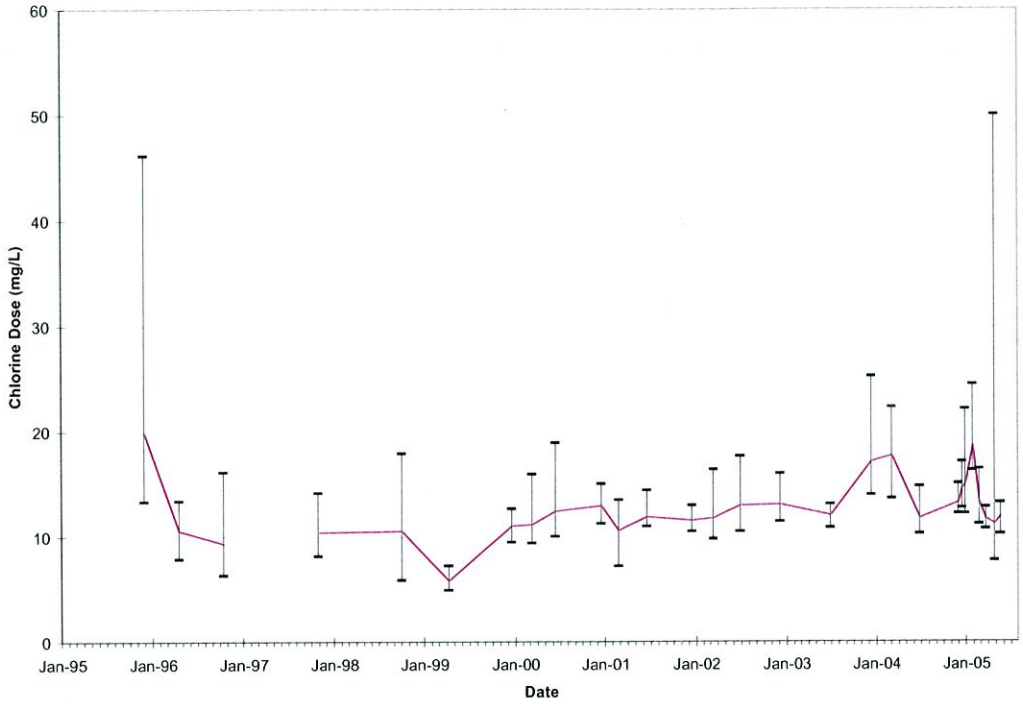

Figure 3-9
Cl_2 Dose versus Time

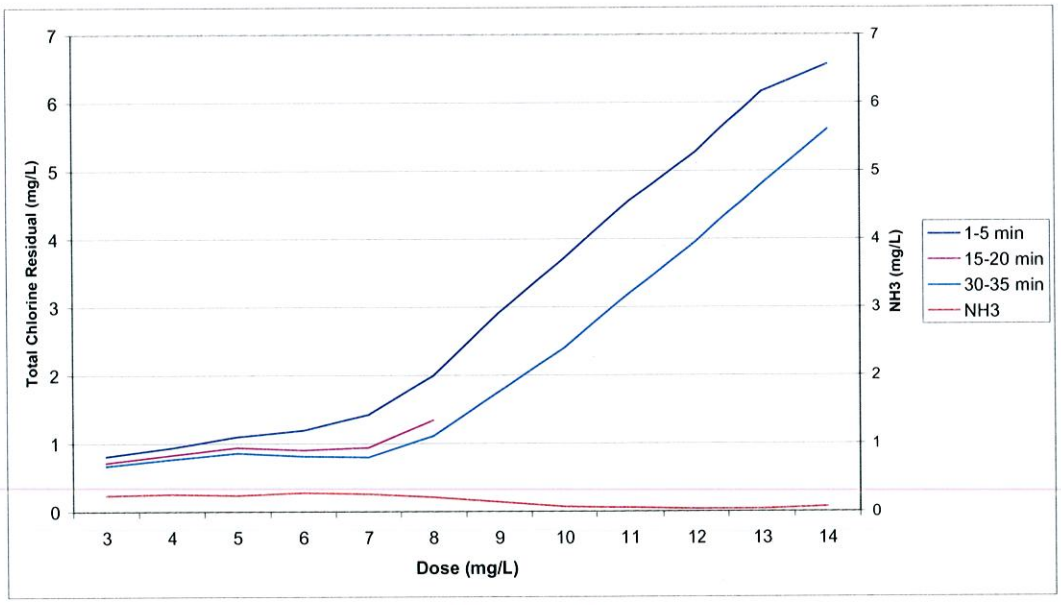

Figure 3-10
6/22/2005 Breakpoint Chlorination Curve

3.2.2 pH and THM

The pH data that was provided by HFCAWTP staff is sampled on the Final Effluent, which is dechlorinated. Since no pH data was available before chlorination and after denitrification, samples were taken after denitrification and before chlorination for ten days to determine the relationship with the final effluent pH. Based on **Figure 3-11**, the pH is reduced 0.93 pH units going through breakpoint chlorination and dechlorination. An adjustment factor of 0.93 was applied to the final effluent pH to determine the denitrification pH. This adjusted denitrifaction pH was then used to investigate potential trends, between pH and THM formation.

The adjusted pH versus Dichlorobromomethane and Dibromochloromethane were plotted on **Figures 3-12 and 3-13** and shows that, in general, as the denitrification pH increases the Dichlorobromomethane and Dibromochloromethane increase as well. Plots showing denitrification pH versus Dichlorobromomethane and Dibromochloromethane can be seen in Appendix A (Figure A-6 and A-7).

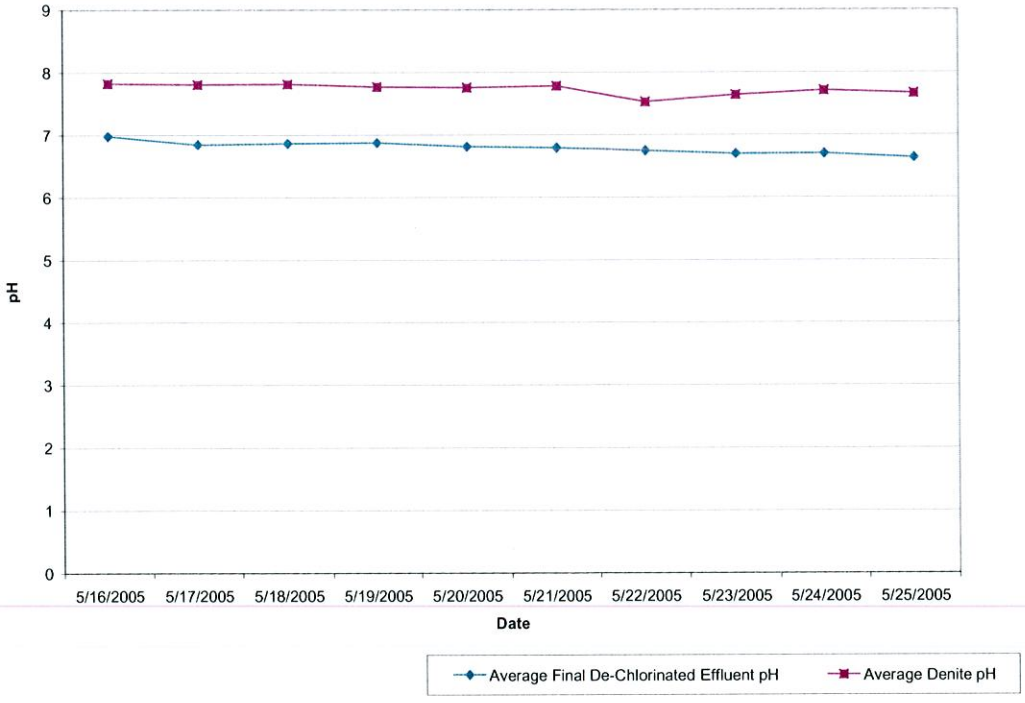

Figure 3-11
pH at Denitrification and pH at Final Effluent versus Time

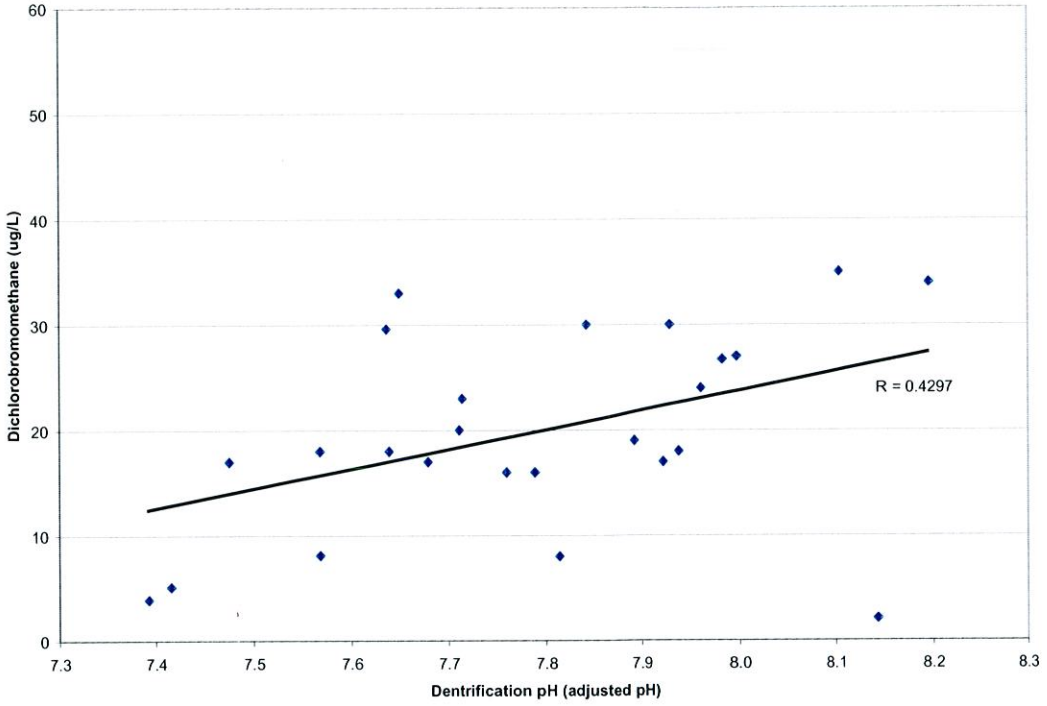

Figure 3-12
Dichlorobromomethane versus Denitrification pH (adjusted pH)

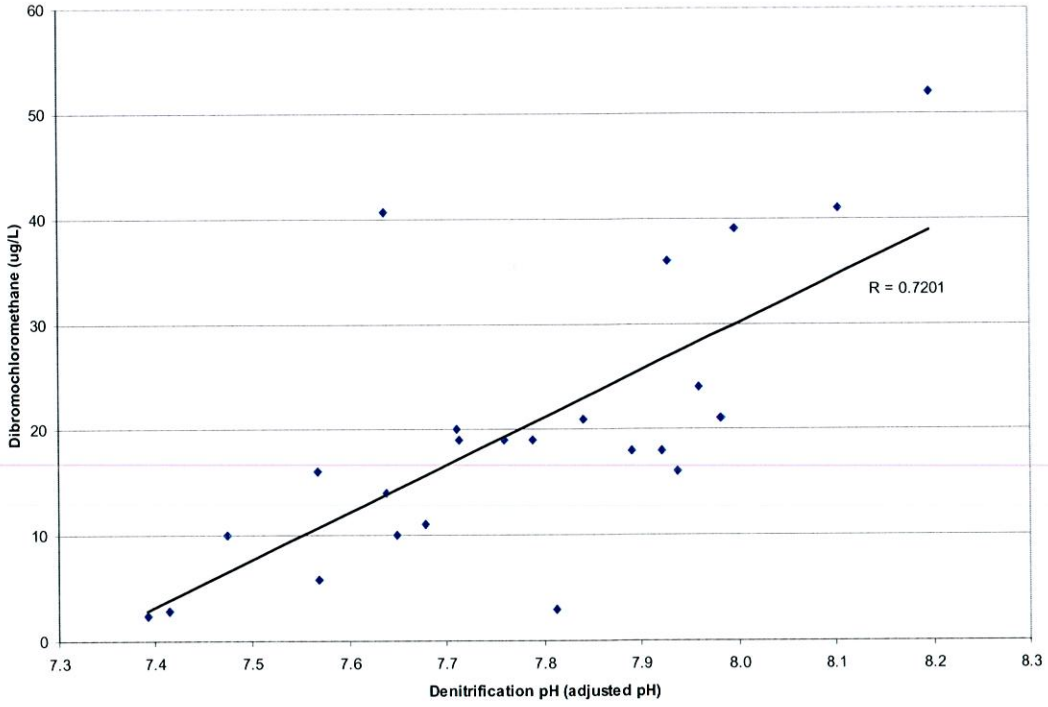

Figure 3-13
Dibromochloromethane versus Denitrification pH (adjusted pH)

3.2.3 TOC and THM

The relationship between TOC of the final effluent and THMs was also investigated. TOC versus dichlorobromomethane and dibromochloromethane can be seen in **Figures 3-14** and **3-15**. The TOC ranges from 8 to 16 mg/L between the time period of October 1998 and March 2005. Dichlorobromomethane, dibromochloromethane, and TOC versus time can be seen in Appendix A (Figure A-8). Based on these figures there does not appear to be any relationship between TOC and THMs.

