

ICR Treatment Study Summary Report

Evaluation of Alum Coagulation Pretreatment and Pilot-scale Test Using A Dupont A15S Membrane Element For Compliance of the Information Collection Rule's Grandfather of A Previously Conducted Study

Information From USEPA Project Report # EPA/600/SR-92/023, April 1992.
Study conducted during the period of July 4, 1990 through February 2, 1991

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**South Water Treatment Plant,
ICR # - 283**

Attachments: 1 diskette containing the *Data Collection Spreadsheets (283ACA15) and
Summary Report*

Section I: Conclusions and Recommendations

Conclusions

1. Several different membranes were able to produce a DBPFP below 0.10 mg/L as Cl^- during membrane selection at the surface water site. The DS5 and A15s were selected for further study because they were the most productive membranes, having the highest MTCs that reduced the DBPFP below 0.10 mg/L as Cl^- .
2. Pretreatment studies at the surface water site clearly demonstrated that conventional nanofiltration pretreatment, scaling control and prefiltration, or sand filtration in addition to conventional pretreatment were not adequate to enable the nanofilters to consistently produce water. Pretreatment studies of the surface water demonstrated that either alum coagulation, microfiltration or GAC filtration greatly reduced the fouling capacity of the surface water. Crossflow microfiltration followed by GAC filtration and alum coagulation was the indicated order of the pretreatment processes capable of reducing the rate of nanofilter MTC decline.
3. Long term operation of six different nanofiltration systems incorporating three different pretreatment systems and two different membranes demonstrated that any of the surface water site nanofiltration systems were capable of achieving consistent production for 16,770.8 of 17,994.5 hours or in excess of 93% of the operational time.
4. Long term operation at the surface water site demonstrated that any of six different nanofiltration systems consistently removed more than 98% of the raw water DBPFP and averaged 22 ug/L as Cl^- in the permeate stream.
5. The ratio of the TOXFP to the DBPFP, THMFP and HAFP was statistically equivalent for the raw, feed and permeate streams for each system at the surface water site. The distribution of brominated species was greater in the permeate stream than in the raw water or feed stream for the surface water systems. The concentration of chlorodibromomethane and dibromoacetic acid was typically the same or greater in the permeate stream, as opposed to the raw water and feed stream. DBPFP accounted for 37% of the TOXFP in the surface water site samples. The HAFP to THMFP ratio was equal in the raw, feed and permeate streams in all systems at the surface water site from October to February. The HAFP exceeded the THMFP, 4/3 ratio, at the surface water site from February to June.
6. The average NPDOC reduction by alum coagulation, microfiltration and GAC filtration was 66, 7 and 21% during the surface water site nanofiltration study.
7. The average MTC decline rates produced by pretreatment with alum coagulation, microfiltration and GAC filtration were $1.55\text{E-}4/\text{d}^2$, $1.88\text{E-}4/\text{d}^2$ and $4.14\text{E-}4/\text{d}^2$. The average MTC decline rates produced by the DS5 and the A15s nanofilters were $1.63\text{E-}4/\text{d}^2$ and $4.06\text{E-}4/\text{d}^2$. Based on MTC decline rates, alum coagulation followed by the DS5 was the most effective pretreatment process and nanofilter combination.
8. The removal of DBP precursors by nanofiltration at the surface water site was independent of pressure and recovery variations and was determined to be sieving. DBP precursor rejection could feasibly be increased by a tighter membrane but would not be decreased by lower recovery or pressure.

9. There was a statistically significant difference between the THMs found using EPA methods 501.2 and 551 in the same samples from the surface water and groundwater sites. THM concentrations determined using EPA method 551 were found to be 80 % of the THM concentrations determined using the EPA method 501.2.

Recommendations

1. Two new pretreatment processes that should be investigated for fouling reduction from highly organic surface waters are bank filtration varying soil type and slow sand filtration.
2. Research involving the surface/liquid interface between the feed stream and membrane surface should be conducted to determine the effect of different membrane materials and feed stream chemical environments on mass transfer mechanisms in membrane processes. It is feasible that rejection of DBP precursors could be increased if a higher feed stream pH could be tolerated. Any ionization of DBP precursors would seemingly increase precursor rejection.
3. Additional research should be conducted on pretreatment processes such as coagulation, GAC filtration and microfiltration for fouling reduction in membrane processes. This and other works have demonstrated that groundwater have a fouling capacity that is several orders of magnitude less than surface waters with the same NPDOC concentrations. It is feasible that very low surface loading rates in filtration processes would reduce the fouling capacity of surface waters, since that is the natural process that recharges groundwater. Shallow well withdrawal from surface water sites is another feasible means of fouling reduction in surface waters.
4. The parallel and series combination of nanofiltration with other water treatment processes should be investigated in order to determine optimum methods of meeting DBP control levels. This research should include bypassing, blending, and series combination of different processes including nanofiltration.
5. Research should be conducted on the improvement of fouling indices that can quickly determine the fouling capacity of waters on membrane processes with pore sizes of 0.01 micron or less. Correlation of the rates of microfilter fouling to water quality, operating pressures and microfilter materials and devices should be determined using different indices and then the indices should be correlated to fouling in pilot or actual plant operation.
6. Model development should be pursued that investigates the effect of horizontal feed stream velocity, vertical feed stream velocity, recovery, feed stream water quality and pretreatment processes control parameters on mass transfer in membrane processes.
7. The effect of cleaning and feed water quality on the mass transfer characteristics of solutes and water on membranes of different materials should be investigated.
8. The comparative cost for construction and operation of membrane processes should be well documented by development of databases for engineering estimates and field verification of these estimates using newly constructed membrane plants.
9. Information regarding the comparative ease or difficulty of operation of water treatment plants using membrane processes should be developed. Membrane processes are more

automated and less subject to variation than conventional water treatment processes and should be significantly easier to operate and maintain, especially for small systems.

10. The effect of the NPDOC concentration in water should be investigated regarding chlorine demand, DBP formation, corrosion, bacterial integrity, and taste and odor in a distribution system. Adverse or beneficial effects on the system of interrelated water quality parameters should be investigated for finished waters from membrane systems. Additional benefits could justify the higher cost of membrane systems relative to conventional treatment.
11. The cost and associated water quality of concentrate disposal needs to be modeled and investigated. Concentrates from nanofiltration processes will not have a TDS concentration over 2000 mg/L and will not have the same adverse effects as concentrates from reverse osmosis processes. Testing methods for the effect of these concentrates should be developed so they can be disposed of within the regulatory environment.
12. A model needs to be developed that would incorporate the normal loss of productivity of membrane MTC to predict membrane replacement. The model should consider water quality, water production, power cost, element and system maintenance, as well as rate of MTC decline.
13. A comparison should be made involving several laboratories on THMFP using different waters analyzed by EPA methods 501.2 and 551. Any differences in this comparison should be fully explained or investigated through appropriate research.

Section II: Background Information

Introduction

The City of Melbourne, Florida utilizes a surface water source with an average TOC above 20 mg/L and serves a combined population of approximately 140,000. In accordance with the ICR the City of Melbourne must conduct pilot studies or grandfather an existing study. The attached forms, computer files and supporting documentation are from an existing membrane study submitted in compliance with the ICR grandfather clause.

The information contained within this report was summarized from membrane pilot studies conducted by the University of Central Florida for the USEPA Risk Reduction Engineering Laboratory, Cincinnati, OH. The results of these studies were published by USEPA in April of 1992 as EPA/600/SR-92/023 and was titled "*Reduction of Disinfection By-Product Precursors by Nanofiltration*". These studies were conducted with the direct objective of using a surface water source with advanced pretreatment and membrane technology to evaluate process capability for compliance with the disinfection by-product regulations proposed at the time. The studies were conducted on the source and finished waters to the South Water Treatment Plant (ICR-ID No. 283).

The City of Melbourne currently has two water treatment facilities. The South Water Treatment Plant treats approximately 10 MGD of surface water from Lake Washington using alum coagulation, flocculation, sedimentation, and PAC followed by filtration with sand and anthracite. The second facility, the RO Water Treatment Plant, is located adjacent to the surface water plant but uses a brackish groundwater as the source for its membrane process. The finished water from both facilities is disinfected using monochloramine prior to blending, storage and distribution.

Treatment Plant Description

The following section will describe the existing treatment process used by the South Water Treatment Plant (WTP). Figure 1 presents the process schematic of the WTP.

