

# **ICR Treatment Study Summary Report**

## **Evaluation of Membrane Technology Using the Rapid Bench-Scale Membrane Test for Compliance with the Information Collection Rule**

**Conducted during the period of April 1998 through February 1999**

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Sioux Falls Water Purification Plant (ICR number 604)

Attachments: CD-ROM containing the *Data Collection Spreadsheets*,  
*Summary Spreadsheets*, and *ICR Treatment Study Summary Report*

## **Preface**

The study team for this project involved personnel from three different entities. Mr. Tim Stefanich, Environmental Engineer, was the technical contact with the City of Sioux Falls Water Purification System. The RBSMT procedures were conducted by personnel from the Northern Great Plains Water Research Center (NGPWRRC) at South Dakota State University. Dr. Delvin DeBoer coordinated the work at SDSU, and Mr. Chad Bachman, Environmental Engineering Graduate Research Assistant, conducted the laboratory procedures for the RBSMT. Laboratory samples requiring analysis by an EPA-approved ICR laboratory were sent to Environmental Health Laboratories in South Bend, IN. Samples collected during the RBSMT that did not require analysis by an EPA-approved ICR laboratory were analyzed in the NGPWRRC Laboratory at SDSU.

The RBSMT testing procedure was chosen over the other membrane treatment study options because 1) the test procedure could be conducted on a relatively small water sample, 2) long-term, non-chlorinated membrane feed water for the alternate membrane protocols would be very difficult to obtain, given the current practice of pre-chlorination ahead of the filters at the Sioux Falls Water plant, 3) the RBSMT test equipment was already available at SDSU, a 45 minute drive from Sioux Falls, and 4) the procedure appeared to be the most cost-effective ICR Bench-Scale test alternative for Sioux Falls.

The treatment study followed protocol described in The ICR Manual for Bench- and Pilot Scale Treatment Studies (EPA 814-B-96-003, April 1996). This manual provided detailed information on setting up, operating, monitoring and sampling procedures needed to fulfill requirements for the ICR RBSMT treatment study.

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## **I. Conclusions and Recommendations**

The RBSMT study encompassed four quarterly runs, occurring from April 22, 1998 to February 10, 1999. The study compared the performance of two conventional softening membranes (Film-Tec NF70-400 and Fluid Systems TFC-S) and two non-softening membranes (Film-Tec NF-200B and Hydranautics NTR-7450). These membranes were evaluated to determine their ability to remove DBP and DBP precursors from the City of Sioux Falls water supply. Quarterly tests were run over a period of one year to determine how seasonal variations in the water supply would affect the performance of these nanofiltration membranes.

All four membranes investigated in this study successfully removed DBP precursors (TOC) and DBPs (measured by SDS tests) from the water. Permeate THM<sub>4</sub> and HAA<sub>6</sub> concentrations of the membrane permeates were well below the Stage 1 MCLs, and in many cases, below the method minimum reporting level. In all cases, DBP concentrations were also below the proposed Stage 2 MCL's of 40 µg/L and 30 µg/L for THM<sub>4</sub> and HAA<sub>6</sub>, respectively. As expected, higher concentrations of constituents were generally present in the permeate stream at higher percent recoveries, but these concentrations never exceeded the proposed Stage 2 MCL's.

The conventional softening membranes and the Film-Tec NF-200B rejected nearly 100 percent of the feed TOC (assuming a permeate concentration below the minimum reporting level is completely removed). The NTR7450 membrane achieved a lower percent rejection of TOC (70-80%.) The DBP and DBP precursor removals achieved in the Sioux Falls RBSMT are typical of the nanofiltration membranes.

Seasonal variation was investigated to determine how it would effect the performance of the membrane. The Big Sioux River contributes approximately 40% of the influent to the water treatment plant. During the spring run-off season, TOC and UV<sub>254</sub> concentrations are relatively high. The RBSMT was operated over the one year period at quarterly intervals (April, July, October, and January). During these quarters, the RBSMT feed water TOC did not vary as much as expected, but temperature and detention time in distribution system varied. Evaluation of the RBSMT data revealed that seasonal variation did not influence the performance of the membranes. Rejections of the various DBP and DBP precursors did not deviate significantly from quarter to quarter.

The RBSMT demonstrated that the Sioux Falls treated water quality can be improved to meet the proposed Step II DBP levels using any one of the four different membranes. One of the well known disadvantages of the RBSMT is its lack of ability to accurately determine operational constraints, such as long-term fouling and long-term cleaning requirements. However, the results from this study encourage further investigation of the use of a membrane system. Selection of a non-softening membrane, such as the Hydranautics NTR-7450 or similar membrane, is recommended if the city pursues further investigations of membranes to help control DBP and DBP precursors.

The Hydranautics membrane exhibited several advantages over the other membranes. Although the organic matter removals exhibited by the NTR-7450 were slightly less than those of the other three membranes, the permeate SDS DBP concentrations were still well below the stage 2 MCL's for THM4 and HAA6. The use of a non-softening membrane would result in lower costs associated with pre-treatment and

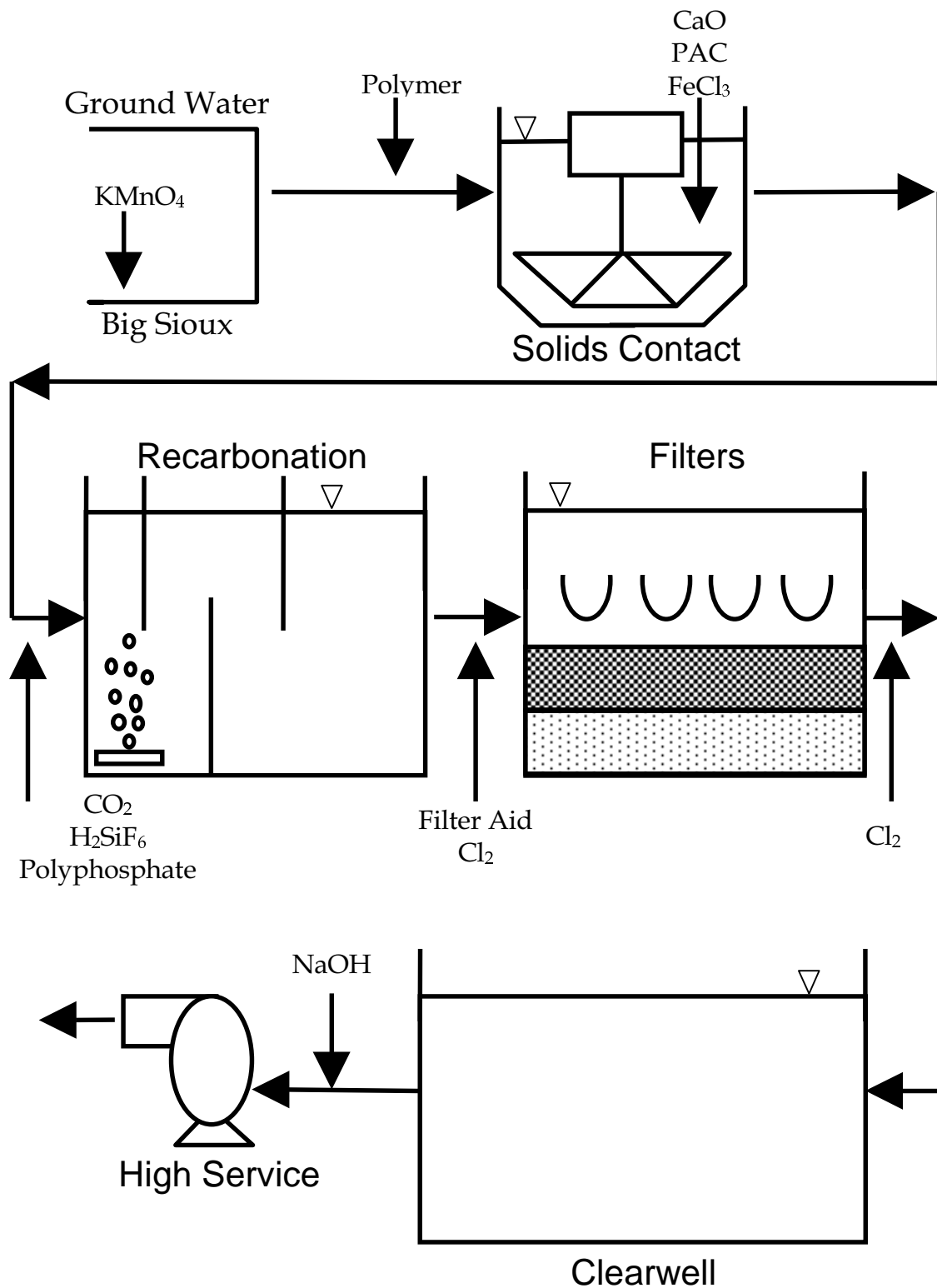
post-treatment, when compared to a softening membrane. Additionally, the NTR-7450 exhibited lower net driving force pressures than the other non-softening membrane, which would contribute to a lower operational cost.

## **II. Background Information**

### **Treatment Plant Description**

The Sioux Falls Water Purification facility obtains source water primarily from the Big Sioux aquifer and the Big Sioux River. In 1998, the City pumped a total of 7.66 billion gallons of water from their sources, 40.6 percent of which came from the Big Sioux River and the remainder was obtained from ground water sources. The City uses a blend of these sources during most of the year. However, the Big Sioux River experiences periods of high organic matter concentration and tastes and odors during spring runoff. During these periods of adverse river water quality, the Big Sioux Aquifer is the primary water source. Depending on source water quality, treatment objectives can include taste and odor control, turbidity removal, hardness removal, organics removal, iron and manganese removal, fluoridation, disinfection, and pH adjustment for corrosion control.

In order to accomplish the desired treatment objectives, the Sioux Falls plant utilizes a process flow schematic shown in Figure 2.1. Taste and odor control is accomplished via oxidation and adsorption. Turbidity, hardness removal, iron and manganese removal, and organics removal are accomplished through the softening/clarification/filtration process. Post-filter free chlorination is currently utilized for disinfection. Treatment plant design data for the major unit processes found at the Sioux Falls Water Purification Plant are summarized in Table 2.1.



**FIGURE 2.1 Schematic of Full-Scale Treatment Processes Found at the Sioux Falls Water Purification Plant.**



**TABLE 2.1 Tabular Summary of Full-Scale Treatment Plant Design Data for Sioux Falls Water Purification Plant.**

<b>Unit Process</b>	<b>Process Description</b>
<b>Solids Contact Clarifier</b>	Clarifier Type: SB Brand Name: Hydrotreator (5 basins), Seftec (1 basin) Surface Area (total): 18,816 ft <sup>2</sup> Baffling Type: PR Lime Addition: Calcium Oxide Lime Dose: 221 mg/L Coagulant Addition: Ferric Chloride Coagulant Dose: 3.2 mg/L Adsorption Addition: Powdered Activated Carbon (PAC) Adsorption Dose: 3.9 mg/L
<b>Recarbonation</b>	Surface Area (total): 1,488 ft <sup>2</sup> (even split to two basins) Liquid Volume: 167,000 gallons Baffling Type: AV Chemical Type: Carbon Dioxide Dose Rate: 12.4 mg/L Chemical Type: Polyphosphate Dose Rate: 0.19 mg/L
<b>Disinfectant Addition</b>	Chemical Type: Chlorine Gas Measured as: Cl <sub>2</sub> Dose Rate: 1.20 mg/L
<b>Filtration</b>	Surface Area (total): 7,000 ft <sup>2</sup> (10 filters) Liquid Volume: 523,600 gallons Total Media Depth: 30 in Depth of GAC: 20 in Media Type: Dual-GACS/Sand Type of Activated Carbon: F3 Minimum Water Depth to Top of Media: 4.0 ft Depth From Top of Media to Top of Backwash Trough: 3.7 ft Chemical Type: Filter Aid Dose Rate: 0.29 mg/L
<b>Disinfection</b>	Chemical Type: Chlorine Gas Measured as: Cl <sub>2</sub> Dose Rate: 4.05 mg/L
<b>Clear Well</b>	Surface Area: 44,350 ft <sup>2</sup> Liquid Volume: 4,000,000 gal Minimum Liquid Volume: 1,000,000 gal Baffling Type: AV Short Circuiting Factor: Covered Contactor: Y Chemical Type: Caustic Soda Dose Rate: 0.32 mg/L

The hydraulic treatment capacity of the treatment plant is 54 MGD. The City continues to follow a capital improvement plan necessary to meet the water needs of its growing population.

The location and dosages of the chemicals used in the treatment processes are summarized in Table 2.2. Since chemical feeds directly affect the quality of the water used for the feed water for the RBSMT, additional discussion of the nature and disposition of the chemical feeds is provided.

**TABLE 2.2 Chemicals and Average Dosages used at the Sioux Falls Purification Plant (1998)**

<b>Chemical</b>	<b>Place of Addition</b>	<b>Dose (mg/L)</b>
Potassium Permanganate	River Intake	3.28
Calcium Oxide	Contact Basins	221
Powdered Activated Carbon	Contact Basins	3.9
Polymer, Anionic	Contact Basins	1.59
Ferric Chloride	Contact Basins	3.2
Carbon Dioxide	Recarbonation Basins	12.4
Polyphosphate	Recarbonation Basins	0.19
Hydrofluosilic Acid	Recarbonation Basins	NA
Filter Aid	Filter Influent	0.29
Chlorine	Filter Influent	NA
	Filter Effluent	4.05
Caustic Soda	High Service Pumps	0.32

KMnO<sub>4</sub> is fed into the raw water at the river intake before the water travels through the water line to the treatment plant. KMnO<sub>4</sub> is added as needed to the raw surface water for taste and odor control.

Lime is added to the six contact basins to precipitate calcium and magnesium and enhance turbidity and TOC removal. The lime slurry is fed directly into the Dorr-Oliver basins in two different locations, 180 degrees apart, on a plan view of the basins. The vertical lime feed flow pattern is intersected by the horizontal flow pattern of the distributed influent water coming in the basin, which mixes the chemical with the hard water. Lime is introduced to the SefTec-equipped basin into the internal mixing compartment of the basin where mixing is accomplished by a mechanical mixer.

Powdered Activated Carbon (PAC) is added to the solids contact basins to help control taste and odor problems. PAC is bulk delivered and wetted to a 0.75 percent slurry. An anionic polymer and/or ferric chloride are added as needed prior to the solids contact basin to enhance floc formation and coagulation.

Carbon dioxide (CO<sub>2</sub>) is added to the recarbonation basins to lower the pH following the softening process. The CO<sub>2</sub> is used to decrease the pH of the softened water to approximately 9.3.

A small dose of polyphosphate is added prior to the recarbonation basins to control scale deposition on the filter media.

The source water has a fluoride average concentration of 0.3 mg/L. Suitable doses of hydrofluosilic acid are added prior to recarbonation to obtain an appropriate fluoride residual in the distribution system.

Currently, the city feeds chlorine to the filter influent and the clearwell influent. Chlorine is added at approximately 1.0 mg/L prior to filtration to control biological growth on the filters. As described in the RBSMT protocol, this feed was discontinued during the sample collection period in order to obtain samples of filtered water that had no prior contact with chlorine. A dose of approximately 4.0 mg/L is added prior to clearwell influent for disinfection. In 1998 an average chlorine residual of 1.2 mg/L was maintained in the distribution system.

Free chlorine is used as the primary disinfectant of the treatment facility. Chlorine can be fed into the water at the plant influent, filter influent, clearwell influent, and clearwell effluent prior to the distribution system.

Treatment Challenges Facing the Plant. The Sioux Falls Water Purification Plant faces the following treatment challenges.

1. Water quality in the spring produces challenging taste and odor problems.

The odors are categorized as having an earthy, musty nature. The problem seems to be provoked by the use of free chlorine, especially in the distribution system. It is thought that the odor is caused by an unknown class of organics in the river. The problem is currently being treated with potassium permanganate and powdered activated carbon.

2. Algae blooms in the river during the summer months are also another treatment challenge. The algae pass through the solids contact basins and

collect on the filters. The build-up of algae on the filters leads to a rapid headloss increase through the filters, thus requiring more frequent backwash.

3. The TTHM formation potential of the natural organic matter in the river limits the percentage of surface water in the blended raw water. This problem is most common during the summer months when a higher water temperature is experienced.

### **Water Quality Summary**

Source water and treated water quality for 1998 are summarized in Tables 2.3 and 2.4. Data for these tables were obtained from the Sioux Falls ICR sampling program for the 12 months of 1998. The impacts of treatment on the water quality are quite obvious, with reductions in hardness and alkalinity through the softening process, and excellent turbidity removal. TOC is removed in the facility, primarily through the softening process. The bromide level of the Sioux Falls water is relatively low.

