Information Collection Rule Treatment Study Summary Report

City of Hollywood, Florida

June 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

Prepared by
Dr. Shankar Chellam
Montgomery Watson Americas Inc.
560 Herndon Parkway #300
Herndon, VA 20170

Prepared for
The City of Hollywood
PWSID # FL4060642
1621 N. 14th Avenue
Hollywood FL 33019
Phone: (954) 921-3288
Fax: (954) 967-4232

Plant Name: Hollywood Water Treatment Plant
Plant ICR #: 298

Section 1
Summary and Conclusions

Four quarters of nanofiltration (NF) testing using pretreated Biscayne Aquifer water were successfully completed. Cartridge filtration was the only NF pretreatment employed. Two NF membranes (TFC-SR and NTR 7450) were used to complete Information Collection Rule (ICR) treatment study requirements using the Rapid Bench Scale Membrane Test (RBSMT) methodology.

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 Hydranautics NTR7450 membrane. For example, the highest recorded TOC concentration in the TFC-SR membrane permeate was only 0.8 mg/L. In comparison, the highest TOC concentration in the NTR7450 membrane permeate was 2.3 mg/L.

Under the SDS conditions employed, the highest SDSTTHM and SDSHAA(5) concentrations in the TFC-SR membrane permeate were near 28 μg/L and 5 μg/L, respectively. However, the highest SDSTTHM and SDSHAA(5) concentrations in the NTR7450 membrane permeate were 59 μg/L and 29 μg/L, respectively. Therefore, SDSTTHM and SDSHAA(5) concentrations in the TFC-SR membrane permeate waters were always below the placeholders under Stage II of the D/DBP rule (40 μg/L for TTHMs and 30 μg/L for HAA(5)) even when free chlorine was employed as the final disinfectant. However, only SDSHAA(5) concentrations in the NTR7450 membrane permeate waters were always below the placeholder under Stage II of the D/DBP rule when free chlorine was employed as the final disinfectant.

The TFC-SR membrane also achieved higher removals of a variety of inorganic water quality parameters compared to the NTR7450 membrane. For example, the average total hardness in the TFC-SR membrane permeate at 70% feed water recovery was 159 mg/L as $CaCO_3$ whereas the average total hardness in the NTR7450 membrane permeate at 70% feed water recovery was 226 mg/L as $CaCO_3$.

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 ~ 50 h – 2,000 h at 70% feed water recovery and an initial flux of ~ 13 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, these membrane fouling rates and cleaning intervals predicted using bench-scale experiments need to be verified at the pilot-scale.

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

Section 2
Introduction

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. 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 were 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) and are summarized in this report.

Existing water treatment processes. A schematic of the existing water treatment processes for the City of Hollywood Water Treatment Plant is given in the flow diagram in Appendix A. This schematic was generated earlier during the development of the initial sampling plan for the 18 months of DBP/microbiological monitoring under the ICR. The water for NF testing was obtained directly from the Biscayne Aquifer.

Basic engineering and chemical feed data for each unit process are summarized in Tables A.2 and A.3, respectively, also in Appendix A. These tables were also generated earlier using the *ICR Water Utility Database System* (EPA 814-B-96-004) to report the results from the 18 months of DBP/microbiological monitoring under the ICR.

Full-scale plant influent and finished water quality. Under the 18 months of water quality monitoring requirements of the ICR, quarterly samples were collected from July 1997 through December 1998 at the City of Hollywood Water Treatment Plant. These data from the influent and finished water of the full-scale plant have been summarized in Tables 1 and 2 respectively.

Table 1. Full-scale influent water quality data

Parameter	Units	Average	Std. Dev.	Min.	Max.	Count
Temperature	ºC	25.7	1.3	23	27.5	12
pH	-	7.4	0.40	6.61	7.9	12
Turbidity	ntu	0.47	0.08	0.4	0.6	12
Alkalinity	mg/L as $CaCO_3$	208	5	200	21	12
Total Hardness	mg/L as $CaCO_3$	255	14	235	289	12
Calcium Hardness	mg/L as $CaCO_3$	242	13	223	275	12
TOC	mg/L	4.03	0.27	3.7	4.5	12
UV_{254}	1/cm	0.142	0.007	0.135	0.161	12
Bromide	µg/L	82	8	69	95	12
TSUVA*	L/(mg-m)	3.52	0.20	3.19	3.76	12

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

Table 2. Full-scale finished water quality data

Parameter	Units	Average	Std Dev	Min	Max	Count
Temperature	ºC	25.7	1.1	23	27	12
pH	unit	8.7	0.36	8.2	9.4	12
Turbidity	ntu	0.32	0.12	0.15	0.5	12
TOC	mg/L	2.2	0.5	1.5	3	12
UV_{254}	1/cm	0.067	0.011	0.051	0.081	12
DS-THM4 [a]	µg/L	13.3	5.5	5.2	20.2	8
DS-HAA5	µg/L	8	2.6	4	11.5	8
DS-HAA6	µg/L	8.9	3.6	4	13.9	8

[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 Membrane Test (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 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 cylinder and a stopwatch.

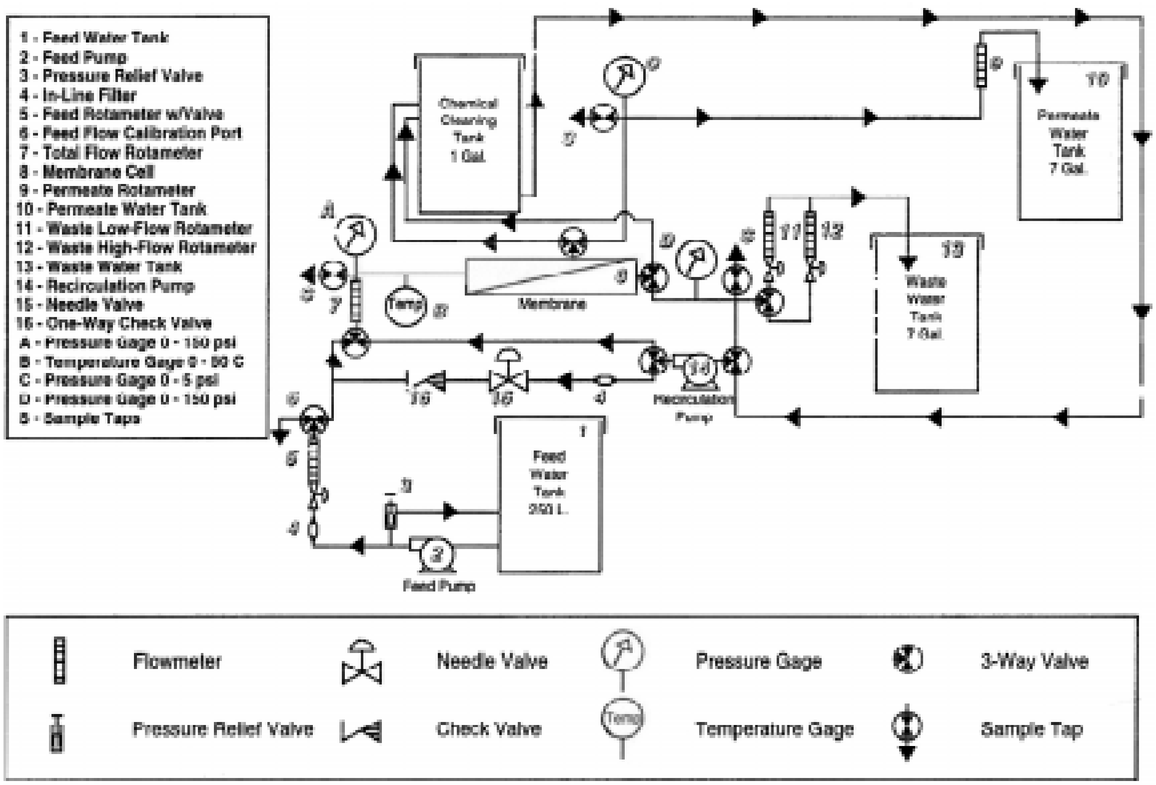


Figure 1. Schematic of the bench-scale NF apparatus

Membranes employed. ICR experiments were conducted using two NF membranes: Hydranautics NTR7450 (Hydranautics Corp., San Diego, CA) and TFC-SR (Koch-Fluid Systems Corp., San Diego, CA). Important characteristics for each membrane (as specified by the manufacturers) are summarized in Table 3.

Table 3. Characteristics of membranes used during ICR testing

Membrane designation	Manufacturer	Composition	MWCO [a] (Daltons)
NTR7450	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 one case, when the base cleaning was not effective (NTR7450 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 the City of Hollywood each quarter for feed water sampling for use in ICR testing. Prior to sending the drums, they were cleaned first with a sodium hydroxide solution at high pH (to remove organic and biological contaminants) and then at a low pH (with sulfuric acid solution) to remove possible metallic deposits. 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 the City of Hollywood for sampling.

As required by the ICR, water was sampled prior to the first point of continuous oxidant addition. Hence, sample water was taken directly from the Biscayne Aquifer. Prior to the RBSMT experiments, the only pretreatment that was employed on this water was filtration using a 5 µm cartridge filter. A simple schematic of the pretreatment processes employed is given in Figure 2.

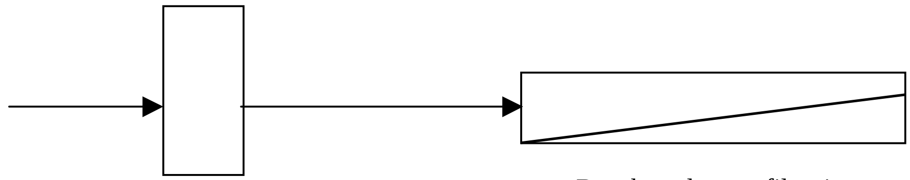


Figure 2. Simple schematic of the pretreatment used prior to bench-scale nanofiltration.

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 4 summarizes the membrane feed water quality for all four seasons of testing.

As seen in Table 4, after pretreatment the NF feed water can be classified as a slightly alkaline hard water, having moderate to high concentrations of the bromide ion, 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]).

