West Basin Municipal Water District Ocean Water Desalination Demonstration Project Final Report

FINAL

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ABBREVIATIONS

BW backwash

CF cartridge filter

CIP Clean-in-Place

ERD energy recovery device

FC fecal coliform

gfd gallons per square foot of membrane per day

gpd gallons per day

gph gallons per hour

gpm gallons per minute

kgal 1,000 gallons

kW kilowatt

kWh kilowatt-hour

LRV Log Removal Value

MC maintenance clean

MCL maximum contaminant level

mgd million gallons per day

MIT membrane integrity test

mV millivolt

NL notification level

ORP oxidation reduction potential

OWDDF Ocean Water Desalination Demonstration Facility

psi pounds per square inch

RO reverse osmosis

SBS sodium bisulfite

SEALab Science, Education & Adventure Lab

SEC specific energy consumption

SWRO seawater reverse osmosis

TC total coliform

TDS total dissolved solids

TMP trans-membrane pressure

TOC total organic carbon

UF ultrafiltration

um micrometer or micron

uS/cm microsiemen per centimeter

UV ultraviolet light

WRF Water Research Foundation

WRRF WateReuse Research Foundation

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1.0 EXECUTIVE SUMMARY

The West Basin Ocean Water Desalination Demonstration Facility (OWDDF) was a temporary installation serving as West Basin's next step of due diligence towards a goal of implementing responsible large-scale ocean water desalination for production of potable water. The OWDDF, located in Redondo Beach, CA, completed construction and commenced operation in February 2011. The Demonstration Facility in Redondo Beach integrated the results of the pilot testing program operated by West Basin from 2002-2009 in El Segundo, CA, with implementation of full-scale components for long-term evaluation. The OWDDF test plan was completed in September 2013. This report summarizes the process operations and water quality data obtained during the thirty-two months of operation. Figure 1-1 presents the timeline of operation for the main components of the treatment system.

The key project objectives were to successfully demonstrate full-scale reverse osmosis (RO) equipment consistent with the Proposition 50 grant; investigate feasibility of wedgewire intake screen technology in an open ocean environment; test and evaluate various pretreatment and post-treatment operating conditions; evaluate a pressure-exchanger energy recovery device; determine the energy consumption of the seawater RO process; and conduct extensive water quality analyses to characterize different stages of the treatment system.

Figure 1-2 provides a simplified process flow diagram, indicating the major treatment components of the facility. The OWDDF utilized an open ocean intake, which included passive wedgewire screens. These screens prevent impingement and minimize the entrainment of marine organisms. Two parallel intake lines were alternated in use, each line equipped with a different slot size screen and individual intake pump. Once the ocean water was drawn through the wedgewire screens, it was delivered to the Arkal disc filter system (100 µm), for coarse filtration. From there, ocean water was sent to the GE-Zenon submerged ultrafiltration (UF) system, which served as final pretreatment prior to the RO system. The RO system was equipped with cartridge filtration (5 µm), an energy recovery device (from ERI™), chemical cleaning and flush systems. A portion of first-pass RO permeate was sent to a second-pass RO system to further remove minerals. The second-pass RO permeate was blended with the remaining first-pass RO permeate to achieve target product water quality goals. A small portion (~0.5 gpm) of this blended permeate underwent post-treatment to meet the potable water standards and supply a visitor tasting station.

Wedgewire Screens

Three different wedgewire intake screen sizes were tested in this study: 0.5 mm, 1 mm, and 2 mm. The intake configuration allowed for two screens to be in the ocean at one time, with one in operation and the other in standby. Each screen had its own dedicated intake lines. Over the course of testing three manufacturers/materials where tested, Cook Legacy CuNi 90/10-7700, Johnson Z-Alloy (a proprietary material composition) and Hendricks Cu/Ni 90/10-7600. The Cook Legacy screen experienced structural failure and extreme mussel/barnacle attachment. The Johnson Z-Alloy experienced significant corrosion, but no biofouling, whereas conversely the Hendricks exhibited no measurable corrosion, but did support some internal mussel growth. Details of the screens performance with respect to corrosion and mussel attachment are in West Basin's Intake Biofouling and Corrosion Study report. Impingement and entrainment details are presented in West Basin's Intake Effects Assessment Study.

Figure 1-1: Summary of Operation Timeline at OWDDF

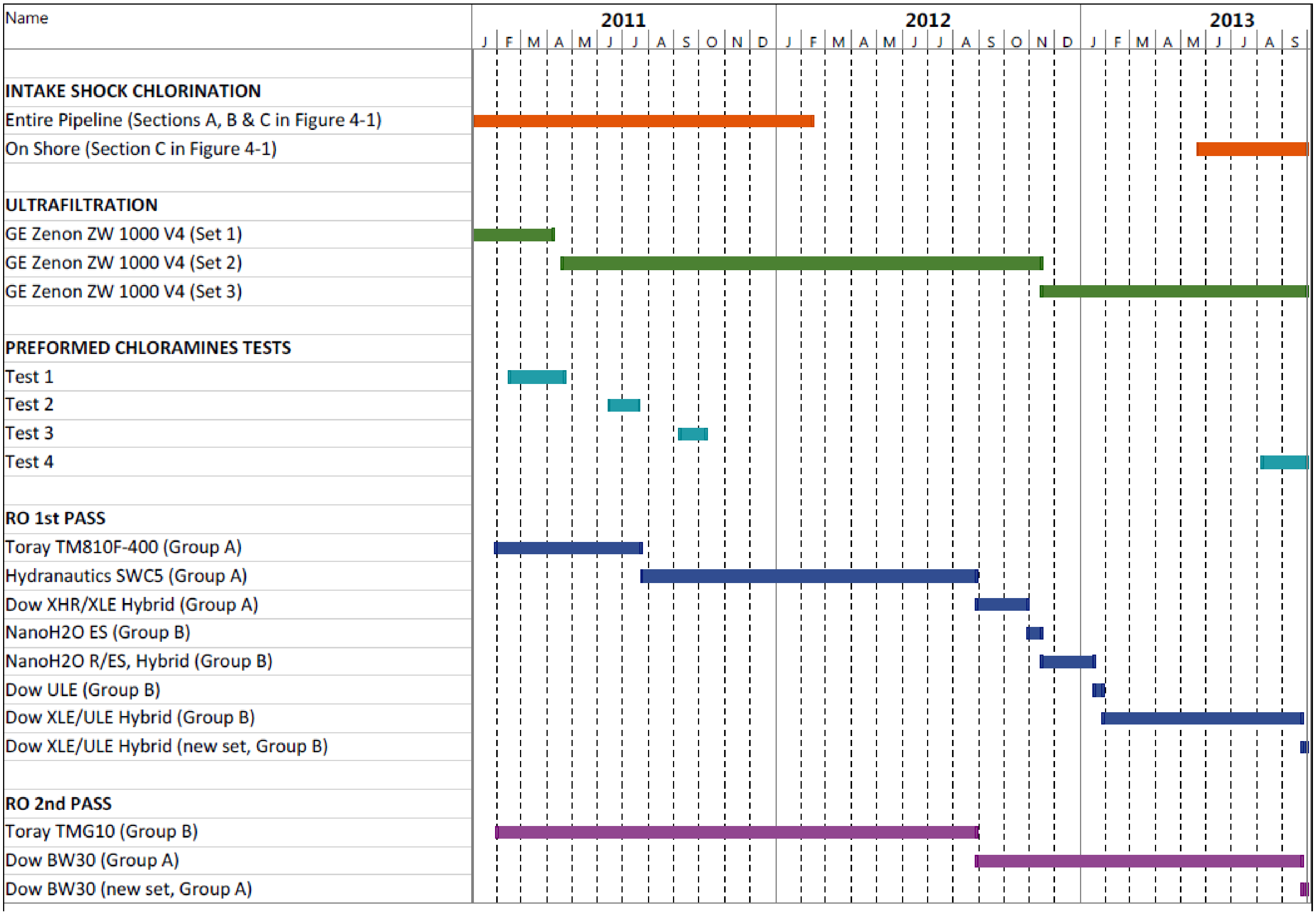
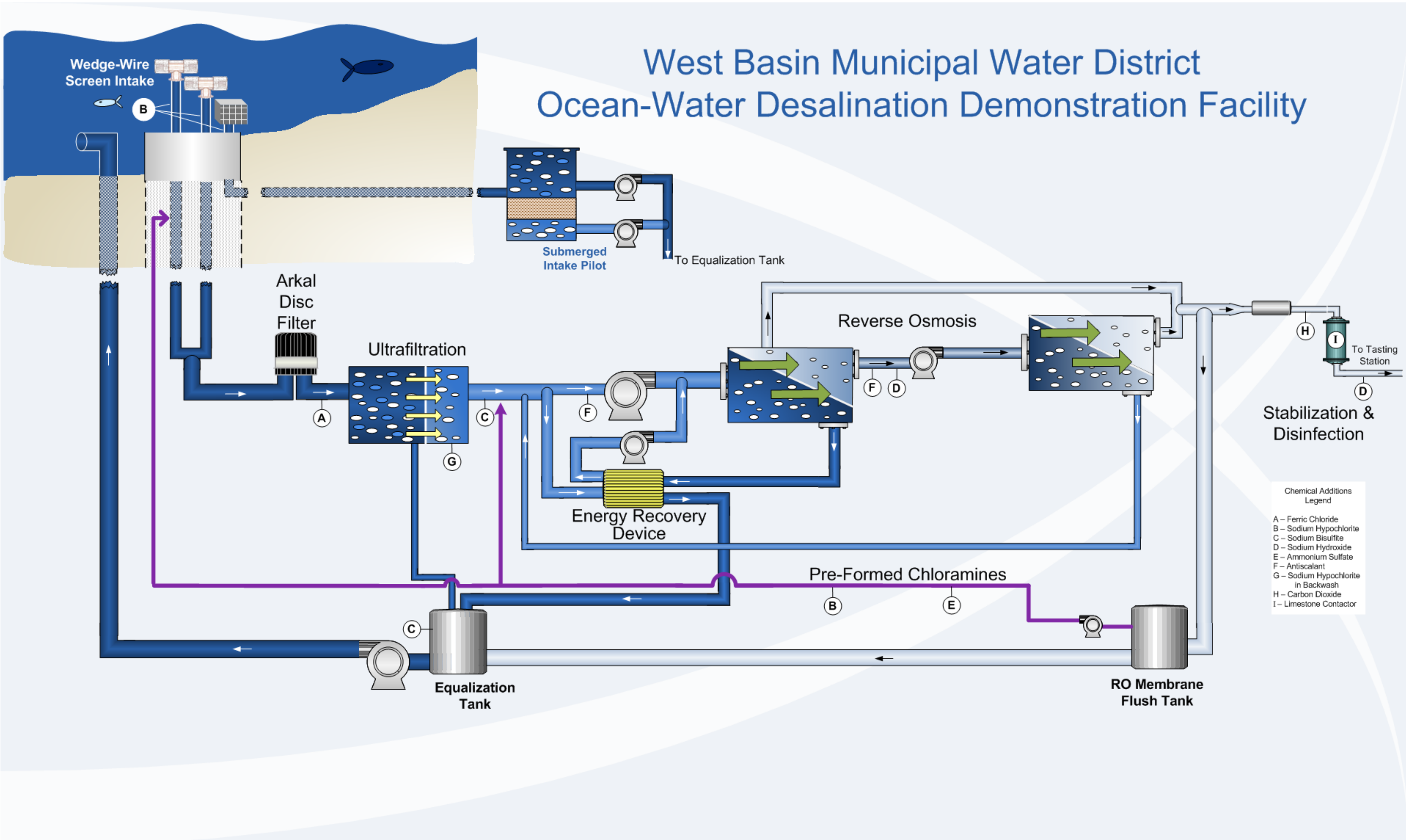