**TABLE 2.3 Summary of Source Water Quality For the Sioux Falls Water Purification Plant in 1998**

<b>Water Quality Parameters</b>	<b>Average. Value</b>	<b>Standard Deviation</b>	<b>Maximum Value</b>	<b>Minimum Value</b>
Temperature, °C	14.2	4.9	22.1	5.0
pH	7.48	0.14	7.86	7.05
Turbidity, NTU	30.2	19.3	200	2.8
Alkalinity, mg/L as CaCO <sub>3</sub>	273	23	333	211
Calcium Hardness, mg/L as CaCO <sub>3</sub>	324	36	439	242
Total Hardness, mg/L as CaCO <sub>3</sub>	541	45	682	428
TOC, mg/L	4.77	0.84	7.78	2.75
UV <sub>254</sub> , /cm	0.120	0.025	0.206	0.062
Bromide, µg/L	70	60	280	0

**TABLE 2.4 Summary of Finished Water Quality for the Sioux Falls Water Purification Plant in 1998**

<b>Water Quality Parameters</b>	<b>Average. Value</b>	<b>Standard Deviation</b>	<b>Maximum Value</b>	<b>Minimum Value</b>
Temperature, °C	12.0	5.1	20.9	4.0
pH	8.71	0.22	9.09	7.82
Turbidity, NTU	0.06	0.01	0.03	0.09
Alkalinity, mg/L as CaCO <sub>3</sub>	44	9	68	27
Calcium Hardness, mg/L as CaCO <sub>3</sub>	143	19	195	100
Total Hardness, mg/L as CaCO <sub>3</sub>	309	29	394	197
TOC, mg/L	3.14	0.48	4.71	1.71
UV <sub>254</sub> , /cm	0.044	0.007	0.062	0.030
Bromide, µg/L	1	6	90	0

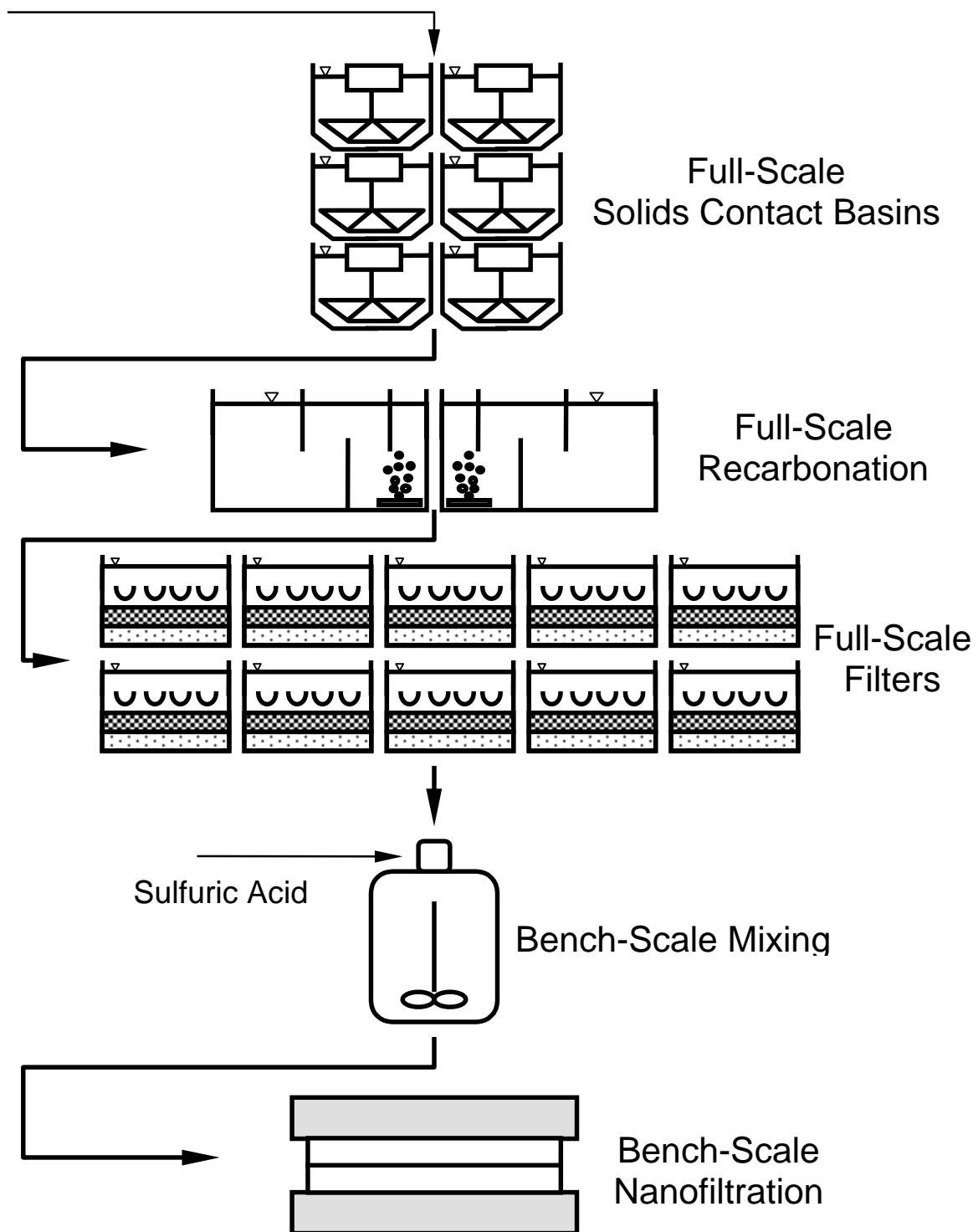
### **III. Materials and Methods**

#### **Pretreatment Prior to Advanced Treatment Process**

The following figures and tables summarize the pretreatment processes used prior to the RBSMT treatment study. Figure 3.1 shows a schematic of the pretreatment processes used for the RBSMT study, including full- and bench-scale treatment processes. In addition, design data for each of these pretreatment units can be seen in Table 3.1.

The feed water to the RBSMT was collected from an 8-inch pipe connected to the combined filter effluent channel, providing a representative sample of water treated by all ten filters. The ICR Manual for Bench and Pilot Scale Treatment Studies protocol requires feed water to the treatment study be collected after all treatment processes currently used to remove DBP precursors. Since the filters at the plant contain GAC, filtration is the final treatment unit used to remove DBP precursors and is the treatment unit immediately prior to disinfection.

The ICR protocol also requires the membrane feed water to be collected at a point in the treatment process before any application of any oxidant or disinfectant that could form DBP's. To satisfy this requirement, prior to collection of the sample, the filter influent chlorine feed was shut off for a sufficient period to deplete the residual to zero chlorine. This procedure resulted in the collection of filtered sample water free of any chlorine residual.



**FIGURE 3.1 Schematic of Pretreatment Processes Used Prior to Bench-Scale Nanofiltration**



**TABLE 3.1 Treatment Plant Design Data for Each Pretreatment Unit Process Prior to the Advanced Treatment**

Unit Process	Process Description
Solids Contact Clarifier (Full-Scale)	Clarifier Type: SB Brand Name: Hydrotreator (5 basins), Seftec (1 basin) Surface Area: 18,816 ft <sup>2</sup> Baffling Type: PR Lime Addition: Calcium Oxide Lime Dose: 221 mg/L Coagulant Addition: Ferric Chloride Coagulant Dose: 3.2 mg/L Adsorption Addition: Powdered Activated Carbon (PAC) Adsorption Dose: 3.9 mg/L
Recarbonation (Full-Scale)	Surface Area: 1,488 ft <sup>2</sup> Liquid Volume: 167,000 gallons Baffling Type: AV Chemical Type: Carbon Dioxide Dose Rate: 12.4 mg/L Chemical Type: Polyphosphate Dose Rate: 0.19 mg/L
Filtration (Full-Scale)	Surface Area: 7,000 ft <sup>2</sup> Liquid Volume: 523,600 gallons Total Media Depth: 30 in Depth of GAC: 20 in Media Type: Dual-GACS/Sand Type of Activated Carbon: F3 Minimum Water Depth to Top of Media: 4.0 ft Depth From Top of Media to Top of Backwash Trough: 3.7 ft Chemical Type: Filter Aid Dose Rate: 0.29 mg/L
Scale Control (Bench-Scale)	Chemical Type: Sulfuric Acid Adjusted pH: 7.3

To inhibit fouling in the RBSMT treatment study, additional bench-scale pretreatment measures were needed. The pH of the sample was decreased to obtain a conservative Langlier Saturation Index (LSI) in the concentrate stream to avoid scaling problems. Equations discussed in the ICR Manual for Bench- and Pilot-Scale Treatment Studies, manufacturer's literature for the selected membranes, and records of past water quality obtained by the Sioux Falls Purification Plant were used to determine the pH needed to prevent inorganic scaling. Sulfuric acid was added to the sample to depress the pH of the sample.

Fouling indices and turbidity are used to determine if colloidal matter will decrease membrane performance. The SDI test was run according to ASTM D-4189-82 specifications on the water obtained after filtration. This sample water typically has a turbidity value of less than 0.01 NTU and produced a SDI value of less than one (1). Due to the low SDI and the extremely low turbidity, it was expected that colloidal matter would not cause a problem and therefore bench-scale cartridge filtration was not needed.

### **Advanced Treatment Process Information**

The RBSMT was the advanced testing procedure used to evaluate membrane technology in removing DBP precursors for the City of Sioux Falls, South Dakota. The intent of this section is to provide a detailed description of the RBSMT and to describe the procedures needed to successfully operate the system.

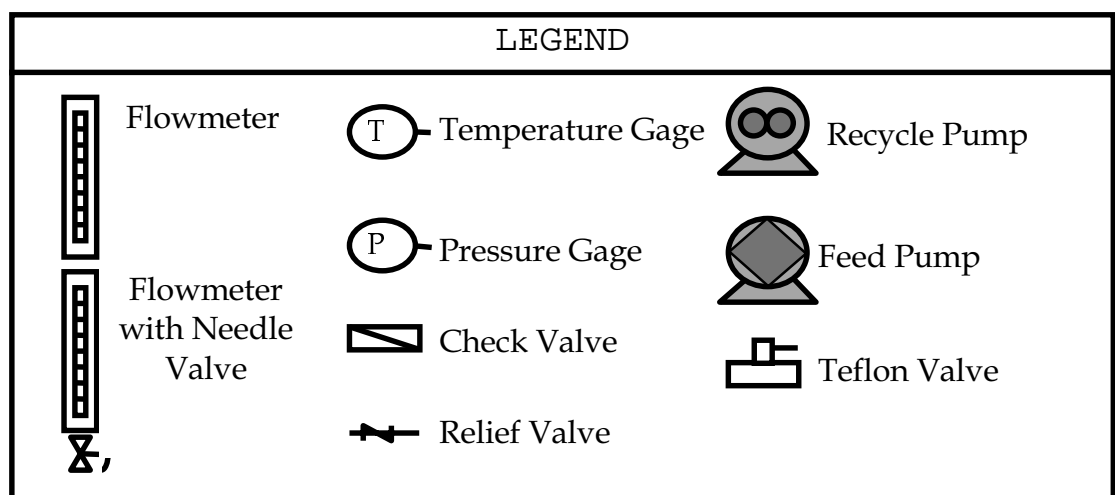
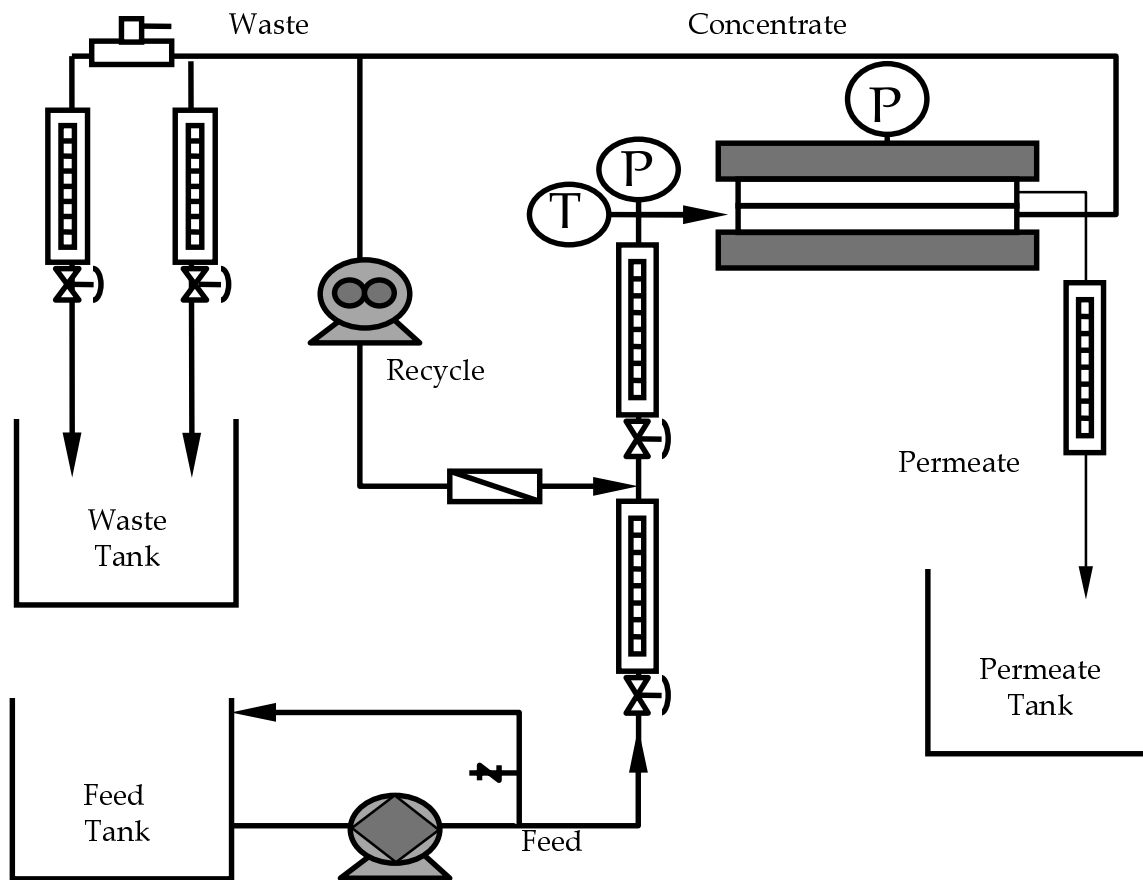
### RBSMT Equipment

The RBSMT system used for ICR treatment study requirement for the Sioux Falls Water Purification Plant is depicted in Figure 3.2. The tangential-cell system used was the SEPA CF membrane cell manufactured by Osmonics. The system consists of a stainless-steel cell body and cell holder as depicted in Figure 3.3. Samples of the feed spacers, permeate carriers, and membrane material from full-scale spiral-wound element are used in the cell. A membrane sheet having an effective surface area of 24 square inches and appropriate permeate spacer and carrier is placed between the two stainless-steel halves of the cell body and placed in the cell holder. The cell holder was pressurized to 150 psi using nitrogen gas.

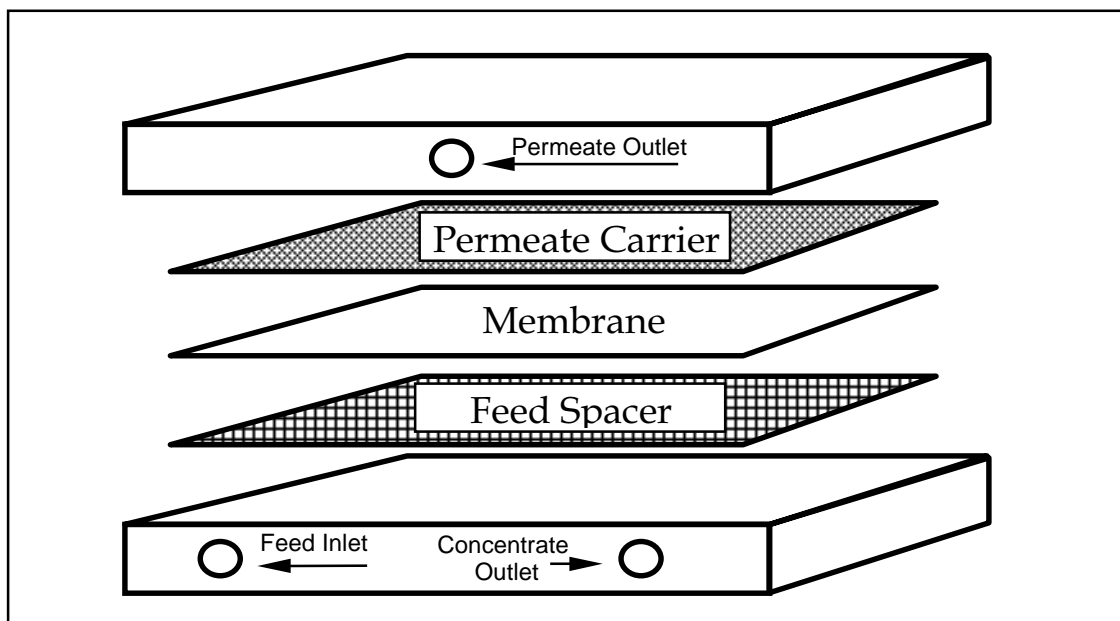
Pumps Two different variable-speed pumps, a feed and a recycle pump, were used to deliver flow to the system. A *MICROPUMP* rotary vane pump with graphite vanes was used to provide feed to the system. A 25mm in-line filter was placed downstream of the feed pump to protect against the occurrence of graphite shedding from the vanes. A second *MICROPUMP* gear pump was used as the recycle pump.

Hydraulic Flow and Connections The flow to the tangential-cell included a recycle loop. The recycle loop was incorporated to provide a portion of the concentrate stream into the system. This recycle loop enabled the system to operate at requisite crossflow velocities, and system recoveries.

Miscellaneous Equipment All parts of the system that came in contact with the water were constructed of either Teflon or stainless-steel. Five different flow meters



**FIGURE 3.2 Schematic of the RBSMT used for the City of Sioux Falls, South Dakota**



**FIGURE 3.3 Schematic of the Tangential-Flow Cell Body**

were needed to properly monitor flows in the RBSMT. Due to the range of required waste water flow measurements, a low-range and a high-range flow meter were used to accurately monitor the waste flow rate. *GILMONT* 150-mm direct reading flowmeters were used to monitor flows. The frame, fittings, floats, and valves of the flowmeters are composed entirely of 316 stainless steel and the meter body was glass. The temperature gauge, pressure gauge, and adjustable pressure relief valve were constructed of stainless steel.

#### RBSMT Design Data

The ICR treatment study for the Sioux Falls Water Purification evaluated four separate nanofiltration membranes, two membranes designed for organics removal and

two traditional softening membranes. The manufacturer-stated characteristics for each membrane are summarized in Table 3.3.

