Information Collection Rule Treatment Study

Summary Report

Lee County Utilities, Florida

July, 1999

MONTGOMERY WATSON

ICR TREATMENT STUDY SUMMARY REPORT

Evaluation of Nanofiltration Using the Rapid Bench Scale Membrane Test Methodology for Compliance with the Information Collection Rule

Conducted during the period: February 1998 – March 1999

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Plant ICR #: 1095

Acknowledgments

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SECTION 1 – EXECUTIVE SUMMARY

SECTION 2 - INTRODUCTION

SECTION 3 – MATERIALS AND METHODS

SECTION 4 – RESULTS AND DISCUSSION

SECTION 5 – QA/QC SUMMARY

APPENDIX A

APPENDIX B

APPENDIX C

LIST OF TABLES

LIST OF FIGURES

Four quarters of nanofiltration (NF) testing using pretreated Caloosahatchee River water following coagulation, flocculation, sedimentation, and cartridge filtration were successfully completed. Three NF membranes were used to complete Information Collection Rule (ICR) treatment study requirements using the Rapid Bench Scale Membrane Test (RBSMT) methodology.

WATER QUALITY

The Koch-Fluid Systems TFC-SR membrane achieved higher removals of total organic carbon (TOC), and precursor materials to trihalomethanes and haloacetic acids compared to the Dow FilmTec NF-200B membrane.

The Hydranautics NTR7450 membrane was more permeable to organic constituents than these two membranes. For example, the highest recorded TOC concentration in the permeate waters using the TFC-SR, NF-200B, and the NTR7450 membranes were 1.1, 1.8, and 3.0 mg/L respectively.

Under the SDS conditions employed, highest SDSTTHM and SDSHAA(5) concentrations using the TFC-SR membrane were near 80 µg/L and 12 µg/L, respectively. Compared to the TFC-SR membrane, higher concentrations of organic constituents were observed in the NF-200B and NTR7450 membrane permeate waters.

Table 1-1
Finished Water Quality

Membrane	Maximum SDSTTHM (ug/L)	Maximum SDSHAA5 (ug/L)
TFC-SR	79.60	12.30
NF-200	137.7	19.60
NTR-7450	137.0	24.65

Thus, SDSHAA(5) concentrations in membrane permeate waters were always below the placeholder under Stage II of the D/DBP rule (30 µg/L for HAA(5). However, maximum SDSTTHM concentrations in membrane permeate waters were above the placeholder under Stage II of the D/DBP rule (40 µg/L for TTHMs).

Hence, NF alone may not be sufficient to meet Stage II THM regulations if free chlorine is employed as the final disinfectant.

The TFC-SR membrane also achieved higher removals of a variety of inorganic water quality parameters compared to the NF-200B and NTR7450 membranes. For example, the average total hardness removal by TFC-SR, NF-200B, and NTR7450 membranes were 55, 47, and 12% respectively at 70% feed water recovery.

Because the concentrations of most water quality parameters in the TFC-SR, NF-200B, and NTR7450 permeates increased with feed water recovery (at constant flux), the transport of dissolved solutes across these polymeric membranes may be controlled by diffusion.

MEMBRANE FOULING

Simple linear regression analysis suggests that there may be seasonal variations in fouling rates for both membranes. Using the RBSMT methodology, membrane chemical cleaning intervals ranged from ~ 41 h – 980 h at 70% feed water recovery and an initial flux of ~ 15 gfd. However, more advanced NF membrane pretreatment may result in longer chemical cleaning intervals. Additionally, more research needs to be done to better establish the validity of the RBSMT methodology in terms of it being able to accurately predict membrane fouling rates (and cleaning intervals) observed in full-scale installations. Hence, membrane fouling rates and cleaning intervals predicted using bench-scale experiments need to be verified at the pilot-scale.

BACKGROUND

Lee County owns and operates two water treatment facilities:

- Corkscrew WTP (supply source: groundwater)
- Olga WTP (supply source: surface water)

As defined under the ICR program requirements, the Corkscrew WTP exceeded allowable TOC concentrations, while the Olga facility was in compliance. Under the ICR requirements, Lee County would have normally been required to perform a bench-scale treatment study on the Corkscrew WTP. However, Lee County requested authorization to perform a rapid-bench scale membrane test (RBSMT) using the surface water supply for the Olga WTP for the following reasons:

1. A utility located adjacent to the Corkscrew WTP was performing a GAC bench-scale study on the same water source utilized by the County's facility.

2. The County was under contract with Montgomery Watson to design and construct a new water treatment facility. The County was investigating the potential of utilizing the same raw water source as the Olga WTP as the supply source for the new water treatment facility. Performing a membrane bench-scale study for the Olga facility provided the County with useful information that could potentially be used in selection of membranes for the new facility.

OBJECTIVES

The primary objective of this Information Collection Rule (ICR) treatment study was to evaluate the ability of two nanofiltration (NF) membranes to remove disinfection by-product (DBP) precursor materials and total organic carbon (TOC).

Figure 2-1. View of the Olga WTP.

Secondary objectives of this treatment study included evaluating inorganics rejection and membrane fouling. Both membrane operation and permeate water quality data from bench-scale experiments conducted using the rapid bench scale membrane test methodology as specified in the *ICR Manual for Bench- and Pilot-Scale Treatment Studies* (EPA 814-B-96-003) are summarized in this report.

EXISTING WATER TREATMENT PROCESSES

A schematic of the existing water treatment processes for Lee County's Olga Water

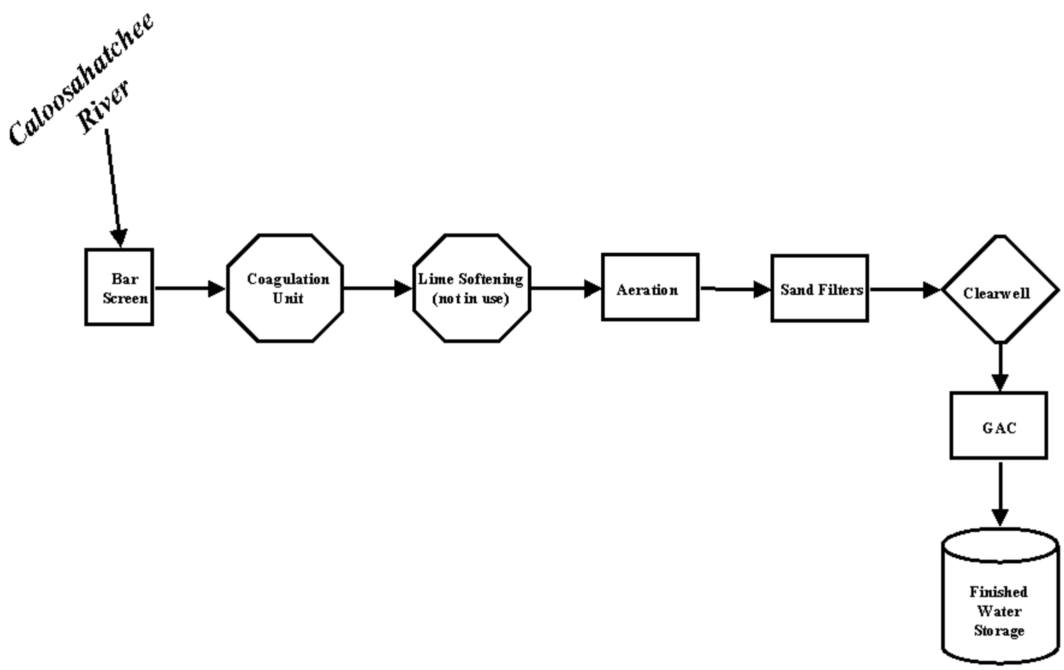


Figure 2-2. Flow schematic for Olga Water Treatment Plant.

Treatment Plant is provided below.

The water for NF testing was obtained following powdered activated carbon addition, coagulation, flocculation, and sedimentation.

Basic engineering and chemical feed data for each unit process are summarized in Tables A-1 and A-2 and also in Appendix A.

FULL-SCALE PLANT INFLUENT AND FINISHED WATER QUALITY

Data from the influent and finished water of the full-scale plant have been summarized in Tables 2-1 and 2-2 respectively.

Table 2-1

Full-scale influent water quality data: April 98 – April 99

Parameter	Units	Average	Std. Dev.	Min.	Max.	Count
Temperature	°C					
pH	-	7.6	0.2	7.4	8.1	12
Turbidity	ntu					
Alkalinity	mg/L as $CaCO_3$	150	24	106	180	13
Total Hardness	mg/L as $CaCO_3$	190	30	136	241	13
Calcium Hardness	mg/L as $CaCO_3$	160	31	105	206	13
TOC	mg/L					
UV_{254}	1/cm					
Bromide	µg/L					
TSUVA*	L/(mg-m)					

*TSUVA = [UV_{254} (1/m)] / [TOC (mg/L)] and was calculated using matched-pair data.