The membrane studies were conducted at the South WTP located northwest of the City of Melbourne, Florida, and adjacent to Lake Washington. The WTP uses the lake, which is connected, to the St. Johns River as its raw water source. The WTP uses alum coagulation followed by flocculation with the addition of polymer, sand filtration, and disinfection using chloramination. In addition it uses powdered activated carbon for odor control and lime for pH stabilization. The AC-DS5 study used the finished water from the South WTP after filtration but before any disinfectant had been used.

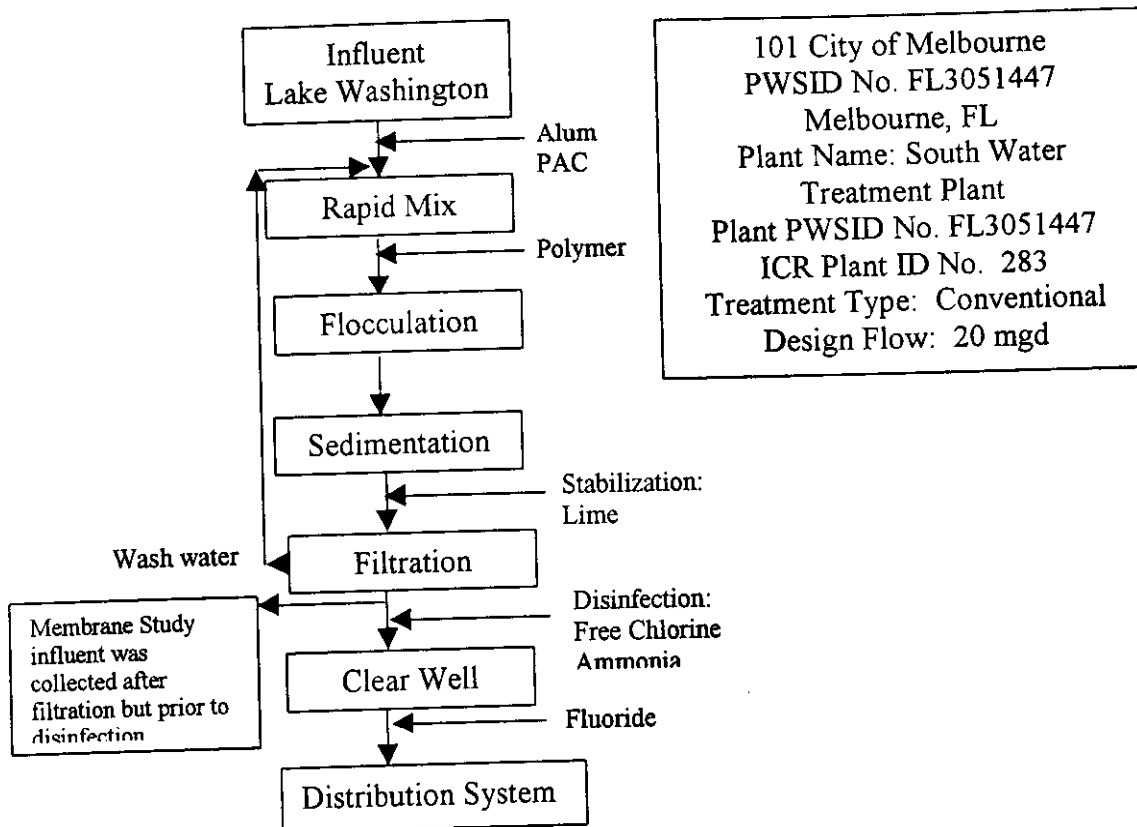


Figure 1: Process Schematic For The South WTP

Table 1 presents the South WTP process design and chemical addition parameters that were also documented in report forms A2 and A3 from the *ICR Sampling Manual* and submitted for the *ICR Water Utility Database System*. The period of time for the information reported in Table 1 was from 7/28/97 to 12/31/98.

The major challenge facing the utility will be to meet both the Surface Water Treatment and DBP Rules. It will take a carefully planned and concerted effort to reduce the DBP concentrations and maintain effective disinfection of the potable water system. The system currently blends with a brackish water reverse osmosis (RO) plant and uses chloramination to reduce the DBP level, which is mainly contributed by the South WTP. The current THM4 and HAA6 results of ICR monitoring indicate that they can meet phase I standards of 80/60; however, they may exceed the proposed phase II standards of 40/30 ug/L. Future plans provide for the expansion of the RO plant, however increases in disinfection "CT" requirements could off-set the DBP reduction benefits derived from the increased blending of the higher quality RO water. It is anticipated that advanced treatment processes for the reduction of the surface WTP finished water TOC and/or alternative disinfection will need further investigation to address anticipated "CT" and DBP requirements of proposed regulations.

Table 1: Process Design and Chemical Addition Parameters

Unit Process	Process Description	Quantity
Plant Information	Treatment Plant Name	South Water Treatment Plant
	ICR Treatment Plant ID	283
	Treatment Plant PWS ID	FL3051447
	Treatment Plant Category	Conventional
	State Approved Plant Capacity	16.5 MGD
	Historical Min. Water Temp.	8.0 deg. C
	Installed Sludge Handling Cap.	500,000 gpd
	Blending Indicator	N
Water Source	Water Source Name	Lake Washington-1
	Water Resource Type	Reservoir/lake
	Average Residence Time	13 days
	Intake Name	South Raw Water Intake
	Water Shed Control	Yes
	Hydrologic Unit Code	Lat. +28°8'46" (deg., min., sec.) Long. -80°44'14" (deg., min., sec.)
	Water Source Name	Lake Washington-2
	Water Resource Type	Reservoir/lake
	Average Residence Time	13 days
	Intake Name	North Raw Water Intake
	Water Shed Control	Yes
	Hydrologic Unit Code	Lat. +28°9'1" (deg., min., sec.) Long. -80°44'10" (deg., min., sec.)
	Wash Water Treated	No
	24 hour Average Flow	0.82 MGD
Coagulation	Alum Dose*	126.5 mg/L $Al_2(SO_4)_3 \cdot 14H_2O$
	Powdered Activated Carbon*	24.1 mg/L
Clarification Solids Contact Unit	Polymer LC-211*	0.1 mg/L
	Surface Area	26,582 ft ²
	Volume	2,906,224 gal.
Stabilization	Calcium Oxide	19.4 mg/L CaO
	Surface Area	4,000 ft ²
	Volume	412,000 gal.
Filters	Surface Area	5,760 ft ²
	Liquid Volume	292,976 gal.
	Total Media Depth	328 in.
	Media Type	TRIM
	Min. Water Depth to Media	3.5 ft
	Top of media to top BW trough	3.0 ft
Disinfection	Chlorine Gas	11.10 mg/L Cl_2
	Anhydrous Ammonia	3.00 NH_3A
Clear Well		8 665 ft ²
	Surface Area	741,500 gal.
	Liquid Volume	246,076 gal
	Min. Liquid Volume	UN
	Baffling Type	N/A
	Short Circuiting Factor	Y
	Covered Index Code	1.34 mg/L Na_2SiF_6
	Hydrofluorosilic Acid	19.3 mg/L CaO
	Calcium Oxide	

Summary of Source and Finished Water Quality

The following section will present, in tabular form the source and finished water quality of the South WTP for the reporting period of July 1990 to June 1991. In addition, it will report a summary of the more current source and finished water monitoring conducted for the ICR with respect to DBPs. Table 2 presents the source water and Table 3 presents the finished water monitoring conducted by the utility during the period of time the pilot study was conducted. Table 4 presents information that was collected for ICR monitoring between October 1997 and September 1998 and represents current conditions of DBP formation. The samples were collected from the "influent" to the South WTP and at the entry to the distribution system after blending of the RO and surface WTP finished waters ("finished"). The "Distribution System" THM4 and HAA6 results were collected at the farthest ICR sample location.

The water quality summary indicates that the source has yearly average TOC concentrations above 27 mg/L. The finished water from the South WTP in 1990 before the RO plant was built removed approximately 70 % of the TOC to an average of 8 mg/L. Table 4 shows that blending with the RO plant has reduced the TOC of the finished water to below 5 mg/L. DBP results indicate that the THM4 and HAA6 concentration can currently meet the phase I levels of 80/60 ug/L, but may not meet the proposed phase II limits of 40/30 ug/L. In addition, bromide concentrations measured in the source water could eliminate ozone as an alternative option for disinfection.