**TABLE 3.3 Summary of Membrane Characteristics Used in the RBSMT Treatment Study.**

	<b>Manufacturer</b>	<b>Element</b>	<b>pH Range</b>	<b>Max. Feed SDI</b>	<b>Max. Feed Turbidity</b>
A	Film-Tec	NF70-400	3 - 9	5	1 ntu
B	Fluid Systems	TFC-S	4 - 11	NA	1 ntu
C	Film-Tec	NF200B-400	3 - 10	5	1 ntu
D	Hydranautics	NTR-7450	3 - 9	NA	1 ntu

Tables 3.4 – 3.7 show the designed flowrates and pressures for the four different membranes being evaluated. The flowrates and pressures were determined using information provided by the membrane manufacturer and the design matrix found in the RBSMT Data Spreadsheets. The RBSMT was operated under the constant flux mode, and the design flux used for all four membranes was 15 gfd.

**TABLE 3.4 Summary of RBSMT Design Information for Membrane A**

<b>Recovery</b>	<b>Pressure</b>	<b>Q<sub>F</sub></b> (ml/min)	<b>Q<sub>I</sub></b> (ml/min)	<b>Q<sub>W</sub></b> (ml/min)	<b>Q<sub>P</sub></b> (ml/min)
70 %	78	9.4	336	2.8	6.6
90 %	103	7.3	336	0.7	6.6
50 %	73	13.2	336	6.6	6.6
30 %	71	21.9	336	15.4	6.6

**TABLE 3.5 Summary of RBSMT Design Information for Membrane B**

<b>Recovery</b>	<b>Pressure</b>	<b>Q<sub>F</sub></b> (ml/min)	<b>Q<sub>I</sub></b> (ml/min)	<b>Q<sub>W</sub></b> (ml/min)	<b>Q<sub>P</sub></b> (ml/min)
70 %	108	9.4	336	2.8	6.6
90 %	136	7.3	336	0.7	6.6
50 %	103	13.2	336	6.6	6.6
30 %	100	21.9	336	15.4	6.6

**TABLE 3.6 Summary of RBSMT Design Information for Membrane C**

<b>Recovery</b>	<b>Pressure</b>	<b>Q<sub>F</sub></b> (ml/min)	<b>Q<sub>I</sub></b> (ml/min)	<b>Q<sub>W</sub></b> (ml/min)	<b>Q<sub>P</sub></b> (ml/min)
70 %	86	9.4	336	2.8	6.6
90 %	102	7.3	336	0.7	6.6
50 %	83	13.2	336	6.6	6.6
30 %	81	21.9	336	15.4	6.6

**TABLE 3.7 Summary of RBSMT Design Information for Membrane D**

<b>Recovery</b>	<b>Pressure</b>	<b>Q<sub>F</sub></b> (ml/min)	<b>Q<sub>I</sub></b> (ml/min)	<b>Q<sub>W</sub></b> (ml/min)	<b>Q<sub>P</sub></b> (ml/min)
70 %	34	9.4	315	2.8	6.6
90 %	48	7.3	315	0.7	6.6
50 %	31	13.2	315	6.6	6.6
30 %	30	21.9	315	15.4	6.6

### RBSMT Procedures

The operating procedures for the RBSMT were prescribed by the ICR Manual For Bench- and Pilot-Scale Treatment Studies. The following section consists of two parts,

one provides a brief description of the protocol followed for the RBSMT and the second summarizes deviations from the recommended protocol.

Protocol Samples of the permeate carriers, membranes, and feed spacers were obtained from membrane manufacturers. A sample was carefully cut from the membrane sample, using previously made template, and sandwiched with the feed spacer and permeate carrier between the two halves of the cell body. The cell body was then inserted into the cell holder, where it was pneumatically sealed using non-combustible nitrogen gas.

Once the cell body was “clamped” into the cell holder, laboratory-grade deionized water was run through the system, at the required flowrates for the first recovery, for approximately 48 hours to set the membrane. A constant performance, with respect to temperature-normalized  $MTC_w$ , was typically obtained in this 48-hour period.

During the last few hours of the membrane setting, feed water was taken from 4°C storage and brought to room temperature. The pH of the water was then adjusted to a pH of 7.3 with sulfuric acid addition. The initial pretreated feed sample was collected at this time. Once setting was complete, pretreated water was then introduced into the RBSMT system. A short period of high flow, low pressure pumping was needed to completely flush the laboratory-grade water out of the system. After successful flushing of the system, the high-flow pumping was halted and flow rates were adjusted to those of the first recovery.

Monitoring of the system consisted of frequent and tedious monitoring procedures. Flow rates for the system were monitored at least every four hours, and



permeate TDS, TOC,  $UV_{254}$ , and pH monitored every eight hours. Feed and concentrate TDS, TOC,  $UV_{254}$  and pH were measured less frequently at only once a day. This was the recommended protocol according to the ICR manual. These were minimum monitoring frequencies, where monitoring after a change in recovery was generally more frequent. Recorded flow rates, temperature, and pressure were used to determine the temperature-normalized  $MTC_w$ .

Once stable membrane performance was obtained at the first recovery (Run #1), one-gallon samples of the permeate, concentrate, and feed water were collected. These samples were then analyzed (or shipped for analysis by Environmental Health labs, for parameters requiring ICR approved laboratory) for the necessary water quality parameters per the ICR RBSMT protocol. After collection of the sample at the first recovery, the flow rates were changed to achieve the second recovery. The same procedure were used for the second, third and fourth recoveries.

After samples were collected for the fourth recovery and before the membrane was removed from the cell body, the membrane was cleaned. Manufacturer information was consulted on recommended cleaning procedures. Initially, cleaning using both an alkaline solution and acidic solution was planned. However, in all cases, significant amounts of  $MTC_w$  were recovered after cleaning with the acidic solution; therefore, cleaning with the alkaline solution was not used.

A 0.2% solution  $HCl$  was used to clean the membrane. The cleaning process took place in 4 phases.

1. The HCl solution was heated to a temperature of 35°C and pumped at a high-rate, low-pressure scenario to flush the sample water from the system.
2. The system was pumped at low-flow, and low-pressure for a period of one hour to soak the membrane in the heated cleaning solution.
3. A high-flow pumping for a period of one hour was used as the third phase. A high-flow rate was needed to achieve a crossflow velocity of 0.5 ft/sec. At this velocity foulants loosened by the soaking phase are removed from the membrane surface. The pressure of the system never exceeds 20 psi during this phase, so avoid compacting the foulants on the surface of the membrane.
4. The feed water was pumped at high-rate, low-pressure to displace all the cleaning solution from the system. After successful flushing of the cleaning solution, feed water was run through the system at the final recovery flow rates and the  $MTC_w$  of the cleaned membrane was recorded.

After recording of the  $MTC_w$  for the cleaned membrane, the cell body was depressurized, and the membrane sample, permeate carrier, and feed spacer were removed. The second membrane to be evaluated for the quarter was then introduced into the system and subjected to the same RBSMT procedures as the first membrane.

Deviations from the ICR Protocol The ICR manual recommends that the permeate TDS, TOC,  $UV_{254}$ , and pH be monitored to ensure stable performance prior to collection of the samples. Values for the permeate TDS, TOC, and  $UV_{254}$  were often

very low (near detection limits), making it hard to distinguish between stable performance and analytical variability. The concentrate UV<sub>254</sub> result was used, in addition to the above parameters, to determine stable performance. When a stable concentration of concentrate UV<sub>254</sub> was achieved from the system in conjunction with relative stability of the other measured permeate parameters, the collection of the one-gallon water quality samples began.

### Experimental Design

The RBSMT treatment study for the Sioux Falls Water Purification Plant was designed to compare the performance of two nanofiltration membranes to successfully remove DBP precursors while investigating seasonal variability on a quarterly basis.

Table 3.8 provides a summary of the experimental design data used for the RBSMT Sioux Falls treatment study.

**TABLE 3.8 Summary of Experimental Design For a RBSMT Study**

Season	Membrane	Pretreatment	Water ( gfd )	Recovery ( % )
Spring	Membrane A	Conventional Filtration w/ Acid	15	30, 50, 70, 90
Spring	Membrane B	Conventional Filtration w/ Acid	15	30, 50, 70, 90
Summer	Membrane A	Conventional Filtration w/ Acid	15	30, 50, 70, 90
Summer	Membrane B	Conventional Filtration w/ Acid	15	30, 50, 70, 90
Autumn	Membrane A	Conventional Filtration w/ Acid	15	30, 50, 70, 90
Autumn	Membrane C	Conventional Filtration w/ Acid	15	30, 50, 70, 90
Winter	Membrane A	Conventional Filtration w/ Acid	15	30, 50, 70, 90
Winter	Membrane D	Conventional Filtration w/ Acid	15	30, 50, 70, 90

A design flux of 15 gfd was used for each membrane at every run. (Typical fluxes reported in the literature for nanofiltration membranes range from 10 to 20 gfd.) A constant flux of 15 gfd was used to ensure that product from the membrane was maximized without excessive fouling.

Two softening nanofiltration membranes, Film-Tec NF-70 and Fluid System TFC-S, were initially selected for the RBSMT treatment study. After the first and second quarters of testing, it was determined that the two membranes were producing very similar results. It was expected that the NF-70 and TFC-S would continue to perform similarly in the remaining two quarters. To provide the largest quantity of information for the ICR treatment study, it was proposed to EPA that two non-softening membranes, Film-Tec's NF-200B and Hydranautic's NTR-7450, would be evaluated in conjunction with the NF-70 membrane for the remaining two quarters. Upon receiving approval from the EPA, the NF-70 and NF-200B were evaluated in the third quarter and the NF-70 and NTR-7450 were evaluated in the fourth quarter.

Seasonal variation was also investigated. In 1998, Sioux Falls withdrew approximately 40% of their raw water from the Big Sioux River. The Big Sioux River experiences water quality variations at different times of the year. Historical seasonal variations of TOC and disinfection byproducts were documented in the original RBSMT proposal. Whereas the peak TOC concentrations typically appear in the Big Sioux River during the spring runoff period, the peak THM concentrations in the Sioux Falls distribution system appear during the warmest summer months, and are at the lowest levels during the winter months. In order to determine the seasonal variability, the quarterly RBSMT tests were conducted April 1998, July 1998, October 1998, and January 1999.

### Sampling and Analytical Methods

All analyses of water quality samples for the RBSMT study were conducted according to QA/QC procedures and methods described in the DBP/ICR Analytical Methods Manual. The procedures and methods used to conduct analyses for the RBSMT will be described in detail in this section. Environmental Health Laboratories (ICRIN004) was the EPA-approved lab was used to analyze the DBP and DBP precursors, ammonia, and bromide of the compliance samples. The remaining water quality parameters were analyzed in a university-affiliated laboratory; Northern Great Plains Water Resource Research Center (NGPWRRRC). Table 3.9 presents a summary of the laboratories involved in the study, including the RBSMT analyses performed by each lab and the period over which these analyses were conducted.

**TABLE 3.9 Summary of Laboratories Conducting Analyses During The RBSMT Study**

Laboratory	Dates of Service	Analyses Performed
University Lab A NGPWRRRC Lab	4/23/98 - 2/5/99	Alkalinity, Calcium Hardness, Chlorine Residual, pH, TDS, Temperature, Total Hardness, Turbidity (TOC and UV <sub>254</sub> only to determine stable membrane operation)
Commercial Lab B Environmental Health Laboratories	4/23/98 - 2/5/99	Ammonia, Bromide, HAA6, THM4, TOC, TOX, UV <sub>254</sub>

Table 3.10 summarizes the methods and MRLs for both the NGPWRRRC Laboratory and Environmental Health Laboratories.

**TABLE 3.10 Summary of Analytical Methods and MRLs Used During The RBSMT Study**

Analyte	Method	Minimum Reporting Level	Hold Time
NGPWRRRC Laboratory			
Alkalinity	SM 2320 B	20 mg/L as CaCO <sub>3</sub>	Immediate
Calcium Hardness	SM 3111-Ca B	0.2 mg/L as CaCO <sub>3</sub>	28 Days
Chlorine Residual	SM 4500-Cl G	0.01 mg/L	Immediate
pH	SM 4500-H <sup>+</sup> B	NA	Immediate
Temperature	SM 2550 B	NA	Immediate
TDS <sup>a</sup>	SM 2540 C	5 mg/L	28 Days
Total Hardness	SM 2340 B	0.2 mg/L as CaCO <sub>3</sub>	28 Days
Turbidity	SM 2130 B	0.05 ntu	Immediate
TOC <sup>a</sup>	SM 5310 C	0.5 mg/L	28 Days
UV <sub>254</sub> <sup>a</sup>	SM 5910	0.009 cm <sup>-1</sup>	2 Days
Environmental Health Laboratories			
Ammonia	SM 4500-NH <sub>3</sub> D	0.30 mg/L NH <sub>3</sub> -N	2 Days
Bromide	EPA 300.0	20 mg/L	28 Days
BCAA, DBAA, DCAA, MBAA, MCAA, TCAA	EPA 552.2	1.0 mg/L for each analyte	14 Days
CHCl <sub>3</sub> , BDCM, DBCM, CHBr <sub>3</sub>	EPA 524.2	1.0 mg/L for each analyte	14 Days
TOC	SM 5310 C	0.5 mg/L	28 Days
TOX	SM 5320 B	25 mg/L	28 Days
UV <sub>254</sub>	SM 5910	0.009 cm <sup>-1</sup>	2 Days

<sup>a</sup>Analyses used to establish stable membrane performance

### Feed Water Collection

Feed water for the RBSMT treatment study was collected directly from a valve connected to the filter effluent channel located in the filter pipe gallery at Sioux Falls Water Purification Plant. Chlorine addition onto the filters was turned off for a period of time before feed water collection to ensure no chlorinated disinfection byproducts were present. Water was collected under ambient head pressure. Water was allowed to flush through the valve for approximately fifteen minutes prior to collection. The water was then transported to the test lab (NGPWRRC) within 1½ hours of collection, where it was stored at 4 degrees Celsius until used.

Sixteen twenty-liter glass bottles (approximately 320 liters total volume) were used to transport the feed water to the test lab. These glass containers were pre-washed with soap and hot water, rinsed three times with reverse osmosis water, rinsed with 50/50 nitric acid, and finally rinsed three times with NANOpure water. At the purification plant, the bottles were rinsed with sample water before collection of the sample. The bottles were then sealed utilizing rubber stoppers protected with aluminum foil. Upon return to the NGPWRRC, a random bottle was chosen and tested for chlorine residual, to ensure that unchlorinated water was obtained.



## NGPWRRRC Laboratory Analysis Protocols

Analytes requiring immediate analyses were measured in the NGPWRRRC Laboratory. Tests were conducted according to the DBP/ICR Methods Manual, with careful attention to calibration, analyses of duplicates, and spiked samples. Various analytical procedures are described below.

Anions Ion chromatography was used at the NGPWRRRC Laboratory to determine chloride, fluoride, nitrate, and sulfate concentrations according to Standard Method 4110B. ICR treatment study guidelines do not require laboratories to analyze anion concentrations; however, these anions help provide a more complete understanding of rejections provided by a membrane. Clean plastic bottles were rinsed three times with the sample, sample collected and then stored until analyzed. Prior to collection, bottles were washed with soap and hot water, rinsed with reverse osmosis water and then rinsed three times with NANOpure water.

Calcium and Total Hardness Samples were collected in plastic bottles, preserved and stored until analyzed. The plastic bottles were washed with soap and hot water, rinsed three times with reverse osmosis water, rinsed three times with 50/50 hydrochloric acid, and finally rinsed three times with NANOpure water. During collection of the sample, the bottle was rinsed three times with the sample and then 125-ml was collected. The hardness sample was preserved with 0.25-ml of nitric acid and stored at 4 degrees Celsius until analysis. At time of analysis, the sample was brought to room temperature and analyzed for calcium and magnesium. Total hardness was determined as the sum of the calcium and magnesium concentrations and expressed in mg/L as  $\text{CaCO}_3$ .

Total Organic Carbon The Environmental Health Laboratory analysed samples collected after each recovery during the RBSMT testing procedure for TOC. However, the NGPWRRRC Laboratory analyzed TOC during the RBSMT as a supplementary test to establish membrane system stability at each recovery. System stability samples were collected in 50-ml glass TOC tubes. TOC tubes were filled completely to the top and sealed. All glass TOC tubes were washed with soap and hot water, rinsed three times with reverse osmosis water, rinsed three times with 50/50 nitric acid, and finally rinsed with NANOpure water. TOC samples were collected every day and stored until substantial samples were obtained, never longer than the ten-day hold period.

The TOC analyzer was operated each time using a clean-out sample, three standards (2.5, 5, 10 mg/L), and a blank, followed by the samples collected during the RBSMT. QA/QC was accomplished by analyzing a known reference each time and performing duplicates on every tenth sample. The blank and the three standards provided data that produced a standard curve. A best fit linear line was then used to determine actual TOC values from data acquired for the instrument.

Simulated Distribution System Test SDS tests were set up at the NGPWRRRC lab. Appropriate set-up conditions for the SDS tests were obtained from the Sioux Falls Water Purification plant personal for each seasonal quarter. Table 3.11 shows a summary of the four seasonal set-up conditions that were used for the SDS test.

**TABLE 3.11 Summary of Seasonal Set-up Conditions Used in the SDS Tests**

<b>Season</b>	<b>pH</b>	<b>Temperature (°C)</b>	<b>Disinfectant Residual (mg/L Cl<sup>-</sup>)</b>	<b>Detention Time (Hours)</b>
Spring (4-98)	8.5	12	1.50	48
Summer (7-98)	8.5	20	1.50	24
Autumn (10-98)	8.7	12	1.50	30
Winter (1-99)	8.7	5	1.50	30

A chlorine dosing solution was used to produce a specific disinfectant residual in the SDS test. The dosing solution was a diluted solution of a commercial available bleach (5.25 percent sodium hypochlorite). The dosing solution was prepared by pipeting 5-ml of solution into a 250-ml volumetric flask and filling the remaining volume with chlorine-demand free water. The chlorine concentration of the stock solution was determined by titrating 100-ml of the solution to a starch-iodine endpoint using 0.100 N sodium thiosulfate. Once the chlorine concentration of the stock solution was known, it was used to make two dosing solutions. Two dosing solutions were needed, one for determining chlorine demand and one for dosing the SDS samples. The dosing solutions were then transferred and stored in a refrigerated amber bottle.