Table 2-2
Full-scale finished water quality data: April 98 – April 99

Parameter	Units	Average	Std Dev	Min	Max	Count
Temperature	°C					
pH	unit	7.9	0.2	7.5	8.0	8
Turbidity	ntu	0.19	0.05	0.12	0.25	13
TOC	mg/L					
UV_{254}	1/cm					
DS-THM4 [a]	µg/L					
DS-HAA5	µg/L					
DS-HAA6	µg/L					

[a] DS represents distribution system

Section 3
Materials and Methods

ICR BENCH-SCALE TREATMENT STUDY APPARATUS

All bench-scale ICR experiments were conducted using the Rapid Bench Scale Test Method (RBSMT) methodology. For these tests, a pressurized cell using a flat membrane sheet was employed. This cell utilized feed and permeate spacers that are also used in spiral-wound elements. The feed water was pumped tangential to the membrane so as to maintain a shear stress on the membrane surface and thereby limit concentration polarization. A schematic of the apparatus used to conduct the ICR bench-scale NF experiments is shown in Figure 3-1. Using positive displacement gear pumps for both feed water and recycle water minimized pressure fluctuations. The feed pump head (Cole-Palmer, Vernon Hills, IL, model # 74011-11) was designed for use at high pressure and low flow, whereas the recirculation pump head (Cole-Palmer, Vernon Hills, IL, model # 07002-23) was designed for use at low pressure and high flow. These pumps used helical gears made of Teflon, a low friction material, to reduce any potential loss due to friction on the gears. All tubing, connections, and the membrane cell were fabricated using stainless steel. Dual float rotameters were used to increase the accuracy of the flow measurements. Further, permeate and waste flows were manually measured using a graduated

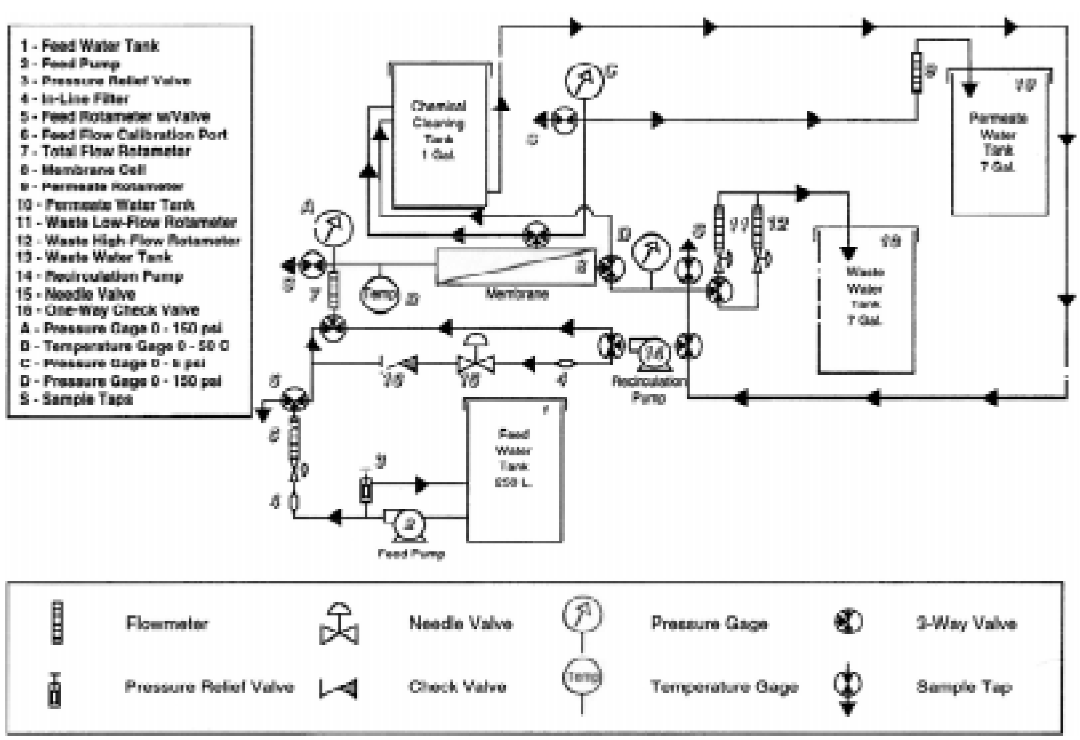


Figure 3-1. Schematic of the bench-scale apparatus

cylinder and a stopwatch.

MEMBRANES EMPLOYED

ICR experiments were conducted using three NF membranes: FilmTec NF-200B (Dow Chemical Company, Midland, MI) and TFC-SR (Koch-Fluid Systems Corp., San Diego, CA), and NTR7450 (Hydranautics Corp., San Diego, CA). Important characteristics for each membrane (as specified by the manufacturers) are summarized in Table 3-1.

Table 3-1
Characteristics Of Membranes Used During ICR Testing

Membrane designation	Manufacturer	Composition	MWCO [a] (Daltons)
NF-200B-400	FilmTec Corp.	Polyamide	200-400
NTR-7450	Hydranautics Corp.	Polysulfone	~ 1,000
TFC-SR	Koch-Fluid Systems	Polyamide	300

[a] Denotes Molecular Weight Cut-Off

MEMBRANE CLEANING

Membrane cleaning was achieved by circulating a sodium hydroxide solution in deionized water at a pH near 12. In two cases, when the base cleaning was not effective (NTR7450 membrane 2nd quarter and NF-200 membrane, 4th quarter), a sulfuric acid solution in deionized water at a pH of approximately (but not less than) 2.5 was also used. Cleaning was conducted at a temperature of approximately 40 °C. The cleaning solution was initially circulated for 15 minutes at a transmembrane pressure of less than 5 psi. The membrane was then allowed to soak for 30 minutes. Finally, the cleaning solution was circulated again for 10 minutes at a transmembrane pressure of less than 5 psi. The crossflow velocity was maintained near 1 fps during the circulation portion of the cleaning cycle. A pressure-flux profile was also established for both membranes, following chemical cleaning using deionized water. After the base cleaning, the membrane cell was physically removed from the RBSMT apparatus, taken apart, and rinsed with deionized water.

NF FEED WATER AND PRETREATMENT

Three, thirty gallon drums were sent to Lee County's Olga Water Treatment Plant each quarter for feed water sampling for use in ICR testing. Prior to sending the drums, they were cleaned first at high pH (to remove organic and biological contaminants) with sodium hydroxide solution and then at low pH to remove possible metallic deposits (with sulfuric acid solution). After base and acid cleaning, these barrels were thoroughly rinsed with tap water and then dried for a minimum of 24 hours prior to shipment. The drums were then sent to Lee County for sampling.

As required by the ICR, water was sampled prior to the first point of continuous oxidant addition. Water samples were collected following powdered activated carbon addition, coagulation, flocculation, and sedimentation but prior to free chlorine addition. Upon receipt of these samples in Montgomery Watson's labs in Herndon VA, this water was further pretreated by filtration using an electronics grade cartridge filter (RyanHerco, Burbank, CA, Model #6711-505) prior to the RBSMT experiments. A simple schematic of the pretreatment processes employed is given in Figure 3-2.

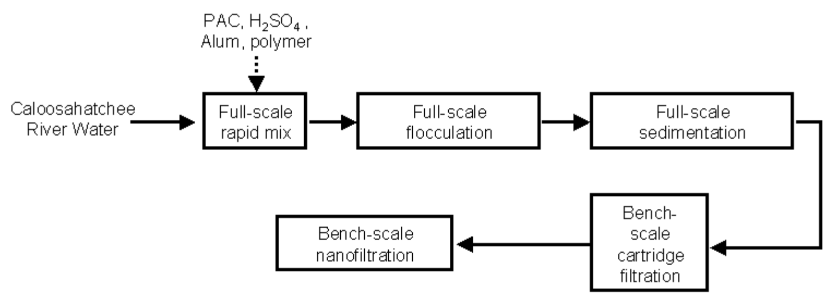


Figure 3-2. Simple schematic of the pretreatment used prior to bench-scale

NF feed water samples were collected at the start of the first set of experiments and the end of the second set of RBSMT experiments. These samples were then analyzed for a variety of physical, inorganic, and organic parameters. Table 3-2 summarizes the membrane feed water quality for all four quarters of testing.

As seen in Table 4, even after substantial pretreatment the NF feed water can be classified as being slightly alkaline, hard, and having moderate to high concentrations of the bromide ion. The concentrations of total organic carbon (TOC), simulated distribution system (SDS) haloacetic acid 5 (SDSHAA5[1]), SDS haloacetic acid 9 (SDSHAA9[2]), and SDS total trihalomethanes (SDSTTHM[3]) were also high.