Table 4. Summary of NF membrane feed water quality for all four seasons of testing

Parameter	Units	I quarter	II quarter	III quarter	IV quarter
Alkalinity	mg/L as $CaCO_3$	140	262	378	290
Ca hardness	mg/L as $CaCO_3$	158	261	224	263
Total hardness	mg/L as $CaCO_3$	188	274	228	310
TDS	mg/L	259	283	250	269
Bromide	μg/L	82	62	70	85
Ammonia	mg NH_3-N/L	BMRL[a]	0.13	BMRL[a]	0.36
SDS Cl_2 demand	mg/L	6.21	3.58	4.23	7.39
TOC	mg/L	3.85	4.00	3.55	4.65
SDS TOX	μg/L	275	387.5	352.5	390
SDS TTHM	μg/L	109.6	154.1	142.1	134
SDS HAA5	μg/L	75.5	61	58.1	65.4
SDS HAA9	μg/L	84	68.9	65.9	74
UV_{254}	cm^{-1}	0.158	0.134	0.144	0.164
pH	-	8.05	7.90	7.63	7.75
Turbidity	NTU	0.33	0.15	0.35	0.32

[a] Denotes Below Minimum Reporting Level

[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 bromoform

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

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

NF experiments using pretreated Biscayne Aquifer water. Table 5 summarizes the sampling and membrane operational dates for RBSMT experiments that were conducted for both membranes.

Table 5. Quarterly dates of RBSMT experiments

Quarter	Sampling date	Dates of membrane operation	
		TFC-SR	**NTR7450**
I	3/23/98	4/6/98 – 4/12/98	4/13/98 – 4/23/98
II	6/10/98	6/15/98 – 6/24/98	6/26/98 – 7/2/98
III	10/1/98	10/12/98 – 10/19/98	10/26/98 – 11/2/98
IV	2/7/99	2/10/99 – 2/17/99	2/18/99 – 2/26/99

During each quarter, experiments using pretreated Biscayne Aquifer 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 and TFC-SR membranes during all quarters of testing are summarized in Tables 6 and 7 respectively.

Table 6. Summary of quarterly RBSMT experiments using NTR7450 membrane

Quarter	Recovery (%)	Net driving pressure (psi)	Permeate flux (gfd)	MTC_w [a] (gfd/psi)
I	69	76	11.0	0.146
I	89	75	10.4	0.139
I	54	76	10.5	0.140
I	28	77	10.4	0.138
II	69	54	12.5	0.244
II	90	54	11.2	0.218
II	54	54	10.7	0.207
II	30	53	10.2	0.205
III	71	64	14.7	0.116
III	92	63	13.2	0.109
III	51	64	13.3	0.108
III	67	63	14.0	0.114
IV	70	47	10.5	0.230
IV	90	47	9.2	0.220
IV	51	47	10.9	0.230
IV	31	48	11.4	0.240

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

Table 7. Summary of quarterly RBSMT experiments using TFC-SR membrane

Quarter	Recovery (%)	Net driving pressure (psi)	Permeate flux (gfd)	MTC_w (gfd/psi)
I	69	52	15.0	0.315
I	93	53	13.9	0.294
I	51	51	15.5	0.333
I	33	54	16.5	0.330
II	69	52	13.8	0.265
II	90	51	12.8	0.256
II	51	50	12.6	0.257
II	31	49	12.5	0.260
III	72	48	13.5	0.288
III	91	47	12.7	0.280
III	53	48	13.7	0.296
III	30	48	13.8	0.298
IV	70	47	12.5	0.273
IV	90	47	11.2	0.243
IV	54	48	12.3	0.264
IV	28	48	12.8	0.280

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 8 and 9 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 and often times hourly for permeate, feed, and concentrate samples. For most analytes, ICR requirements were exceeded.

Table 8. 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 hours
6xD – six times per 24 hours

Water quality parameters listed in Table 9 were analyzed on composite samples collected for each recovery.

Table 9. 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 10.

Table 10. Simulated distribution system test conditions used in this study

Parameter	I quarter	II quarter	III quarter	IV quarter
Disinfectant	Free chlorine	Free chlorine	Free chlorine	Free chlorine
Temperature (°C)	24	24	24	24
pH	8.2	8.2	7.9	8.0
Holding time (hour)	24	24	24	24
Free chlorine residual (mg/L)	~1	~1	~1	~1

Analytical methods and laboratories involved. A list of all analytical methods and the corresponding minimum reporting levels (MRLs) is given in Table 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).

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 12.

Table 11. Summary of analytical methods and MRLs 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

Table 12. 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

Section 4
Results and Discussion

MEMBRANE OPERATION

New 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 TFC-SR membranes are given in Figures 3 and 4 respectively. The linearity of the pressure-flux profiles suggests that compaction effects were negligible for these membranes in the range of pressures used.

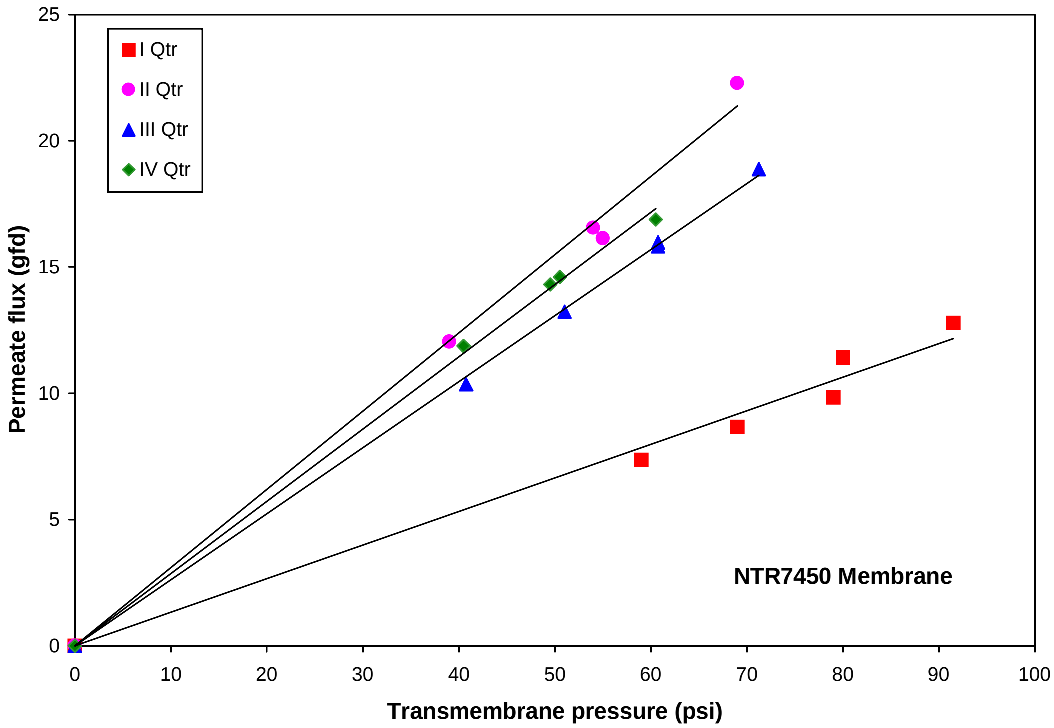


Figure 3. Resistances of the new NTR7450 membranes used in each quarter.

These data were used to calculate new membrane resistances and the 95% confidence intervals using Eq. 1 which are summarized in Table 13. Table 13 also summarizes membrane resistances calculated following chemical cleaning. New NTR7450 membrane resistance values were in the range of 4.71 x 10^{13} – 1.09 x 10^{14} m^{-1} with an average value of 6.58 x 10^{13} m^{-1}. Initial R_m values for the TFC-SR membrane ranged from 4.54 x 10^{13} - 5.44 x 10^{13} m^{-1} with an average value of 5.09 x 10^{13} m^{-1}. From Table 13 it is observed that the TFC-SR membrane resistances before and after cleaning were very similar. However, large increases in NTR7450 membrane resistances were observed following chemical cleaning. These data suggest that the cleaning procedure employed was effective only in removing TFC-SR membrane foulants present in the Biscayne Aquifer water. Different cleaning protocols need to be developed for the NTR7450 membrane.

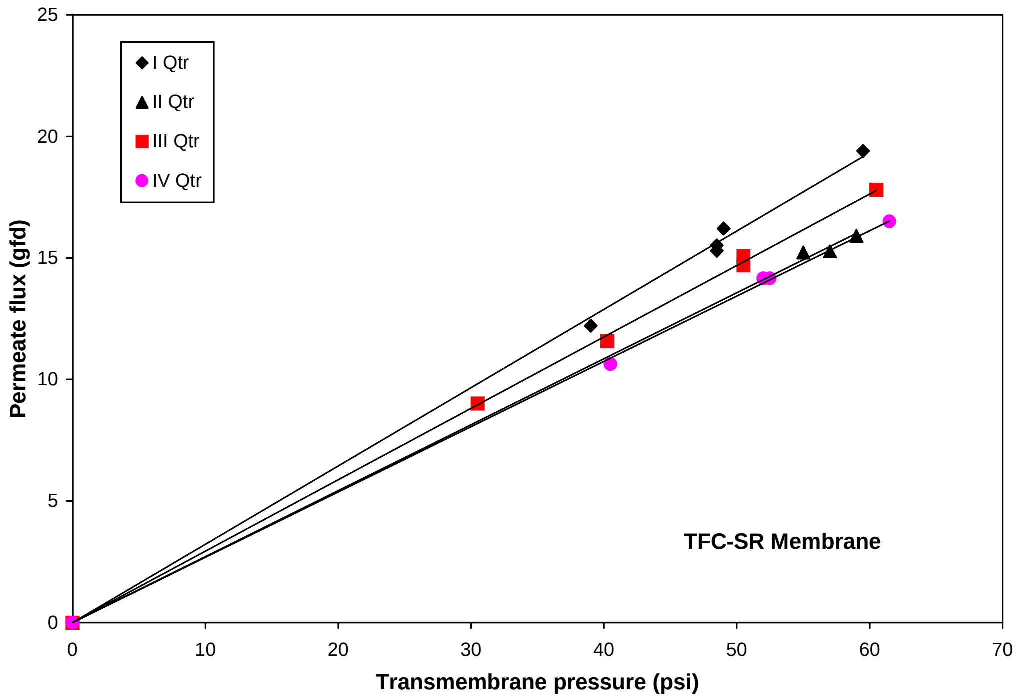


Figure 4. Resistances of the new TFC-SR membranes used in each quarter.