Figure 1-2: Process Flow Diagram



Intake Maintenance

The intake lines were constructed of high-density polyethylene (HDPE) with chemical addition lines running within the pipe from the treatment facility to the intake (a pipe-in-pipe configuration). This configuration allowed delivery of chloramine and sodium hypochlorite to the intake line, just downstream of the intake screens. For the first thirteen months of the study, the intake lines were shock chlorinated for two hours at 8-10 mg/L of residual chlorine (frequencies varied from every week to every month). This dosing strategy proved successful in maintaining a steady intake flow through the system. For this period, the chlorination dosing point was offshore downstream of the wedgewire intake screens. Shock chlorination of the intake lines ceased in February 2012, due to a mechanical failure from poor construction. Thereafter, the intake line biocontrol method was alternating the flow between the two intake lines every four (4) days, allowing the inactive line to go anoxic. This method was effective in preventing large biogrowth development. However, biogrowth accumulated from the common discharge section of the two intake pumps all the way to the Arkal filters (single line prevented inactive period). This was coincidental with decline of intake flow. The line was removed and replaced with new "clean" pipe. Shock chlorination to this on-shore section was resumed in July 2013 with a monthly frequency (18-20 mg/L residual for 5 hours). This appeared sufficient for biogrowth control in this section of pipeline, which had previously experienced heavy growth.

Arkal Filters

Arkal filters (100 um) were successful in protecting the UF system from sharp or abrasive debris (such as shell shards) which if not removed could result in UF fiber damage. Three sets of UF membrane were operated during the duration of the test, due to warranty replacement (permeability loss). The first two sets of UF membranes maintained integrity and low filtrate turbidity, while the third UF set experienced integrity problems/damage. However, inspection of the fibers did not reveal any particulate related damage. High turbidity water (>2 NTU), often correlated to wind events or algal blooms, resulted in an increased number of backwashes and generally required a reduction in the hydraulic load by adding an additional filter into operation. For a given feedwater quality, the frequency of backwashes increased with increase in hydraulic load or reduction in backwash duration. Design criteria were developed for operation under normal feedwater turbidity (<2 NTU), as well as high turbidity events (2-4 NTU).

Table 1-1: Arkal System

Parameter	Value
Model	Arkal 4" Galaxy
# of Duty/Standby Filters (Pods)	2/2
# of Disc Sets (Spines) per Filter	5
Filter Rating	100 microns
Operating Pressure	15 psig
Differential Pressure – clean filters	2 psig
Differential Pressure – dirty filters	7 psig

Ultrafitration

Three identical membrane sets were tested successively in the submerged ultrafiltration system from GE. For the first two sets, permeability stabilized at approximately 3.5 gfd/psi, which was below the level recorded from the pilot in El Segundo. The use of ferric chloride as a coagulant in the feed water of the third membrane set, was beneficial in stabilizing the permeability at 6.5 psi/gfd. Interruptions in ferric dosing led to permeability decline to 3.5 gfd/psi confirming its benefit. Concentration of ferric chloride in the feedwater varied from 1 to 4 mg/L and it appeared that 1 mg/L may be optimal for periods of normal feed water quality. Membrane fiber integrity was maintained with the first two sets of membrane. Poor integrity test results correlated with elevated filtrate turbidity in the third set, requiring corrective action (pinning). Filtrate water quality was excellent, with turbidity values below 0.2 NTU 95% of the time. Design recommendations were developed for a sustainable operation in terms of flux, backwashing and cleaning regimes.

Table 1-2: UF System

Parameter	Operating Condition
Model	GE ZeeWeed ZW-1000
Nominal pore size	0.02 micron
Membrane material	Proprietary PVDF
Number of Process Tanks	2
Number of Modules per Tank	6
UF Membrane Surface Area per Module	550 sq-ft
Instantaneous Filtrate Flow	117 gpm
Design Membrane Flux	25.5 gfd
Maximum Trans-Membrane Pressure	13 psi
UF Filtrate/backwash pump flow	150 gpm
Recovery	91%

First Pass RO

The first pass RO operated at 50% recovery and a flux of 9 gfd. Operating performance confirmed these operating setpoints to support stable, sustainable operation. Over the course of OWDDF operation, seven sets of membranes from four (4) different manufacturers were tested for the first pass RO. The membranes were classified into two groups: Group A – a higher salt rejection/lower permeability membrane (supplied by Toray, DOW and Hydranautics) and Group B - a lower salt rejection/higher permeability membrane (supplied by NanoH$_2$0 and Dow). The feed pressure for Group A membranes was in the range of 850-900 psi whereas the permeate total dissolved solids (TDS) ranged from 150 to 250 mg/L. The feed pressure for Group B membranes was in the range of 790-810 psi, however the permeate TDS was approximately 400 mg/L.

A total of eight (8) chemical clean-in-place (CIP) procedures were performed on the first pass RO due to an increase in differential pressure across the feed-concentrate channel due to biofouling. The significant differential pressure increase occurred when preformed-chloramine addition was not in use. Initial cleanings were performed with Avista P-112, then changed to Avista P-111, which was more effective in reducing the differential pressure. In two instances, repeated CIPs needed to be performed in order to reduce the differential pressure. In general, the CIPs performed with Avista P-111 were efficient in cleaning the membranes. An effective dual CIP was performed with Avista P-111 and citric acid, as fouling with traces of precipitated iron was suspected, during trials of ferric coagulant. Since many new RO membrane sets were tested during the 32 months of study, a calculation of average CIP frequency is not possible. For reference, the RO membranes were cleaned on the following schedule: Hydranautics (Group A) every three (3) months, NanoH_2O R/ES (Group B) after one month, and the Dow XLE/ULE (Group B) membranes were first cleaned after three months of operation and a second time two months later.

Over the course of operation, several chemical oxidation events occurred resulting in first pass RO membrane damage. Oxidation events occurred in three distinct circumstances: due to mechanical equipment failure, misoperation and extended shutdowns with chloramines present in the feedwater. The first two causes were understood and steps were taken to prevent reoccurrence. The membrane oxidized after a prolonged shutdown and upon inspection it appears that the membrane was exposed to a strong oxidant (bromo-chloramines) formed by the reaction of chloramines in the flush water (RO permeate), with bromides diffusing from the annular space of the pressure vessels into the feed/concentrate channel of the membrane elements.

With the presence of pre-formed chloramines in RO feedwater, which were operated for a total of 5.5 months, the differential pressure across RO membrane elements was relatively stable. Although the pre-formed chloramines showed promise for control of biofouling in RO, they posed unexpected operational risks on the membrane elements in terms of potential for chemical oxidation upon shutdown. Additional shutdown procedure development is needed to allow reliable use of this approach.

Outside of oxidation events, all first pass RO membrane sets delivered as-expected water quality which met the final product water quality goals when blended with permeate from the second pass RO. As expected, Group A membranes operated at higher operating pressure than group B, but lower permeate mineral concentration, thus requiring less second-pass treatment. The ultimate selection of membranes in a full scale design for the first pass and second pass RO is dictated by the lifecycle analysis of membranes capital and operational costs, with a large component being power consumption.