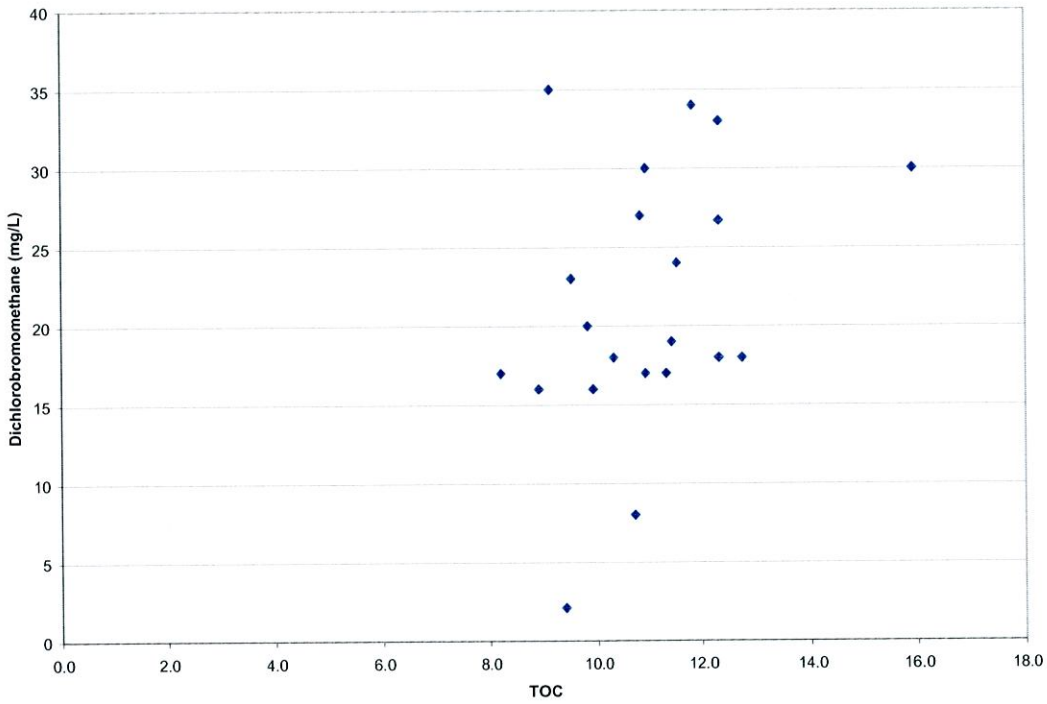

Figure 3-14
Dichlorobromomethane versus TOC

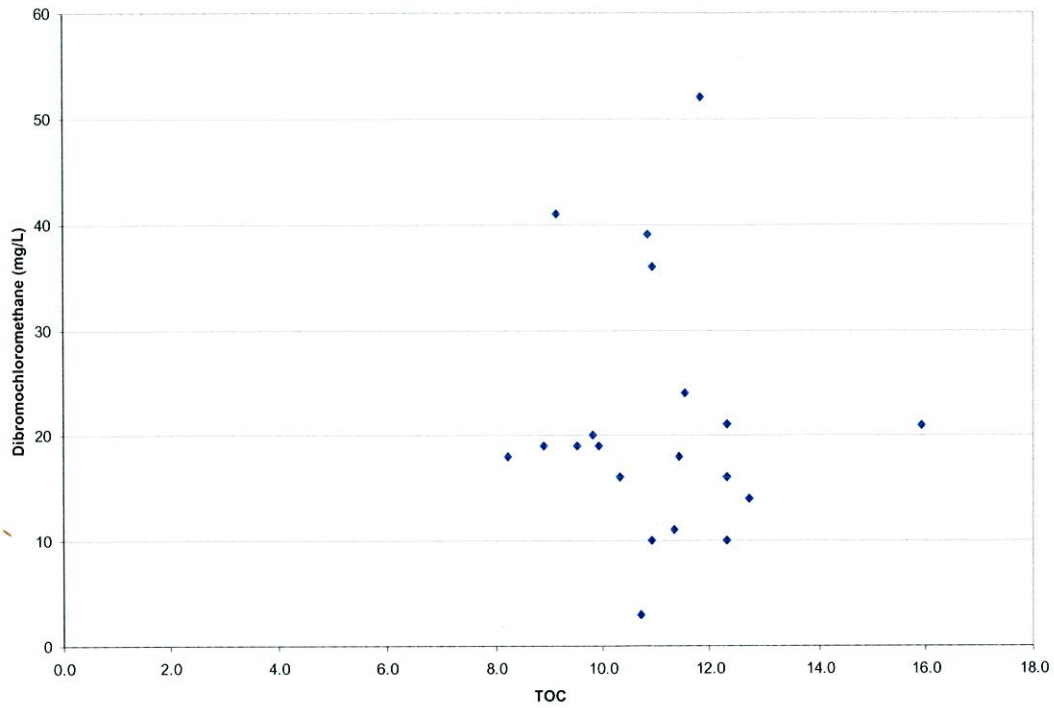

Figure 3-15
Dibromochloromethane versus TOC

3.2.4 Methanol and THM

The relationship between methanol and THMs were evaluated. The methanol concentration at denitrification between October 1998 to March 2005 was less than 0.21 mg/L for the days when dichlorobromomethane and dibromochloromethane were sampled. A graph of the methanol, dichlorobromomethane, and dibromochloromethane versus time can be seen in Figure A-9 in Appendix A. Based on this analysis there is no relationship between methanol and THMs.

3.2.5 Bleach Dose at the Gravity Thickeners and THM

It was discovered during discussions with the HFCAWTP staff that bleach is used at the gravity thickeners. The variation of bleach dose at the gravity thickeners along with relationship between the bleach dose and THMs can be seen in **Appendix A (Figures A-10, A-11, and A-12)**. The contribution of the chlorinated flow from the gravity thickeners to the total THM concentration is very small and not significant.

3.2.6 Ammonia and THM

The relationship between ammonia and THMs were evaluated to determine if a relationship existed. Based on **Figures A-13 and A-14** in **Appendix A,** there is no relationship present.

3.3 Tampa Bay Water Downstream Augmentation Project, THM Study

As part of the Tampa Bay Water Downstream Augmentation Project, a THM formation study was performed on the HFCAWTP de-nitrified effluent. A twenty-gallon sample of filtered undisinfected reclaimed water was collected from the HFCAWTP and delivered to the MWH Applied Research Department testing laboratory in Monrovia, CA. Using the reclaimed water, several series of bench-scale tests were conducted to determine rate of disinfection decay and chlorine demand and evaluate disinfection by-product (DBP) formation.

3.3.1 Free Chlorine Demand and Rate of Decay

To evaluate how the existing disinfection strategy would impact the concentrations of TTHMs and HAA5 formed, a series of 24-hour simulated distribution system (SDS) tests were performed. These SDS tests simulate the water as it passes through the pipeline used to augment flow to the Hillsborough River, Tampa Bypass Canal, or Alafia River. In these SDS tests, the reclaimed water was dosed with disinfectant and allowed to incubate headspace-free in the dark at 20°C up to 24 hours. Samples were collected and analyzed for TTHM and HAA5 concentrations at various times. A maximum time period of 24 hours was selected since the reclaimed water could remain in the pipeline for 24 hours. However, calculated pipeline residence times could vary between 2 and 8 hours when augmentation is occurring.

The first step in preparing the SDS tests was to evaluate how the disinfectant reacts in the reclaimed water. The decays of free chlorine over the 24-hour period are graphically presented in **Figure 3-16**. Based on the rate of decay, the chlorination dose of 21-mg/L resulted in a free chlorine residual of less than 0.8 mg/L after 24 hours. This was therefore an appropriate dose to ensure that a positive free chlorine residual (0.5 – 1 mg/L) would be maintained throughout the reclaimed water pipeline. If the chlorination dose were increased by only 1.0 mg/L (to 22 mg/L free chlorine), a positive residual of 1.2 mg/L would be present after 24 hours. Additionally, it was determined that the calculated instantaneous demand of the reclaimed water sampled is 13 mg/L.

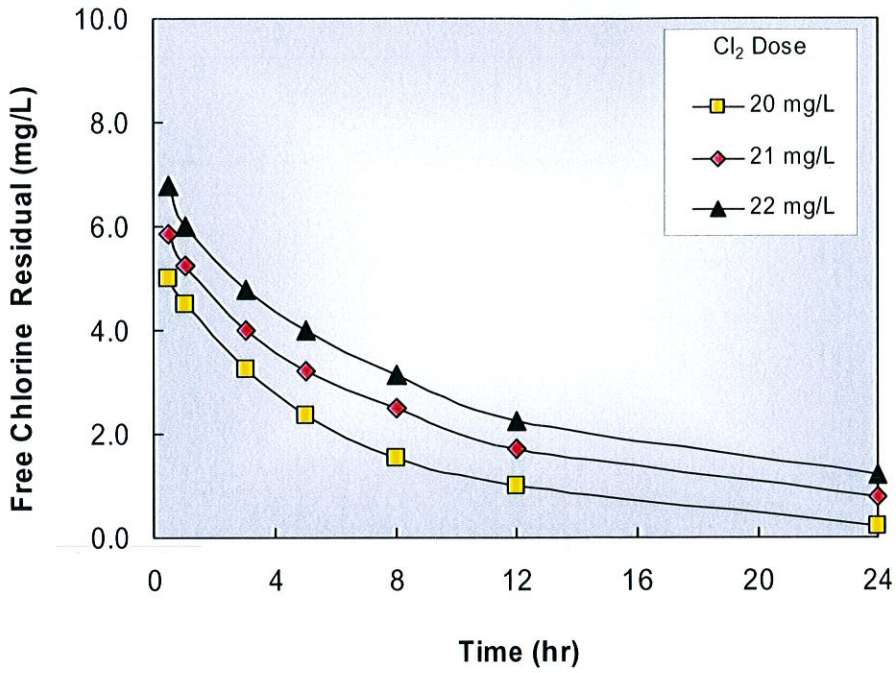

Figure 3-16
Rate of Free Chlorine Decay

3.3.2 Disinfection By-Product Testing

Once the demand and rate of decay had been determined, disinfection and simulated distribution system (SDS) tests were performed to compare the anticipated formation of disinfection by-products from chlorine. TTHM and HAA5 samples were collected over time to characterize DBP formation kinetics.

Free Chlorine DBP Formation Test

Reclaimed water was dosed with 21-mg/L free chlorine and stored headspace-free in the dark at 20°C. Samples were collected from this batch after 30 min, 1 hr, 3 hr, 5 hr, 8 hr, 12 hr, and 24 hr, and analyzed for TTHM and HAA5 concentrations. The free chlorine residual after 24 hours was 0.7 mg/L, as expected from previous demand/decay experiments.

Figure 3-17 graphically compares the concentrations of TTHMs and HAA5 formed during the 24-hour contact period. DBP formation was increased with increased chlorine contact time, and at 30 minutes TTHM and HAA5 levels were 88 and 50 µg/L, respectively. DBP levels continued to increase over the total incubation time, and after 24 hours TTHM and HAA5 levels were at 245 and 110 µg/L, respectively. **Table 3-1** shows the free and total chlorine residual measured along with pH.

Table 3-2 details the THM and HAA species measured at each contact time. Chlorodibromomethane and bromodichloromethane are the two THM species that are regulated by the NPDES permit. The state NPDES standards are 22 µg/L and 34 µg/L

for bromodichloromethane and chlorodibromomethane, respectively. Table 3-2 shows that these regulatory limits are exceeded after 0.5 hours for bromodichloromethane and 1 hour for chlorodibromomethane following disinfection at a chlorine dose of 21 mg/L.

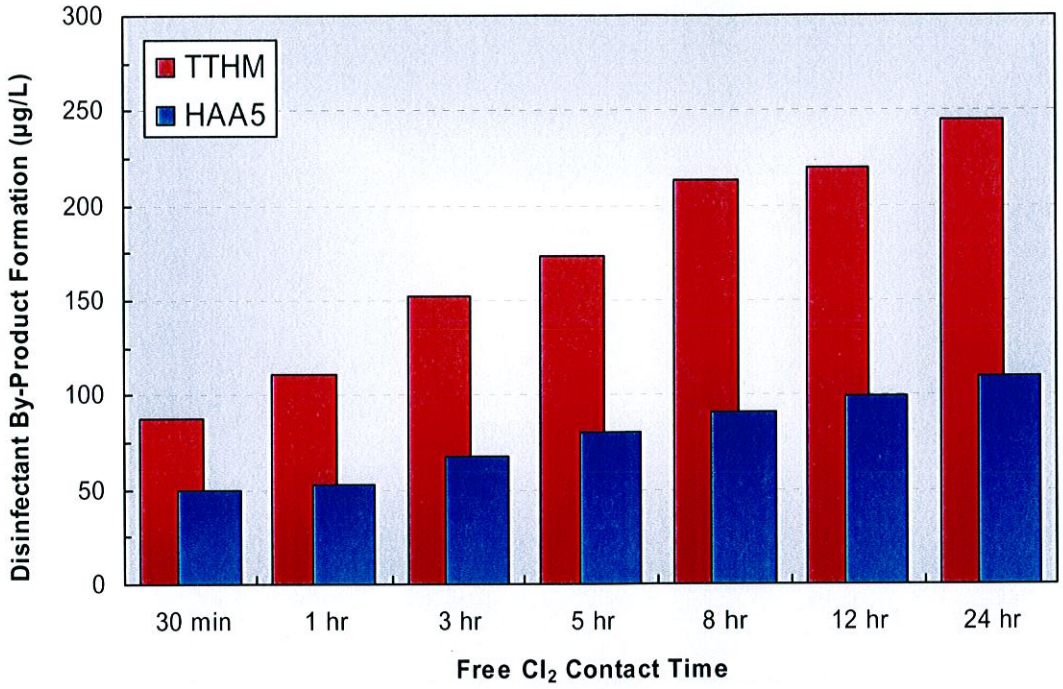

Figure 3-17
DBP Formation Kinetics (21 mg/L free chlorine)

Table 3-1
Free Chlorine SDS Water Quality

Contact Time	Water Quality Parameters		
(hr)	Free Cl_2 Residual (mg/L)	Total Cl_2 Residual (mg/L)	pH
0.5	5.0	5.8	7.9
1	4.5	5.3	7.9
3	3.3	4.4	7.9
5	2.4	3.1	7.9
8	1.6	2.6	7.9
12	1	1.7	7.9
24	0.7	1	7.9

Table 3-2
Free Chlorine SDS Disinfection By-Product Summary

Haloacetic Acids	Units	0.5 hr	1 hr	3 hr	5 hr	8 hr	12 hr	24 hr
bromochloroacetic acid	(µg/L)	13	14	17	20	22	23	26
dibromoacetic acid	(µg/L)	7.7	7.1	6.2	9.4	9.3	10	11
dichloroacetic acid	(µg/L)	19	19	26	30	35	39	45
monobromoacetic acid	(µg/L)	4.1	4.2	4.7	5.1	5.4	5.4	5.6
monochloroacetic aid	(µg/L)	<2	<2	<2	<2	<2	<2	<2
trichloroacetic acid	(µg/L)	19	23	31	36	41	45	51
HAA5	(µg/L)	*50*	*53*	*68*	*81*	*91*	*99*	*113*
Trihalomethanes								
bromoform	(µg/L)	6.3	7.2	8.8	9.4	11	10	11
chloroform	(µg/L)	19	29	43	51	95	73	86
chlorodibromomethane	(µg/L)	31	36	46	51	68	61	64
bromodichloromethane	(µg/L)	32	39	54	62	89	76	84
TTHM	(µg/L)	*88*	*111*	*152*	*173*	*263*	*220*	*245*

An additional test was performed to determine if air stripping could be used to remove any DBPs formed during the SDS test. A portion of the 24-hour sample (containing 245 µg/L TTHM and 113 µg/L HAA5) was sparged with air for 10 minutes at 60 mL/min in a glass-washing bottle. A sample was collected and analyzed for DBPs. **Figure 3-18** compares the formation of TTHMs and HAA5 for sparged and unsparged samples. As a result of the sparging, TTHM levels reduced by 14 percent (from 245 to 214 µg/L). Sparging had no effect on HAA5. **Figure 3-19** shows the impact of sparging on individual DBPs.