Table 2: Source Water Quality Summary For South WTP (1990-91)

Water Quality Parameter	Average Yearly Concentration	Standard Deviation	Maximum Yearly Average	Minimum Yearly Average
Temperature (°C)	24.5	4.32	32.8	13.3
pH	7.98	0.06	8.38	7.57
Turbidity (ntu)	45.6	4.3	564	38.4
Alkalinity (mg/L CaCO ₃)	69	1.8	75	64
Calcium Hardness (mg/L CaCO ₃)	104	14	144	88
Total Hardness (mg/L CaCO ₃)	137	19	192	113
NPDOC (mg/L C)	27.7	3.06	36.3	19.6

Table 3: Finished Water Quality Summary For The South WTP (1990-91)

Water Quality Parameter	Average Yearly Concentration	Standard Deviation	Maximum Yearly Average	Minimum Yearly Average
Temperature (°C)	24.9	4.3	32.8	13.3
pH	7.84	0.04	8.13	7.60
Turbidity (ntu)	0.24	0.10	0.96	0.10
TOC (mg/L C)	8.24	0.31	10.9	6.6
THM	15	2	11	20

Table 4: Current Source and Distribution Water Quality (1997-98)

Water Quality Parameter	Average Yearly Concentration	Standard Deviation	Maximum Yearly Average	Minimum Yearly Average
Influent				
Bromide(mg/L)	0.19	0.12	0.44	0.035
UV-254 (cm ⁻¹)	0.770	0.108	0.922	0.544
TOC (mg/L C)	21.2	3.6	27	11
Finished				
pH	8.0	0.3	8.7	7.6
UV-254 (cm ⁻¹)	0.092	0.015	0.117	0.066
TOC (mg/L C)	4.2	0.9	6.1	2.7
THM4 (µg/L)	25.2	14.4	48	11.1
HAA6 (µg/L)	21.3	8.0	30.6	13.6
Distribution System				
Distribution System THM4 (µg/L)	42.3	18.6	69.5	22.8
Distribution System HAA6 (µg/L)	15.4	10.1	30.7	3.5

Section III: Methods and Materials

Integrated Membrane System

A flow diagram of the AC-A15S system, sampling locations and points for monitoring flow and pressure is shown in Figure 2. The membrane treatment study was conducted using the South WTP finished water after sand filtration but before disinfection. From a tap in the raw water after filtration the water was pumped to the membrane pilot unit.

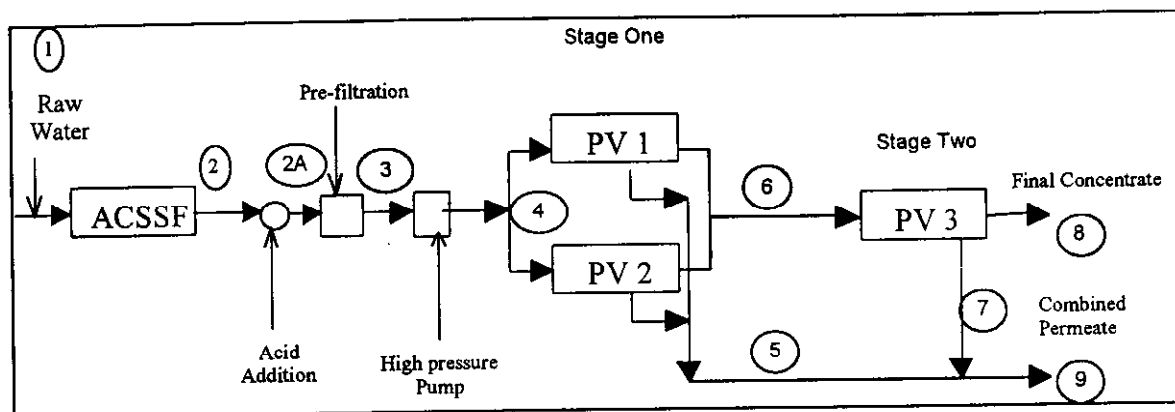


Figure 2: AC-A15S Pilot-Scale Unit Flow Diagram

A 4-2-1 array pilot plant housed in a 30 foot by 8-foot trailer used for the Daytona Beach groundwater study portion of the project was modified for use in Melbourne. The seventh pressure vessel (stage 3) was not used. The 4-2 array remaining was divided into two 2-1 systems. Each pressure vessel held three membranes; therefore each system contained a total of nine membranes. One system used alum-coagulated pretreated water. The second used GAC pretreated water. Both systems evaluated both Desal DS5 and DuPont A15s membranes. Each combination (GAC-DS5, GAC-A15s, AC-DS5 and AC-A15s) was evaluated for four months. Since the AC and GAC systems operated simultaneously, this resulted in eight months of operation. Four combinations of operating parameters were evaluated. These combinations were 10 gsf - 45% recovery, 10 gsf - 65% recovery, 15 gsf - 45% recovery, and 15 gsf - 65% recovery. Each combination was tested for one month. A water quality sample was obtained for each month.

Alum-coagulated settled sand filter water was obtained from the water treatment plant prior to chlorination. This water was used as a pretreated feed water for the AC-DS5 and AC-A15s systems. A section of four-inch pipe was removed from an obsolete backwash system on the South WTP filter #2. A connection was made between the South WTP process stream to a one horsepower centrifugal pump, which boosted the water pressure to 30 psi and moved the pretreated water to the AC-A15S pilot plant. Sulfuric acid was injected inline to reduce and maintain the pH between 3.5 and 4.5 for inhibition of aluminum hydroxide scaling. The water then passed through a 5-micron bag filter. Table 5 presents a summary of some of the pretreatment design parameters. After prefiltration, the water passed through a high pressure feed pump which boosted the pressure to approximately 100 psi and passed the water through the membrane process.

Table 5: Membrane Pilot Unit Pretreatment Design Parameters

Unit Process	Process Description
Full Scale Plant	Alum Coagulation
	Sedimentation
	Sand Filtration
	(see Figure 1 and Table 1)
Scale Control (Pilot-Scale)	Chemical Type: Sulfuric Acid
	Adjust pH: 3.5 – 4.5
Bag Filtration (Pilot-Scale)	Filter Specialists, Inc.
	Total Surface Area (ft ²): ~5
	Nominal Pore Size (μm): 5
	Filter Material: Polypropylene felt

The pilot plant utilized a 2-stage Christmas tree configuration similar to the ICR pilot unit design described in the *ICR Manual for Bench- and Pilot-Scale Treatment Studies*. The first stage consisted of two pressure vessels in parallel, which in turn fed concentrate to a single pressure vessel in the second stage. It incorporated three 4040 elements per pressure vessel for a total of nine elements. Trisep Corporation now manufactures the DUPONT A15S. The manufacturer reported membrane characteristics are presented in Table 6. The permeate and concentrate streams were combined and discharge to the South WTP backwash pond for reuse.

Cleaning Procedures

Each system was cleaned every two to four weeks, depending upon the degree of fouling. The membranes were cleaned with a solution of high phosphate detergent and sodium hydroxide for approximately one hour. To clean the system, the permeate valves were closed and a 3/4 horsepower Sta-rite centrifugal pump recirculated cleaning solution from a 60 gallon cleaning tank to the feed/concentrate side of the membranes at approximately 6 gpm. Both first and second stages (all nine membranes) were cleaned at the same time.

Experimental Design

Table 7 presents the overall schedule of operation and the experimental design associated with each of the pilot unit combinations. The AC-A15S pilot-scale study was one of six different pilot- and bench-scale unit combinations to be operated at the South WTP. The pilot-scale studies included combinations of 2 pretreatment (Alum coagulation, sedimentation, Sand filtration and filtration with GAC) and two membrane elements (Desal DS5 and Dupont A15S) used in a 2-stage (nine elements total) pilot unit. The bench-scale studies used combinations of 2 pretreatment (cross-flow or direct flow micro-filtration) and one membrane type, the Desal DS5. As is shown in Table 7 the AC-A15S pilot unit was scheduled to operate from October 1990 to the end of January 1991. However, scheduling changes and membrane replacement resulted in the operation of the system from July 1990 to

February 1991. Table 7 also shows the scheduled dates for water quality monitoring which was once a month. The extended operational time resulted in a total of 7 sample sets.

