Alternative TOC Removal Requirements: Cost-Saving Practice without Compromising Your Treatment Goals

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ABSTRACT

The City of Houston's Southeast Water Purification Plant (SEWPP) is a conventional surface treatment plant consisting of coagulation, flocculation, sedimentation, and filtration processes. The SEWPP presently has a treatment capacity of 120 million gallons per day (MGD), serving the City's southeast area and eleven co-participants. The plant will be expanded to 200 MGD by additional 80 MGD to meet the increasing water demands in the area.

Ferric sulfate is currently used as a primary coagulant at the SEWPP for enhanced coagulation. Based on the raw water alkalinity of 80-100 mg/L as $CaCO_3$, and total organic carbon (TOC) of 7-9 mg/L, the SEWPP is required to achieve at least 35% or 40% of TOC removal under the Stage 1 D/DBP Rule. Bench-scale test indicated that the required dosage of ferric sulfate would be 50 mg/L (dry weight) in order to achieve the TOC removal goal.

According to the Texas Commission on Environmental Quality (TCEQ) TOC Guidance Manual published in September 2002, surface water treatment plants are in compliance with TOC removal by meeting Step 1 matrix of required TOC removal percentage, or alternatively, Step 2 Alternative TOC removal requirement (ATRR), or Alternative Compliance Criteria (ACCs).

The raw water quality study was conducted to identify the low UV absorbance in the raw water. The ACCs were adopted by the SEWPP for TOC compliance. Weekly standard UV adsorption (SUVA) tests for raw and finished water as required under the ACCs were also conducted. As indicated in the SEWPP can also meet TOC removal requirements by meeting SUVA consistently less than 2.0 L/mg-m as indicated in ACCs Nos. 5 and 6.

By adopting alternative TOC removal requirements, the SEWPP reduces the average dosage of ferric sulfate to 25 mg/L, while achieving 17 to 25% TOC removal. Meanwhile, the treated water quality has not been compromised. The SEWPP meets all the Federal and State drinking water standards. The average filtered water turbidity is 0.04-0.08 NTU, and over 98% of 15-minute filtered water turbidities are less than 0.10 NTU in the past 2 years, meeting the AWWA Partnership for Safe Water (PSW) goal. By controlling the ratio of chlorine to ammonia, the free chlorine residual has been minimized and treated water disinfection by-products (DBPs) well controlled. Both annual average total trihalomethanes (TTHMs) and haloacetic acids (HAAs) leaving the plant are below 30 ug/L. In addition, by using the alternative TOC removal compliance, it save the City of Houston and other co-participants approximately $545,000 annually in the plant operation.

KEYWORD

TOC removal	UV Absorbance	SUVA	DBPs	Cost Savings

INTRODUCTION

TCEQ TOC Removal Guidance

To be in compliance with Disinfection byproduct (DBP) rules, all surface water treatment plants using conventional treatment processes are required to meet total organic carbon (TOC) requirements, which are specified in the Texas Administrative Code (30 TAC), Chapter 290, Section 290.112. Conventional treatment processes are composed of coagulation, flocculation, sedimentation and filtration processes. For the system serving 10,000 people or more must start monitoring in January 2001, and compliance was calculated starting in January 2002.

As specified in the TCEQ Total Organic Carbon Guidance Manual, there are three alternatives to be in compliance with the TOC removal requirements for surface water treatment plants:

- meet the Step 1 TOC removal requirement
- or meet the Step 2 TOC removal requirement
- or meet any of the Alternative Compliance Criteria (ACCs)

Table 1 presents the Step1 TOC removal requirements for the surface water treatment plants. The removal percentage varies with the raw water TOC and alkalinity. Typically, the TOC removal is more difficult as the alkalinity increases and TOC decreases. When alkalinity is high, more acid or coagulant has to be added to force the pH to be within the optimal pH range for coagulation process. TOC removal cannot be achieved easily as the TOC level decreases because there are few opportunities for particles to contact each other and form floc. Because of the changes in the raw water TOC and alkalinity levels, the TOC removal percentage is determined by the monthly raw and treated water compliance sample results.