[1] SDSHAA5 denotes the sum of monochloro, dichloro, trichloro, monobromo and dibromo acetic acids
[2] SDSHAA9 denotes the sum of HAA(5) and tribromo, chlorobromo, dichlorobromo, and chlorodibromo acetic acids
[3] SDSTTHM denotes the sum of chloroform, dichlorobromo methane, chlorodibromo methane and

Table 3-2
Summary Of NF Membrane Feed Water Quality For All Four Quarters Of Testing

Parameter	Units	I quarter	II quarter	III quarter	IV quarter
Alkalinity	mg/L as $CaCO_3$	43	60	145	217
Ca hardness	mg/L as $CaCO_3$	104	137	164	225
Total hardness	mg/L as $CaCO_3$	141	197	199	268
TDS	mg/L	215	254	247	354
Bromide	µg/L	110	180	150	305
Ammonia	mg NH_3-N/L	0.08	0.19	BMRL	0.15
SDS Cl_2 demand	mg/L	6.10	7.58	11.16	9.55
TOC	mg/L	6.3	5.8	8.3	7.8
SDS TOX	µg/L	540	545	1,580	893
SDS TTHM	µg/L	123.8	216	343	325
SDS HAA5	µg/L	91	100.3	214.8	113
SDS HAA9	µg/L	133	156.3	280.7	191.7
UV_{254}	cm^{-1}	0.123	0.112	0.209	0.170
pH	-	7.35	7.19	7.85	7.6
Turbidity	NTU	0.14	0.20	0.21	0.22

[a] Denotes Below Minimum Reporting Level

MEMBRANE SETTING

Deionized water (TDS concentration less than ~ 1 mg/L) was filtered at the start of each set of RBSMT experiments for approximately 24 hours. This period is sometimes referred to as "membrane setting". All experiments were conducted at room temperature (~23°C). Thus, any effects caused by seasonal variability in temperature were not reflected in the ICR experiments. A pressure-flux profile was conducted at the end of the first day or the beginning of the second day of testing, prior to switching to the feed water. During these measurements, transmembrane pressure was changed in random order in the range of 0 – 80 psi to reduce systematic biases in calculating the membrane resistance. Results from pressure-flux profiles were modeled using Darcy's law (Eq. 1) where J denotes

bromoform

the permeate flux (m/s), R_m (m^{-1}) denotes the membrane resistance, P_{tm} is the transmembrane pressure (Pa), and μ ($N\text{-}s/m^2$) denotes the absolute viscosity of water.

$$J = \frac{P_{tm}}{\mu R_m} \quad (1)$$

NF EXPERIMENTS USING PRETREATED CALOOSAHATCHEE RIVER WATER

Table 3-3 summarizes the sampling and membrane operational dates for RBSMT experiments that were conducted for all three membranes. The TFC-SR membrane was employed for all four quarters. However, the NTR7450 membrane was employed for the first two quarters and the NF200B membrane was used for the third and fourth quarters to satisfy ICR requirements.

Table 3-3
Quarterly Dates Of RBSMT Experiments

Quarter	Sampling date	Dates of membrane operation		
		NTR7450	NF-200B	TFC-SR
I	3/9/98	3/24/98-3/31/98	NA	3/17/98-3/22/98
II	6/9/98	7/6/98-7/13/98	NA	6/23/98-6/29/98
III	8/28/98	NA	9/14/98-9/21/98	9/28/98-10/5/98
IV	3/1/98	NA	3/16/99-3/23/99	3/8/99-3/15/99

During each quarter, experiments using pretreated Caloosahatchee River water were conducted continuously for a period of approximately 150 hours with each membrane. The feed water recovery, R_f, for the first experiment (~ 78 h duration) was maintained near 70%. This was followed by experiments where R_f was maintained at values near 90%, 50%, and 30%. As required under the ICR, these experiments were run without any cleaning when changing the feed water recovery. The average experimental conditions (net driving pressure, permeate flux, and water mass transfer coefficient) used for the NTR7450, NF-200B and TFC-SR membranes during all quarters of testing are summarized in Tables 3-4, 3-5 and 3-6 respectively.

Table 3-4
Summary Of Quarters I And II RBSMT Experiments Using NTR-7450 Membrane

Quarter	Recovery (%)	Net driving pressure (psi)	Permeate flux (gfd)	MTC_w [a] (gfd/psi)
I	70	62.0	14.3	0.23
I	89	62.5	14.8	0.22
I	50	62.6	13.7	0.22
I	29	62.8	13.4	0.21
II	68	62.6	13.9	0.21
II	91	62.7	12.3	0.19
II	49	62.7	12.1	0.19
II	30	62.2	12.4	0.19

[a] denotes water mass transfer coefficient which is also referred to as the specific flux

Table 3-5
Summary Of Quarters III And IV RBSMT Experiments Using NF200B Membrane

Quarter	Recovery (%)	Net driving pressure (psi)	Permeate flux (gfd)	MTC_w (gfd/psi)
III	71	39.3	10.9	0.26
III	90	37.8	9.5	0.24
III	51	40.2	10.9	0.26
III	32	40.4	11.1	0.26
IV	67	58.0	12.7	0.21
IV	89	57.5	11.7	0.20
IV	49	58.3	12.7	0.21
IV	30	58.5	12.9	0.21

Table 3-6
Summary Of Quarterly RBSMT Experiments Using TFC-SR Membrane

Quarter	Recovery (%)	Net driving pressure (psi)	Permeate flux (gfd)	MTC_w (gfd/psi)
I	70	56.2	12.8	0.24
I	86	54.2	10.8	0.21
I	56	56.4	11.9	0.22
I	33	57.8	12.7	0.23
II	72	57.4	17.6	0.30
II	88	56.1	15.0	0.26
II	51	57.6	15.7	0.26
II	32	57.2	15.0	0.26
III	72	39.7	13.3	0.68
III	91	38.3	10.6	0.57
III	53	40.5	12.8	0.64
III	30	41.7	13.2	0.65
IV	73	48.8	12.5	0.26
IV	85	48.0	10.8	0.23
IV	51	51.4	13.3	0.27
IV	33	52.2	13.9	0.27

MEMBRANE FOULING ANALYSIS

Membrane fouling was analyzed using only the 70% feed water recovery experiment for both membranes. This experiment was selected because of its extended operation time (~ 78 hours) compared to the other three recoveries (~ 24 hours). Further, the rate of fouling appeared to be highly dependent on the feed water recovery. Hence, using data from all four recoveries in each quarter resulted in very low regression coefficients. Additionally, full-scale plants would be operated at one fixed feed water recovery based either on pilot-scale tests or previous design experience. Therefore, fouling rates were calculated using linear regression using permeate flux data obtained at 70% recovery. Results from this regression analysis were then modeled using a simple equation of a straight line (Eq. 2).

$$J = -mt + b \qquad (2)$$

Where J = permeate flux at room temperature (gfd)
m = fouling rate (gfd/h)
t = time (h)
b = initial permeate flux (gfd)

Cleaning intervals (t_{clean}) were calculated assuming a 20% drop in initial specific flux (Eq. 3).

$$t_{clean} = \frac{0.2b}{m} \qquad (3)$$

Similar calculations can be made for 10% and 15% initial flux declines based on manufacturer recommendations or pilot-scale results for full-scale operation.

MONITORING

Routine monitoring for membrane operation and water quality was conducted according to the recommended minimum EPA requirements as described in Tables 3-7 and 3-8 respectively. Flow, pressure, and temperature measurements for feed, permeate, concentrate, and influent were recorded hourly during each recovery. TDS, pH, and UV_{254} were monitored at least three times a day for permeate, feed, and concentrate samples. For most analytes, ICR requirements were exceeded and TDS, UV_{254}, and pH were monitored hourly for permeate, feed, and concentrate samples.

Table 3-7
ICR Recommended Minimum Monitoring Frequencies For The RBSMT

Routine RBSMT Study Monitoring Requirements					
Parameter	**Feed**	**Permeate**	**Concentrate**	**Influent**	**Recycle**
Flow	none	6xD	6xD	6xD	none
Pressure	none	none	6xD	6xD	none
Temperature	none	none	none	6xD	none
TDS	1xD	3xD	1xD	none	none
pH	1xD	3xD	1xD	none	none
UV_{254}	1xD	3xD	1xD	none	none

1xD – once per 24 hours
3xD – three times per 24 hour
6xD – six times per 24 hours

Water quality parameters listed in Table 3-8 were analyzed on composite samples collected for each recovery.