The first pass RO system was equipped with an energy recovery device (ERD) provided by Energy Recovery, Inc. Over the course of operation, the efficiency of the device was steady at 95%. This demonstrated efficiency was similar to levels reported by ERI for full-scale operating plants.

Table 1-3: First-Pass RO System

Parameter	Operating Condition
First Pass RO Array Configuration	Two vessels in parallel
Quantity of RO elements per vessel	7
Design Membrane Flux	9 gfd
Recovery	50%

Second Pass RO

The second-pass RO functioned as a polisher for a portion of the permeate from first-pass RO. The second pass RO was operated with three sets of membranes, divided in two groups, similar to the first pass RO membranes. Group A (Dow BW30) represented a high salt rejection/lower permeability type of membranes and Group B (Toray TMG10) was a lower salt rejection/higher permeability type. The feed pressure for the Group A membranes was in the range of 180-200 psi with a permeate TDS less than 10 mg/L. The feed pressure for the Group B membranes was in the range of 70-90 psi, with an approximate permeate TDS of 25 mg/L.

Table 1-4: Second-Pass RO System

Parameter	Operating Condition
Second Pass RO Array Configuration	2:2:1:1 (equivalent to 2:1 with seven elements per vessel)
Quantity of RO elements per vessel	4:3:4:3
Vessel diameter	4 inch
Design Membrane Flux	16-21 gfd
Recovery	90%

Despite different rejection and permeability ranges, both Group A and Group B second pass RO membranes were successful in achieving the overall (final blended) water quality goals for the project. Recovery was maintained at 90% throughout the testing. Two flux setpoints were tested, 16 gfd and 22 gfd. The operating data did not indicate any fouling associated with these relatively high flux setpoints. In a full scale design, the amount of second pass RO is dictated by a series of factors, such as the temperature and water quality of the first pass RO permeate, the final water quality goals and the choice of membrane. The second-pass RO was operated at pH 10.2 to demonstrate increased boron rejection. Over the duration of operation only one permeability loss event occurred in the second-pass RO. Symptoms suggested calcium carbonate precipitation. This was finding was consistent with the success achieved by cleaning with citric acid.

Post-treatment (Tasting Station)

The combined permeate from the RO treatment was subjected to a 100 mJ/cm2 dose of ultra-violet light (UV) and stabilization for the demonstration plant tasting station was accomplished by adding CO_2 to the UV treated RO permeate water, then running the water through a column of limestone ($CaCO_3$) chips. Adjustment of the CO_2 dose was necessary to attain hardness targets for the product water. Final pH was established through equilibration with the $CaCO_3$. The post treatment in the tasting station successfully added hardness and alkalinity to the desalinated water, providing drinking water at a pH suitable for consumption.

Table 1-5: Post-Treatment System

Parameter	Purpose	Target
UV	Disinfection	100 mJ/cm^2
CO_2 Dosing	Reduce pH to optimize calcite contactor performance	10 mg/L
Hardness	Re-mineralize RO permeate for corrosion control	30 mg/L as $CaCO_3$
Alkalinity	Add buffering capacity to final product	30 mg/L as $CaCO_3$
NaOH Dosing	pH adjustment	pH 6.5-8.5

Energy Consumption

Electrical energy consumption of the first and second pass RO feed pumps was measured in the field. These values were used to calculate the electrical consumption per unit volume of RO permeate produced, commonly referred to as Specific Energy Consumption (SEC). Two classes of RO membrane were selected in the first pass: Group A (Dow XHR/XLE hybrid) commonly characterized as a high-rejection seawater membrane and Group B (NanoH_2O R/ES hybrid) commonly characterized as a low-pressure seawater membrane. The second pass RO operated a high-rejection brackish membrane (Dow BW30-4040). As anticipated, first pass Group A required a higher SEC than the Group B (9.8 vs. 9.3 kWh/kgal). However, it required a significantly smaller second pass than Group B to achieve the target product quality goals (i.e. boron and bromide). The energy consumption to produce final product water (both RO passes) of a given water quality was calculated to be 9% lower when the first pass RO operated with Group A membrane (high-rejection) vs. Group B membrane (low-pressure).

Water Quality

West Basin's water quality objectives were to meet drinking water requirements and comply with all Ocean Plan regulations. The OWDDF collected data to provide water quality predictions for future full-scale UF/RO seawater desalination process components. A total of fifteen monitoring locations were used in assessing the water quality throughout the desalination treatment train and thousands of grab samples and continuous monitoring results were collected over the life of the project to characterize process performance. The OWDDF represents one of the most thorough projects to date in evaluating the potential water quality of ocean water desalination.

The water assessment characterized the source ocean water and effluent of the key processes such as UF and RO. Specific parameters of importance included total dissolved solids (TDS), conductivity, chloride, bromide, and boron levels, all of which are present at elevated levels in ocean water that require treatment with reverse osmosis. In some cases, most notably boron and bromide may require a partial second-pass RO step to meet water quality targets. In addition, turbidity, total organic carbon (TOC), and chlorophyll-a are constituents that are monitored as potential indicators of water quality conditions in the source ocean water (e.g. red tide events and storms) that may challenge the Arkal spin disc kiln filter pretreatment, as well as the UF pretreatment and the RO.

Table 1-6 indicates mean values of key constituents through the treatment process.

Table 1-6: Mean Water Quality Values

Date	Ocean Water	UF Filtrate	1st Pass Permeate	2nd Pass Permeate	Combined Permeate	Target
Chloride	20,100	20,100	121	3.9	14	<100
Boron	4.7	4.7	0.82	0.17	.033	<0.5
Bromide	68	68	0.50	0.02	0.08	<0.3
TDS	35,000	35,000	277	16	45	<450
Turbidity	0.52	0.03				
TOC	1.1		0.1			

(mg/L, except Turbidity in NTU)

- The median TDS in the source ocean water was 35,000 mg/L, a level consistent with ocean water in Southern California.
- The median Ocean water/UF feed turbidity level was 0.52 NTU, with 99% of the samples over the life of the project less than or equal to 3.1 NTU.
- The median TOC level in the ocean water was 1.1 mg/L, with 99% of the samples less than or equal to 1.6 mg/L.
- The UF process was effective in removing particles from the Raw Ocean Water. Mean UF filtrate was 0.03 NTU, with ≤0.22 NTU in 95% of the samples.
- The removal of TDS in the first-pass RO membranes was above 99.4% for membranes in Group A, with removal for the membranes in Group B typically greater than 99.0%.

Overall, bacteriological parameters were either non-detect or reported at low levels that do not present health concerns. Bacteriological results for the source ocean water showed that in 99% of the sampling:

Total coliform data was < 23 MPN/100 mL

Fecal coliform data was < 14 MPN/100 mL

E. Coli data was < 13 MPN/100 mL

Enterococcus data was < 15 MPN/100 mL.

All bacteriological parameters were removed to levels below detection in the combined first-pass RO permeate.

An extensive monitoring program was conducted and compared to drinking water regulations under the Safe Drinking Water Act (SDWA) as well as unregulated constituents with California Division of Drinking Water (CA-DDW) health based advisory levels called Notification Levels (NLs). All constituents with primary MCLs were reduced in the combined first-pass RO permeate to levels lower than regulatory limits at all times. Additionally, the combined permeate after partial second-pass RO was able to consistently meet project water quality objectives for boron, chloride, and bromide, as indicated in Table 1-6.

Conclusions and Recommendations

Operation of the OWDDF successfully demonstrated operation of the desalination process, meeting the objectives of the project and yielding the following conclusions and recommendations.

- Three different wedgewire intake screen sizes were tested in this study: 0.5 mm, 1 mm, and 2 mm. Over the course of testing three materials where operated, Cook Legacy CuNi 90/10-7700, Johnson Z-Alloy and Hendricks Cu/Ni 90/10-7600. Results of this testing is provided in West Basin's *Intake Biofouling and Corrosion Study* and *Intake Effects Assessment Study* reports.

- Shock Chlorination of intake lines was used successfully in maintaining the lines clear of biological attachment and a steady intake flow for the period of use. The recommended regimen is every 3-4 days for two (2) hours at 8 to 10 mg/L residual chlorine.

- Arkal filters (100 um) were successful in preventing fiber breakage in the UF system downstream for the first two set of UF membranes (22 months). While fiber breaks were experienced with the third membrane set there is no indication they were associated with particulates or shell fragments. It is possible the fiber breaks were present when the modules were initially installed. During normal feedwater quality (turbidity < 2 NTU), operation at a hydraulic load of 100 to 125 gpm/filter was sustainable, however this needed to be decreased to 65-80 gpm/filter during high turbidity feedwater. The Arkal filter model used in this study was 4" Galaxy, suitable to reduced flow rates at OWDDF. However, in a full scale design the 12" Galaxy Super Flow Systems should be considered. Spare capacity should be included to reduce the hydraulic load during events which result in degradation of the intake water quality, such as red tides. The necessity of backwash pumps should be reconsidered in a full scale design system if the feed pressure is be sufficient for direct backwash. Also, Arkal filtrate should be considered for backwash water; OWDDF used UF filtrate for backwash due to space limitations which restricted the addition of another tank.