The purpose of Step 2 Jar Test is to establish an alternative TOC removal requirement. In a Step 2 jar test, 10 mg/L increments of alum (or an equivalent amount of iron coagulant) are added to determine the incremental removal of TOC. TOC removal is calculated for each 10 mg/L increment of coagulant added. Coagulant must be added in the required increments until a target pH is achieved (see Table 2). The target pH varies with the raw water alkalinity level. The point where adding another 10 mg/L dose of alum (or an equivalent amount of iron coagulant) could not remove at least 0.3 mg/L of TOC is defined as the point of diminishing return (PODR). The percentage TOC removal achieved at the PODR in the Step 2 jar test is the plant's required percent removal rate, subject to approved by the TCEQ. The actual monthly plant TOC removal percentage has to be no less than the Step 2 Jar test result. As approved by the TCEQ, this result could be valid up to six months.

Table 1: Step 1 Matrix of Required TOC Removal Percentage*

Raw Water TOC (mg/L)	Raw Water Alkalinity (mg/L as $CaCO_3$)		
	0 –60	60 – 120	> 120
2.0 <= TOC <= 4.0	35%	25%	15%
4.0 <=TOC <= 8.0	45%	35%	25%
TOC >= 8.0	50%	40%	30%

Table 2: Step 2 Jar Test Target pH*

Raw Water Alkalinity (mg/L as CaCO3)	Target pH
0 – 60	5.5
> 60 – 120	6.3
> 120 – 240	7.0
> 240	7.5

Table 3: Summary of Alternative Compliance Criteria (ACCs)*

ACC	Description	Additional Sampling
1	Raw water TOC < 2.0 mg/L	None
2	Treated water TOC < 2.0 mg/L	None
3	TTHM < 40 ppb, HAA5<30 ppb, raw water TOC < 4.0 mg/L, and raw water alkalinity > 60 mg/L as $CaCO_3$	None
4	TTHM < 40 ppb, HAA5<30 ppb, and the system uses only chlorine	None
5	Raw water SUVA < 2.0 L/mg-m	Raw water SUVA
6	Treated water SUVA < 2.0 L/mg-m	Treated water SUVA (jar test)
7	Softening; treated water alkalinity less than 60 mg/L as $CaCO_3$	Treated water alkalinity
8	Softening; treated water alkalinity less than 60 mg/L as $CaCO_3$	Raw and treated water magnesium

* - Texas Commission on Environmental Quality Total Organic Carbon (TOC) Guidance Manual in Sept. 2002

Southeast Water Purification Plant Background

Southeast water purification plant (SEWPP), located at southeast corner of the City of Houston, has been put in service since 1991. With the firm capacity of 120 million gallons per day (MGD), the SEWPP is currently treating and pumping annual daily average 85 MGD finished water into the distribution system.

The SEWPP is receiving the Trinity River water as a sole resource. The Trinity River originating from Northeast of Dallas flows through rolling hills and coastal plains of Central and Southeast Texas into Lake Livingston. The Trinity River Pump Station located at the downstream of the Lake Livingston is pumping the water to Lynchburg Reservoir through a 22-mile main canal. The Lynchburg Reservoir is approximately 200 acres in size, with a storage capacity of 1.5 billion gallons. Lynchburg pump station at this reservoir is used to supply the raw water to the SEWPP via a 96-inch pipeline.

The Trinity River raw water quality parameters are presented in the following table. The Trinity River water can be characterized as moderately hard water, with moderate levels of dissolved solids, turbidity, color, and suspended solids. The average total alkalinity levels at 95 mg/L as calcium are sufficiently high to allow effective coagulation with ferric, even following massive influx of fresh water after heavy rain events or regional flooding. Overall, the Trinity River water is not subject to sudden water quality changes due to the fact that it is well buffered prior to entering into the water treatment processes.