Table 3-8
RBSMT Water Quality Monitoring Requirements According To The ICR

Water Quality Parameters To Be Evaluated At Each Recovery			
Parameter	**Feed**	**Permeate**	**Concentrate**
pH	TPR	FTPR	FTPR
Total Hardness	TPR	FTPR	FTPR
Calcium Hardness	TPR	FTPR	FTPR
Alkalinity	TPR	FTPR	FTPR
Total Dissolved Solids	TPR	FTPR	FTPR
Turbidity	TPR	FTPR	FTPR
Total Organic Carbon	TPR	FTPR	FTPR
UV_{254}	TPR	FTPR	FTPR
Bromide	TPR	FTPR	none
SDS-THM4	TPR	FTPR	none
SDS-HAA6	TPR	FTPR	none
SDS-TOX	TPR	FTPR	none
SDS-Cl_2 demand	TPR	FTPR	none

TPR – twice per run
FTPR – five times per run

SIMULATED DISTRIBUTION SYSTEM TESTS

One of the important components of ICR treatment studies was the simulated distribution system (SDS) testing of NF feed and permeate waters. Backup permeate samples were collected overnight during the 70% recovery experiment. These samples were then used to conduct a trial chlorine demand experiment with at least 2 different chlorine doses. Using the predetermined quarterly SDS conditions of temperature, pH, and holding time, the samples were then analyzed for chlorine concentrations using the DPD method. Based on these trial SDS experiments, appropriate chlorine dosages were determined for the actual SDS testing. During this test the sample water was dosed with free chlorine after pH adjustment to obtain a free chlorine residual near 1 mg/L at the conclusion of the incubation period. The samples were then incubated under conditions that closely simulated “average” conditions of the existing distribution system. Following incubation, the chlorinated waters were sampled for THMs, HAAs, and TOX. The SDS conditions employed during the four quarters of testing are summarized in Table 3-9.

Table 3-9
Simulated Distribution System Test Conditions Used In This Study

Parameter	Winter	Spring	Summer	Autumn
Disinfectant	Free chlorine	Free chlorine	Free chlorine	Free chlorine
Temperature (°C)	24	24	24	24
pH	8.0	8.0	8.0	8.0
Holding time (hour)	24	48	72	48
Free chlorine residual (mg/L)	~1	~1	~1	~1

ANALYTICAL METHODS AND LABORATORIES INVOLVED

All analytical measurements were made by the operator conducting the RBSMT experiments, or by Montgomery Watson Laboratories, CA. The analyses performed as well as some information regarding these different laboratory sites are provided in Table 3-10.

Table 3-10
Laboratory Information

Laboratory	Service dates	Analyses performed	Contact information
Field site	March, 1998 – March 1999	Alkalinity, calcium and total hardness, pH, Cl_2 residual, TDS, temperature, turbidity, UV_{254}	Dr. Shankar Chellam Montgomery Watson 560 Herndon Pkwy #300 Herndon, VA 20170
Montgomery Watson labs	March, 1998 – March 1999	Bromide, Ammonia, TOC, HAA, THM, TOX	ICR ID #: CA013 Dr. Andrew Eaton 555 E. Walnut St. Pasadena, CA 91101 Phone: (626) 568-6425 Fax: (626) 568-6324

A list of all analytical methods and the corresponding minimum reporting levels is given in Table 3-11. All analyses were performed using the methods and QA/QC procedures described in the *DBP/ICR Analytical Methods Manual* (EPA 814-B-96-002, April 1996).

Table 3-11
Summary of Analytical Methods and MRL's Used in This Study

Analyte	Method	Units	Minimum Reporting Level
Alkalinity	SM 2320 B	mg/L as $CaCO_3$	2
Ammonia	EPA 350.1	mg/L	0.05
Bromide	EPA 300	µg/L	40
Calcium hardness	SM 3500 Ca D	mg/L as $CaCO_3$	5
Total hardness	SM 2340 C	mg/L as $CaCO_3$	5
Chlorine residual	SM 4500 Cl G	mg/L	0.5
pH	SM 4500 H^+ B	-	-
TDS	SM 2510 B (probe)	mg/L	10
Temperature	SM 2550 B	°C	-
Turbidity	SM 2130 B	NTU	0.05
TOC	SM 5310 C	mg/L	0.50
UV_{254}	SM 5910 B	cm^{-1}	0.009
$CHCl_3$, BDCM, DBCM, $CHBr_3$	EPA 524.2	µg/L	1 for each analyte
MCAA, DCAA, TCAA, MBAA, DBAA, TBAA, BCAA, BDCAA, DBCAA	SM 6251 B	µg/L	2, 1, 1, 1, 1, 4, 1, 1, and 2 respectively
TOX	SM 5320 B	µg Cl^-/L	25

Section 4 – Results and Discussion

MEMBRANE OPERATION

Clean Membrane Resistances and Cleaning

Results from pressure-flux profiles conducted at the start of the experiments for all quarters of testing using new NTR7450 and NF-200B membranes are given in Figure 4-1. Corresponding data for the TFC-SR are provided in Figure 4-2. The linearity of the pressure-flux profiles suggests that compaction effects were negligible for these membranes in the range of pressures used.

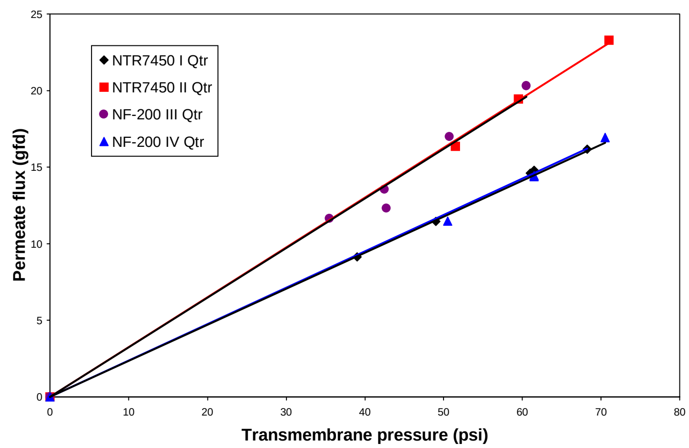


Figure 4-1 - Resistances of new NTR7450 and NF200B membranes used in each quarter.

These data were used to calculate new membrane resistances and the 95% confidence intervals using Eq. 1 and are summarized in Table 4-1. Table 4-1 also summarizes membrane resistances calculated following chemical cleaning. The average resistance of new NTR7450 and NF200B membranes were both equal to 5.33 x 10^{13} m^{-1}. Initial R_m values for the TFC-SR membrane ranged from 3.96 x 10^{13} – 6.09 x 10^{13} m^{-1} with an average value of 4.94 x 10^{13} m^{-1}. From Table 4-1 it is observed that the TFC-SR and NF-200B membrane resistances before and after

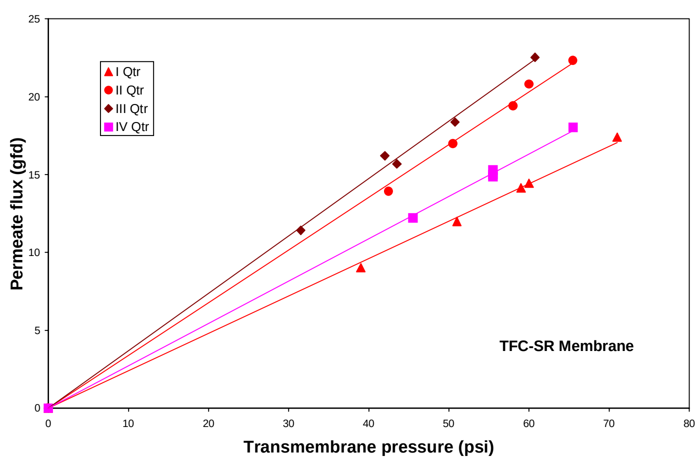


Figure 4-2 . Resistances of the new TFC-SR membranes used in each quarter.

cleaning were very similar. However, during the second quarter of testing a large increase in NTR7450 membrane resistance were observed following chemical cleaning. These data suggest that the cleaning procedure employed was effective only in removing TFC-SR and NF-200B membrane foulants present in pretreated Caloosahatchee water. Different cleaning protocols may need to be developed for the NTR7450 membrane.