- The GE-Zenon ZW-1000 UF system operated at a design flux set point of 25.5 gfd. It stabilized at significantly lower permeability (3.5 gfd/psi) than anticipated based on pilot results from El Segundo. This may have been a function of the current product performance or the site specific water quality differences between the Redondo Beach and El Segundo sites. A full scale design using this membrane should consider permeabilities of 3.5 gfd/psi or lower, as this study did not test UF membranes for the average membrane life. The longest period of operation with one membrane set was 1.6 years. A coagulant (ferric chloride) proved beneficial in stabilizing permeability and it is recommended for full scale design at 1 to 4 mg/L as $FeCl_3$, with the larger concentration considered for degraded seawater quality (e.g. during red tides).

- First pass RO system operated successfully at 50% recovery and average flux of 9 gfd. With the exception of oxidation events, all SWRO membrane sets delivered water quality which met the water quality goals (Boron ≤0.5 mg/L; Bromide ≤0.3 mg/L; Chloride ≤100 mg/L) when partly blended with the permeate from the second pass RO.

  Although different in salt rejection and permeability, both the Toray TMG10 and Dow BW30 membrane models used in the second pass RO were successful in achieving the water quality goals for the project. Recovery was maintained at 90% whereas two flux setpoints were considered, 16 gfd and 22.4 gfd, both allowing a stable operation. First pass RO system was equipped with an isobaric energy recovery device (ERD) provided. The ERD maintained a high efficiency (~95%) for the entire duration of the study.

- Calculations of Specific Energy Consumption (SEC) for this study showed values between 9.3 and 9.8 kWh/kgal first pass permeate for first pass RO and between 2.1 and 2.4 kWh/kgal second pass permeate for second pass RO.

- The use of pre-formed chloramines in the RO feedwater, while showing benefit for biogrowth control in the cartridge filters and RO membranes, posed operational risks on the membrane elements in terms of potential for chemical oxidation. When the RO system was shut down for longer than a few hours, membranes were chemically damaged by a strong oxidant formed by reaction of chloramines with bromides present in seawater trapped in the annular space of the pressure vessels. It is recommended that further development of flush sequences and redundancy would need to be addressed prior to full scale implementation.

2.0 INTRODUCTION

The West Basin Ocean Water Desalination Demonstration Facility (OWDDF), located in Redondo Beach, CA, completed construction and commenced operation in February 2011. The OWDDF was a temporary installation serving as West Basin's next step of due diligence towards a goal of implementing responsible large-scale ocean water desalination for production of potable water.

The project was located within the boundaries of the Science, Education, & Adventure Lab (SEALab), a hands-on coastal science and education center operated by the Los Angeles Conservation Corps (e intake and treatment system. Figure 2-1). The sharing of common ocean water intake and discharge facilities minimized environmental impacts and helped reduce the costs for the District's temporary facility and associated technical evaluation, permitting and construction.

The demonstration facility utilized reverse osmosis (RO) technology to remove impurities from seawater and produce permeate. The source water was pre-screened, pre-treated through microfiltration/ultrafiltration systems, and desalinated through reverse osmosis membrane systems. The permeate was stored temporarily in on-site facilities, tested, and then recombined with the reverse osmosis seawater concentrate stream and pretreatment backwash stream and discharged through the existing outlet tunnel into the nearby coastal waters. The outlet was the existing AES discharge tunnel, which is adjacent to the proposed inlet tunnel. Waste streams that include cleaning chemicals, coagulants and other similar water treatment chemicals (used infrequently, as described further below) were routed to a sanitary sewer system. Details of the treatment system are presented in Section 3. Figure 2-2 presents a schematic of the intake and treatment system.

Figure 2-1: Aerial Photo of the Site

The facility was designed to utilize approximately 580,000 GPD (347 GPM) of ocean water, testing various pretreatment and post-treatment options, using full-scale size equipment in the key points. The Reverse Osmosis (RO) process utilized approximately 110,000 GPD (70 GPM) of the source water, producing approximately 55,000 GPD of permeate (product water) and 55,000 GPD of ocean water concentrate, which was recombined and discharged through the existing outlet tunnel (there was not any "brine" discharged into the ocean, and the nominal chemicals used in the RO testing processes were neutralized prior to discharge, or discharged to the existing sanitary sewer). Approximately 80,000 GPD (55 GPM) of source water was utilized for a subsurface intake pilot study.

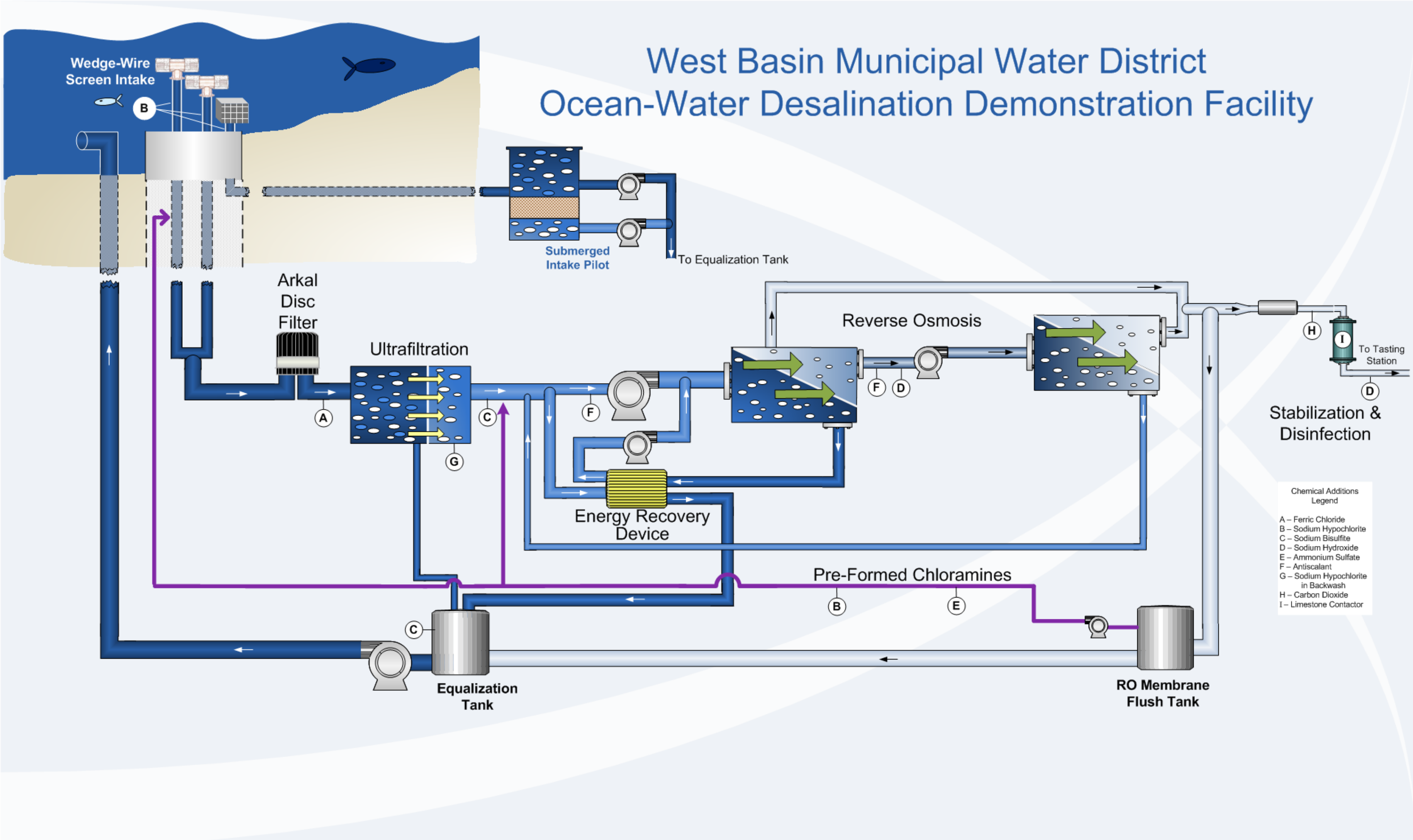
The Project had the following key objectives:

1) Successfully demonstrate full-scale RO equipment consistent with the terms of a California Department of Water Resources grant (Proposition 50);
2) Investigate feasibility of wedgewire technology in an open ocean environment;
3) Investigate intake shock chlorination as means of macro-biogrowth control (e.g. mussels) on the intake pipelines;
4) Implement a subsurface intake pilot to evaluate bed clogging and generate impingement/entrainment data;
5) Test various pretreatment and post-treatment operating conditions;
6) Demonstrate 8-inch diameter SWRO membrane element long term performance and confirm operating parameters established on 4-in diameter pilot elements;

7) Investigate the use of pre-formed chloramines for biogrowth control mainly on RO system;
8) Evaluate the Pressure Exchanger Energy Recovery Device and determine energy consumption of SWRO process;
9) Confirm SWRO permeate quality on 8-inch diameter membrane elements;
10) Conduct extensive water quality to characterize different stages of the treatment system;

The Demonstration Facility in Redondo Beach integrated the results of the pilot testing program operated by West Basin from 2002-2009 in El Segundo, CA, with implementation of full-scale components for long-term evaluation. The OWDDF operating program was completed in September 2013. This report summarizes the process operations and water quality data obtained during the 32 months of operation.