Table 6: Membrane Design Parameters

General Information	
Membrane manufacturer	Trisep
Membrane trade name	TS80
Membrane element model number	TS80-4040-TSA
Molecular weight cutoff (Daltons)	200 - 300
Membrane material (e.g., PVD, polyamide, etc.)	Polyamide
Membrane construction (e.g., thin-film composite)	Thin Film Composite
Membrane hydrophobicity	
Membrane charge (e.g., negative, highly negative, neutral, etc.)	Neutral to slightly negative
Design Parameters	
Element size (e.g., 2.5" x 40", 4" x 40", etc.)	4" x 40"
Active membrane area of membrane element used, A (ft ²)	92
Design flux, F_w (gfd)	22.7
Net driving pressure at the design flux, NDP (psi)	105
Water mass transfer coefficient, MTC_w (gfd/psi)	0.22
Temperature at which the MTC_w was determined, T°C (°C)	25.0
Maximum flow rate to the element, $Q_{l, max}$ (gpm)	20
Minimum flow rate to the element, $Q_{l, min}$ (gpm)	7.0
Total width of all membrane envelopes in the element, w (ft)	28
Feed spacer thickness, T (ft)	0.0023
Active membrane area of an equivalent 8" x 40" element (ft ²)	360
Purchase price for an equivalent 8" x 40" element (\$)	750-900
Additional Information	
Design cross-flow velocity (fps)	
Required influent flow to permeate flow rate ratio, $Q_i:Q_p$	5
Maximum element recovery (%)	15
Variability of design flux (%)	+15
Rejection of reference solute and conditions of test (e.g., solute type and concentration)	98% MgSO ₄ @ 100 psi
Variability of rejection of reference solute (%)	10
Standard testing recovery (%)	15
Standard testing pH	7.0
Acceptable range of operating pressures	40 - 200 psig
Acceptable range of operating pH values	2 - 11
Typical pressure drop across a single element (psi)	2
Maximum permissible SDI	5
Maximum permissible turbidity (ntu)	1
Chlorine/oxidant tolerance (e.g., < 0.1 mg/L for extended use, etc.)	<0.1

Table 7: Experimental Plan and Schedule For Membrane Studies

PILOT-SCALE ACSSF-NF & GAC-NF MEMBRANE PILOT PLANT SYSTEM												
System	Oct-90	Nov-90	Dec-90	Jan-91	Feb-91	Mar-91	Apr-91	May-91	May-03	May-10	May-16	May-23
Sample Date	Oct-05	Nov-10	Dec-02	Jan-02	Feb-07	Mar-05	Apr-03	May-06	May-06	May-13	May-17	May-27
ACSSF-A15S												
10gsfd-65% R	1											
15gsfd-65% R		1										
10gsfd-45% R			1									
15gsfd-45% R				1								
ACSSF-DS5												
10gsfd-65% R					1							
15gsfd-65% R						1						
10gsfd-45% R							1					
15gsfd-45% R								1				
GAC-A15S												
10gsfd-65% R					1							
15gsfd-65% R						1						
10gsfd-45% R							1					
GAC-A15S												
10gsfd-20% R									1			
15gsfd-45% R										1		
15gsfd-20% R											1	
10gsfd-45% R												1
GAC-DS5												
10gsfd-65% R	1											
15gsfd-65% R		1										
10gsfd-45% R			1									
15gsfd-45% R				1								
BENCH-SCALE MF-NF PILOT PLANT SYSTEM												
SAMPLE PERIOD	31-Aug 13-Sep	28-Sep 21-Oct	21-Oct 16-Nov	27-Nov 15-Dec	15-Dec 03-Jan	09-Jan 28-Jan	02-Feb 28-Feb	28-Feb 23-Mar	24-Mar 07-Apr	07-Apr 19-Apr	19-Apr 02-May	02-May 16-May
Sample Date	13-Sep	05-Oct	27-Oct	02-Dec	27-Dec	21-Jan	07-Feb	02-Mar	30-Mar	14-Apr	02-May	06-May
CFMF-DS5												
50gsfd-15% R		1										
50gsfd-24% R			1									
75gsfd-15% R				1								
75gsfd-24% R					1							
100gsfd-15% R						1						
100gsfd-24% R	1											
DFMF-DS5												
50gsfd-15% R							1					
50gsfd-24% R								1				
75gsfd-15% R									1			
75gsfd-24% R										1		
100gsfd-15% R											1	
100gsfd-24% R												1

Analytical Methods

The following section presents a summary of the analytical methods used for the water quality analysis of samples collected during the membrane studies conducted at the City of Melbourne South WTP.

The City of Melbourne does use chloramination for disinfection. However, the DBP formation potential conditions were selected to simulate DBP formation in the distribution if the City used a free chlorine residual. The distribution system is extensive and has a relatively long detention time. The conditions for DBP formation potential were selected to provide a conservative SDS formation for this system. These conditions were set at an incubation pH of 7.6, temperature of 22°C, a reaction time of 96 hours at doses of 5 mg/L for the permeate samples, 100 mg/L for the raw and 50 mg/L for the microfilter filtrate. The free chlorine residuals after the 96 hours for the permeate samples were no less than 0.2 mg/L CL_2 .

The DBPs for the long-term membrane pilot studies were measured using the USEPA 501, 551 and 552 methods, which included the measurement of 26 different compounds. While the University of Central Florida was conducting membrane research for the USEPA project titled "*Reduction of Disinfection By-Product precursors by Nanofiltration*", (EPA/600/SR-92/023, April 1992) it was required to participate in DBP analytical methods comparison. The comparison was associated with the THM4 methods EPA 501.2 and EPA 551. These studies were conducted in anticipation of the adoption of both EPA 551 and 552 methods. Included with the request for approval to grandfather information was a paper titled "*Comparison of THM Analyses by EPA Method 501.2 and 551*". This paper was presented during an AWWA WQTC conference, (Orlando, 1992) and summarizes the results of the comparison of THMs by EPA 501.2 and 551. The THMs for this study were analyzed by both EPA 501.2 and 551 methods.

Overall, the value determined by method 501.2 was higher than method 551. The combined EPA project data showed that total THMs as determined by method 551 were approximately 80% of the value determined by method 501.2. Similarly, chloroform as determined by method 551 was 78% of the value by method 501.2. Dichlorobromomethane and chlorodibromomethane as determined by method 551 were approximately 90% of the value by method 501.2. Only the values for bromoform as determined by 551 were higher than those by method 501.2. Bromoform averaged 113% of 501.2 bromoform. Due to the low levels of bromoform detected, an accurate regression could not be made for some data types. Table 8 presents the results of regression statistics applied to the results of samples collected during the studies conducted at the South WTP.

In this report all values discussed for THMFP were determined by method 551 unless otherwise specified. If the corresponding THMFP value by method 501.2 is desired, an approximate conversion from method 551 can be made using the factors described in the previous paragraph.

**Table 8: Individual And Total THMFP Regression Of EPA Method 551 (Y)
And EPA Method 501.2 (X)**

DATA TYPE	Regression Species	EQUATION	n	R-Squared	F	Alpha
MELBOURNE PERMEATE DATA						
	Total	y=1.139x	49	0.978	2136	<1E-15
	Chloroform	y=0.927x	64	0.286	25	<1E-5
	Dichlorobromomethane	y=0.926x	64	0.965	1722	<1E-15
	Chlorodibromomethane	y=0.968x	74	0.969	2320	<1E-15
	Bromoform	y=1.339x	64	0.956	1356	<1E-15
MELBOURNE FEED DATA						
	Total	y=0.798x	32	0.980	1528	<1E-14
	Chloroform	y=0.771x	49	0.976	1989	<1E-14
	Dichlorobromomethane	y=0.937x	53	0.944	884	<1E-14
	Chlorodibromomethane	y=1.052x	48	0.953	955	<1E-15
	Bromoform	#N/A	#N/A	#N/A	#N/A	#N/A
MELBOURNE RAW DATA						
	Total	y=0.768x	31	0.971	1021	<1E-15
	Chloroform	y=0.748x	35	0.952	679	<1E-15
	Dichlorobromomethane	y=0.941x	32	0.979	1418	<1E-15
	Chlorodibromomethane	y=1.097x	33	0.708	78	<1E-9
	Bromoform	#N/A	#N/A	#N/A	#N/A	#N/A

This membrane study evaluated the water quality of the flow streams for more parameters than the ICR protocol requires. However, there were 2 parameters that were not measured during this study that are required of a proposed ICR study, bromides and UV-254. These parameters have been presented for the South WTP source and finished water in the previous section. In addition, instead of measuring total organic carbon (TOC) this study analyzed for non-purgeable dissolved organic carbon (NPDOC).