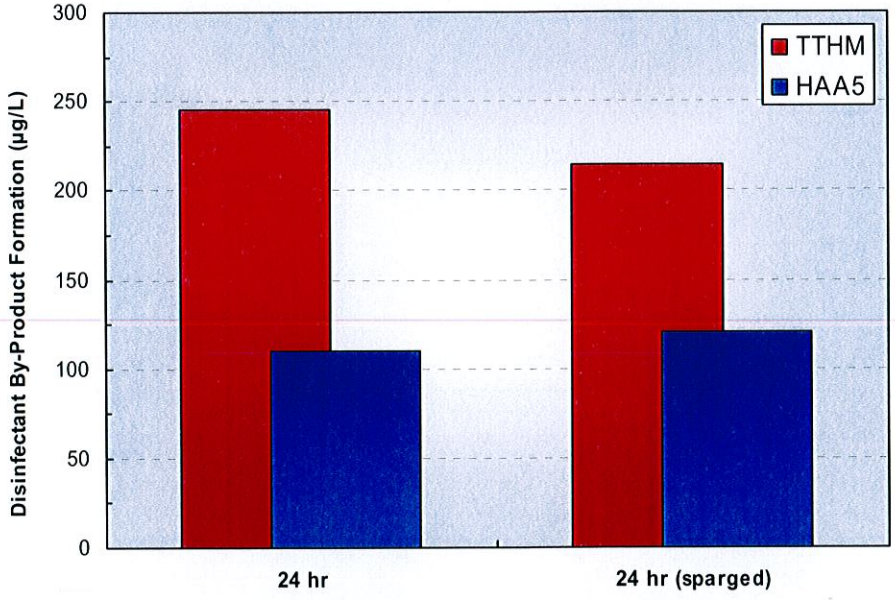

Figure 3-18
Impact of Air Stripping on DBP Formation of Chlorinated Samples

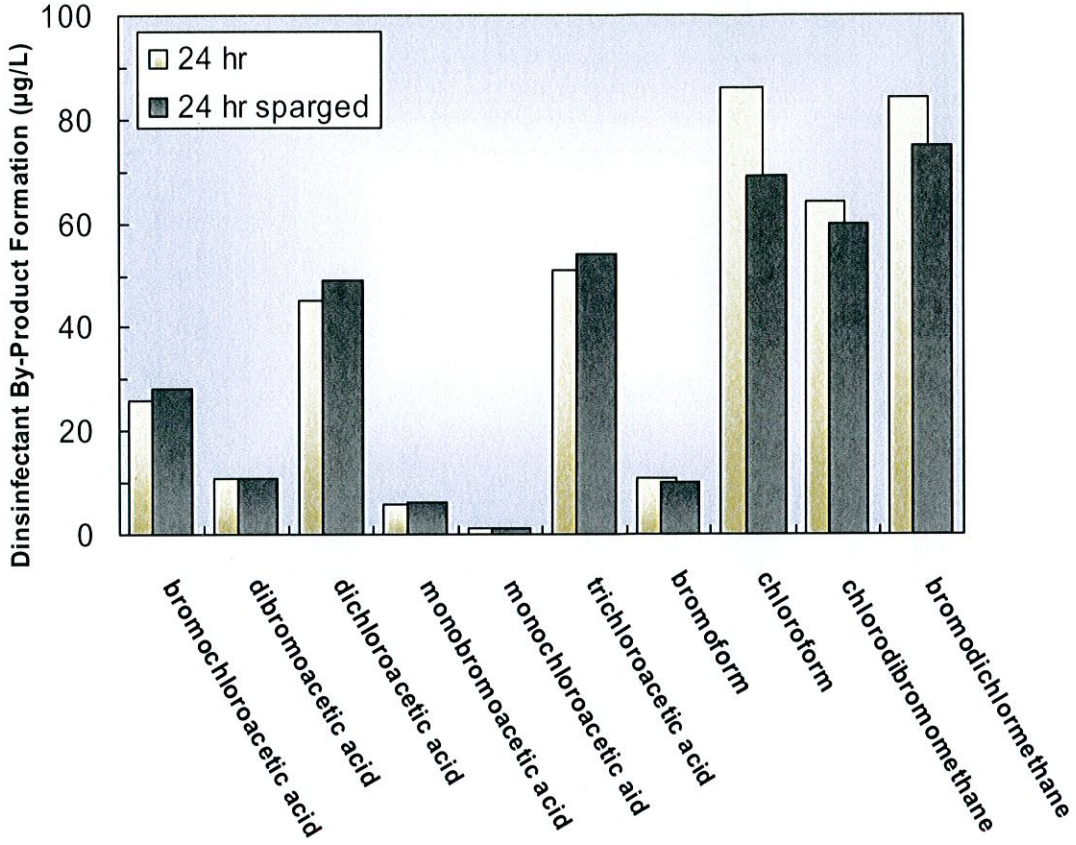

Figure 3-19
DBP Speciation of Sparged and Unsparged Chlorinated Samples

3.3.3 Additional Free Chlorine DBP and Microbial Inactivation Testing

An additional experiment was designed to determine if a lower free chlorine dose could achieve sufficient microbial inactivation while curbing DBP formation. Using a fresh reclaimed water sample, a free chlorine dose was chosen to achieve a 1.0 mg/L total chlorine residual immediately after dosing, to comply with State of Florida high level disinfection requirements. Samples were then collected after 15 and 30 minutes of contact time, dechlorinated, and TTHM, HAA5, coliform/HPC were analyzed.

Table 3-3 and **Figure 3-20** summarizes results from the additional experiment. A free chlorine dose of 5.8 mg/L was required to achieve a 1 mg/L total chlorine residual, after dosing. Free chlorine was measured as 0.2 mg/L. Samples collected after 15 minutes of contact time had low TTHM and HAA5 levels (13 and 19 µg/L). There was little to no difference in DBP formation in the 30-minute contact time sample. The total chlorine residual after 15 and 30 minutes were both measured at approximately 0.5 mg/L, however, no free chlorine was present in the treated sample. The absence of free chlorine was expected due to the presence of approximately 2.1-mg/L total nitrogen in the undisinfected reclaimed water sample. It is important to note that although low TTHM

and HAA5 levels were observed after 30 minutes, the total chlorine residual would most likely be consumed within a couple hours.

Table 3-3
Results of Additional Testing Performed with 5.8 mg/L Free Chlorine Dose

Haloacetic Acids	Units	0 min	15 min	30 min
bromochloroacetic acid	(µg/L)	--	3.5	3.6
dibromoacetic acid	(µg/L)	--	1.3	1.3
dichloroacetic acid	(µg/L)	--	5.8	5.9
monobromoacetic acid	(µg/L)	--	1.4	1.4
monochloroacetic aid	(µg/L)	--	<2	<2
trichloroacetic acid	(µg/L)	--	4.1	4.1
HAA5	(µg/L)	--	*13*	*13*
Trihalomethanes				
bromoform	(µg/L)	--	1	1.1
chloroform	(µg/L)	--	6.5	6.6
chlorodibromomethane	(µg/L)	--	4.6	4.8
bromodichloromethane	(µg/L)	--	7.1	7.6
TTHM	(µg/L)	--	*19*	*20*
Water Quality				
Free Chlorine	(mg/L)	<0.01	0.05	0.04
Total Chlorine	(mg/L)	<0.01	0.56	0.51
pH		7.9	7.9	7.9
Fecal Coliform	(MPN/100mL)	170	<2	<2
Total Coliform	(MPN/100mL)	11000	17	50
HPC	(CFU/mL)	>5700	64	52

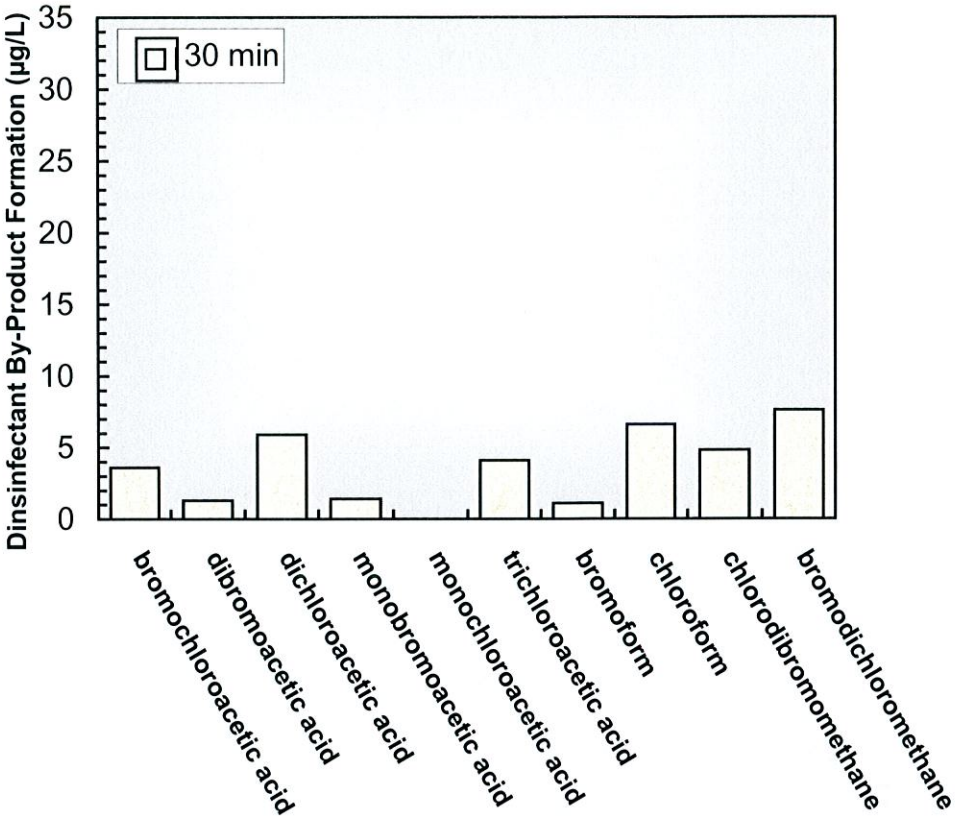

Figure 3-20
DBP Speciation of Unsparged Chlorinated Samples for 5.8 mg/L applied Cl_2

Fecal and total coliform of the un-disinfected denitrification reclaimed water were measured at 170 and 11000 MPN/100 mL. After 15 minutes of contact time with 5.8-mg/L free chlorine, fecal coliform was not detected in the treated water (<2 MPN/100 mL). The HFCAWTP is required by the NPDES permit to have 75 percent less than detection and a single sample of 25 per 100 mL. The total coliform levels reduced from 11000 to 17 MPN/100 mL, and HPCs dropped from >5700 to 64 CFU/mL. A higher total coliform count (50 MPN/100 mL) was observed in the 30-minute sample. However, despite the slight discrepancy, the microbial inactivation results were similar to the 15-minute sample. This data indicates that at a controlled laboratory scale, a lower chlorine dose can achieve effective microbial kill and have lower THM concentrations.

4.0 TREATMENT AND THM CONTROL OPTIONS

4.1 Prevention and Reduction of THMs

Prevention and reduction of THMs through the current treatment process at the HFCAWTP will be discussed in this section. The following treatment and THM control options are evaluated below:

- Gravity Thickener
- pH control
- Cooling Water Return Control
- Bromide control
- Methanol Reduction and TOC Control
- Cl_2 dose control
- Alternative Disinfection
- Mixing Zone
- Aeration control

4.1.1 Gravity Thickener

Table 4-1 shows the dichlorobromomethane and dibromochloromethane concentrations at two locations: final effluent and gravity thickener discharge. This table shows that the THM concentrations at the gravity thickener discharge make up approximately 5 percent of the final effluent THM concentrations and is not a significant contributor to the dichlorobromomethane exceedance.

Table 4-1
THM concentrations at Final Effluent and Gravity Thickener Discharge

	Final Effluent		Gravity Thickener Discharge	
	Dichlorobromo methane MCL 22ug/l	Dibromochloro methane MCL 34ug/l	Dichlorobromo methane MCL 22ug/l	Dibromochloro methane MCL 34ug/l
11/29/2004	19	18		
12/14/2004	18	16		
1/26/2005	17	11		
2/22/2005	18	14		
3/21/2005	17	10	3.6	2
4/25/2005	20	20	4.6	3.5
5/19/2005	32	29		
6/21/05	31	37		
7/20/05	30	27		
8/15/2005	25	18		
Running Avg.	22.7	20.0	4.1	2.8

4.1.2 pH

The level of the pH during chlorination has a correlation with the level of DBPs that are found in the effluent. During the free-chlorine contact time, the pH of the water can be decreased to reduce the formation of DBPs in the effluent at the HFCAWTP. This correlation between pH and THMs were presented previously in Figures 3-12 and Figure 3-13. As the pH increases the THMs increase. However, lowering the pH may cause the pH to be lower than the required pH permit limitation of 6.0. Controlling the pH would require additional chemical treatment to lower the pH prior to disinfection and use of a caustic chemical to raise the pH prior to surface discharge (to above 6 pH units).

4.1.3 Recycle (cooling water)

HFCAWTP staff took a cooling water return sample to determine the impact cooling water return of dechlorinated reclaimed water was having on the formation of dichlorobromomethane and dibromochloromethane. The cooling water return enters after denitrification and before chlorination. A sample was taken on May 19, 2005. The concentrations of dichlorobromomethane and dibromochloromethane were determined to be 40 ug/L and 34 ug/L, respectively. The flow for that day was 4.32 mgd. Based on the amount on the cooling water return flow rate, there would be an increase of less than 10 percent in the formation of dichlorobromomethane and dibromochloromethane. While this is a source of additional DBP's, removal of this source would probably not significantly impact plant compliance with the DBP limits.

4.1.4 Bromide

Based on discussions with HFCAWTP operations staff, seawater infiltration may be occurring at some locations in the wastewater collection system prior to entering the HFCAWTP. Bromide is present in seawater and could contribute to bromide found in the treated reclaimed water. Average bromide levels were found in an earlier study performed in the late 1980's to vary between 0 and 2.35 mg/L with an average concentration of less than 1.8 mg/L. The presence of bromide in wastewater will cause an increase in the brominated THMs and will actually decrease the chlorinated THMs in the final effluent. In some cases the total THMs will decrease, when brominated ones increase. Preventing or reducing saltwater intrusion in the wastewater collection system may reduce bromide concentrations and thus the levels of DBPs in the final effluent. While the average bromide level was relatively high in the late 1980's study, the variability in the wastewater does not indicate that bromide control could be a long-term viable DBP control strategy.

4.1.5 Methanol Reduction and TOC Control

Based on the historical data (see **Figure A-9 in Appendix A**) that was provided, the methanol is less than the detection limit of 0.21 mg/L at the denitrification filters between October 1998 and March 2005 on the days when the THMs were analyzed at the HFCAWTP. There does not seem to be a relationship between methanol dosing and THM formation.

4.1.6 Lower the Cl_2 dose

Based on the chlorine demand curves (see **Appendix B**) that were performed on days during 1998, 1999 and 2005, the chlorine residual was greater than 1.0 mg/L with Cl_2 dosing ranging from 3 mg/L to 8 mg/L. It appears that lowering the Cl_2 dose may be an alternative but FDEP's high level disinfection criteria of 1.0 mg/L total chlorine residual would still need to be met. Based on the Tampa Bay Water Downstream Augmentation Project THM laboratory analysis, a lower chlorine dose did get the required fecal coliform kill. However, there would be some risk involved with lowering the Cl_2 dose due to the variability of the chlorine demand curves and the diurnal and day to day variability in reclaimed water quality. This variability of the chlorine demand curves and the total nitrogen concentration may cause the Cl_2 residual to drop below the 1.0 mg/L high level disinfection requirement and not routinely meet the fecal coliform inactivation requirements if a lower Cl_2 dose was applied. Further study over a wide range of plant operating conditions is required before this alternative can be relied upon to achieve FDEP permit requirements.

Table 4-2 shows the Cl_2 dose, total Cl_2 residual, Dichlorobromomethane, and Dibromochloromethane from June 8, 2000 to August 15, 2005. The HFCAWTP staff lowered the Cl_2 dose after May 19, 2005, which is shown as being shaded in Table 4-2 below. The average of the maximum and average Cl_2 doses between June 8, 2000 and May 19, 2000, was 38.30 mg/L and 13.42 mg/L, respectively. The average of the maximum and average Cl_2 doses after May 19, 2005, was 15.24 mg/L and 10.55 mg/L, respectively. There was a reduction in the average of the maximum and average Cl_2 doses by approximately 23 mg/L and 2 mg/L, respectively. Table 4-2 also shows that the total Cl_2 residual was also reduced but remained above the minimum total Cl_2 residual requirement of 1.0 mg/L. The average dichlorobromomethane and dibromochloromethane concentration between June 8, 2000 and May 19, 2000, was 23.83 mg/L and 23.01 mg/L, respectively. The average dichlorobromomethane and dibromochloromethane concentration after May 19, 2000, was 28.67 mg/L and 27.33 mg/L, respectively. This comparison shows that the reduction in the Cl_2 Dose after May 19, 2005, did not result in a reduction of the dichlorobromomethane and dibromochloromethane concentration.

Table 4-2
Cl_2 Dose, Total Cl_2 Residual and THM concentrations

	Cl_2 Dose			Total Cl_2 Residual			Dichlorobromo methane	Dibromochloro methane
Date	MIN (mg/L)	MAX (mg/L)	AVG (mg/L)	MIN (mg/L)	MAX (mg/L)	AVG (mg/L)	(ug/L)	(ug/L)
6/8/2000	2.82	32.99	12.39	1.25	5.00	2.83	34.00	52.00
12/14/2000	0.00	50.00	12.89	1.38	4.38	2.61	16.00	19.00
2/23/2001	0.00	16.07	10.53	1.29	5.00	2.84	16.00	19.00
6/13/2001	8.30	17.26	11.84	1.33	4.62	2.22	27.00	39.00
12/12/2001	8.38	16.54	11.51	1.24	4.10	2.37	17.00	18.00
3/12/2002	0.00	50.00	11.82	1.41	3.89	2.49	-	-
6/26/2002	8.43	50.00	12.98	1.46	5.00	2.92	35.00	41.00
12/4/2002	0.00	36.31	13.22	1.41	3.89	2.53	23.00	19.00
6/26/2003	8.95	14.72	11.93	1.45	4.43	2.76	26.70	21.10
12/10/2003	0.00	50.00	17.77	1.10	5.00	2.99	24.00	24.00
3/2/2004	11.09	42.49	17.92	1.43	5.00	3.21	33.00	10.00
6/23/2004	0.00	50.00	12.07	1.94	4.57	2.79	30.00	36.00
11/29/2004	8.73	50.00	13.60	1.57	4.23	2.63	19.00	18.00
12/14/2004	0.00	50.00	15.12	1.34	4.15	2.66	18.00	16.00
12/27/2004	9.98	50.00	15.44	0.85	5.00	2.86	30.00	21.00
1/26/2005	0.00	50.00	19.03	0.92	5.00	2.79	17.00	11.00
2/22/2005	0.00	50.00	13.53	1.28	4.98	3.09	18.00	14.00
3/21/2005	7.12	26.34	11.75	1.54	5.00	2.95	17.00	10.00
4/25/2005	7.72	50.00	11.19	2.22	3.50	2.85	20.00	20.00
5/19/2005	10.23	13.19	11.89	2.42	3.25	2.77	32.00	29.00
6/21/05	9.43	15.09	10.72	1.95	2.69	2.30	31.00	37.00
7/20/05	9.66	16.64	10.72	1.98	2.85	2.40	30.00	27.00
8/15/05	8.96	14.00	10.20	2.18	3.11	2.62	25.00	18.00

4.2 Alternative Disinfection System

The following disinfection systems have been identified as alternative disinfection systems: Ultraviolet (UV) and Ozone.