Table 4: SEWPP Raw Water Parameters

Parameters	**Max.**	**Min.**	**Avg.**
PH	8.3	7.5	7.8
Turbidity (NTU)	65	10	20
Alkalinity (mg/L as $CaCO_3$)	110	76	94
Hardness (mg/L as $CaCO_3$)	110	90	96
Calcium (mg/L as Ca)	50	40	44
Color	60	10	20
Total Dissolved Solids (mg/L)	244	190	215

Chlorine and ammonia at the ratio of 4:1 are being fed to produce chloramines at Lynchburg Pump Station to prevent the slime growth inside the 96-inch raw water pipeline. The chlorinated raw water travels six(6) hours into the SEWPP through the 96-inch pipe, and it remains 1.8-2.2 mg/L total chlorine residual. As a conventional surface water treatment plant, the SEWPP is feeding ferric sulfate and cationic polymer at the head of the plant for coagulation process. Lime slurry is also fed there to increase the alkalinity levels for enhanced coagulation. During the coagulation, flocculation and sedimentation processes, chlorine and aqueous ammonia are being fed to maintain the total chlorine residual at 4.0 mg/L for meeting disinfection CT requirements. The settled water from the sedimentation basins flows through dual-media filters (sand + anthracite) by gravity, and enters into the clearwell. Then the filtered water at clearwell is being pumped to two(2) ground storage tanks by clearwell transfer pumps. Caustic soda is also fed there to bring the pH close to the stability pH level. The finished water from the ground storage tanks is discharged into the distribution system by high service pumps. Prior to the treated water leaving the plant, the chlorine is being added to the water to maintain 3.5-4.0 mg/L total chlorine.

In order to meet the Step 1 TOC removal requirement as specified in the TCEQ TOC Removal Guidance, the ferric dosage has been increased from 25 to 50 mg/L for enhanced coagulation since January 2002. As the consequence of this dosage change, the lime slurry and the sludge production volume were largely increased accordingly. Facing the higher cost of the treatment processes in the SEWPP, the City of Houston and plant operation staff from American Water Service (AWS) started to look for alternatives to be in TOC removal compliance.

RAW WATER QUALITY STUDY

City of Houston Water Quality Lab and AWS jointly took and analyzed weekly samples for raw water TOC, dissolved organic carbon (DOC), and specific UV absorbance (SUVA) at Lynchburg Reservoir prior to feeding any chemicals in September 2001. The following table presents the raw water TOC, DOC and UV 254nm from September 2001 to December 2002. The raw water TOC ranged from 6.9 to 9.1 mg/L, while the range of the DOC was from 6.2 to 8.4 mg/L. As indicated in Table 5, approximately 90% of organic carbon is DOC, which could pass through 0.45-um filter paper. Normally, the NOMs containing the high percentage DOC are very difficult to be removed by coagulation processes due to its high solubility.

Another interesting finding is that the Trinity River water usually has fairly low UV 254nm results. Organic compounds that are aromatic in structure or that have conjugated double bonds could absorb light in the ultraviolet wavelength range. The organic compounds with the aromatic structure or conjugated double bonds have high molecular weight. The high molecular weight organic compounds have the high UV absorbance, due to absorbing lights from the UV at a wavelength of 254 nm. On the contrary, the small molecular weight compounds have the low UV absorbance. The ratio of the UV absorbance to the DOC concentration is SUVA, which could be used as an indicator of the molecular weight distribution of the NOM in the water. The calculated raw water SUVA results from September 2001 to December 2002 are presented in the following table and figure. As indicated, all raw water SUVAs except one in September 2001 are below 2.0 L/mg-m. Normally, the raw water with the SUVA less than 2.0 L/mg-m tends to have a low humic acid. Moreover, for treating the low SUVA raw water, the effect the DOC on the coagulant dosage will be negligible, and relatively low TOC removal percentages are likely (Edzwald et al, 1990).