The UCF ESEI Laboratory conducted all of the analysis associated with the membrane studies. The UCF ESEI laboratory was certified by the State of Florida and participated in USEPA performance evaluations during these studies. The City of Melbourne Utilities Laboratory and their contract laboratory (Environmental Health Labs) conducted the more recent analysis reported as associated with the ICR Monitoring requirements. The sample analysis related to ICR monitoring was used to produce Table 4, which presents the most recent source and blended finished water quality for the South WTP.

A summary of the analytical methods and detection limits for the UCF ESEI Laboratory analysis associated with the membrane studies is presented in Table 9. The contact personnel and information for the three laboratories are presented in Table 10.

Table 9: Summary Of Analytical Procedures

Procedure	Description	Reference	Reporting Level
Alkalinity	Acid titration	SM 403	2 mg/L
Chloride	Argentometric	SM 407A	1 mg/L
Chlorine Residual	Amperometric titration	SM 408C	0.1 mg/L
	DPD Ferrous titrimetric	SM 408D	0.1 mg/L
Color	Spectrophotometric	SM 204B	0.5 cpu
Fluoride	SPADNS	SM 413C	0.05 mg/L
Hardness, Total Ca ⁺⁺	EDTA titration	SM 314B	2 mg/L
		SM 311C	2 mg/L
Metals, General	Plasma Emission	SM 305	Fe = 10 µg/L
pH	Meter	SM 429	N/A
Sulfate	Turbidimetric	SM 426C	1 mg/L
Total Dissolved Solids	Gravimetric	SM 209B	1 mg/L
Turbidity	Ratio turbidimeter	SM 214	0.05 NTU
Silica	Heteropoly Blue	SM ¹⁹ 4500-SiE	1 mg/L
Sodium	Plasma Emission	SM 305	1 mg/L
Non-purgeable dissolved Organic Carbon	Persulfate-Ultraviolet Oxidation	SM 505B	0.3 mg/L
Disinfection By-Products	Micro-extraction, GC-ECD	EPA551,552*	1 µg/L Individual
Trihalomethane	Liquid-Liquid extraction	EPA 501.2	1 µg/L Individual
Total Organic Halide	Adsorption-Pyrolysis, Titrimetric	SM 506	2 µg/L
Formation Potential	Chlorination followed by 501.2, 551, 552, and TOX Analysis	TEXT	N/A

*EPA 551 analyzed the base-neutral function, while EPA 552 analyzed the haloacetic fraction.

SM = 16th Edition of Standard Methods. SM¹⁹ = Referenced under 19th edition of Standard Methods.

EPA = U.S. Environmental Protection Agency

Table 10: Laboratories Conducting Analysis For Report

Laboratory	ICR I.D.	Contact	Address	Phone
City of Melbourne Utilities	FL-051	Yvonne Gonsalves Chief Lab Tech.	6055 Lake Washington Rd Melbourne, FL 32934	Phone - (407)-255-4622 FAX - (407)-255-4636
Environmental Health Labs	IN-004	Richard Radclift		
UCF Environmental Systems Engineering Institute	N/A	Dr. James S. Taylor, Director	University of Central Florida CEE Department 4000 Central Florida Blvd. Orlando, FL 32816- 2450	Phone - (407)-823-2785 FAX - (407)-823-6562

Section IV: Results And Discussions

Operations Description

The flow diagram of the AC-A15S membrane pilot unit was presented in Figure 2. The flux and recovery for the different operating conditions is shown in Table 11 by period of operation for each time interval of operation used in the AC-A15s study. Five different operating periods were utilized with recovery varying from 45% to 65%, and flux varying from 10 to 15 gsf. The membranes were cleaned 13 times within the 5 operation periods. The time intervals between these cleanings are referred to as runs. The same A15s membranes used at Daytona Beach for the groundwater studies were used during the first seven operating periods shown in Table 11. New A15s membranes were installed following 1755.4 hours of operation during the AC-A15s study and used for the remainder of the project. These membranes were replaced so that they could be more equally compared with the DS5 membranes, which had not been used nor fouled during the groundwater study. Water quality samples were collected approximately on monthly increments after half of the operating period runtime had been expended.

Table 11: Schedule Of Operation For The AC-DS5 Membrane Pilot Plant

Period	Run	Hours Of Operation	Recovery %	Flux (Gsf)
1	1	0.0 - 324.9	45	15
1	2	324.9 - 605.7	45	15
1	3	607.4 - 714.2	45	15
1	4	714.2 - 969.4	45	15
1	5	969.4 - 1282.7	45	15
1	6	1282.7 - 1437.3	45	15
2	7	1437.3 - 1755.4	65	10
2	8	1755.5 - 2121.0	65	10
2	9	2121.0 - 2390.5	65	10
3	10	2390.5 - 2917.2	65	15
4	11	2917.2 - 3296.2	45	10
4	12	3296.2 - 3600.2	45	10
5	13	3600.2 - 4359.7	45	15

* Replaced A15s membranes

A time balance for operation of the AC-A15s nanofiltration pilot plant study was developed from the operation log and is presented in Table 12. The time balance is divided into run time and downtime. The downtime is subdivided into avoidable and unavoidable

downtime. The avoidable downtime is defined as non-operational time encountered during the operation of the AC-A15s pilot plant that was necessary for research. Examples of such time are pump or line modifications when a change in system configuration was needed to accommodate planned investigations, when initial system setup was required at the beginning of a system operation and when a cleaning solution for prefilters had to be made up in order to conserve project funds. These bag filters were usually replaced but were found to be reusable following cleaning in a high pH EDTA solution. The total time of operation of the AC-A15s system was 5107.0 hours which was divided into 4368.7 hours of actual runtime, 446.6 hours of avoidable downtime and 291.6 hours of unavoidable downtime. The percentage of runtime based on a total of runtime and unavoidable downtime was 94%. The largest category of unavoidable downtime was low pressure shut off which happens when the membranes or the prefilters become fouled and the control system inactivates the high pressure pumps for their protection. The membrane cleaning was done by project personnel. The time necessary for project personnel to get to the pilot plant was counted as avoidable downtime but the cleaning time was counted as unavoidable downtime. The percentages of unavoidable downtime by category was low pressure shut off (31%), membrane cleaning (15%), bag filter replacement (4%), water treatment plant shutdown (15%), plant filter backwash (17%) and pilot plant repair and maintenance (18%). The pilot plant had to be shutdown when the South WTP backwashed the sand filter that was used in the AC-A15s pretreatment system.

Table 12: Time Balance For The Operation Of The AC-DS5 Nanofiltration Pilot Plant

Classification	Item	Time (Hours)
Unavoidable	Low Pressure Shut Off	90.0
Unavoidable	Membrane System Cleaning	44.8
Unavoidable	Replacement of Bag Filter	11.6
Unavoidable	WTP Shut Down	43.0
Unavoidable	Filter #2 Backwash	50.8
Unavoidable	Repair/Maintenance	51.4
	Total Unavoidable Downtime	291.6
Avoidable	Setup Runs/Membrane Cleaning	333.4
Avoidable	Pump/Line Modifications	93.2
Avoidable	Replacement of Bag Filter	20.1
	Total Avoidable Downtime	446.7
	Total Downtime	738.3
	Total Downtime	738.3
	Run Time	4368.7
	Total Time	5107.0

Water Production

All recorded observations of flow and pressure during the AC-A15S unit operation are presented in the computer file and the Appendix. Recovery, flux and MTCs for water were determined for each observation of pressure and flow and are also presented in the files and Appendix. All of the physical observations in these tables are correlated to date, time of recording, and run time.

Figure 3 has been divided into periods of operation and reflects the changing flux and pressure that defines an operating condition. Recovery was seen to be relatively constant within a given period of operation being relatively close to the intended 45 or 65%. Flux was seen to decline with time of operation within a given period of operation and was initially relatively close to the intended 10 or 15 gsfd. The MTC is shown to also decline with time of operation within a given period of operation and was less variable than flux. However the MTC is seen to increase from approximately 0.01/d to 0.02/d at 1755 hours or when the A15s membranes that had been used for the groundwater study were replaced with new A15s membranes for the remainder of the surface water study. Figure 3 is developed from the ICR spreadsheets and therefore the MTCw is expressed in units of gsfd/psi. The conversion factor is 17.253 to change to day⁻¹.