4.2.1 UV

The radiation created through UV rays is used to inactivate microorganisms in the wastewater. Sufficient dosages of UV can disinfect wastewater to any degree required. UV is an effective way of disinfecting wastewater and it does not create disinfection byproducts.

4.2.2 Ozone

The HFCAWTP currently uses oxygen on site at the wastewater treatment plant, which would seem like ozone would be simpler alternative disinfection system to implement at the HFCAWTP. However, due to the variability in the water quality in wastewater using

ozone makes is difficult to achieve the required fecal coliform kill consistently. Also, the ozone demand would cause potentially high doses to be employed. Therefore, ozone is not recommended as an alternative disinfection system and the cost was not evaluated.

4.3 Methods for Removing the THMs after they are formed

4.3.1 Mixing Zone

The vertical distance between the end of the discharge pipe and the effluent boil sample point is approximately 29 feet. The effluent boil sample point is on the surface directly above the discharge pipe. Based on **Table 4-3**, the dichlorobromomethane and dibromochloromethane concentrations at the effluent boil are reduced by a factor of approximately 3:1 or on average 14 µg/L and 12 µg/L, respectively. This shows that a mixing zone could be a viable approach.

Table 4-3
THM concentrations at Final Effluent and Effluent Boil

	Final Effluent		Effluent Boil	
	Dichlorobromo methane MCL 22ug/l	Dibromochloro methane MCL 34ug/l	Dichlorobromo methane MCL 22ug/l	Dibromochloro methane MCL 34ug/l
11/29/2004	19	18		
12/14/2004	18	16		
1/26/2005	17	11		
2/22/2005	18	14	7.4	5.7
3/21/2005	17	10	5.1	3.1
4/25/2005	20	20	6.3	5.8
5/19/2005	32	29	9.6	9
6/21/05	31	37	12.0	13.0
7/20/05	30	27	14	12.0
8/15/2005	25	18	8.1	6.0
Running Avg.	22.7	20.0	8.9	7.8

A mixing zone would be a volume of surface water containing the area of the discharge and would allow the opportunity for mixture of the wastewater with the receiving surface waters. A mixing zone of approximately 29 feet appears more than adequate and is a viable alternative to achieving plant compliance with FDEP DBP requirements. This alternative would require future work with the FDEP to establish the mixing zone for dichlorobromomethane.

4.3.2 Aeration

Aeration of the reclaimed water was shown to remove approximately 10 percent of the DBPs in the reclaimed water at the laboratory scale. The HFCAWTP historical DO data on the dates when THMs were analyzed shows that the DO ranged from 6.4 mg/L to 8.2 mg/L (**Figure 4-1**). The current operation at the HFCAWTP already employs a significant post-chlorination aeration step (see **Figure 4-2**). Therefore, a reduction in THMs through the current operation is probably already occurring at the HFCAWTP after chlorination and additional aeration is not likely to improve or reduce THM formation.

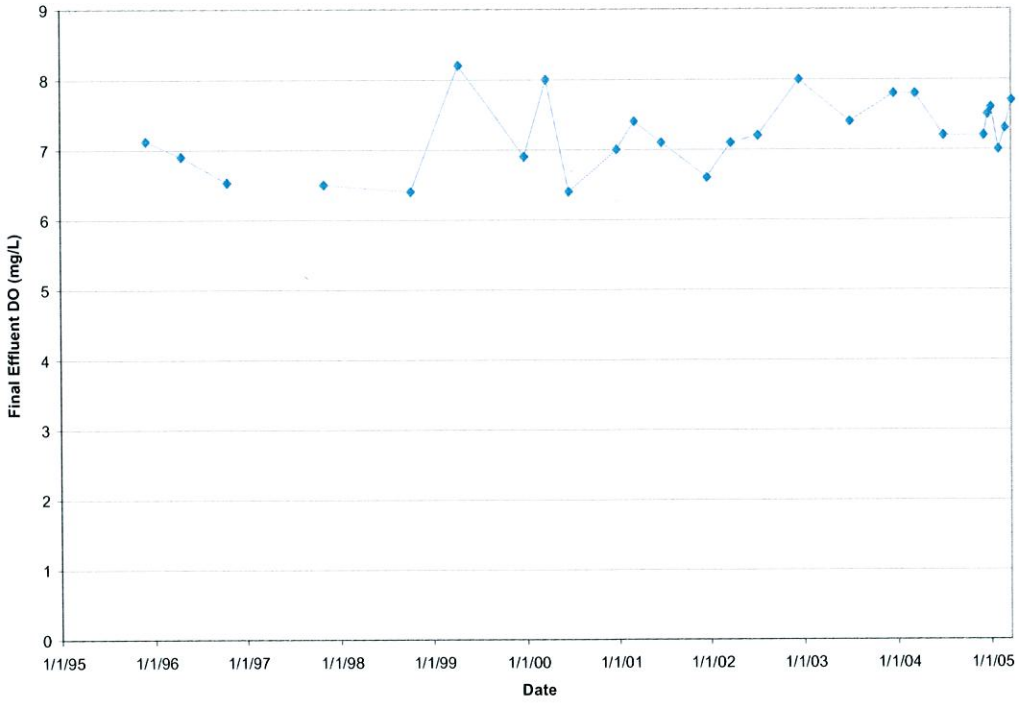

Figure 4-1
Final Effluent Dissolved Oxygen versus Time

Figure 4-2
Aeration occurring at Post Aeration Chlorination Tanks

5.0 COST EVALUATION

A present order of magnitude costs for implementation of the following three alternatives will be presented in the following section: UV disinfection system, pH control, and mixing zone. This conceptual cost estimate will consist of the capital, and operation and maintenance costs (O&M).

5.1 Capital and Operation and Maintenance Costs

The capital costs include 15 percent for engineering and a 30 percent contingency. The estimated conceptual capital cost estimates represent a budget level estimate (+50%, -30%) of the expected or nominal costs as defined by the American Association of Cost Engineers. These estimates were made without detailed engineering data and should be only used for preliminary feasibility studies.

As part of the cost evaluation, estimated conceptual annual operation and maintenance costs including labor, and power consumption have been developed. It was assumed that the O&M costs are based on the average daily effluent flow of 55 MGD.

5.1.1 UV System

The UV system conceptual capital cost estimate was developed based on a permitted discharge of 96 MGD and a peak discharge of 220 MGD. **Table 5-1** presents the estimated conceptual capital and O&M cost for the UV system. Pilot and bench scale testing would be needed to further define the UV facility at the HFCAWTP. A more detailed cost estimate will need to be conducted if UV is selected for further analysis.

Table 5-1
UV Facility Capital and O&M Costs

Capital Costs	
Description	**Cost**
UV Facility (100 mj/cm^2)	$30,000,000
Engineering @ 15% of Capital Cost	$4,500,000
Contingency @ 30% of Capital Cost	$9,000,000
Total Capital Cost	$43,500,000
O&M Costs	
Description	**Cost/year**
UV Facility	$1,500,000 to $2,500,000

Note: It was assumed the pH would range between 6 to 8.5

5.1.2 pH Control

The pH control conceptual capital cost estimate was developed based on a permitted discharge of 96 MGD and a peak discharge of 220 MGD. **Table 5-2** presents the estimated conceptual capital and O&M cost to control the pH at the HFCAWTP. Testing would be needed to further define the chemical feed systems that would be needed to control the pH. A more detailed cost estimated would need to be conducted.

Table 5-2
pH Control Capital and O&M Costs

Capital Costs	
Description	**Cost**
Acid Storage and Pumping Facility	$2,500,000
Caustic Storage and Pumping Facility	$2,500,000
Miscellaneous Controls	$500,000
Engineering @ 15% of Capital Cost	$825,000
Contingency @ 30% of Capital Cost	$1,650,000
Total Capital Cost	$7,975,000
O&M Costs	
Description	**Cost/year**
Acid	$1,200,000
Caustic	$600,000
Labor	$100,000
Total	$1,900,000

5.1.3 Mixing Zone

Table 5-3 presents the estimated conceptual capital and O&M cost for the mixing zone alternative at the HFCAWTP. Creating a mixing zone for the HFCAWTP discharge would require coordination with the FDEP along with studies of the discharge.

Table 5-3
Mixing Zone Capital and O&M Costs

Capital Costs	
Description	**Cost**
Permitting and Studies	$300,000
Contingency @ 30% of Capital Cost	$90,000
Total Capital Cost	$390,000
O&M Costs	
Description	**Cost/year**
Monitoring	$10,000 to $50,000

6.0 SUMMARY AND RECOMMENDATIONS

The report addresses the investigation of the formation and control of THMs in the HFCAWTP effluent. In particular, this study addressed the chemistry of formation and etiology of THMs in the effluent, summarized the historical plant data and plant processes related to THM formation, treatment and control options, and a cost evaluation of alternative disinfection.

6.1 Conclusions

Utilizing a UV disinfection system to replace the chlorination system that is currently used at the HFCAWTP is generally more expensive than the other THM control alternatives, with a estimated conceptual total capital cost of $43,500,000 and a estimated conceptual O&M cost between $1,500,000 to $2,500,000. Conversion to a UV disinfection system would not be in the public interest.

Controlling the pH at the HFCAWTP to reduce THM concentrations does not appear to be a viable approach due to its significant costs. This alternative has an estimated conceptual capital cost of $7,975,000 and an estimated conceptual O&M cost of $1,900,000 per year. There is an additional risk associated with handling additional chemicals on site at the HFCAWTP and additional process compliance points. There also would need to be further study undertaken to evaluate the level of pH required to meet the permitted DBP levels over a wide range of operating conditions.

The use of a mixing zone is a viable approach. A mixing zone would allow for the regulatory standard to be met, would provide for continuation of proven operational practices that achieve a high quality reclaimed water product, and is significantly less cost than the other alternatives that were analyzed. Based on the previous Table 4-5, it appears there is approximately a 3 to 1 dilution of the THM concentrations occurring at the effluent boil within 29 feet of the end of the discharge pipe. Implementing a mixing zone will require an application to FDEP and coordination through the application review process. The City of Clearwater applied for a mixing zone for dichlorobromomethane and did ultimately receive a mixing zone consisting of a distance of two meters in circumference around the centerline of the outfall.