Table 4-1
Summary of New Membrane Resistances and After Membrane Cleaning [a]

Quarter	Membrane	Initial R_m (m^{-1})	R_m after cleaning (m^{-1})	Change (%)	Cleaning solution
I	NTR7450	$6.15 \times 10^{13} \pm 9 \times 10^{11}$	$6.45 \times 10^{13} \pm 3 \times 10^{11}$	5	NaOH
I	TFC-SR	$6.09 \times 10^{13} \pm 1.3 \times 10^{12}$	$6.02 \times 10^{13} \pm 1.6 \times 10^{12}$	-1	NaOH
II	NTR7450	$4.50 \times 10^{13} \pm 1.1 \times 10^{12}$	9.3×10^{13}	107	NaOH & H_2SO_4
II	TFC-SR	$4.32 \times 10^{13} \pm 9 \times 10^{11}$	$4.02 \times 10^{13} \pm 5 \times 10^{11}$	-7	NaOH
III	NF-200	$4.50 \times 10^{13} \pm 2.7 \times 10^{12}$	$4.87 \times 10^{13} \pm 7 \times 10^{11}$	8	NaOH
III	TFC-SR	$3.96 \times 10^{13} \pm 1 \times 10^{12}$	$3.86 \times 10^{13} \pm 8 \times 10^{11}$	-3	NaOH
IV	NF-200	$6.16 \times 10^{13} \pm 4.5 \times 10^{12}$	$6.1 \times 10^{13} \pm 4.5 \times 10^{12}$	-1	NaOH & H_2SO_4
IV	TFC-SR	$5.38 \times 10^{13} \pm 8 \times 10^{11}$	$5.23 \times 10^{13} \pm 3.8 \times 10^{12}$	-3	NaOH

[a] All cleanings were conducted at a temperature of ~ 40 °C

Specific Flux Profiles

Normalized specific flux profiles for the entire duration the experiments using the NTR7450 and NF-200B membranes are depicted in Figure 4-3. Corresponding data for the TFC-SR membrane are provided in Figure 4-4. It was observed that all membranes experienced a decline in flux initially and sometimes during the 90% recovery experiment.

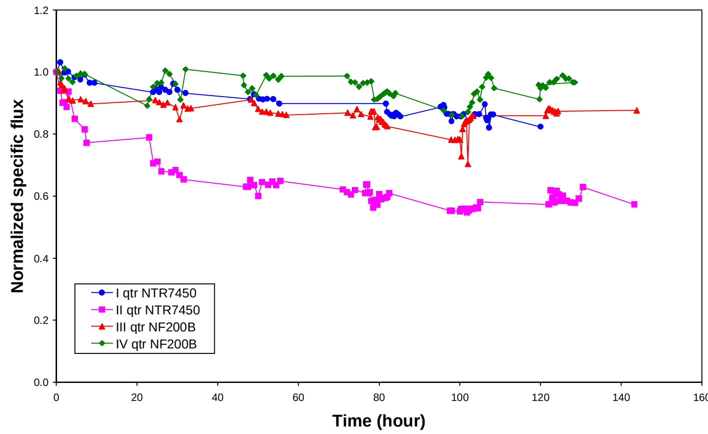


Figure 4-3. Normalized specific flux profiles using the NTR7450 and NF200B membranes

However, the flux appeared to stabilize for the duration of the remaining experiments at 30% and 50% recoveries. The NTR7450 membrane experienced major fouling during second quarter of testing and the TFC-SR membrane depicted erratic specific flux behavior during fourth quarter experiments. Overall, the NF-200B and TFC-SR membranes experienced relatively stable operation throughout the duration of the experiment.

quarter of testing and the TFC-SR membrane depicted erratic specific flux behavior during fourth quarter experiments. Overall, the NF-200B and TFC-SR membranes experienced relatively stable operation throughout the duration of the experiment.

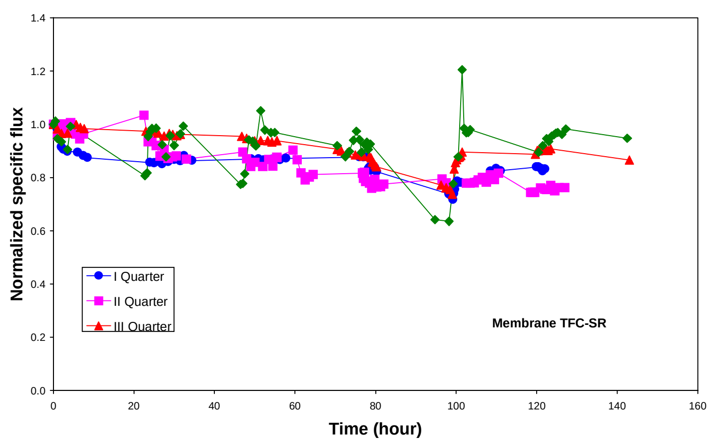


Figure 4-4. Normalized specific flux profiles for 4 quarters using the TFC-SR membrane

Table 4-2 summarizes the average permeate flux during membrane setting as well as the lowest recorded permeate flux during each experiment. It was observed that the initial permeate flux ranged from 12.6 – 19.1 gfd with an average value of 15.8 gfd. The lowest recorded permeate flux ranged from 8.4 – 14.8 gfd with an average value of 11.1 gfd.

This constituted a decrease of approximately 30% in flux from the membrane setting period to the lowest recorded permeate flux, which always occurred at 90% recovery.

Table 4-2
Summary of Worst Case Permeate Fluxes

Quarter	Membrane	DI water permeate flux (gfd)	Lowest permeate flux [a] (gfd)
I	NTR7450	16.0	13.0
I	TFC-SR	14.3	10.5
II	NTR7450	19.1	11.6
II	TFC-SR	18.8	14.8
III	NF-200	12.6	8.9
III	TFC-SR	15.9	10.3
IV	NF-200	14. 5	11.2
IV	TFC-SR	15.1	8.4

[a] Recorded always during 90% recovery

Fouling Analysis and Cleaning Intervals

Fouling rate parameters obtained using Eq. 2 for the RBSMT experiments conducted at 70% recovery are listed in Table 4-3. These data were obtained by linear regression analysis (the 95% confidence intervals are shown following the ± sign). Good straight-line fits were obtained for the first three quarters of testing as indicated by the high coefficient of regression (R^2: 0.52 – 0.90). However, poor straight line fits were observed for the 4th quarter permeate flux data ($R^2 = 0.03$). The corresponding cleaning intervals were obtained using Eq. 3 and ranged from 41 to 980 hours. Therefore, it appears that under the conditions employed, chemical cleaning needs to be conducted at an average of once every three days of operation at 70% recovery for the NTR7450 membrane, once every 24 days for the NF200B membrane and once every seven days for the TFC-SR membrane. However, it should be understood that no attempt was made to "optimize" membrane operation and to increase the duration between cleanings by pH adjustment, anti-scalent addition, or by incorporating more advanced pretreatment processes such as micro- or ultrafiltration. (It is not the intent of the ICR to determine optimum operating conditions for NF.)

Table 4-3
Summary of Statistical Fits To Permeate Flux Profiles at 70% Recovery

Quarter	Membrane	Fouling rate (gfd/h)	Initial flux (gfd)	R^2	Cleaning interval (h)*
I	NTR7450	0.0264 ± 0.0047	15.39 ± 0.15	0.86	116.6
II	NTR7450	0.0883 ± 0.0170	18.16 ± 0.70	0.80	41.1
III	NF-200	0.0146 ± 0.0043	11.62 ± 0.18	0.62	159.2
IV	NF-200	0.0026 ± 0.0055	12.79 ± 0.25	0.03	983.8
I	TFC-SR	0.0202 ± 0.0081	13.87 ± 0.33	0.52	137.3
II	TFC-SR	0.0474 ± 0.0098	19.40 ± 0.38	0.76	81.9
III	TFC-SR	0.0204 ± 0.0027	14.16 ± 0.12	0.90	138.8
IV	TFC-SR	0.0088 ± 0.0178	12.84 ± 0.74	0.03	291.8

*Cleaning interval was calculated assuming a 20% drop in initial flux.

[a] Straight line fits to 4th quarter flux data were poor as indicated by low R^2 values. Hence, cleaning intervals for this quarter should be interpreted with caution.

PERMEATE WATER QUALITY

Composite Sample Collection

Permeate water quality was monitored frequently to establish a "steady-state" before collecting composite permeate and concentrate samples. Upon switching recoveries for each experiment, permeate water samples were collected every 20 minutes and analyzed for TDS and UV_{254}. Once consistent readings were achieved, and the experiment reached "steady-state" composite samples were then collected. These composite samples were analyzed for a variety or organic and inorganic water quality parameters. SDS testing was performed on the composite permeate samples and the feed water.

Table 4-4 provides a summary of all physical, organic and inorganic permeate water quality parameters obtained using the NTR7450 and NF-200B membranes at 70% feed water recovery for all four quarters of testing. Corresponding data for the TFC-SR membrane are provided in Table 4-5.