Table 13. Summary of membrane resistances before and after membrane cleaning [a]

Quarter	Membrane	Initial R_m (m^{-1})	R_m after cleaning (m^{-1})	Change (%)	Cleaning solution
I	NTR7450	$1.09 \times 10^{14} \pm 7 \times 10^{12}$	$1.12 \times 10^{14} \pm 4 \times 10^{12}$	+3	NaOH
I	TFC-SR	$4.54 \times 10^{13} \pm 1 \times 10^{12}$	$4.25 \times 10^{13} \pm 9 \times 10^{11}$	-6	NaOH
II	NTR7450	$4.71 \times 10^{13} \pm 2.5 \times 10^{12}$	$6.78 \times 10^{13} \pm 3.7 \times 10^{12}$	+44	NaOH
II	TFC-SR	$5.39 \times 10^{13} \pm 1.4 \times 10^{12}$	$4.88 \times 10^{13} \pm 5 \times 10^{11}$	-9	NaOH
III	NTR7450	$5.59 \times 10^{13} \pm 8 \times 10^{11}$	$7.42 \times 10^{13} \pm 6 \times 10^{11}$	+33	NaOH
III	TFC-SR	$4.98 \times 10^{13} \pm 7 \times 10^{11}$	$4.78 \times 10^{13} \pm 8 \times 10^{11}$	-4	NaOH
IV	NTR7450	$5.11 \times 10^{13} \pm 1.4 \times 10^{12}$	$7.21 \times 10^{13} \pm 3.9 \times 10^{12}$	+41	NaOH & H_2SO_4
IV	TFC-SR	$5.44 \times 10^{13} \pm 8 \times 10^{11}$	$5.21 \times 10^{13} \pm 3 \times 10^{11}$	-4	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 NTR7450 and TFC-SR membranes are depicted in Figures 5 and 6, respectively. It was observed that the NTR7450 membrane experienced a steady decline in flux throughout the experiment during the first and third quarters of testing. During the second quarter of testing, the flux declined 40% by the end of the last experiment. The TFC-SR membrane experienced initial flux decline particularly during the second and third quarters of testing. In general, the TFC-SR membrane exhibited more stable operation compared to the NTR7450 membrane.

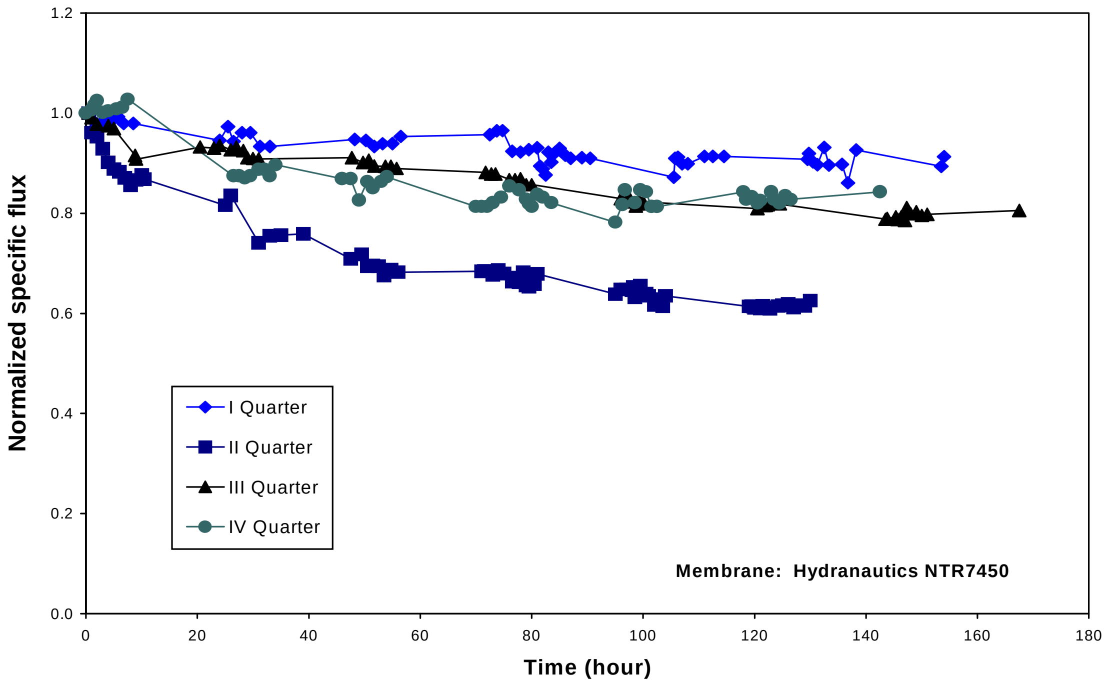


Figure 5. Normalized specific flux profiles for 4 quarters using the NTR7450 membrane

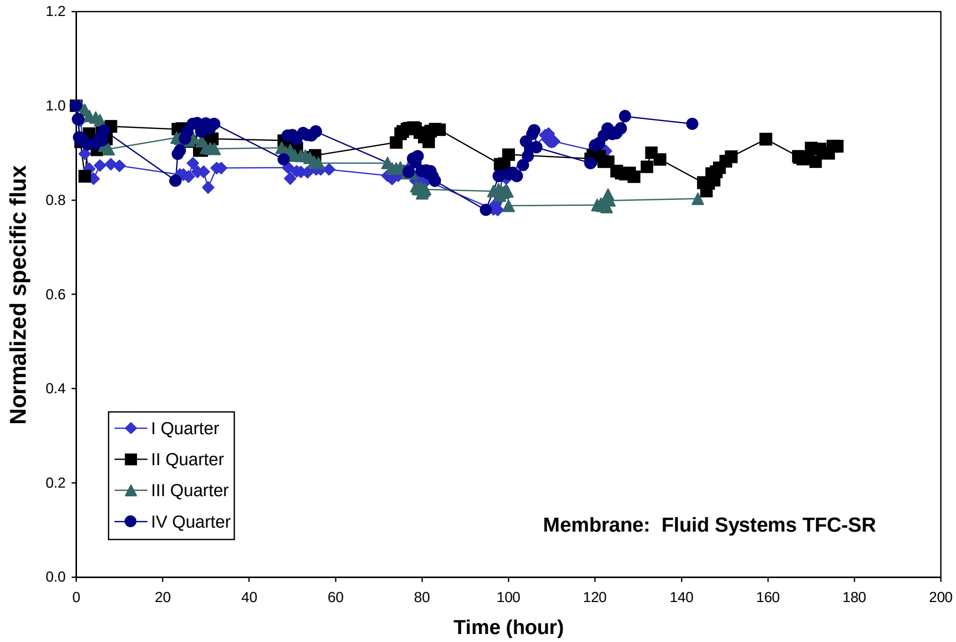


Figure 6. Normalized specific flux profiles for 4 quarters using the TFC-SR membrane

Table 14 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 10.3 – 16.6 gfd with an average value of 14.3 gfd. The lowest recorded permeate flux ranged from 9.7 – 13.9 gfd with an average value of 11.4 gfd. This constituted a decrease of approximately 20% in flux from the membrane setting period to the lowest recorded permeate flux, which always occurred at 90% recovery.

Table 14. Summary of worst case permeate fluxes.

Quarter	Membrane	DI water permeate flux (gfd)	Lowest permeate flux [a] (gfd)
I	NTR7450	10.3	10.0
I	TFC-SR	15.4	13.3
II	NTR7450	16.6	10.0
II	TFC-SR	15.5	11.9
III	NTR7450	14.3	13.9
III	TFC-SR	14.5	12.4
IV	NTR7450	14.1	9.7
IV	TFC-SR	13.8	10.3

[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 15. These data were obtained by linear regression analysis (the 95% confidence intervals are shown following the ± sign). Better straight-line fits were obtained for the NTR7450 membrane compared to the TFC-SR membrane. The coefficient of regression ranged from 0.38 to 0.89 for the NTR7450 membrane. The corresponding cleaning intervals were obtained using Eq. 3 and ranged from 52 to 376 hours. The TFC-SR membrane exhibited relatively more stable performance (compare Figures 5 and 6) and poor fits were observed (low R^2 values). Longer chemical cleaning intervals were calculated using Eq. 3. Therefore, it appears that under the conditions employed, membrane cleaning needs to be conducted approximately every 8 days of operation at 70% recovery for the NTR7450 membrane and every 44 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 15. Summary of statistical fits to permeate flux profiles at 70% recovery [a]

Quarter	Membrane	Fouling rate (gfd/h)	Initial flux (gfd)	R^2	Cleaning interval (h)*
I	NTR7450	0.0086 ± 0.0027	11.36 ± 0.13	0.62	264
II	NTR7450	0.0591 ± 0.0075	15.42 ± 0.34	0.89	52
III	NTR7450	0.0079 ± 0.0037	14.84 ± 0.18	0.38	376
IV	NTR7450	0.0332 ± 0.0058	12.38 ± 0.26	0.83	75
I	TFC-SR	0.0015 ± 0.0032	14.82 ± 0.29	0.01	1,976
II	TFC-SR	0.0024 ± 0.0016	13.87 ± 0.28	0.02	1,155
III	TFC-SR	0.0034 ± 0.0032	13.66 ± 0.15	0.13	804
IV	TFC-SR	0.0102 ± 0.0077	12.78 ± 0.29	0.20	251

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

[a] Straight line fits to TFC-SR membrane flux data were poor as indicated by low R^2 values. Hence, cleaning intervals for this membrane 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 16 and 17 provides a summary of all physical, organic and inorganic permeate water quality parameters obtained using the NTR7450 and TFC-SR membranes, respectively, at 70% feed water recovery for all four quarters of testing.

