ICR Treatment Study Summary Report

Evaluation of Membrane Technology Using the Pilot Scale Test for Compliance with the Information Collection Rule

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Conducted During the Period of:
April 24, 1998 through April 14, 1999

Prepared for:

City of North Miami Beach, #FL131618
Public Utilities Department
2080 NE 160th Street
North Miami Beach, FL 33162
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Norwood – W. A. Oeffler Water Treatment Plant
ICR #305

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Attachments: 3 Diskettes Containing the Data Collection Spreadsheets
1 Diskette Containing the Treatment Study Spreadsheet
1 Diskette Containing Electronic Copy of Treatment Study Summary Report

OR-H68-200-01 July 1999

HAZEN AND SAWYER Environmental Engineers & Scientists BOYLE

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1.0 Conclusions And Recommendations

1.1 Conclusions

The City of North Miami Beach owns and operates the Norwood – W. A. Oeffler Water Treatment Plant (Norwood WTP). The Norwood WTP utilizes three process softening units to provide cold lime softening for treatment of approximately 15 million gallons per day (MGD) average daily demand (ADD). The facility has a permitted capacity of 17.7 MGD. The process reduces the hardness of the raw water from 200 mg/L to 60-80 mg/L as calcium carbonate. The total demand needs for the City's service area are approximately 30 MGD ADD, therefore, the City purchases an additional 15 MGD ADD from the Miami-Dade Water and Sewer Department (MD-WASD) through interconnections at the Norwood WTP and throughout the distribution system.

Based on the relatively high quality water produced at the Norwood WTP, the City of North Miami Beach would like to pursue independence from MD-WASD. In order to do so, it is estimated that the City will need to expand their existing facilities to provide an additional 15 MGD of capacity. The expansion will include improvements to the existing process and/or the addition of a new membrane softening facility. Existing and proposed federal and state regulations are expected to impact existing process trains and the design of the expansion. The primary drinking water regulations that will impact future design include: the Total Coliform Rule (TCR), the Lead and Copper Rule (LCR), the Groundwater Rule (GWR), and the Disinfectant and Disinfection By-Products Rule (D-DBPR).

The results of the Information Collection Rule (ICR) Pilot Study coupled with the results from the City's Enhanced Lime Softening Pilot Study will provide the basis for planning the 15 MGD expansion at the Norwood WTP site. It appears that the solution to future water quantity and quality needs will include improvements to the existing 17.7 MGD of lime softening facilities, and the addition of approximately 15 MGD of membrane softening facilities. Based on this assumption, the ICR Pilot Study included several hours of data that can be utilized for design of a full-scale membrane softening facility.

This pilot study determined that treatment of the City of North Miami Beach's raw water supply with membrane softening is both technically and economically feasible. It was also determined that pretreatment would consist of acid addition alone, and that pre-filtration of the raw water prior to cartridge filtration may be necessary depending on the final results of the well rehabilitation program. Based on the need to minimize concentrate from the full scale facility, the City will be interested in maximizing recovery through multiple stages, or an integrated membrane system that incorporates post treatment of the nanofiltration concentrate with a reverse osmosis (RO) recovery unit. These concepts will be incorporated into preliminary and final design.

1.2 Recommendations

Based on preliminary analysis of the ICR pilot data and the enhanced lime softening data, it appears that the most feasible means of expansion of the Norwood WTP is to provide 15 MGD of membrane softening to blend with 15 MGD from existing lime softening facilities. Improvements to the existing lime softening facilities will be evaluated during preliminary design. In order to further assess the future operation of the proposed membrane softening facilities, it is recommended that the pilot testing program continue beyond the scope of the ICR pilot testing. In order to provide more design information on acceptable membrane elements for the City it is recommended that at a minimum one additional membrane element be tested for a minimum of thirty (30) days. It is also recommended that additional pilot testing be conducted to provide data on maximizing recovery and minimizing concentrate production.

Based on the challenge of providing a cost effective means of concentrate disposal, it will be beneficial to evaluate the quantity and quality of concentrate produced under various operational scenarios. Although the ICR study provided data regarding various system recoveries by utilizing two - and three – stage systems, it is recommended that a pilot study be conducted that investigates the benefits of providing a post-nanofiltration reverse osmosis (RO) recovery unit. The RO recovery unit would utilize RO elements to maximize system recovery.

Data from this pilot study will allow the evaluation of other concentrate disposal alternatives as the system recovery will be increased beyond 90-percent. As the volume of concentrate decreases, concentrate disposal alternatives such as transmission to the wastewater collection system become more economically feasible. The proposed design, construction and operation of the membrane softening facility will also be evaluated during preliminary design.

Based on the proposed schedule it is anticipated that the City of North Miami Beach will complete the expansion of its facilities by December 2003. In order to reach this goal there are several milestones that should be met by certain dates. Table 1.1 provides the proposed schedule of implementation for improvements at the Norwood WTP.

1.0 Conclusions And Recommendations

Table 1.1
Schedule for City of North Miami Beach
Water Treatment Plant Expansion

Date	Item
July 1999	Submit completed ICR Report
July 1999	Authorize additional Pilot Testing and Preliminary Design
October 1999	Complete additional Pilot Testing
November 1999	Complete Preliminary Design
December 1999	Finalize Contract for Raw Water with MD-WASD
December 1999	Authorize Final Design
November 2000	Complete Final Design
April 2001	Obtain South Florida Water Management District Permit
August 2001	Finalize Site Rezoning
September 2001	Obtain FDEP Facility Permit
October 2001	Project to Bid
January 2002	Funding Finalized
March 2002	Issue Notice to Proceed
December 2003	Water Treatment Plant in Operation

2.0 Background Information

2.1 General

The Information Collection Rule (ICR) for Public Water Systems (Subpart M of the National Primary Drinking Water Regulations, §141.141(e)) requires Public Water Systems (PWSs) that meet certain applicability criteria to conduct disinfection by-product (DBP) precursor removal studies, referred to as "treatment studies." These treatment studies are intended to provide cost and performance data on membrane processes for meeting the forthcoming DBP regulations. The general requirements of the ICR pilot plant are described in further detail in the USEPA document *ICR Manual for Bench- and Pilot-Scale Treatment Studies* (EPA 814-B-96-003).

The City of North Miami Beach (City) is located in the Northeastern developed portion of Dade County. The City owns and operates the Norwood WTP. The City uses groundwater as a supply source, and serves over 100,000 persons. Based on the initial water quality data collected under the ICR rule, the City was required to perform an ICR treatment study. The ICR requires that the pilot testing be performed using a spiral-wound membrane with a molecular weight cutoff of less than 1,000 Daltons. In addition, the pilot system must operate at a minimum water recovery of 75 percent for at least 6,600 hours during a one-year period. To meet these requirements, a state-of-the-art nanofiltration pilot plant was installed at the Norwood WTP that simulates a full-scale membrane softening treatment plant design.

The City conducted the ICR pilot scale study from April 24, 1998 to April 14, 1999 to comply with the requirements of the ICR, and to determine if membrane treatment is cost effective and can meet the requirements of the DBP regulations with the City's existing water supply. The City is also concurrently investigating and evaluating alternatives to upgrade and expand the existing Norwood WTP. Therefore, operation of the full-scale pilot plant will not only satisfy the requirements of the ICR, but it will provide greater confidence with respect to achieving water quality objectives. In addition, information collected during the treatment study would also be used to develop preliminary design criteria to be used in the engineering planning and design activities of a full-scale membrane softening water treatment plant.

2.2 Norwood Water Treatment Plant

2.2.1 Process Description

The Norwood WTP has a permitted capacity of 17.67 MGD. The City provides potable water to approximately 160,000 customers, and hence is classified as a large community public water system (PWS). These customers include bulk sales to the City of Hallandale and MD-WASD. Additional water to meet system demands is purchased from MD-WASD through system interconnects in the distribution system. There is also a connection from the MD-WASD system directly into the finished water storage tanks if needed.

Average daily purchases from the MD-WASD are approximately 15 mgd. Treatment at the Norwood WTP consists of a cold lime softening process to reduce the raw water hardness from approximately 200 mg/L to 60-80 mg/L as calcium carbonate. There are three process basins (Hydro-Treators) used in the cold lime softening process at the Norwood WTP.

2.2.2 Treatment Plant Design

The Norwood WTP is permitted to withdraw 17.67 MGD of raw water from the Biscayne Aquifer by the South Florida Water Management District (SFWMD). Raw water for the plant is obtained from twelve production wells. Seven of these are located on the plant site and five are located at other sites. Typically, one or more wells are out of service due to maintenance reasons. The other wells are used alternatively, with at least six wells normally on-line. Raw water flow pumped to the plant is measured by a raw water flow meter and enters a receiving basin. This basin serves as a distribution box that routes flow from this location to the Hydro-Treators. The raw water is dosed with anhydrous ammonia and approximately one-half of the total dose of an anionic polymer just prior to the raw water receiving basin. Ammonia is added at a dose of approximately 2.1 mg/L, for the first step in forming chloramines for disinfection. An anionic polymer (Calgon 692) is added at a dose of 0.05 mg/L to help reduce turbidity in the effluent of the Hydro-Treators.

Water from the receiving basin flows to the three Hydro-Treator (lime softening clarifiers), where lime, recycle solids, and the remainder of the polymer dose is added. Water flow, lime dosage and solids recycle flow to each Hydro-Treator is manually balanced by plant staff, and flows and chemical dosages to each unit are estimated. A flow meter is provided on the influent piping to each unit to aid in flow controlling. Hydro-Treator Unit No. 1 operates at an average flow rate of 1 MGD, No. 2 at 5 MGD and No.3 at 10 MGD for a total of 16 MGD. The facility has a permitted capacity of 17.67 MGD.

In 1988, modifications to the treatment process were performed which significantly increased the operating capacity to match the originally designed capacities using a modification in the treatment process known as “split lime” treatment. This method involves separating the raw water influent immediately before the lime softeners, which are the limiting factor with respect to flow. A percentage of the total influent bypasses the softening unit while the majority of the flow continues through the softener. The softener effluent is then combined with the bypass water immediately upon discharging from the lime softening unit. Because normal plant operations soften the water well below the level that is required, good finished water quality is still maintained. This split train approach is used for Hydro-Treator No. 3 where some additional flow is diverted around the Hydro-Treator and blended in the effluent pipe to achieve the desired level of hardness.

After softening, the treated water flows to the recarbonation basins where carbon dioxide is added for pH adjustment, orthophosphate is added for corrosion control, and chlorine is added to form chloramines (with the previously added ammonia) for disinfection. Because Hydro-Treator No. 1 is at a lower elevation than the other two units, its effluent is separated into a different flow train. This flow train

consists of recarbonation basin No. 1 and Filters 1 and 2. Flow from the other two Hydro-Treators comprise a second flow train which conveys most of the plant flow, including the split flow around Hydro-Treator No. 3. This flow enters recarbonation basins 2 and 3, which are interconnected.

Effluent from the recarbonation basins 2 and 3 flows to filters 3 through 11, which are also interconnected. Filtered water from these filters enters the west clearwell, and filtered water from Filters 1 and 2 enters the east clearwell. Separate pumps are provided in each clearwell to convey flow to one of the three finished water storage tanks where the two flow trains are again combined. Water is then pumped into the distribution system using the high service pumps. A finished water flow meter is also provided to monitor water quantity leaving the plant. Figure 2.1 presents a treatment process schematic of the Norwood WTP. Design data for Norwood WTP is provided in Table 2.1.

Currently, the carbon dioxide units are out of service and carbon dioxide is not added. To reduce pH and stabilize the treated water, unsoftened water is by-passed to the effluent of the Hydro-Treators, prior to the filters. Orthophosphate is typically dosed at 0.4 mg/L (as product), and chlorine is added at a dose of approximately 7 mg/L.

2.0 Background Information

Figure 2.1: Norwood WTP Process Schematic

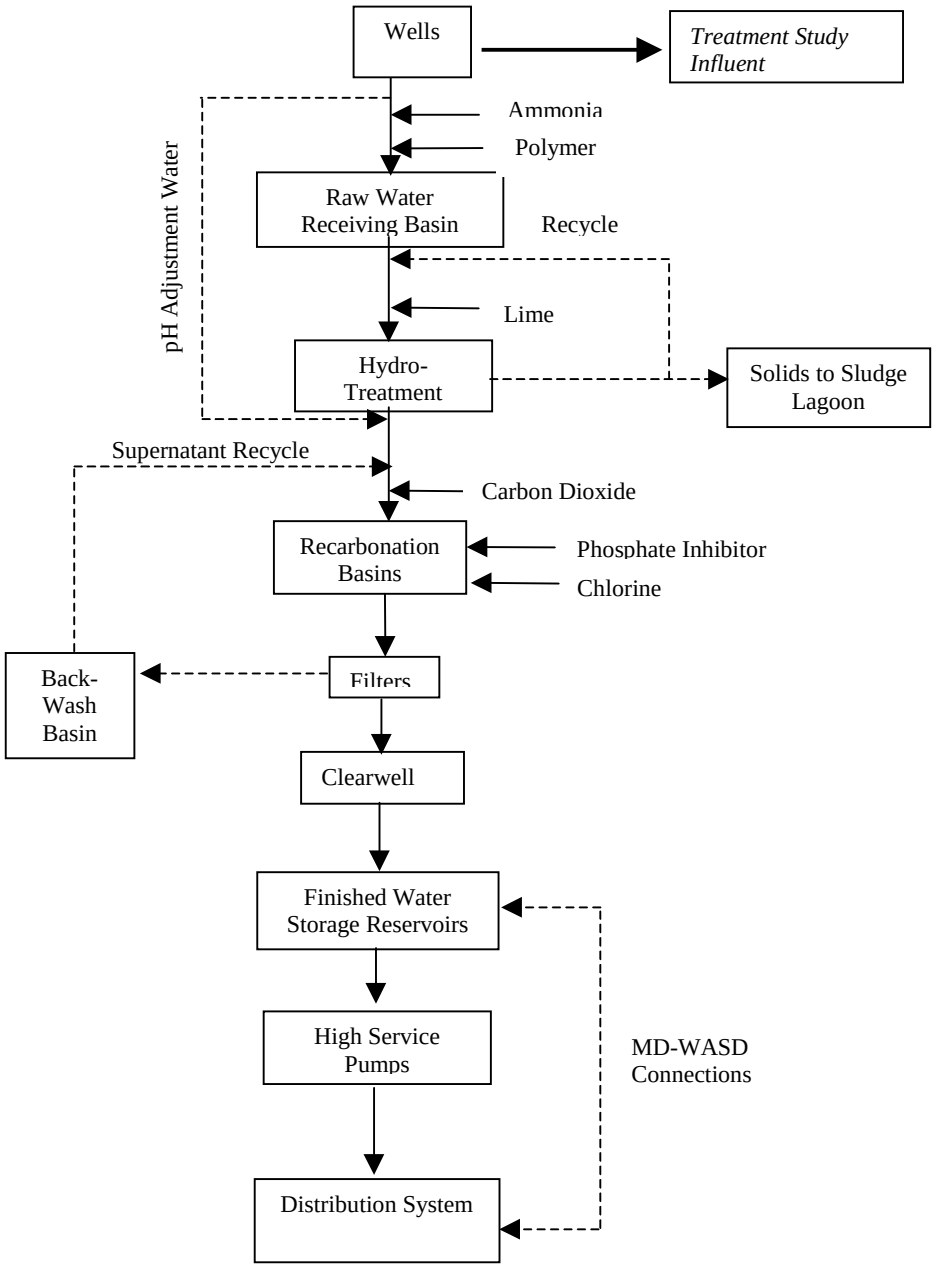


Table 2.1
Norwood WTP Design and Performance Data for Existing System

Unit Process	Process Description	Value
Raw Water Receiving Basin	Liquid Volume: Baffling Type: Coagulant Aid: Coagulant Aid Dose: Disinfection Chemical: Disinfection Dose:	35,900 gal Inlet/Outlet only Anionic Polymer 0.05 mg/L Ammonia 2.1 mg/L
HydroTreaters	Type of Clarifier: Baffling Type: Capacity: Diameter: Weir Loading Rate: Upflow Velocity: Detention Time: Type of Clarifier: Baffling Type: Capacity: Diameter: Weir Loading Rate: Upflow Velocity: Detention Time: Type of Clarifier: Baffling Type: Capacity: Diameter: Weir Loading Rate: Upflow Velocity: Detention Time:	Hydro-Treator #1 In/Out/Intermediate 1 MGD 30 ft 10,600 gpd/lf 0.98 gpm/sf 1.9 hr Hydro-Treator #2 Average – In/Out/Intermediate 5 MGD 45 ft 39,700 gpd/lf 2.18 gpm/sf 0.91 hr Hydro-Treator #3 In/Out/Intermediate 10 MGD 60 ft 52,900 gpd/lf 2.46 gpm/sf 0.81 hr
Lime Addition	Chemical Type: Chemical Dose:	CaO (Lime) 156 mg/L

Table 2.1
Norwood WTP Design and Performance Data for Existing System (Continued)

Unit Process	Process Description	Value
Recarbonation Basins	West Basin Surface Area: Liquid Volume: East Basin Surface Area: Liquid Volume: Chemical Type: Dose Rate:	 273 sf 30,630 gal 70 sf 7,854 gal Carbon Dioxide 11 mg/L
Chemical Addition	Disinfection Chemical Type: Dose Rate: Corrosion Inhibitor Type: Inhibitor Dose:	Chlorine Gas 7 mg/L Orthophosphate 0.4 mg/L
Filtration	Number: Surface Area(ea): Liquid Volume(ea): Total Media Depth(ea): Media Type: Min. Water Depth to Top of Media(typ): Top of Media to Top of Backwash Trough(typ):	11 filters 357 sf 16,022gal 60 in Dual 3.0 ft 3.0 ft
Clearwell	East: Liquid Volume: West: Liquid Volume:	 314,160 gal 250,250 gal
Finished Water Storage Reservoirs	Number: Total Volume:	3 4 MG (two 1 MG and one 2 MG)

2.2.3 Treatment Challenges Facing Plant

The Norwood WTP is presently in compliance with all current and future regulations. However, as mentioned previously, the City of North Miami Beach distribution system is supplied by finished water from both the Norwood WTP and the MD-WASD. The water quality of the finished water produced at the Norwood WTP differs greatly from the finished water produced by the MD-WASD. The relatively high quality of the source water and the finished water at the Norwood WTP suggests that the City of North Miami Beach may want to operate independently of the MD-WASD system in the future. In order to accomplish this the City is evaluating enhanced lime softening and membrane softening expansion alternatives for producing a sufficient quantity of finished water to satisfy the total demand of the North Miami Beach service area. Average daily purchases from MD-WASD are approximately 15 MGD. Table 2.2 compares distribution system water quality for areas served by the Norwood WTP and areas served by the MD-WASD.