Table 4-4
NTR7450 and NF-200B Permeate Water Quality at 70% Recovery

Parameter	Units	NTR7450 membrane		NF200B membrane	
		I quarter	II quarter	III quarter	IV quarter
Alkalinity	mg/L as $CaCO_3$	43	54	122	112
Ca hardness	mg/L as $CaCO_3$	96	117	83	115
Total hardness	mg/L as $CaCO_3$	130	165	98	155
TDS	mg/L	199	223	147	262
Bromide	μg/L	110	170	195	325
Ammonia	mg NH_3-N/L	0.08	0.16	0.10	BMRL
SDS Cl_2 demand	mg/L	1.86	4.25	2.30	1.47
TOC	mg/L	2.3	1.6	0.9	0.9
SDSTOX	μg/L	168	185	108	70
SDSTTHM	μg/L	62.0	101.7	66.3	82.0
SDSHAA(5)	μg/L	19.6	24.7	13.0	7.6
SDSHAA(9)	μg/L	37.0	53.2	29.8	22.0
UV_{254}	cm^{-1}	0.048	0.030	0.019	0.012
pH	-	7.8	7.9	7.9	7.9
Turbidity	NTU	0.08	0.08	0.1	0.08

Table 4-5
TFC-SR Permeate Water Quality For All 4 Quarters of Testing at 70% Recovery

Parameter	Units	I quarter	II quarter	III quarter	IV quarter
Alkalinity	mg/L as $CaCO_3$	31	55	132	93
Ca hardness	mg/L as $CaCO_3$	28	63	76	80
Total hardness	mg/L as $CaCO_3$	57	94	90	128
TDS	mg/L	103	136	138	197
Bromide	µg/L	99	170	160	220
Ammonia	mg NH_3-N/L	0.08	0.25	ND	0.10
SDS Cl_2 demand	mg/L	1.35	2.06	0.95	0.97
TOC	mg/L	0.5	0.6	0.55	0.6
SDSTOX	µg/L	60	ND	53	52
SDSTTHM	µg/L	19.3	30.1	46.8	38.2
SDSHAA(5)	µg/L	4.9	5.8	6.0	4.2
SDSHAA(9)	µg/L	10.6	11.6	14.2	9.5
UV_{254}	cm^{-1}	BMRL	BMRL	0.010	BMRL
pH	-	7.4	7.4	8.0	8.1
Turbidity	NTU	0.05	0.06	0.08	0.11

Total Organic Carbon Removal

TOC removal measured at 70% feed water recovery by all three membranes are summarized in Figure 4-5 Of the three membranes tested at the bench-scale, the TFC-SR membrane achieved highest rejection of TOC whereas the NTR7450 was most permeable to TOC.

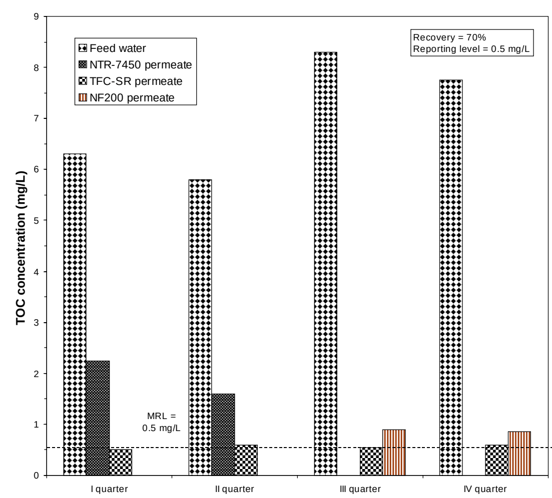


Figure 4-5. TOC removals by various membranes at 70% recovery.

As seen in Table 4-6, the highest permeate TOC concentration using the TFC-SR membrane was 1.1 mg/L. The highest recorded permeate TOC concentrations using

NTR7450 and NF-200B membranes were 2.3 and 1.8 mg/L respectively (see Table 20). Thus, the lowest TOC removal percentage using the TFC-SR membrane was 87 %. In contrast, the lowest TOC removal percentages using NTR7450 and NF-200B membranes were 60 and 78% respectively.

Table 4-6
Summary of Toc Concentrations in the Permeate Water Using the TFC-SR Membrane

Recovery (%)	I Quarter		II Quarter		III Quarter		IV Quarter	
	Concentration (mg/L)	Removal (%)	Concentration (mg/L)	Removal (%)	Concentration (mg/L)	Removal (%)	Concentration (mg/L)	Removal (%)
30	0.5	92	BMRL	> 91	0.7	91	BMRL	> 94
50	BMRL	> 92	BMRL	> 91	0.7	91	0.6	92
70	0.5	92	0.6	90	0.6	93	0.6	92
90	BMRL	> 92	0.7	88	1.1	87	0.7	91

[a] Calculated using 0.5 mg/L as the TOC minimum reporting level

Table 4-7
Summary of TOC Concentrations in the Permeate Water Using the NTR7450 and NF-200B Membranes

Recovery (%)	NTR7450 membrane				NF-200B membrane			
	I Quarter		II Quarter		III Quarter		IV Quarter	
	Concentration (mg/L)	Removal (%)	Concentration (mg/L)	Removal (%)	Concentration (mg/L)	Removal (%)	Concentration (mg/L)	Removal (%)
30	1.5	76	0.9	84	0.7	92	0.5	94
50	1.6	74	1.0	83	0.5	94	0.5	94
70	2.3	63	1.6	72	0.9	89	0.9	89
90	3.0	52	2.3	60	1.6	81	1.8	78

Disinfection By-Product Precursor Removal

Highest SDSTTHM and SDSHAA(5) concentrations using the TFC-SR membrane were near 80 µg/L and 12 µg/L, respectively. Compared to the TFC-SR membrane, higher concentrations of organic constituents were observed in the NF-200B and NTR7450 membrane permeate waters. For example, the highest SDSTTHM and SDSHAA(5) concentrations using these membranes were 140 µg/L and 27 µg/L, respectively.

Under the SDS conditions employed, SDSHAA(5) concentrations in membrane permeate waters were always below the place holder under Stage II of the D/DBP rule (30 µg/L for HAA(5)). However, maximum SDSTTHM concentrations in membrane permeate waters were above the place holder under Stage II of the D/DBP rule (40 µg/L for TTHMs). Hence, NF alone may not be sufficient to meet proposed THM regulations if free chlorine is employed as the final disinfectant.

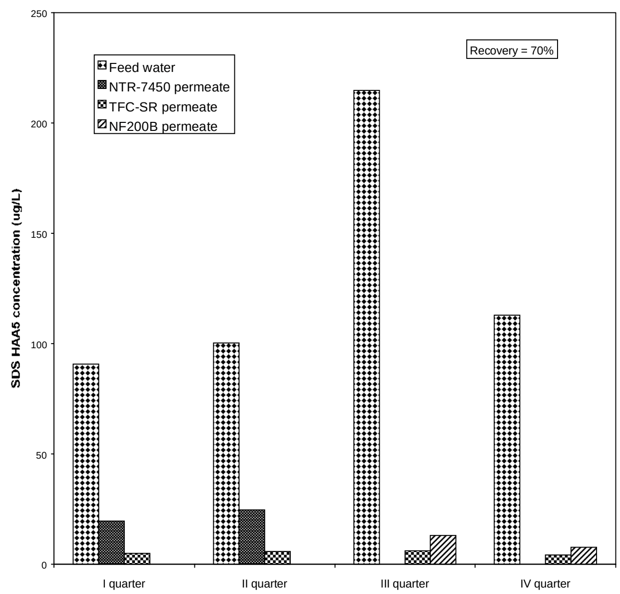


Figure 4-7...HAA5 precursor removals by various membranes at 70% recovery.

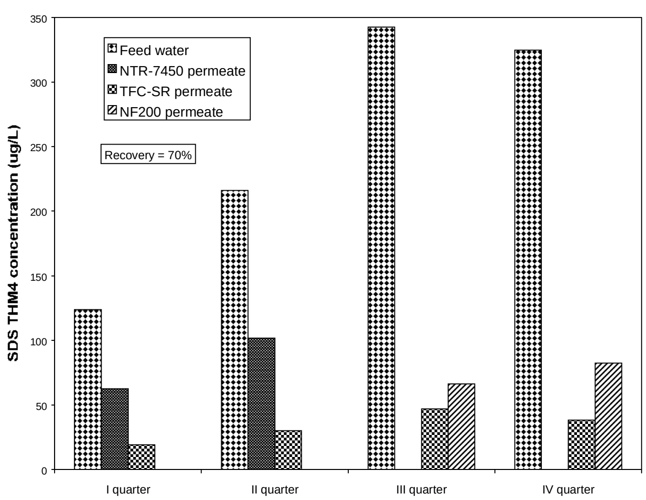


Figure 4-6...THM precursor removal by various membranes at 70% recovery.

HAA(5) and THM precursor removals from pretreated Caloosahatchee River water by the membranes employed (at 70% recovery) are summarized in Figures 4-6 and 4-7 respectively.