Appendix A

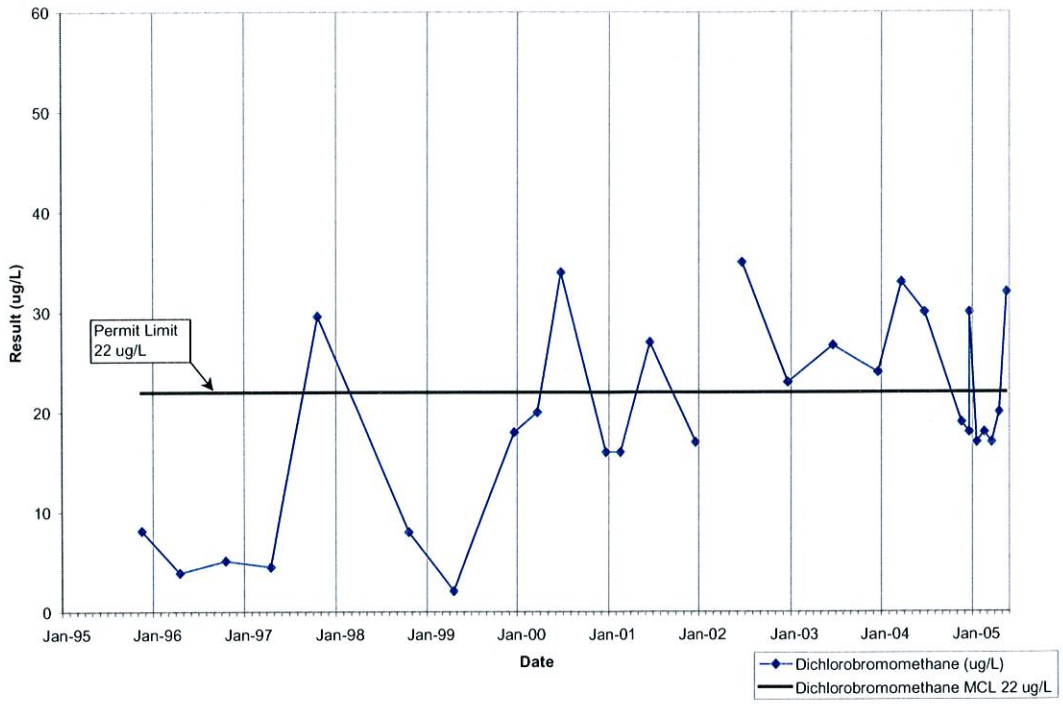

Figure A-1
Dichlorobromomethane versus time

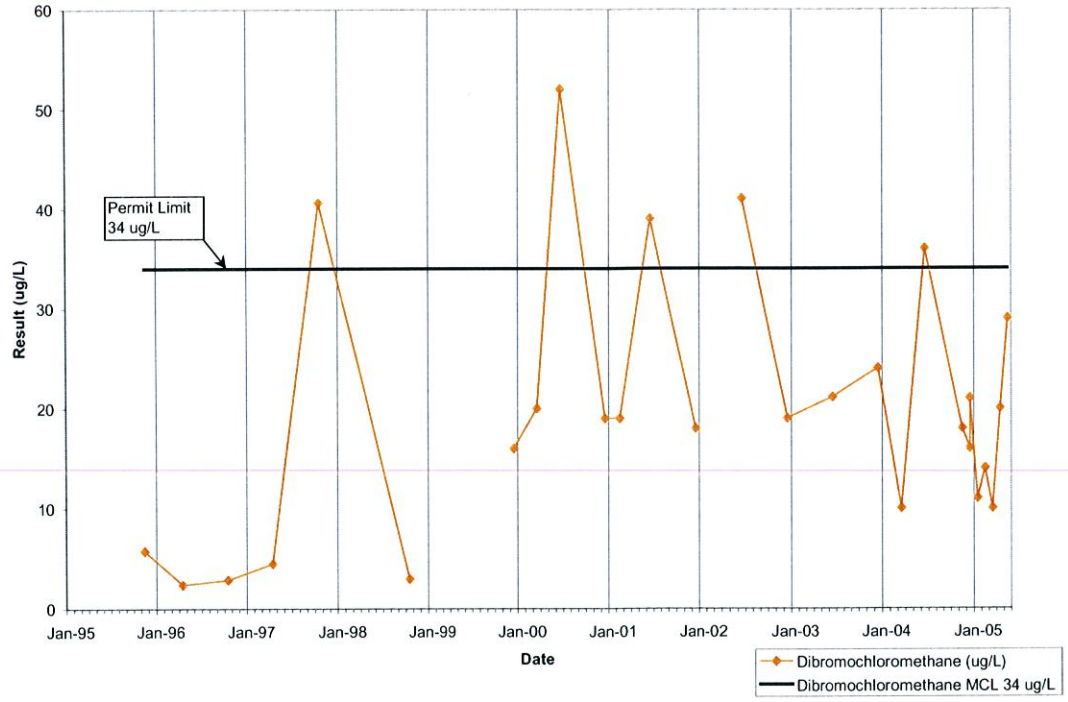

Figure A-2
Dibromochloromethane versus time

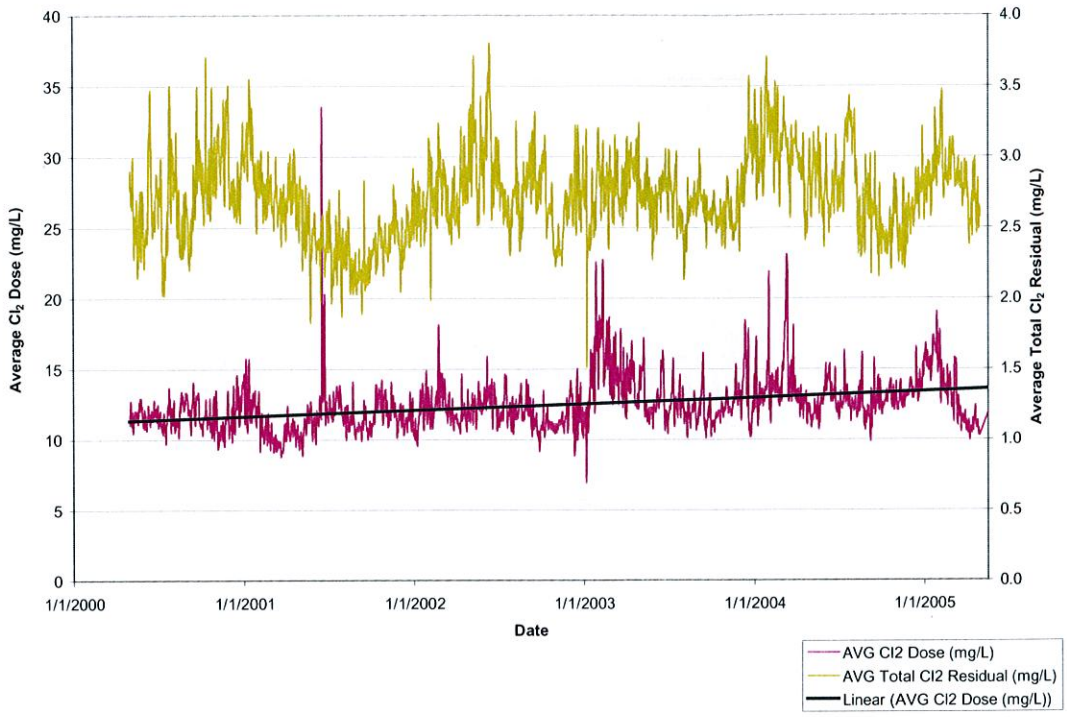

Figure A-3
Cl_2 Dose and Cl_2 Residual versus Time

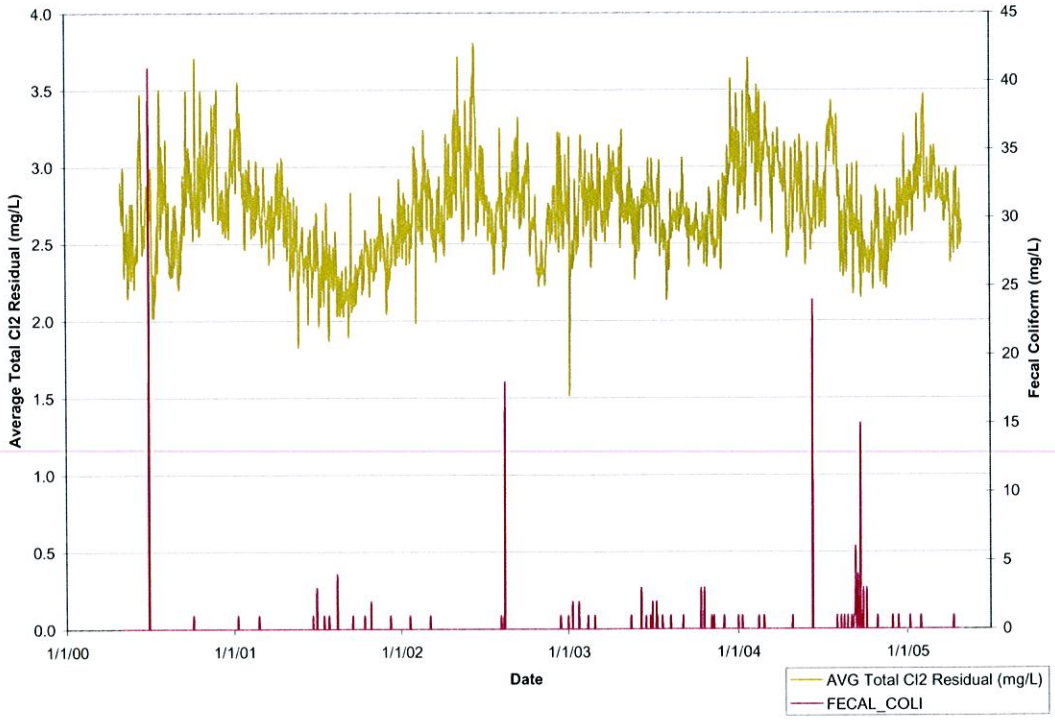

Figure A-4
Average Total Cl2 Residual and Fecal Coliform versus Time

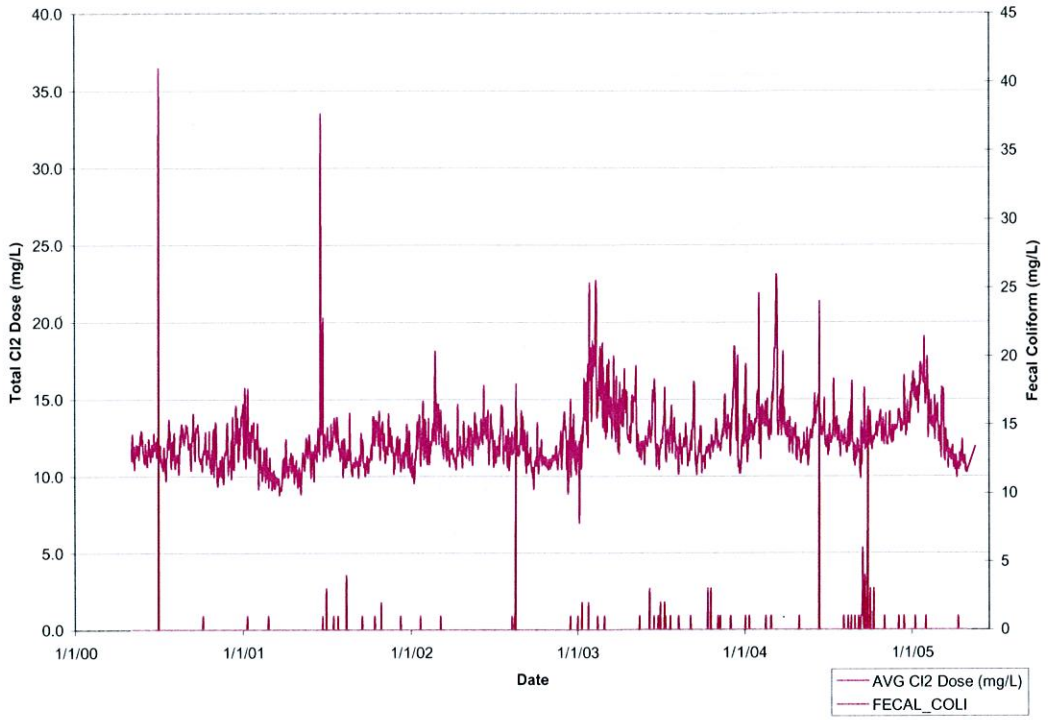

Figure A-5
Average Total Cl_2 Dose and Fecal Coliform versus Time

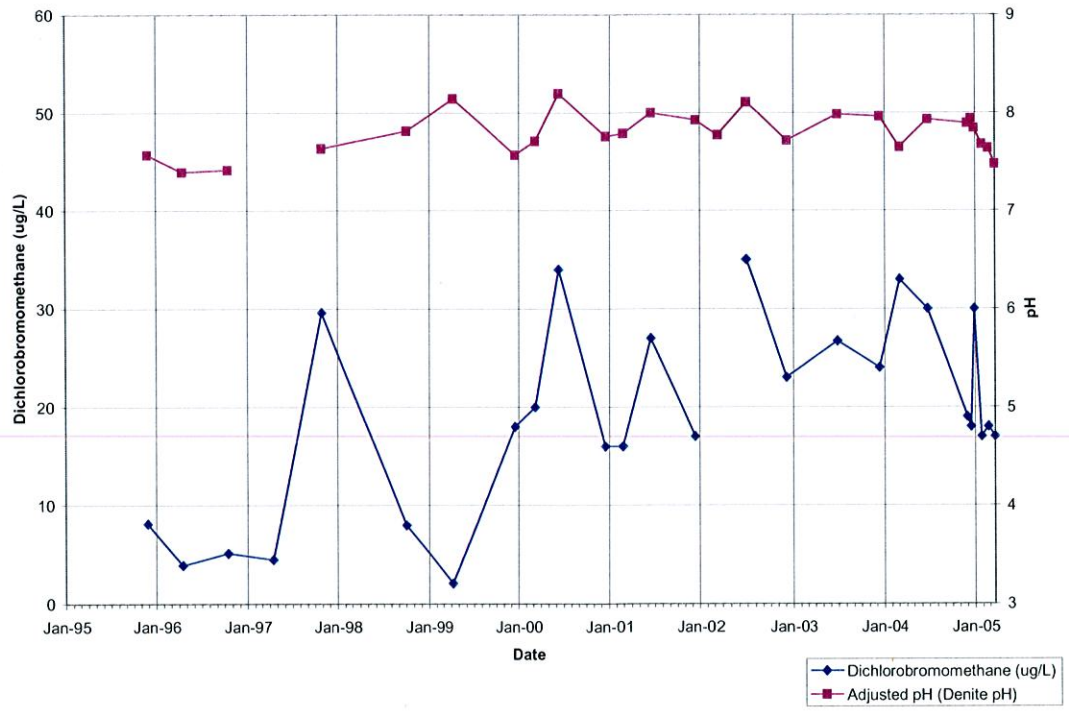

Figure A-6
Dichlorobromomethane and Denitrification pH (Adjusted pH) versus Time

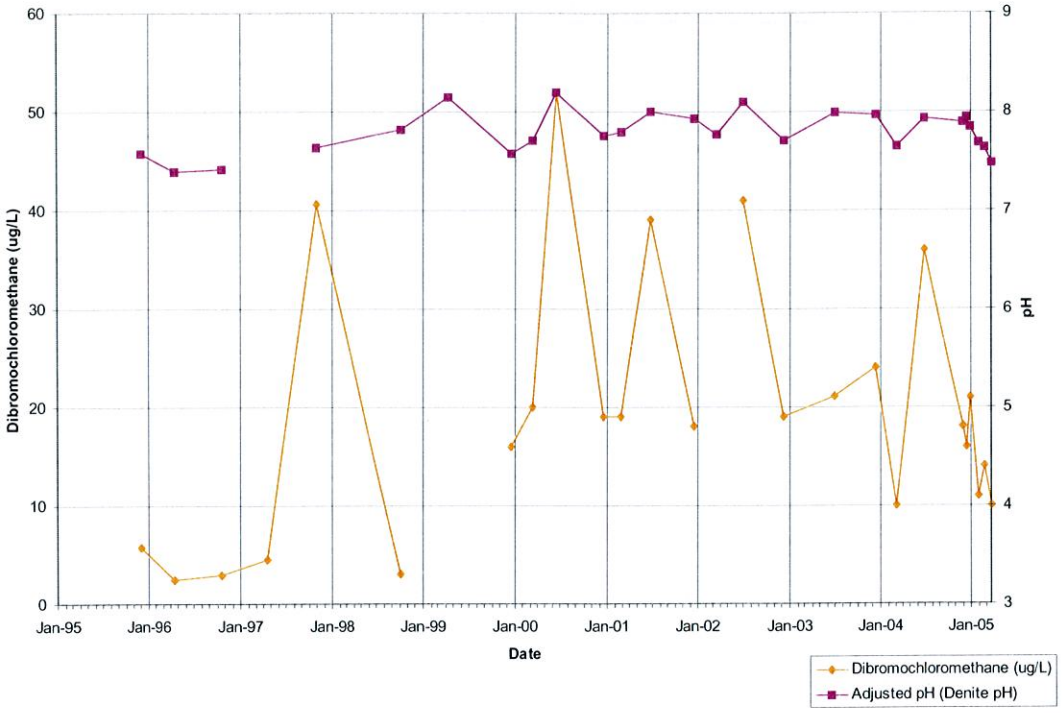

Figure A-7
Dibromochloromethane and Denitrification pH (Adjusted pH) versus Time