FINISHED WATER SUVA TEST

Our preliminary raw water SUVA study indicated that the SEWPP could use the ACC No. 5 as shown in the Table 3 for the compliance of the TOC removal. However, the limited raw water DOC and UV absorbance data could not guarantee the raw water SUVA would always be less than 2.0 L/mg-m in the future for compliance, especially that the raw water DOC and UV absorbance are largely affected by the rain events, temperature, and other factors. Due to the low SUVA results in the raw water, the lower SUVA results in the treated water should be anticipated. The ACC No. 6 requires that the finished water SUVA results be less than 2.0 L/mg-m for alternative TOC compliance. The AWS personnel conducted the finished water SUVA test in a weekly basis following the standard procedures as described in the TCEQ TOC Removal Guidance since January 2002. The finished water SUVA test is very similar to the routine chemical jar test performed in the water treatment plant, which is using the same coagulant, lime, and polymer dosages as those at full-scale treatment processes. However, due to the interference with UV absorbance measurements by the ferric, the alum sulfate as coagulant is being used in the SUVA test.

In this test, 26.3 mg/L as alum sulfate (equivalent to 25 mg/L as ferric sulfate), 1.2 mg/L as cationic polymer, and 5.0 mg/L as lime slurry were fed in the SUVA test. After completion of the jar test, the settled water DOC and the UV 254nm were measured for the calculation of the SUVA. Figure 2 presents the finished water SUVA during that period. All finished water SUVA results are less than 2.0 L/mg-m, which is consistently in compliance with the ACC No. 6. In January 2003, the SEWPP started to use the finished SUVA test for alternative TOC removal compliance. Since then, the weekly finished water SUVA results have been in compliance all the time.

Table 5: SEWPP Raw Water TOC and DOC (Sept. 01 – Dec. 02)

Items	TOC (mg/L)	DOC (mg/L)	SUVA (L/mg-m)	DOC/TOC Pct. (%)
Max.	9.1	8.4	2.97	
Min.	6.9	6.2	0.90	
Avg.	8.2	7.4	1.68	89.9%