Table 16. NTR7450 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 $CaCO_3$	184	232	341	206
Ca hardness	mg/L as $CaCO_3$	206	225	177	198
Total hardness	mg/L as $CaCO_3$	217	250	193	244
TDS	mg/L	239	257.5	236.5	250
Bromide	μg/L	74.5	60	68	82.5
Ammonia	mg NH_3-N/L	BMRL[a]	0.5	BMRL[a]	0.43
SDS Cl_2 demand	mg/L	2.59	1.11	1.28	4.47
TOC	mg/L	1.30	1.25	1.30	1.6
SDSTOX	μg/L	102.5	90.5	95.5	84
SDSTTHM	μg/L	40.9	47.3	48.6	41.1
SDSHAA(5)	μg/L	15.75	10.3	10.4	9.7
SDSHAA(9)	μg/L	21.1	14.8	14.7	13.9
UV_{254}	cm^{-1}	0.033	0.026	0.034	0.028
pH	-	8.05	8.47	7.80	7.76
Turbidity	NTU	0.09	0.06	0.29	0.08

a: Denotes Below Minimum Reporting Level

Table 17. 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 $CaCO_3$	132	170	272	191
Ca hardness	mg/L as $CaCO_3$	133	157	118	163.5
Total hardness	mg/L as $CaCO_3$	137	163	136	201
TDS	mg/L	170.5	221.5	163	218
Bromide	μg/L	66.5	57.5	54	76.5
Ammonia	mg NH_3-N/L	BMRL[a]	0.21	0.17	0.47
SDS Cl_2 demand	mg/L	1.86	1.67	1.19	4.20
TOC	mg/L	BMRL[a]	BMRL[a]	BMRL[a]	0.70
SDSTOX	μg/L	BMRL[a]	28	BMRL[a]	32
SDSTTHM	μg/L	7.05	19.15	7.25	18.80
SDSHAA(5)	μg/L	2.60	2.10	0.50	2.85
SDSHAA(9)	μg/L	2.60	2.10	0.50	4.30
UV_{254}	cm^{-1}	BMRL[a]	BMRL[a]	BMRL[a]	BMRL[a]
pH	-	8.25	7.94	7.72	7.83
Turbidity	NTU	0.30	0.04	0.15	0.07

a: Denotes Below Minimum Reporting Level

Total organic carbon removal. TOC removal measured at 70% feed water recovery by both membranes are summarized in Figure 7. Of the two membranes tested at the bench-scale, the TFC-SR membrane achieved higher rejections of total organic carbon. As seen in Table 18, many of the permeate TOC concentrations using the TFC-SR membrane were below the minimum reporting level of 0.5 mg/L. The highest recorded permeate TOC concentration using this membrane was 0.8 mg/L. Thus, the lowest TOC removal percentage using the TFC-SR membrane was 83%. In contrast, the NTR7450 membrane achieved lower TOC removal (see Table 19). The highest recorded permeate TOC concentration using this membrane was 2.3 mg/L. Thus, the lowest TOC removal percentage using the NTR7450 membrane was 48%.

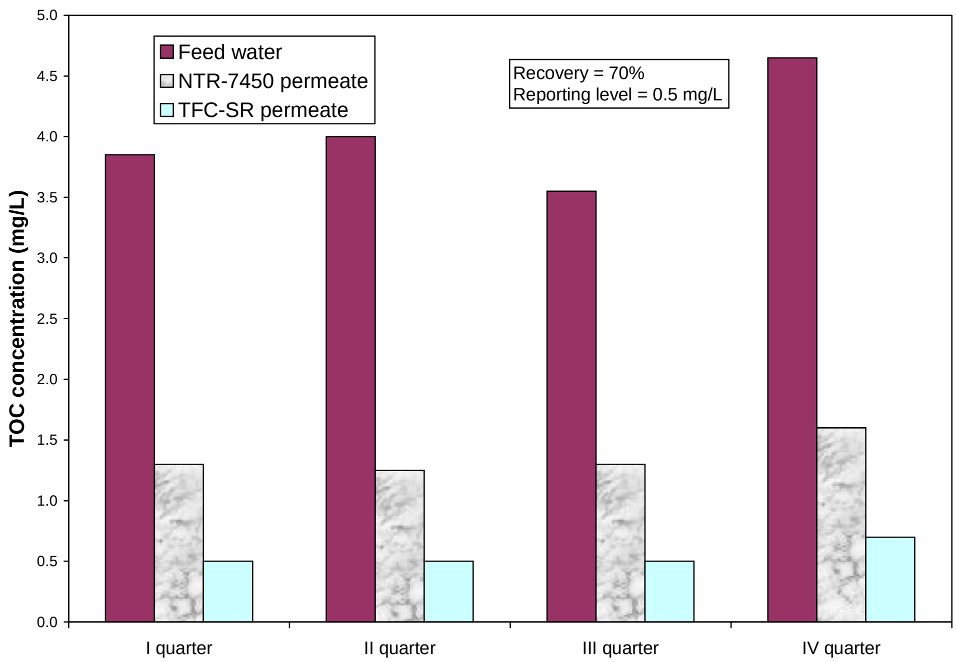


Figure 7. TOC removals by various membranes employed in the study at 70% recovery.

Table 18. 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	BMRL [a]	87	BMRL [a]	87	BMRL [a]	86	0.5	89
50	BMRL [a]	87	BMRL [a]	87	BMRL [a]	86	0.6	87
70	BMRL [a]	87	BMRL [a]	87	BMRL [a]	86	0.7	85
90	BMRL [a]	87	0.6	85	0.7	80	0.8	83

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

Table 19. Summary of TOC concentrations in the permeate water using the NTR7450 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	0.9	77	0.8	80	0.7	80	0.9	81
50	1.2	69	0.9	77	0.9	75	1.0	78
70	1.3	66	1.25	69	1.3	63	1.6	66
90	2.0	48	1.6	60	1.5	58	2.3	51

Disinfection by-product precursor removal. Highest SDSTTHM and SDSHAA(5) concentrations using the TFC-SR membrane were near 28 μg/L and 4.9 μg/L, respectively. Compared to the TFC-SR membrane, higher concentrations of organic constituents were observed in the NTR7450 membrane permeate water (see Tables 16 and 17). For example, the highest SDSTTHM and SDSHAA(5) concentrations using the NTR7450 membrane were 58 μg/L and 29 μg/L, respectively.

Under the SDS conditions employed, SDSHAA(5) concentrations in both membrane permeate waters were always below the place holder under Stage II of the D/DBP rule (30 μg/L for HAA(5)). Further, the TFC-SR membrane also always reduced SDSTTHM precursor concentrations to below the place holder under Stage II of the D/DBP rule (40 μg/L for TTHMs). However, on some occasions, the SDSTTHM concentrations in the NTR7450 membrane permeate were greater than 40 μg/L.

HAA(5) and TTHM precursor removals from pretreated Biscayne Aquifer water by the membranes employed (at 70% recovery) are summarized in Figures 8 and 9 respectively.

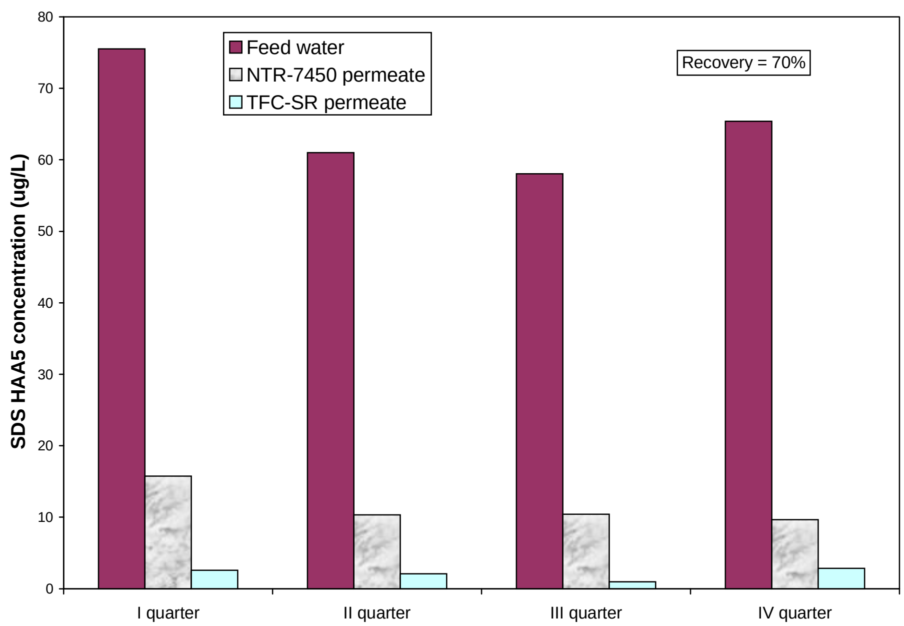


Figure 8. HAA5 precursor removals by both membranes employed in this study.

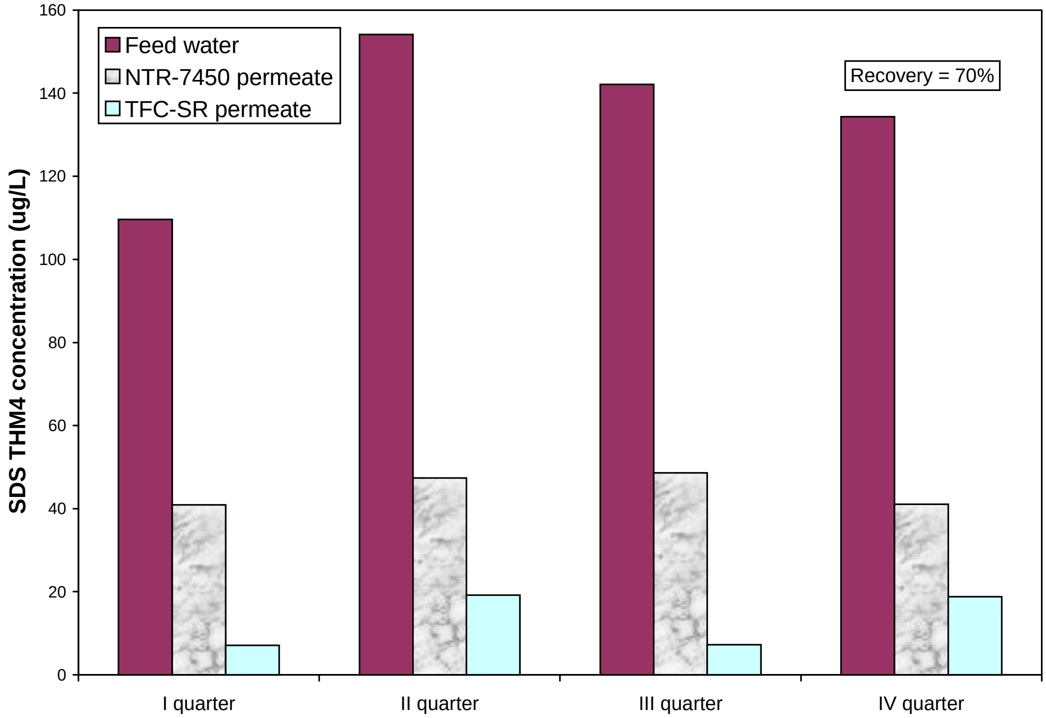


Figure 9. THM precursor removal by both membranes employed in this study.

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 concentration of 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 both the feed and permeate waters so as to achieve a free chlorine concentration of ~ 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 10 by expressing each THM species as a mole fraction. As observed, chloroform was dominant in the NF feed water. However, as the ratio of the concentration of bromide ion concentration to TOC concentration increased, the mixed chloro-bromo species increased in relative concentrations in the NF permeate water.