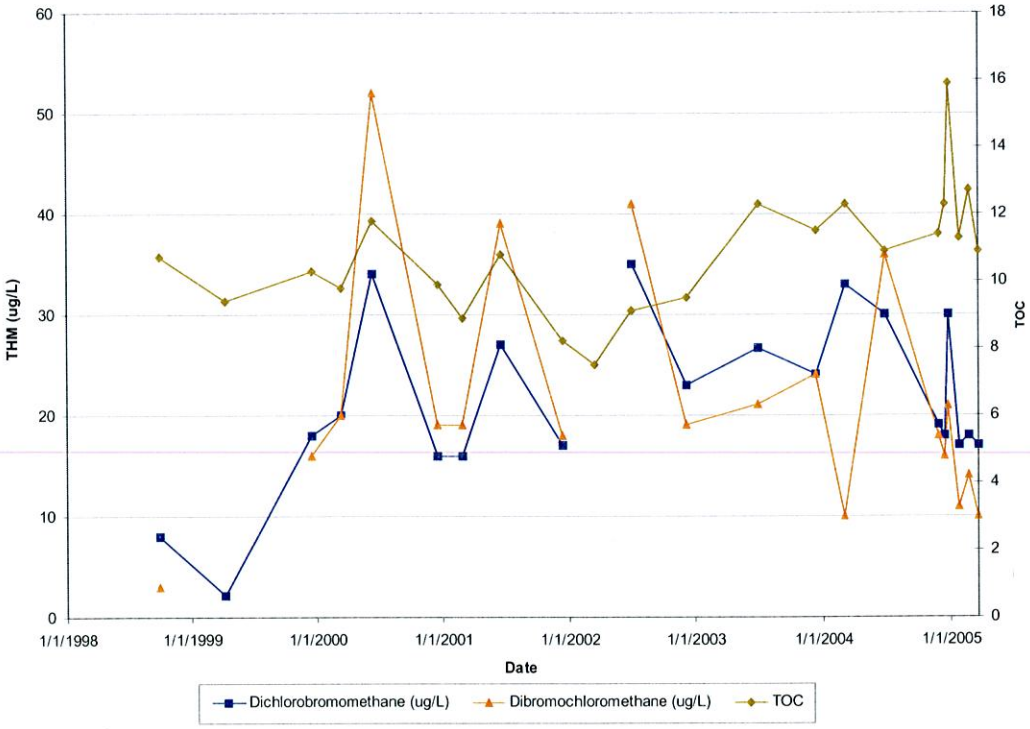

Figure A-8
Dichlorobromomethane, Dibromochloromethane, and TOC versus Time

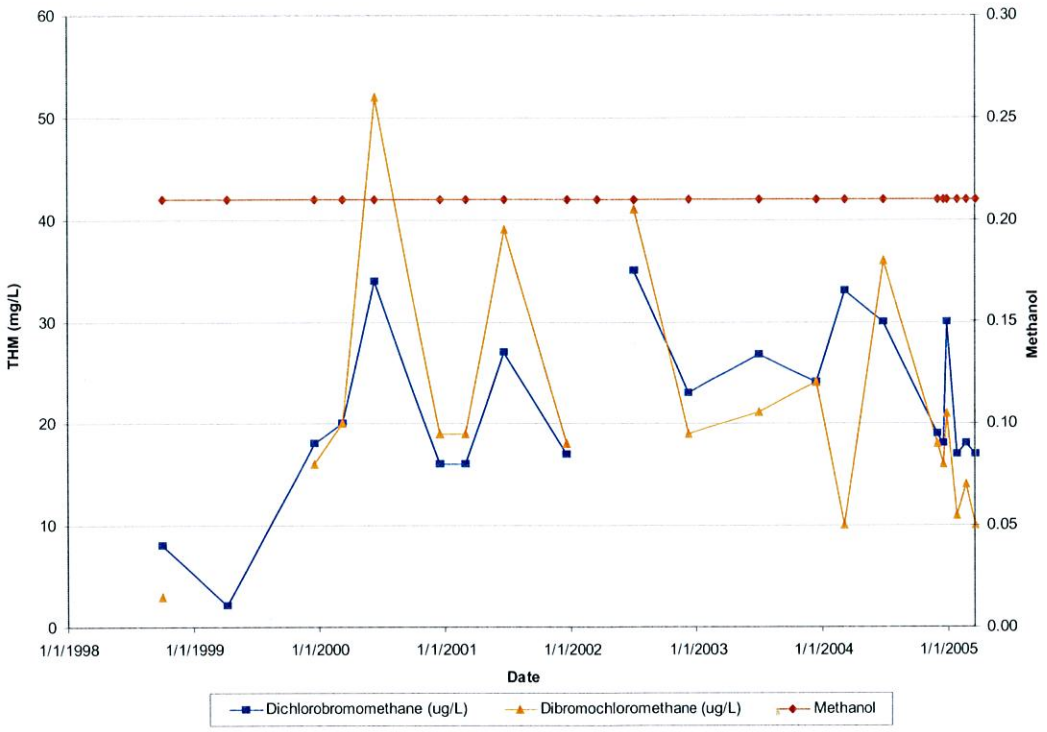

Figure A-9
Dichlorobromomethane, Dibromochloromethane, and Methanol versus Time

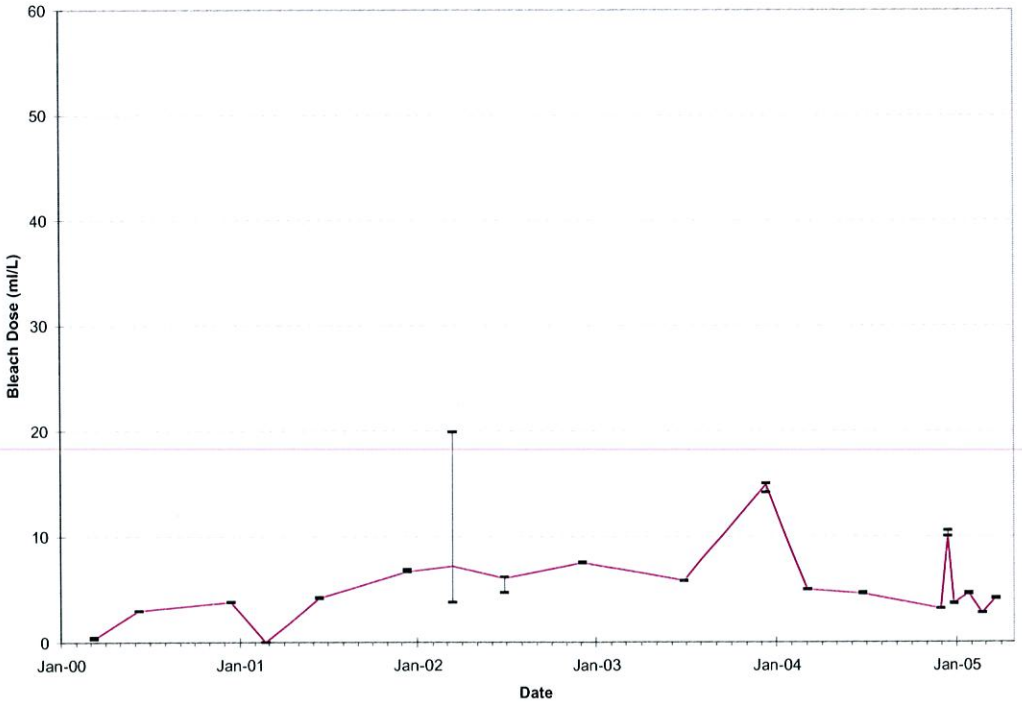

Figure A-10
Bleach Dose Variation at the Gravity Thickeners

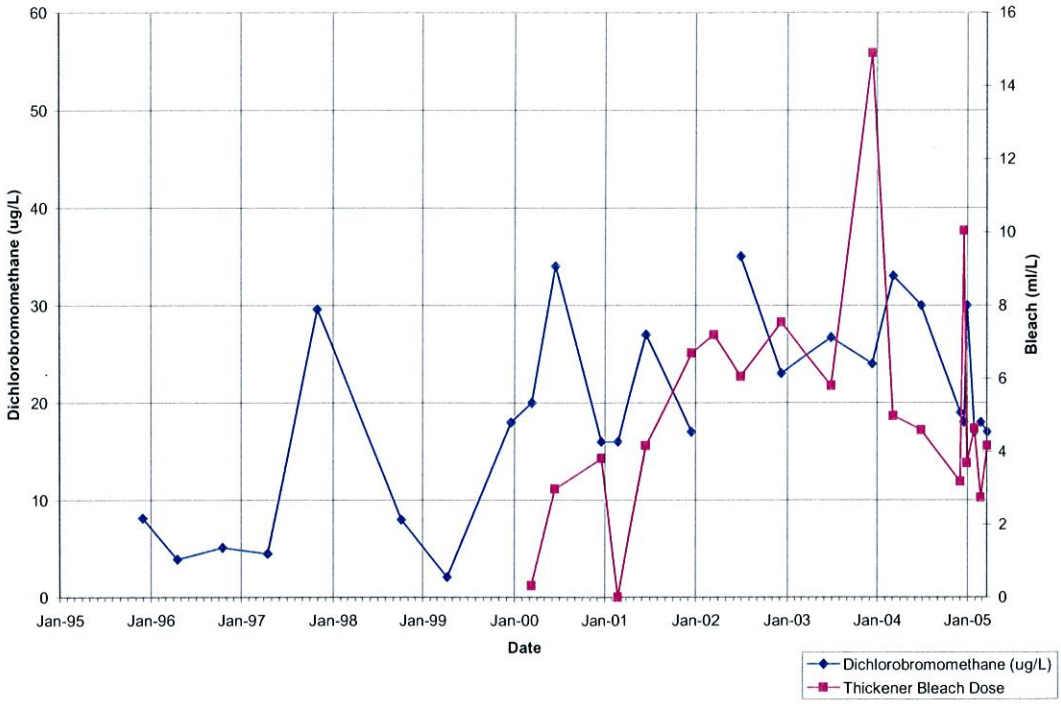

Figure A-11
Dichlorobromomethane and Bleach Dose versus Time

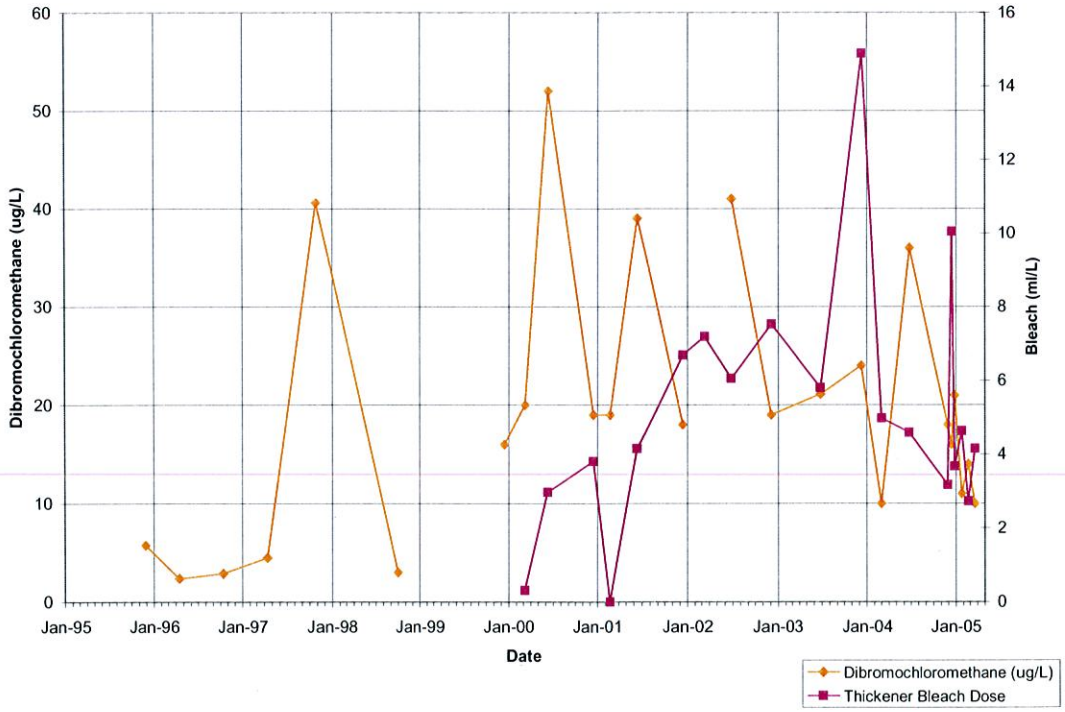

Figure A-12
Dibromochloromethane and Bleach Dose versus Time

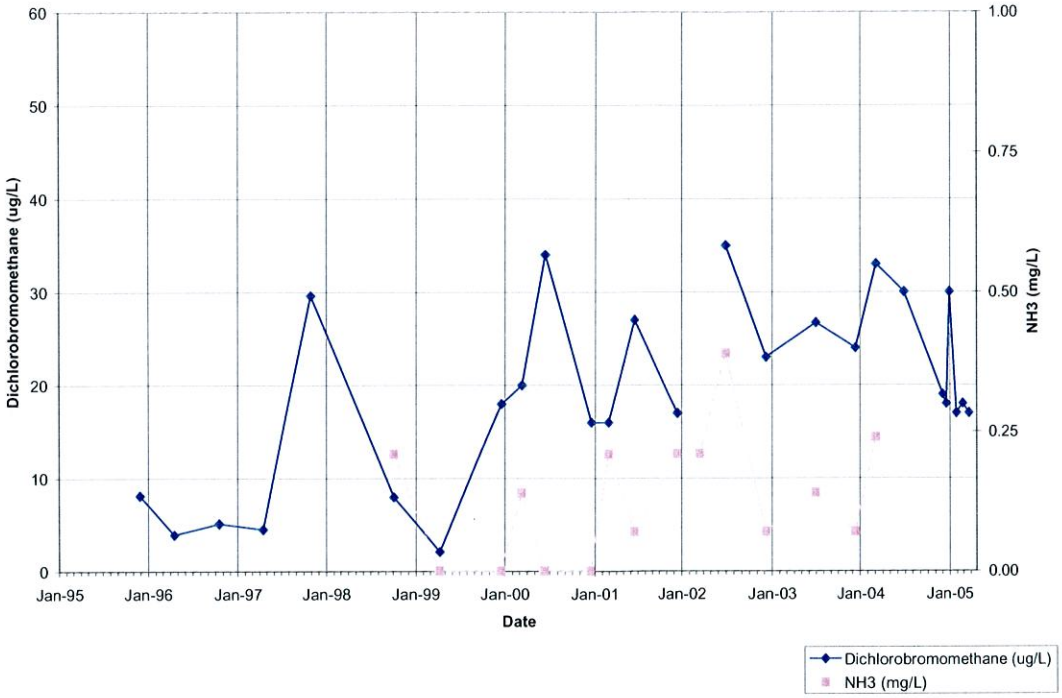

Figure A-13
Dichlorobromomethane and Ammonia versus Time

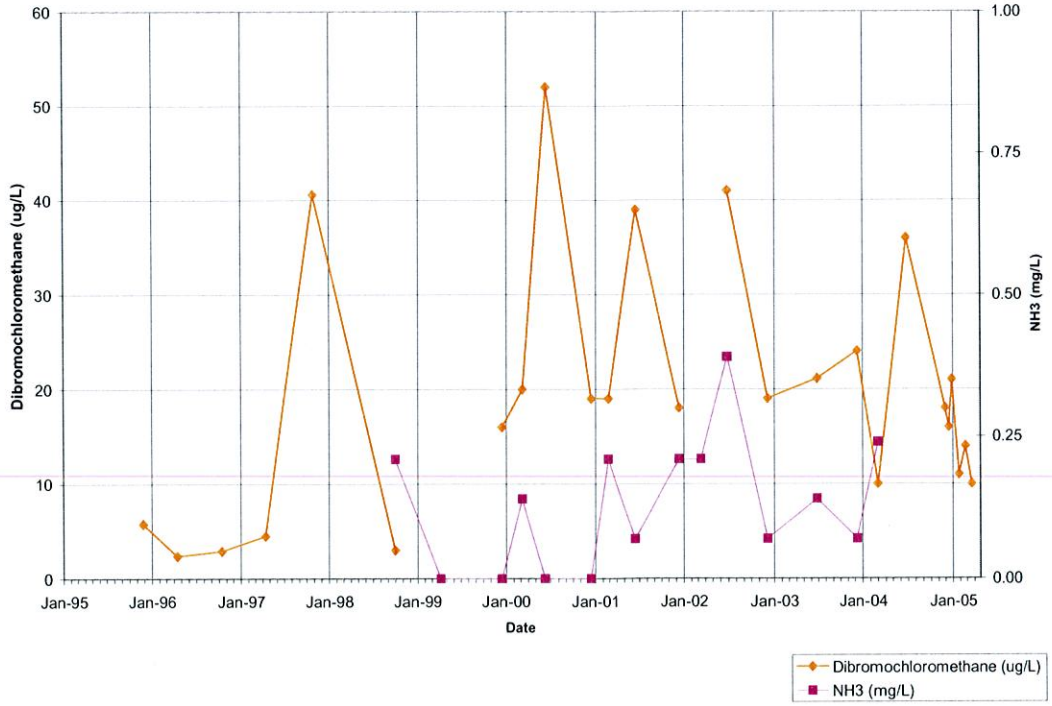