Table 2.2
Distribution System Water Quality

Treatment Plant/ Description	Location	TOC (mg/L)	THM (• g/L)	HAA (• g/L)
MD-WASD	MD-WASD Service Area	---	89	26
Norwood WTP	1441 NW 179 Street	5.8	16.6	17.7
Norwood WTP	2551 NE 192 Street	6.3	10	12
Norwood WTP	SDS	6	19.0	20.6
Stage 1 MCL	---	---	80	60
Stage 2 MCL (proposed)	---	6.3	40	30

2.3 Source and Finished Water Quality

Twelve production wells are permitted to withdraw raw water from the Biscayne Aquifer. As discussed previously, the source water for the Norwood WTP is of good quality. Table 2.3 presents a tabular summary of the minimum, maximum, and average source water quality based on twenty three samples, and Table 2.4 presents a tabular summary of the minimum, maximum, and average finished water quality based on 12 samples. Characterization of the raw and finished water quality for the current treatment at the WTP is needed to assess the performance of the membrane pilot system for the removal of raw water contaminants. Raw and finished water characterization will demonstrate seasonal effects on the raw water contaminant concentrations, and develop maximum and minimum concentrations for the contaminant. Finished water quality goals are based on existing and proposed state and federal regulations.

Table 2.3
Norwood WTP Raw Water Quality(1)

Water Quality Parameter	Average Concentration	Standard Deviation	Minimum Value	Maximum Value
Temperature (^oC)	25.7	0.8	25	27
pH	7.1	0.2	6.8	7.4
Turbidity (ntu)	0.62	0.35	0.32	1.6
Alkalinity (mg/L $CaCO_3$)	179	18	142	210
Total Hardness (mg/L $CaCO_3$)	213	9	200	246
Calcium Hardness (mg/L $CaCO_3$)	207	9	190	232
TOC (mg/L)	8	0.6	7	9.1
UV_{254} (cm^{-1})	0.344	0.025	0.246	0.366
Bromide (• g/L)	0.088	0.009	<0.020	0.1

Notes: (1) Summary Based on twenty three sampling events.

Table 2.4
Norwood WTP Finished Water Quality

Water Quality Parameter	Average Concentration	Standard Deviation	Minimum Value	Maximum Value
Temperature (^oC) (1)	25.5	0.66	24	26
pH (1)	8.86	0.26	8.2	9.23
Turbidity (ntu) (1)	0.62	0.31	0.35	1.5
TOC (mg/L) (1)	5.8	0.45	5	6.7
UV_{254} (cm^{-1}) (1)	0.202	0.01	0.16	0.202
DS-THM4 (• g/L) (2)	17.4	4.1	12.8	22.4
DS-HAA5 (• g/L) (2)	23	5.1	18	30
DS-HAA6 (• g/L) (2)	25.4	5.9	19.9	33.7

Notes: (1) Summary Based on twelve sampling events.
(2) Summary Based on four sampling events

3.0 Materials And Methods

3.1 General

The installation and testing of the pilot plant unit was designed to meet the requirements of the and provide preliminary design criteria for use by the City. The pilot nanofiltration system was designed as a staged array of elements similar to the design of a full-scale membrane water treatment plant. Staging was used to increase the system recovery by feeding concentrate from previous stages to downstream stages. The nominal permeate production rate was approximately 20,000 gallons per day (gpd).

3.2 Equipment and Materials

3.2.1 Pretreatment

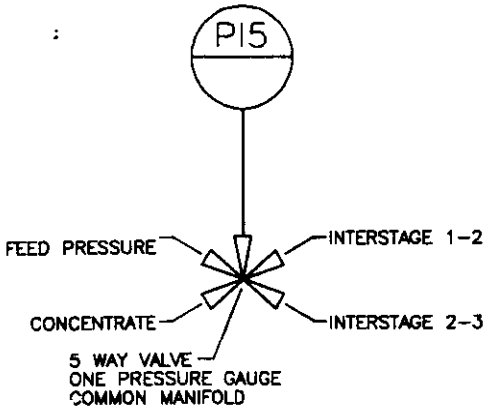
The purpose of pretreatment was to control membrane fouling (flux decline). Flux decline, indicated by a reduction in membrane process productivity can be a result of scaling, colloidal fouling, biological fouling, chemical fouling or a combination of phenomena. Each mechanism should be understood in order to develop strategies to control flux decline. Raw water quality was measured prior to system operation and then monitored twice during the 12-month testing period. This data assisted in determining limiting salts that may cause flux decline. Pretreatment consisted of the following:

- cartridge filtration for colloidal removal and membrane protection;
- sulfuric acid addition to control inorganic scaling; and
- scale inhibitor addition to control typical performance scaling.

Prefiltration was accomplished with cartridge filters, which removed all particles greater than 5 µm with a removal efficiency at a minimum of 90%. Feed water discharged from the cartridge filter and was injected with pretreatment chemicals, which included acid and/or scale inhibitor. Because of the location of chemical injection a static mixer was provided downstream of the injection points to provide proper mixing of the chemicals. Chemicals that were used in this pilot test are NSF approved. Chemical diaphragm-metering pumps were provided to inject the scale inhibitor and sulfuric acid. A nominal range of 5 to 100 strokes per minute with stroke length adjustable from 0 to 100% was available with the pump. The speed and stroke were maintained at a constant rate relative to the feedwater rate on each chemical pump. The day tank level of the scale inhibitor was recorded daily. Sulfuric acid supply was also monitored daily by monitoring acidified feed water pH.

The scale inhibitor solution was manually mixed to 0.5 gallons of scale inhibitor with 20 gallons of RO permeate water to obtain the proper concentration. The diluted scale inhibitor solution was then injected into the raw water for pretreatment prior to nanofiltration. Scale inhibitor addition was terminated shortly after the installation of the TriSep elements when fouling and decreased performance of the system occurred. Figure 3.1 illustrates a schematic of the pretreatment process. Table 3.1 outlines the design data for the pretreatment process.

5 WAY SELECTOR VALVE
PRESSURE RANGE (0–400 PSI)



P15 ENLARGEMENT OF
COMMON HP GAUGE

SCALE: NONE

PRESSURE SCHEDULE

PRESSURE GAUGE NO.	PRESSURE RANGE PSI
PI–1	TBD
PI–2	TBD
PI–3	TBD
PI–4	TBD
PI–5	TBD
PI–6	TBD
PI–7	TBD

TBD = TO BE DETERMINED

NOTES:

1. EACH PRESSURE VESS
2. PIPING MATERIALS: FR
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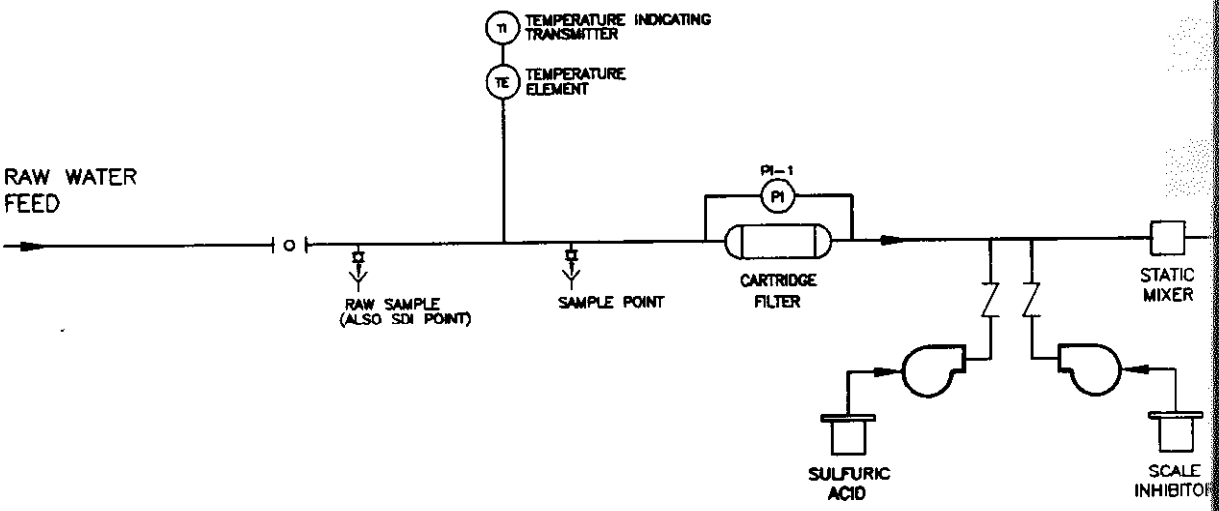
   BOOSTER PUMPS INCL
   SHALL BE 316 SS HI

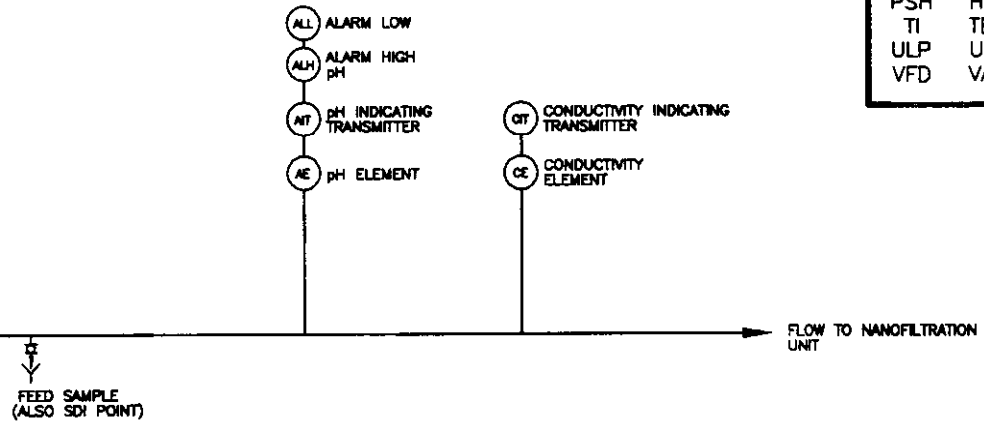


SHALL CONTAIN 3 – NANOFILTRATION MEMBRANE ELEMENTS.

RAW WATER SUPPLY TO SUCTION SIDE OF HIGH PRESSURE
BE SCHEDULE 80 PVC; HIGH PRESSURE PIPING DOWNSTREAM OF
ING CONCENTRATE AND RECYCLE STREAMS UP TO CONTROL VALVES
PRESSURE TUBING; PERMEATE PIPING SHALL BE SCHEDULE 80 PVC.

LEGEND	
	PRESSURE ACTUATED VALVE
	GLOBE VALVE
	BALL VALVE
	CHECK VALVE
	NEEDLE VALVE
	HIGH PRESSURE PUMP
	SAMPLE PORT
	PANEL MOUNTED INSTRUMENT
	LOCALLY MOUNTED INSTRUMENT
	BALL CHECK VALVE
	ROTAMETER
	3 WAY MULTI–PURPOSE VALVE
	5 WAY VALVE

ABBREVIATIONS	
AE pH	pH METER
FE	FLOW ELEMENT
FS	FLOW SWITCH
LS	LEVEL INDICATOR
PI	PRESSURE GAUGE
PSL	LOW PRESSURE SWITCH
PSH	HIGH PRESSURE SWITCH
TI	TEMPERATURE GAUGE
ULP	ULTRA LOW PRESSURE
VFD	VARIABLE FREQUENCY DRIVE



PILOT PLANT PROCESS FLOW DIAGRAM PRETREATMENT PROCESS

BOYLE

CITY OF NORTH MIAMI BEACH
MEMBRANE SOFTENING - WATER TREATMENT PILOT PLANT

BEC PROJECT NO. OR-H68-200-01

FIGURE 3-1

Table 3.1
ICR Pilot Plant Pretreatment Design Data

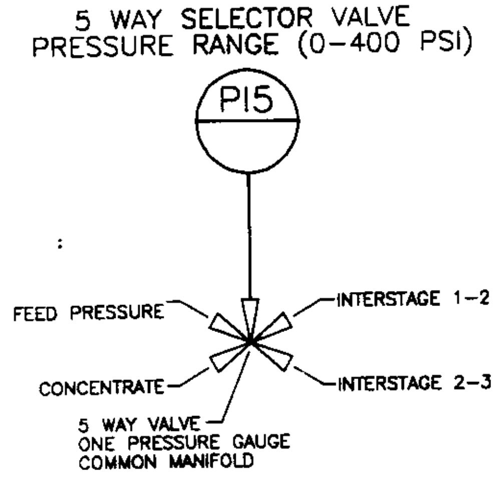
Unit Process	Design Data
Cartridge Filtration	a) Prefiltration was accomplished by one Eden Excel® cartridge filter housing containing six, 20-inches in length, string wound filter elements or equal. This provided a maximum flow rate of 60 gpm @ 5 gpm/10" length. b) Cartridge filter vessels were constructed of fiber reinforced plastic. Cover used 316 stainless steel bolts with 304 stainless steel hex nuts. The o-ring cover gaskets were Buna-N. c) Cartridge elements were polypropylene FDA grade media on 316 stainless steel or polypropylene core. These elements complied with FDA regulations and were suitable for potable water use. d) The cartridge filters were designed to remove all particles greater than the "filtering particles" 5 μm with a removal efficiency at a minimum of 90%. e) Cartridge filters were pressure tested in accordance with ASME requirements.
Sulfuric Acid Addition	a) All piping materials utilized for sulfuric acid addition were PVDF, polyurethane, Teflon, CPVC or equal and were capable of resisting chemicals to a pH of 2. b) Chemical diaphragm metering pump was constructed of PVDF head/fittings with Teflon seats and o-rings. Nominal range of 5 to 100 strokes per minute with stroke length adjustable from 0 to 100%. The pump was a LMI Series A diaphragm metering pump. c) Adjusted pH: 5.8 to 6.2 units.
Scale Inhibitor Addition	a) The scale inhibitor day tank was constructed of high density polyethylene (HDPE) or cross-linked high density polyethylene (XLPE) capable of resisting chemicals to a pH of 2. b) Chemical diaphragm metering pump was constructed of PVDF head/fittings with Teflon seats and o-rings. Nominal range of 5 to 100 strokes per minute with stroke length adjustable from 0 to 100%. The pump was LMI Series A diaphragm metering pumps or equal.
Static Mixer	a) The static mixer was constructed downstream of chemical pretreatment.

3.2.2 Nanofiltration

Following chemical injection the feed stream was directed to the high-pressure booster pump that provided the necessary feed pressure for treatment utilizing the nanofiltration process. The objectives of this effort was process optimization, and verification of selected membrane operation under various operating conditions. Silt density index, membrane mass transfer coefficient, flux and recovery were used as the operating parameters in this pilot test program. For membrane processes, extremes of feedwater quality (e.g., low temperature, high TOC concentration, high turbidity) are the conditions under which membranes are most prone to fouling and to failure.

The supply of the pilot plant assembly by the vendor included membrane elements, pressure vessels, support structures (skids), piping, valves, instrumentation and panels, data logger, sample panels with tubing and accessories, electrical connections, supports, bolts, fasteners, and tie downs, and installation, operator training, spare parts list, and O&M manual. Advanced treatment consisted of a three-stage 4:2:2 array. Figure 3.2 illustrates the nanofiltration membrane system for advanced treatment. Table 3.2 outlines the design data for the nanofiltration system and associated equipment.

Chemical cleaning of the membranes was performed as necessary for the removal of reversible foulants per manufacturer specifications. These cleaning events were documented and used as an aid in determining the nature of the fouling or scaling conditions experienced by the system.