Figure 2-2: Schematic of Treatment System



3.0 TREATMENT PROCESS DESCRIPTION

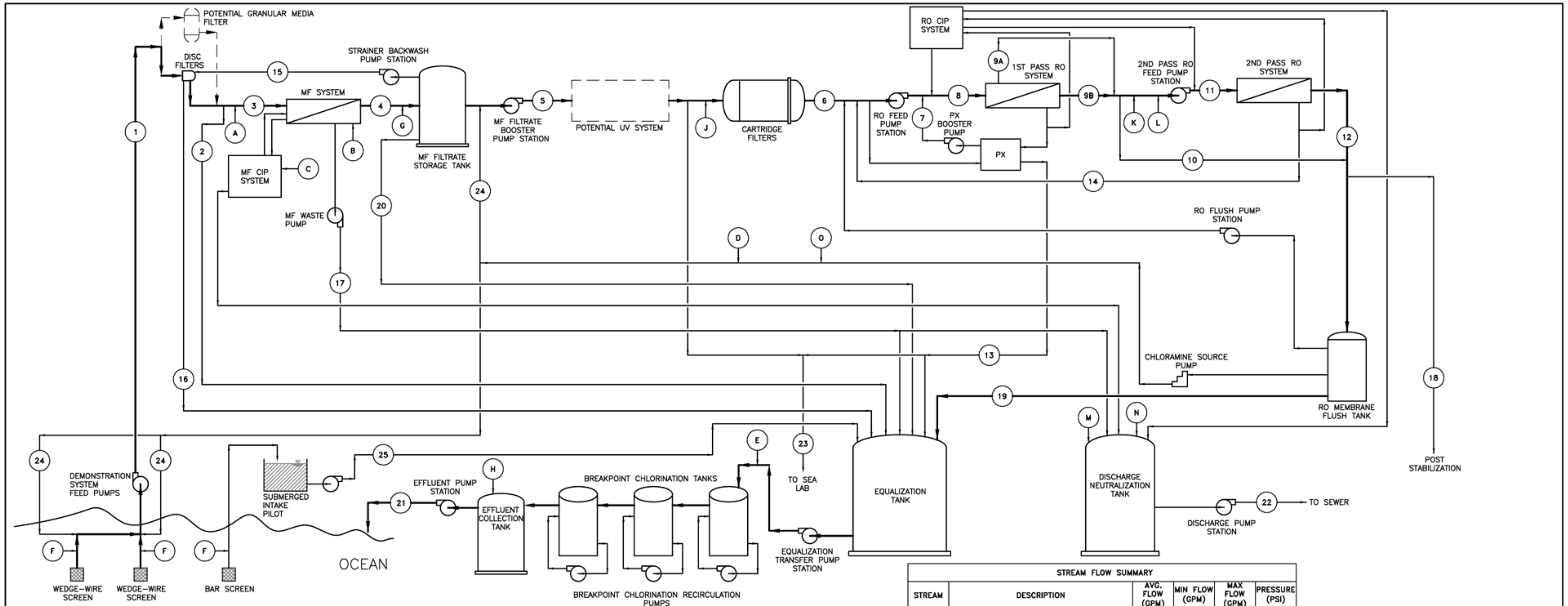
The overall treatment process consisted of various components used to treat ocean water to drinking water quality. The major process components included the following:

- Ocean Water Intake System
- Arkal Disc Filter System
- Ultrafiltration (UF) Membrane Pretreatment
- Seawater Reverse Osmosis (RO) System
- Second Pass Reverse Osmosis System
- Preformed Chloramine System
- Product Water Post Treatment

The overall process flow diagram is shown in Figure 3-1. The ocean water is first drawn through the wedgewire intake screens and was delivered to the Arkal disc filter system (100 µm). the Arkal disc filter system strains out particles which might pass through the intake screen The Arkal system filtrate was sent to the GE Zenon submerged UF system, which removed any remaining suspended solids. The UF served as final pretreatment to the RO system. Before RO treatment, feedwater was periodically dosed with preformed chloramines in order to minimize biofouling on the membrane. The chloraminated water was then sent to the RO system, after passing through cartridge filtration (5 µm). An energy recovery device (from ERI™) was used to take the high pressure brine and transfer that energy to low pressure RO feed water. A chemical cleaning system and flush process were also used intermittently.

A portion of first pass RO permeate was sent to a second pass RO system to achieve further removal of key minerals (i.e. chloride, boron and bromide). The second pass RO permeate was blended with the remaining first pass RO permeate in order to achieve product water quality goals. A small portion (~0.5 gpm) of this blended permeate received post treatment to meet potable water standards and supply a visitor tasting station. RO permeate, concentrate and excess Arkal filtrate were all diverted to an equalization tank, which subsequently fed the effluent collection tank prior to discharge to the ocean outfall. Chemical wastes were collected in the neutralization tank, neutralized and discharged to the sewer.

Figure 3-1: Process Flow Diagram



ESTIMATED CHEMICAL ADDITIONS/DISCHARGES			
STREAM	DESCRIPTION	FREQUENCY	USE
A	40% FeCL3	INTERMITTENT	6.5 GPD
B	12% SODIUM HYPOCHLORITE	INTERMITTENT	0.6 GPD
C	12% SODIUM HYPOCHLORITE	INTERMITTENT	0.3 GPD
D	12% SODIUM HYPOCHLORITE	CONTINUOUS	25 GPD
E	12% SODIUM HYPOCHLORITE	CONTINUOUS	33 GPD
F	12% SODIUM HYPOCHLORITE	INTERMITTENT	4.3 GPD
G	38% SODIUM BISULFITE	INTERMITTENT	0.1 GPD
H	38% SODIUM BISULFITE	CONTINUOUS	4 GPD
J	RO THRESHOLD INHIBITOR 1ST PASS	CONTINUOUS	0.1 GPD OR 10 GPD IF DILUTED
K	RO THRESHOLD INHIBITOR 2ND PASS	CONTINUOUS	0.04 GPD OR 4 GPD IF DILUTED
L	5% SODIUM HYDROXIDE	CONTINUOUS	4 GPD
M	5% SODIUM HYDROXIDE	INTERMITTENT	–
N	50% CITRIC ACID	INTERMITTENT	–
O	36% AMMONIUM SULFATE	CONTINUOUS	12 GPD
P	MF CIP BLOWDOWN INTER		
Q	RO CIP BLOWDOWN INTER		

STREAM FLOW SUMMARY					
STREAM	DESCRIPTION	AVG. FLOW (GPM)	MIN FLOW (GPM)	MAX FLOW (GPM)	PRESSURE (PSI)
1	MF ARKAL FEED	347	55	347	15
2	BYPASS	219		347	2
3	PRESCREENED MF FEED	128	70	137	13
4	MF FILTRATE	118	70	137	2
5	UV FEED	67–70		70	50
6	1ST PASS RO LOW PRESSURE FEED	67–70		70	30
7	RO HIGH PRESSURE FEED FROM PX PUMP	33			1000
8	1ST PASS RO HIGH PRESSURE FEED	70		70	1000
9A	1ST PASS RO PERMEATE – TAIL END	35		35	2
9B	1ST PASS RO PERMEATE – FEED END				
10	1ST PASS RO PERMEATE OVERFLOW	7–35		35	2
11	2ND PASS RO HIGH PRESSURE FEED	0–28		28	300
12	2ND PASS RO PERMEATE	0–25		25	2
13	1ST PASS RO CONCENTRATE	35		35	2
14	2ND PASS RO CONCENTRATE	0–3		3	30
15	ARKAL PRESTRAINER BACKWASH INLET	3		225	50
16	ARKAL PRESTRAINER BACKWASH OUTLET	3		225	2
17	MF BACKWASH WASTE	10		400	1
18	POST STABILIZATION	5		5	2
19	RO PERMEATE OVERFLOW	30		35	2
20	MF FILTRATE OVERFLOW	45		137	2
21	EFFLUENT RETURN TO OCEAN	349		500	5
22	NEUTRALIZATION TO SEWER	10		50	20
23	SEA LAB SAMPLE				
24	5000 mg/L CHLORAMINE	0.5		1	55
25	SUBMERGED INTAKE PILOT	2			5

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WEST BASIN MUNICIPAL WATER DISTRICT

TEMPORARY OCEAN WATER DESALINATION DEMONSTRATION PROJECT
PROCESS FLOW DIAGRAM
SHEET G–6
2366

3.1 Details of the Treatment Process

3.1.1 Intake System

The facility utilized the existing 10-foot diameter concrete intake tunnel previously operated by AES Redondo Beach Generating Station (RBGS). While RBGS no longer uses this intake, it is being used by SEALab for nominal intake for their aquariums. The intake was located approximately 1,600 feet offshore. The OWDDF utilized a "pipe-in-pipe" concept, in which four new, smaller diameter pipelines were installed within the existing tunnel: two 6" diameter HDPE plastic pipes (to feed the treatment system), one 6" diameter HDPE plastic pipe (to carry air-burst lines and nominal chlorine for intake system cleaning), and one 4" diameter HDPE plastic pipe (to feed the subsurface intake pilot described below). The two RO intake pipes were fitted with a state-of-the-art "wedgewire" screen, for the purpose of minimizing or avoiding marine life impacts. The wedgewire screens were installed at the approximate depth of 25 feet Mean Lower Low Water (MLLW) and 10 ft from the ocean floor. Two submersible vertical pumps were installed in the "wet well" at the existing SEALab pump vault, in order to test several wedgewire screen sizes.