Figure A-14
Dibromochloromethane and Ammonia versus Time

Appendix B

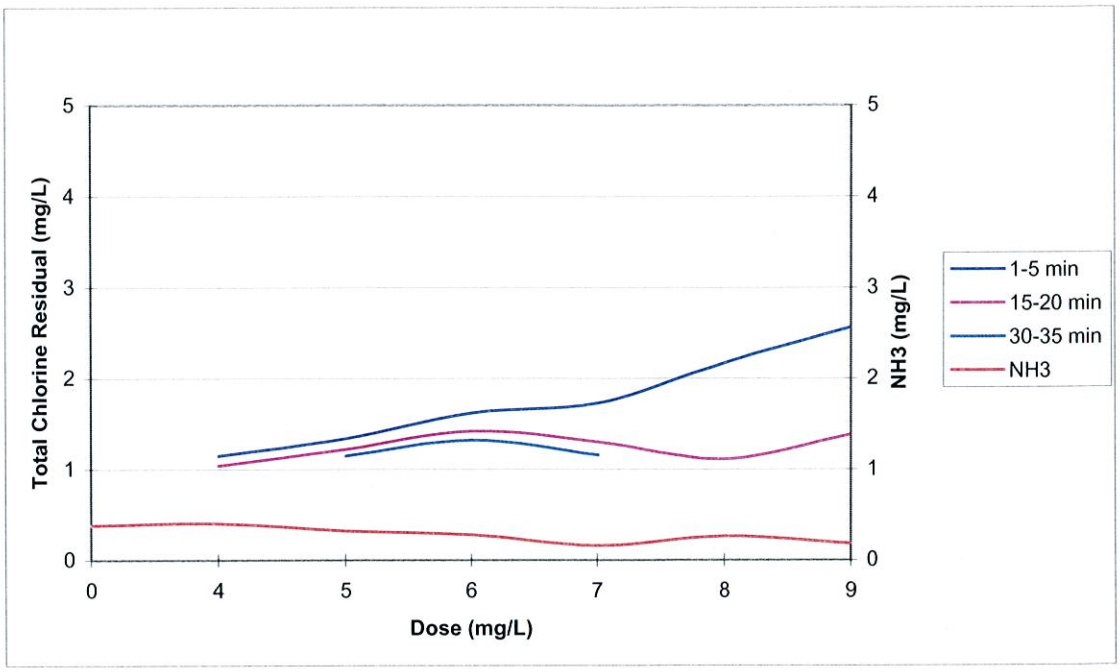

Figure B-1
9/22/1998 Breakpoint Chlorination Curve

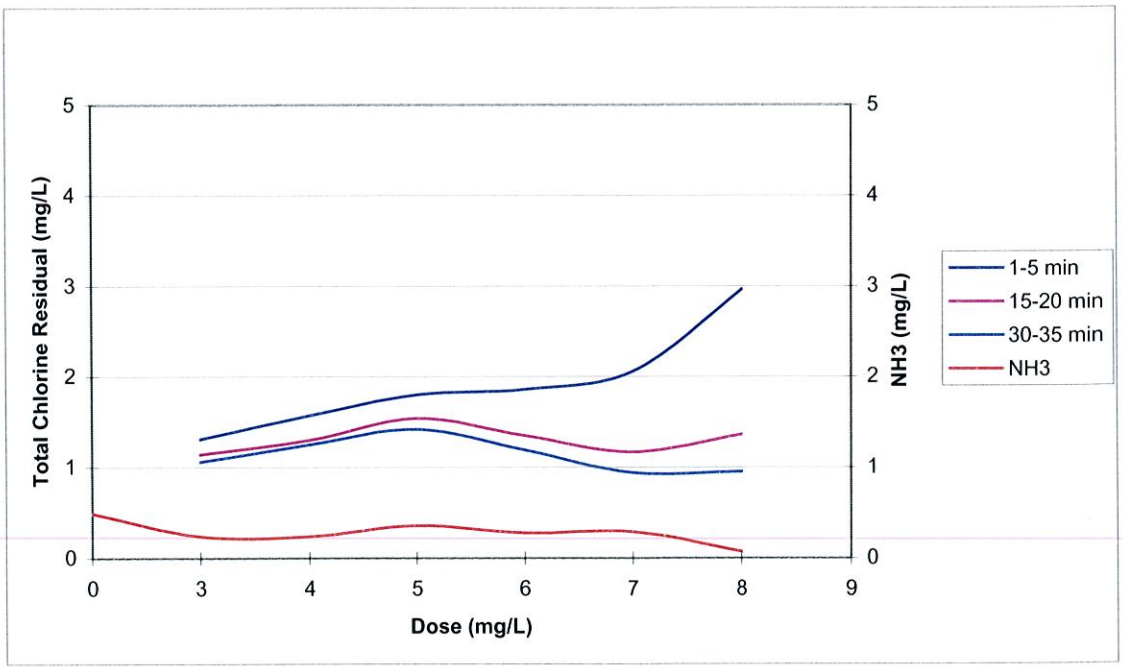

Figure B-2
9/23/1998 Breakpoint Chlorination Curve

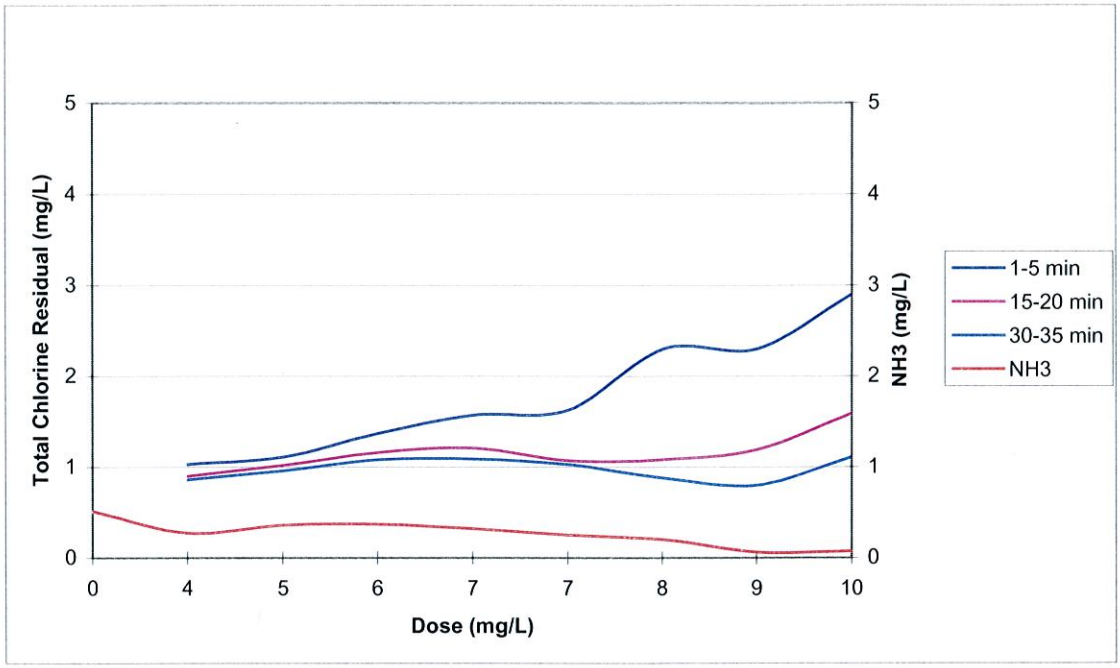

Figure B-3
9/24/1998 Breakpoint Chlorination Curve

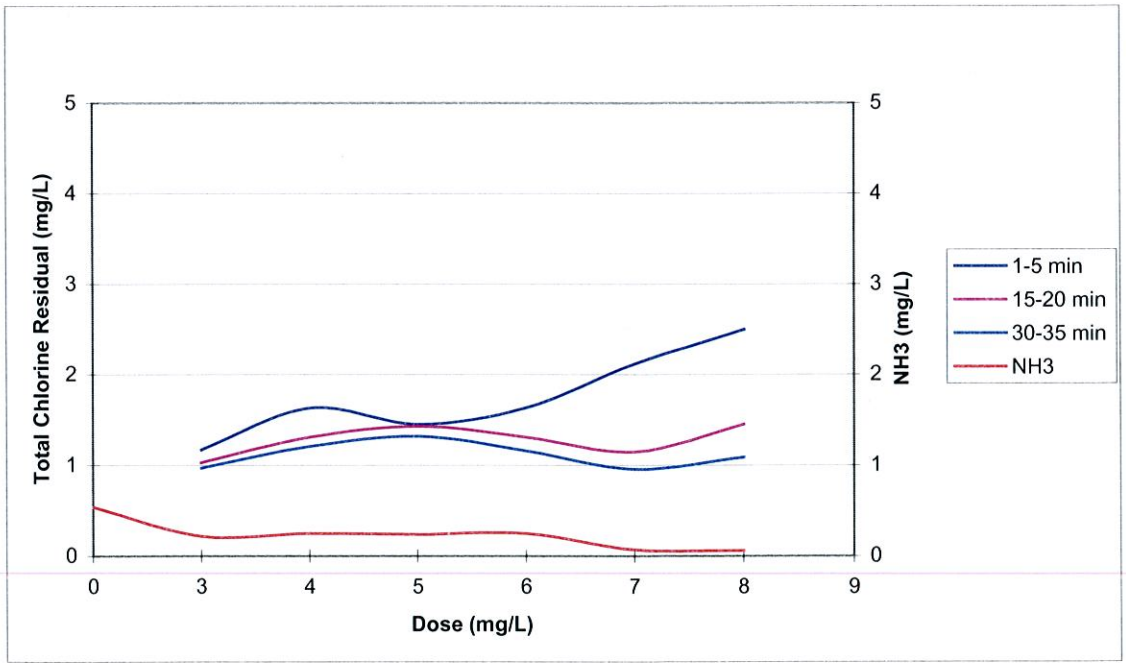

Figure B-4
9/26/1998 Breakpoint Chlorination Curve

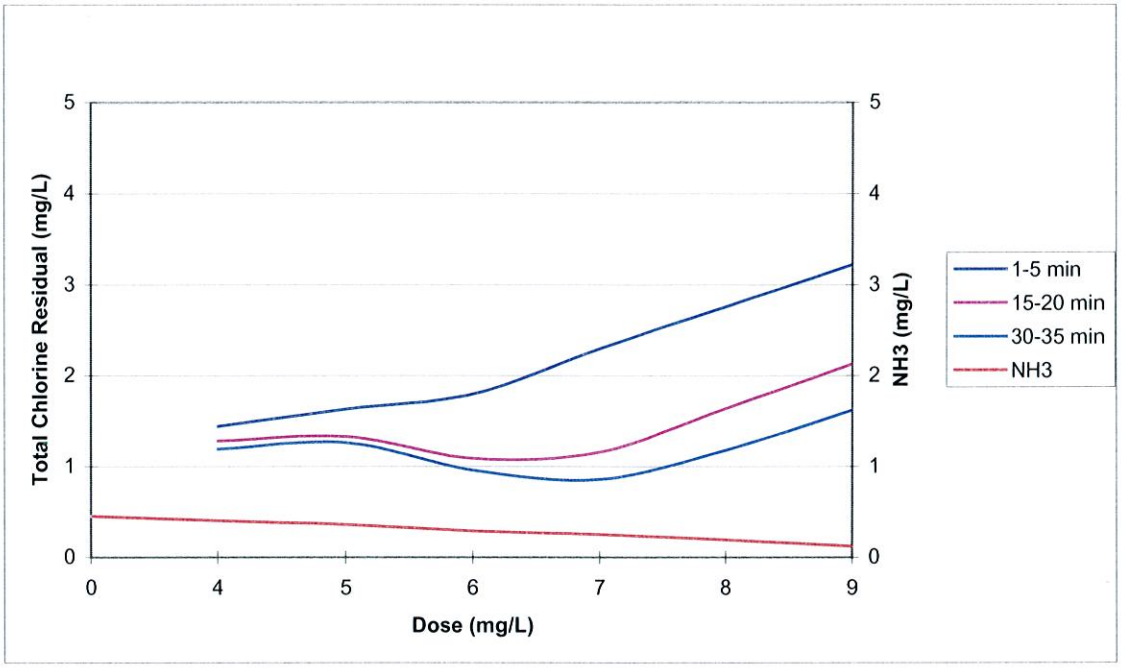

Figure B-5
9/28/1998 Breakpoint Chlorinaton Curve

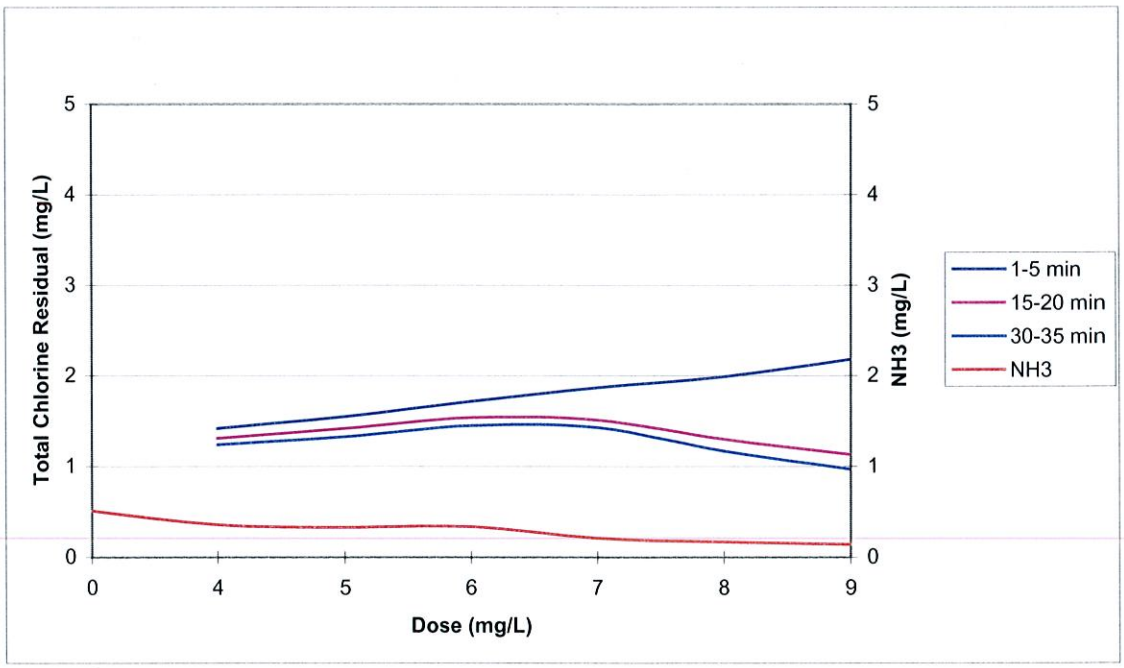

Figure B-6
10/1/1998 Breakpoint Chlorination Curve

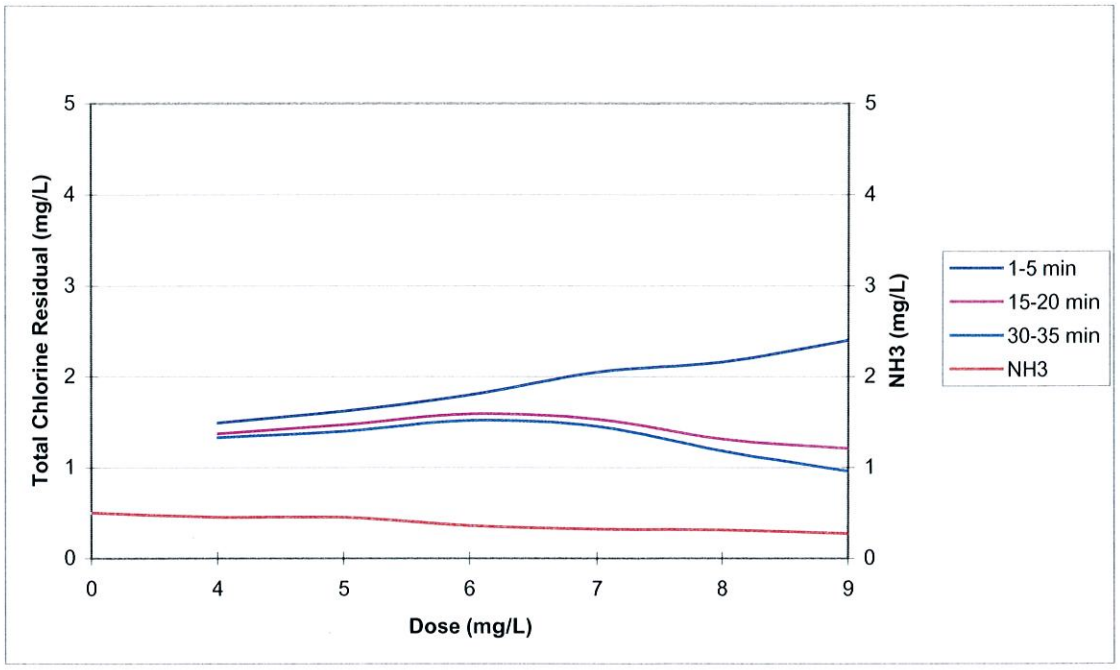

Figure B-7