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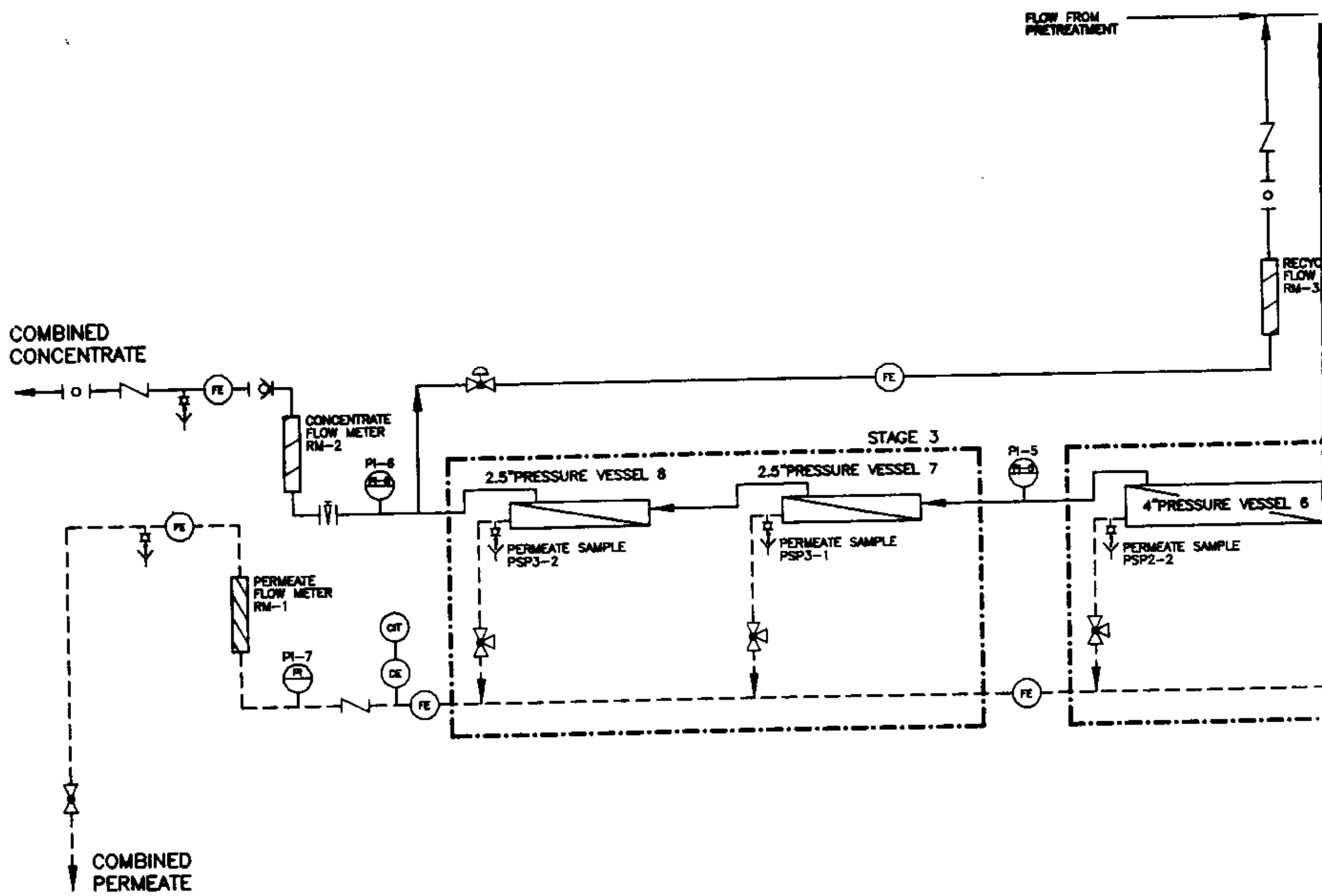

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3 WAY MULTI–PURPOSE VALVE
5 WAY VALVE

ABBREVIATIONS	
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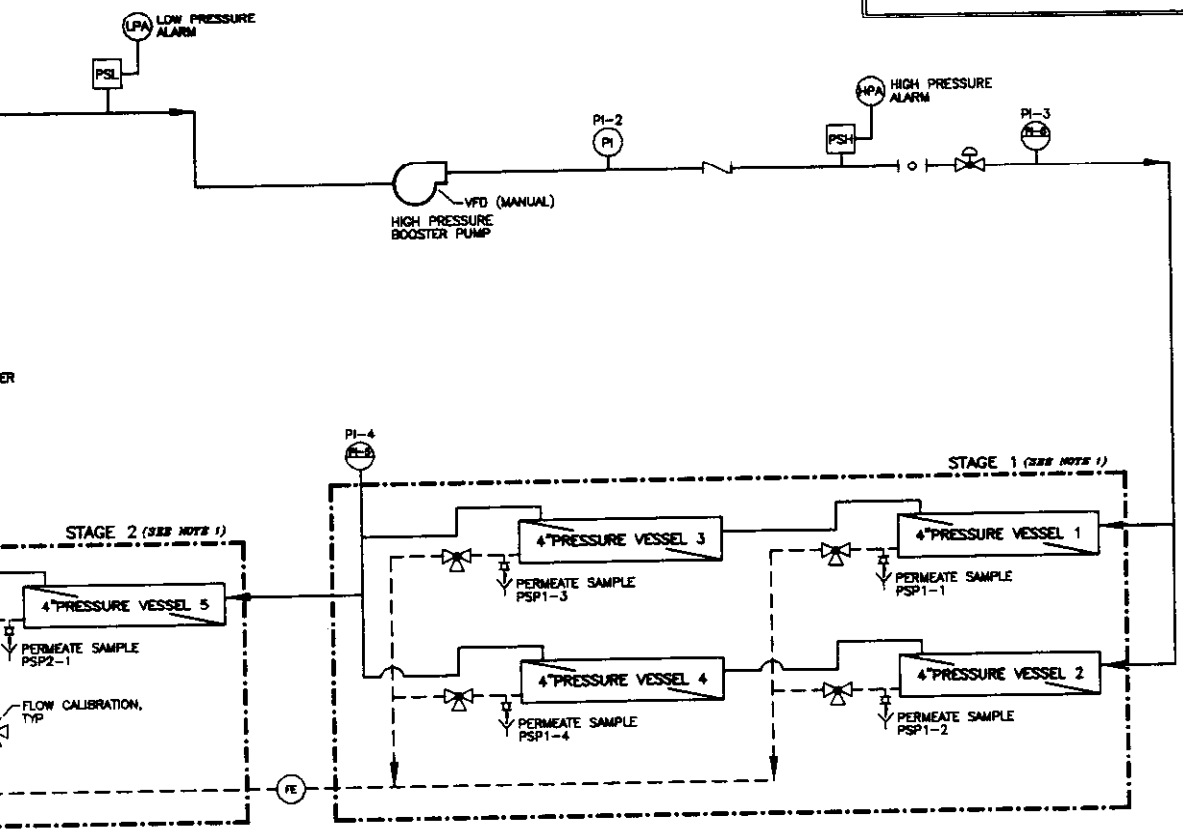


PILOT PLANT PROCESS FLOW DIAGRAM ADVANCED TREATMENT PROCESS

BOYLE

CITY OF NORTH MIAMI BEACH
MEMBRANE SOFTENING - WATER TREATMENT PILOT PLANT

BEC PROJECT NO. OR-H68-200-01

FIGURE 3-2

Table 3.2
ICR Pilot Plant Nanofiltration Design Data

Unit Process	Design Data
Nanofiltration System	a) Pressure available at the suction flange of the raw water feed pumps: (30 to 50 psig) b) Permeate backpressure as required to achieve hydraulic balance across membrane stages. c) A variable frequency drive was used to control the RO feed pump. d) Number of stages: 3 e) Pressure vessel array: 2:2:1:1:1:1 f) Number of 40" elements per pressure vessel: 3 Number of 4-inch membrane elements: 18 Number of 2.5-inch membrane elements: 6 g) Minimum Recovery: 75% Maximum Recovery: 90% h) Nominal Permeate Production Rate: 13-14 gpm i) System Feed Flow Rate: @ 75% recovery, 17.3-18.7 gpm @ 90% recovery, 14.4-15.6 gpm j) Minimum Feed Flow Rate for 4-inch elements: 3 to 6 gpm k) Minimum Feed Flow Rate for 2.5-inch elements: 0.75 to 1.5 gpm l) Recovery Rates: From a minimum of 75 percent, up to 90 percent m) Electrical service available 480 volts, 3 phase, 60 hertz. Supplier provided the full load current required for this system.

Table 3.2 (Continued)
ICR Pilot Plant Nanofiltration Design Data

Membrane and Pressure Vessels	a) Membranes were spiral wound, non-cellulosic thin-film composite membranes, specifically designed for softening high color, TOC water via nanofiltration. The selected membrane elements must have a molecular weight cut-off (MWCO) less than 1000 Daltons. Maximum feed flow rate that can be applied to each element was specified by the membrane manufacturer. Average flux did not exceed 20 gsfd for any element (or 15 gsfd for any stage). Brine seals and o-rings were manufactured from Viton, EDPM or equivalent. b) Pressure vessels were constructed of fiberglass reinforced plastic (FRP) or 316 stainless steel. Vessel dimensions were for three membrane elements of 4-inch diameter x 40-inch length and/or for three membrane elements of 2.5-inch x 40-inch length Each vessel was equipped with two end closures, with suitable retaining devices. The end closure surfaces in contact with process fluid were fabricated from PVC or other inert plastic. Each end closure had ports for permeate. The permeate ports were fabricated for PVC or other plastic material. The end closure and retaining devices were designed as a unit to form a drip-tight seal. The pressure vessels were equipped with either end- or side-entry feed/brine ports. c) The pressure vessel was rated for a minimum working pressure of 250 psi at 75 ^{o}F.
Pressure Vessel Supports	a) All of the RO pilot plant components were mounted on a single skid assembly. The vendor was responsible for providing and installing the skid assembly. The pressure vessels were supported in two places on a structure fabricated from FRP structural shapes. All joints were glued and riveted. Prior to applying the coating system, all cut sections were properly sealed to prevent the absorption of water. b) The coating system for the pressure vessel support structure was white epoxy enamel applied to a thickness of 2 mils. c) All mounting hardware, for pressure vessels, manifolds, instrument panels and sample boards were type 316 stainless steel. Bolts and washers were type 316 stainless steel, with passivated 304SS nuts. d) The vessels were supported on plastic saddles, with 1/8-inch rubber padding, between vessel and saddle, and secure in place with 316 stainless steel mounting bands.

Table 3.2 (Continued)
ICR Pilot Plant Nanofiltration Design Data

Feed, Interstage, Concentrate, and Permeate Piping	a)	All piping from the raw water supply connection to the RO skid was provided by the Vendor and was installed with the RO skid.
	b)	The piping from the raw water supply connection to the RO pilot skid was 1-1/2" schedule 80 PVC.
	c)	High pressure piping downstream of the RO feed pump including the concentrate stream to 18" downstream of the concentrate control valve was 316 SS high pressure tubing.
	d)	All permeate piping was schedule 80 PVC.
	e)	Feed and concentrate manifolds were fabricated from 316 stainless steel piping. All stainless steel piping was thoroughly cleaned inside and out, and all scale and welding slag removed. Completed components were leak-tested after to final assembly.
	f)	All permeate manifolds and connections were with Schedule 80 PVC piping and connectors. Provisions were made for a sample port in each permeate connection, 1/4-inch female threaded.
	g)	All stainless steel pipe, after fabrication, was electropolished, or acid-dipped to a bright reflective finish.
Sampling Ports	a)	Two sampling ports for the raw water stream (before and after chemical addition);
	b)	One sampling ports for the feed water stream;
	c)	One sampling ports for each permeate stream from each pressure vessel (8 total);
	d)	One sampling ports for the combined permeate stream; and,
	e)	One sampling ports for the combined concentrate stream.
	f)	Sample ports were 1/4-turn plug valves, 1/4-inch size NUPRO, or equal. Raw, feed and concentrate sample valves were 316 stainless steel. Permeate sample valves were schedule 80 PVC.

3.3 Experimental Design

The experimental design provided for this pilot study was developed to satisfy the requirements of the ICR, and also to provide data on various pretreatment chemicals, manufactured membrane elements, number of stages and system recoveries to facilitate preliminary design decisions. Table 3.3 provides the experimental design summary for the City of North Miami Beach ICR pilot plant for the period April 24, 1998 through April 14, 1999.

Table 3.3
Experimental Design Summary

Testing Period	Pretreatment Process	Membrane Element Manufacturer	Number of Stages	System Recovery (%)
1. 4/24/98 – 5/21/98	Scale Inhibitor	Fluid Systems	2	65
2. 5/21/98 – 7/16/98	Scale Inhibitor/Acid	TriSep	2	75
3. 7/16/98 - 9/18/98	Acid	TriSep	2	75
4. 9/18/98 – 11/12/98	Acid	TriSep	3	90
5. 11/12/98 – 12/2/98	Acid	TriSep	2	85
6. 12/2/98 – 4/14/99	Acid	Hydranautics	2	75

In order to evaluate the various experimental design scenarios several operational and water quality parameters were analyzed and recorded. Operational data was recorded once per shift (three times daily) for the entire period of operation. Water quality was analyzed biweekly in accordance with the ICR requirements. Table 3.4 lists the total number of samples to be collected as required by the ICR. The total number of samples is based on a minimum of twenty biweekly sampling events and four duplicate sampling events required by the ICR. The North Miami Beach study consisted of 8600 hours of operational data and 24-biweekly water quality sampling events. The extended run time was due to providing adequate run time for additional testing of the Hydranautics elements.

The pilot plant included a main control and sample panel which contains seventeen sampling ports, one low and one high common 5-way pressure gauges, system differential pressure gauge, and three rotameter flow meters. Several other water quality sampling ports were included in the system. Table 3.4 lists the water quality parameters and sampling frequency that was required for this pilot study. The sample ports required are illustrated in Figure 3.2 and described in Table 3.5.

Table 3.4
Summary of Water Quality Parameters Sampling

Parameter	Raw	System			1st Stage	2nd Stage		3rd Stage	
		RO Feed $C_{F\text{-}Sys}$	Permeate $C_{P\text{-}Sys}$	Conc. $C_{C\text{-}Sys}$	Permeate $C_{P\text{-}S1}$	Feed $C_{F\text{-}S2}$	Permeate $C_{P\text{-}S2}$	Feed $C_{F\text{-}S3}$	Permeate $C_{P\text{-}S3}$
Alkalinity		B	B	B	B	B	B	B	B
TDS		B	B	B	B	B	B	B	B
Total Hardness		B	B	B	B	B	B	B	B
Calcium Hardness		B	B	B	B	B	B	B	B
Bromide		B	B						
pH	D	D, B	B	B	B	D, B	B	D, B	B
Conductivity	D	D			D		D		D
Turbidity		B	B	B	B	B	B	B	B
Ammonia		B	B	B	B	B	B	B	B
Temperature	D	B	B	B	B	B	B	B	B
TOC		B	B	B	B	B	B	B	B
UV-254		B	B	B	B	B	B	B	B
SDS Testing		B	B						

Note: "Conc." – concentrate stream. The D indicates a sample was collected daily (once per shift) and analyzed for this parameter. The B indicates a sample was collected bi-weekly and analyzed for this parameter. Additionally, the system feed sample ($C_{F\text{-}sys}$) is same as 1st stage feed sample ($C_{F\text{-}S1}$). SDS testing is comprised of THM4 (four species of trihalomethanes), HAA6 (six species of haloacetic acids), TOX (total organic halide), and chlorine demand (chlorine dose, residual, demand, temperature and pH).

Table 3.5
Sample Port Descriptions

ICR Sample Identifier	Pilot Plant Sample Port Location	
	Nomenclature	Exhibit Identification
Raw	Raw Sample	PSP1
$C_{F\text{-}SYS}$	RO Feed Sample	PSP5
$C_{P\text{-}SYS}$	Total Permeate Sample	PSP12
$C_{C\text{-}SYS}$	Total Concentrate Sample	PSP10
$C_{P\text{-}S1}$	1st Pass Permeate Sample	PSP7
$C_{F\text{-}S2}$	Interstage 1 Sample	PSP6
$C_{P\text{-}S2}$	2nd Pass Permeate Sample	PSP9
$C_{F\text{-}S3}$	Interstage 2 Sample	PSP8
$C_{P\text{-}S3}$	3rd Pass Permeate Sample	PSP11

The characterization of the source water was essential in the evaluation of the resulting permeate water quality and the effectiveness of the membrane treatment process. Sampling of the raw water quality facilitated the investigation of the effects that the water imposes and provided a means for future membrane system analysis (modeling) and planning. The raw water sample was a composite sample of the water entering the WTP from the wellfield. It was recorded which wells are operating at the time the sample is collected. Raw water quality was measured prior to system operation and then monitored at a minimum of three times during the testing period. This helped track limiting salts that might cause flux decline. The following parameters were evaluated in the raw water:

- pH (field)
- Conductivity
- Chloride
- Calcium (Ca)
- Sodium (Na)
- Manganese (Mn)
- Ammonia (NH_4)
- Strontium (Sr)
- Temperature (field)
- Total Hardness
- Fluoride (F)
- Magnesium (Mg)
- Iron (Fe)
- Potassium (K)
- Barium (Ba)
- Sulfate (SO_4)
- Nitrate (NO_3)
- Color
- Turbidity
- Total Alkalinity
- Bromide (Br)
- Nitrate (NO_3)
- Silica (Si)
- Total Dissolved Solids

Other parameters that were evaluated for the raw water included:

- Total Organic Carbon (TOC)
- Radium 226/228
- Total Suspended Solids (TSS)
- Sulfide (Total)
- Dissolved Oxygen (DO)
- Heterotrophic Plate Count (HPC)
- Non-Purgeable Dissolved Organic Carbon (NPDOC)
- UV-254

Mass balances were calculated on the system for water quality parameters measured in the feed, permeate and concentrate streams. This enabled an additional quality control check on the accuracy and reliability of the analyzed data. Mass balances provide insight into the mechanism for rejection of individual constituents. For example, mass balances showing incomplete recovery for calcium may suggest possible adsorption onto the membrane surface.

3.4 Methods

3.4.1 Analytical Methods

Table 3.6 presents recommended standard methods for water quality analysis.

Table 3.6
Water Quality Standard Methods

Parameter	Standard Method	Parameter	Standard Method
Alkalinity	SM 2320-B	Temperature	SM 2550B
TDS	SM 2540	TOC	SM 5310C
Total Hardness	SM 2340-B, 2340-C	UV absorbence at 254 nm (UV_{254})	SM 5910B
Calcium Hardness	SM 3111-B	Simulated Distribution System (Testing)	SM 5710 E
Bromide	EPA 300.00	TOX	SM 5320B
pH	SM 4500-H+B	THM4	EPA 524.2
Turbidity	EPA 180.1	HAA6	SM 6251 B
Ammonia	SM 4500-NH_3-F		

3.4.2 Chlorination Procedures

As required by the ICR rule, samples collected during the ICR treatment study are to be chlorinated under site-specific simulated distribution system (SDS) conditions to evaluate the formation of THM4, HAA6 and TOX. The incubation time, free chlorine residual at the end of the incubation period, pH during incubation, and the temperature during incubation were determined and recorded for each set of biweekly samples. These site specific conditions represent average distribution system conditions. These conditions for the biweekly SDS sampling are presented later in this document.

3.4.3 Laboratory Summary

Table 3.7 presents the various laboratories that performed analyses during the ICR Membrane Pilot Test. The analyses were performed by Montgomery Watson Laboratories in Pasadena, CA., and the City of North Miami Beach Laboratories. The *Calibration Verification and Quality Control Procedures* for the Montgomery Watson Laboratories are presented in Appendix A.

Table 3.7
Laboratory Summary

Laboratory	Dates of Service	Analyses Performed
Montgomery Watson Laboratories (818) 568-6400	5/24/98-5/14/99	Bromide, Ammonia Nitrogen, Total Organic Carbon, Total Organic Halogen, UV absorbence at 254 nm, HAAs, and THMs
North Miami Beach Laboratories (305) 651-8520	5/24/98-5/14/99	Alkalinity, TDS as Conductivity, Total hardness, Calcium Hardness, pH, Turbidity, Temperature

3.4.4 Standard Sampling Methods

The analytical methods utilized in this study for on-site monitoring of raw water, feed water, concentrate and permeate water quality followed methods described in the *Standard Methods for the Examination of Water and Wastewater (Standard Methods)*, 18th edition (1992). Bench-top and on-line field analytical equipment was used for the Test Program.