The primary objective of the wedgewire screens was to prevent impingement and minimize the entrainment of marine organisms. The slot sizes for these screens were 0.5 mm, 1 mm and 2 mm. The intake configuration allowed for two screens to be in the ocean at one time, with one in operation and the other in standby. Each screen had its own dedicated intake lines and pump. Over the course of testing three manufacturers/materials where tested, Cook Legacy CuNi 90/10-7700, Johnson Z-Alloy (a proprietary material composition) and Hendricks Cu/Ni 90/10-7600. Additional information on the screens is available in West Basin's Intake Biofouling and Corrosion Study report. Shock chlorination and chloramination systems were utilized for a period of the study, delivering free chlorine or chloramines, respectively, to the intake pipeline for biogrowth control.

A parallel submerged intake pilot system was also operated to develop data on a submerged subsurface intake approach. For the subsurface intake system, a 4" diameter subsurface intake pipe was fitted with a 1.5" bar screen and operate at very low intake velocities to simulate natural ocean conditions. At the intake pump station, the subsurface intake pilot system was installed within the intake "wet well", consisting of a sand media filter (to simulate ocean water intake through the ocean floor), which was tested under various conditions and flow regimes (The subsurface intake pilot experienced operational challenges which were not resolvable. As such, the objectives of the subsurface intake pilot could not be achieved).

3.1.2 Arkal Disc Filters

Once ocean water entered the wedgewire screens and travelled through the intake piping, the water entered the Arkal Disc Filters (Figure 3-2). The filters operate using a specially designed disc filtration technology consisting of polypropylene discs, which are diagonally grooved on both sides to a specific micron size (100 micrometers in this case). The filters are designed to remove phytoplankton, algae, and marine flora, shells, sand, and grit. A series of these discs are then stacked and compressed on a specially designed spine. During the filtration process, the discs are compressed together by a spring and the differential pressure in the pod. Filtration occurs while water is forced radially from the peripheral surface to the core of the disc stack.

Figure 3-2: Arkal Filters

There were a total of four filters installed in a parallel configuration. Filters #1 and #2 were the default on-line filters. The model was 4" Galaxy and each filter pod contained five (5) spines. The filters utilized a self-clean backwash process without any interruption of the filtration process. The backwash cycle was triggered by a set differential pressure reading, typically seven (7) psig across the filters. The backwash pump was fed from the UF filtrate storage tank. The filters also underwent an osmotic shock once a day for a period of 10 minutes where the filters were soaked in RO permeate water. By introducing water with much lower salinity, and therefore lower osmotic pressure than the raw seawater, the potential growth of any organisms inside the filters may be disrupted and/or destroyed. Under normal operational conditions, the wash water was collected in a tank along with the reverse osmosis permeate and seawater concentrate to be discharged to the ocean.

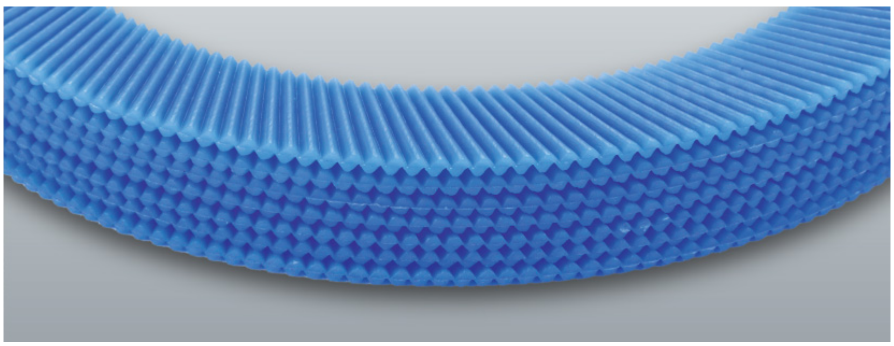


Table 3-1: Arkal System Design Paramters

Design Parameter	Operating Condition
Model	Arkal 4" Galaxy
# of Duty/Standby Filters (Pods)	2/2
# of Disc Sets (Spines) per Filter	5
Filter Rating	100 microns
Operating Pressure	15 psig
Differential Pressure – clean filters	2 psig
Differential Pressure – dirty filters	7 psig

3.1.3 Ultrafiltration

Arkal filtrate fed an ultrafiltration system provided by GE-Zenon (Figure 3-3). The Zenon ultrafiltration system utilized ZeeWeed ZW 1000 hollow fiber membranes (Version 4, pore size 0.02 microns), immersed directly into two process tanks. The membrane cassettes were connected to a UF filtrate collection header and aeration hoses. The UF filtrate pump applied a suction to the filtrate collection header, drawing water through the membrane in an outside-in flow pattern. Table 3-1 presents the operating conditions for normal filtration conditions.

Figure 3-3: UF Filtration System.

Table 3-2: UF System Operating Parameters

Parameter	Operating Condition
Model	GE ZeeWeed ZW-1000
Nominal pore size	0.02 micron
Membrane material	Proprietary PVDF
Number of Process Tanks	2
Number of Modules per Tank	6
UF Membrane Surface Area per Module	550 sq-ft
Instantaneous Filtrate Flow	117 gpm
Design Membrane Flux	25.5 gfd
Maximum Trans-Membrane Pressure	13 psi
UF Filtrate/backwash pump flow	150 gpm
Recovery	91%

The UF system employed a periodic reverse (inside-out) flow backpulse to remove the accumulated particles from the membrane surface and maintain the design filtrate flow. The backpulse utilized UF filtrate water from the backpulse tanks to which a small amount of sodium hypochlorite was added in order to enhance biofoulant removal. During the backpulse cycle, coarse bubble aeration was also used to scour debris from the outside of the membrane surface. Process air was supplied by the compressed air system and introduced at the bottom of the module on the outside of the fibers. The wastewater (backpulse water with dislodged particles) was sent to the equalization tank using the UF waste pump. Table 3-3 presents operating conditions for the backpulse cycle.

Table 3-3: UF System Backpulse Conditions

Design Parameters	Operating Conditions
Backpulse Initiation	Based on totalized filtrate volume
Backpulse Frequency (approximate)	Every 35 min
Backpulse Duration	30 sec
Backpulse Liquid Flow per Module	7.5 gpm
Backpulse Liquid Flow Duration	30 sec
Air Scour Flow per Module	3 scfm
Air Scour Pressure	4 psig
Backpulse Air Scour Duration	30 sec
Backpulse NaOCl dosing	4 mg/L

UF Membrane Integrity Testing

The integrity of the hollow fiber membranes is verified by performing a membrane integrity test (MIT). The test is based on air pressure decay where process air at a certain pressure is sent to the lumen side of the module while the shell side is open to atmosphere. The decay in the air pressure inside the lumen is observed over time (typically five minutes) and if exceeds a predetermined level, it is an indication that membrane fibers are damaged and/or broken. The MIT is performed and if the test is successfully passed, the module is returned to service. This test was performed daily.

UF Maintenance Cleans and CIP

Periodically, chemical cleanings such as the Maintenance Clean (MC) and the Cleaning-In-Place (CIP), were used to fully restore membrane performance. To reduce permeability lost to fouling of the membranes, oxidant and acid cleaning regimes are applied to the UF membranes. The MC cycle was designed to be performed every 24 hours, however it was necessary that a second MC be performed every 24 hours in order to maintain permeability. CIP was performed every three (3) weeks.

The MC cycle has an approximate duration of 30 minutes. During this cycle, membranes are soaked in a 100 mg/L, 40 degrees C NaOCl solution, which is transferred to the cell by the UF cleaning pump and an inline dosing system. The CIP/MC makeup water used for the chemicals was heated RO permeate. During a MC cycle, the UF cleaning pump transfers the RO Permeate into the UF cell. The associated chemical transfer pump then injects the required chemical into the water as it is transferred to the membrane unit to achieve the desired concentration. This is followed by an automatic system drain down, refill, and rinse. The UF cell is then returned to filtration.

The CIP sequence is similar to the MC, the differences being longer exposure and soaking periods as well as the use of acid cleaning in addition to oxidant (NaOCl) cleaning. Each chemical cycle has an approximate duration of five (5) hours. Table 3-4 presents the operating parameters for the MC and CIP.

Table 3-4: UF System Maintenance Clean and CIP

Design Parameters	Operating Conditions
UF Cleaning Pump Flow	60 gpm
UF Cleaning Pump Head	10 ft
Maintenance Clean (MC)	
MC Frequency	Twice Daily
MC NaOCl dosing	100 mg/L
MC Water Temperature	40 degC
MC Soak Time	30 min
MC Duration	~ 30 min
CIP	
CIP Frequency	Every 3 weeks
CIP steps	2
CIP NaOCl dosing	500 mg/L
CIP Citric Acid	2%
CIP pH for acid cleaning	2.0
CIP soak time/step	5 hours
CIP Water temperature	40 C

3.1.4 Reverse Osmosis

UF filtrate was sent to the UF filtrate storage tank which fed the RO system (Figure 3-4). Reverse osmosis is a pressure driven separation process, whereby approximately 50% of the feed water passes through a semi-permeable membrane. Most dissolved constituents are rejected by the membrane. The reverse osmosis process separates the feedwater into two streams:

- Permeate which has passed through the membrane
- Concentrate (also referred to as brine) which is the remaining feedwater containing the rejected salts. Thereby having a salinity of approximately twice that of source water.

The RO system is configured with two passes. Seawater was fed to the first-pass and a portion of its permeate was treated again by a second-pass RO. The balance of the first-pass permeate was blended with the second-pass permeate to create the final RO product stream.