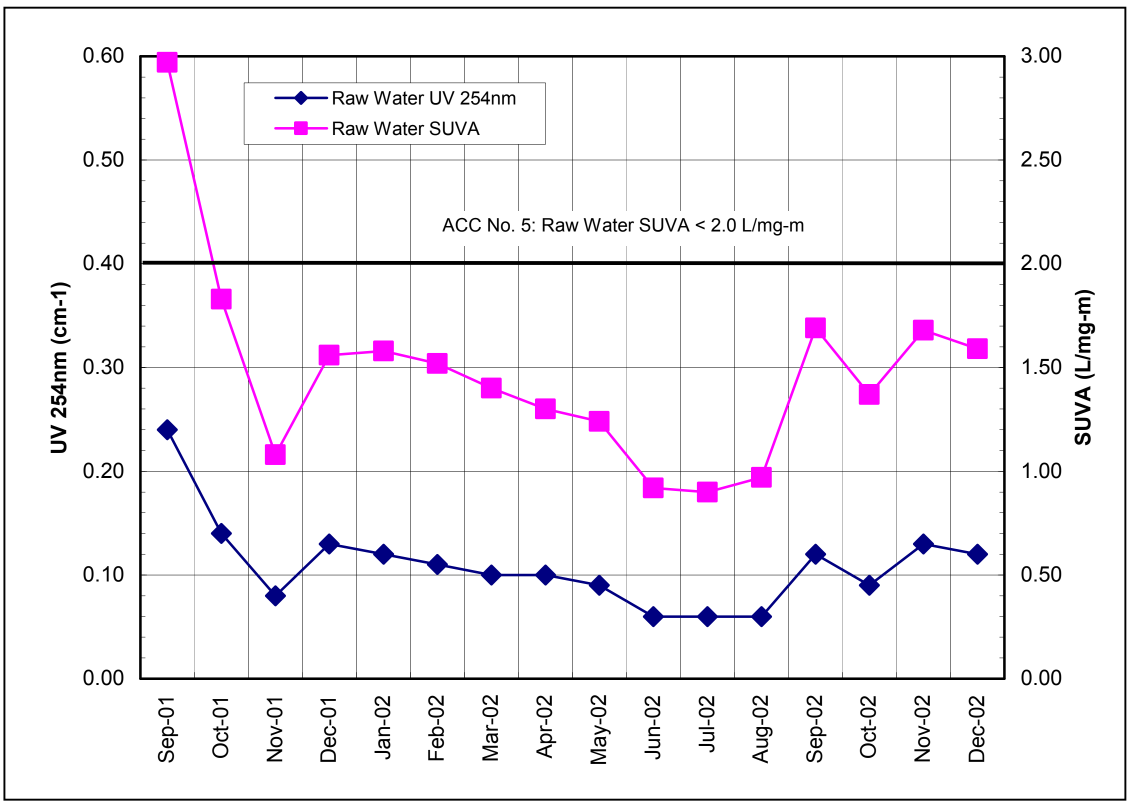

Figure 1 Raw Water UV 254nm and SUVA

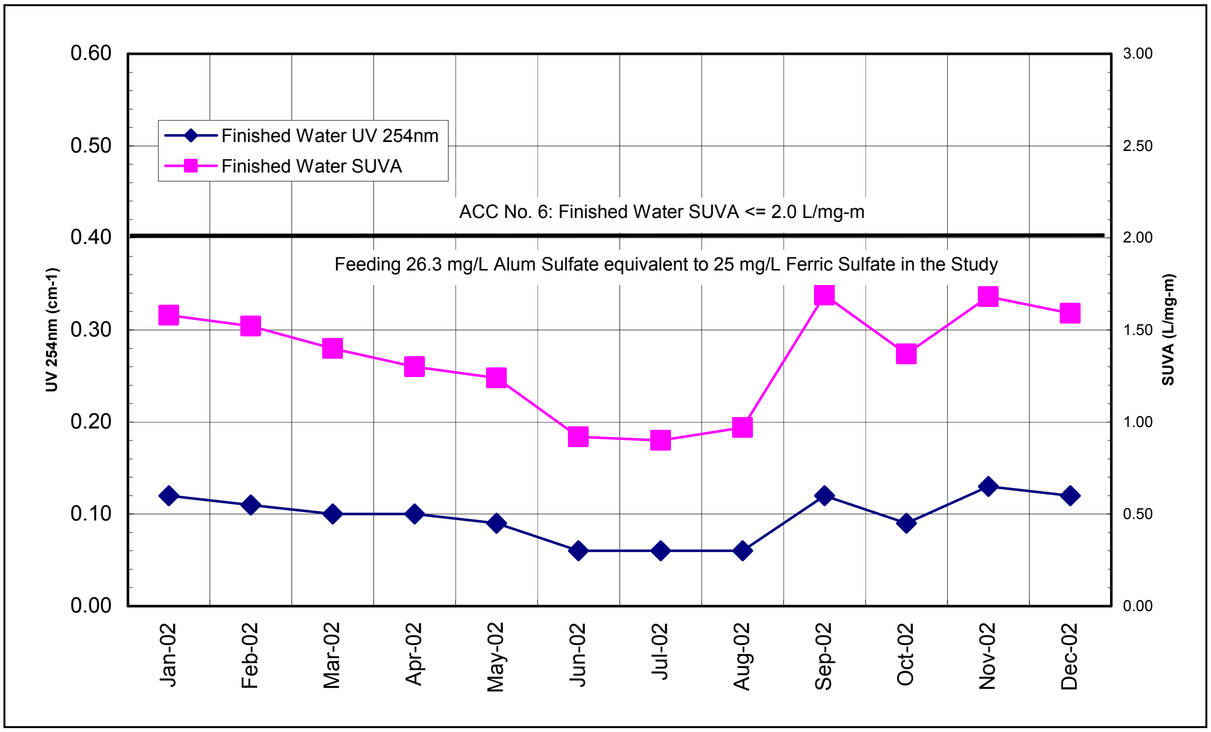

Figure 2 Finished Water UV 254nm and SUVA

MAINTAIN THE FILTERED WATER TURBIDITY

During the finished SUVA test study, the SEWPP operation staff also conducted the bench-scale jar test for optimizing the polymer dosage to maintain the low filtered water turbidity below 0.10 NTU with the lower coagulant dosages. The optimal cationic polymer dosage as the coagulation aid was determined at level of 1.0-1.2 mg/L with 25 mg/L Ferric Sulfate by the study, which was the three times as before. The SEWPP started feeding the ferric sulfate ranged from 20-30 mg/L, and 1.0-1.2 mg/L cat-polymer in January 2003. The monthly average combine filtered turbidity has been well controlled below 0.08 NTU since then (see Figure 3). Based on the statistic analysis of the historic plant operation data from Year 2003 to 2006, over 98% of turbidity on-line readings at 15-minute interval are below 0.10 NTU, while TCEQ only requires that the 95% of the monthly turbidity readings at 4-hour interval be less than 0.3 NTU. The SEWPP also volunteered to join in the American Water Works Association (AWWA) Partnership for Safe Drinking Water Program, and received the Director's award in Year 2005.

CONTROL THE DBP FORMATION

Since January 2003, the SEWPP has been using raw and finished SUVA test in lieu of the Step 1 TOC removal requirement for compliance. During the full-scale treatment processes, the TOC removal percentage is roughly 20%. In terms of TOC level, the SEWPP settled water contains the organic compounds at a high level. To monitor the DBPs production through the treatment processes, the weekly samples on the chlorinated raw water, settled water, filtered water, and finished water samples were taken at SEWPP all the time.