Sample preservation was done in accordance with *Standard Methods.* Strict adherence to the protocol set forth in *Standard Methods* was essential for obtaining accurate, meaningful results. It is important to note that each sample container was rinsed with water, a minimum of two times, and then preserved prior to sampling. In addition, the sample ports were rinsed with 70% isopropyl alcohol prior to any bacteriological sampling. Bacteriological samples were the last type of sample collected during each sampling event.

The necessary sampling and monitoring instruments were calibrated prior to each day's use. Only fresh pH buffers were used for calibration of the pH meter. A new buffer solution was prepared at least once every four weeks. The pH meter calibration included two points that represented the range of measurements that were made (i.e., pH of 4 to a pH of 10). A chain-of-custody form accompanied each group of samples. The chain-of-custody form was obtained from the laboratory performing the analytical services, and included the temperature and pH of the sample at the time of collection. This form noted any variance from typical operations of the pilot plant.

The sample collector used proper fitting, protective eyewear and rubber latex gloves that was dedicated sampling, primarily for safety and contamination avoidance. Each sample container had the following information inscripted on it:

- sample location,
- sample identification, number, if appropriate,
- date,
- time of collection,
- type of preservative, if any, and
- initials of sample collector.

For the water quality parameters requiring analysis at an ICR-qualified laboratory, water samples were collected in appropriate containers (containing necessary preservatives as applicable) prepared by the ICR-qualified, off-site laboratory. These samples were preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

Table 3.8 summarizes water quality analyses that were performed during the pilot testing period as required by the ICR.

Table 3.8
Water Quality Parameter Sampling Requirements

Parameter	*Preservation Description*	*Holding Time*	*Storage Container Type*	*Minimum Sample Volume*
pH, Conductivity, Temperature	***Field Measurement***	***Field***	***Field***	***Field***
Alkalinity	*Cool, at 4 °C*	*14 days*	*Polyethylene*	*150 mL*
Total Dissolved Solids (TDS)	***Field Measurement** and Laboratory*	*7 days*	*Polyethylene*	*250 mL*
Total Hardness	*HNO_3 to pH < 2*	*6 months*	*Polyethylene or glass*	*100 mL*
Calcium Hardness	*HNO_3 to pH < 2*	*6 months*	*Polyethylene or glass*	*100 mL*
Bromide	*None required*	*28 days*	*Polyethylene or glass*	*100 mL*
Turbidity (NTU)	*Cool, at 4 °C*	*48 hours* (store in dark)	*Polyethylene*	*150 mL*
UV_{254}	*Cool, at 4 °C*	*7 days*	*Amber glass (ashed)*	*100 mL*
Total Organic Carbon (TOC)	*Cool, at 4 °C*	*7 days*	*Amber glass (ashed) TFE-lined caps*	*250 mL*
*SDS Samples**	*Cool, at 4 °C*	*Analyze as soon as possible*	*Amber glass (ashed) TFE-lined caps*	*4 L*
Ammonia	*H_2SO_4 to pH <2, Cool, at 4 °C*	*Analyze as soon as possible*	*Polyethylene or Glass*	*500 mL*

3.4.5 Membrane Cleaning Procedure

During operation of the pilot unit the membrane system became fouled with foulants such as colloids, organic matter, metallic scales, and biological constituents. These materials built up on the membrane surface and in the feed channels. The accumulation of such foulants resulted in the loss of performance. Indicators to loss of performance include increased pressure requirements to maintain flow, pressure drop increases, and solids rejection suffer. In order to remedy this situation and to avoid irreversible damage, the membrane elements were cleaned to regain production.

Since this was a pilot plant operation, installed RO cleaning skids were not available at this facility. Therefore, cleaning was performed by an experienced RO contractor. The transportable RO cleaning skid was provided by the RO contractor and included a solution storage tank, a cartridge filter, a pump, and adequate valves and piping. Cleaning solution was pumped from the storage tank through a cartridge filter to the RO system. The volume of solution provided was calculated based on the volume

of the vessels, filters, and piping. The feed pressure for the solution was in the range of 20 to 60 psi. The feed flow for 2.5-inch elements was be 3 to 5 gpm per vessel. The feed flow for 4-inch elements was 8 to 10 gpm per vessel.

Low pH solutions are typically used to clean metallic scales while alkaline solutions are used to clean biological and organic fouling. Typical cleaning agents include citric acid for low pH flushes and caustic for base flushes. Cleaning of this pilot unit included an acid-base flush. Cleaning solutions were prepared in accordance with the instructions provided by the membrane element manufacturer. The cleaning solution was pumped into the membrane vessels. The elements were soaked for a minimum of one hour. After the soaking period the elements were flushed using a recycle of the cleaning solution to displace the foulants from the membrane. The membrane vessels were then flushed with permeate water or pre-filtered water. Since the unit was not producing permeate during the cleaning process, a separate storage tank was used to be provide for the storage of permeate to be used for the final flush.

4.0 Results And Discussion

4.1 Summary of Significant Events and Results

During approximately one year of operation with six various experimental design scenarios the City of North Miami Beach was able to obtain data that led to significant findings that will affect the ultimate design of the proposed WTP expansion with membrane filtration. A summary of significant results is summarized below.

The ICR pilot plant was placed on line on April 24, 1998 by Boyle Engineering Corporation and Harn RO Systems. The initial installation consisted of cartridge filters, and a two-stage membrane system using elements manufactured by Fluid Systems. Chemical pretreatment was provided using scale inhibitor only. The system was run at a recovery rate of 65-percent for 640 hours.

On May 21, 1998 the Fluid Systems elements were replaced with elements manufactured by TriSep. The chemical pretreatment continued to consist of scale inhibitor injection, but sulfuric acid injection was started on this date. The recovery for this system was set to 75 percent using manufacturer projections. This system ran until July 16, 1998 when it was taken off line to be cleaned. Fouling of the elements had reduced the recovery of the system to approximately 45-percent. The system was cleaned with an acid/base flush of the elements. While the unit was taken off line several of the existing elements were also replaced. Approximately one-half of the existing set of TriSep elements were replaced with new elements provided by TriSep. When the system was placed back into service the system recovery returned to 75-percent.

An autopsy was performed on one of the elements removed from the membrane pilot system. Autopsy results from the foulant identification analysis performed on August 17, 1998 revealed clay, iron, biological slime and silica fouling. Microbiological material was also detected. The silica was suspected to come from the silicone grease found on the brine seal and the internal O-ring surface of the central tube, or from the clay. Residual liquid in the shipment bag had an orange hue, which was later confirmed to be caused by the presence of iron. The fouling was severe enough that damage was seen by visual inspection alone. The autopsy report is provided in Appendix B.

The chemical pretreatment was reduced to sulfuric acid only after the cleaning. On September 18, 1998 the third stage of the ICR pilot plant was placed on line. The third stage consists of six 2.5-inch diameter TriSep membrane elements. The addition of the third stage provided a recovery of approximately 90-percent. Chemical pre-treatment continued to consist of sulfuric acid addition alone. Based on the performance of the TriSep membranes, it was determined that another membrane element should be tested during the ICR pilot testing. On October 8, 1998 more valving capabilities were installed on the ICR pilot plant so that backpressure could be provided to the second pass permeate. This allowed sufficient flow to pass to the third stage, and the operation of the pilot plant to match projections provided by the manufacturer.

At about this same time the City staff began to investigate possible scenarios for providing wellfield rehabilitation. The City contracted the services of Aquifer Maintenance and Performance Systems, Inc. (AMPS) to inspect, perform video surveys, and provide chemical treatment to seven (7) of the City's twelve (12) raw water supply wells. The City provided raw water quality monitoring at the seven wells before and after well cleaning treatments. These analyses will determine the effectiveness of the well cleanings, as well as determine raw water quality at the existing wells to aid in future design decisions. The well rehabilitation will benefit the operation of the proposed nanofiltration plant. Well cleaning and rehabilitation began on Monday, October 19, and is complete except for one remaining well that is receiving repairs. During well rehabilitation the City staff had to change the cartridge filters twice in October, once on October 5 and once on October 15.

The ICR pilot plant operated with TriSep elements at a recovery of 90-percent, utilizing all three stages of the pilot system until November 12, 1998. On November 12, 1998 the third stage was taken off line and the two-stage membrane system was operated at a recovery of 85-percent with the TriSep elements. Chemical pre-treatment continued with sulfuric acid addition alone.

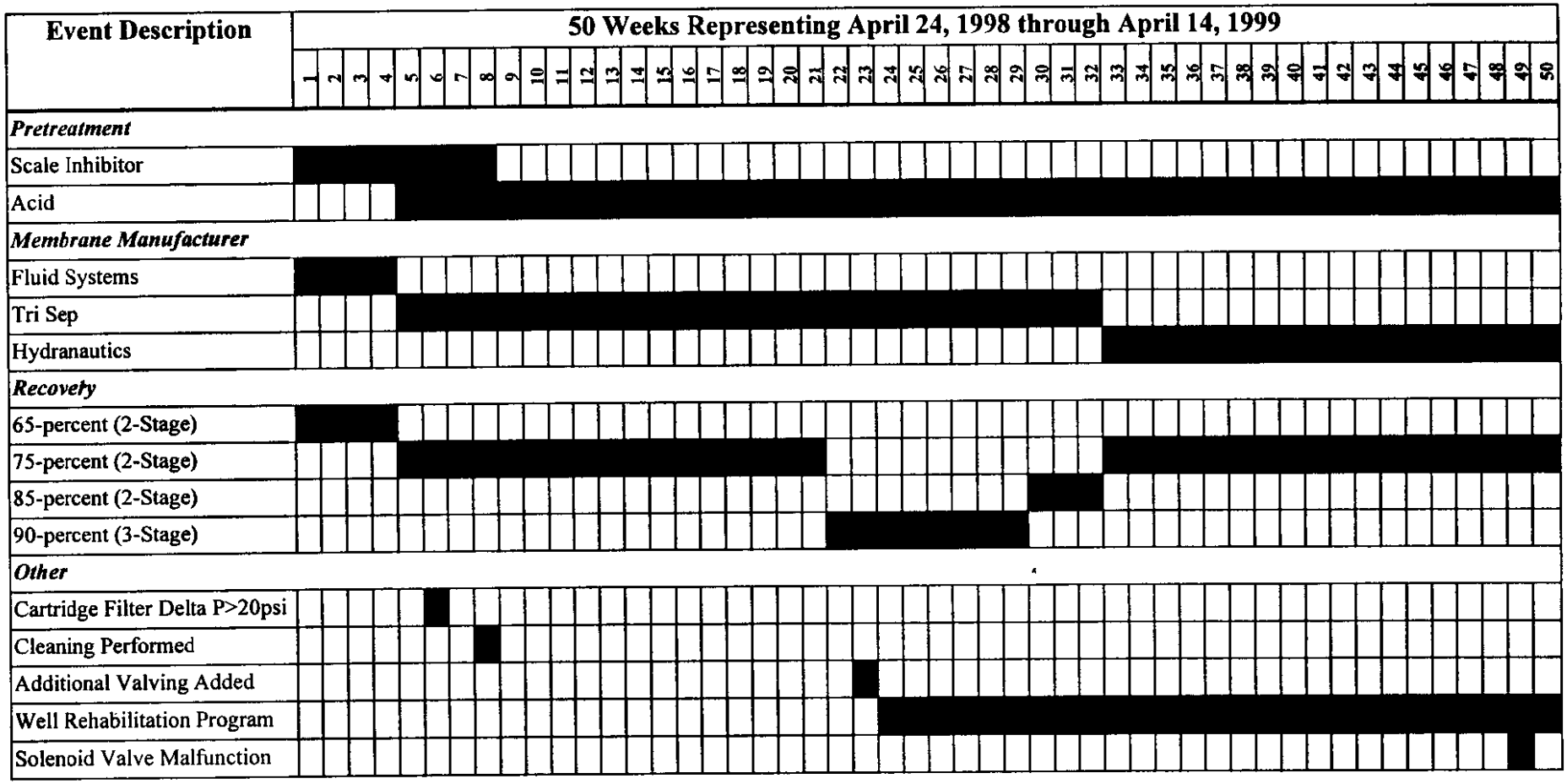
On December 2, 1998 the TriSep elements were removed from the membrane system, and replaced with Hydranautics membrane elements. The pilot plant was set to operate at a recovery of 75-percent with the two-stage Hydranautics system. The addition of the Hydranautics membrane testing extended the total run time by approximately 1600 hours in order to accommodate a minimum run time of 3000 hours for the new Hydranautics elements. Chemical pre-treatment continued with sulfuric acid addition alone. Testing of the Hydranautics elements was completed on April 14, 1999. A timeline of events is presented in Figure 4.1.

4.2 Problems Encountered

4.2.1 Pretreatment

The proper pretreatment of the raw water was critical for optimizing performance of the nanofiltration pilot. Several obstacles were presented, and several lessons were learned through the course of this pilot study. The major finding regarding pretreatment of this source water for membrane softening was related to the addition of scale inhibitor. Although the addition of scale inhibitor did not seem to negatively affect performance during the testing of the Fluid Systems low pressure RO elements, pretreatment with scale inhibitor and acid during the first test period with TriSep elements at 75-percent recovery, appeared to significantly affect the system mass transfer coefficient, as well as the system recovery. During a period of approximately 1500 hours the recovery declined from 75- to 45-percent. After the elements were cleaned and the system returned to operation, pretreatment was limited to sulfuric acid addition alone.

FIGURE 4.1: City of North Miami Beach Membrane Pilot Plant Time Line of Events



Cartridge filtration was successful for the most part. There were two instances of complications with this pretreatment process. By June 1998 the original cartridge filters were demonstrating a differential pressure of approximately 20 psi. The cartridge filters were replaced immediately. After review of the historical pilot plant records for April 1998 through June 1998, it was realized that the increase in differential pressure across the cartridge filters was not a result of an instantaneous slug, but rather a gradual increase of build-up in the cartridge filters. It was concluded that the condition of the cartridge filters at this time was responsible for the passage of silt or biological material to the membranes, and at least in part responsible for the eventual production decline that ensued. The operators at the WTP were advised that the cartridge filters should be replaced when the differential pressure reaches approximately 10 psi to avoid passage of silt or biological material to the membranes. The cartridge filters were changed regularly from that point forward in the pilot study.

During the well rehabilitation program at the City's raw water supply wells the pilot plant began experiencing large slugs of silt to the cartridge filters. The cartridge filters successfully protected the membranes during these slugs, however, the cartridge filters were requiring replacement two to three times a day. The slugs appeared to coincide with the rehabilitated wells being flushed and brought back on-line. Once this problem was identified, we initiated a strategy to not operate the pilot plant while these wells were being placed back into service, and the operation and maintenance of the cartridge filters returned to normal.

4.2.2 Nanofiltration

The TriSep elements were tested from May 21, 1998 through December 2, 1998 at various recoveries. The TriSep membranes were first pilot tested at a system recovery of 75-percent. During May and June it was discovered that the TDS rejection provided by the TriSep elements was less than projected by the manufacturer. After reviewing the system rejection the manufacturer agreed to replace approximately one-half of the membranes in the pilot unit to optimize rejection of TDS. Around this same time the pilot began to experience a significant decline in productivity. The decrease may have been caused by the overloaded cartridge filters, the addition of scale inhibitor, the quality of the TriSep elements, or a combination thereof. Based on the rate of production decline it was recognized by early July that a cleaning should be performed. Therefore, the replacement of the TriSep elements was delayed until the cleaning was performed.

The cleaning event consisted of an acid/base flush. Following the cleaning it was observed that the system flux had not only been recovered, but had increased above the original flux rate recorded for these elements. It was suspected that it the elements were over-cleaned, which would result in increased flux, but may result in decreased rejection. The half-set of TriSep elements were replaced, and the two-stage system continued to operate at 75-percent recovery.

The next challenge that was faced in the pilot study was bringing the third-stage on-line to increase recovery to 90-percent. When the third stage was brought on-line it was difficult to provide any amount

of flow to the third stage. The existing pilot plant was not equipped with the adequate valving to increase flow to third stage. After a short period of time more valving capabilities were installed on the ICR pilot plant so that backpressure could be provided to the second pass permeate. These improvements allowed the system to operate as the manufacturer had projected.

4.2.3 Electrical, Instrumentation, and Controls

The electrical, instrumentation, and controls provided on the pilot plant operated effectively for the majority of the pilot study. The pilot plant was equipped with a data logger that recorded data for two week periods. The data logger was equipped with a screen that displayed current operation. During certain periods of the study the pH data reported on the data logger differed from the actual measured pH. Since the data logger pH was not reliable, pH was sampled with every operational field data summary.

On multiple occasions during the beginning of the study it was discovered that electrical surges were resulting in the shut-down of the pilot plant. Since the Norwood WTP is manned twenty-four hours per day, the shut down of the facility could be remedied. The electrical staff solved and remedied this problem in the early fall of 1998 with minimum interruptions to operation. The pilot study was scheduled to be completed by April 7, 1999. However, during the final week of pilot testing the solenoid valve on the raw water influent began to function improperly. The valve was repaired, and the pilot plant was brought back on-line. The down time, however, was approximately one week, which delayed completion of the ICR testing to April 14, 1999.

4.3 Water Quality Data

4.3.1 Water Quality Of Feed and Permeate

Water quality samples were taken biweekly for the feed, permeate, and concentrate for the one year of operation as required by the ICR. A list of biweekly analyses are located in Appendix C. Figures 4.2 through 4.7 present feed and permeate quality for six of the water quality parameters monitored. These parameters include: alkalinity (as $CaCO_3$), Total Dissolved Solids (TDS), Bromide, Total Hardness (as $CaCO_3$), Total Organic Carbon (TOC), and UV254.

4.3.2 DBP Data and Data Analysis

As mentioned previously, water quality samples were taken biweekly for the feed, permeate, and concentrate for the one year of operation as required by the ICR. A list of biweekly analyses are located in Appendix C. The ICR also required Simulated Distribution System (SDS) testing. Figures 4.8 through 4.10 represent conditions for the SDS testing, and Figures 4.11 through 4.16 illustrate the results of the SDS testing on THM4 and HAA6 species for feed and permeate samples.