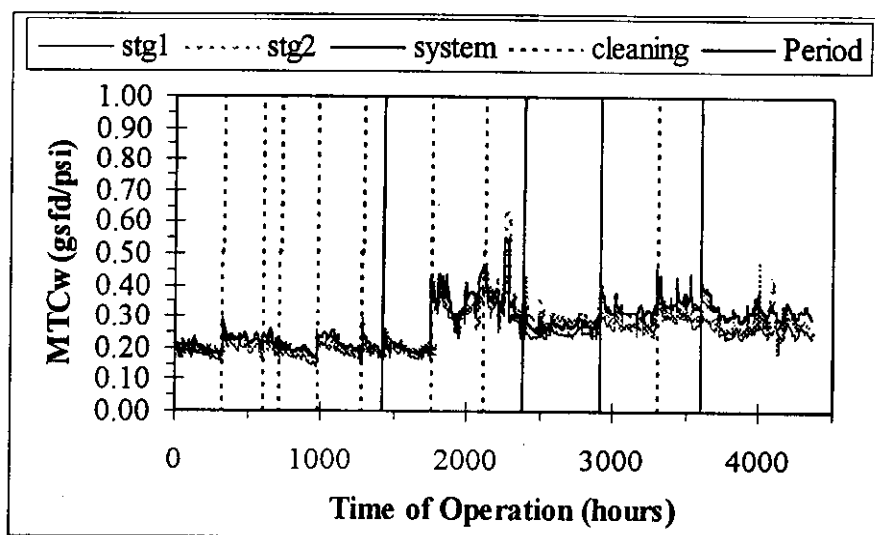


Figure 3: AC-A15S Nanofiltration Water Production

The decline of the MTC over time or S , a simple slope determined using linear regression by cleaning interval which corresponded to changes in operating conditions is presented in Table 13 with the F statistic (F), alpha value (A), number of observations (n) and the coefficient of determination (r^2) for each regression. The F statistic concerning this linear regression is a ratio of sum of squares of the regression over the sum of the squares of the error. If the calculated F statistic is greater than specified for a given alpha and degrees of freedom, the null hypothesis, S equals 0, can be rejected. The alternative hypothesis, S is not equal to zero, can not be rejected which supports the regression model. The A can be interpreted as the level of confidence that the model correctly describes the trend between the MTC and time. The lower A values indicate a higher level of significance. The coefficient

of determination accounts for what fraction of the variation in the data can be accounted for by the proposed model. The F and A values that are given in the following figures are the calculated values from the paired data sets of MTC and time. In this work it S was found to decline with time, generally at high but varying levels of confidence. A linear model represents the trend between the MTC and time but does not adequately fit all data sets in this work.

The rate of MTC decline varied from $0.000127/d^2$ to $0.000441/d^2$ and averaged $0.000253/d^2$ during the first 1755 hours of operation when the old A15s membranes were used. The F and R were set initially at 15 gsfd and 45%, respectively. A variation in MTC decline was observed although the same operating conditions were in place. The AC-A15s system was operated from 1755 to 4560 hours with new membranes. The MTC decline varied from $0.000055/d^2$ to $0.000547/d^2$ and averaged $0.000210/d^2$, which were similar to the MTC decline of the older membranes. The two highest MTC declines, $0.000547/d^2$ and $0.000330/d^2$ occurred for operating conditions of 10 gsfd-65% R and 10 gsfd-45% R. The lowest MTC decline occurred at 10 gsfd-45% R. This indicates that flux and recovery alone can not be directly correlated to MTC decline for the AC-A15s study.

Table 13: MTC Regression With Time Of Operation For The NF Membrane Using The AC-A15S System

Run #	Beginning Run (Hour)	NF Recovery %	NF Flux (Gsfd)	Slope (1/Day ²)	F	Alpha	R ²	Feed Avg. Color (Cpu)	Feed Avg. NPDOC (mg/L C)	Avg. Temp. (F)
1	0.0	45	15	-0.000161	79	.0000	.46	3.07	8.26	83.9
2	324.9	45	15	-0.000221	78	.0000	.50	2.85	7.72	83.9
3	607.4	45	15	-0.000385	18	.0002	.36	3.33	8.35	87.8
4	714.2	45	15	-0.000215	218	.0000	.77	3.08	8.19	86.1
5	969.4	45	15	-0.000219	160	.0000	.65	3.86	7.97	84.5
6	1282.7	45	15	-0.000441	126	.0000	.75	4.00	8.70	84.4
7	1437.3	65	10	-0.000127	64	.0000	.43	3.53	8.75	84.1
8	1755.5	65	10	-0.000141	6	.0151	.12	3.45	7.95	80.8
9	2121.0	65	10	-0.000547	22	.0000	.44	3.40	7.83	75.9
10	2390.5	65	15	-0.000102	44	.0000	.41	3.17	8.38	70.4
11	2917.2	45	10	-0.000330	168	.0000	.78	2.94	8.54	66.4
12	3296.2	45	10	-0.000055	1	.2704	.03	3.38	8.06	66.4
13	3600.2	45	15	-0.000086	51	.0000	.35	2.72	8.43	68.7

Water Quality

There were a total of 7 sets of water quality samples collected and analyzed for the FMF-DS5 system over the 4368.7 hours of operation. The high, low and average raw, feed (South WTP finished water) and NF permeate from the AC-A15S system are presented in Table 14.

The A15S nanofilter on average reduced the TOXFP by 95% from 1259 ug/L as Cl^- to 59 ug/L as Cl^- . The THMs were reduced by 96%, from 385 ug/L as species in the feed stream to 16 ug/L in the nanofilter permeate on average. HAA5s were reduced by the nanofilter on average 96% with feed at 251 ug/L and the permeate average concentration at 16 ug/L as the species.

The raw, feed and permeate streams inorganic water quality, in addition to NPDOC are also shown in Table 14 for the AC-A15s surface water site nanofiltration system. The average NPDOC reduction was from 34 to 8 mg/L by the plant alum coagulation process. The A15s nanofilter average NPDOC reduction was more than 98% from 8 to 0.1 mg/L. The color was reduced on average from 15 to 1 cpu. The plant process achieved excellent average color reduction from 252 to 15 cpu. The TDS was reduced from 456 to 38 mg/L by the A15s nanofilters. The permeate pH averaged 4.79 because of the acid addition to control $\text{Al}(\text{OH})_3$ scaling. Correspondingly, there was little alkalinity in the permeate, 4 mg/L on average. However, alkalinity in any nanofiltration or reverse osmosis system can be easily recovered by carbon dioxide conversion with the addition of a base immediately following the membranes. However, the membrane system could be designed and operated to produce a water that would have a lower pH_s by using membranes with higher MWC, operating at a higher recovery or using CaO before aeration. All of which would increase the calcium hardness and alkalinity in the finished water. The net effect would be to lower pH_s which is sometimes thought of as producing a less corrosive water. The alkalinity can be completely recovered which will give an average final alkalinity of at least 80 mg/L as CaCO_3 . The calcium concentration in the permeate would be at least 6 mg/L as CaCO_3 which would be increased to more than 80 mg/L as CaCO_3 if CaO is used to recover the alkalinity. The resulting pH_s would be 7.9 which is representative of finished waters with desirable alkalinity and calcium hardness. Sodium was reduced from 44 mg/L to 15 mg/L by the A15s nanofilters. Turbidity was reduced on average from 0.56 NTU to 0.11 NTU, however the heterotrophic plate count (HPC) averaged 409 CFU/ml in both the alum coagulated feed and A15s permeate streams. The lack of HPC reduction should not be interpreted as passage of coliform bacteria by the nanofilters but the ubiquitous growth of non-pathogenic bacteria everywhere including the permeate piping system following the nanofilters. The inorganic water quality indicates that the A15s nanofilters softened the water, achieved a desirable TDS and sodium reduction, reduced turbidity and had no adverse effects on the measured inorganic water quality.