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

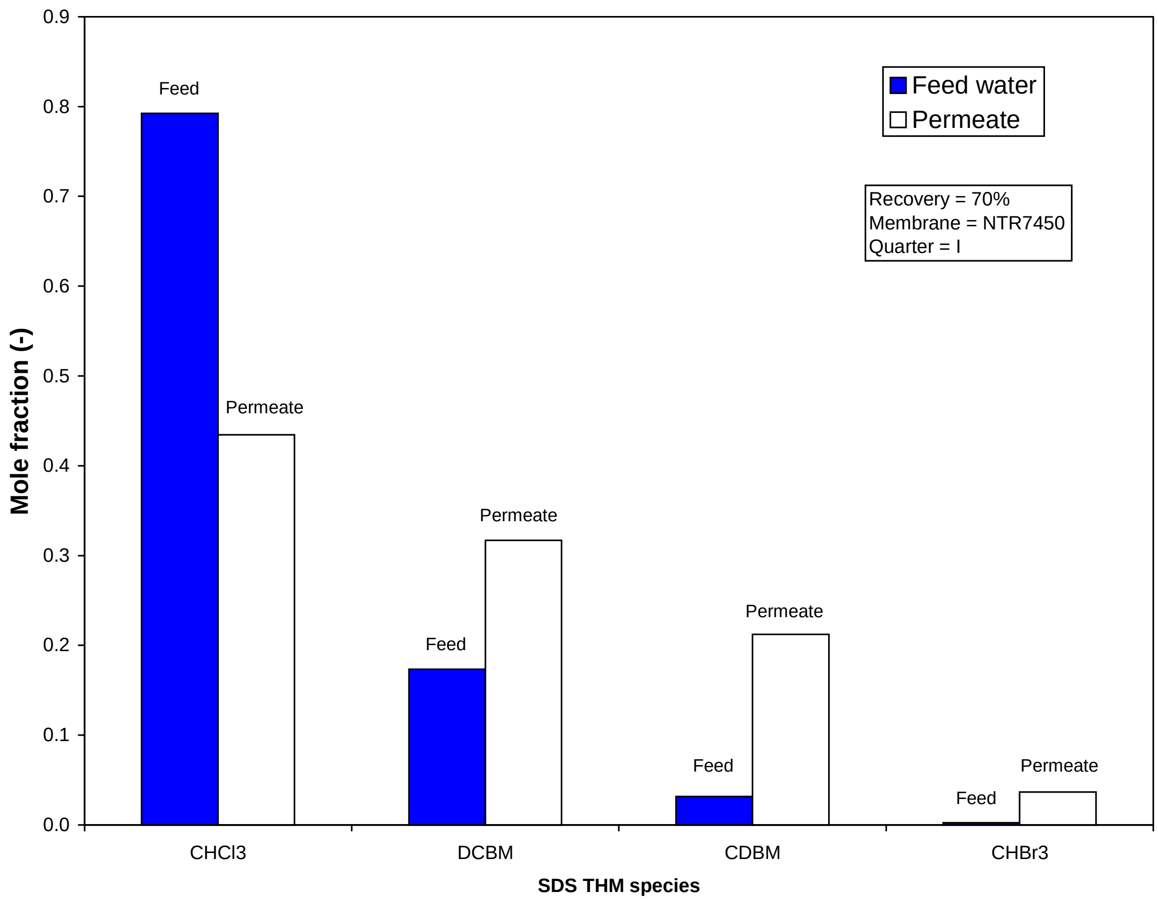


Figure 10. Changes in THM speciation expressed as mole fraction upon nanofiltration (data from I quarter experiments at 70% feed water recovery and NTR-7450 membrane).

Inorganics removal. The NTR7450 membrane achieved only ~ 20% TDS rejection. But the TFC-SR membrane was able to remove ~ 55% TDS from the Biscayne Aquifer water. Additionally, the TFC-SR membrane removed approximately 36% of total hardness (at 70% recovery). However, the NTR7450 membrane removed only 15% 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 10, 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. Tables 20 and 21 show the effects of recovery on the rejection of selected water quality parameters by the NTR7450 and TRC-SR membranes, respectively. These data were obtained by averaging data from all quarters of testing. The median and range for each parameter are also listed. In general, permeate concentrations increased with increasing feed water recovery suggesting that the transport of many water quality constituents across these polymeric membranes were controlled by diffusion.

The effects of feed water recovery on permeate TDS concentrations using the NTR7450 and the TFC-SR membranes are depicted graphically in Figure 11 for the first quarter of testing. 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 the first quarter data:

TFC-SR membrane: Permeate TDS (mg/L) = 126 exp(0.0043R_f) (R^2 = 0.96)

NTR7450 membrane: Permeate TDS (mg/L) = 228 exp(0.0008R_f) (R^2 = 0.90)

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 20. Effect of feed water recovery on rejection of selected water quality parameters using the NTR7450 membrane

Parameter	Units	30% recovery		50% recovery		70% recovery		90% recovery	
		Median	Range	Median	Range	Median	Range	Median	Range
Ca hardness	mg/L as $CaCO_3$	187	152-232	182	158-228	206	170-232	217	178-248
Total hardness	mg/L as $CaCO_3$	211	192-246	209	194-252	222	184-262	264	200-314
Alkalinity	mg/L as $CaCO_3$	195	152-340	195	164-332	226	170-346	250	192-368
TDS	mg/L	228	224-233	239	231-261	244	236-263	253	244-268
Bromide	mg/L	66	58-77	67.5	61-81	70.5	60-83	69.5	63-84
SDS Cl_2 demand	mg/L	0.84	0.5-3.79	1.3	0.6-3.88	1.85	0.94-4.49	1.51	1.05-4.50
TOC	mg/L	0.85	0.7-0.9	0.95	0.9-1.2	1.3	1.2-2.0	1.8	1.5-2.3
TOX	µg/L	62.5	50-82	72	58-95	91	82-105	125	120-160
THM	µg/L	33.5	30.2-38.8	38.9	35.5-40.1	44.0	39.4-50.2	56.4	53.1-58.5
HAA(5)	µg/L	6.5	4.1-17.3	8.1	6-13.4	10.4	9.4-17	14.5	13.7-29.1
HAA(9)	µg/L	14.8	12.2-31.2	17.8	14.6-28.6	21.1	19.5-31.5	27.6	25.5-49.4
UV_{254}	cm^{-1}	0.015	0.011-0.021	0.022	0.015-0.025	0.031	0.026-0.034	0.040	0.034-0.051

Refer to Table 12 for the minimum reporting levels for various water quality parameters

Table 21. Effect of feed water recovery 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 $CaCO_3$	118	104-142	125	106-156	149	116-164	172	118-208
Total hardness	mg/L as $CaCO_3$	134	108-164	140	114-202	154	128-204	192	154-256
Alkalinity	mg/L as $CaCO_3$	184	112-234	155	114-266	172	124-278	267	136-348
TDS	mg/L	168	139-201	178	150-211	187	162-247	213	187-238
Bromide	mg/L	56	49-67	60	51-75	62	52-77	71	64-85
SDS Cl_2 demand	mg/L	1.25	0.33-4.48	1.28	0.30-4.34	1.86	0.88-4.27	1.76	0.39-4.20
TOC	mg/L	0.31	0.18-0.50	0.38	0.31-0.60	0.38	0.26-0.8	0.65	0.31-0.80
TOX	μg/L	32	ND-32	33	ND-33	29	ND-35	37	ND-38
THM	μg/L	10.6	4.6-20	12.8	7-22	13.1	6.3-19.6	18.5	10.3-28.1
HAA(5)	μg/L	2.3	ND-4	1.85	1.1-4.4	2.0	ND-3.9	3.8	1.8-4.9
HAA(9)	μg/L	2.3	ND-7	2.4	1.1-7.7	3.0	1.0-6.7	7.6	5.8-9.0
UV_{254}	cm^{-1}	BMRL	BMRL	BMRL	BMRL	BMRL	BMRL	0.009	BMRL-0.013

Refer to Table 12 for the minimum reporting levels for various water quality parameters

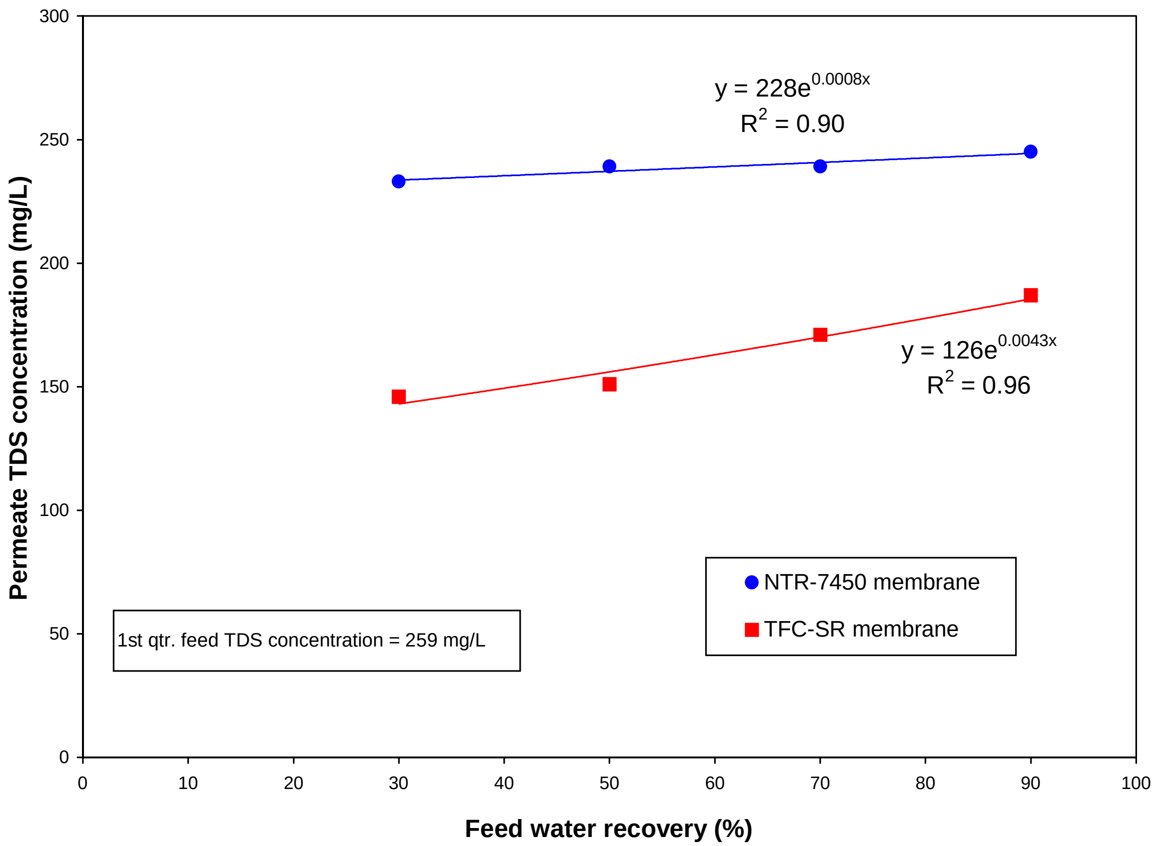


Figure 11. Effect of feed water recovery on permeate TDS concentration during I quarter of testing.