Figure 4 shows the trends of total trihalomethanes (TTHMs) through the treatment processes in the past four years. As shown in this figure, it is interesting that the chlorinated raw water did not carry the high TTHMs into the SEWPP without any processes for the TOC removal. The primary reason is that the raw water SUVA results are consistently less than 3.0 L/mg-m. The NOMs in this type of water are more likely low humic acid and low molecular organic compounds, which will not tend to be precursors to form the DBPs with the chlorination process. In addition, the free chlorine residual through the water treatment modules was also monitored by grabbing samples for every four(4) hours. By adjusting the chlorine and ammonia feed ratio, the free chlorine value in the processed water was controlled less than 0.1 mg/L all the time. Therefore, during the treatment processes in the plant, the DBPs have not been increased much and maintained much leaa than the TCEQ MCL requirements in the finished water leaving the plant in the past four years.

COST SAVINGS

The cost comparison discussed in this section is based on chemical costs specifically for the City of Houston. The costs of the ferric sulfate, polymer, lime slurry, and sludge processing were considered in the in the comparison. Other chemicals (chlorine, ammonia, flocculant aid polymer, filter aid polymer, and caustic soda for post filtration pH adjustment) were not included in the comparisons because they were not impacted by the coagulant dosage changes.

1) Coagulant Cost

Using the SUVA test in lieu of Step 1 TOC Removal to be in compliance at SEWPP directly brings the ferric sulfate usage ranging from 50-60 mg/L in Year 2002 down to annual average 20-30 mg/L thereafter. The approximate 50% Ferric Sulfate dosage decrease is equivalent to a $13.25 per million gallons, or an annual saving of $400,000 based on an annual average daily flow of 85 MGD.

2) Lime Slurry Cost

The lime slurry was used to increase the alkalinity and pH adjustment for coagulation processes. Due to the lower ferric sulfate dosage being used in the coagulation process, the lime usage has been also reduced consequently. The reduced dosage of the lime was approximately 5 mg/L, which cost us approximately $85,000 less per year.