Table 14: Water Quality For The AC-A15S Membrane Pilot System

Parameters	Units	Raw			Feed			Permeate		
		High	Low	Avg.	High	Low	Avg.	High	Low	Avg.
THMFP**	(ug/L)	1710	668	1160	538	266	385	32	5	16
HAA5FP	(ug/L)	1450	713	1307	332	144	251	18	2	10
TOXFP	(ug/L as Cl ⁻)	7120	3400	5131	1500	870	1259	94	33	56
COLOR	(CPU)	350	86	252	45	6	15	7	0	1
NPDOC	(mg/L)	34	21	29	10	7	8	0.6	0	0.1
TDS	(mg/L)	490	310	380	540	340	456	130	38	38
Sodium	(mg/L)	66	32	43	66	35	44	25	10	15
Total Hardness	(mg/L as CaCO ₃)	180	120	140	220	170	196	91	7	26
Calcium Hardness	(mg/L as CaCO ₃)	130	85	103	190	92	155	90	6	23
Chloride	(mg/L)	150	68	97	150	70	97	58	14	34
Sulfates	(mg/L)	2	0	0.9	120	72	97	16	0	6
Alkalinity	(mg/L as CaCO ₃)	110	81	90	86	57	72	16	0	4
pH		7.80	7.30	7.51	7.70	6.80	7.30	7.00	3.00	3.66
Iron	(ug/L)	680	96	387	500	2	83	28	0	11
Turbidity	(NTU)	4.4	1.1	2.2	2.9	0.11	0.56	0.40	0	0.11
Heterotrophic Plate Count	(CFU/ml)	11000	77	3115	1580	0	419	1920	0	409

* South WTP finished water after filtration but prior to disinfection

** Method USEPA 501.2

Impact of Seasonal Variability

The seasonal change in Central Florida is relatively small compared to the upper U.S. During this testing from July 1990 to February 1991, the average feed water temperature only ranged from 67 to 87 °F. In addition, the pilot unit design and location further reduced the variability of the temperature. The data presented in Table 13 for MTC decline and the water quality analysis did not indicate any adverse effects based on the season changes experienced during this study.

Cost Information

Capital cost for the alum pretreatment option are all based upon the EPA manual for estimating water treatment costs. These estimated capital costs are reported in Table 15. The largest capital cost for alum pretreatment is the cost of the sand filter and upflow solids contact unit. Three 90-foot diameter upflow solids contact units with sidewall depths of 16 feet were needed to handle the incoming raw water flow of 12 MGD. A rapid sand filter with a total surface area of 1400 sf was used for filtration after alum coagulation. Additional process equipment needed for this pretreatment option are the alum feed system at \$400,000, and sludge handling at \$300,000. The alum sludge concentration was assumed to be 0.1% to size the sludge pump. Instrumentation and electrical requirements are estimated as 15% of the total process equipment cost, and process piping as 20%. The total capital cost for alum pretreatment, amortized at 20 years and 10%, is \$0.18/Kgal of nanofilter product water.

For the alum pretreatment option, estimated labor costs are \$960,000/year. This labor cost includes one head supervisor at \$50,000/year, two senior shift supervisors at \$40,000/year each, six class A operators at \$30,000/year each, 12 class B operators at \$25,000/year each and 17 class C operators at \$20,000/year each. As with the conventional membrane plant, benefits have been included in the yearly salary. The power cost reflects the cost of the alum operation, and was estimated as \$450,000/year at a power cost of \$0.075/kwh. The liquid alum dose was calculated as 140 mg/L, at a cost of \$0.06/lb, for a chemical supply cost of \$420,000/year. This cost was increased to \$900,000/year to include other required supplies. The maintenance cost was estimated as \$450,000/year. The yearly O & M costs for alum pretreatment totals \$2,835,000/year or \$0.78/Kgal of nanofilter product water.

The total estimated capital cost for the alum pretreatment option was \$5,494,000. The major cost components of this are the upflow solids contact unit, at 36% of the total capital cost, and the sand filter, at 23% of the capital cost. The unit amortized capital cost, 20 years at 10%, is \$0.18/Kgal. The total O & M cost was estimated as \$2,835,000/year, or \$0.78/Kgal. The major O & M cost components were labor and chemical supplies representing 33% and 32% respectively of the total O & M cost. The total alum coagulation pretreatment cost is estimated at \$0.96/Kgal of nanofilter product water.

Table 15: Cost Estimate For 12 Mgd Alum Coagulation Pretreatment Plant For Surface Water Site Nanofiltration Plant

Category	Cost
<u>Capital</u>	
Land	\$72,000
Site Work	\$143,000
Building	\$115,000
Process Equipment	
Upflow Solids Contact Unit	\$2,000,000
Sand Filter	\$1,250,000
Alum Feed	\$400,000
Sludge Handling	\$300,000
Process Piping	\$790,000
Instrumentation and Electrical	<u>\$424,000</u>
Total:	\$5,494,000
\$/Kgal (20 yrs at 10%)	\$0.18
<u>O & M per year</u>	
Wages	\$960,000
Power	\$450,000
Chemical Supplies	\$900,000
Maintenance	\$450,000
Other	<u>\$75,000</u>
Total:	\$2,835,000
\$/Kgal	\$0.78

Table 16 presents the capital and O & M cost estimate for the nanofiltration system associated with the surface water using the pretreatment option of alum coagulation. The estimate only includes costs related to the nanofiltration facilities and excludes the advanced pretreatment (alum coagulation plant) costs presented earlier.

The surface water membrane system was designed to operate at 85% recovery; 100 psi feed pressure and a water flux of 10 gsf/d. This design requires 13 membrane skids, each producing 0.8 MGD, for 12 duty and 1 standby skid. The additional membrane skids also require additional process piping and instrumentation. The capital cost for the surface water membrane system with alum is estimated as \$20,908,250 or \$0.67/Kgal amortized at 20 years and 10%.

The power costs for the surface water nanofiltration system was estimated using 75% recovery, pump and motor efficiency of 85%, and a power cost of \$0.075/kwh. The difference in surface water nanofiltration system O & M cost are a result different cleaning frequencies according to pretreatment option. The changing cleaning frequencies are a result of different rates of water MTC decline in the nanofiltration system depending upon the pretreatment alternative utilized. Increased cleaning frequency will increase chemical costs and labor costs, while decreasing membrane life. A decreased membrane life will increase maintenance costs in the form of membrane replacement.

Table 16: Cost Estimate For 10 Mgd Nanofiltration Plant For Surface Water Scenario

Category	Cost
<u>Capital</u>	
Land	\$35,000
Site work	\$300,000
Buildings	
Membrane	\$1,400,000
Chemical Feed	\$224,000
Bulk Chemical Storage	\$168,000
Chlorine Feed	\$168,000
Clearwell and pumps	\$244,000
Administration and Lab	\$140,000
Power Vault	\$15,000
Process Equipment	
Membranes and pumps	\$7,840,000
Chemical Feed	\$115,000
Chlorination	\$100,000
Aerator	\$400,000
Storage	\$1,600,000
Process Piping	\$1,691,000
Instrumentation and electrical	\$1,268,250
High Service Pumps	\$200,000
Deep Well	
Injection Well	\$3,000,000
Unlined Lagoon Back-up	\$200,000
Monitoring System	\$950,000
Transport Pipeline	\$850,000
Total:	\$20,908,250
\$/Kgal (20yrs at 10%)	\$0.67
<u>O & M (per year)</u>	
Wages	\$255,000
Power	\$500,000
Chemical Supplies	\$230,000
Maintenance	\$1,240,000
Telephone	\$12,000
Deep Well	\$15,000
Other	\$52,000
Total:	\$2,304,000
\$/Kgal	\$0.63

Alum coagulation pretreatment produced a MTC decline of $1 \times 10^{-4}/d^2$, resulting in a cleaning frequency of 8.7 days. Three additional operators at \$20,000/each were estimated to cover increased cleaning, for a labor cost of \$255,000/year. Cleaning chemicals were

estimated at \$30,417/year and added to the base requirement of \$197,000/year for a total chemical supply cost of \$230,000/year. Membrane replacement costs were estimated using a membrane life of 3 years for a cost of \$1,109,600/year, and a total maintenance cost of \$1,240,000/year. The total O & M cost for nanofiltration utilizing alum coagulation pretreatment is estimated as \$2,304,000/year or \$0.63/Kgal of finished water.

Section V: QA/QC Summary

The following section will present a summary of the quality assurance and quality control results compiled during the membrane pilot studies

Solute Mass Balances

The USEPA project involved one year of membrane operations at a groundwater site and the operation of six different membrane systems at the South WTP. Due to the large scope of this project, certain concessions had to be made as to monitoring. This particular system did not include water quality and pressure monitoring of the concentrate stream. Therefore mass balance calculation cannot be accomplished.

Precision

Precision was the reproducibility observed between duplicate analyses. Duplicates were two determinations of a given parameter for the same sample by repeating the analytical procedure. The precision was expressed as percent relative deviation for each pair of analyses and was calculated by the following formula:

$$\% \text{ RSD} = \left(\frac{S}{X} \right) \times 100$$

where:

S = standard deviation

X = mean (average for a pair)

The standard deviation (S) for a data pair was calculated using the following equation:

$$S = \sqrt{(X_1 - X_2)^2} \cdot 0.89$$

where: X_1 and X_2 were individual observations.