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 = 135 μg/L, average feed water SDSHAA9 concentration = 74 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. During the first quarter of testing with the NTR7450 membrane, the unit was shut off over a weekend during the 70% recovery experiment because no operators were available to monitor the unit. The raw feed pump malfunctioned during the third quarter of testing with the NTR7450 membrane, causing a delay of approximately four hours. The unit was restarted without difficulty during both incidents. Waste flow rates occasionally dropped by approximately 2 - 8% when the RBSMT apparatus was left unattended during overnight operation, especially during the experiment at 90% feed water recovery.

Section 5
QA/QC Summary

Laboratory analyses. As described in Table 12, samples were shipped to Montgomery Watson Laboratories, CA which is an ICR certified laboratory. The tables in this section (see next few pages) summarize 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 City of Hollywood, 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, the City of Hollywood has 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 B. All comments have been addressed and incorporated into the Data Collection Spreadsheets. Our detailed responses are as described below:

<u>Global Comments Applicable to Both Membrane Worksheets:</u>

1. Missing information in Field 1 has been provided.
2. Cost of an 8x40 TFC-SR membrane element is not available from manufacturer.
3. No water quality parameters (including potential foulants) were measured prior to pretreatment because they were not required under the ICR.
4. Cartridge filtration was the only membrane pretreatment employed.
5. "-" has been deleted from cell AP5 to facilitate the calculation of MTC_w.
6. All missing dates have been entered.
7. Cost data have been provided.

<u>TFC-SR Membrane 1st Quarter:</u>

1. "NA" has been entered for the 2nd THM4 sum.
2. "NA" has been entered for the 2nd HAA5 and HAA6 sums.
3. All water quality parameters measured at 90% recovery have been checked. Only TDS values changed because all others were found to be entered correctly.
4. Concentrate alkalinity value checked and found to be correct for 90% recovery. No changes made.

TFC-SR Membrane 2nd Quarter:

1. TDS values checked and found to be correct. No changes were made.
2. All water quality parameters measured at 70% and 90% recoveries have been checked and found to be entered correctly. No changes made.
3. Permeate alkalinity concentration at 30% recovery checked and found to be entered correctly. No changes made.

TFC-SR Membrane 3rd Quarter:

1. Formulas for SUVA have been entered.
2. TDS and hardness values were verified and found to be correct. No changes made.

TFC-SR Membrane 4th Quarter:

1. Alkalinity concentrations were verified and found to be correct. No changes made.

NTR-7450 Membrane 1st Quarter:

1. The MTC_w values were verified and found to be correct. No changes made.
2. All water quality parameters measured at 30, 50, 70 and 90% recoveries have been checked and found to be entered correctly. No changes made.

NTR-7450 Membrane 2nd Quarter:

1. "ND" entries replaced with "BMRL."
2. Alkalinity and hardness concentrations in the 2nd feed sample checked and found to be entered correctly. No changes made.
3. All water quality parameters for the 90% recovery run were verified and found to be correct. No changes made.

NTR-7450 Membrane 3rd Quarter:

1. Entry in cell EH5 changed to 30%.
2. SUVA formula entered in cell Z19.
3. All water quality parameters for the 90% recovery run were verified and found to be correct. No changes made.
4. 4th run recovery changed to 30%.

NTR-7450 Membrane 4th Quarter:

1. Ammonia concentrations verified and found to be correct.
2. Ammonia, calcium hardness, and UV values checked and found to be correct. No changes made.

CALIBRATION VERIFICATION AND QUALITY CONTROL PROCEDURES - METHOD SPECIFIC

Performance Criteria	Method → Analytes	EPA300.0 A, B *Br*	SM 6251B Haloacetic Acids *(HAA)*	*UV 254* SM 5910 B *UV 254*
↓	**Target Analytes**	Bromide (Br^-)	Monochloroacetic (MCAA) Dichloroacetic acid (DCAA) Dibromoacetic acid(TCAA) Trichloroacetic acid (TCAA) Monobromoacetic acid (MBAA) Bromochloroacetic acid (BCAA)	**UV Absorbance at 254 nm**
1.0 IDC				
1.1 IDLSB	**Method Blank**	< 1/2 MRL	< 1/2 MRL	< 1/2 MRL
1.2 IDA	**QC check sample (external source)**	+/- 20% of true value	+/- 20% of true value	+/- 20% of true value
1.3 IDP	**No. of replicates**	5	5	5
	Spike conc.	Br^- 0 .10 mg/L	20	6.5 mg/L ± 0.5 mg/L DOC (Dissolved Organic Carbon)
	% RSD	< 20	< 20	< 20
	% Recovery	80-120	80-120	80-120
	No. of replicates	7	7	7
	Spike conc.	1/2 MRL	1/2 MRL	0.5 mg/L DOC (Dissolved Organic Carbon) = 0.009 cm^{-1}
	% Recovery	50-150	50-150	50-150
2.0 MRL		Br: 0.020 mg/L	MCAA: 2.0 ug/L Others:1.0 ug/L	0.009 cm^{-1}
3.0 Calibration Verification/ Frequency		Lowest level std. analyzed at the beginning of each 24 hour- before first sample run Mid level and high level analyzed alternately after 10th sample and after the last sample.	Lowest level std. analyzed at the beginning of each 24 hour- before first sample run Mid level and high level analyzed alternately after 10th sample and after the last sample.	Lowest level std. analyzed at the beginning of each 24 hour- before first sample run Mid level and high level analyzed alternately after every 10th sample and after the last sample.
Calibration Verification Concentrations and Acceptance Criteria		***Br-*** ***(mg/L) (% rec.)***	***MCAA*** ***(ug/L) (% rec.)***	***UV254*** ***(cm^{-1}) (% rec.) (%RPD)***
	Low	0.02 50-150	2.0 50-150	0.009 75-125 </= 20
	MIdlevel	0.10 90-110	20 80-120	0.088 85-115 </= 10
	High	0.30 90-110	32 80-120	0.866 85-115 </= 10
			All others ***(ug/L) (% rec.)***	
	Low		1 50-150	
	MIdlevel		20 80-120	
	High		32 80-120	
4.0 Reagent (Method) Blank				
Frequency		one per analysis batch	one per analysis batch (one per extraction batch)	Initial zero; Check after each 10 samples
QC Criteria		< 1/2 of MRL	< 1/2 of MRL	< 1/2 of MRL (<0.0045 cm^{-1})

CALIBRATION VERIFICATION AND QUALITY CONTROL PROCEDURES - METHOD SPECIFIC

Performance Criteria	Method → Analytes	**EPA300.0 A, B** ***Br***	**SM 6251B** **Haloacetic Acids** ***(HAA)***	***UV 254*** **SM 5910 B** ***UV 254***
5.0 Shipping Blank	**Travel Blank/ Field Reagent Blank**	NA	NA	NA
QC Criteria		NA	NA	NA
6.0 LFM	**Fortified Sample**			
Frequency		5 % per analysis batch	one sample per extraction batch	NA
Matrix spike Level		same concentration as cal verification. If no historical data for sample level, rotate low, mid, high as spike conc.	same concentration as cal verification. If no historical data for sample level, rotate low, mid, high as spike conc.	NA
QC criteria		NA	NA	NA
7.0 Field/Lab Duplicate				Lab duplicate
Frequency		5% of the samples per analysis batch	one lab duplicate per extraction batch	all samples analyzed in duplicate
% RPD				</= 20 % (UV $_{254}$ </=0.045)
QC criteria		NA	NA	</= 10 % (UV $_{254}$ >0.045)
8.0 Internal Std.		NA	1,2-dibromopropane or 1,2,3-trichloropropane in each extract	NA
QC criteria		NA	+/- 30% of calibration curve AVG IS response 70-130 %	NA
9.0 Surrogate Standards		NA	2,3-dibromopropionic acid	NA
9.0 Surrogate Standards			or 2,3,5,6-tetrafluorobenzoic acid in each sample	
QC Criteria		NA	70-130 %	NA
10.0 Method Calibration Procedures	**Initial Calibration Curve**	Bromide Concentration (mg/L)	MCAA Concentration (ug/L)	NA
	Standard 1	0	2	
	Standard 2	0.02	5	
	Standard 3	0.05	10	
	Standard 4	0.1	20	
	Standard 5	0.3	40	
	Standard 6	0.5	-	
			All others Concentration (ug/L)	
	Standard 1		1	
	Standard 2		2	
	Standard 3		5	
	Standard 4		10	
	Standard 5		20	
	Standard 6		40	

CALIBRATION VERIFICATION AND QUALITY CONTROL PROCEDURES - METHOD SPECIFIC

	Performance Criteria	Method	THMs EPA 551.1	TOC SM 5310 C	TOX SM 5320B
		Analytes **Target Analytes**	***THM*** **Trihalomethanes (THMs)** Chloroform (CHCl3) Bromodichloromethane (BDCM) Dibromochloromethane(DBCM) Bromoform (CHBR3)	***TOC*** **Total Organic Carbon**	***TOX*** **Total Organic Halide** **(Dissolved Organic Halogen)** **(DOX)**
1.0	**IDC**				
1.1	**IDLSB**	**Method Blank**	< 1/2 MRL	< 1/2 MRL	< 1/2 MRL
1.2 **1.3**	**IDA** **IDP**	**QC check sample** **No. of replicates** **Spike conc.** **% RSD** **% Recovery**	+/- 20% of true value 5 THM 20 ug/L < 20 80-120	+/- 20% of true value 5 TOC 4 mg/L < 20 80-120	+/- 20% of true value 5 TOX 250 ug/L < 20 80-120
1.4	**MDL**	**No. of replicates** **Spike conc.** **% Recovery**	7 1/2 MRL 50-150	7 0.5 50-150	7 1/2 MRL 50-150
2.0	**MRL**		THM 1.0 ug/L Others: 0.5 ug/L	0.70 mg/L 0.50 mg/L (during treatment studies)	50 ug Cl^-/L 25 ug Cl^-/L (during treatment studies)
3.0	**Calibration Verification** **Conc. and QC criteria (%rec)**	**Verification Frequency** **Low** **Mid-level** **High**	Lowest level std. analyzed at the beginning of each 24 hr before the first sample Mid level and high level analyzed alternately after every 10th sample and last sample *THM* ***(ug/L) (% rec)*** 1.0 50-150 20 80-120 40 80-120	Lowest level std. analyzed at the beginning of each 24 hr before the first sample Mid level and high level analyzed alternately after every 10th sample and last sample *TOC* ***(mg/L) (% rec)*** 0.7 (0.5) 50-150 4 90-110 9 90-110	3 microcoulometer titration cell checks with NaCl std at start of 8-10 hr. work shift. Lowest level std. analyzed before the first sample. Mid level and high level analyzed alternately after every 7th sample and last sample ***TOX*** (ug Cl-/L) (% rec) 50 (25) 75-125 200 85-115 500 85-115
4.0	**Reagent (Method) Blank** **QC criteria**	***Frequency***	One per analysis batch (one per extraction batch) < 1/2 MRL	One per analysis batch < 1/2 MRL,< 0.35, or< 0.25	2 nitrate-washed activated carbon at the start of ea analysis batch, then 1 after every 7 samples (run in duplicate)- minimum of 3 per day; Analyze 1 system blank per analysis batch. <0.80 ug/Cl-/40 mg of activated carbon; < 1/2 of MRL, <25 or < 12.5
5.0	**Shipping Blank Criteria**	**Travel Blank**	NA	NA	NA
6.0	**LFM Frequency**	***Fortified Sample***	one sample in each extraction batch	at least 5% of ICR samples in an analysis batch (fortified sample analyzed in duplicate)	at least 5% of all ICR samples analyzed each quarter (fortified sample analyzed in duplicate

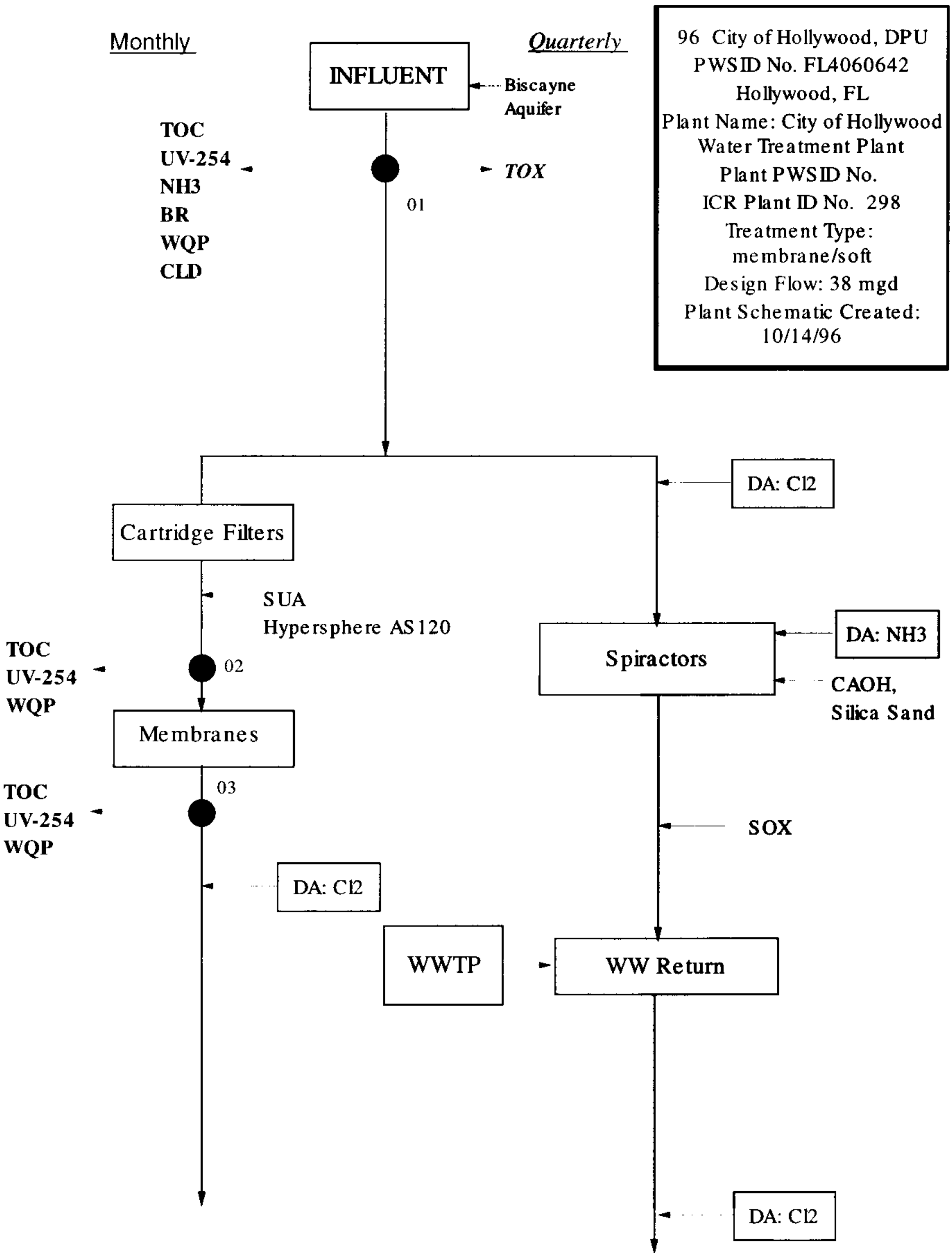
CALIBRATION VERIFICATION AND QUALITY CONTROL PROCEDURES - METHOD SPECIFIC

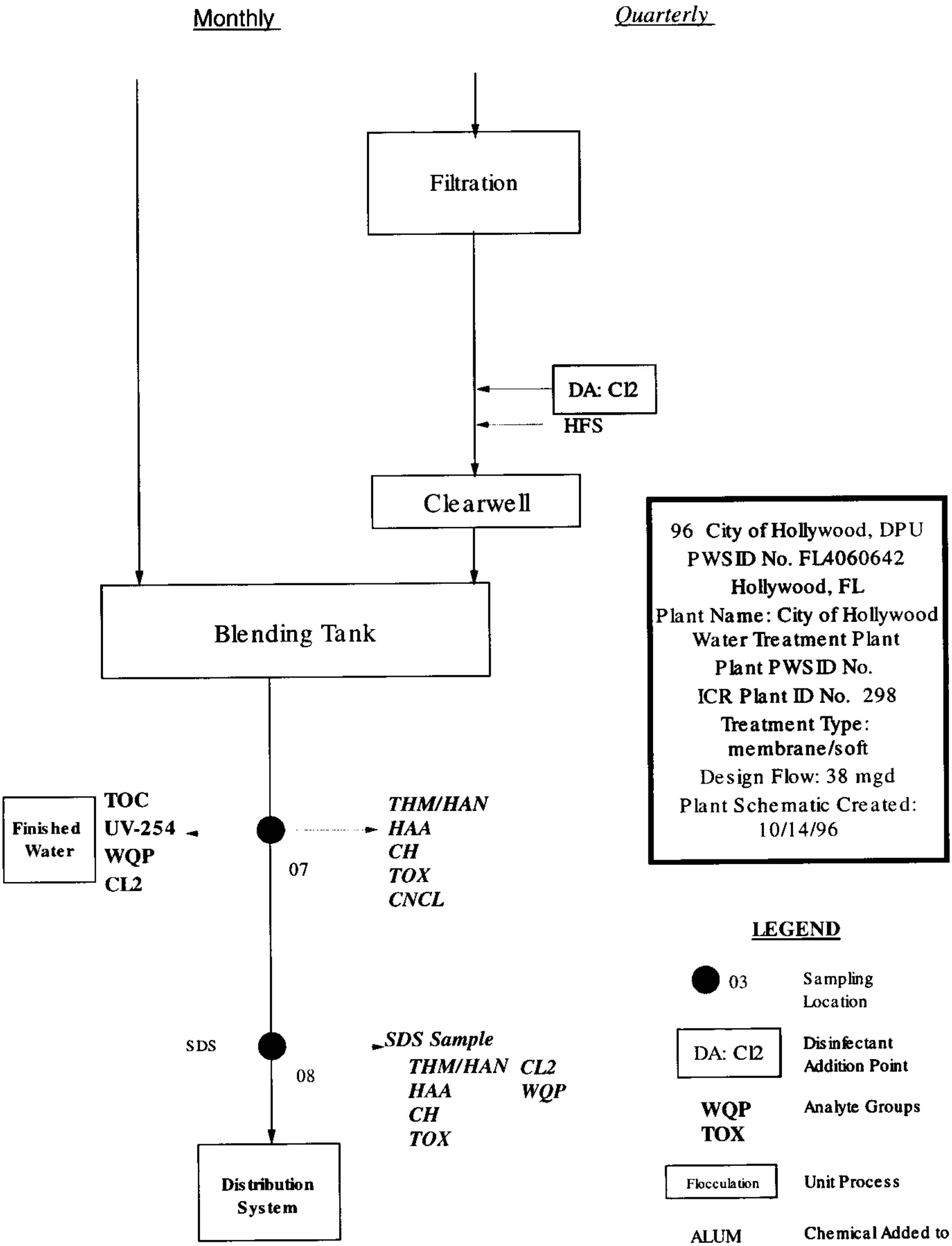
	Performance Criteria	Method	THMs EPA 551.1	TOC SM 5310 C	TOX SM 5320B
	Matrix spike level		same concentration as cal verification. If no historical data for sample level, rotate low, mid, high as spike conc.	same concentration as cal verification. If no historical data for sample level, rotate low, mid, high as spike conc.	same concentration as cal verification. If no historical data for sample level, rotate low, mid, high as spike conc.
	QC criteria	**% Recovery**	NA	NA	NA
7.0	**Lab (Field) Duplicate**		field duplicate	lab duplicate	lab duplicate
	QC Criteria	**% RPD**	NA	</= 10 % (TOC conc > 2.0 mg/L) </= 20 % (TOC conc </= 2.0 mg/L)	NA
8.0	**Internal Std.**		BFB if pentane solvent is used; Optional if MTBE is the extracting solvent	NA	NA
	QC Criteria	**IS Recoveries**	+/- 30% of calibration curve AVG IS response 70-130 % Rec.	NA	NA
9.0	**Surrogate QC Standards**		decafluorobiphenyl in ea sample	NA	NA
		Surrogate Recoveries	70-130 % Rec.	NA	NA
10.0	**Method Calibration Procedures Trihalomethane**	**Initial Calibration Curve**	THMs: CHCL3, BDCM Concentration (ug/L)	Conc. (mg/L)	
		Standard 1	0.5	0.5	
		Standard 2	1	1.0	
		Standard 3	2	5	
		Standard 4	5	10	
		Standard 5	10	20	
		Standard 6	20		
		Standard 7	30		
		Standard 8	40		
		Standard 9	50		
			THMs: DBCM, CHBR3 Concentration (ug/L)		
		Standard 1	0.25		
		Standard 2	0.5		
		Standard 3	1		
		Standard 4	2.5		
		Standard 5	5		
		Standard 6	10		
		Standard 7	15		
		Standard 8	20		
		Standard 9	25		

Section 6
Acknowledgments

The laboratory testing and analysis component of this ICR treatment study would not have been completed without the assistance of Jennifer Abrajano, Dan Bush, Andy Eaton, Jim Hein, and Jason Radgowski. Dr. Dan Askenaizer and David Wilkes provided valuable comments during their review of this summary report. Becky Fierle Hachenburg served as the project manager. Priti Shah, Wayne Welch, and Joanne Misiag assisted in data gathering and administrative functions.