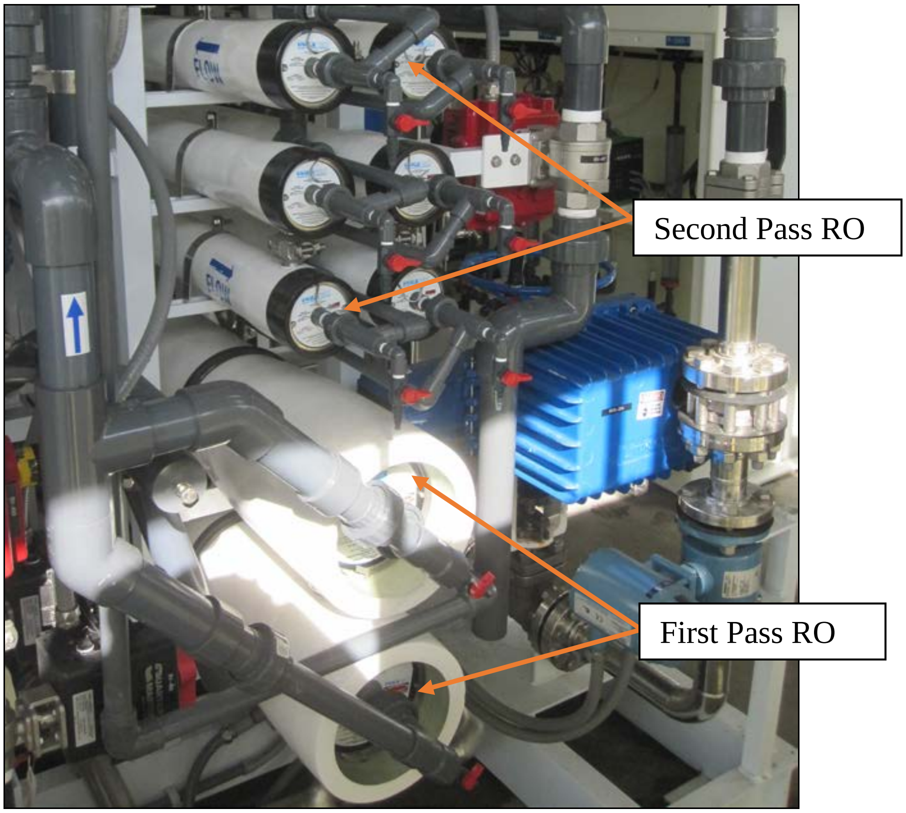
The first step in the RO process was filtration using 5-micron cartridge filters. These filters provided protection to the RO high pressure pump, energy recovery device and RO membrane from debris, possibly introduced in the UF filtrate tank. The water then split to feed a high pressure pump and energy recovery device. Each elevated the pressure of approximately half the feed flow which was recombined and applied to the first pass RO membrane.

The first pass RO system was equipped with two 8-inch diameter membrane housings, each containing seven RO elements, for a total of fourteen 8-in diameter membrane elements. The RO system utilized a split permeate design, where product water is pulled from both ends of the housing. The higher concentration permeate of the tail end is sent to the second-pass RO unit. This split-permeate approach is more efficient than sending a portion of the blended composite first-pass permeate water to the second pass and is typically employed in full-scale facilities.

Table 3-5: First-pass RO System Design Parameters

Parameter	Operating Condition
First Pass RO Array Configuration	Two vessels in parallel
Quantity of RO elements per vessel	7
Vessel diameter	8 inch
Design Membrane Flux	9 gfd
Recovery	50%

Figure 3-4: Reverse Osmosis System



As mentioned previously, the RO system was equipped with a Pressure Exchanger energy recovery device (ERD). The ERD pressurizes the RO feedwater by direct contact with the high pressure concentrate stream from the reverse osmosis system. The concentrate from the reverse osmosis membranes passes through the ERD, where its pressure is transferred directly to a portion of the incoming feedwater. This pressurized feedwater stream is approximately equal in volume and pressure of the concentrate stream. The ERD pumps the feedwater in parallel with the high pressure reverse osmosis pump. This reduces the high pressure pump flow requirement and therefore reduces energy consumption.

The second pass RO unit treats water from the tail end of the first pass system to achieve the overall finished water quality goals. Second pass RO utilized 4-in brackish water membrane elements arranged in a two-stage configuration.

Table 3-6: Second-Pass RO System Design Parameters

Parameter	Operating Condition
Second Pass RO Array Configuration	2:2:1:1 (equivalent to 2:1 with seven elements per vessel)
Quantity of RO elements per vessel	4:3:4:3
Vessel diameter	4 inch
Design Membrane Flux	16-21 gfd
Recovery	90%

3.1.5 Post-treatment

Whereas the final RO permeate is extremely low in calcium and alkalinity, it is aggressive/corrosive (negative Langelier Saturation Index). Post-treatment stabilization is generally accomplished by adding calcium and alkalinity. At the OWDDF a small portion of the product (0.5 gpm) was post-treated to meet potable water standards and supply a visitor tasting station. A portion of the blended permeate (front end permeate from the first pass RO and permeate from second-pass RO) was subjected to a 100 mJ/cm2 dose of ultraviolet light (UV) for disinfection while the stabilization was accomplished by adding CO_2 , then running the water through a calcite contactor (column of limestone ($CaCO_3$) chips). Adjustment of CO_2 dose was performed to attain the calcium targets for the product water.

Table 3-4: Post-treatment System Targets

Parameter	Purpose	Target
UV	Disinfection	100 mJ/cm^2
CO_2 Dosing	Reduce pH to optimize calcite contactor performance	10 mg/L
Hardness	Re-mineralize RO permeate for corrosion control	30 mg/L as $CaCO_3$
Alkalinity	Add buffering capacity to final product	30 mg/L as $CaCO_3$
NaOH Dosing	pH adjustment	pH 6.5-8.5

4.0 SYSTEM PERFORMANCE

This section describes in detail the operation and findings of each component of the OWDDF. A master timeline was developed (Figure 4-2) to facilitate identification of the operational components at a given time.

4.1 Intake

4.1.1 Wedgewire Screens

Three different wedgewire intake screen sizes were tested in this study: 0.5 mm, 1 mm, and 2 mm. The intake configuration allowed for two screens to be in the ocean at one time, with one in operation and the other in standby. Each screen had its own dedicated intake lines. Over the course of testing three manufacturers/materials where tested, Cook Legacy CuNi 90/10-7700, Johnson Z-Alloy (a proprietary material composition) and Hendricks Cu/Ni 90/10-7600. The Cook Legacy screen experienced structural failure and extreme mussel/barnacle attachment. The Johnson Z-Alloy experienced significant corrosion, but no biofouling, whereas conversely the Hendricks exhibited no measurable corrosion, but did support some internal mussel growth. An air burst system was installed to prevent particulate fouling; however, it was deemed unnecessary and not used apart from some short tests. Details of the screens performance with respect to corrosion and mussel attachment are in West Basin's Intake Biofouling and Corrosion Study report. Impingement and entrainment details are presented in West Basin's Intake Effects Assessment Study.

4.1.2 Intake Lines

The original configuration of the intake piping (Figure 4-1) consisted of two intake lines leading to dedicated intake pumps. Originally, the intake lines joined to a single line immediately following the intake pumps. Shock clorination of the lines was performed as indicated in Table 4-1. During the Feb 2011-Feb 2012 period, shock chlorination was performed on both intake lines with various frequencies, from every week to once every 30 days. Each shock chlorination lasted for two hours with a residual chlorine level of 8 to 10 mg/L. Shock chlorination was interrupted on February 13, 2012 and not resumed until May 22, 2013, when it was reintroduced to a location further downstream (Figure 4-1 and Table 4-1).

Additionally, the operation of the two intake lines was alternated every 2-3 days until May 10, 2012, after which the lines were switched every four (4) days.

Figure 4-1: Shock Chlorination Injection Points.