Precision of a given analytical method was continuously determined by using the mean range and variance determinations. The range was the difference between the two duplicates. The normalized mean range, \bar{R} , was calculated using the following equation:

$$\bar{R} = \frac{\sum_{n=1}^N R}{N}$$

where:

$$\sum_{n=1}^N R = \text{sum of the relative standard deviations}$$

N = number of data pairs

The variance, S_R^2 , was calculated by:

$$S_R^2 = \frac{\sum_{n=1}^N R^2 - (N \bar{R}^2)}{(N-1)}$$

where:

$$\sum_{n=1}^N R^2 = \text{sum of the relative standard deviations}$$

$$\bar{R}^2 = \text{square of the mean range}$$

N = number of data pairs

The warning limits (WL) and control limits (CL) were calculated by the following equations:

$$WL = \bar{R} + 2S_R$$

$$CL = \bar{R} + 3S_R$$

where:

$$\bar{R} = \text{mean range}$$

$$S_R = \text{square root of variance}$$

Data was assessed by interpreting the mean range (also referred to as the central line), with regard to the warning and control limits. A graph of concentration versus sample occurrence or number was used to facilitate the interpretation. The mean range, WL and CL were shown as horizontal lines on the graph. The results of an individual paired duplicate analysis were entered on the graph and interpreted by where they fell within the boundaries on the graph. A minimum of twenty pairs of duplicate analyses were used to construct the graph.

Table 17 and 18 lists the compilation of the precision data obtained for the parameters monitored during the project and the percentage of the time that the data was within the ninety-five percent confidence interval.

Table 17: Precision For Organic Parameters

Parameter	Precision RSD	Std. Dev	Mean	UWL	UCL	%C.I.
Chloroform	0 - 23	6	4	12	18	98
Bromodichloromethane	0 - 16	5	3	9	14	100
Dibromochloromethane	0 - 44	10	4	20	30	93
Bromoform	0 - 16	4	3	8	12	80
Monochloroacetic acid	0 - 110	28	22	55	83	90
Monobromoacetic acid	0 - 95	24	18	49	73	98
Dichloroacetic acid	0 - 94	29	25	58	87	98
Dibromoacetic acid	0 - 48	15	14	29	44	93
Trichloroacetic acid	0 - 129	34	29	69	103	98
Color	0 - 9	3	2	6	9	100
NPDOC	0 - 14	4	4	8	12	98
TOX	0 - 15	4	6	9	13	98

Table 18: Precision For Inorganic Parameters

Parameter	RSD Precision	Std. Dev.	Mean	UWL	UCL	%C.I.
Alkalinity	0 - 4	1	1	2	4	100
Turbidity	0 - 17	4	6	9	13	93
TDS	0 - 13	4	4	8	12	98
Total Hardness	0 - 12	4	2	8	12	100
Ca Hardness	0 - 9	2	2	5	7	93
Chloride	0 - 11	3	2	7	10	93
Sulfate	0 - 75	20	8	41	61	93
Fluoride	0 - 16	5	4	11	16	100
Silica	0 - 8	3	1	5	8	100
Sodium	0 - 7	2	2	4	6	98
Iron	0 - 8	3	2	5	8	100

Accuracy

The data obtain through spike analyses was used as a measure of accuracy, the degree of difference between observed and known values. Known concentrations were added to samples and the following equation used to determine the recovery of the specific parameter:

$$\% \text{ Recovery} = \left(\frac{(Z - X)}{T} \right) \times 100$$

where:

Z = observed spike concentration

X = concentration of unspiked sample

T = True concentration of spike

The percent recovery, the mass of the spike, spiked and unspiked sample concentration was reported on quality control report forms. As with the duplicates, the mean, variance, warning and control limits were calculated using at least twenty data points. For the spikes, percent recovery was used instead of relative standard deviation; and as with the duplicates the mean, variance, warning and control limits were calculated using the previously cited equations. One additional difference between the presentation of the spike and duplicate data is that the warning and control limits were expressed in terms of plus or minus standard deviations. The upper limits were positive deviations. The lower limits were negative standard deviations. A graph of the data and the statistically calculated control were developed. This graph was used to assess the acceptability of the data in the same manner as previously described for the duplicate analyses. Table 19 and 20 list the compilation of accuracy data for the parameters monitored in this study and the percentage of time that the data was within the ninety-five percent confidence interval.

In addition to the duplicate and spike data, purchased reference check samples were also used to assess analytical quality. The samples came with preparation instructions, a true value, and a ninety-five percent confidence interval that was computed by the manufacturer. These samples were used for the inorganic analyses, since most of the samples could be maintained and reanalyzed on a daily basis for three months if refrigerated. Sample analysis was not to take place if the results of the reference analysis were outside the given confidence interval. Additionally some analyses made use of a check sample that was prepared by the laboratory staff to monitor analytical performance.

Table 19 Accuracy For Organic Parameters

Parameter	Accuracy	Std. Dev.	Mean	Warning Limit	Control Limit	% C.I.
Chloroform	52 - 104	15	83	±31	±46	98
Bromodichloromethane	76 - 112	8	91	±16	±24	100
Dibromochloromethane	76 - 178	15	96	±30	±45	93
Bromoform	83 - 128	9	93	±18	±27	80
Monochloroacetic acid	16 - 190	39	63	±79	±118	93
Monobromoacetic acid	25 - 180	41	74	±83	±124	98
Dichloroacetic acid	20 - 196	44	77	±87	±131	100
Dibromoacetic acid	22 - 230	42	68	±85	±127	95
Trichloroacetic acid	6 - 74	20	33	±40	±60	98
NPOC	86 - 110	7	98	±14	±21	100
TOX	90 - 120	10	108	±20	±30	100

% C.I. refers to % of time analysis is within 95% confidence interval.

Table 20: Accuracy For Inorganic Parameters

Parameter	Accuracy	Std. Dev.	Mean	Warning Limit	Control Limit	% C.I.
Alkalinity	92 - 111	5	100	±11	±16	100
Total Hardness	88 - 106	6	99	±11	±17	100
Ca Hardness	89 - 105	5	99	±10	±15	100
Chloride	88 - 112	6	101	±11	±17	100
Sulfate	89 - 127	10	106	±21	±31	100
Fluoride	106 - 128	9	113	±18	±27	100
Silica	92 - 110	6	101	±11	±17	100
Sodium	86 - 115	9	98	±17	±26	100
Iron	93 - 110	6	100	±13	±19	100

USEPA Performance Evaluation

Eight performance evaluation studies were performed during the course of the project. The results of the evaluations are summarized in Table 21.

Table 21: USEPA Performance Evaluation Summary

Parameter	Units	WS020	WS021	WS022	WS023	WS024	WS025	WS026	WS027
Chloroform	µg/l	19.6 56	13.1 76.6	44.9 24.3	37.5 45.1	9.9 67.8	83.8 28.7	6.7 51	87.3
Bromoform	µg/l	44 20.5+	67.1 27.8	56.7 25.7	70 15.9	11 60.8	49.4 10.2	16 92	25.5
Bromodichloromethane	µg/l	22.6 73	10.4 39.7	18.6 61.5	12 65.4	22.1 59.9	76.5 9.7	24 58	35.4
Dibromochloromethane	µg/l	63.7 30.2+	44.3 16.4	69 15.7	26.9 44.7	8.1 80.2	48.4 16.5	21 86	33.6
Total THM's	µg/l	149.9 179.7	134.9 160.5	189.2 127.2	146.8 171.1	51.1 268.7	258.1 65.1	67.7 287	181.8
Residual Free Chlorine	mg/l	0.64 1.42		0.31 1.13	0.35 1.26	0.7 1.18	0.54 1.47	0.89 0.27	0.36
Turbidity	NTU	4.4 0.7						5.83 1.28	0.99 0.7
Fluoride	mg/l			0.72 1.55	0.27+ 1.32	1.39 1.77	2.46 1.44	3.43 1.33	4.32
Calcium (as CaCO ₃)	mg/l	116		152				122	138
pH	Units	9.11						9.04	9.21
Alkalinity (as CaCO ₃)	mg/l	34.9		51.0+				40.6	37.9+
Sodium	mg/l							15.6	-15.3
Sulfate	mg/l							22.8 8.79	13.9
Dibromoacetic acid	µg/l								4.4
Dichloroacetic acid	µg/l								6.3
Monobromoacetic acid	µg/l								3.5
Monochloroacetic acid	µg/l								7.1
Trichloroacetic acid	µg/l								9.5

- = Value outside acceptable range on the low side

+ = Value outside acceptable range on the high side

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