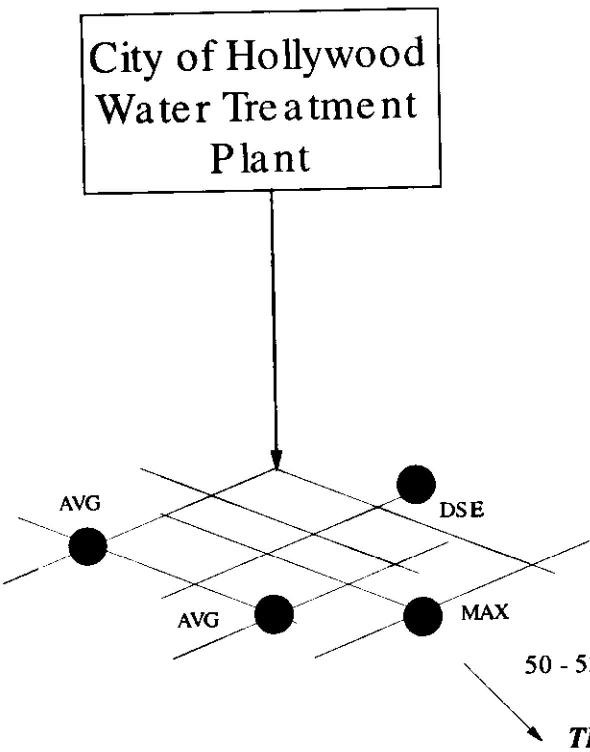
Robert Boyce and Joseph Entwistle from the City of Hollywood Water Treatment Plant assisted during raw water collection and shipment, as well as providing data necessary to complete the ICR Treatment Study Data Collection Spreadsheets and the final report.


Monthly
Quarterly
96 City of Hollywood, DPU
PWSID No. FL4060642
Hollywood, FL
Plant Name: City of Hollywood Water Treatment Plant
Plant PWSID No.
ICR Plant ID No. 298
Treatment Type: membrane/soft
Design Flow: 38 mgd
Plant Schematic Created: 10/14/96
INFLUENT
Biscayne Aquifer
TOC
UV-254
NH3
BR
WQP
CLD
TOX
01
DA: Cl2
Cartridge Filters
SUA
Hypersphere AS120
TOC
UV-254
WQP
02
Membranes
03
TOC
UV-254
WQP
DA: Cl2
Spiractors
DA: NH3
CAOH,
Silica Sand
SOX
WWTP
WW Return
DA: Cl2


Monthly
Quarterly
Filtration
DA: Cl2
HFS
Clearwell
Blending Tank
96 City of Hollywood, DPU
PWSID No. FL4060642
Hollywood, FL
Plant Name: City of Hollywood Water Treatment Plant
Plant PWSID No.
ICR Plant ID No. 298
Treatment Type: membrane/soft
Design Flow: 38 mgd
Plant Schematic Created: 10/14/96
Finished Water
TOC
UV-254
WQP
CL2
07
THM/HAN
HAA
CH
TOX
CNCL
SDS
08
SDS Sample
THM/HAN
HAA
CH
TOX
CL2
WQP
Distribution System
LEGEND
03
Sampling Location
DA: Cl2
Disinfectant Addition Point
WQP
TOX
Analyte Groups
Flocculation
Unit Process
ALUM
Chemical Added to Unit Process

96 City of Hollywood, DPU
PWSID No. FL4060642
Hollywood, FL
System Schematic Created:
07/21/96

Quarterly



THM/HAN	***CL2***
HAA	***WQP***
CH	***CNCL(MAX)***
TOX	

LEGEND

● 50 - 53	Sampling Locations
DSE	Distribution System Equivalent--Corresponds to SDS Residence Time
AVG	Average Residence Time in the Distribution System
MAX	Maximum Residence Time in the Distribution System

A.2 -- Design Plant Parameters

Date: 6/18/99

PWS Name: City of Hollywood Water Treatment Plant
PWS ID: FL4060642
WIDB:
ICR Contact Person: Mr. Joseph Entwistle

Sampling Period: Design
Design Sampling Start Date: 7/18/97
Design Sampling End Date: 1/5/99

Treatment Plant Name: City of Hollywood Water Treatment Plant
ICR Treatment Plant ID: 298
Treatment Plant PWS ID:
Treatment Plant Category: SOFT

State Approved Plant Capacity (MGD): 37.5
Historical Min. Water Temperature (deg C): 26.0
Installed Sludge Handling Capacity (DPD): 0.00
Blending Indicator: N

Water Resource Name: Biscayne Aquifer
Water Resource Type: Ground water
Intake Name: Hollywood Wellfield
Wellhead Protection: Y

Hydrologic Unit Code:
Latitude (degrees, minutes, seconds): +26°0'39"
Longitude (degrees, minutes, seconds): -80°10'25"

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

Process Train Name: Membrane Softeners
Process Train Category: MEMBRANE

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
1	Membrane	Membrane		Membrane Type: UL Membrane Model Name: Hydranautics PVD1

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
				Number of Stages: 3 Surface Area (ft2): 160,000 Molecular Wt. Cutoff (daltons): 42 Design Flux (gpd/ft2): 14 Design Pressure (psi): 170 Percent Recovery: 90.0
2	Chlorine gas	Disinfectant Addition		Chemical Code: SOY Measurement Formula: CL2 Dose Rate (mg/L): 2.00

Process Train Name: Spiractors
Process Train Category: SOFT

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
1	Chlorine gas	Disinfectant Addition	3	Chemical Code: SOY Measurement Formula: CL2 Dose Rate (mg/L): 2.00
2	Anhydrous ammon	Disinfectant Addition		Chemical Code: NH3A Measurement Formula: NH3 Dose Rate (mg/L): 0.80
3	Spiractor Soft	Other Treatment Process	2	Surface Area (ft2): 2,100 Liquid Volume (gal): 1,200,000 Short Circuiting Factor: 0.0
4	Na3PO4	Other Treatment Process		Surface Area (ft2):

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
				Liquid Volume (gal): Short Circuiting Factor:
5	Reclaim	Washwater Return	4	Washwater Treated: N Coagulation/Sedimentation: N Filtration: N Disinfectant Addition: N Plain Sedimentation: Y Other Treatment: 24 hr average Water flow Returned (MGD): 0.1
6	Reclaim	Washwater Return Sample Point	5	
7	Chlorine gas	Disinfectant Addition		Chemical Code: SOY Measurement Formula: CL2 Dose Rate (mg/L): 2.00
8	Filtration	Filtration	6	Surface Area (ft2): 7,687 Liquid Volume (gal): 472,855 Total Media Depth (in): 36 Depth of GAC (in): Media Type: DUAL Type of Activated Carbon: Minimum Water Depth To Top of Media (ft): 9.0 Depth From Top of Media to Top of Backwash Trough (ft): 3.0

Seq. No.	Sample Location Name	Sample Location Type	Sample Loc. No.	
9	Membrane Soften	Additional Water Source	14	Water Source Type: TGW
10	H2SiF6	Other Treatment Process		Surface Area (ft2): Liquid Volume (gal): Short Circuiting Factor:
11	Clearwell	Clearwell		Surface Area (ft2): 2,400 Liquid Volume (gal): 1,000,000 Minimum Liquid Volume (gal): 350,000 Baffling Type: AV Short Circuiting Factor: 0.0 Covered Indicator Code: Y
	Finished Water	FIN	7	

<u>End of Report   A.2 -Design Plant Parameters</u>

A.3 -- Design Plant Chemical Parameters

Date: 6/18/99

PWS Name: City of Hollywood Water Treatment Plant
PWS ID: FL4060642
WIDB:
ICR Contact Person: Mr. Joseph Entwistle

Sampling Period: Design
Sampling Start Date: 7/18/97
Sampling End Date: 1/5/99

Sep. No.	Sample Location Name	Sample Location Type	Sample Location Number	Chemical Name	Measurement Formula	Dose (mg/L)
Treatment Plant Name: City of Hollywood Water Treatment Plant						
ICR Treatment Plant ID No: 298						
Treatment Plant Category: SOFT						
Process Train Name: Membrane Softeners						
Process Train Category: MEMBRANE						
1	Membrane	Membrane				
				Other chemical	AF-200	4.50
				Sulfuric acid	H2SO4	150.00
2	Chlorine gas	Disinfectant Addition				
				Sodium hypochlorite	CL2	2.00
Process Train Name: Spiractors						
Process Train Category: SOFT						
1	Chlorine gas	Disinfectant Addition	3			
				Sodium hypochlorite	CL2	2.00
2	Anhydrous ammon	Disinfectant Addition				
				Anhydrous ammonia	NH3	0.80

Sep. No.	Sample Location Name	Sample Location Type	Sample Location Number	Chemical Name	Measurement Formula	Dose (mg/L)
3	Spiractor Soft	Other Treatment Process	2			
				Calcium hydroxide	CaOH	214.00
4	Na3PO4	Other Treatment Process				
				Sodium hexametaphosphate	Na2PO4	1.25
5	Reclaim	Washwater Return	4			
6	Reclaim	Washwater Return Sample Point	5			
7	Chlorine gas	Disinfectant Addition				
				Sodium hypochlorite	CL2	2.00
8	Filtration	Filtration	6			
				Sodium hexametaphosphate	Na2PO4	1.25
9	Membrane Soften	Additional Water Source	14			
10	H2SiF6	Other Treatment Process				
				Hydrofluorosilic acid	H2SiF6	0.90
11	Clearwell	Clearwell				

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