Effect of Nanofiltration on THM Speciation

As described in the previous sections, the NF membranes employed achieved high TOC removals. However, these membranes achieved essentially no bromide ion rejection. In other words, these membranes were completely permeable to the bromide ion. Hence, the ratio of the bromide ion concentration to TOC concentration increased dramatically in the NF permeate water compared to the NF feed water. At the same time, SDS experiments were conducted by employing similar free chlorine concentration to TOC concentration ratios in the feed and permeate waters so as to achieve a similar free chlorine concentration (~ 1 mg/L) at the end of the SDS incubation period.

Because of these SDS experimental conditions, large changes in the relative concentrations of the individual THM species were detected in the NF feed and permeate waters. This phenomenon is depicted in Figure 4-8 by expressing each THM specie as a mole fraction. As observed, chloroform and dichlorobromo methane were dominant in the NF feed water. However, as the ratio of the concentration of bromide ion concentration to TOC concentration increased dramatically, bromoform and chlorodibromo methane mole fractions increased in the NF permeate water.

Similar observations were also made in haloacetic acid speciation but those data are not depicted in this report for the sake of brevity.

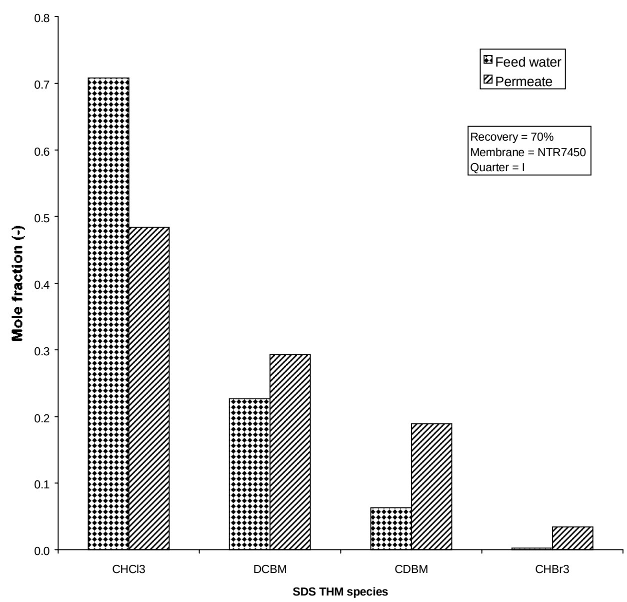


Figure 4-8...Changes in THM speciation expressed as mole fraction upon nanofiltration (data from I quarter experiments at 70% feed water recovery and NTR-7450 membrane).

Inorganics removal

The NTR7450 membrane achieved only ~ 30% TDS rejection. The NF200B and TFC-SR membranes removed ~ 60% and 73% TDS from pretreated Caloosahatchee River water. Additionally, the TFC-SR and NF200B membranes removed approximately 55% and 47% of total hardness respectively (at 70% recovery). However, the NTR7450 membrane removed only 12% of total hardness from the membrane feed water (at 70% recovery). None of the membranes employed in this study were able to achieve substantial removal of the bromide ion. As explained earlier and as shown in Figure 4-6, this resulted in large changes in trihalomethane and haloacetic acid speciation in the permeate water compared to the feed water.

Effect of Feed Water Recovery on Rejection

The concentrations of a variety of inorganic and organic permeate water quality parameters were dependent on feed water recovery for both membranes. Table 4-8 shows the effects of recovery on the rejection of selected water quality parameters by the NF-200B and NTR7450 membranes. These data were obtained by averaging data from both membranes using all four quarters of testing. The median and range for each parameter are also listed. Corresponding data for the TFC-SR membrane are summarized in Table 4-9. In general, permeate concentrations increased with increasing feed water recovery.

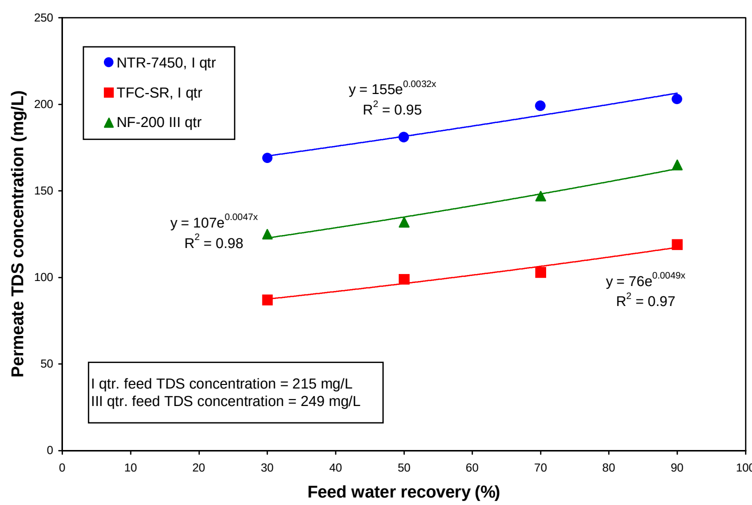


Figure 4-9...Effect of feed water recovery on permeate TDS

The effects of feed water recovery on permeate TDS concentrations using the NTR7450, NF200B and the TFC-SR membranes are depicted graphically in Figure 4-9. Data obtained during the first and third quarters of testing have been used. It can be observed that permeate TDS concentrations increased exponentially with feed water recovery (R_f) for both membranes. The following empirical fits were obtained using these data:

TFC-SR membrane: Permeate TDS (mg/L) = 76 exp(0.0049R_f) (R^2 = 0.97)
NF200B membrane: Permeate TDS (mg/L) = 107 exp(0.0047R_f) (R^2 = 0.98)
NTR7450 membrane: Permeate TDS (mg/L) = 155 exp(0.0032R_f) (R^2 = 0.95)

Empirical correlations relating other organic and inorganic permeate water quality parameters to feed water recovery could be derived using simple linear regression techniques if necessary.

Table 4-8
Effect of Feed Water Recovery on Rejection of Selected Water Quality Parameters Using the NT-7450/NF-200B Membrane

Parameter	Units	30% recovery		50% recovery		70% recovery		90% recovery	
		Median	Range	Median	Range	Median	Range	Median	Range
Ca hardness	mg/L as $CaCO_3$	81	66-88	87	72-96	104	82-124	118	92-186
Total hardness	mg/L as $CaCO_3$	108	80-146	131	92-156	145	96-166	151	114-244
TDS	mg/L	176.0	125-229	188.5	132-245	213	146-263	220	165-300
Bromide	mg/L	160	100-320	160	100-330	170	NA-330	170	110-320
Ammonia	mg NH_3-N/L	0.08	BMRL-0.08	0.09	BMRL-0.1	0.09	BMRL-0.16	0.09	BMRL-0.09
SDS Cl_2 demand	mg/L	1.52	0.97-3.24	1.65	1.04-3.54	2.09	1.47-4.24	2.37	2.02-4.24
TOC	mg/L	0.9	ND-1.5	1.0	ND-1.6	1.25	0.7-2.3	2.05	1.6-3.0
TOX	µg/L	103	54-125	95.5	65-135	140	44-190	180	145-230
THM	µg/L	54.45	35.8-83	53.6	47.4-93	72.2	60.9-109.0	107.5	59-140
HAA(5)	µg/L	8.15	4.3-12.4	10.30	5.2-13.5	16.05	3.9-27	19.50	18.2-22.9
HAA(9)	µg/L	18.40	14.3-23.3	21.65	17.8-24.6	32.90	14.4-60.8	43.45	32.4-49
UV_{254}	cm^{-1}	0.013	0.002-0.027	0.017	0.004-0.031	0.024	0.010-0.050	0.043	0.032-0.060

Refer to Table 3-11 for the minimum reporting levels for various water quality parameters

Table 4-9
Effect of Feed Water Recover on Rejection of Selected Water Quality Parameters Using the TFC-SR Membrane

Parameter	Units	30% recovery		50% recovery		70% recovery		90% recovery	
		Median	Range	Median	Range	Median	Range	Median	Range
Ca hardness	mg/L as $CaCO_3$	51	22-68	68	NA-72	69	28-86	70	38-186
Total hardness	mg/L as $CaCO_3$	66	38-102	80	61-104	90	56-130	114	52-232
TDS	mg/L	121.5	87-180	131	99-187	137.5	103-237	150.5	119-264
Bromide	mg/L	160	100-180	165	96-210	165	99-230	170	110-280
Ammonia	mg NH_3-N/L	0.17	BMRL-0.25	0.15	BMRL-0.22	0.11	BMRL-0.25	0.07	BMRL-0.22
SDS Cl_2 demand	mg/L	1.25	0.85-2.12	1.30	0.85-2.22	1.17	0.94-2.06	1.47	1.26-2.50
TOC	mg/L	0.70	ND-0.7	0.65	ND-0.7	0.55	ND-0.7	0.7	ND-1.10
TOX	µg/L	47	ND-58	46	ND-81	53	ND-68	66	ND-93
THM	µg/L	18.7	13-55.6	24.8	15.6-60.5	33.95	18.4-49.2	47.8	23.3-79.6
HAA(5)	µg/L	3.35	1.9-8.7	3.85	2.5-10.5	5.10	4.1-6.2	6.70	5.2-12.3
HAA(9)	µg/L	5.45	3.1-18.7	8.00	5.6-21.4	10.10	7.3-14.6	13.0	9.6-29.8
UV_{254}	cm^{-1}	BMRL	BMRL - 0.013	BMRL	BMRL - 0.014	BMRL	BMRL - 0.009	0.011	BMRL - 0.022

Refer to Table 3-11 for the minimum reporting levels for various water quality parameters

Permeate and Feed Water Blending

Because of the high rejection capabilities of some nanofiltration membranes employed in water treatment, the concentrations of many water quality parameters in the permeate water are often much lower than regulatory maximum contaminant levels. This may allow the possibility of blending NF feed water with NF permeate thereby reducing membrane area and/or energy requirements for the full-scale membrane plant.