This pH buffer for the SDS test was a phosphate buffer solution, prepared according to Standard Methods for the Examination of Water and Wastewater, 18<sup>th</sup> Ed. (1992) 5710B.3c. Sodium Hydroxide (NaOH) was used to increase the pH of the buffer

solution to the desired pH. The buffer was stored in an airtight amber bottle and refrigerated until needed. Fresh buffer was prepared every 7 days.

The chlorine demand for each sample was determined prior commencing the SDS tests. The demand was needed to calculate the dosage required to produce the correct residual after the incubation time. Two milliliters of the phosphate buffer and three different volumes of the chlorine dosing solution were added to three 125-ml bottles containing appropriate feed or permeate sample water to achieve three different chlorine concentrations. The three bottles were incubated at the desired time and temperature. After the proper period time the bottles were analyzed for free chlorine concentrations. The initial dosage minus the remaining residual was the chlorine demand for the sample. This chlorine demand, plus the desired residual, revealed the concentration at which to dose the SDS sample.

The SDS samples were collected in 2.5-liter amber bottles, dosed with 10-ml of buffer and the desired amount of dosing solution. The bottles were washed with soap and hot water, rinsed three times with reverse osmosis water, rinsed with 50/50 nitric acid, and rinsed three times with NANOpure water. The dosed bottles were stored in a dark, temperature controlled atmosphere for the duration of the incubation period. At the end of the incubation period, a sample of the bottle contents was analyzed for pH, temperature, and free chlorine residual. THM4, HAA6, and TOX samples were then collected, quenched, preserved and shipped.

### Samples analyzed at Environmental Health Labs

Samples of the initial and final feed water, permeate at each recovery, duplicate at the 70% recovery, and SDS tests were sent to Environmental Health Labs for appropriate analysis of ammonia, bromide, HAA6, THM4, TOC, TOX and UV<sub>254</sub>. To ensure that all samples were analyzed within their hold time, samples were sent to the lab by overnight mail in bottles that had been received from Environmental Health Laboratories.

Ammonia, Bromide, TOC, and UV<sub>254</sub> samples were shipped immediately after each recovery. HAA6, THM4 and TOX samples were collected and shipped immediately after completion of the SDS test.

All samples collected were packaged in Styrofoam containers, packed with frozen ice packs and sent to Environmental Health Laboratories. If samples were collected on a Saturday or Sunday, the sample was refrigerated at 4 degrees Celsius and sent to the laboratory on the following Monday morning. Experimental time-lines were set up so that samples requiring same-day shipping were not collected on Saturday or Sunday. If a sample was sent the day before a weekend or holiday, Environmental Health Laboratories was notified and staff was made available to analyze samples within their hold times. Table 3.12 is a summary of the bottle, preservative, and hold time of each sample sent to Environmental Health Laboratories.

**TABLE 3.12 Summary of Samples Shipped to Environmental Health Laboratories  
for Each Membrane Used During the RBSMT Treatment Study**

<b>Sample</b>	<b>Volume (ml)</b>	<b>Bottle</b>	<b>Quantity</b>	<b>Preservative (Other than Ice Pack)</b>	<b>Hold Time (Days)</b>
Ammonia	125	Plastic	1	None	7
Bromide	125	Plastic	1	None	28
HAA6	40	Amber Glass	3	NH <sub>4</sub> Cl	14
THM4	40	Clear Glass	3	L-Ascorbic	14
TOC	250	Amber Glass	1	H <sub>2</sub> SO <sub>4</sub>	28
TOX	250	Amber Glass	1	Na <sub>2</sub> SO <sub>3</sub>	14
UV <sub>254</sub>	125	Amber Glass	1	None	2

## **IV. Results and Discussion**

### **Problems Encountered**

Problems encountered during the operation of the RBMST are discussed in this section. This portion of the report are subdivided into two different sections, operational problems and scaling problems.

#### Operational Problems

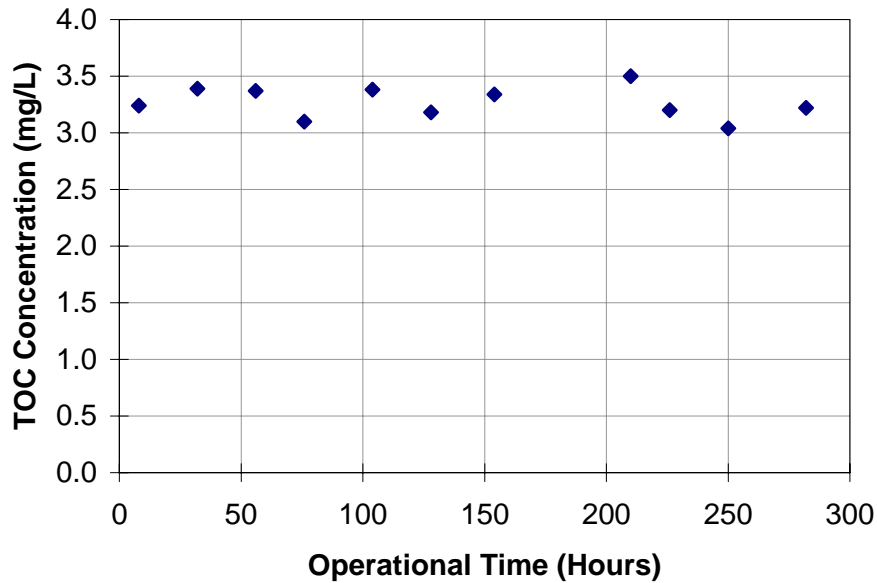
The first operational problem was encountered during the second membrane run (Fluid Systems TFCS) of the first quarter. During the evening hours of the 4<sup>th</sup> of May 1998, it was discovered that the feed pump had become air locked and was no longer pumping feed water into the system. The system was turned off and inspected for any problems that may have been a result of the air-locked pump. It was determined that the system was unharmed, and the pumps were turned on again. The membrane was completely sealed within the cell body during this time. The system was monitored closely to determine that membrane performance had not been jeopardized by the air-locked pump, and no anomalous indicators appeared.

During the third quarter of the RBSMT on the Film-Tec NF70, a SDS bottle was broken in the constant temperature room. The broken bottle was for the SDS test of the 70% recovery permeate sample. The SDS test was in the final hours of holding at constant temperature when the bottle was found broken. The RBSMT was operating at a different recovery, so a second sample could not be taken. Since the 70% recovery requires a duplicate of the SDS test be performed, the duplicate sample bottle was processed and analyzed for all the necessary parameters. An additional set of samples

were taken from this SDS duplicate bottle and analyzed again for all necessary water quality parameters. This was done to acquire the necessary duplicate data.

Another problem encountered during the third quarter run of the RBSMT, when several sample bottles from the Environmental Health Laboratories were not in our possession at the required time of sample collection for the first recovery. While some of the boxes had arrived at our laboratory prior to the start of the third quarter run, it was later determined that a few necessary sample bottles were missing from the boxes. Rather than completely restarting the RBSMT, it was decided that sample collection would begin after 96 hours of operation, rather than the normal 72. This allowed for the necessary bottles to be shipped to our laboratory. Due to the extra time required by this delay, our concern was that the feed water would degrade due to the longer than anticipated run. As shown in Figure 4.1, the TOC concentration did not degrade appreciably during the test, and showed similar stability when compared to other water quality parameters.

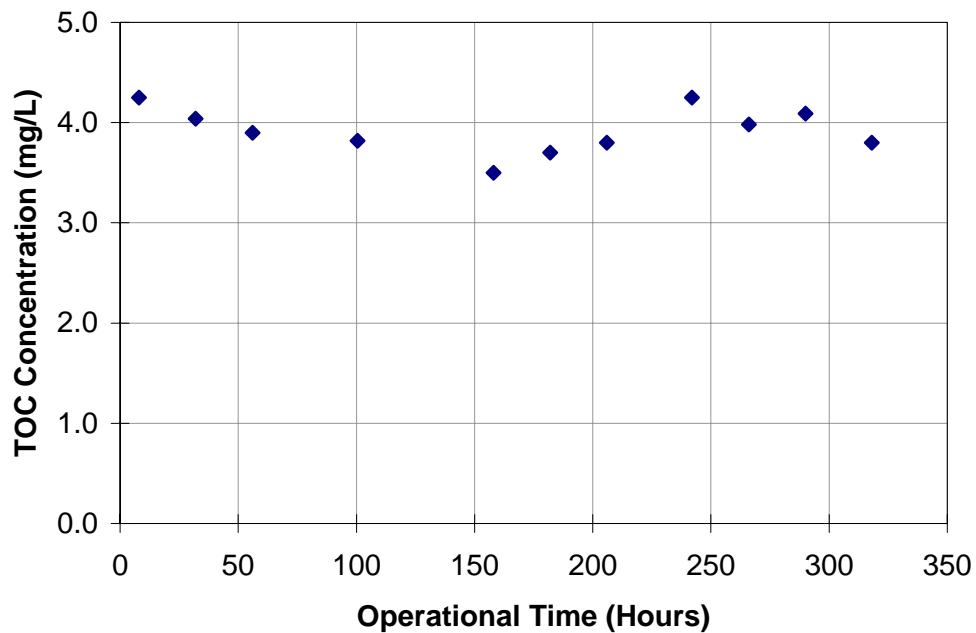




**Figure 4.1 TOC Concentration with respect to time (October 1998)**

The final operational problem was a power outage during the fourth quarter testing of the Hydranautics NTR-7450. The power outage occurred during the 60<sup>th</sup> hour of operation before the first recovery sample was collected. The membrane was closely monitored after the event in order to determine if membrane performance was stable. It was discovered that the membrane was slowly losing the performance that was obtained in the previous hours of the run. TOC and  $UV_{254}$  concentrations in the permeate were slowly approaching the feed water concentrations. The system was turned off and the membrane was removed from the cell body. Upon inspection of the membrane, two hair line rips were discovered. It was surmized that the power outage caused the feed pump to surge, increasing the fluid pressure and causing the membrane to fail.

A new sample was cut from the manufacture-supplied membrane and installed into the cell body. The membrane was exposed to the necessary setting period and the run was restarted. Again, the TOC concentration of the feed water was closely monitored to observe potential degradation. Figure 4.2 shows the feed water TOC concentration versus operational time. It can be seen that the TOC concentration remained reasonably constant during the run, which was successfully completed.



**Figure 4.2 TOC Concentration with respect to time (January 1999)**

### Scaling Problems

A potential scaling problem was seen when evaluating the mass balance errors for the softening membranes (Film-Tec NF70 and Fluid Systems TFC-S) in the data

reporting spreadsheets. It was determined that the mass balance errors were extremely high in the runs at the higher recoveries. The mass balances calculated at the higher recoveries were large negative values, insinuating the actual values were less than theoretical values. To further investigate the reason why the large mass balance errors were occurring, the Langelier Saturation Index was calculated for the waste streams for each membrane in each quarterly run. These calculations are shown in Table 4.1. The larger LSI numbers associated with the waste stream at the higher recoveries lead us to believe that scaling was a problem at the higher recoveries.

Further investigation of the non-softening membranes (Film-Tec NF70 and Hydranautics NTR-7450), revealed that LSI values for the waste streams in these membranes were just slightly above zero and mass balance errors values were considerably smaller than those achieved by the softening membranes. The larger positive LSI values for the waste stream at the higher recoveries and the fact that non-softening membranes produced smaller mass balance errors seem to explain the large mass balance errors associated with the softening membranes at high recoveries.

**TABLE 4.1 Langlier Saturation Index Of Concentrate Stream At Different Recoveries**

1 <sup>st</sup> Quarter		Film-Tec NF-70			
Recovery	90%	70%	50%	30%	Feed
Temperature	24.5	20.9	23.5	22.9	21.8
Total Dissolved Solids	1895.0	1155.0	885.0	625.0	451
pH	8.20	8.05	7.97	7.92	7.49
Ca <sup>2+</sup>	157	48	71.6	49.6	35.3
Alkalinity (mg/L as CaCO <sub>3</sub> )	147	220	70	53	44.5
LSI =					-0.83

1 <sup>st</sup> Quarter		Fluid Systems TFCS			
Recovery	90%	70%	50%	30%	Feed
Temperature	26.8	25.4	23.9	22.0	21.6
Total Dissolved Solids	1970.0	1090.0	855.0	651.0	440
pH	8.32	8.15	8.00	7.88	7.46
Ca <sup>2+</sup>	164	92.4	69	51	35.5
Alkalinity (mg/L as CaCO <sub>3</sub> )	178	89	69	53	40
LSI =					-0.91

2 <sup>nd</sup> Quarter		Film-Tec NF-70			
Recovery	90%	70%	50%	30%	Feed
Temperature	22.0	21.0	20.9	21.3	20.5
Total Dissolved Solids	2010.0	1272.0	956.0	699.0	525
pH	7.95	8.05	7.81	7.71	7.38
Ca <sup>2+</sup>	218	140	105	75	56.5
Alkalinity (mg/L as CaCO <sub>3</sub> )	270	180	142	115	78
LSI =					-0.53

2 <sup>nd</sup> Quarter		Fluid Systems TFCS			
Recovery	90%	70%	50%	30%	Feed
Temperature	21.8	20.5	19.0	19.9	17.7
Total Dissolved Solids	2112.0	1324.0	979.0	716.0	530
pH	8.14	7.99	7.93	7.64	7.42
Ca <sup>2+</sup>	238	146	110	84	58.9
Alkalinity (mg/L as CaCO <sub>3</sub> )	296	194	148	112	82
LSI =					-0.49

**TABLE 4.1 (continued). Langlier Saturation Index Of Concentrate Stream At Different Recoveries**

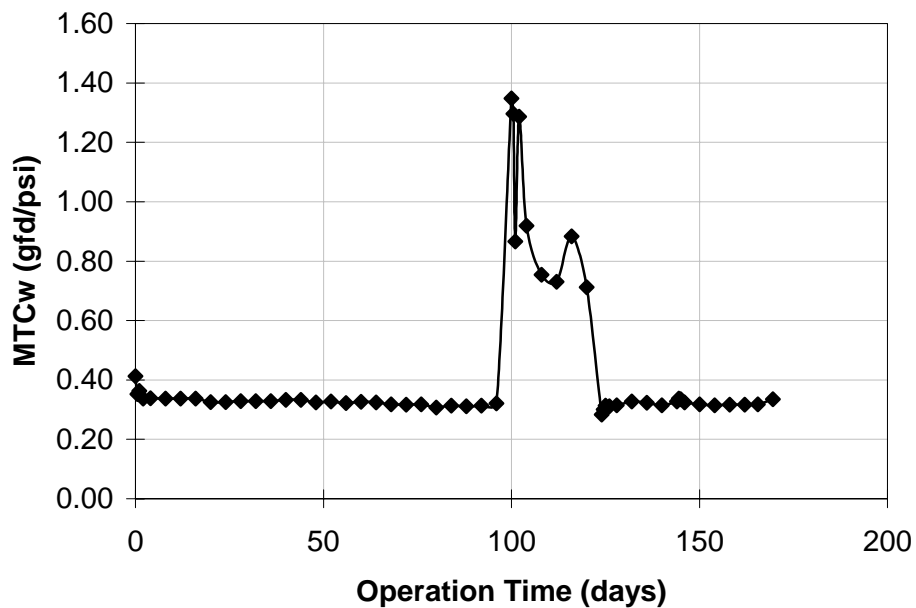
<b>3<sup>rd</sup> Quarter</b>		<b>Film-Tec NF-70</b>			
<b>Recovery</b>	<b>90%</b>	<b>70%</b>	<b>50%</b>	<b>30%</b>	<b>Feed</b>
<b>Temperature</b>	24.8	25.5	24.7	22.9	20.7
<b>Total Dissolved Solids</b>	2130.0	1295.0	930.0	720.0	540
<b>pH</b>	8.18	7.84	7.71	7.72	7.35
<b>Ca<sup>2+</sup></b>	218	128	89	64	57
<b>Alkalinity (mg/L as CaCO<sub>3</sub>)</b>	102	66	46	35	26
<b>LSI =</b>					<b>-1.03</b>

<b>3<sup>rd</sup> Quarter</b>		<b>Film-Tec NF-200B</b>			
<b>Recovery</b>	<b>90%</b>	<b>70%</b>	<b>50%</b>	<b>30%</b>	<b>Feed</b>
<b>Temperature</b>	22.3	21.7	20.7	22.5	19.6
<b>Total Dissolved Solids</b>	2070.0	1255.0	915.0	685.0	515
<b>pH</b>	7.82	7.8	7.62	7.44	7.37
<b>Ca<sup>2+</sup></b>	220	130	93	72	58
<b>Alkalinity (mg/L as CaCO<sub>3</sub>)</b>	53	45	40	34	28
<b>LSI =</b>					<b>-0.99</b>

<b>4<sup>th</sup> Quarter</b>		<b>Film-Tec NF-70</b>			
<b>Recovery</b>	<b>90%</b>	<b>70%</b>	<b>50%</b>	<b>30%</b>	<b>Feed</b>
<b>Temperature</b>	20.8	20.4	20.3	20.4	19.7
<b>Total Dissolved Solids</b>	2404.0	1451.0	1095.0	772.0	570
<b>pH</b>	8.18	8.04	7.83	7.5	7.30
<b>Ca<sup>2+</sup></b>	542	320	247	176	125
<b>Alkalinity (mg/L as CaCO<sub>3</sub>)</b>	175	120	88	64	46
<b>LSI =</b>					<b>-0.52</b>

<b>4<sup>th</sup> Quarter</b>		<b>Hydranautics NTR7450</b>			
<b>Recovery</b>	<b>90%</b>	<b>70%</b>	<b>50%</b>	<b>30%</b>	<b>Feed</b>
<b>Temperature</b>	20.4	20.7	20.7	21.1	20.6
<b>Total Dissolved Solids</b>	922.0	799.0	780.0	690.0	540
<b>pH</b>	7.96	7.87	7.46	7.47	7.40
<b>Ca<sup>2+</sup></b>	216	184	175	156	128
<b>Alkalinity (mg/L as CaCO<sub>3</sub>)</b>	54	50	50	50	45
<b>LSI =</b>					<b>-0.40</b>

The EPA data collection spreadsheets produced a higher than expected MTCw of all the 90% recovery results, thus producing data that appears anomalous. An example of this higher than expected MTCw obtained during the 90% recovery can be seen in Figure 4.3.



**Figure 4.3 Specific flux with regard to time (Film-Tec NF-70, October 1998)**

The data collection spreadsheets calculate temperature corrected MTCw as the water flux at average temperature divided by the net driving pressure. The net driving pressure is the measured pressure divided by the osmotic pressure gradient. The osmotic pressure gradient is a direct function of the TDS concentration of the three fluid streams into and out of the system (feed, permeate and concentrate). The daily measured TDS data that is collected during the RBSMT is used to calculate an average bulk TDS

rejection value. The average bulk TDS rejection value is then used to calculate the TDS concentration in the waste stream. This theoretical TDS concentration in the waste stream is the problem. At the 90% recovery, the waste TDS concentration was significantly less than the theoretical concentration, due to the previously discussed scaling problems. The spreadsheets use this theoretical concentration to calculate the osmotic pressure gradient. If the theoretical waste TDS concentration is higher than the actual waste TDS concentration, the spreadsheets calculate the osmotic pressure gradient as being greater than actual. The net driving pressure is equal to the actual operating pressure minus the theoretical osmotic pressure; therefore, a higher than actual osmotic pressure will result in a lower than actual net driving pressure. This is the reason why the calculated MTC<sub>w</sub> is significantly higher at the 90% recoveries.

To correct for this problem and utilize all information collected during the RBSMT, the MTC<sub>w</sub> was recalculated using the actual waste TDS concentration rather than the theoretical concentration. The osmotic pressure and net driving pressure were recalculated by using the actual waste TDS concentration achieved after stable membrane performance was obtained at the 90% recovery. The corrected MTC<sub>w</sub> versus operational time figures using the actual waste TDS concentration are shown in the Additional Significant Results section.

## Water Quality Data

Water quality data are presented below in view of the objectives to investigate seasonal variability of membrane performance and compare the performance of four different membranes. Table 4.2 is a summary of the average pretreated feed water quality during the four seasons of the RBSMT.

**TABLE 4.2 Summary of the Average Pretreated Feed Water Quality  
During Four Seasons of the RBSMT Study**

<b>Water Quality Parameter</b>	<b>Apr '98 Average (SD)</b>	<b>July '98 Average (SD)</b>	<b>Oct '98 Average (SD)</b>	<b>Dec '99 Average (SD)</b>
Temperature ( °C)	21.7 (1.4)	19.05 (1.76)	20.13 (2.79)	20.15 (0.73)
pH	7.47 (0.05)	7.4 (0.03)	7.36 (0.07)	7.38 (0.07)
Turbidity (ntu)	0.11 (0.01)	0.08 (0.01)	0.06 (0.01)	0.06 (0.01)
Alkalinity (mg/L as CaCO <sub>3</sub> )	42.3 (6.13)	80 (7.12)	26.75 (0.96)	45.5 (3)
Calcium Hardness (mg/L as CaCO <sub>3</sub> )	88.3 (0.54)	144.14 (5.31)	143.78 (0.63)	126.29 (1.57)
Total Hardness (mg/L as CaCO <sub>3</sub> )	239.4 (0.95)	287.69 (10.07)	280.08 (0.37)	324.5 (2.69)
Bromide (mg/L)	0.09 (0.01)	0.13 (0.01)	0.07 (0.02)	0.32 (0.45)
TOC (mg/L)	3.65 (0.06)	3.68 (0.09)	3.03 (0.15)	3.65 (0.06)
UV <sub>254</sub> (cm <sup>-1</sup> )	0.07 (0)	0.06 (0)	0.06 (0)	0.06 (0)
SDS- THM4 (mg/L)	63 (4.97)	70.58 (3.24)	43.1 (2.06)	41.78 (2.72)
SDS - HAA5 (mg/L)	42.3 (6.67)	31.5 (5.31)	27.53 (3.95)	25 (2.94)
SDS - HAA6 (mg/L)	48.65 (7.59)	39.08 (6.59)	34.15 (5.07)	32 (2.97)
SDS - Chlorine Demand (mg/L)	2.87 (0.08)	3.1 (0.03)	2.6 (0.07)	3.05 (0.18)

The feed water TOC and turbidity were remarkably consistent from quarter to quarter. The feed water TOC did not vary as widely as was expected (from Table 2.3, the



monthly source water TOC in 1998 varied from 2.75 to 7.78 mg/L). TOC variations in the Big Sioux River appear to be dampened by blending with aquifer water, during the days feed water was collected for the RBSMT tests, and by the pretreatment provided in the full-scale treatment processes prior to the point of RBSMT feed water collection. Turbidity of the feed water was excellent, ranging from 0.06 to 0.11 NTU. It is noted that the feed water SDS DBPs met the Stage 1 DBP levels (THM4 = 80 µg/L, HAA5 = 60 µg/L), but did not meet the proposed Stage 2 DBP levels (THM4 = 40 µg/L, HAA5 = 30 µg/L). Feed water alkalinity is quite low, leading to potential required permeate pH adjustment if the membrane process was implemented at full scale.

Permeate water TOC and DBP results are summarized in Table 4.3. The membranes generally accomplished remarkable TOC removal. Permeate TOC concentrations were below the minimum reporting level for all recoveries except for the NTR7450 membrane which, for the January run, exhibited permeate TOC ranging from 0.6 to 1.2 mg/L. As a result of this excellent removal, SDS HAA5 results of the membrane permeates were also below the minimum reporting level, again with the exception of the NTR7450 membrane, which exhibited membrane permeate HAA5 ranging from 4.1 – 14 µg/L. As expected, permeate SDS THM4 concentrations generally increased with percent recovery, were generally less than 10 µg/L, and were in the range of 13.7 – 23.0 µg/L for the NTR7450 membrane. These results are well below the proposed Stage 2 DBP levels.

**Table 4.3 Permeate TOC and DBP Concentrations**

	TOC	SDS THM4	SDS HAA5	SDS HAA6
Membrane/Month	mg/L	mg/L	mg/L	mg/L
90% Recovery				
NF70/April	BMRL	3.8	BMRL	BMRL
NF70/July	BMRL	8.4	1.2	2.2
NF70/October	BMRL	BMRL	BMRL	BMRL
NF70/January	BMRL	1.1	BMRL	BMRL
TFC-S/April	BMRL	5.2	BMRL	BMRL
TFC-S/July	BMRL	6.2	BMRL	BMRL
NF-200B/October	BMRL	9.4	BMRL	1.1
NTR7450/January	1.2	23.0	9.6	13.4
70% Recovery				
NF70/April	BMRL	0.5	BMRL	BRML
NF70/July	BMRL	5.3	0.6	1.7
NF70/October	BMRL	BMRL	BMRL	BMRL
NF70/January	BMRL	BMRL	BMRL	BMRL
TFC-S/April	BMRL	5.0	BMRL	BMRL
TFC-S/July	BMRL	2.6	BMRL	BMRL
NF-200B/October	BMRL	7.0	0.5	0.5
NTR7450/January	1.0	21.4	10.0	14.0
50% Recovery				
NF70/April	BMRL	2.5	BMRL	BMRL
NF70/July	BMRL	4.5	BMRL	BMRL
NF70/October	BMRL	BMRL	BMRL	BMRL
NF70/January	BMRL	1.2	BMRL	BMRL
TFC-S/April	BMRL	2.6	BMRL	BMRL
TFC-S/July	BMRL	2.3	BMRL	BMRL
NF-200B/October	BMRL	4.8	BMRL	BMRL
NTR7450/January	0.7	16.8	6.3	9.2
30% Recovery				
NF70/April	BMRL	1.1	BMRL	BMRL
NF70/July	BMRL	2.4	BMRL	BMRL
NF70/October	BMRL	BMRL	BMRL	BMRL
NF70/January	BMRL	1.0	BMRL	BMRL
TFC-S/April	BMRL	2.5	BMRL	BMRL
TFC-S/July	BMRL	2.2	BMRL	BMRL
NF-200B/October	BMRL	3.3	BMRL	BMRL
NTR7450/January	0.6	13.7	4.1	6.3

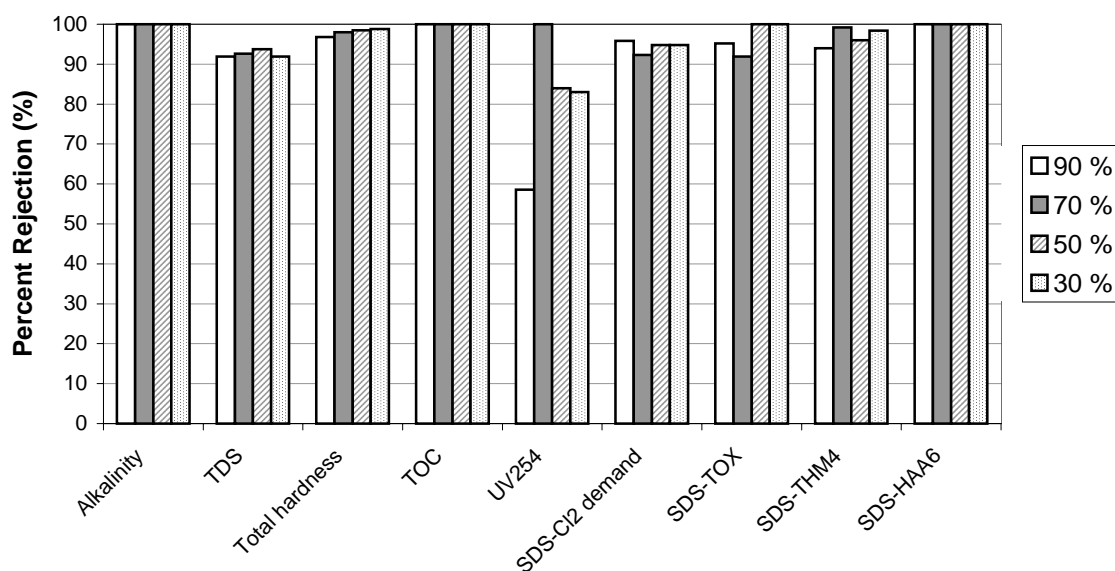
### **Impact of Seasonal Variability**

Impacts of seasonal variation on membrane performance can be assessed by reviewing the quarterly data from the NF70 membrane. The data indicate no impact of season on TOC removal, since the membrane removed TOC to concentrations below the minimum reporting level. However, the impacts of season are apparent in the SDS THM4 data for the NF70 membrane. The highest THM4 occurred during the summer quarter (July), whereas the lowest THM4 concentration appeared during the winter quarter (January). Additionally, the only quarter in which HAA5 concentrations appeared in the NF70 permeate were the July results at the 70 and 90 % recoveries. Very likely, the effect of temperatures used in the SDS tests had the greatest impact on these results, yielding the highest THM4 and HAA5 production during the warmest SDS temperatures. Seasonal impacts on performance of the remaining three membranes could not be assessed because a full suite of quarterly data were not collected for each of the three membranes.

The impacts of season on membrane process performance is also revealed by the percent rejections exhibited by each membrane. Percent rejections for each run with each membrane are tabulated in Tables 4.4 - 4.11 and plotted in Figures 4.4 - 4.11. Although anion data were not required by the ICR RBSMT protocol, the rejections of anions are included with the data to further compare the performance of the membranes.

**TABLE 4.4 Percent Rejection of Various Water Quality Parameters  
Film-Tec NF-70 (April '98)**

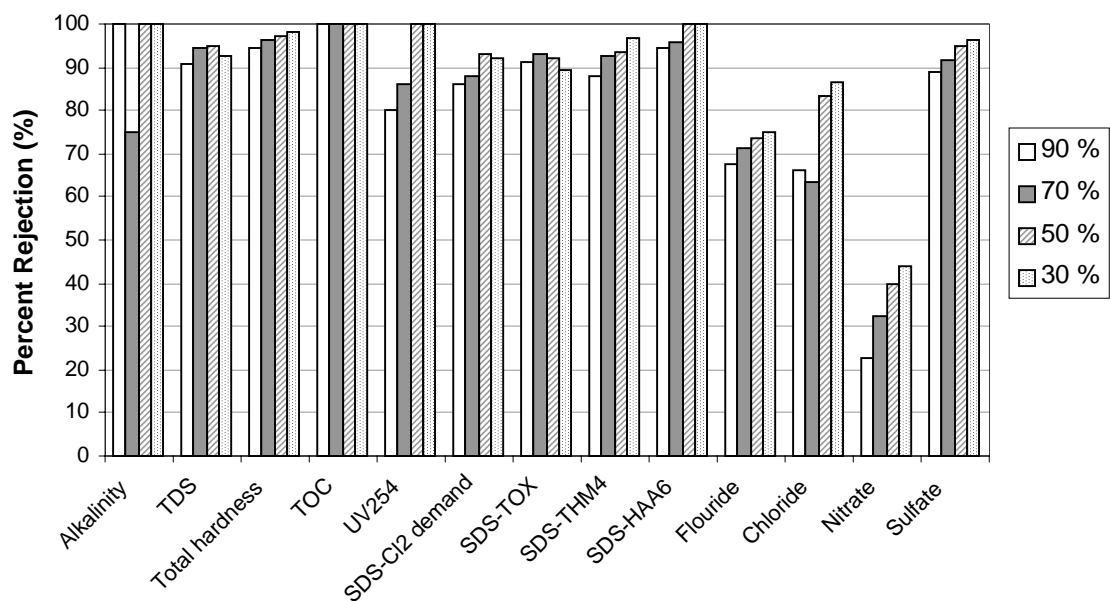
Water Quality Parameters	90% NF-70	70% NF-70	50% NF-70	30% NF-70
Alkalinity	100	100	100	100
TDS	92	93	94	92
Total hardness	97	98	98	99
TOC	100	100	100	100
UV <sub>254</sub>	57	100	84	83
SDS-Cl <sub>2</sub> demand	96	92	95	95
SDS-TOX	100	92	100	100
SDS-THM4	94	99	96	98
SDS-HAA6	100	100	100	100



**FIGURE 4.4 Rejection Summary For Film-Tec's NF-70 Treating Filtered Sioux Falls Water, April 1998**

**TABLE 4.5 Percent Rejection of Various Water Quality Parameters  
Film-Tec NF-70 (July '98)**

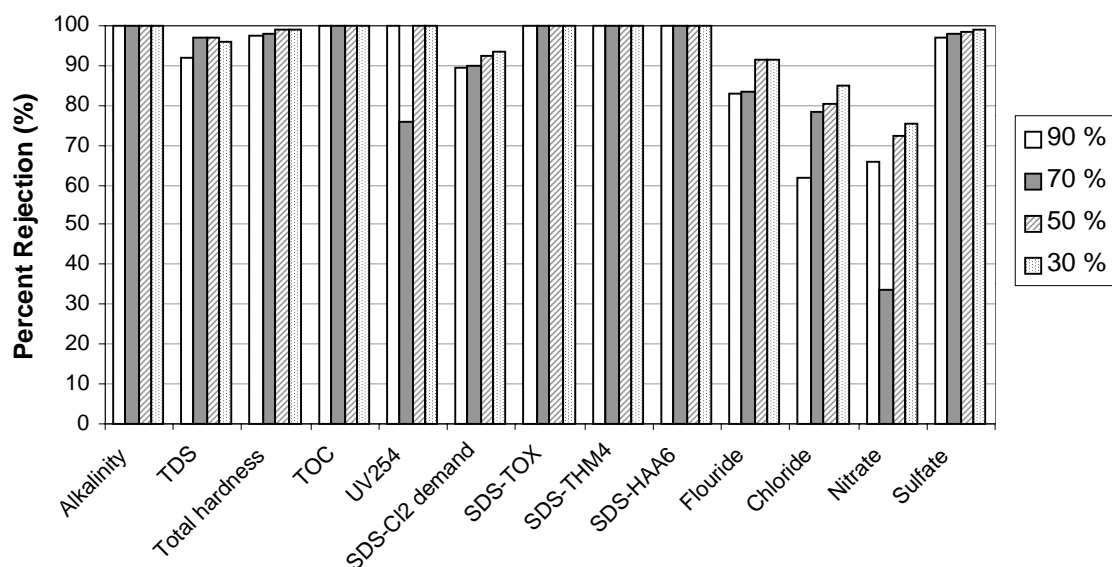
Water Quality Parameters	90% NF-70	70% NF-70	50% NF-70	30% NF-70
Alkalinity	100	75	100	100
TDS	91	94	95	93
Total hardness	94	96	97	98
TOC	100	100	100	100
UV <sub>254</sub>	80	86	100	100
SDS-Cl2 demand	86	88	93	92
SDS-TOX	91	93	92	89
SDS-THM4	88	93	94	97
SDS-HAA6	94	96	100	100
Fluoride	68	71	73	75
Chloride	66	63	83	87
Nitrate	23	32	40	44
Sulfate	89	92	95	96



**FIGURE 4.5 Rejection Summary For Film-Tec's NF-70 Treating Filtered Sioux Falls Water, July 1998**

**TABLE 4.6 Percent Rejection of Various Water Quality Parameters  
Film-Tec NF-70 (October '98)**

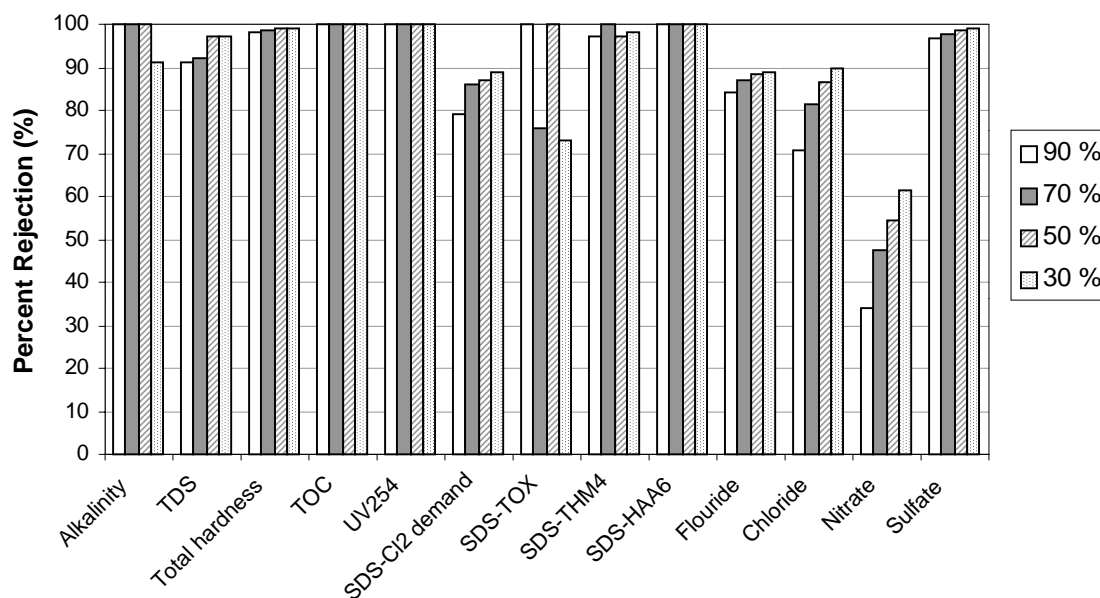
Water Quality Parameters	90% NF-70	70% NF-70	50% NF-70	30% NF-70
Alkalinity	100	100	100	100
TDS	92	97	97	96
Total hardness	98	98	99	99
TOC	100	100	100	100
UV <sub>254</sub>	100	76	100	100
SDS-Cl2 demand	89	90	93	94
SDS-TOX	100	100	100	100
SDS-THM4	100	100	100	100
SDS-HAA6	100	100	100	100
Fluoride	83	83	92	92
Chloride	62	78	80	85
Nitrate	66	34	73	75
Sulfate	97	98	99	99



**FIGURE 4.6 Rejection Summary For Film-Tec's NF-70 Treating  
Filtered Sioux Falls Water, October 1998**

**TABLE 4.7 Percent Rejection of Various Water Quality Parameters  
Film-Tec NF-70 (January '99)**

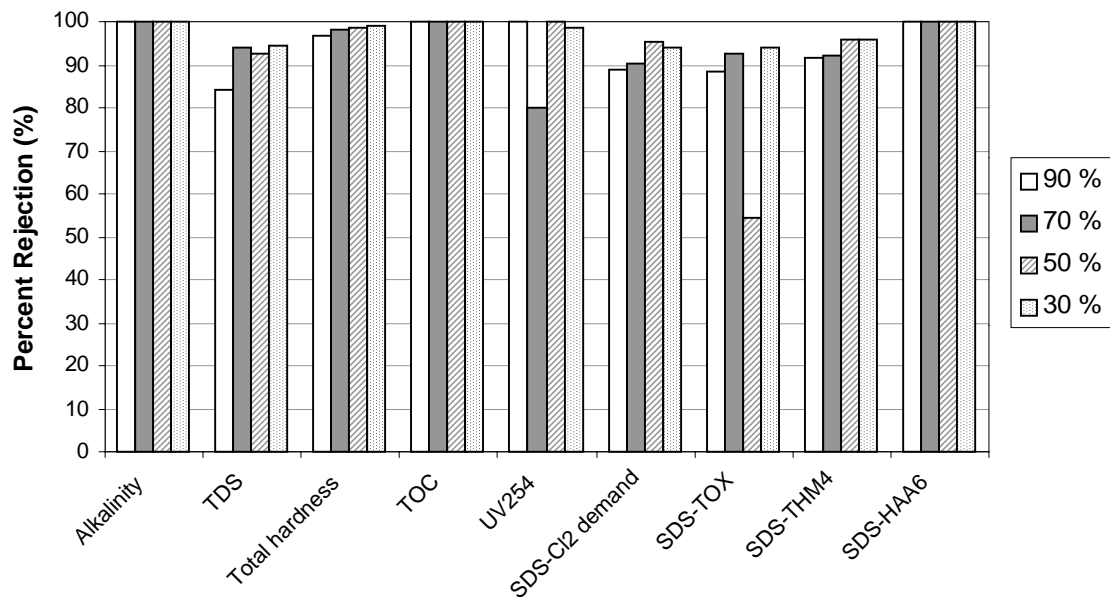
Water Quality Parameters	90% NF-70	70% NF-70	50% NF-70	30% NF-70
Alkalinity	100	100	100	91
Total dissolved solids	91	92	97	97
Total hardness	98	98	99	99
Total organic carbon	100	100	100	100
UV <sub>254</sub>	100	100	100	100
SDS-Cl <sub>2</sub> demand	79	86	87	89
SDS-TOX	100	76	100	73
SDS-THM4	97	100	97	98
SDS-HAA6	100	100	100	100
Fluoride	84	87	88	89
Chloride	71	81	86	90
Nitrate	34	47	54	61
Sulfate	97	98	99	99



**FIGURE 4.7 Rejection Summary For Film-Tec's NF-70 Treating Filtered Sioux Falls Water, January 1999**

**TABLE 4.8 Percent Rejection of Various Water Quality Parameters  
Fluid Systems TFCS (April '98)**

Water Quality Parameters	90% TFCS	70% TFCS	50% TFCS	30% TFCS
Alkalinity	100	100	100	100
TDS	84	94	92	94
Total hardness	97	98	99	99
TOC	100	100	100	100
UV <sub>254</sub>	100	80	100	98
SDS-Cl <sub>2</sub> demand	89	90	95	94
SDS-TOX	88	93	55	93
SDS-THM4	92	92	96	96
SDS-HAA6	100	100	100	100

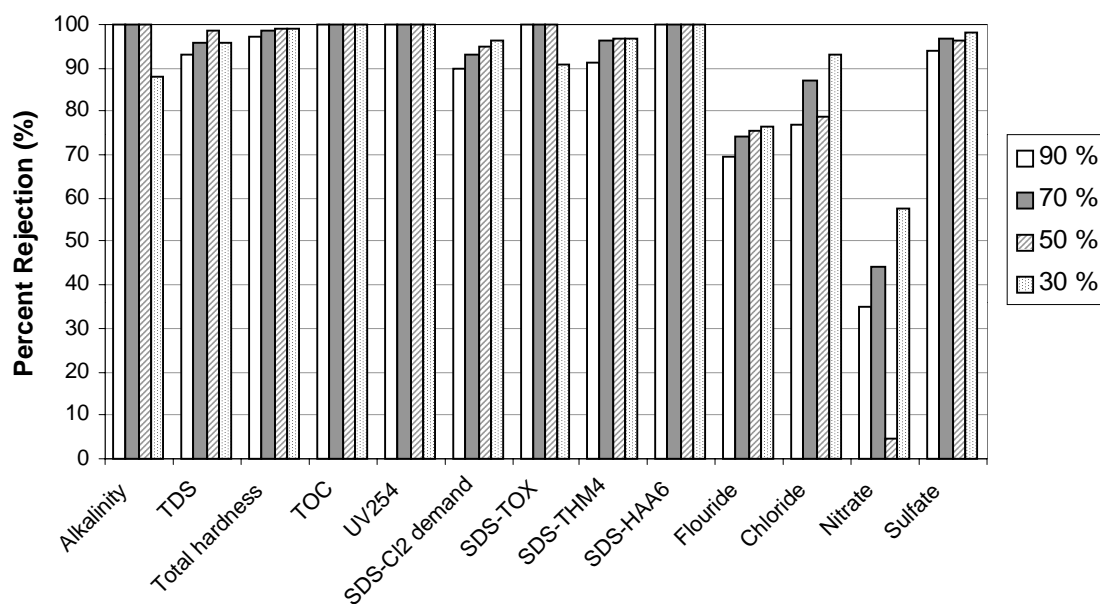


**FIGURE 4.8 Rejection Summary For Fluid System TFC-S Treating Filtered Sioux Falls Water, April, 1998**



**TABLE 4.9 Percent Rejection of Various Water Quality Parameters  
Fluid Systems TFC-S (July '98)**

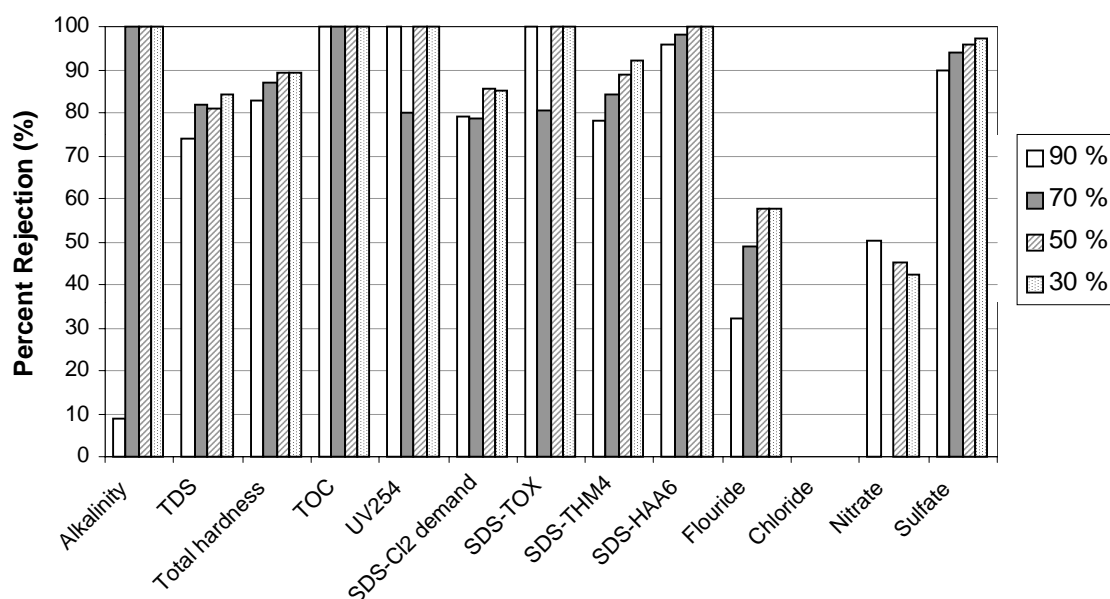
Water Quality Parameters	90% TFCS	70% TFCS	50% TFCS	30% TFCS
Alkalinity	100	100	100	88
TDS	93	96	98	96
Total hardness	97	99	99	99
TOC	100	100	100	100
UV <sub>254</sub>	100	100	100	100
SDS-Cl <sub>2</sub> demand	90	93	95	96
SDS-TOX	100	100	100	91
SDS-THM4	91	96	97	97
SDS-HAA6	100	100	100	100
Fluoride	70	74	75	76
Chloride	77	87	79	93
Nitrate	35	44	5	57
Sulfate	94	97	96	98



**FIGURE 4.9 Rejection Summary for Fluid System's TFC-S Treating Filtered Sioux Falls Water, July 1998**

**TABLE 4.10 Percent Rejection of Various Water Quality Parameters  
Film-Tec NF-200B (October '98)**

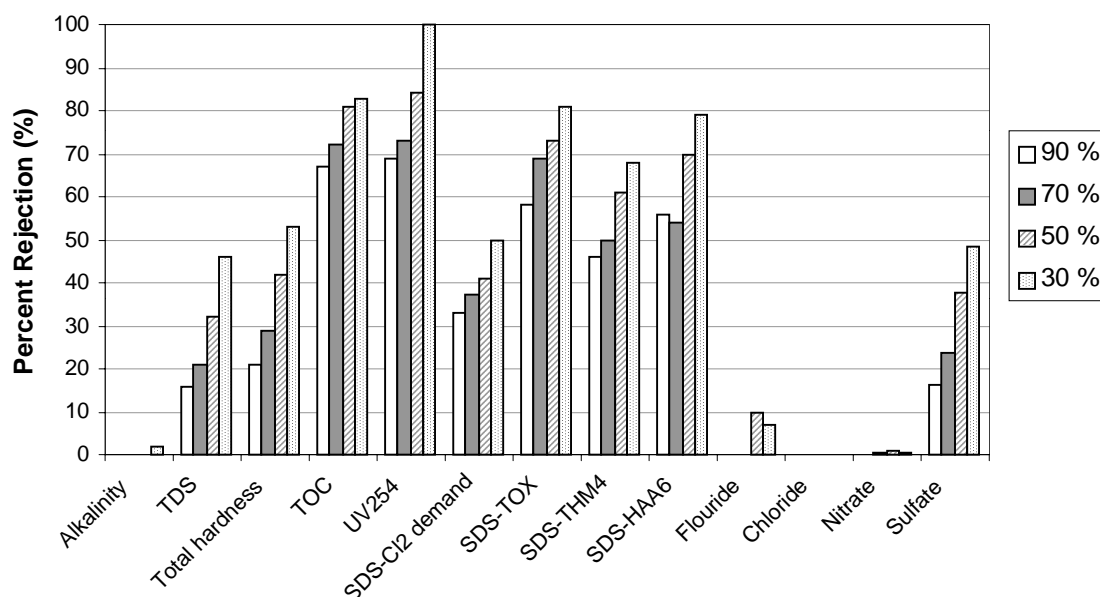
Water Quality Parameters	90% NF-200	70% NF-200	50% NF-200	30% NF-200
Alkalinity	9	100	100	100
TDS	74	82	81	84
Total hardness	83	87	89	89
TOC	100	100	100	100
UV <sub>254</sub>	100	80	100	100
SDS-Cl <sub>2</sub> demand	79	79	85	85
SDS-TOX	100	81	100	100
SDS-THM <sub>4</sub>	78	84	89	92
SDS-HAA <sub>6</sub>	96	88	100	100
Fluoride	32	49	58	57
Chloride	0	0	0	0
Nitrate	50	0	45	42
Sulfate	90	94	96	97



**FIGURE 4.10 Rejection Summary For Film-Tec NF-200B Treating Filtered Sioux Falls Water, October, 1998**

**TABLE 4.11 Percent Rejection of Various Water Quality Parameters  
Hydranautics NTR-7450 (January '98)**

Water Quality Parameters	90%	70%	50%	30%
	NTR-7450	NTR-7450	NTR-7450	NTR-7450
Alkalinity	0	0	0	2
Total dissolved solids	16	21	32	46
Total hardness	21	29	42	53
Total organic carbon	67	72	81	83
UV <sub>254</sub>	69	73	84	100
SDS-Cl <sub>2</sub> demand	33	37	41	50
SDS-TOX	58	69	73	81
SDS-THM <sub>4</sub>	46	50	61	68
SDS-HAA <sub>6</sub>	56	54	70	79
Fluoride	0	0	10	6
Chloride	0	0	0	0
Nitrate	0	1	1	0
Sulfate	17	24	38	48

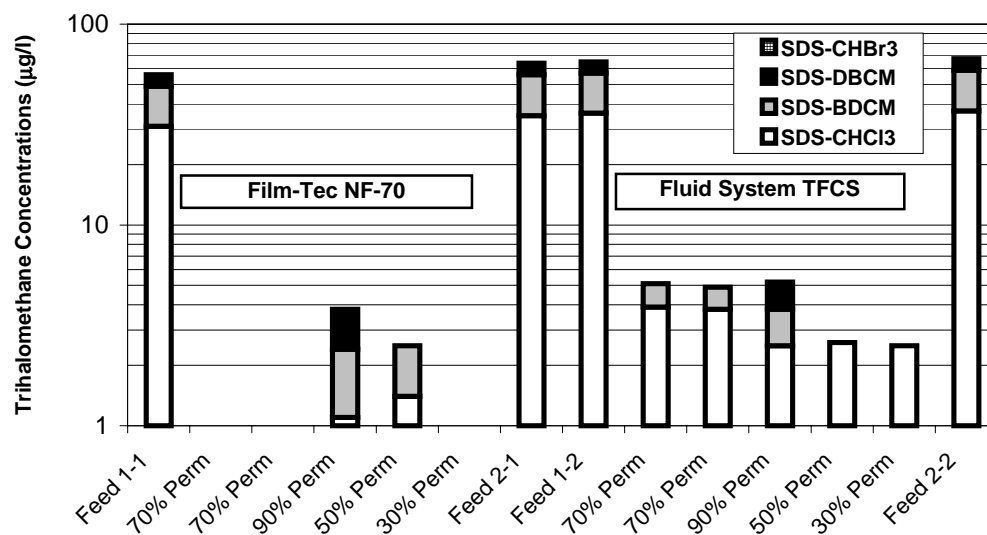


**FIGURE 4.11 Rejection Summary For Hydranautics NTR-7450 Treating Filtered  
Sioux Falls Water, January 1999**

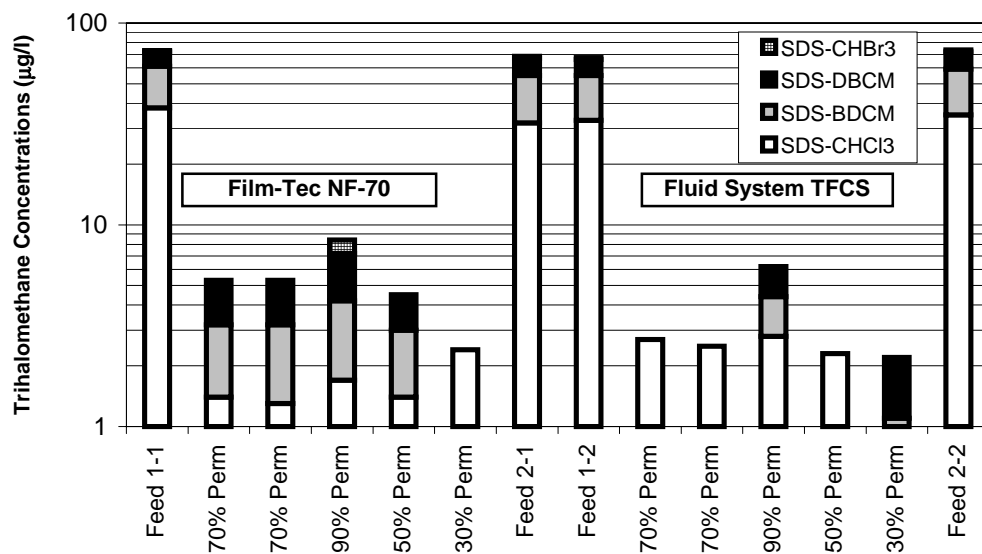
As shown in the rejection data for the NF-70 membrane in Tables 4.4-4.7, the percent rejections exhibited by the data are very consistent from quarter to quarter. For the NF-70 membrane, performance was not compromised by seasonal variation in water quality. TOC and DBP rejections were consistently in the 90% range, while percent rejections of anions were consistently at lower values.

### **Impact of Membrane Type**

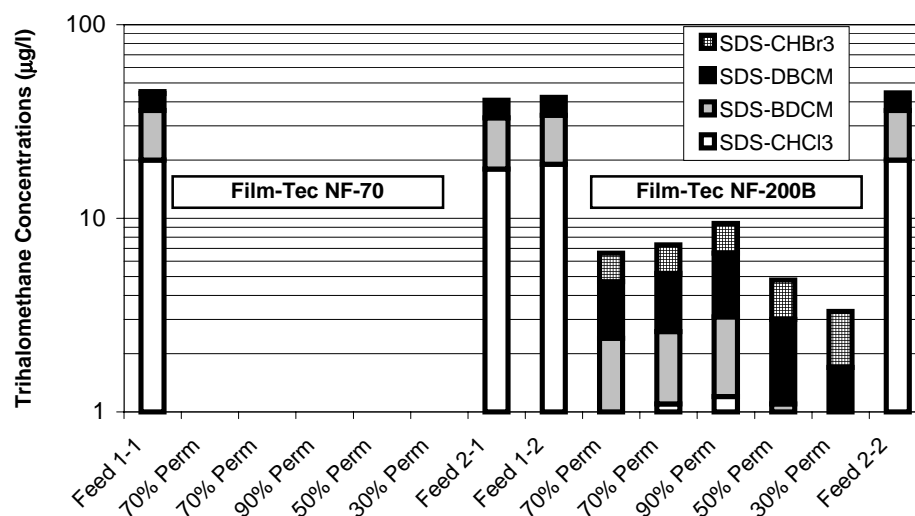
The water quality data presented in the previous sections indicated a difference in the performance of the four membranes that were evaluated in this study. Since the membranes removed TOC so well (for the most part, below the minimum detection level except for the NTR-7450) it is difficult to provide direct visual evidence of the impact of the membrane type. The HAA5 data exhibits similar characteristics. The most revealing comparison of the membranes is made by comparing the THM data. These data are presented in graphical form in Figures 4.12-4.15. As shown in Figures 4.12 and 4.13, the Film-Tec NF70 and the Fluid System TFCS membranes produced similar permeate qualities. The manufacturers represent these membranes as softening membranes, and they produced permeate with less than 10 µg/L THM4 concentrations in April and July. However, as shown in Figures 4.14 and 4.15, the Film-Tec NF200B and the NTR-7450 produced progressively higher SDS THM concentrations, respectively, when compared



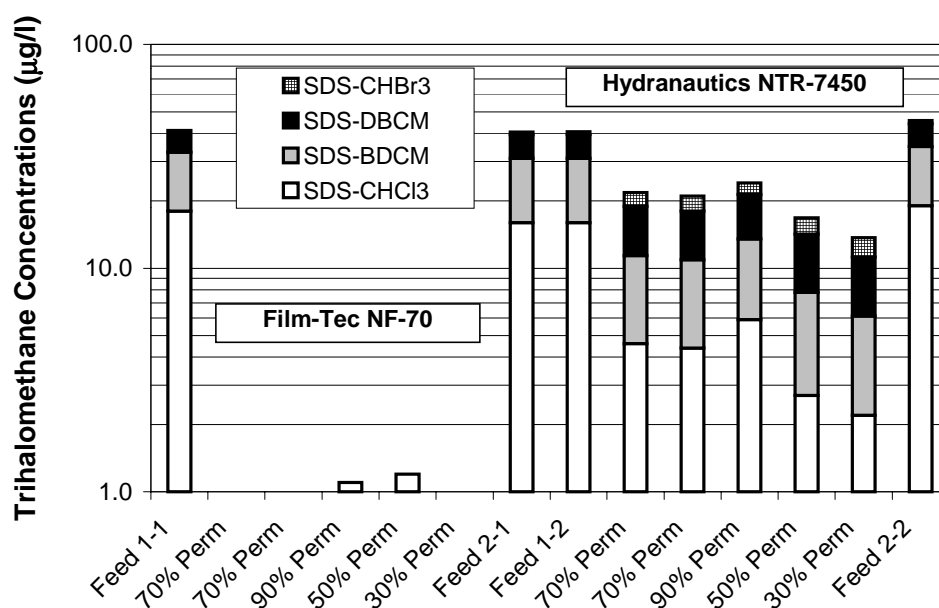
**FIGURE 4.12 Membrane Permeate SDS THM Concentrations, April 1998**



**FIGURE 4.13 Membrane Permeate, SDS THM Concentrations, July 1998**



**FIGURE 4.14 Membrane Permeate SDS THM Concentrations, October 1998**

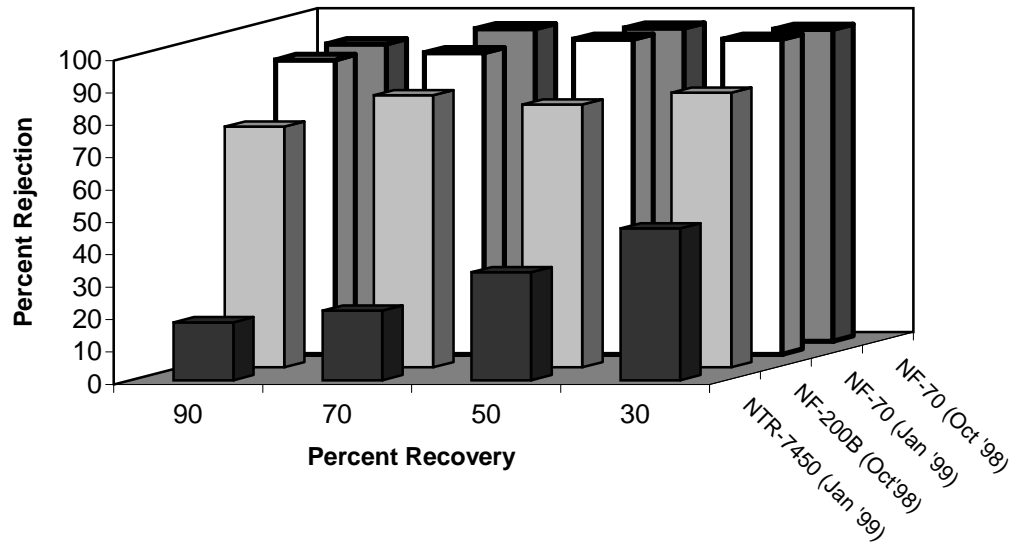


**FIGURE 4.15 Membrane Permeate SDS THM Concentrations, January 1999**

softening membrane (Film-Tec NF-70). The anion rejection data shown in Tables 4.4-4.11 provide which are helpful in comparing the collateral performance of the membranes in improving water quality. A general comparison of performance is shown in the plot of percent rejection of TDS at each recovery (Figure 4-16). The NF-70 membrane consistently removed approximately 90% of the TDS during both quarters. The NF-200B exhibited 10-20% lower rejection during the October quarter, whereas the NTR-7450 exhibited comparatively poorer rejection of TDS in the January quarter.

Of greater interest is the performance relative to DBPs and organic rejection. The NF-70, TFC-S and NF-200B performed well with respect to TOC rejection, routinely removing TOC to below the minimum reporting levels. In the fourth quarter, NTR-7450 exhibited 20 to 30% lower TOC rejections than the NF-70 membrane. The SDS DBP rejections for the NTR-7450 membrane were in the range of 70 to 85%; however, all SDS DBP concentrations never exceeded the stage 2 MCL's.

In summary, the softening membranes provided the best overall rejection of TOC and ions, the NF-200B performed nearly as well as the softening membrane in TOC rejection but somewhat poorer relative to ion rejection, and the NTR-7450 performed the least favorably of the four membranes. However, all the membrane types performed to the expectations represented by their manufacturers, and all removed TOC to the extent that the SDS DBP concentrations were decreased below proposed Stage 2 levels.

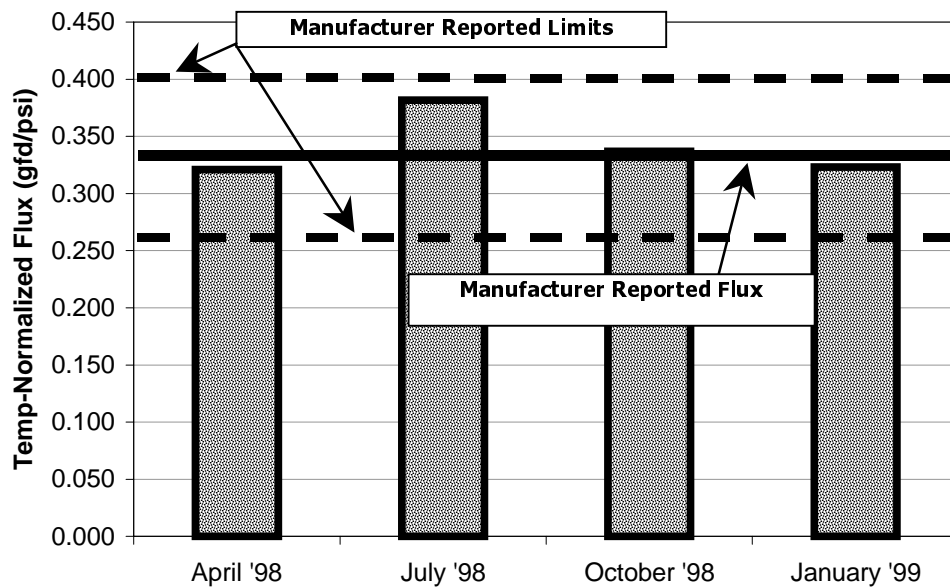


**FIGURE 4.16 Percent Rejection of Total Dissolved Solids With Softening and Non-Softening Membranes**



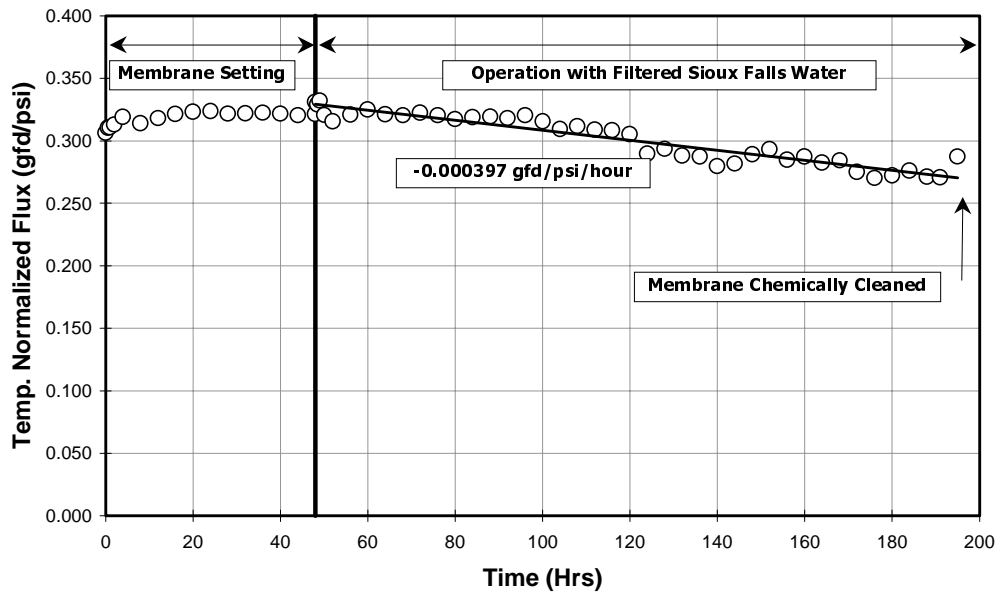
### Additional Significant Results

Figure 4.25 is a summary of the initial MTCw obtained for the NF-70 through the course of the study. All four of the MTCw were within the manufacturer reported limits.

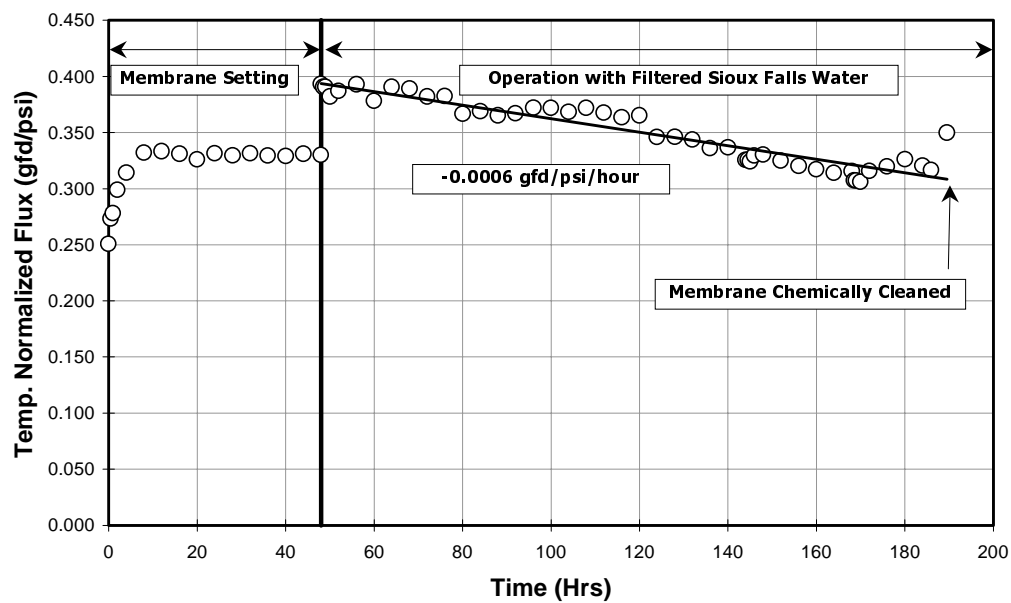


**FIGURE 4.17 Temperature Normalized Specific Flux For Film-Tec NF-70 Treating Filter Sioux Falls Water**

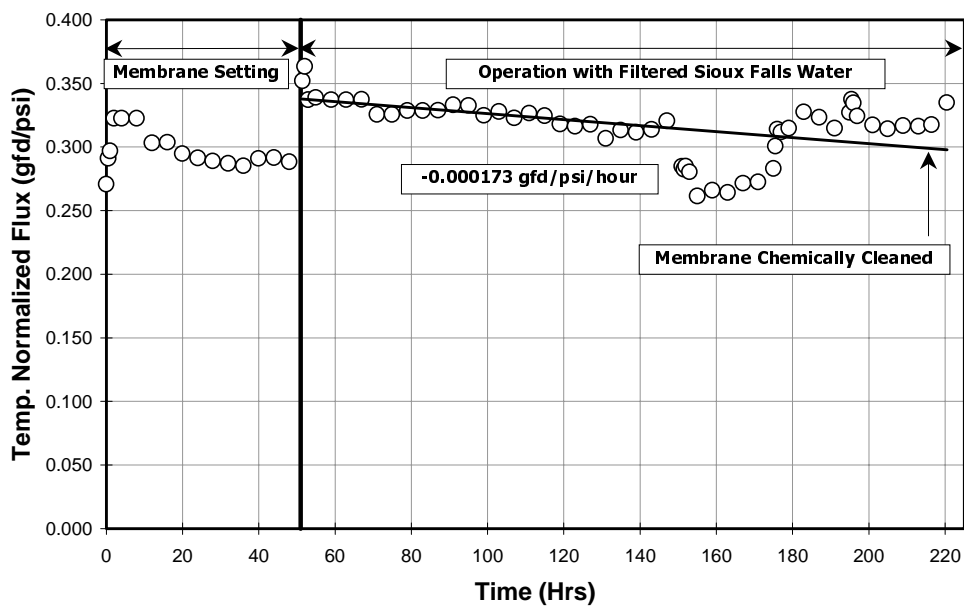
The MTC<sub>w</sub>, plotted as a function of time, can be used to determine fouling rates and cleaning frequencies. Figures 4.18 through 4.25 are plots of temperature normalized MTC<sub>w</sub> with respect to time. During the first few hours of the test, a period of rapid increase or decrease, followed by a period of steady MTC<sub>w</sub> was seen in all quarterly studies. This change occurs during the first hours of the study and is known as membrane setting. Each of the following figures shows the exact time when setting was discontinued and the approximate time when the membrane was cleaned. The rate of MTC<sub>w</sub> decline was calculated using linear regression and then used to determine the cleaning interval.



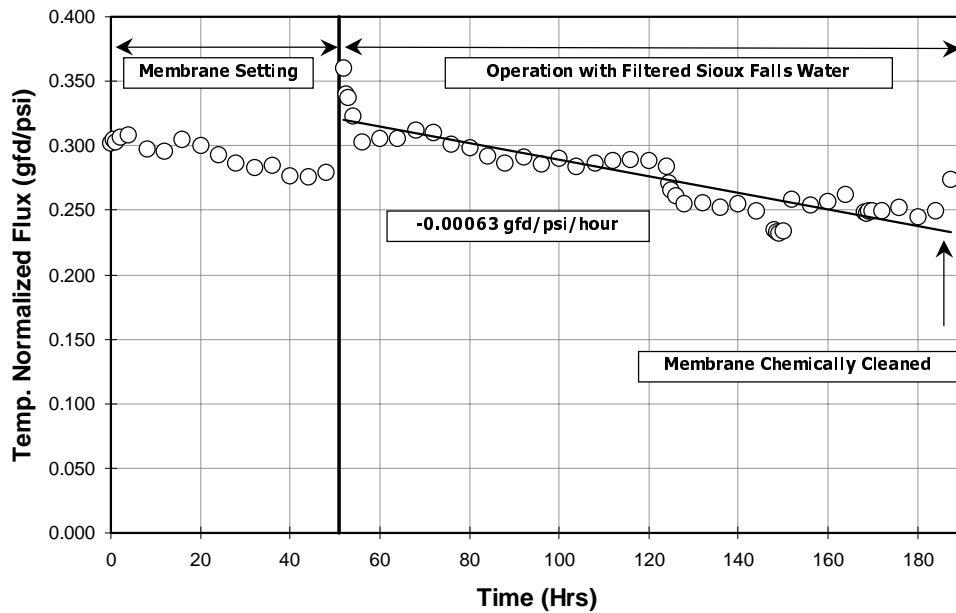
**FIGURE 4.18 Membrane Productivity As a Function of Time (Film-Tec NF-70, April 1998)**



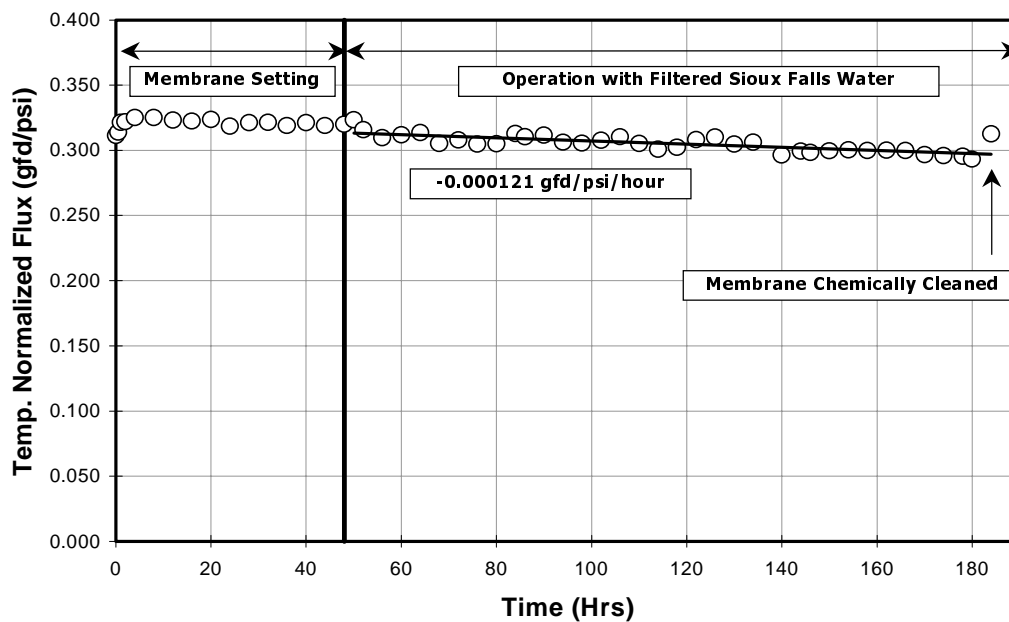
**FIGURE 4.19 Membrane Productivity As a Function of Time**  
**Film-Tec NF-70, July 1998**



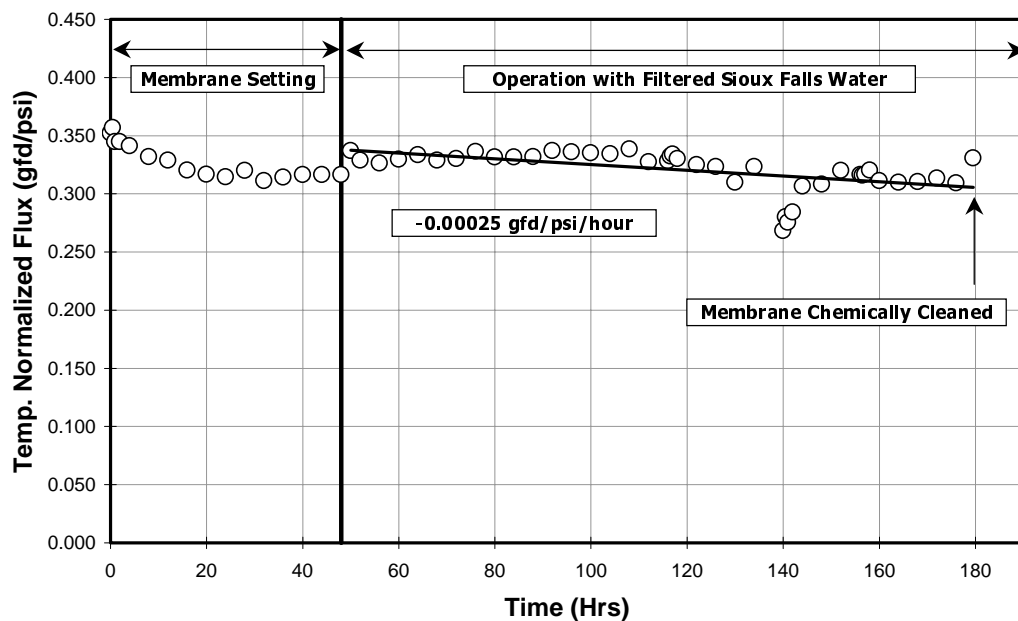
**FIGURE 4.20 Membrane Productivity As a Function of Time**  
**Film-Tec NF-70, October 1998**



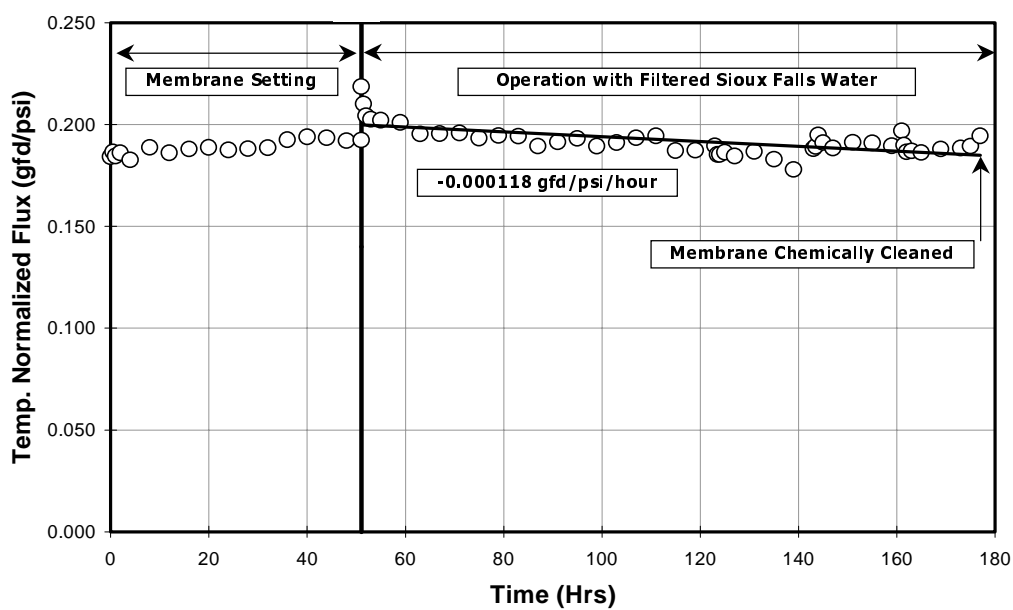
**FIGURE 4.21 Membrane Productivity As a Function of Time**  
**Film-Tec NF-70, January 1999**



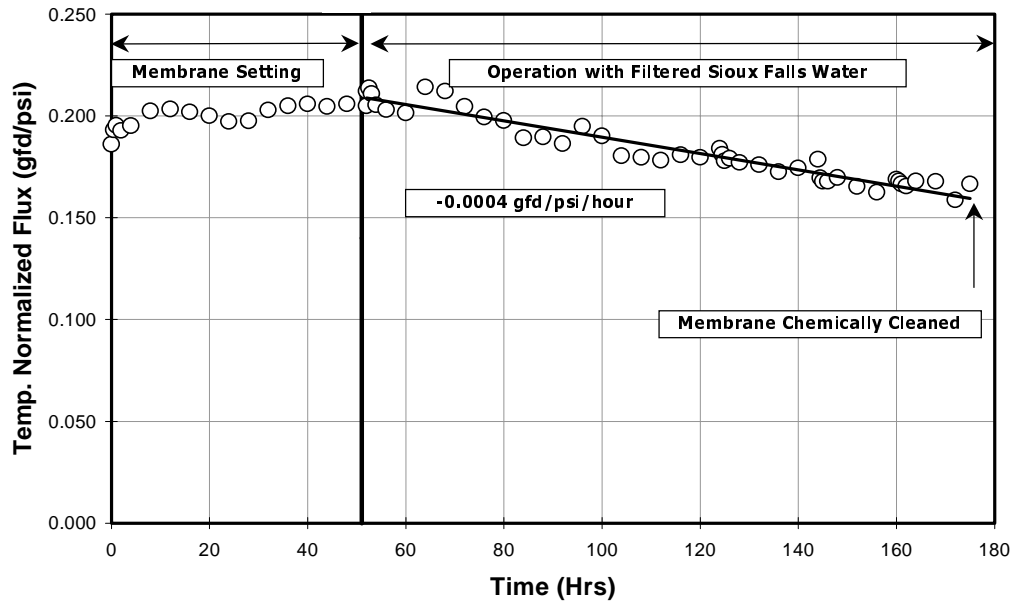
**FIGURE 4.22 Membrane Productivity As a Function of Time**  
**Fluid Systems TFCS, April 1998**



**FIGURE 4.23 Membrane Productivity As a Function of Time  
Fluid Systems TFCS, July 1998**



**FIGURE 4.24 Membrane Productivity As a Function of Time  
Film-Tec NF-200B, October 1998**



**FIGURE 4.25 Membrane Productivity As a Function of Time  
Hydranautics NTR-7450, January 1999**

The rate of MTCw decline, especially for the softening membranes, seems to decrease faster than what was expected. This rapid decrease indicates that cleaning is needed on a frequent basis. This rapid decrease could be a result of scaling with inorganic salts at the high recoveries. Tables 4.12-4.15 summarize the average membrane productivity observed during the different recoveries for each quarter. Based on the data gathered from the RBSMT tests, the cleaning interval (based on a 20% MTCw drop) would range between 5 and 24 days. If membranes receive further consideration for treating Sioux Falls water, pilot scale testing would reveal necessary antiscalant additions necessary to extend the cleaning frequency into the desirable range of greater than 30 days.

**TABLE 4.12 Summary of Average Membrane Productivity Observed Under  
Different Operating Conditions During A Membrane Treatment Study**  
Film-Tec NF-70

<b>Operating Conditions</b>	<b>Average Rate of MTC<sub>w</sub> Decline (gfd/psi/hour)</b>	<b>Average Cleaning Interval* (days)</b>	<b>Initial MTC<sub>w</sub> (gfd/psi)</b>	<b>Final MTC<sub>w</sub> (gfd/psi)</b>	<b>MTC<sub>w</sub> After Cleaning (gfd/psi)</b>
<b>Apr '98</b>	$-3.97 \times 10^{-4}$	8	0.341	0.276	0.291
<b>July '98</b>	$-6.0 \times 10^{-4}$	6	0.405	0.326	0.360
<b>Oct '98</b>	$-1.37 \times 10^{-4}$	22	0.352	0.318	0.335
<b>Jan '99</b>	$-6.3 \times 10^{-4}$	5	0.341	0.250	0.274

*\* Cleaning Interval is Calculated assuming a 20% drop in MTC<sub>w</sub> prior to cleaning*

**TABLE 4.13 Summary of Average Membrane Productivity Observed Under  
Different Operating Conditions During A Membrane Treatment Study**  
Fluid System TFC-S

<b>Operating Conditions</b>	<b>Average Rate of MTC<sub>w</sub> Decline (gfd/psi/hour)</b>	<b>Average Cleaning Interval* (days)</b>	<b>Initial MTC<sub>w</sub> (gfd/psi)</b>	<b>Final MTC<sub>w</sub> (gfd/psi)</b>	<b>MTC<sub>w</sub> After Cleaning (gfd/psi)</b>
<b>Apr '98</b>	$-1.21 \times 10^{-4}$	24	0.335	0.302	0.317
<b>July '98</b>	$-2.50 \times 10^{-4}$	13	0.360	0.319	0.341
<b>Oct '98</b>					
<b>Jan '99</b>					

*\* Cleaning Interval is Calculated assuming a 20% drop in MTC<sub>w</sub> prior to cleaning*

**TABLE 4.14 Summary of Average Membrane Productivity Observed Under  
Different Operating Conditions During A Membrane Treatment Study  
Film-Tec NF-200B**

<b>Operating Conditions</b>	<b>Average Rate of MTC<sub>w</sub> Decline (gfd/psi/hour)</b>	<b>Average Cleaning Interval* (days)</b>	<b>Initial MTC<sub>w</sub> (gfd/psi)</b>	<b>Final MTC<sub>w</sub> (gfd/psi)</b>	<b>MTC<sub>w</sub> After Cleaning (gfd/psi)</b>
<b>Apr '98</b>					
<b>July '98</b>					
<b>Oct '98</b>	-1.18 x 10 <sup>-4</sup>	16	0.219	0.189	0.194
<b>Jan '99</b>					

*\* Cleaning Interval is Calculated assuming a 20% drop in MTC<sub>w</sub> prior to cleaning*

**TABLE 4.15 Summary of Average Membrane Productivity Observed Under  
Different Operating Conditions During A Membrane Treatment Study  
Hydranautics NTR-7450**

<b>Operating Conditions</b>	<b>Average Rate of MTC<sub>w</sub> Decline (gfd/psi/hour)</b>	<b>Average Cleaning Interval* (days)</b>	<b>Initial MTC<sub>w</sub> (gfd/psi)</b>	<b>Final MTC<sub>w</sub> (gfd/psi)</b>	<b>MTC<sub>w</sub> After Cleaning (gfd/psi)</b>
<b>Apr '98</b>					
<b>July '98</b>					
<b>Oct '98</b>					
<b>Jan '99</b>	-4.0 x 10 <sup>-4</sup>	5	0.212	0.159	0.166

*\* Cleaning Interval is Calculated assuming a 20% drop in MTC<sub>w</sub> prior to cleaning*



## **V. QA / QC Summary**

### **Summary of Calibration Procedures**

The following is a summary of the QA/QC procedures that were used by Environmental Health Laboratories for the DBP, bromide and TOC analyses. All tests were conducted according to the DBP/ICR Analytic Methods Manual. The QA/QC included relative duplicates, laboratory fortified matrix spikes, and internal standards for calibration and quantitation purposes.

The relative percent difference sample was divided into two aliquots and each sample was analyzed. The duplicate data was evaluated and if any sample did not meet the criteria set forth in the Analytical Methods Manual, the data was not reported in the ICR spreadsheets.

Laboratory fortified samples were conducted on all DBP and DBP precursors. The Environmental Health Laboratories also conducted duplicate spikes for TOC and THM4 for each quarter. Laboratory fortified samples for quarterly THM4 and HAA6 samples were analyzed using a 40 µg/L, 20 µg/L, and 1 µg/L spikes. Dosages of 1.0 mg/l and 0.7 mg/L were used as spikes for TOC samples analyzed each quarter. Spike dosages for all other parameters were not reported by Environmental Health Laboratories.

The performance evaluation results performed by Environmental Health Laboratories are reported in the ICR spreadsheets. Additional PE results from the laboratory were still being compiled by the laboratory and not available at the time of this report. All results that were outside the warning limits were not reported in the ICR spreadsheets. All the first quarter internal standard results were within the limits.

All data collected from the Environmental Health Laboratories was closely evaluated. QA/QC results provided by the laboratory were checked to ensure that only properly executed and correct data was reported in the RBSMT treatment study. There was only one instance where a UV<sub>254</sub> sample was collected and analyzed, and then not reported due to failure to meet QA/QC criteria.

Environmental Health Laboratories used one of the approved calibration procedures for each of the DBP and DBP precursor analysis. The THM4, HAA6, TOX, Bromide, and TOC analysis utilized a calibration curve based on detector responses to the analyte, relative to an internal standard. The UV<sub>254</sub> calibration was accomplished through single point calibration efforts. Verification of the calibrations were checked after every tenth sample, with the exception of TOX. Verification of the TOX calibration was accomplished after every seventh sample.