10/8/1998 Breakpoint Chlorination Curve

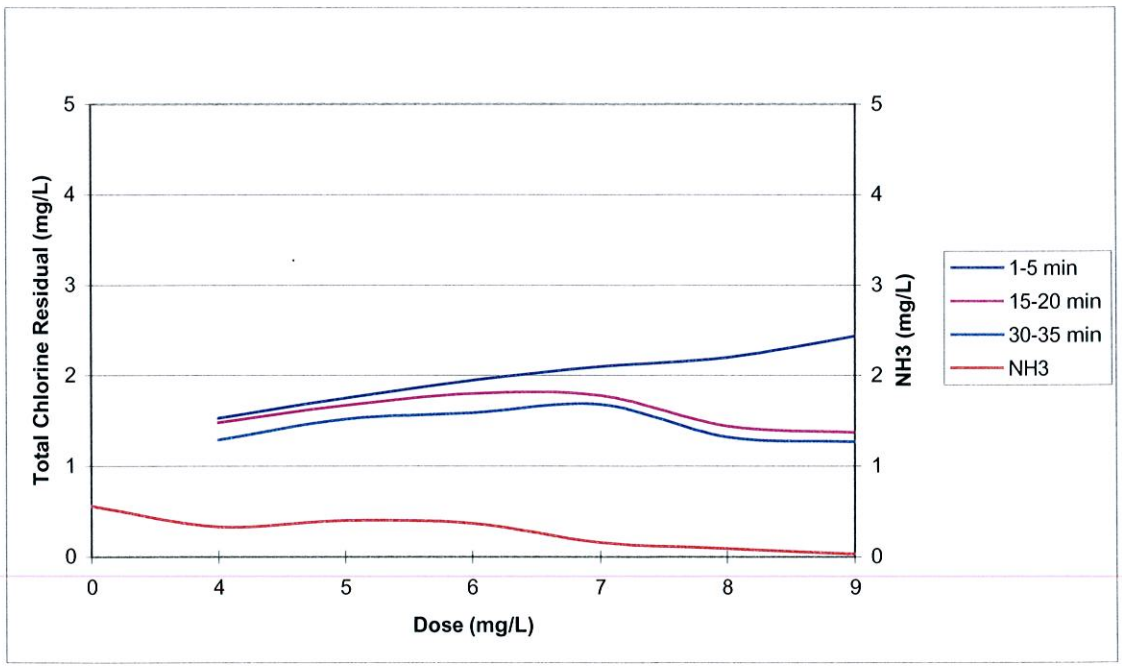

Figure B-8
11/16/1998 Breakpoint Chlorination Curve

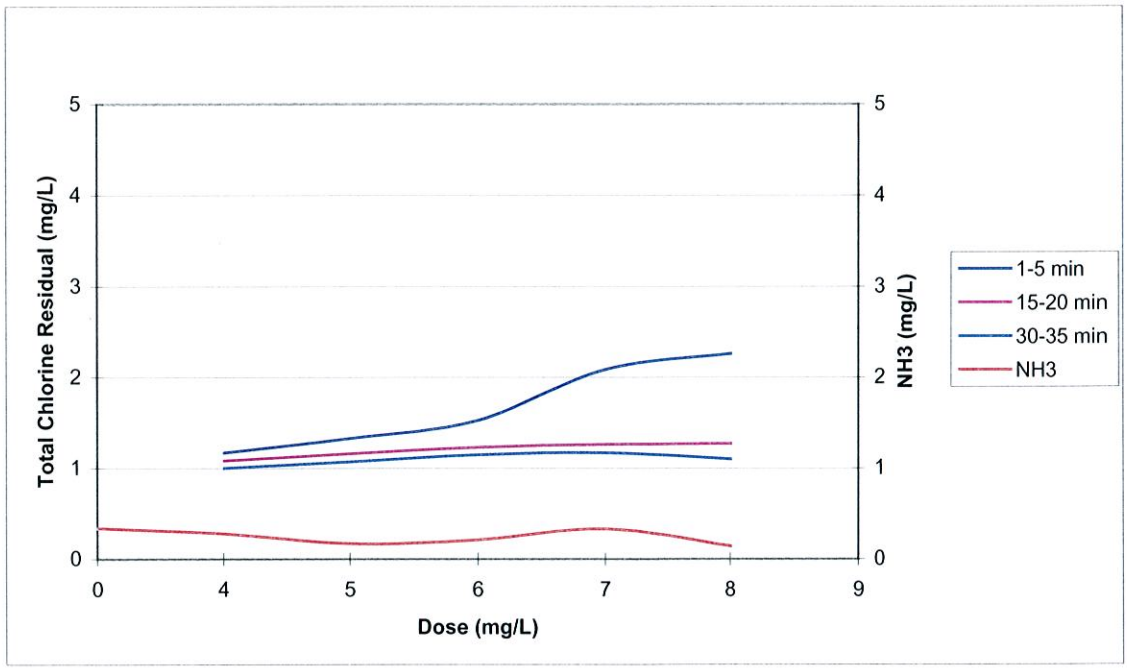

Figure B-9
12/28/1998 @ 12 PM Breakpoint Chlorination Curve

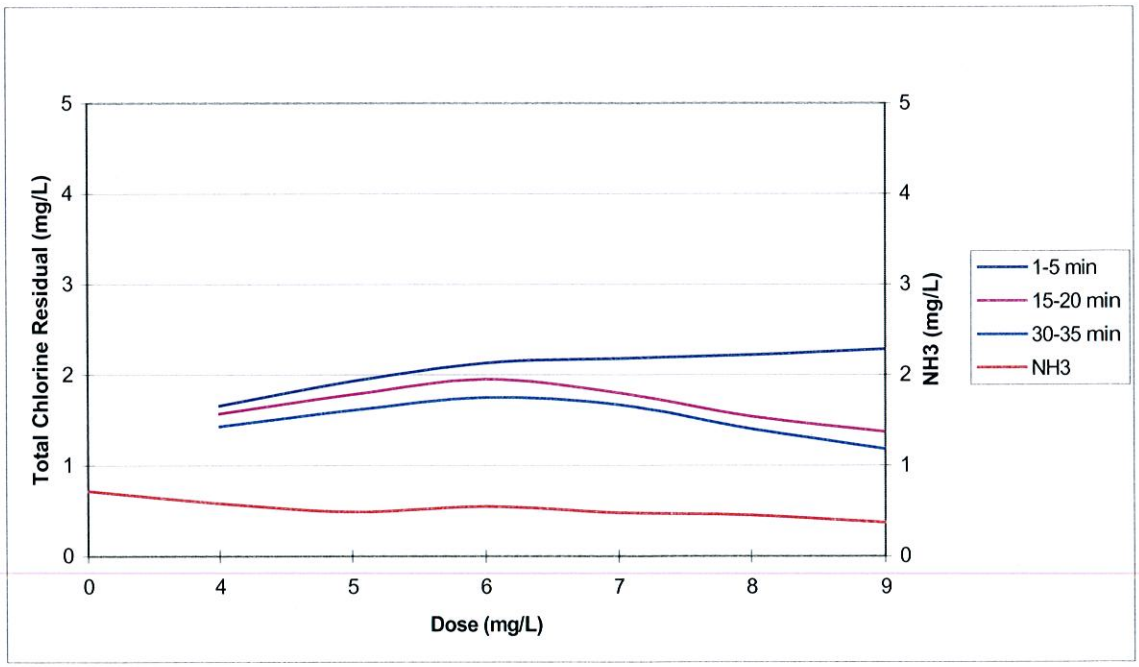

Figure B-10
12/28/1998 @ 2:30 PM Breakpoint Chlorination Curve

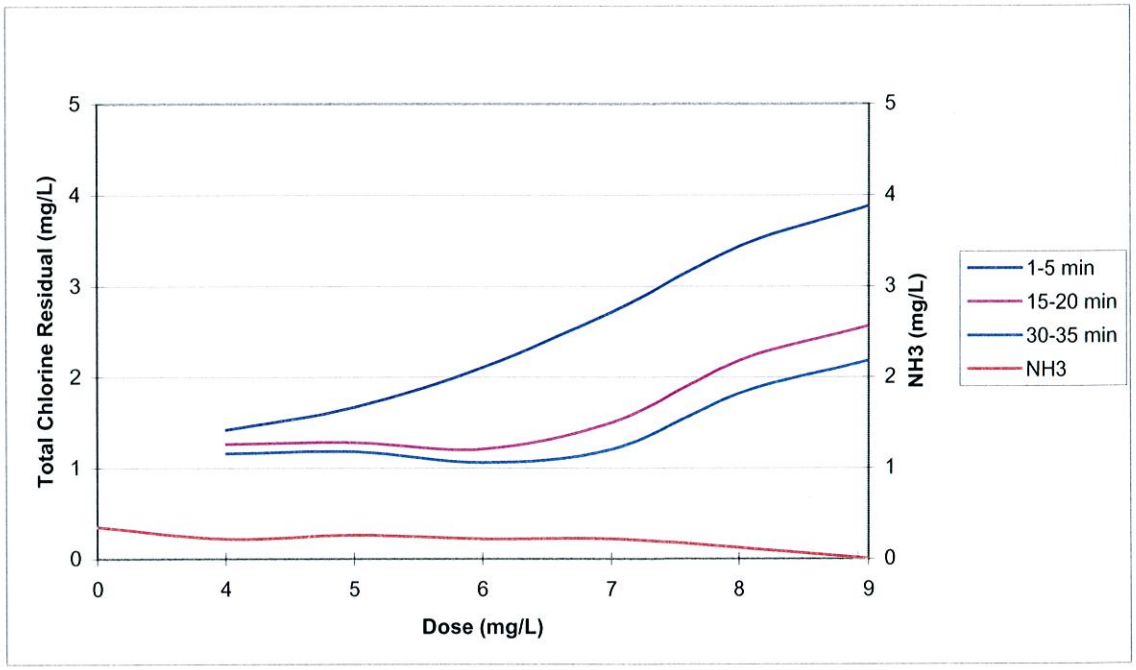

Figure B-11
12/28/1998 @ 6:30 PM Breakpoint Chlorination Curve

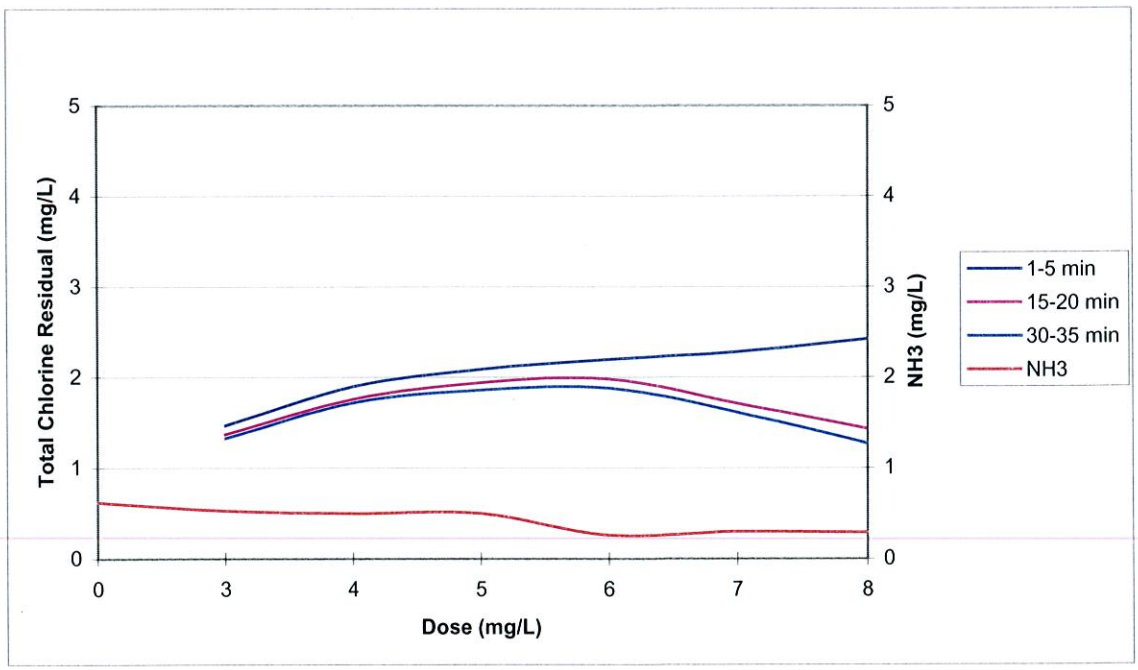

Figure B-12
12/29/1998 Breakpoint Chlorination Curve

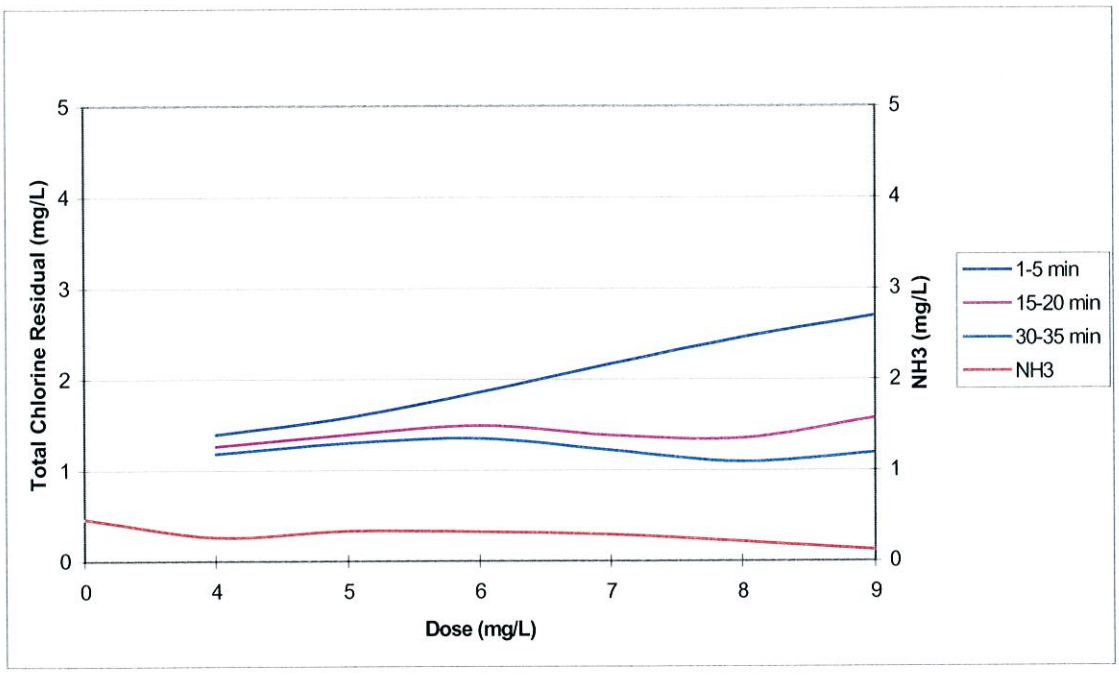

Figure B-13
12/30/1998 Breakpoint Chlorination Curve

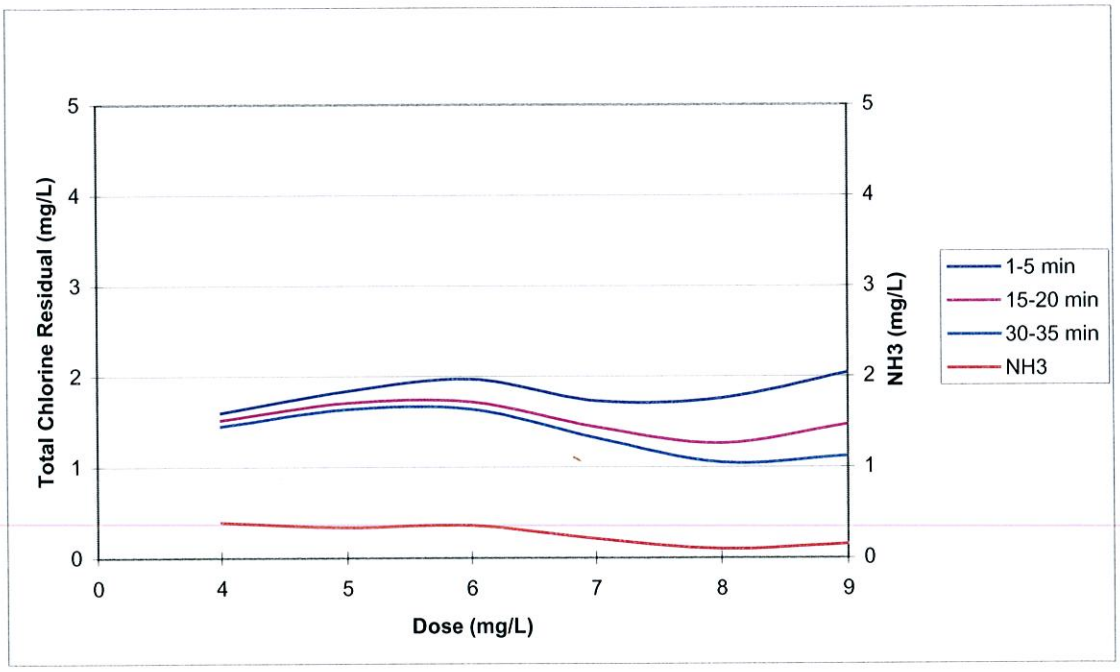

Figure B-14
1/2/1999 Breakpoint Chlorination Curve