Figure 4.2: Feed and Permeate Alkalinity

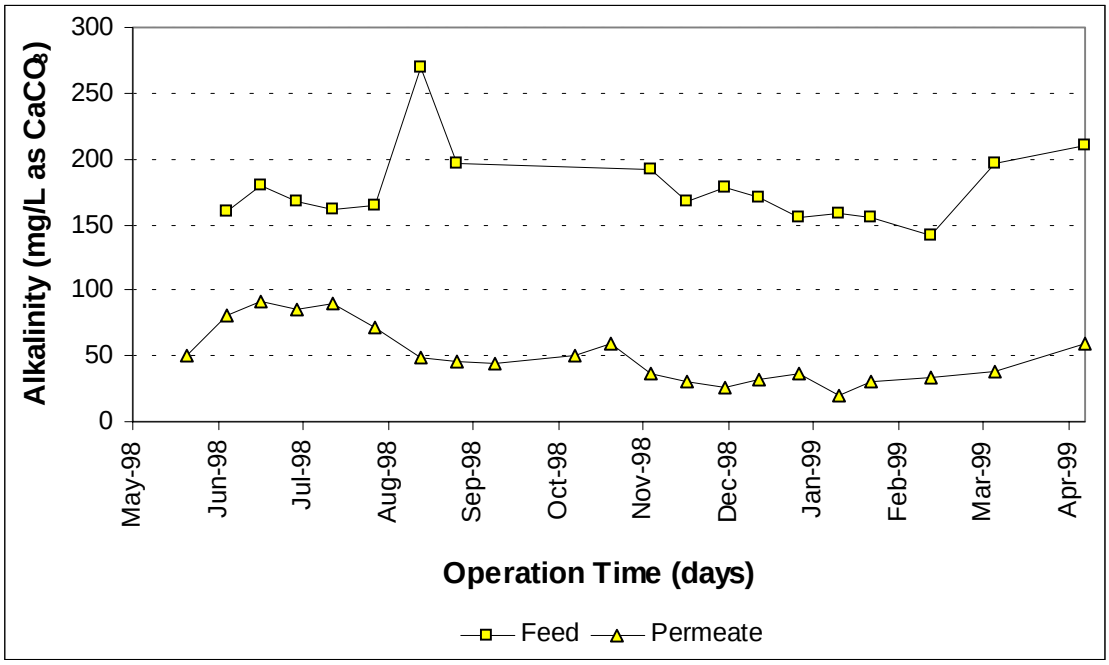


Figure 4.3: Feed and Permeate TDS

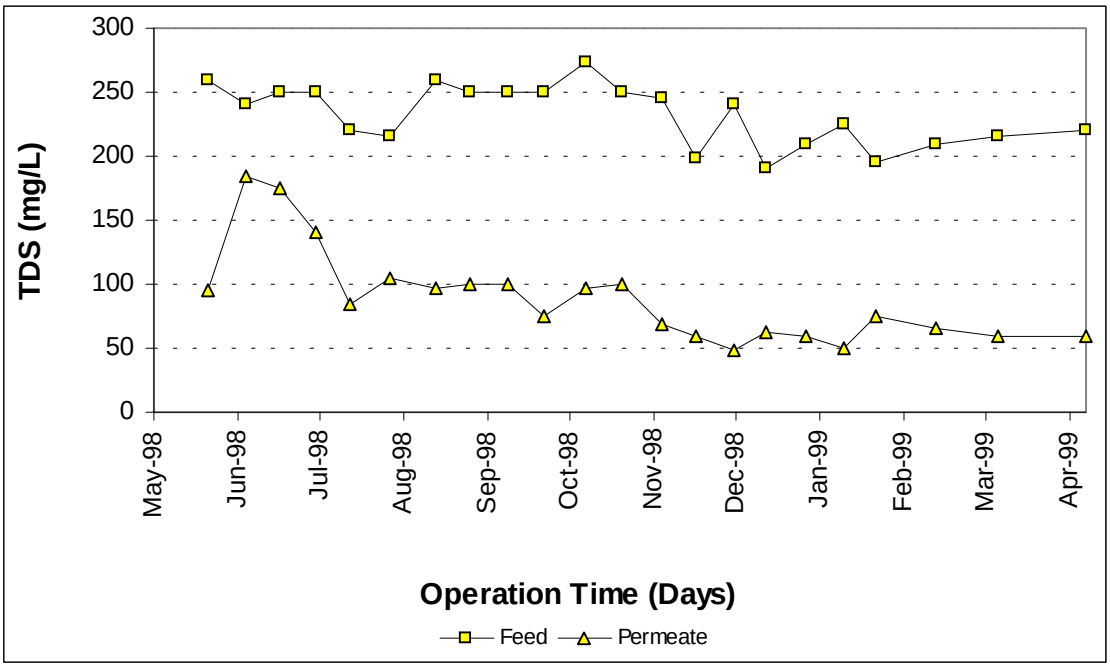


Figure 4.4: Feed and Permeate Bromide

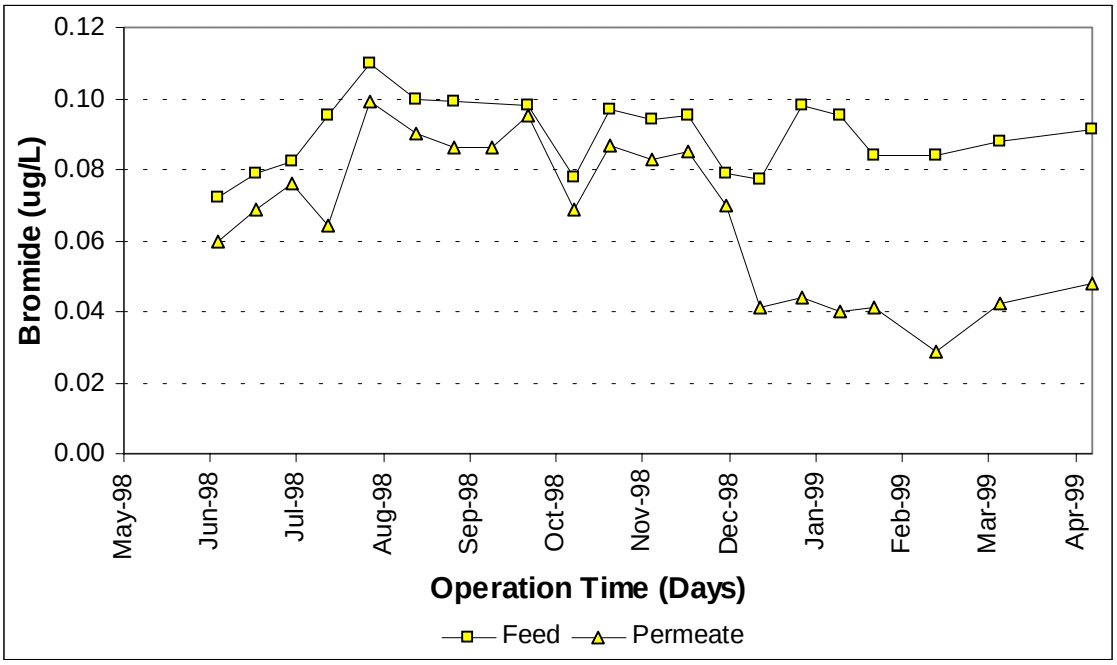


Figure 4.5: Feed and Permeate Total Hardness

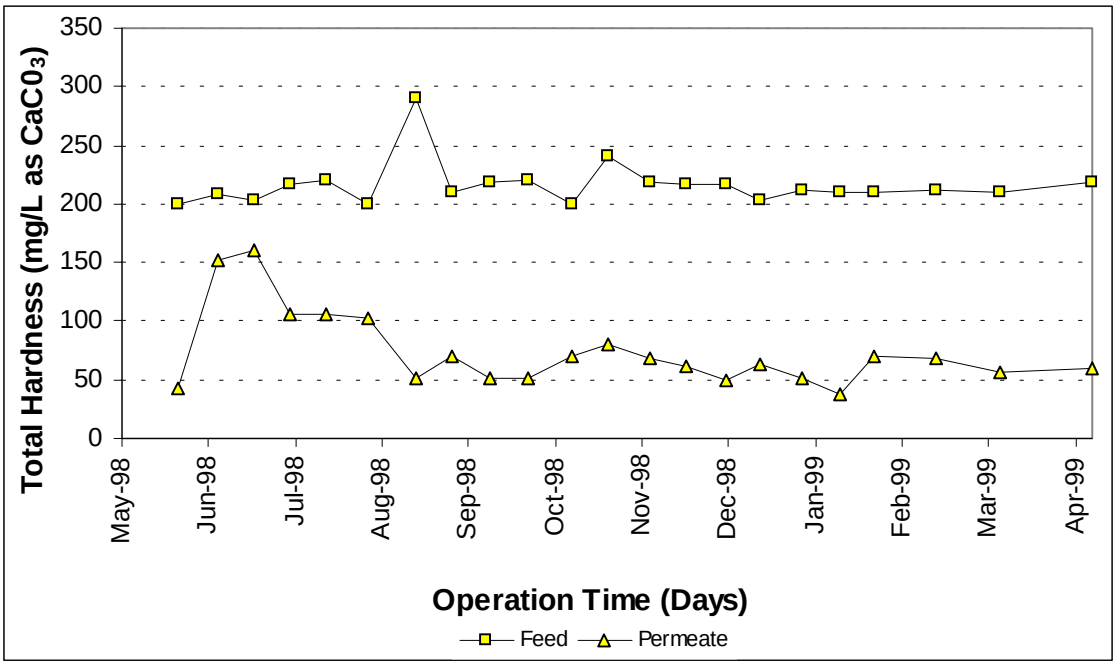


Figure 4.6: Feed and Permeate TOC

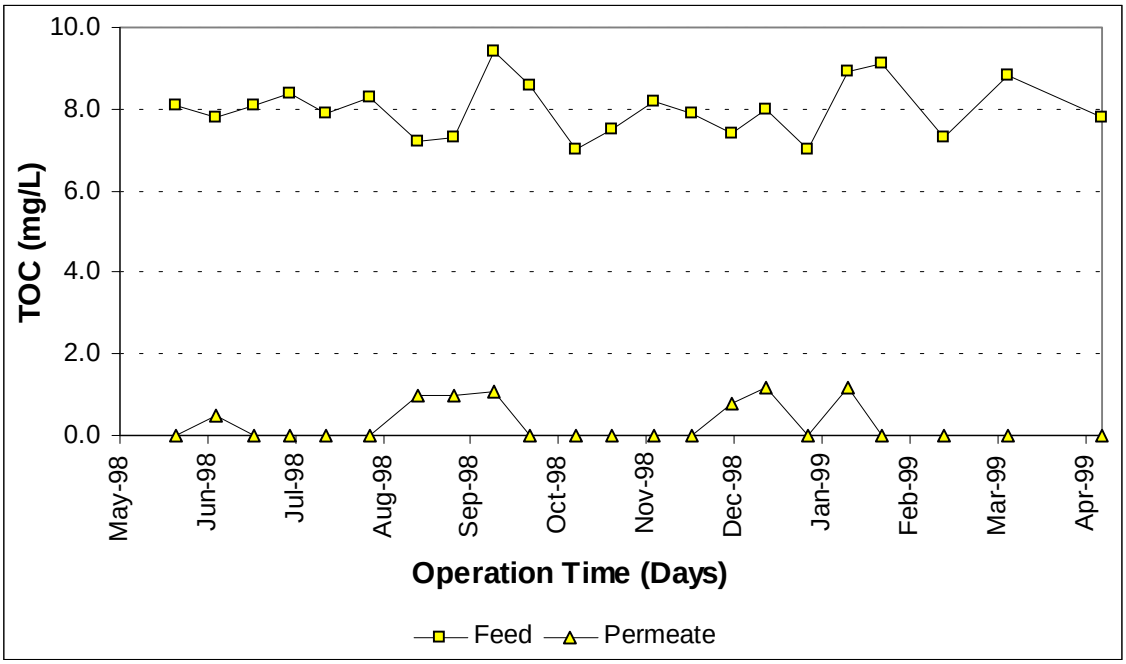


Figure 4.7: Feed and Permeate UV-254

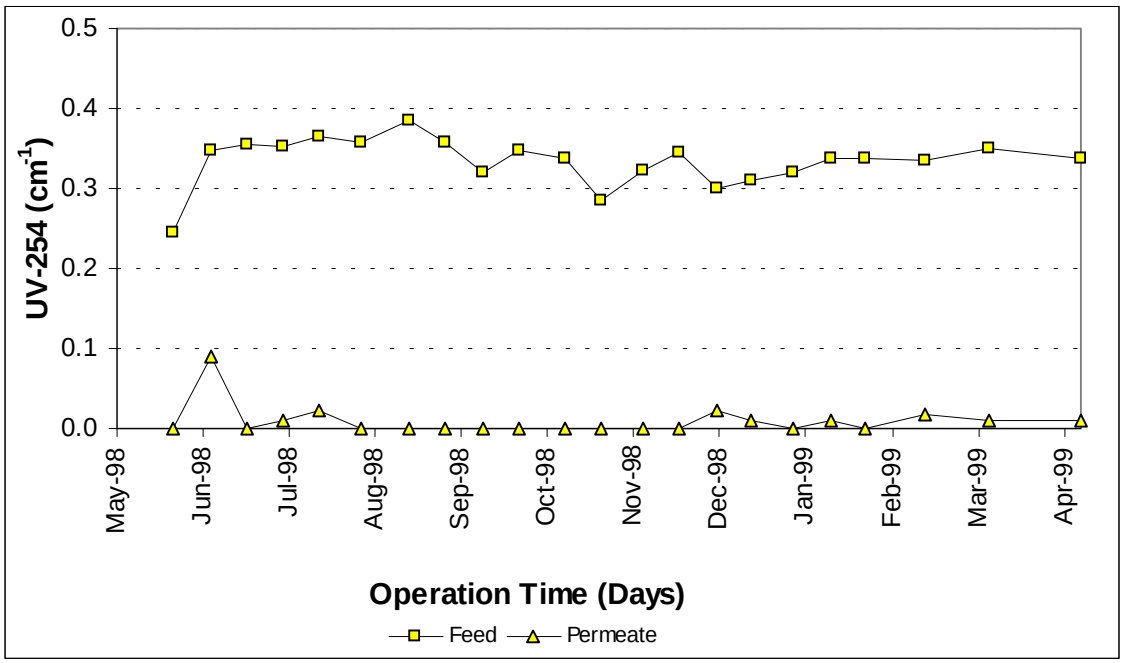


Figure 4.8: SDS Dose and Residual

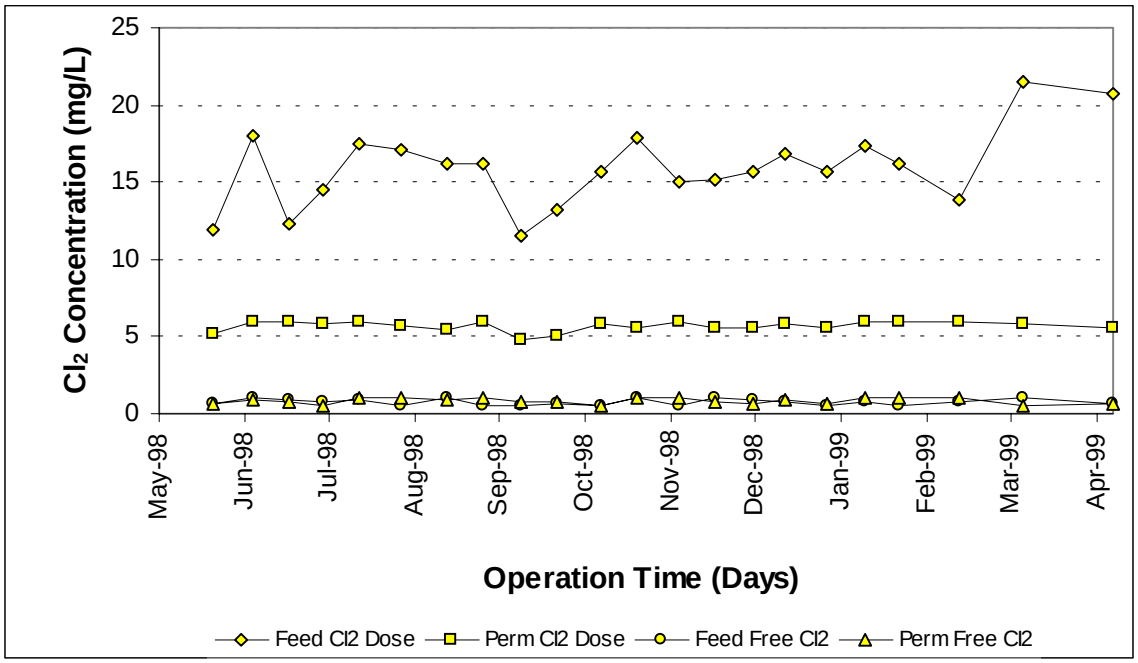


Figure 4.9: SDS Chlorination Incubation Temperature

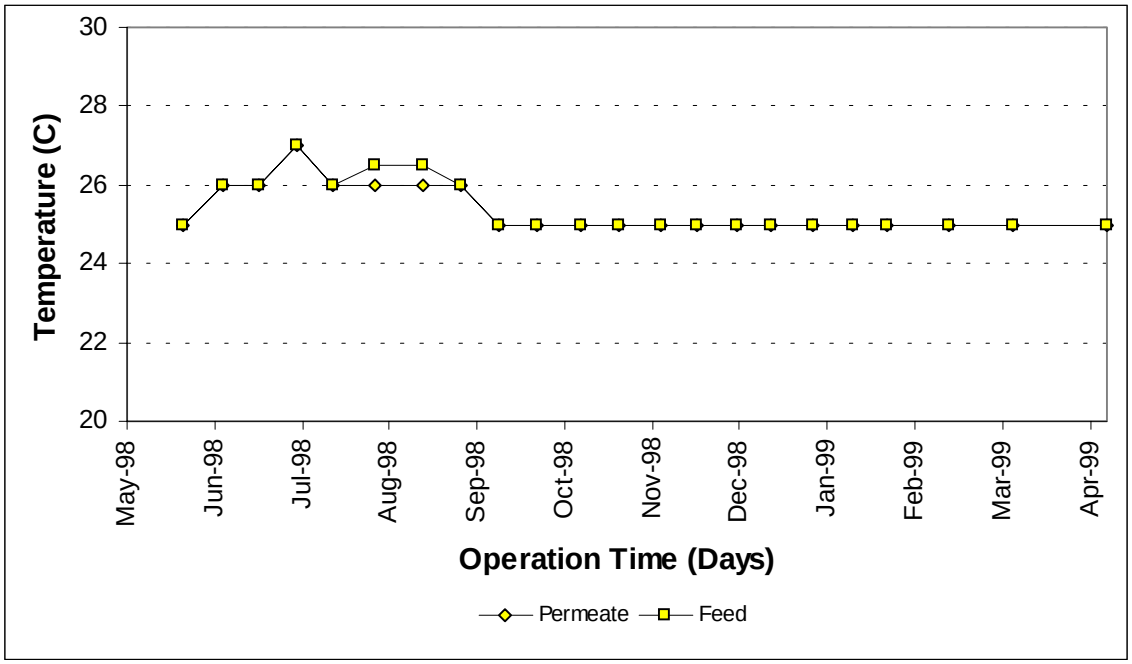


Figure 4.10: SDS Chlorination pH

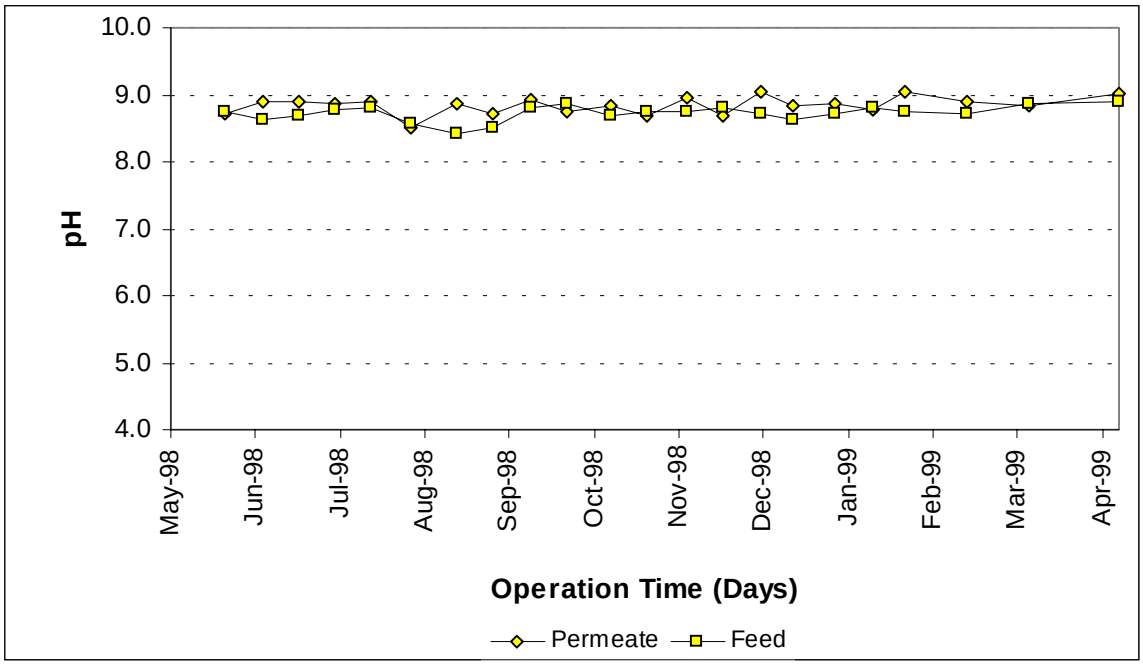


Figure 4.11: SDS Feed THM Species

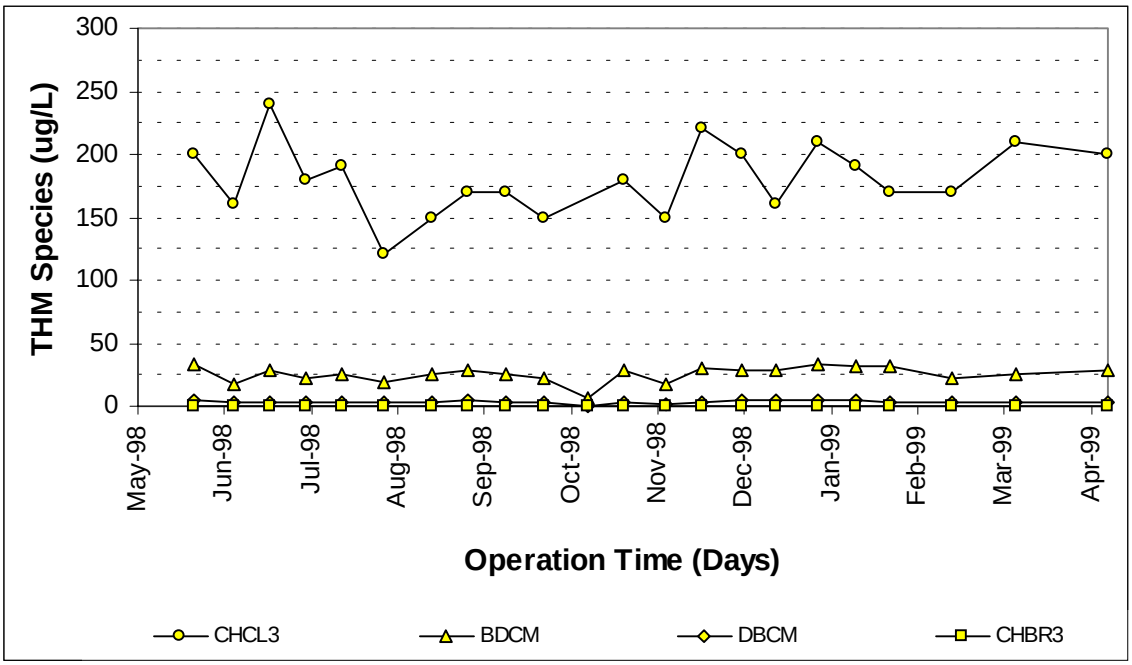


Figure 4.12: SDS Permeate THM Species

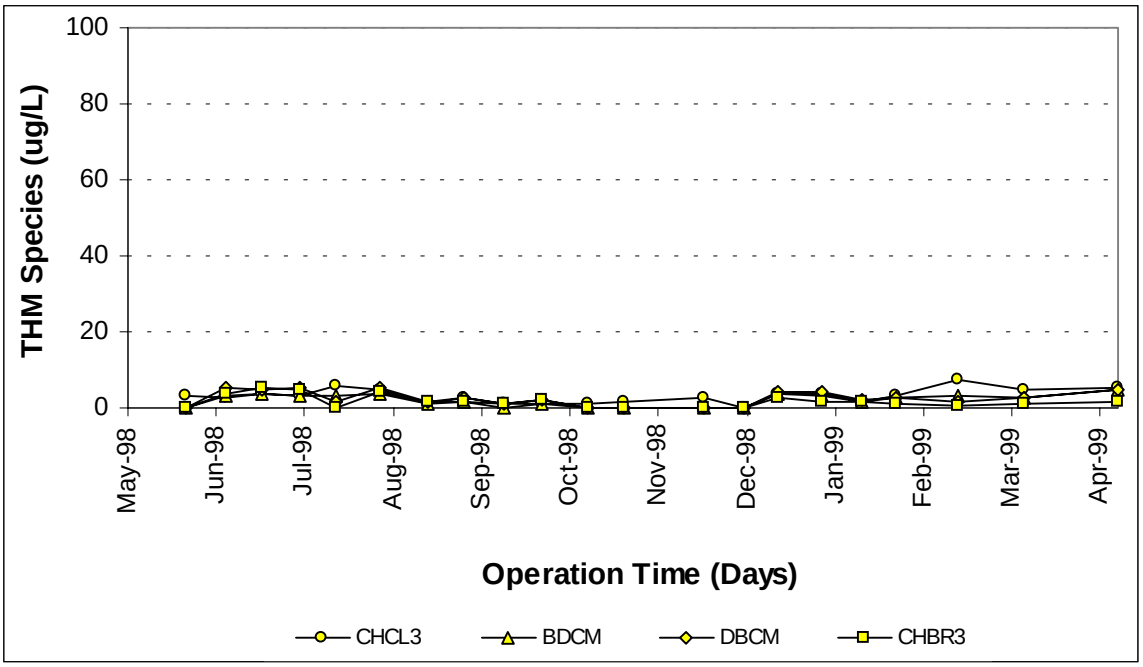


Figure 4.13: SDS Feed and Permeate THM4

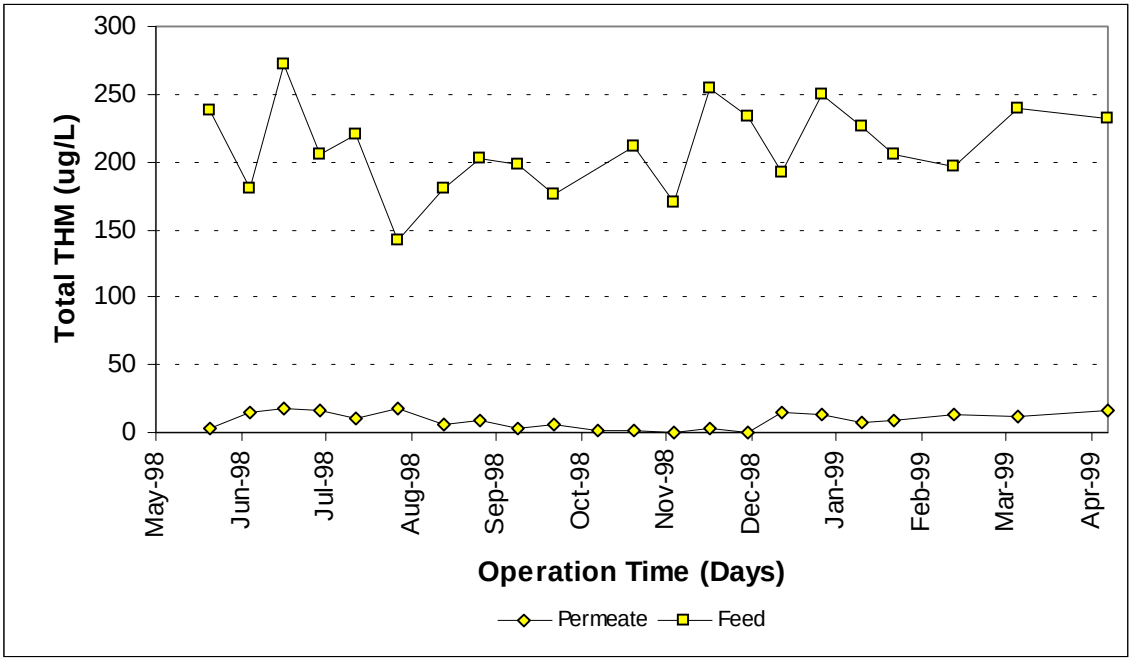


Figure 4.14: SDS Feed HAA6 Species

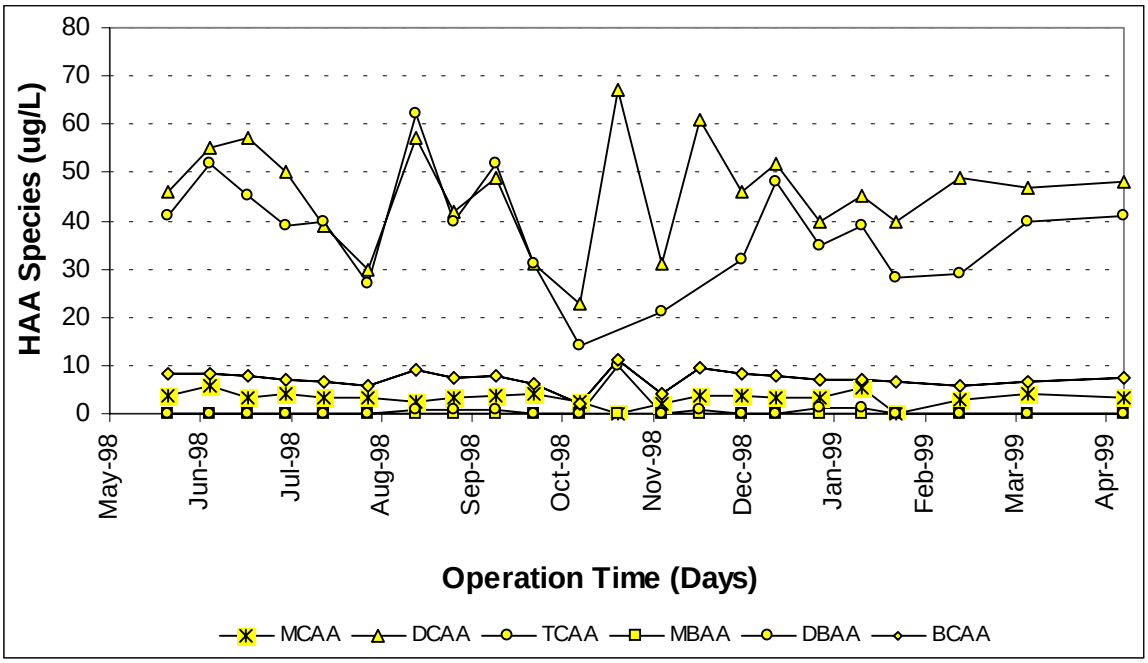


Figure 4.15: SDS Permeate HAA6 Species

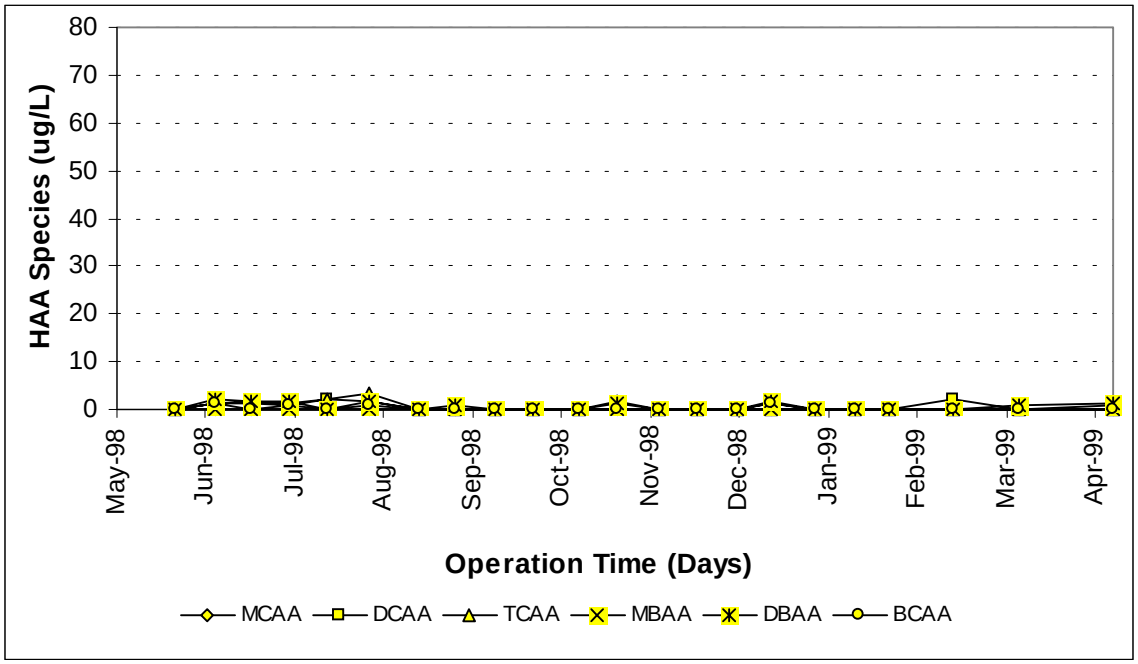
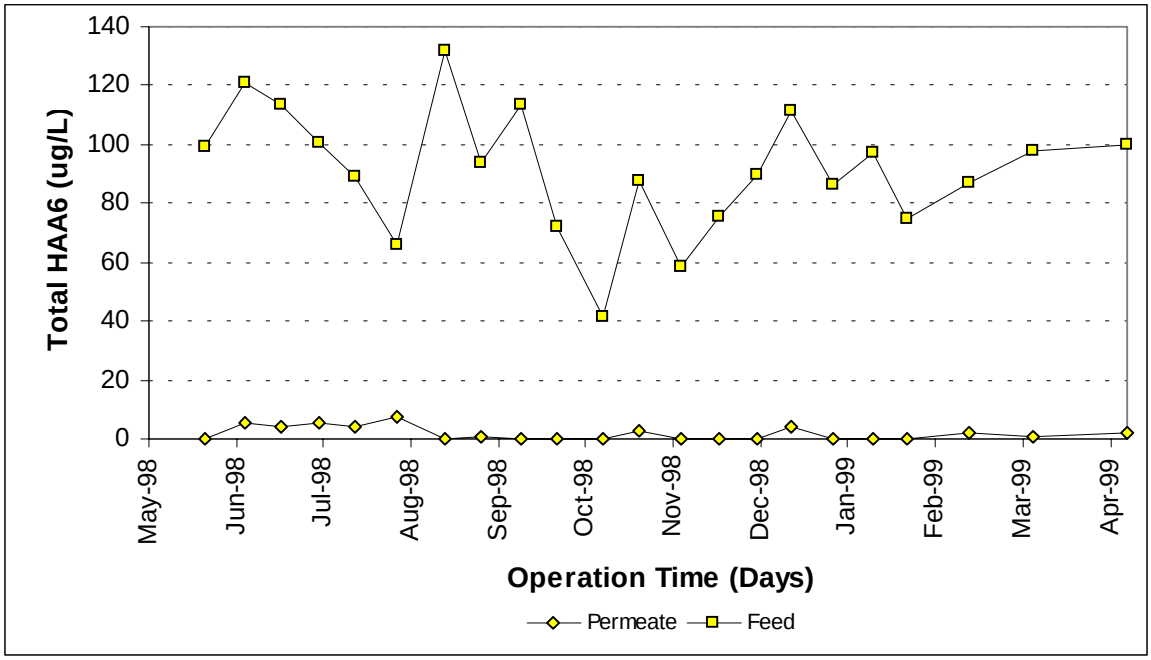


Figure 4.16: SDS Feed and Permeate HAA6 Species



4.3.3 Impact Of Specific Variables On Water Quality

The experimental design varied membrane pilot plant design to produce various operational scenarios. These scenarios resulted in variations of overall system permeate water quality. The major variables that were investigated include chemical pretreatment and NF assembly components. Seasonal variability was also monitored during the course of the year of operation, however feed water temperature did not vary significantly, and therefore, did not have a noticeable impact on water quality. The use of various chemical pretreatment altered feed pH. When sulfuric acid addition was utilized the acidified feed pH ranged from 5.0 to 6.5 units.

The most significant impact on water quality was the use of various system configurations. The experimental design included six different system configurations, five relating to various manufactured elements, system recoveries, and number of stages. Table 4.1 presents the impact of these various system designs on total dissolved solids (TDS) rejection.

The effect of NF assemblies on SDS permeate samples for Total Trihalomethanes (THM4), and Haloacetic Acids (HAA6) was minimal. Concentrations of THM4s and HAA6s did not vary significantly throughout the course of the pilot study.

Table 4.1
Experimental Design with Average TDS Rejection

Testing Period	Pretreatment Process	Membrane Element Manufacturer	Number of Stages	System Recovery (%)	System TDS Rejection (%)
1. 4/24/98 – 5/21/98	SI	Fluid Systems	2	65	63.4
2. 5/21/98 – 7/16/98	SI/Acid	TriSep	2	75	34.9
3. 7/16/98 - 9/18/98	Acid	TriSep	2	75	58.1
4. 9/18/98 – 11/12/98	Acid	TriSep	3	90	61.9
5. 11/12/98 – 12/2/98	Acid	TriSep	2	85	67.5
6. 12/2/98 – 4/14/99	Acid	Hydranautics	2	75	68.9

4.4 Water Production Data

4.4.1 Production Data and Data Analysis

Figure 4.17 presents the mass transfer coefficients normalized to 25°C ($MTC_{w\ 25°C}$) over hours of operation for the overall system. Figure 4.18 illustrates the system recovery over hours of operation. Figure 4.19 shows the flux (F_w) over hours of operation for the overall system. Figure 4.20 presents the feed flow to the membranes over hours of operation for the overall system. Figure 4.21 shows the pressure drop over hours of operation for the overall system. Figure 4.22 presents the system permeate total dissolved solids (TDS) over hours of operation. Figure 4.23presents the net driving pressure (NDP) over hours of operation for the overall system. Figure 4.24 illustrates the feed pH verses the hours of operation.

Water production and water quality data for the entire period of pilot testing operation are provided on diskettes located in Appendix D.

Figure 4.17:System Mass Transfer Coefficient

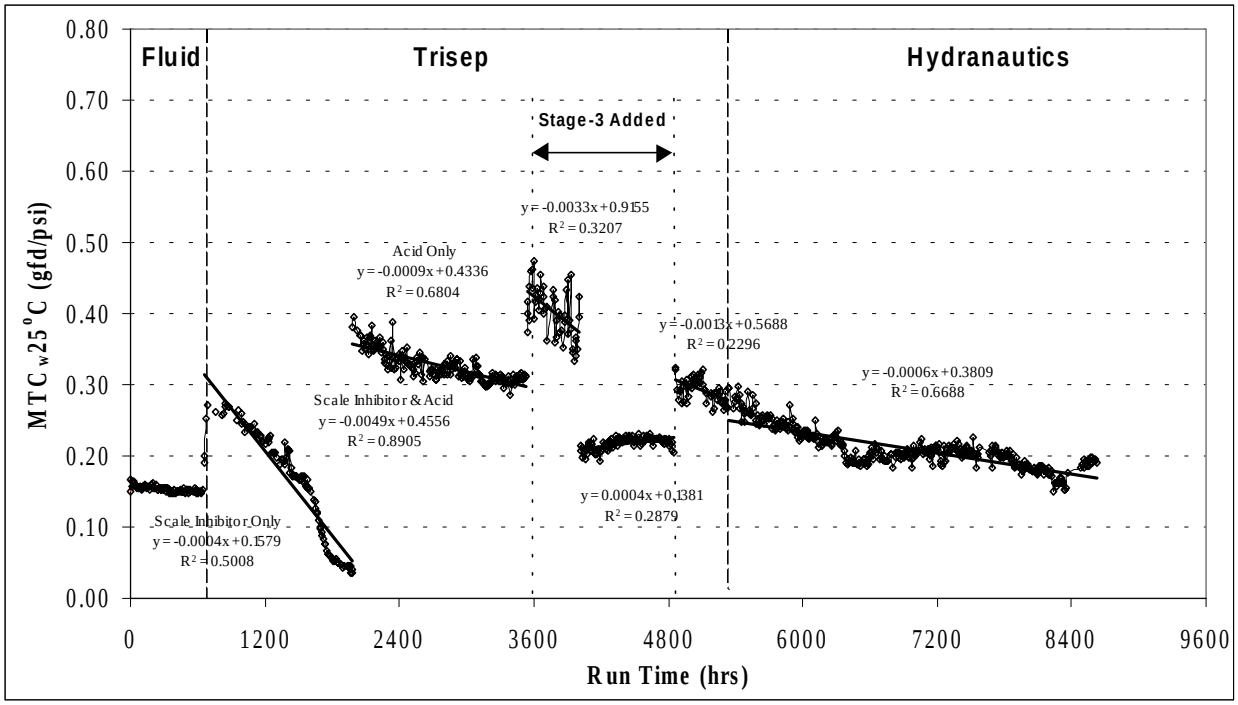


Figure 4.18: System Percent Recovery

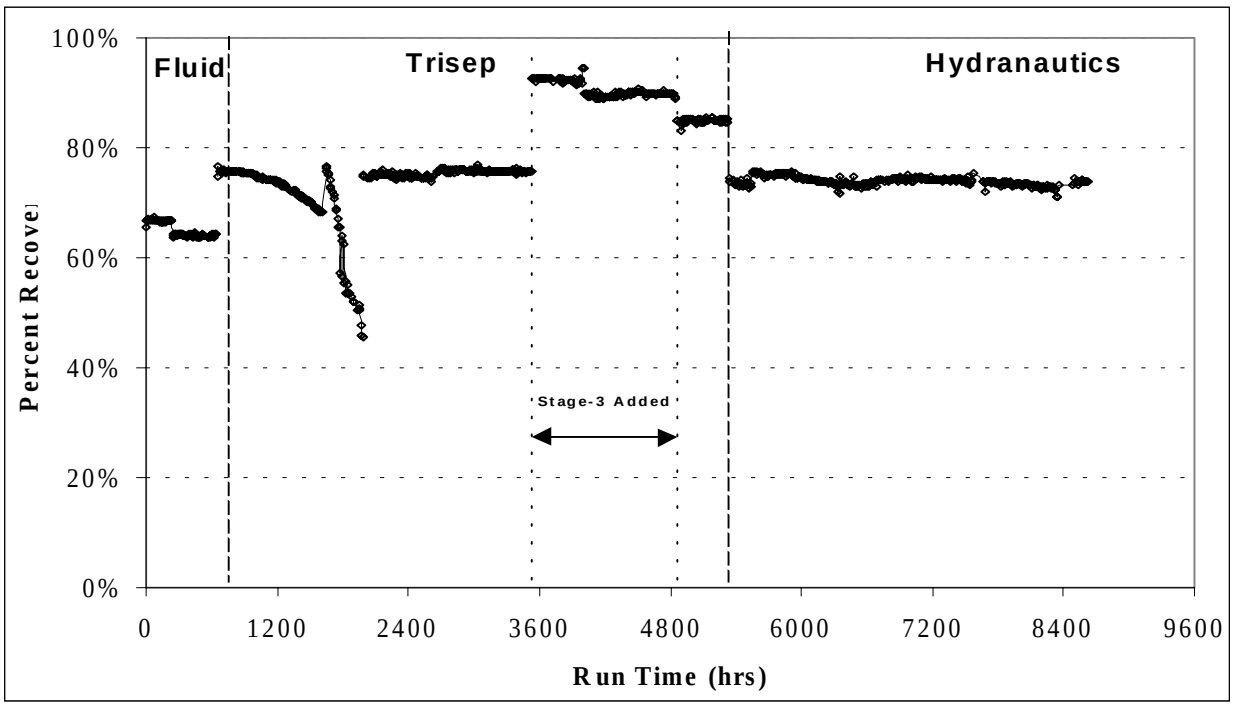


Figure 4.19: System Normalized Flux (25°C)

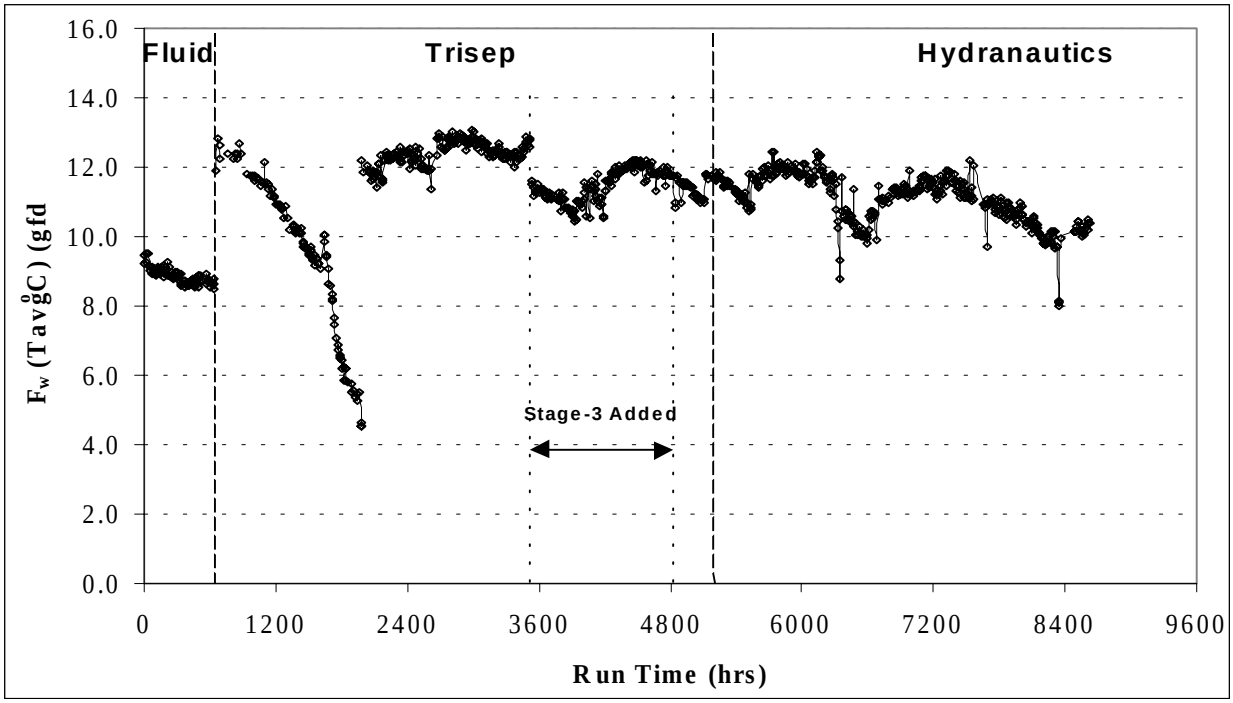


Figure 4.20: System Feed Flow Rate

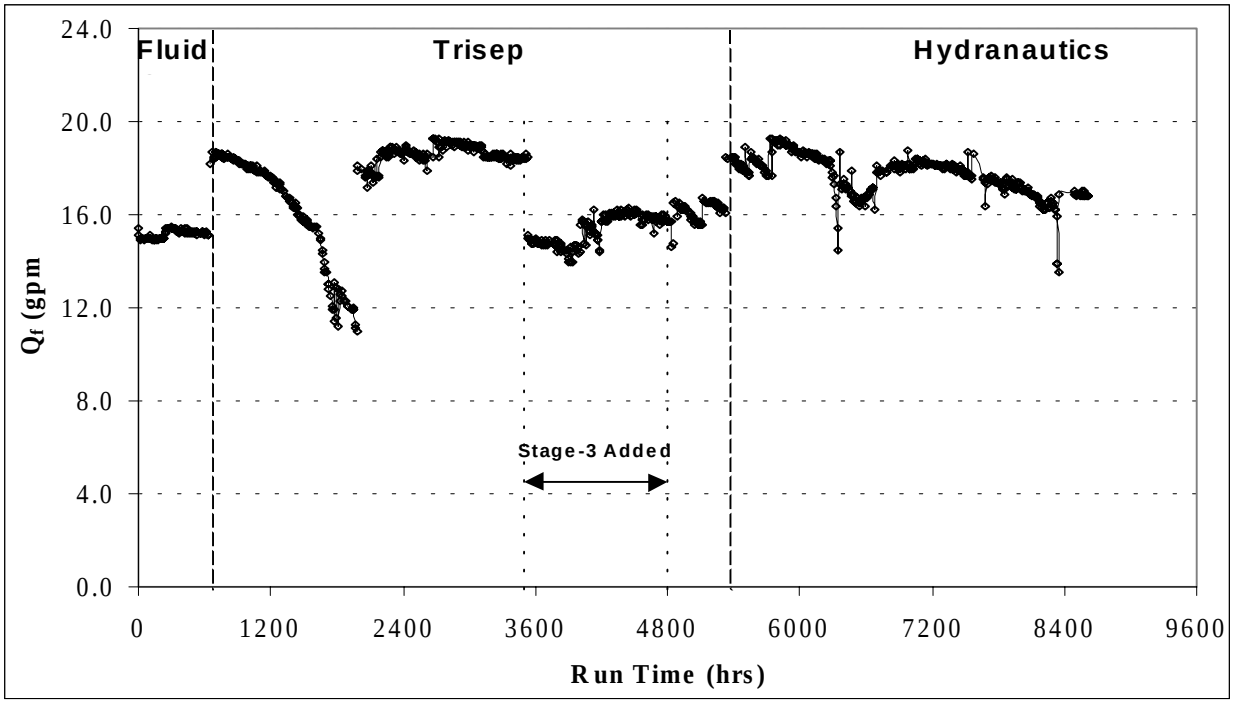


Figure 4.21: System Net Driving Pressure

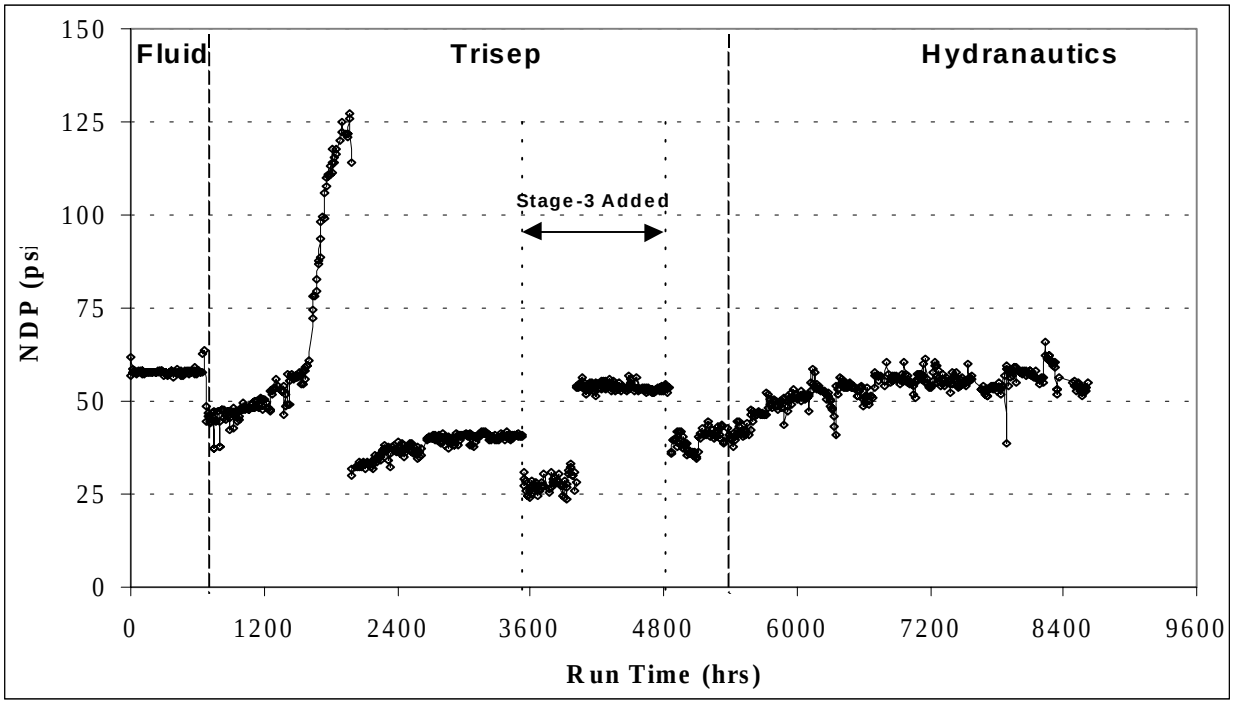


Figure 4.22: System Permeate TDS

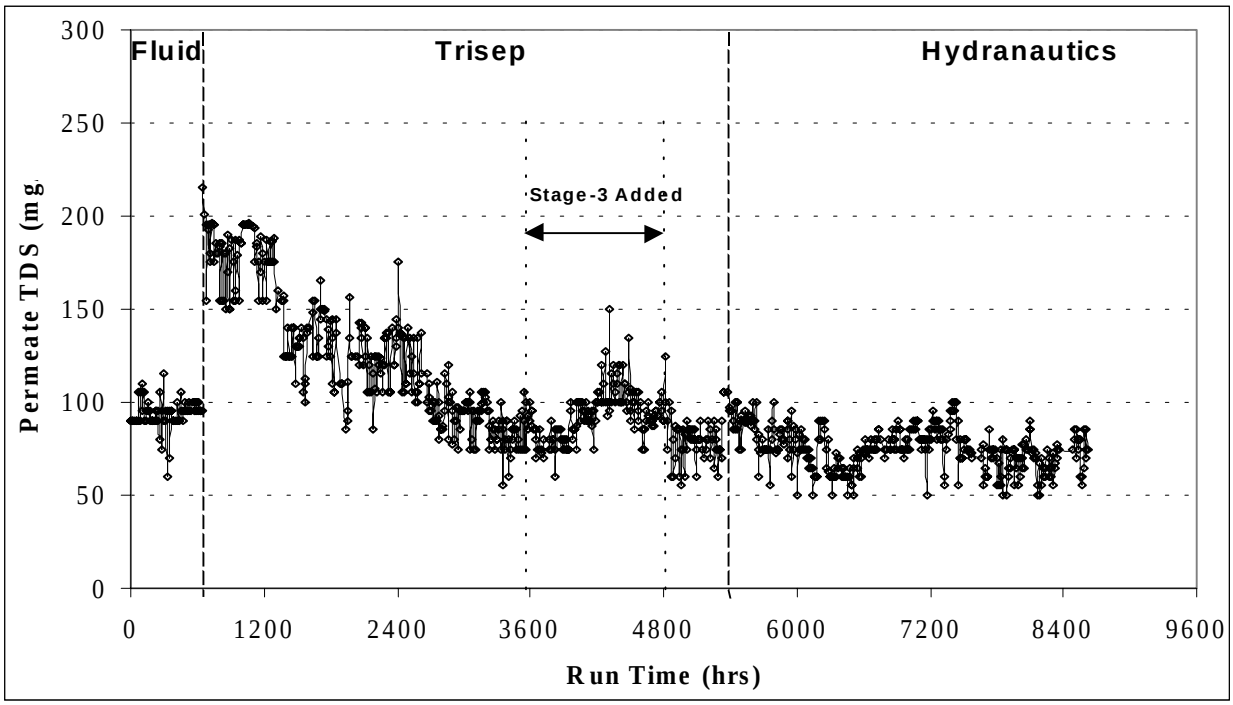


Figure 4.23: System Headloss

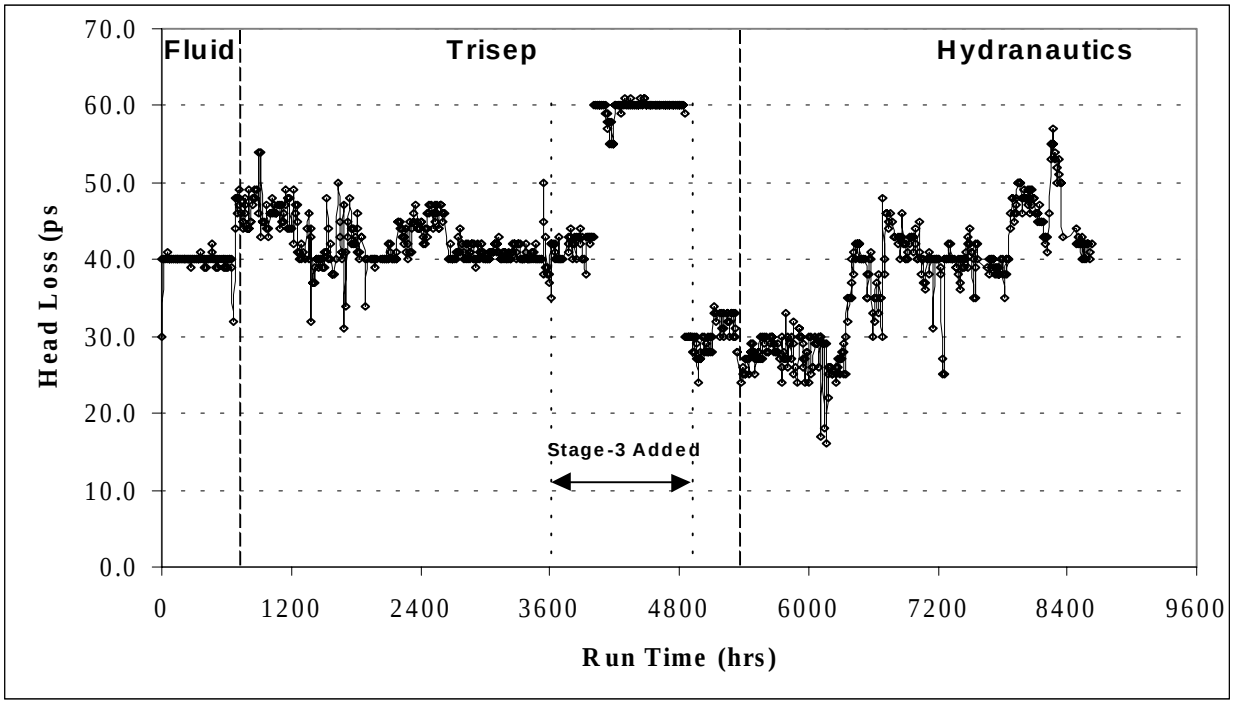
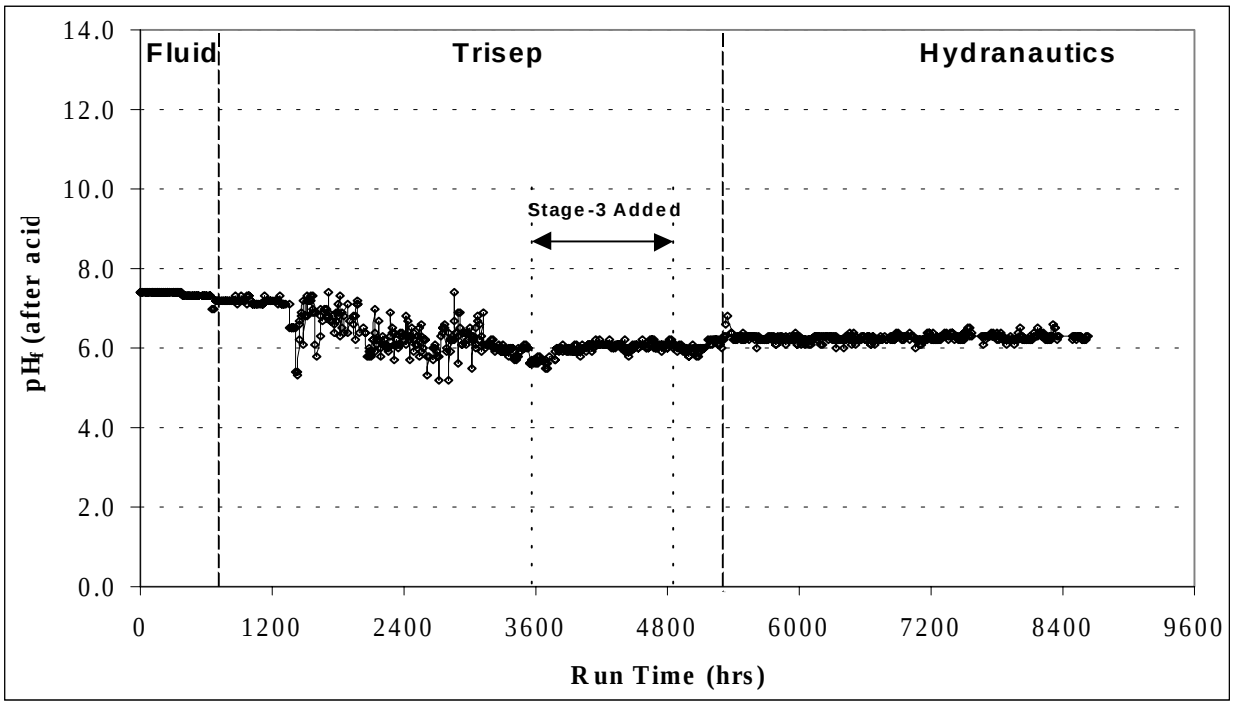


Figure 4.24: System Feed pH After Acid Addition



4.4.2 Impact Of Specific Variables On Production

As discussed previously, the experimental design varied membrane pilot plant design to produce various operational scenarios. These scenarios resulted in variations of overall system production. The major variables that were investigated include chemical pretreatment and NF assembly components. Seasonal variability was also monitored during the course of the year of operation, however, as discussed previously feed water temperature did not vary greatly, and therefore, did not have a noticeable impact on production.

During the operation of the pilot plant chemical pretreatment consisted of various combinations of scale inhibitor and sulfuric acid. During operation with the Fluid Systems elements the use of scale inhibitor alone proved to be effective pretreatment and did not result in fouling during the one month period of operation. However, when the TriSep elements were used in the pilot plant assembly, and pretreatment consisted of both scale inhibitor and sulfuric acid, as projected necessary by the manufacturer, there was an immediate substantial decline in production as can be noted on the MTC graph in Figure 4.17. After the membranes were cleaned chemical pretreatment was reduced to sulfuric acid only, and production decline for the TriSep and then Hydranautics was kept to a minimum. The feed pH versus operation time is depicted in Figure 4.24.

Only one cleaning was required during the operation of the pilot plant. This cleaning occurred in mid-September, 1998. Based on a gradual decline in production with use of the Hydranautics elements at the end of the testing period, the MTC graph suggests that a system cleaning may be necessary before additional pilot testing is performed. It was not necessary to perform a cleaning prior to the completion of the ICR pilot study.

During the pilot testing five element configurations were analyzed. These configurations impacted permeate water production by utilizing various manufactured elements, number of stages, and system recoveries. System recoveries are depicted in Figure 4.18. As system recoveries were increased, permeate production increased. As system production decreased NDP increased as illustrated in Figure 4.21. The MTC is an indicator of production per energy exerted. Based on MTC data it appears that the Fluid Systems (0.16 gfd/psi) and the Hydranautics (0.18-0.30 gfd/psi) elements provide the most stable operation. However, when the third stage was balanced for 90-percent recovery for the TriSep three stage system, the MTC stabilized between 0.20 and 0.30 gfd/psi.

Based on the data Figure 4.23 illustrates that the largest headloss across the system during the year of operation occurred during the operation with 90-percent recovery after additional valving had been added. This increased headloss is approximately 20 psi greater than headloss during other operational scenarios. This is a direct result of the increased valving that was installed in order to apply permeate back pressure to the second stage.

4.5 Conceptual Estimate of Full-Scale Costs

This section presents the conceptual estimate of costs for the design and construction, and the operation and maintenance of a full-scale 15 MGD - MDD WTP. It is assumed that the WTP will provide 15 MGD – MDD utilizing six 2.5 MGD skids with a system recovery of 90-percent. The capital cost includes costs associated with improvements to and expansion of the existing well field. Blend of the permeate and the raw water will not be provided, and it is assumed that the means of concentrate disposal is by deep well injection. Tables 4.2 and 4.3 provide conceptual estimates of full scale costs for the design and construction, and the operation and maintenance, respectively, of the 15 MGD MDD WTP. These costs are subject to change due to variable factors such as the economy and raw material availability. Actual equipment design and selection is also subject to change during preliminary and final design.

Table 4.2 [(1)]
Conceptual Estimate of Capital Cost
(15 MGD MDD Membrane Softening Facility)

Item	Cost
Raw Water Supply Facilities	$1,630,000
Process Building	$1,500,000
Sand Separation	$100,000
Cartridge Filtration	$210,000
NF Feed Pumps	$450,000
NF Process Units	$3,000,000
Chemical Storage and Feed	$300,000
Permeate Degassifiers	$600,000
Disinfection	$250,000
Clearwell and Transfer Pumps	$750,000
Ground Storage	$600,000
High Service Pumps	$400,000
Concentrate Disposal	$3,500,000
Yard and Process Piping	$3,000,000
Subtotal	***$16,290,000***
Mobilization	$326,000
Site Work	$250,000
Electrical	$1,629,000
Instrumentation	$815,000
HVAC and Plumbing	$815,000
Subtotal	***$20,125,000***
Engineering	$2,444,000
Permitting	$25,000
Contingency	$3,258,000
Total Cost	**$25,852,000**
Total Capital Cost per gallon per day installed	***$1.72***

Notes: (1) The costs presented in this table are intended to be used for planning purposes only as they do not represent design-based engineering evaluations or engineering opinions of probable cost.

Table 4.3[(1) (2)]
Conceptual Estimate of Operation and Maintenance Costs
(15 MGD Membrane Softening Facility)

Item	Cost ($/1,000 gal)
Labor	$0.14
Chemicals	$0.09
Power	$0.15
Membrane Replacement [(3)]	$0.09
Other	$0.06
Total	**$0.53**
Total Annual O&M Cost	***$2,900,000***

Notes: (1) Estimated costs are based on average O & M costs for Florida Membrane Softening Facilities of Similar Size. Actual O & M costs for this facility will vary.
(2) The costs presented in this table are intended to be used for planning purposes only as they do not represent design-based engineering evaluations or engineering opinions of probable cost.
(3) Membrane replacement is based on a 5-year replacement schedule. Actual membrane life may vary.

Appendix

Appendix A – Calibration Procedures

Table A-1
Calibration Verification and Quality Control Procedures – Method Specific
Montgomery Watson Laboratories

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

Table A-1 (Cont.)
Calibration Verification and Quality Control Procedures – Method Specific
Montgomery Watson Laboratories

Performance Criteria	Method / Analytes	EPA300.0 A, B *Br*	SM 6251B Haloacetic Acids *(HAA)*	*UV 254* SM 5910 B *UV 254*
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-***	***MCAA***	***UV254***
		(mg/L) (% rec.)	***(ug/L) (% rec.)***	***(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})

Table A-1 (Cont.)
Calibration Verification and Quality Control Procedures – Method Specific
Montgomery Watson Laboratories

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	NA
9.0	**Surrogate Standards**		NA	70-130 % 2,3-dibromopropionic acid	NA

Table A-1 (Cont.)
Calibration Verification and Quality Control Procedures – Method Specific
Montgomery Watson Laboratories

Performance Criteria	**Method** **Analytes**	**EPA300.0 A, B** ***Br***	**SM 6251B** **Haloacetic Acids *(HAA)***	***UV 254*** **SM 5910 B *UV 254***
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	

Table A-2
Calibration Verification and Quality Control Procedures – Method Specific
Montgomery Watson Laboratories

Performance Criteria	Method	THMs EPA 551.1	TOC SM 5310 C	TOX SM 5320B
	Analytes	***THM***	***TOC***	***TOX***
	Target Analytes	**Trihalomethanes (THMs)** Chloroform (CHCl3) Bromodichloromethane (BDCM) Dibromochloromethane (DBCM) Bromoform (CHBR3)	**Total Organic Carbon**	**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 IDA	**QC check sample**	+/- 20% of true value	+/- 20% of true value	+/- 20% of true value
1.3 IDP	**No. of replicates**	5	5	5
	Spike conc.	THM 20 ug/L	TOC 4 mg/L	TOX 250 ug/L
	% RSD	< 20	< 20	< 20
	% Recovery	80-120	80-120	80-120
1.4 MDL				
	No. of replicates	7	7	7
	Spike conc.	1/2 MRL	0.5	1/2 MRL
	% Recovery	50-150	50-150	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)

Table A-2 (Cont.)
Calibration Verification and Quality Control Procedures – Method Specific
Montgomery Watson Laboratories

	Performance Criteria	Method	THMs EPA 551.1	TOC SM 5310 C	TOX SM 5320B
3.0	**Calibration Verification**	**Verification Frequency**	Lowest level std. analyzed at the beginning of each 24 hr before the first sample	Lowest level std. analyzed at the beginning of each 24 hr before the first sample	3 microcoulometer titration cell checks with NaCl std at start of 8-10 hr. work shift. Lowest level std. analyzed before the first sample.
	Conc.		Mid level and high level analyzed alternately after every 10th sample and last sample	Mid level and high level analyzed alternately after every 10th sample and last sample	Mid level and high level analyzed alternately after every 7th sample and last sample
	and QC criteria (%rec)		*THM* *(ug/L)* *(% rec)*	*TOC* *(mg/L)* *(% rec)*	***TOX*** (ug Cl-/L) (% rec)
		Low	1.0 50-150	0.7 (0.5) 50-150	50 (25) 75-125
		Mid-level	20 80-120	4 90-110	200 85-115
		High	40 80-120	9 90-110	500 85-115
4.0	**Reagent (Method) Blank**	***Frequency***	One per analysis batch (one per extraction batch)	One per analysis batch	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.
	QC criteria		< 1/2 MRL	< 1/2 MRL,< 0.35, or< 0.25	<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

Table A-2 (Cont.)
Calibration Verification and Quality Control Procedures – Method Specific
Montgomery Watson Laboratories

	Performance Criteria	Method	THMs EPA 551.1	TOC SM 5310 C	TOX SM 5320B
6.0	**LFM**	***Fortified Sample***			
	Frequency		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
	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

Table A-2 (Cont.)
Calibration Verification and Quality Control Procedures – Method Specific
Montgomery Watson Laboratories

	Performance Criteria	Method	THMs EPA 551.1	TOC SM 5310 C	TOX SM 5320B
10.0	**Method Calibration Procedures**	**Initial Calibration Curve**	THMs: CHCL3, BDCM Concentration (ug/L)	Conc. (mg/L)	
	Trihalomethane	**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		

Appendix B – Autopsy Report

Appendix C – List of Biweekly Sampling Events

Table C-1
Completed Biweekly
Sampling Events

Sampling Event No.	*Sampling Event Date*	*Membrane Element Tested (Manufacturer)*
1.	*5/21/98*	*Fluid Systems*
2.	*6/4/98*	*TriSep*
3.	*6/17/98*	*TriSep*
4.	*6/30/98*	*TriSep*
5.	*7/13/98**	*TriSep*
6.	*7/28/98*	*TriSep*
7.	*8/14/98*	*TriSep*
8.	*8/26/98*	*TriSep*
9.	*9/10/98*	*TriSep*
10.	*9/23/98*	*TriSep*
11.	*10/9/98**	*TriSep*
12.	*10/22/98*	*TriSep*
13.	*11/6/98*	*TriSep*
14.	*11/19/98*	*TriSep*
15.	*12/2/98*	*TriSep/Hydranautics*
16.	*12/15/99**	*Hydranautics*
17.	*12/29/99*	*Hydranautics*
18.	*1/13/99**	*Hydranautics*
19.	*1/25/99*	*Hydranautics*
20.	*2/16/99*	*Hydranautics*
21.	*3/11/99*	*Hydranautics*
22.	*4/13/99**	*Hydranautics*

Note: The asterisk denotes sampling events on which duplicate field analyses were performed.

Appendix D – Treatment Study Diskettes