However, because of the high concentrations of THM and HAA9 precursor materials in the NF feed water (average feed water SDSTTHM concentration = 205 μg/L, average feed water SDSHAA9 concentration = 190 μg/L) blending is not expected to be feasible especially to meet the current place holders for THM concentrations under Stage 2 of the Disinfectant/Disinfection By-Products Rule if free chlorine is employed as the disinfectant.

Problems Encountered

In general ICR experiments were conducted smoothly. Waste flow rates occasionally dropped by approximately 2 – 8% when the RBSMT apparatus was left unattended overnight, most often during the experiment at 90% feed water recovery. During the 4th quarter testing using the TFC-SR membrane from 3/9/99 – 3/10/99 the pH instrument malfunctioned and therefore no pH data were collected during the early portion of the experiment at 70% recovery.

Section 5 – QA/AC Summary

LABORATORY ANALYSES

As described in Table 3-9, samples were shipped to Montgomery Watson Laboratories, CA which is an ICR certified laboratory. Appendix B summarizes the QA/QC information provided by Montgomery Watson Laboratory using the format required under the ICR.

Quality assurance and quality control (QA/QC) summary data from Montgomery Watson Laboratories reflects not only ICR samples for the Lee County, but other bench-scale test utilities as well, as per agreement with Mr. Steve Allegeier ICR Technical Coordinator.

ICR RBSMT DATA COLLECTION SPREADSHEETS

To ensure the integrity of the data collected and reported in this treatment study, we have already undergone one preliminary review of the ICR Treatment Study Data Collection Spreadsheets by the U.S. EPA. The comments generated during this preliminary review process are in Appendix C. We have addressed all of your comments into the Data Collection Spreadsheets. Our detailed responses are as described below:

Global Comments Applicable to Both Membrane Worksheets

- Missing information in Field 1 has been provided.
- Cost of an 8x40 TFC-SR membrane element is not available from manufacturer.
- No water quality parameters (including potential foulants) were measured prior to pretreatment because they were not required under the ICR.
- Cost data have been provided.
- Missing equations for SUVA, THM4 etc. have been entered.
- Information for all pretreatment processes including chemical formula of alum has been reported for all quarters of testing.
- SDS incubation times reflect seasonal variations in full-scale distribution system.

TFC-SR Membrane 1st Quarter

- Alkalinity concentrations verified and found to be correct. No change made.
- Permeate total hardness concentrations verified and found to be correct. No change made.

TFC-SR Membrane 2nd Quarter:

- All water quality parameters for 90% recovery experiment were verified and found to be correct. No change made.

TFC-SR Membrane 3rd Quarter:

- Feed water TOX and $CHCl_3$ concentrations were verified and found to be correct. No changes made.
- All water quality parameters including TDS were verified for the 90% recovery experiment and found to be correct. No changes made.
- Permeate TOC, UV254, THM4, HAA and TOX values for the 70% recovery experiment were verified and found to be correct. No changes made.

TFC-SR Membrane 4th Quarter:

- No pH data are available during the early portion of the run because there was a problem with the instrument then.
- All membrane operational data were verified and found to be correct. Erratic behavior of MTC_w and flux may be just due to experimental variability.

NTR-7450 Membrane 1st Quarter:

- All water quality parameters were verified for the 90% recovery experiment and found to be correct. No changes made.
- Rejections are higher for the 3rd and 4th quarter because the membrane was changed from NTR7450 to NF200B.

NTR-7450 Membrane 2nd Quarter:

- TCAA concentrations were verified for the 90% recovery experiment and found to be correct. No changes made.
- Rejections are higher for the 3rd and 4th quarter because the membrane was changed from NTR7450 to NF200B.

NF200B Membrane 3rd Quarter:

- Feed water TOX and $CHCl_3$ concentrations were verified and found to be correct. No changes made.
- Rejections are higher for the 3rd and 4th quarter because the membrane was changed from NTR7450 to NF200B.

NF-200B Membrane 4th Quarter:

- Feed water MBAA concentrations were verified and found to be correct. No change made.
- Alkalinity concentrations were verified and found to be correct. No change made.
- Rejections are higher for the 3rd and 4th quarter because the membrane was changed from NTR7450 to NF200B.

APPENDIX A

Design Plant Parameters

Date: July 8, 1999

PWS Name: Lee County, Florida
PWS ID: FL5364048
ICR Contact Person: A. Glenn Greer, P.E.

Treatment Plant Name: Olga Water Treatment Plant
ICR Treatment Plant ID: 1095
Treatment Plant PWS ID: FL
Treatment Plant Category: SOFT

State Approved Plant Capacity (MGD):
Historical Min. Water Temperature (deg C):
Installed Sludge Handling Capacity (GPD):
Blending Category: N

Water Resource Name: Caloosahatchee River
Water Resource Type: Surface water
Intake Name: Surface Water Intake at WTP site
Wellhead Protection: N/A

Latitude (degrees, minutes, seconds):
Longitude (degrees, minutes, seconds):

Unit Process	Quantity	Type	Capacity
Coagulation Reactor	1		5 MGD rating 1 gpm/ft^2 SLR
Softening Reactor	1		5 MGD rating 1 gpm/ft^2 SLR
Filters	2	Greenleaf	5 MGD (rating total) 2 gpm/ft^2 loading rate
Contact Basin (baffled)	1		19 minutes @ 5 MGD
GAC Contactors			5 MGD
Ground Storage Tank	1		1 MG

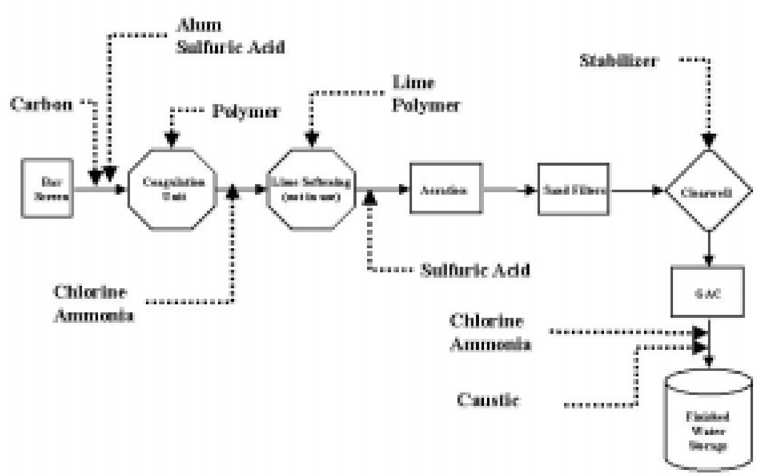
Design Plant Chemical Parameters

Date: July 8, 1999

PWS Name:	Lee County, FL	**Treatment Plant Name:**	Olga Water Treatment Plant
PWS ID:	FL6354048	**ICR Treatment Plant ID:**	1095
ICR Contact Person:	A. Glenn Greer, P.E.	**Treatment Plant Category:**	SOFT

Chemical Addition Points:

Chemical Name	Chemical Formula	Dose (mg/L)
Alum	$Al_2(SO_4)_3 \bullet x\ H_2O$	140 – 150 mg/l
Sulfuric Acid	H_2SO_4	15 – 30 mg/l
Polymer	Copolymer of acrylamide & sodium acrylate	0.42 – 1.0 mg/l
Lime	CaO (quick lime)	70 – 120 mg/l
Chlorine	Cl_2	12 – 16 mg/l
Ammonia	NH_3 (anhydrous)	2.0 – 5.0 mg/l
Stabilizer		2.5 mg/l
Caustic	NaOH	10 – 40 mg/l
Powdered Activated Carbon	C	0 – 5 mg/l



Sampling Points: