Kennedy/Jenks Consultants

11 July 2006

Technical Memorandum No. 10

To: Bob Castle, MMWD
David Furukawa, SCI

From: Todd Reynolds, Kennedy/Jenks
Val Frenkel, Kennedy/Jenks

Reviewed: Jim Lozier, CH2M HILL

Subject: SWRO Membrane Performance
MMWD Seawater Desalination Pilot Plant Program
K/J 0468029

BACKGROUND

This technical memorandum summarizes probable contributors to the seawater reverse osmosis (SWRO) membrane fouling associated with operation of MMWD SWRO pilot units; influence of the pre-treatment, and performance of the SWRO pilot units, including types and frequency of chemical cleanings (CIPs); and describes how the CIPs and their impacts on membrane performance translate to predicted frequency and type of CIPs that would be required for a full-scale SWRO desalination facility that may be constructed by the MMWD in the future.

SWRO MEMBRANE ELEMENT FOULING

The nature and rapidity of fouling experienced by RO systems operated on sea or estuarine waters depends on many factors, most notably source water quality and the type of treatment the source water is provided (pretreatment) prior to RO processing. Since both source water quality and pretreatment varies from location to location, the frequency and type of RO cleaning needed to maintain system performance also varies. The typical frequency of CIP cleaning for SWRO facilities is generally two to three times per year (every 4 to 6 months) where feed water pretreatment is satisfactory. Some SWRO facilities perform cleanings less frequently while other facilities clean more often depending upon the level of foulants present and the ability of the pretreatment to adequately reduce or manage these foulants. Seasonal feed water characteristic variations and events such as algal blooms can also impact on the CIP requirements and frequencies.

RO membrane fouling is a function of four primary factors:

1. Scaling and depositions - precipitation of sparingly soluble salts.
2. Particulate fouling - accumulation of particulate inorganic and particulate organic matter.
3. Bio-fouling - attachment and growth of microbes, microorganisms and/or marine life.

4. Organic fouling - deposition of colloidal and dissolved organics.

In the MMWD pilot study, MF/UF and conventional pretreatment systems are employed to control fouling caused by accumulation of inorganic/organic matter (factor #2) while scale inhibitor (and if needed, acid) is used to control scaling (factor #1). Biofouling (factor #3) is managed on an as-needed basis by periodic shock chlorination of pretreatment systems, including filtrate tanks and piping, as well as reduction in bacterial concentrations through coagulation and/or filtration. Based on the SDI values of the filtrates produced from the two pretreatments, fouling by inorganic and organic particulate matter should be adequately controlled. The use of antiscalant, combined with the low scaling potential of the Bay water at the moderate feedwater recoveries employed in the study, should effectively prevent scaling.

The primary foulants present in the feedwater to the MMWD SWRO pilot units are soluble organics and marine organisms including bacteria, associated nutrients and water temperature that can cause biofouling. Ferric-coagulated colloids, not completely retained by the granular media filter, also represent a secondary class of foulants. During the early part of the pilot testing, biogrowth occurred in the filtrate tanks and downstream piping, which is believed to have contributed to or been the main cause of the observed decreases in normalized product flow and increases in differential pressure in the SWRO units at that time.

CIPs are conducted to remove these materials from the membrane surface and element feed spacer using two general chemical regimes: acidic solutions, which are formulated to solubilize precipitated salts, and alkaline solutions, which are formulated to remove inert inorganic material as well as organic and biological matter.

The extent to which RO membrane fouling occurs and the resultant changes in RO performance that fouling causes is evaluated using the following:

- Normalized permeate flow (NPF), which measures the change in resistance of water flow through the RO membrane.
- Normalized salt passage (NSP), which measures the change in resistance to salt (conductivity) flow through the membrane.
- Normalized differential pressure (NDP), which measures the degree of accumulation of material in the feed/brine spacer.

The operating data from the SWRO units must be “normalized” through the above performance parameters to account for the effects of variations in feedwater temperature and salinity as well as membrane flux and recovery that would otherwise mask changes caused by fouling. Pilot data Figures 4.2 through 4.8 present time-dependent operational and normalized data for SWRO #1 over the pilot study period. Pilot data Figures 5.2 through 5.8 present time-dependent operational and normalized data for SWRO #2 over the pilot study period.

SWRO MEMBRANE SYSTEM CLEANING

Chemical cleaning is recommended when the SWRO system shows evidence of fouling, before a long-term shutdown or as a routine maintenance item. During normal operation, the performance changes that signal the need for cleaning are:

- A 10 to 15-percent decrease in NPF.
- A 10 to 15-percent increase in NSP.
- A 10 to 15-percent increase in NDP.

In addition to the above, more detailed information on fouling can be ascertained through:

- Analysis of the clean and spent solutions used to clean the SWRO units to determine what has been removed during the cleaning.
- Autopsy of one or more membrane elements from the SWRO unit after some period of operation to characterize the nature of the foulants present on the membrane surface.

For the purposes of the MMWD pilot study, CIPs were also conducted in conjunction with changes in the operating conditions of the SWRO units (flux and recovery) so that the effect of a change could be more clearly determined. Thus, the frequency of CIPs conducted during the pilot study will be greater than for a full-scale plant where such changes are not part of a typical operating scenario.

SELECTION OF CLEANING SOLUTIONS AND CIP USE WITH PILOT SWRO UNITS

Table 1 below summarizes typical SWRO CIP formulations and the foulants that the solution is targeting for removal.

Table 1: Typical SWRO Cleaning Chemical Solutions

Cleaning Solution	Chemical Ingredients	Percent Solution	Target Foulant
1	Citric Acid	2%	Inorganic scale/colloids
2	STPP (sodium tripolyphosphate) Na-EDTA (sodium salt of ethylaminediaminetetraacetic acid)	2% 0.8%	Inorganic scale/ mixed inorganic and organic coloids

Cleaning Solution	Chemical Ingredients	Percent Solution	Target Foulant
3	STPP (sodium tripolyphosphate) Na-DDBS (sodium salt of dodecylbenzene sulfonate)	2% 0.25%	Biological matter/ natural organic matter (NOM)
4	HCL Acid (hydrochloric acid)	0.5%	Inorganic scale/colloids
5	Sodium hydrosulfite	1%	Metal oxides
6	NaOH (sodium hydroxide) SDS (sodium dodecylsulfate)	0.1% 0.03%	Biological matter/ mixed inorganic and organic coloids
7	NaOH (sodium hydroxide)	0.1%	Biological matter/ NOM

Given that the primary foulants present in the feedwater to the SWRO units is organic in nature, solutions 2, 3, 6 and 7 are most applicable. To minimize the number of chemicals in the spent cleaning solution and to minimize issues associated with solution disposal, it is desirable to use solution 7 initially and progress to one of the other solutions if this solution is not effective. Because inorganic, acid soluble foulants are often matrixed with organic foulants in most natural waters, it is common to conduct an acid CIP (using either solution 1 or 4) in conjunction with an alkaline cleaning.

Tables 2 and 3 present the CIPs that were performed on the MMWD Seawater Desalination Pilot Plant SWRO equipment, the cleaning solutions used and the reason for the cleaning. Operating hours achieved prior to conduct of the cleaning are listed by element type: Hydranautics (H); Dow/Filmtec (D); Toray (T); and Koch (K). The element operating hours are different within a given SWRO unit because the Dow FilmTec and Toray elements were replaced in August 2005 due to water quality performance issues. The operating hours for SWRO Unit #1 are greater than for SWRO Unit # 2 due primarily to the longer time required to optimize the associated (conventional) pretreatment system performance.

Table 2: MMWD Pilot Plant SWRO #1 Cleaning Schedule

CIP # / Date	SWRO Unit #	SWRO Element Operating Hours	Operating Hours Since Last CIP	Cleaning Solutions Used	Reason for Cleaning/Comments
1 / 9/1/05	1	H - 1132 D - 102 T - 65	N/A	1 and 7	Remove fouling caused by biogrowth in filtrate tank and downstream piping. Effect of cleaning on restoration of NPF was minimal.
1A / 9/30/05	1	H - 1560	H - 428	3	Hydranautics Only. Improve restoration of NPF using stronger cleaning formulation. Effect of cleaning on restoration of NPF was minimal.
2 / 12/6/05	1	H - 2380 D - 1350 T - 1313	H - 820 D - 1248 T - 1248	1 and 3	Change in SWRO operating conditions – increased flux rate. Effect of cleaning on restoration of NDP was minimal.
3 / 3/8/06	1	H -3711 D - 2681 K - 1205	H – 1331 D – 1331 K - NA	1 and 3	Increase in NDP for all elements due to possible biofouling. Cleaning was effective in restoring NDP for Dow FilmTec and Koch. The cleaning was less effective for Hydranautics.

Table 3: MMWD Pilot Plant SWRO #2 Cleaning Schedule

CIP # / Date	SWRO Unit #	SWRO Element Operating Hours	Operating Hours Since Last CIP	Cleaning Solutions Used	Reason for Cleaning/Comments
1 / 9/8/05	2	H - 873 D - 592 T - 450	N/A	1 and 7	Remove fouling caused by biogrowth in filtrate tank and downstream piping. Effect of cleaning on restoration of NPF was minimal.

CIP # / Date	SWRO Unit #	SWRO Element Operating Hours	Operating Hours Since Last CIP	Cleaning Solutions Used	Reason for Cleaning/Comments
1A / 10/3/05	2	H - 1171	H - 298	3	Hydranautics Only. Improve restoration of NPF using stronger cleaning formulation. Effect of cleaning on restoration of NPF was minimal.
2 / 11/30/05	2	H - 2297 D - 1874 T - 1758	H - 1126 D - 1424 T - 1424	1 and 3	Increasing NDP for Hydranautics. Change in SWRO operating conditions – increased flux rate. Cleaning improved NPF for all element types and reduced N delta P for Hydranautics.
3 / 3/1/06	2	H - 3543 D - 3120 T - 3004	H - 1246 D - 1246 T - 1246	1 and 3	Increasing NDP and decreasing NPF for Hydranautics and other elements to a lesser degree. Cleaning improved NPF and reduced NDP for all element types.
4 / 3/20/06	2	H - 3749 D - 3326 T - 3210	H - 206 D - 206 T - 206	3	Conventional pretreatment system upset caused rapid increase in NDP. Changed CF's and performed CIP. Cleaning reduced NDP for all element types.

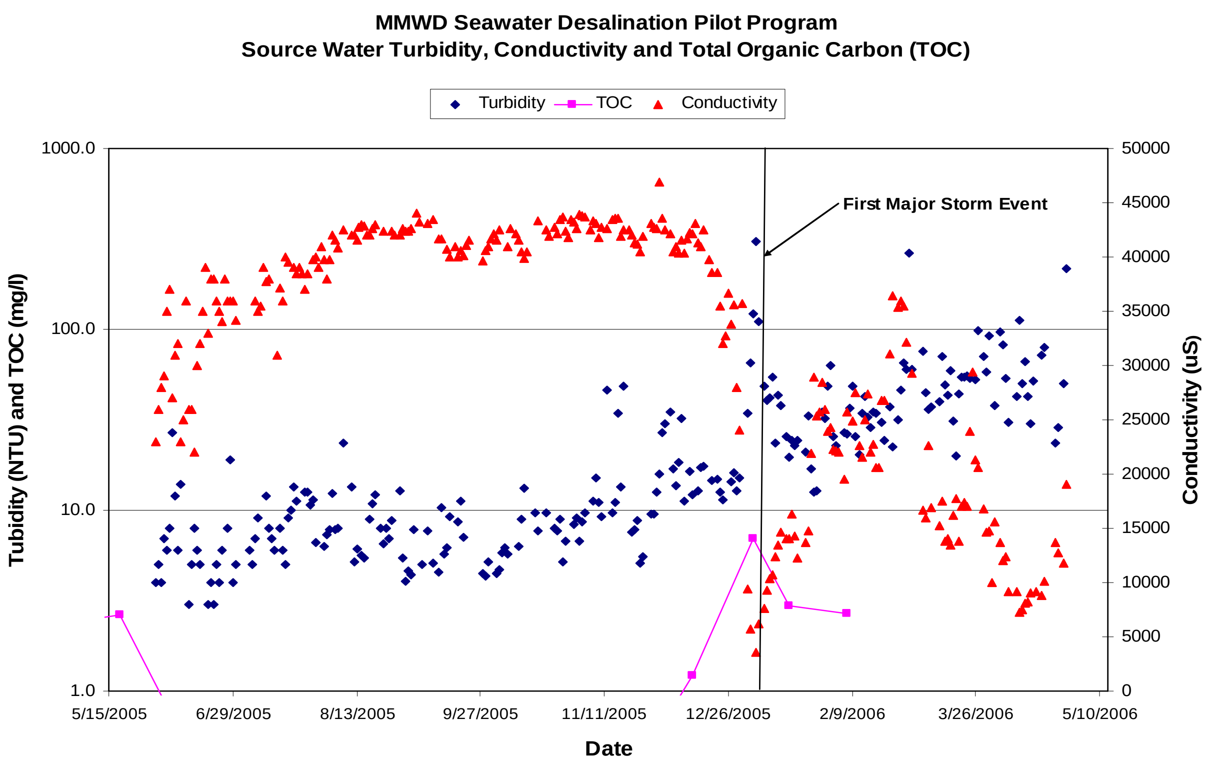
SUMMARY OF SWRO UNIT PERFORMANCE

The performance of the SWRO Units and the effect of the cleanings in terms of the NPF, NSP and NDP for each SWRO unit are presented in figures and tables below. Pilot data figures igures 4.5 through 4.8 present time-dependent normalized operational data for all three membrane element trains in SWRO #1 over the pilot study period. Pilot data figures 5.5 through 5.8 present time-dependent operational data all three membrane element trains in SWRO #2 over the pilot study period.
The figures are also divided into five distinct operational periods for evaluation of the trends:

1. Period 1: June and July 2005. 8 gfd flux and 40% recovery. Initial operation with unpainted filtrate tanks.
2. Period 2: August and September 2005. 8 gfd flux and 40% recovery.
3. Period 3: October to Early December 2005. 8 gfd flux and 50% recovery.
4. Period 4: December 2005 to late February 2006. 10 gfd flux and 50% recovery. This was the start of the wet season with accompanying high source water turbidity and organics.
5. Period 5: March and April 2006. 8 gfd flux and 50% recovery. This was the continuation of the wet season with high turbidity and moderate organics source water quality.

Figure 1 below presents the variation of source water salinity, turbidity and TOC over the entire pilot study period.

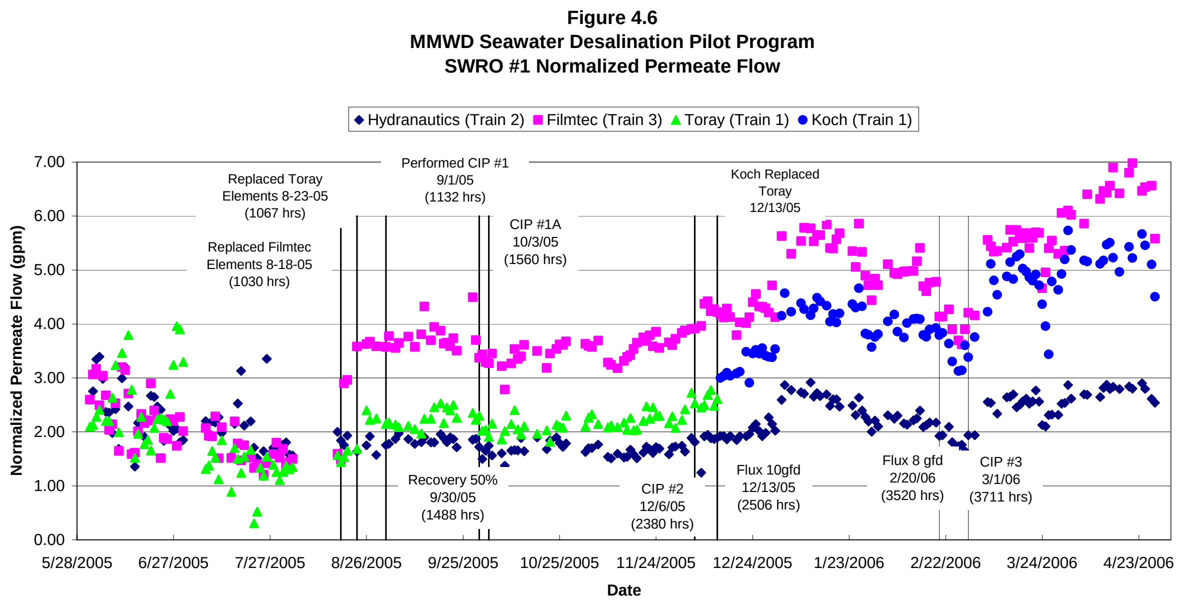
Figure 1: Source Water Salinity Variation



SWRO UNIT #1 PERFORMANCE

Pilot data figures 4.6, 4.7 and 4.8 below present the NPF, NSR and NDP for SWRO Unit #1. Table 4 summarizes the performance observations listed below and presents an estimated CIP frequency for the operating conditions.

Pilot Data Figure 4.6: SWRO #1 Normalized Permeate Flow

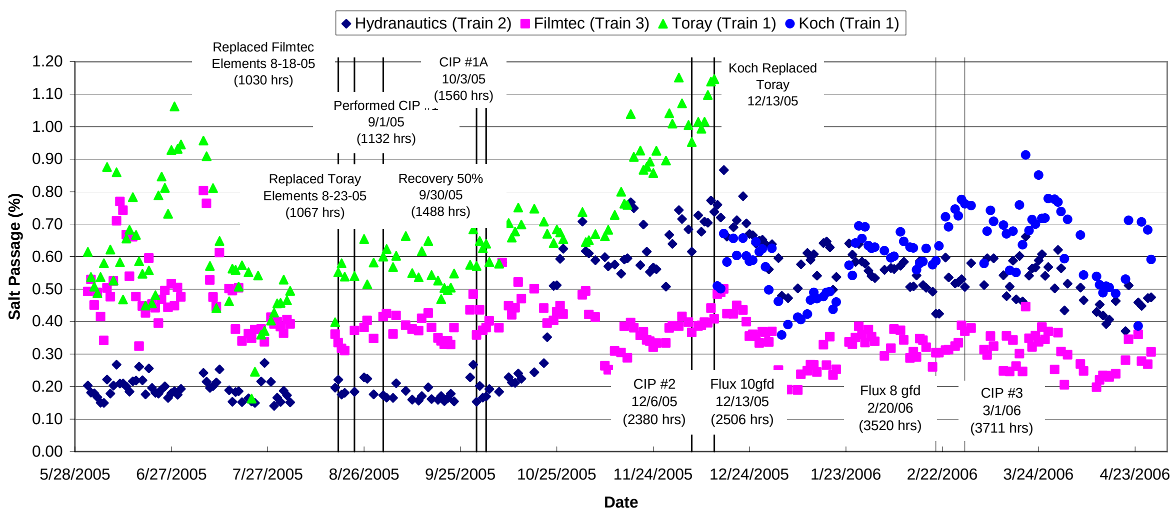


<u>SWRO #1 NPF Performance – Pilot Data Figure 4.6</u>

1. Rapid decline in NPF of all elements in Period 1 attributed to biofouling from MF/UF filtrate tank biogrowth.
2. NPF stable for all three elements in Period 2 after biofouling issues addressed.
3. NPF stable for all three elements in Period 3 with higher system recovery.
4. In Period 4, NPF initially stable at higher flux. NPF increased and decreased in direct relation to decrease and subsequent increase in source water salinity. This relationship indicates that product flow data is not being satisfactorily normalized for changes in feedwater TDS (osmotic pressure).
5. NPF stable for all three elements in Period 5.

Pilot Data Figure 4.7: SWRO #1 Normalized Salt Passage

Figure 4.7.2
MMWD Seawater Desalination Pilot Program
SWRO #1 Normalized Salt Passage



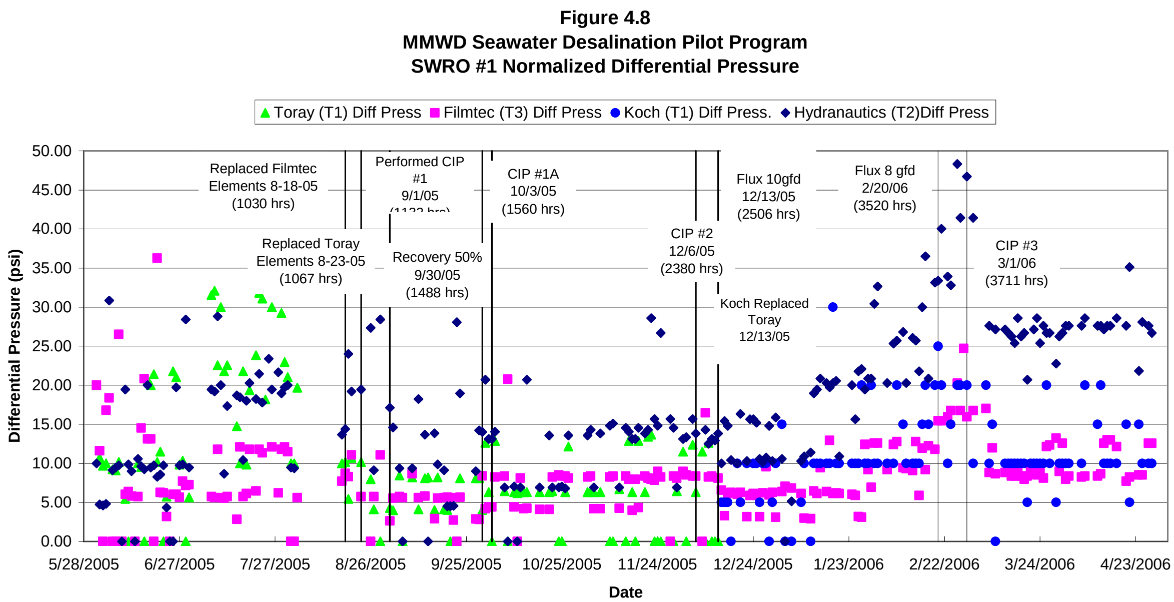
<u>SWRO #1 NSP Performance – Pilot Data Figure 4.7</u>

1. NSP stable for all three elements in Period 1. Biofouling did not impact salt passage.
2. NSP stable for all three elements in Period 2.
3. NSP appears steady for Dow FilmTec elements in Period 3. Increase in NSP for the Hydranautics elements in mid October attributed to leakage in/at element four. Increase in NSP for Hydranautics, and most significantly, Toray in November 2005 was thought to be possible oxidant damage from an incident where UF permeate was shock chlorinated and shut down SWRO Unit #1 on high ORP. However, autopsy of the Dow FilmTec element from SWRO #1 at the end of the pilot study showed no oxidant damage to the elements. Source water salinity during these increases was stable.
4. NSR/NSP generally stable for all three elements in Period 4. Some variation due to widely varying source water salinity.
5. NSR/NSP generally stable for all three elements in Period 5. Some variation due to widely varying source water salinity.

Technical Memorandum No. 10

SWRO Membrane Performance
10 July 2006

Pilot Data Figure 4.8: SWRO #1 Normalized Differential Pressure



<u>SWRO #1 NDP Performance – Pilot Data Figure 4.8</u>

1. Increase in NDP for Hydranautics and Toray elements in Period 1 attributed to biofouling in the MF/UF filtrate tank.
2. NDP steady for all three elements in Period 2 after biofouling issues addressed.
3. NDP steady for all three elements in Period 3 with higher system recovery.
4. In Period 4, NDP initially stable at higher flux then increased for all three elements due to probable bio-fouling from high levels of source water organics. Increase for Hydranautics elements more significant than for Dow FilmTec or Koch.
5. NDP stable for all three elements in Period 5 at lower flux, but high source water turbidity and moderate source water TOC.

Table 4: SWRO #1 Performance Summary

SWRO Flux and Recovery	Source Water Conditions	Performance Parameter	Trend	Expected CIP Frequency
Period 2: 8 gfd / 40% recovery	Dry season – low turbidity, low organics, high salinity	NPF	stable	> 4 to 6 months
		NSR	stable	> 4 to 6 months
		NDP	stable	> 4 to 6 months
Period 3: 8 gfd / 50% recovery	Dry season – low turbidity, low organics, high salinity	NPF	stable	> 4 to 6 months
		NSR	stable	> 4 to 6 months
		NDP	stable	> 4 to 6 months
Period 4: 10 gfd / 50% recovery	Wet season – high turbidity, high organics, low salinity	NPF	decreasing	2 to 3 months
		NSR	stable	> 4 to 6 months
		NDP	increasing	2 months
Period 5: 8 gfd / 50% recovery	Wet season – high turbidity, moderate organics, low salinity	NPF	stable	> 3 to 4 months
		NSR	stable	> 4 to 6 months
		NDP	stable	> 3 to 4 months

The steady increase in NSP for the Toray elements during period 3 cannot be explained by changes in source water temperature or salinity. Incorrect data normalization is not believed to be the cause since all element's data was normalized using the same (Hydranautics) program. It is unlikely that chlorine damage was the cause since the Dow elements exposed to the same source water did not show oxidant damage from the autopsy data. Conductivity profiling of the Toray Vessels did not show obvious o-ring or end connector leakage and the Koch elements that replaced the Toray elements performed within expected NSP for the system. It is believed that there was a failure within these specially rolled 4-inch elements unrelated to the type of pretreatment system. The specially rolled Toray elements in SWRO #2 performed well and standard 8-inch Toray elements would also be expected to perform to their published specifications.

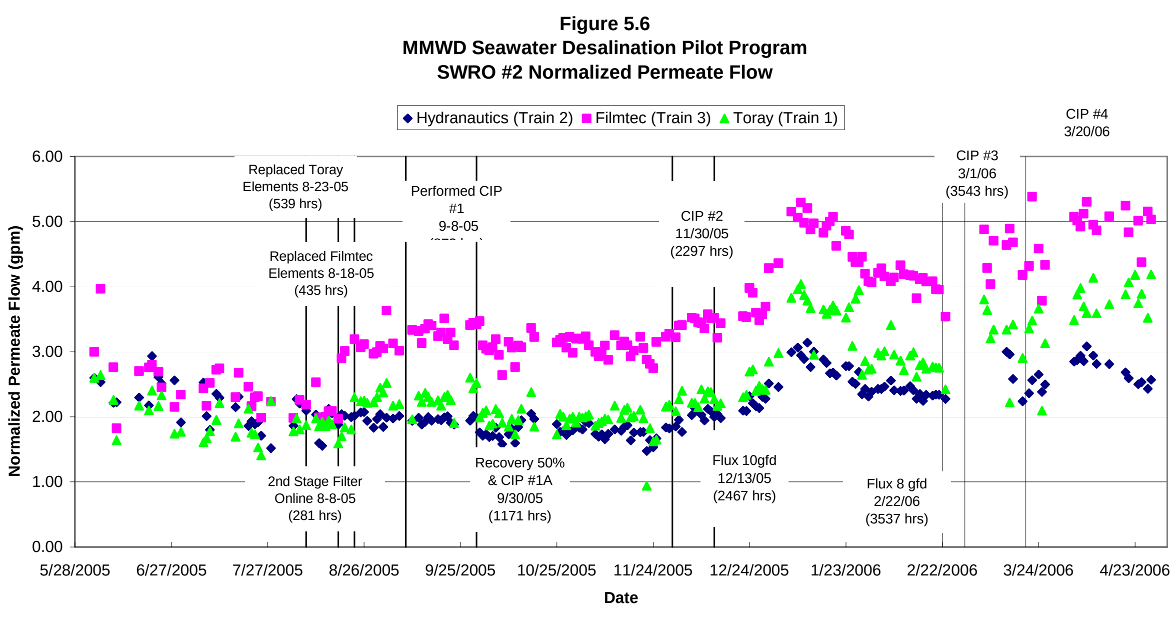
The Hydranautics elements showed a greater level of NDP increase in period 4 than did the Dow FilmTec and Koch elements. Also, the CIP cleaning did not restore the NDP of the Hydranautics elements to the same degree that the NDP of the Dow FilmTec and Koch elements were restored. This could be due to several reasons including:

- The Hydranautics elements have a smaller feed/brine channel spacer (26 mm) than the Dow FilmTec and Koch elements (28 mm). The smaller feed channel may lead to greater deposition of foulants and reduce the effectiveness cleanings in flushing of particulate foulants out of the channel during cleanings.
- The Hydranautics elements were in operation for a longer period than the other elements and could have been impacted by the initial fouling due to bio-growth in the filtrate tanks.
- The lead elements in all of the SWRO trains in SWRO #1 had small plastic shavings that came from the high pressure pump on that unit -- primarily when the pump failed in early July. Because the initial set of Dow FilmTec and Toray elements were replaced for other reasons after this pump failure, these lead elements had fewer plastic shavings. These shavings could have contributed to higher NDP values and reduced the cleaning flowrates through the Hydranautics elements (as was noticed during CIP cleanings) as compared to the other elements.

SWRO UNIT #2 PERFORMANCE

Pilot data figures 5.6, 5.7 and 5.8 below present the NPF, NSR and NDP for SWRO Unit #2. Table 5 summarizes the performance observations listed below and presents an estimated CIP frequency for the operating conditions.

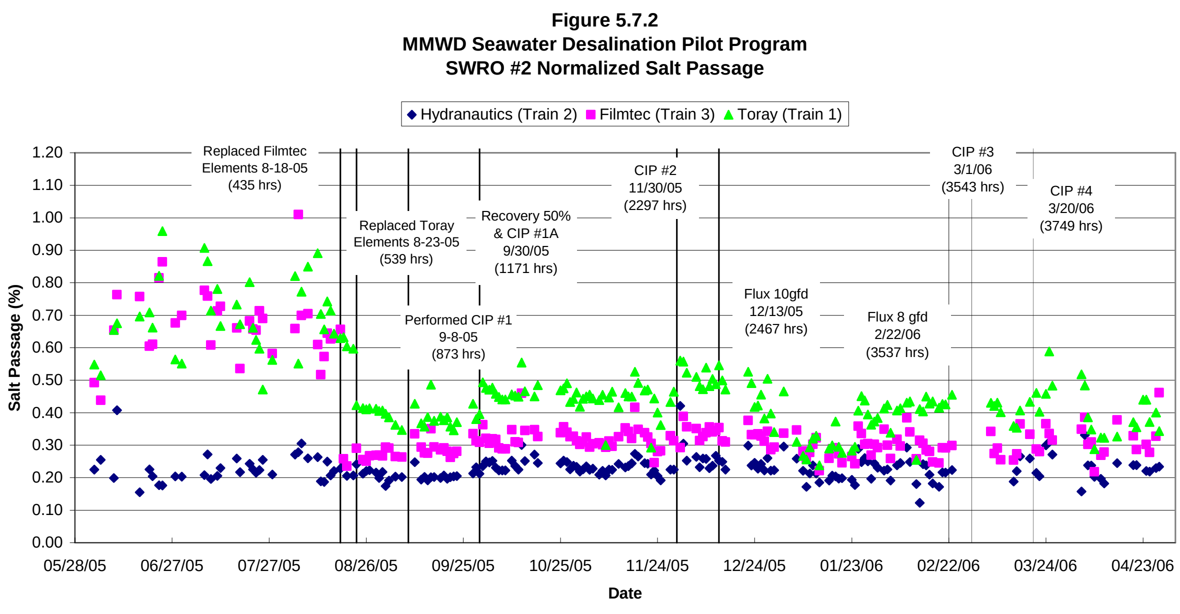
Pilot Data Figure 5.6: SWRO #2 Normalized Permeate Flow



SWRO #2 NPF Performance – Pilot Data Figure 5.6

1. Rapid decline in NPF of all elements in Period 1 attributed to biofouling from in conventional filtrate tank biogrowth.
2. NPF stable for all elements during Period 2 after biofouling issues addressed. NPF stable to slightly decreasing for Hydranautics elements. (Hydranautics specific fouling most likely related to prior fouling during initial operating period.)
3. NPF stable for Toray and Dow FilmTec elements during Period 3 with higher system recovery. Small decline for Hydranautics, possibly related to previous fouling incident.
4. In Period 4, NPF initially stable at higher flux. NPF increased and decreased in direct relation to decrease and subsequent increase in source water salinity. This relationship indicates that product flow data is not being satisfactorily normalized for changes in feedwater TDS (osmotic pressure).
5. NPF more variable in Period 5, most likely due to variations in source water salinity (osmotic pressure). Decreasing NPF for Hydranuatics differs from that of other two element types.

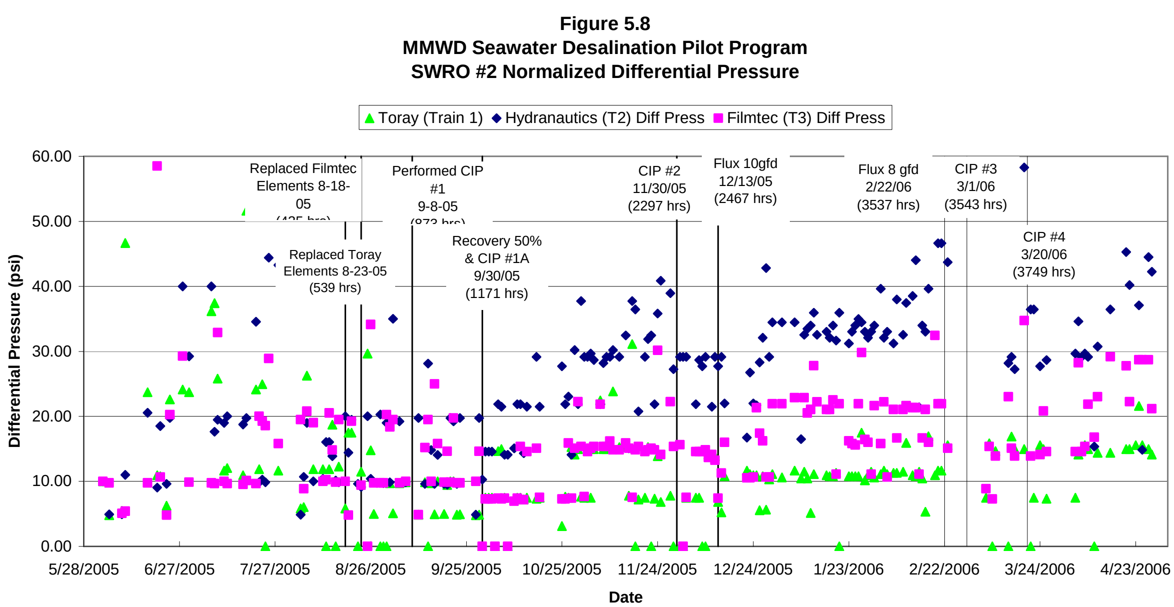
Pilot Data Figure 5.7: SWRO #2 Normalized Salt Passage



<u>SWRO #2 NSP Performance – Pilot Data Figure 5.7</u>

1. NSP stable for all three elements in Period 1.
2. NSP stable Hydranautics and slight decrease in NSR (slight increase in NSP) for Dow FilmTec and Toray elements in Period 2.
3. NSP stable for all three elements in Period 3. Slight increase in NSP for all elements with increased recovery.
4. NSP generally stable for all three elements in Period 4. Some variation due to widely varying source water salinity.
5. NSP generally stable for all three elements in Period 5. Some variation due to widely varying source water salinity.

Pilot Data Figure 5.8: SWRO #2 Normalized Differential Pressure



<u>SWRO #2 NDP Performance – Pilot Data Figure 5.8</u>

1. Increase in NDP for all elements in Period 1 attributed to biofouling in the conventional filtrate tank. Increase most dramatic for Hydranautics.
2. NDP steady for all three elements in Period 2 after biofouling issues addressed.

3. NDP steady for Dow FilmTec and Toray elements in Period 3. Hydranautics element NDP increased in Period 3 attributed to possible particulate fouling. Cleaning reduced Hydranautics NDP.
4. In Period 4, at higher flux rate NDP increased for all three elements due to probable particulate fouling from high levels of source water turbidity and organics.
5. NDP increasing for all three elements in Period 5 with lower flux due to probable particulate fouling from higher levels of source water turbidity and organics. Increase most significant for Hydranautics.

Table 5: SWRO #2 Performance Summary

SWRO Flux and Recovery	Source Water Conditions	Performance Parameter	Trend	Expected CIP Frequency
Period 2: 8 gfd / 40% recovery	Dry season – low turbidity, low organics, high salinity	NPF	stable	> 4 to 6 months
		NSR	stable	> 4 to 6 months
		NDP	stable	> 4 to 6 months
Period 3: 8 gfd / 50% recovery	Dry season – low turbidity, low organics, high salinity	NPF	stable	> 4 to 6 months
		NSR	stable	> 4 to 6 months
		NDP	stable to increasing	2 to 3 months
Period 4: 10 gfd / 50% recovery	Wet season – high turbidity, high organics, low salinity	NPF	decreasing	2 to 3 months
		NSR	stable	> 4 to 6 months
		NDP	increasing	2 to 3 months
Period 5: 8 gfd / 50% recovery	Wet season – high turbidity, moderate organics, low salinity	NPF	stable to decreasing	2 to 3 months
		NSR	stable	> 4 to 6 months
		NDP	increasing	2 to 3 months

The Hydranautics elements showed a greater level of NDP increase in periods 4 and 5 than did the Dow FilmTec and Toray elements. Also, the CIP cleaning did not restore the NDP of the Hydranautics elements to the same degree that the NDP of the Dow FilmTec and Toray elements were restored. This could be due to several reasons including:

- The Hydranautics elements have a smaller feed/brine channel spacer (26 mm) than the Dow FilmTec and Toray elements (28 mm and 31mm respectively). The smaller feed channel may lead to greater deposition of foulants and reduce the effectiveness cleanings in flushing of particulate foulants out of the channel during cleanings.
- The Hydranautics elements were in operation for a longer period than the other elements and could have been impacted by the initial fouling due to bio-growth in the filtrate tanks.

COMPARISON OF FOULING IN SWRO #1 AND SWRO #2

Comparison of Normalized Permeate Flow

Figure 2 below shows the normalized permeate flow (NPF) for the Dow FilmTec membrane trains in SWRO #1 and SWRO #2 to permit comparison of the effect of the two pretreatment systems on this performance parameter.

The NPF values for the Dow/Filmtec elements from SWRO #1 (MF/UF pretreatment) and from SWRO #2 (conventional pretreatment) are similar, and essentially the same, for the majority of the pilot study. The Dow/Filmtec elements were replaced in August 2005 and the difference in the NFP between SWRO #1 and SWRO #2 remained essentially constant until March 2006. The divergence of the NPFs in March and April of 2006 could be an indication of greater fouling in SWRO #2.

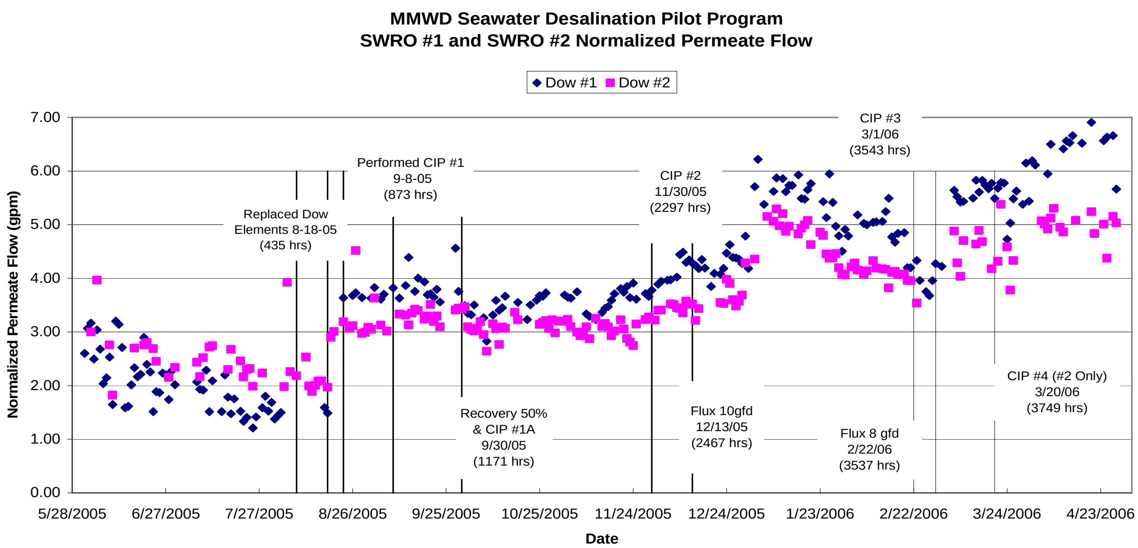
The jump in the NPF values in late December 2005 and January 2006 corresponds to a significant decrease in source water salinity. Although the normalization program should account for the effects of variations in feed water temperature and salinity as well as membrane flux and recovery that would otherwise mask changes caused by fouling, we believe that the algorithms used in the program are not fully capable of normalizing the product flow based on the large salinity variations. Consequently, the decrease in NPF from January 2006 to March 2006, which would normally be indicative of membrane fouling, are largely the result of recovering (increasing) source water salinity as it went from the low of 5,000 uS back up to approximately 25,000 uS. See Figure 1 above for variations in the source water salinity over the pilot period. This is supported by the post-pilot wet testing of the second element from each of the Dow Filmtec arrays. As shown in the table below, both elements (one from each RO unit) were within the expected product specifications in NPF compared to the initial wet test data for these elements. However, assuming both elements would see an approximately equal increase in NPF during this initial operation period, the smaller increase in NPF for SWRO #2 could be due to increased fouling. Based on the Dow FilmTec element autopsies, this fouling is most likely particulate and biological in nature.

Going forward, it is recommended that District engage with the membrane element suppliers regarding the limitations of NPF normalization observed in this study. Although the Hydranautics normalization program was used during this study, the Kennedy/Jenks-Ch2M Hill team has observed similar outcomes with the normalization programs from other membrane manufacturers. Unless rectified, the poor normalization limits the usefulness of NPR (or it's corollary, water transport coefficient) as a performance monitoring tool.

Table of Initial and Post Operation NPF Wet Test Data

SWRO Element	Initial Wet Test Flow Data, gpd	Post Operation Wet Test Flow Data, gpd	Difference, %
SWRO #1 : A9941826 (MF/UF Pretreatment)	1101	1356	23% increase
SWRO #2: A9906540 (Conventional Pretreatment)	1067	1185	11% increase

Figure 2: Comparison of SWRO Normalized Permeate Flow



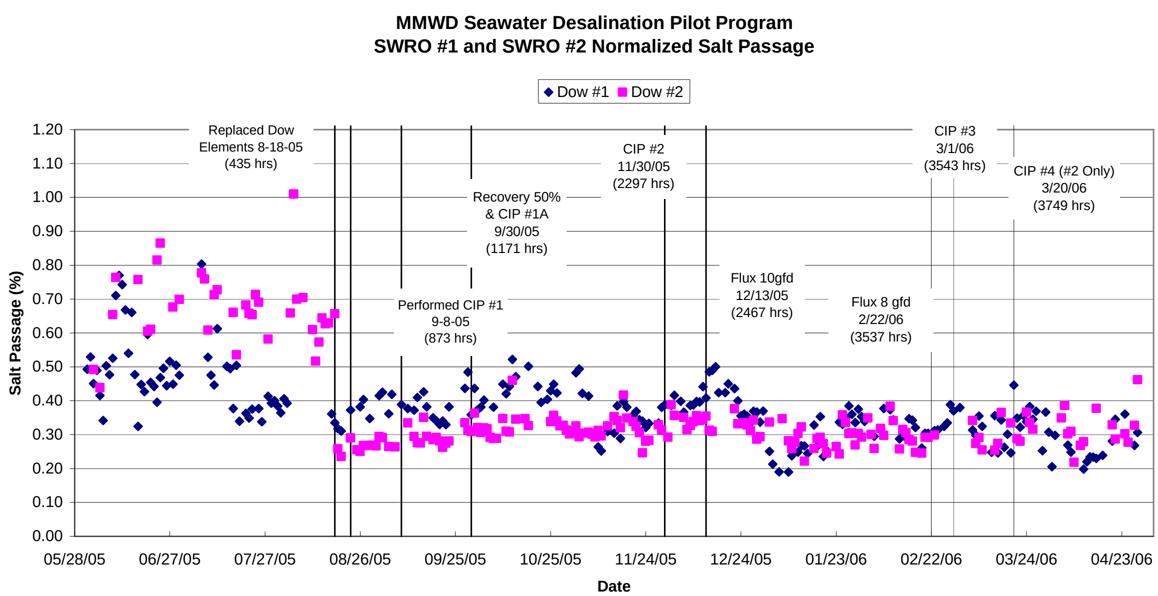
Comparison of Normalized Salt Passage

The normalized salt passage (NSP) for the Dow/Filmtec elements from SWRO #1 and from SWRO #2 are presented in Figure 3 below as a function of operating date. The NSP of the two units are essentially the same over the period of the pilot study. The NSP is generally stable to slightly decreasing over the pilot study. The decrease in NSP could be indicative of the formation of a fouling layer having some salt rejection properties, the significant decrease in source water salinity in late December 2005 and January 2006 that continued through April 2006 or both. Wet testing of the number 2 Dow FilmTec elements in the two trains at the end of the pilot testing showed salt passage was equal to or very slightly less following testing compared with new. This indicates that fouling experienced during the testing (and chemical cleaning) had no adverse impact on salt rejection.

Table of Initial and Post Operation NSR Wet Test Data

SWRO Element	Initial Wet Test Salt Rejection Data, %	Post Operation Wet Test Salt Rejection Data, gpd	Difference, %
SWRO #1 : A9941826 (MF/UF Pretreatment)	99.8	99.8	NA
SWRO #2: A9906540 (Conventional Pretreatment)	99.8	99.7	0.1% decrease

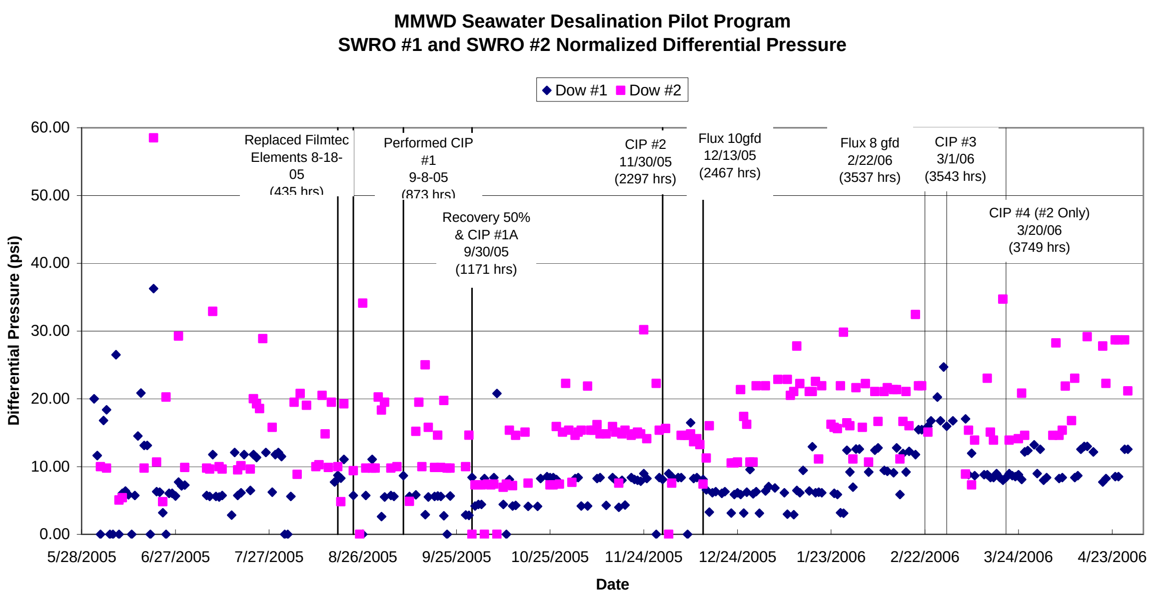
Figure 3: Comparison of SWRO Normalized Salt Passage



Comparison of Normalized Differential Pressure

Figure 4 below shows the normalized differential pressure (NDP) for the Dow FilmTec membrane trains in SWRO #1 and SWRO #2 to permit comparison of the effect of the two pretreatment systems on this performance parameter. The NDP is the difference between vessel feed-end and concentrate-end pressures, normalized to correct for changes in feedwater temperature. Pressures were manually recorded data using pressure gauges with a minimum pressure increment of 20 psi (due to the gauge range of 0 to 1500 psi). Therefore, some data scatter is evident in NDP values in the plot due to different operators reading the gauges differently. However, the trend in the NDP data over time indicate are useful in determining the degree of foulant accumulation in the feed/brine spacer of the RO elements. For example, during the early part of the pilot testing, bio-growth occurred in the filtrate tanks and downstream piping, which is believed to have contributed to or been the main cause of the observed increase in NDP in the SWRO units in the first two months.

Figure 4: Comparison of SWRO Normalized Differential Pressure



The NDP values for the Dow/Filmtec elements from SWRO #1 and from SWRO #2 are similar and stable during the initial and middle of the pilot study period but show some divergence beginning in January 2006, which corresponds with an increase in Bay water turbidity and organics. See Figure 1 above for the variation in source water turbidity and TOC.

SWRO #1 NDP was stable through the initial period of increased turbidity and TOC, but began increasing in mid January and continued through the beginning of March at which time a CIP was performed and the flux rate decreased to 8 gfd. The cleaning reduced the NDP to just above pre-January levels. NDP was stable during the remainder of the testing. The increase in SWRO #2 NDP values beginning in January 2006 coincide with the start of the wet period and increased Bay water turbidity and organics. SWRO #2 was cleaned on March 20, which did reduce the NDP, but during the subsequent operating period, the NDP increased again to pre-CIP levels.

The delayed increase in SWRO #1 NDP (relative to the start of the wet season and turbidity/TOC increases) indicates that the MF/UF system was effectively controlling particulate fouling (as expected) but that biofouling levels may have occurred after two weeks of operation on the higher TOC water. The results of the membrane autopsy of the lead Dow membrane elements showed that while there was a greater amount of organic foulants (as measured by protein and carbohydrate mass) on the conventional pretreatment elements (SWRO #2) there was slightly more measured bacteria on the MF/UF pretreatment elements (SWRO #1). The bacteria on the MF/UF were also more of a mono-culture indicating that they could be growing in the piping and tanks downstream of the MF/UF system as opposed to getting through the 0.2 micron MF or 0.02 micron UF filter. The MF/UF system may have been more conducive to bacteria growth in the system because of slightly different water chemistry conditions than the conventional pretreatment system. With the MF/UF system, there was generally no coagulant, no coagulant aid polymer, the pH of the water was slightly higher, and there was probably more assimilable carbon (AOC) available as a food source. These factors could have lead to greater growth of the bacteria in the MF/UF system. See Technical Memorandum 11 for a detailed discussion on the membrane autopsy results.

Therefore, we believe that the SWRO #1 NDP increase in January 2006 was mainly due to the growth of bacteria (mainly originating from the pilot tanks and piping as opposed to the source water) in the SWRO elements when TOC food for the bacteria increased. As the bacteria in the system increased, the differential pressure in the SWRO system increased.

Recommendations to minimize bio-fouling in a full scale facility include:

- Adding a coagulant before the MF/UF filters during storm events and other periods with high source water TOC to reduced bio-assimilable organic matter.
- Operating the SWRO elements with a flux rate of 8 gfd during storm events and other periods with high source water TOC.
- Initiating or increasing the frequency of chlorine chemical washes of the MF/UF system to inactivate bacteria.

- Removing the MF/UF system from service and disinfecting the filtrate piping and storage systems with chlorine to inactivate bacteria to minimize bacterial loading to and growth within the RO system.

In contrast, the near concurrent increase in NDP of SWRO #2 with the start of the wet season indicates that the conventional pretreatment system was not as effective as the MF/UF system in controlling solids breakthrough to the RO system. The results of the membrane autopsy of the lead and second Dow FilmTec membrane elements showed that there was a greater amount of inorganic and organic foulants on the conventional pretreatment elements (SWRO #2) than there were on the MF/UF pretreatment elements (SWRO #1). In particular, there was a predominance of clay (aluminum silicate) in the SWRO #2 foulant layer, indicating that colloidal clay passed through the conventional treatment system and accumulated on the RO membrane surface despite chemical coagulation, sedimentation and two-stage filtration. (No clays were found following MF/UF pretreatment). Further, iron was observed visually and by ICP analysis in the SWRO #2 element's foulant. These results are consistent with the increased NDP observed for SWRO #2 system.

Potential Future Membrane System NDP

From Figure 4 above, the normalized differential pressure (NDP) values for the SWRO elements from the MF/UF pretreatment system (SWRO #1) were slightly lower at the end of the pilot study that the NDP values for the conventional pretreatment SWRO system (SWRO #2). Based on the SWRO membrane autopsy data, the conventional pretreatment SWRO system had greater levels of inorganic and organic foulants. While the standard CIP cleanings generally remove most of these foulants, a very small amount of foulant typically remains in the membrane element. Over time, the foulants that are not removed will lead to greater differential pressure across the SWRO system. Therefore, even though there was only a small difference in the NDP values between SWRO #1 and SWRO #2 after nine months of pilot operation, it is likely that the NDP for the conventional pretreatment SWRO system could increase faster than that of the MF/UF pretreatment SWRO system over several years of operation. If CIPs are not effective in managing the increase, the SWRO membrane elements following conventional pretreatment would have greater NDP values over time, a shorter life and higher cleaning and spent cleaning solution disposal costs.

CONCLUSIONS

The performance of the elements operated in SWRO Unit #1, which received MF/UF pretreated water is acceptable with respect to all performance parameters (NPF, NSP and NDP). The increase in NDP and presence of bacteria on membrane surface of lead elements can be effectively managed through periodic disinfection and coagulation.

Expectations and recommendations for a full scale facility with MF/UF pretreatment include:

- Flux of 8 gfd is recommended.
- During wet season conditions or high organics conditions, we recommend using a coagulant to reduce potential bio-fouling by reducing the level of dissolved organics that can promote biofouling (additional food source).
- Frequency of disinfection (chlorination) of facilities from intake through RO piping should be increased during rainfall periods when biofouling potential is greatest.
- CIPs every 4 to 6 months or less often under dry season operating conditions.
- CIPs may be required every 3 to 4 months during wet season conditions depending upon the effectiveness of recommended coagulation and periodic disinfection biofouling control methods.

The performance of the elements operated in SWRO Unit #2, which received conventionally pretreated water is acceptable based on observed changes in NPF and NSP. The rate of NDP increase from particle fouling was higher than for SWRO #1 and will increase the frequency of CIP chemical cleaning. Membrane life may be shorter and CIP cleaning costs would be greater. Expectations and recommendations for a full scale facility with conventional pretreatment include:

- Flux of 8 gfd is recommended.
- Frequency of disinfection (chlorination) of facilities from intake through RO piping should be increased during rainfall periods and when biofouling potential is greatest.
- CIPs every 4 to 6 months under dry season operating conditions.
- CIPs may be required every 2 to 4 months during wet season conditions.

Estimated Annual Number of SWRO CIP's

The estimated annual number of CIP cleanings for each SWRO system during a typical year are presented in Table 6 below. A typical year could have a dry season of approximately 7 to 8 months and a wet period of approximately 4 to 5 months. The number of CIPs presented in Table 6 are based on the fouling performance of the SWRO systems described above and on the results of the membrane element autopsy's conducted at the end of the pilot. The autopsy results indicated that the SWRO elements after the conventional pretreatment generally had a greater amount of foulants than did the SWRO elements after the MF/UF pretreatment. This greater amount of fouling would lead to more frequent CIP cleanings.

Table 6: Estimated Annual Number of SWRO CIP's

SWRO System	Pretreatment Type	Typical Source Water	Estimated # of CIP's	Estimated Total Annual CIP's
SWRO #1	MF/UF Pretreatment	Dry Season	1	--
		Wet Season	2	--
		Total	--	3
SWRO #2	Conventional Pretreatment	Dry Season	1 to 2	--
		Wet Season	3	--
		Total	--	4 to 5

The number of CIPs presented in Table 6 above are estimates based on looking at a 24 month operational period with typical dry and wet season operational periods as described above. Based on the fouling characteristics of SWRO #1 and an estimated CIP frequency of 4 to 6 months or less in the dry period and 3 to 4 months in the wet period, a SWRO system with MF/UF pretreatment could have approximately 3 CIP's per year. Based on the fouling characteristics of SWRO #2 and an estimated CIP frequency of 4 to 6 months in the dry period and 2 to 3 months in the wet period, a SWRO system with conventional pretreatment could have approximately 4 to 5 CIP's per year.

For the MMWD desalination facility, a SWRO system with MF/UF pretreatment is estimated to have one to two fewer CIPs per year than a SWRO system with conventional pretreatment. Depending on the effectiveness of cleaning, this may result in a shorter membrane life for RO system operated on feedwater pretreated by conventional treatment.

cc: Joel Faller
File