3) Polymer Cost

To maintain the settled water turbidity less than 2.0 NTU continuously, the jar test was performed to determine the optimal cationic polymer dosage at the low coagulant dosage. The polymer dosage was increased from 0.4 to 1.2 mg/L by the test results. The 0.8 mg/L increase in the polymer equates to additional $2.90 per million gallons treated. The annual cost increases of approximately $90,000 per year based on current polymer prices at a flow of 85 MGD.

4) Sludge Processing Cost

Due to the lower coagulant and lime slurry dosages, the sludge produced was approximately 30% reduction in the total sludge volume. The annual sludge process cost savings was $150,000 per year at a flow of 85 MGD.

Overall, by using the alterative TOC removal compliance in lieu of the Step 1 TOC removal requirement, the chemical and sludge processes cost savings at SEWPP were approximately $545,000 annually.

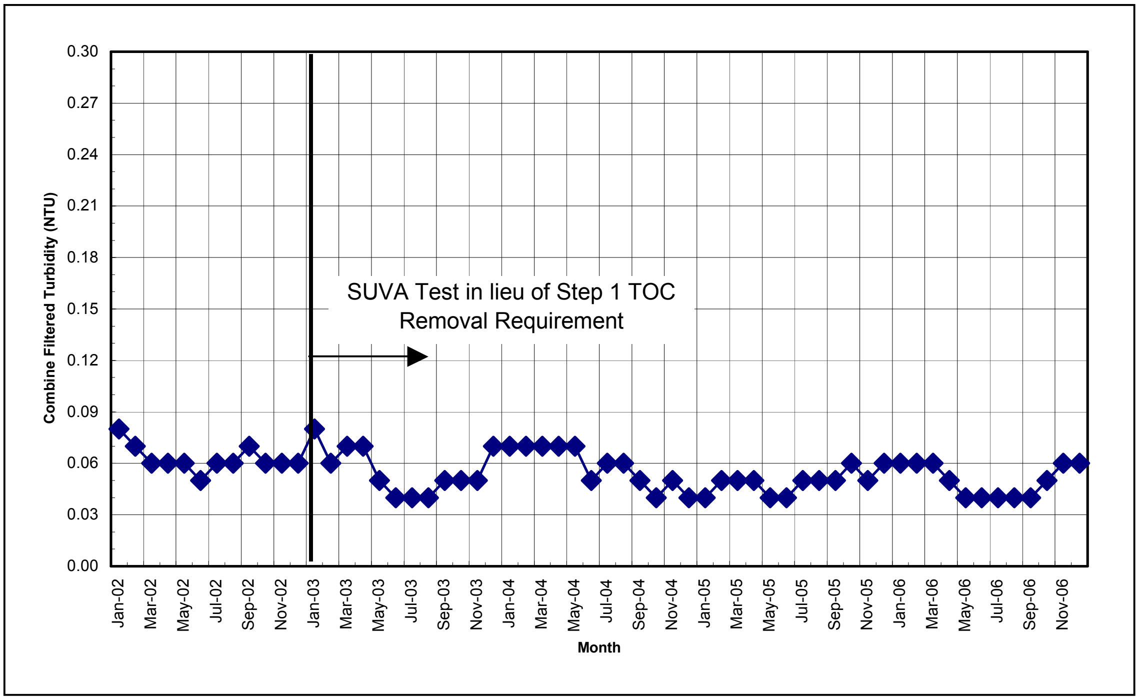

Figure 3 Monthly Combine Filtered Water Turbidity

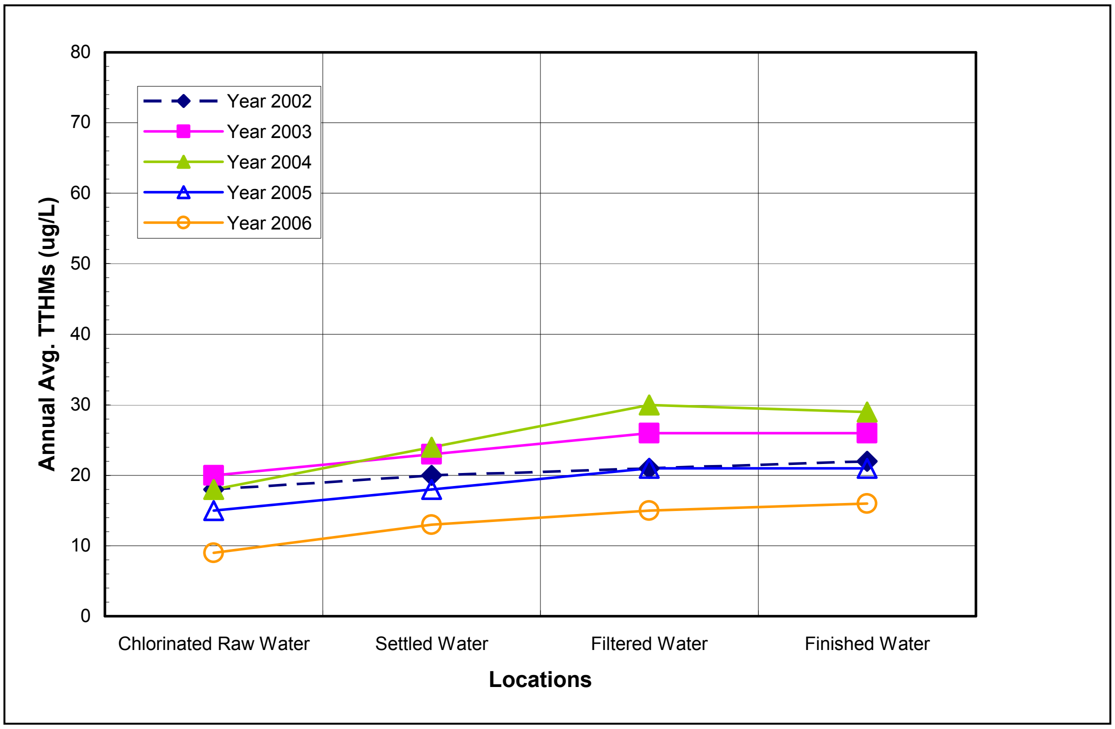

Figure 4 TTHMs through the Treatment Processes

SUMMARY

The SEWPP used the raw water and finished water SUVA results for alternative TOC compliance starting from January 2003. In the past four years, most of the raw water and all finished water SUVA results in the weekly basis have been below 2.0 L/mg-m for meeting the ACC Nos. 5 or 6. The ferric sulfate dosage has been reduced to 25 mg/L since then, and it also led to the reduction of the lime dosage and sludge production at SEWPP. The cationic polymer dosage was increased enough to maintain the settled water turbidity less than 2.0 NTU so that the monthly average combined filtered turbidity ranged from 0.04 to 0.07 NTU. 98% of the combine filtered turbidity readings at 15-minute interval in Year 2003-2006 were less than 0.10 NTU, which is exceeding the TCEQ requirement, and AWWA Partnership for Safe Drinking Water Phase IV requirement, which is 95% of the readings less than 0.10 NTU. In addition, though the high TOC may not be removed by the current coagulation process, the annual average TTHMs and HAA5s have been controlled below 30 ug/L leaving the plant due to the low humic acid in the raw water and minimizing the free chlorine residual in the disinfection processes.

The treatment process changes directly reduced the chemical and sludge process costs significantly at SEWPP. It is estimated that using the alternative TOC removal compliance directly save the City of Houston and eleven (11) co-participants approximately $545,000 annually. More importantly, the finished water quality leaving the SEWPP has been continuously maintained at the high level.

ACKNOWLEDGEMENTS

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