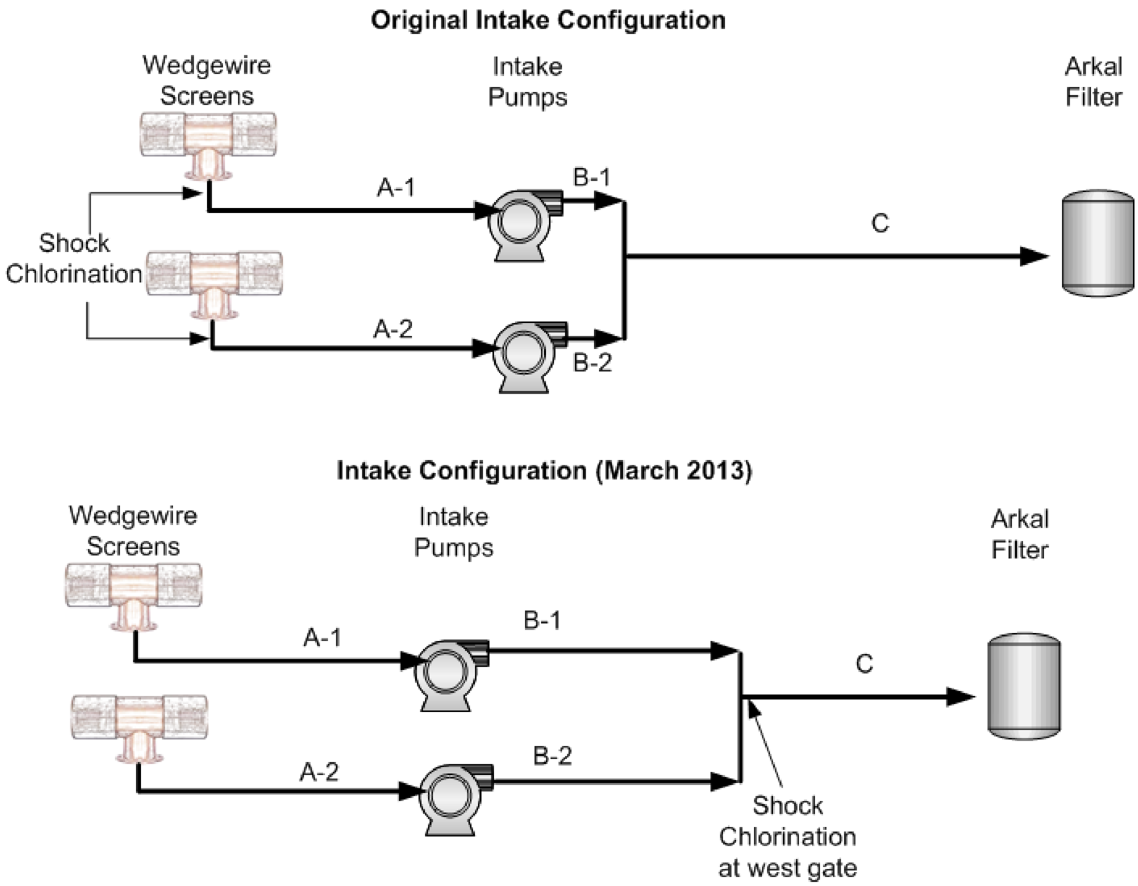
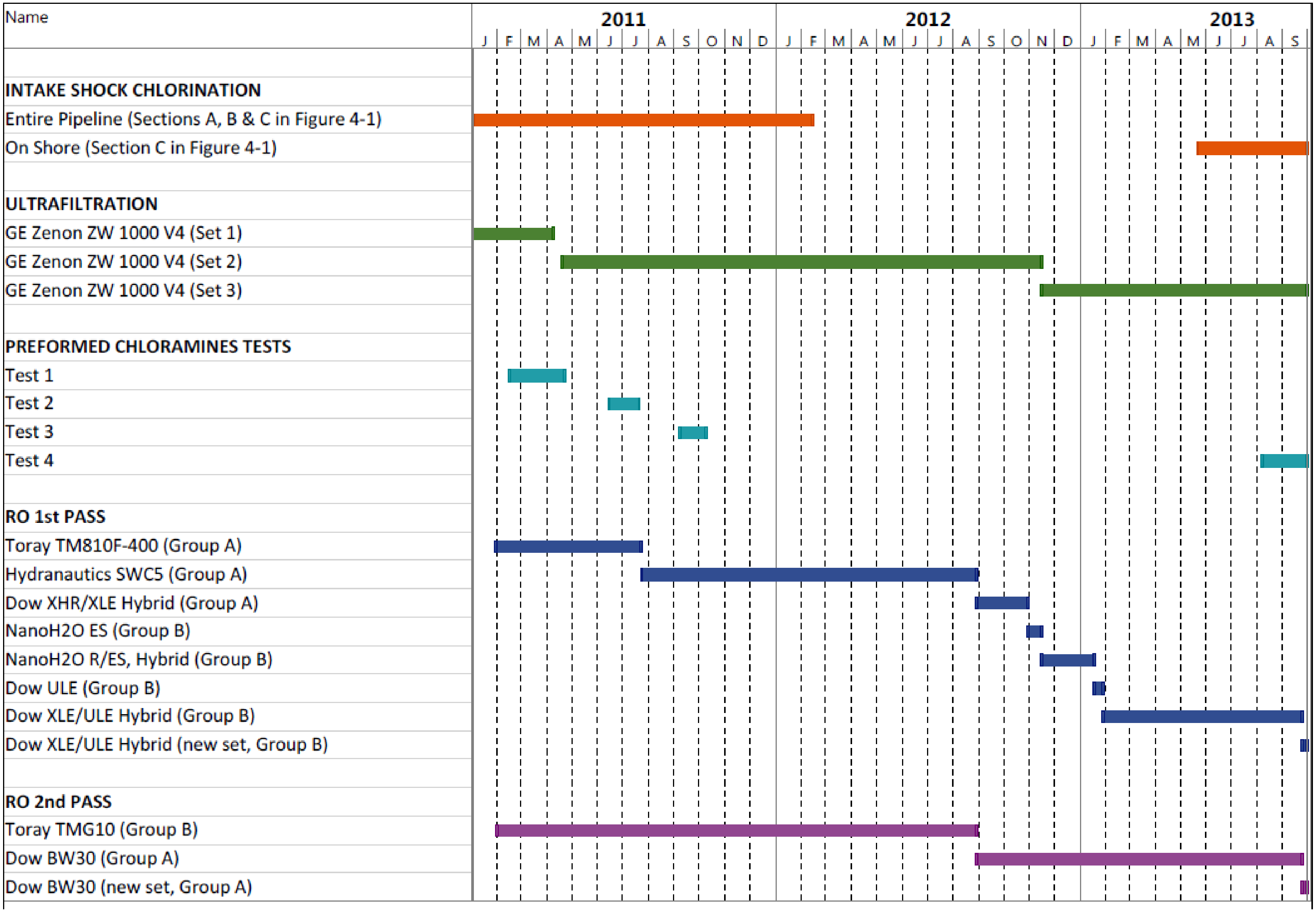


Table 4-1: Shock Chlorination and Piping Configuration

Period	Shock Chlorination	Intake Piping
Feb 2011 – Feb 2012	At Intake	Original Configuration
Feb 2012 – May 2013	None	Original Configuration
May 2013 – Sept 2013	At West Gate	Modified Configuration

Figure 4-2: Summary Timeline for Operation at OWDDF.



At the beginning of the demonstration project (February 2011), feed flow was 300-350 gpm (Figure 4-3). The intake pumps were noisy at such flowrates, with vibration and cavitation being of concern. As such, flow was reduced to approximately 275 gpm on March 23, 2011 by throttling the bypass valve located downstream of the Arkal filters. The feed flow was steady at 275 gpm until the end of October 2011, when flow was again reduced to approximately 225 gpm due to micro-bubbles appearing in the influent flow, which were detrimental to marine life in an aquarium study being fed by this supply. The intake flow was stable at approximately 225 gpm until April 2012.

Following the cessation of shock chlorination in February 2012, the feed flow steadily declined from 225 gpm in April 2012 to 125 gpm in November 2012, likely due to resulting biogrowth development. In the absence of chlorination, the two intake lines were alternated every four (4) days for the purpose of creating an anoxic environment in the alternate stagnant pipeline, which could prevent development of biogrowth. This alternating operation continued to the end of the project.

On November 14, 2012, feed flow increased to approximately 175 gpm following an adjustment to the pressure control valve on the bypass line. Flow remained stable until the end of February 2013, when it began to decrease and the system was shut down for intake line cleanup and pipeline modifications (March 4, 2013 to March 10, 2013). During this shutdown, the intake pipeline on the discharge side of the intake pumps was found to contain significant loads of mussels, shells, and other biogrowth. This demonstrated that the discharge side of the intake pumps was subject to biogrowth accumulation in the absence of shock chlorination or periods of anoxic condition. The wall-mounted pipeline at the forebay was cut and replaced with two parallel lines, while the section from the west gate to the Arkal feed was pressure washed. Following this cleaning, flow stabilized at approximately 200 gpm. An intake line video inspection performed on April 3, 2013 showed that the intake lines 150-ft upstream of the intake pumps were clean. This confirmed that alternating intake lines every four (4) days was effective in preventing biogrowth on the suction side of the intake pumps.

Starting in May 2013, three shock chlorination events occurred at a new location. The chlorination dose point was relocated further downstream to a point approximately 50 ft upstream of Arkal filters. At the same time, the portion of pipeline from the intake pumps to the new dosing point was segregated in two pipes, with the purpose of extending the pipeline currently benefiting from the anoxic regime induced by the line switching from the pump discharge to the new chlorination point (Figure 4-1). The first shock chlorination event at the new location occurred on May 22, 2013 with a 17 mg/L chlorine residual for a duration of two (2) hours. Two more shock chlorination events took place on July 24, 2013 and August 28, 2013, each for a duration of five (5) hours with an 18-20 mg/L chlorine residual.

The intake lines were video inspected on July 18, 2013, with minimal loading found on the suction side of the intake pumps as well as on the discharge section up to the point where the lines combined. However, the common line from the newly installed chlorination point to the Arkal filters showed a noticeable load of mussels and marine life. This suggests the shock chlorination frequency and/or exposure were not adequate in preventing biogrowth development on this section of the pipe.

At the end of August 2013, flow started to decline significantly, falling to 150 gpm at the end of the project (October 1, 2013). It is noteworthy that two months elapsed following the cleaning before the first shock chlorination event occurred at the new location. The last intake pipeline inspection occurred on October 10, 2013. At this time, the suction side of intake pumps pipelines (Section A in Figure 4-1) were found to be largely free of debris, with only a few shells found on the two parallel pipelines between the intake pumps and 6-in manifold by the west gate (Section B in Figure 4-1). The remaining portion of the intake pipe, from the west gate to the Arkal filters, contained the largest portion of shells, approximately 20% of the pipeline volume. The cause of flow decline is unclear, with the intake pumps also suspected of malfunctioning.

Figure 4-3: Intake Water Flow

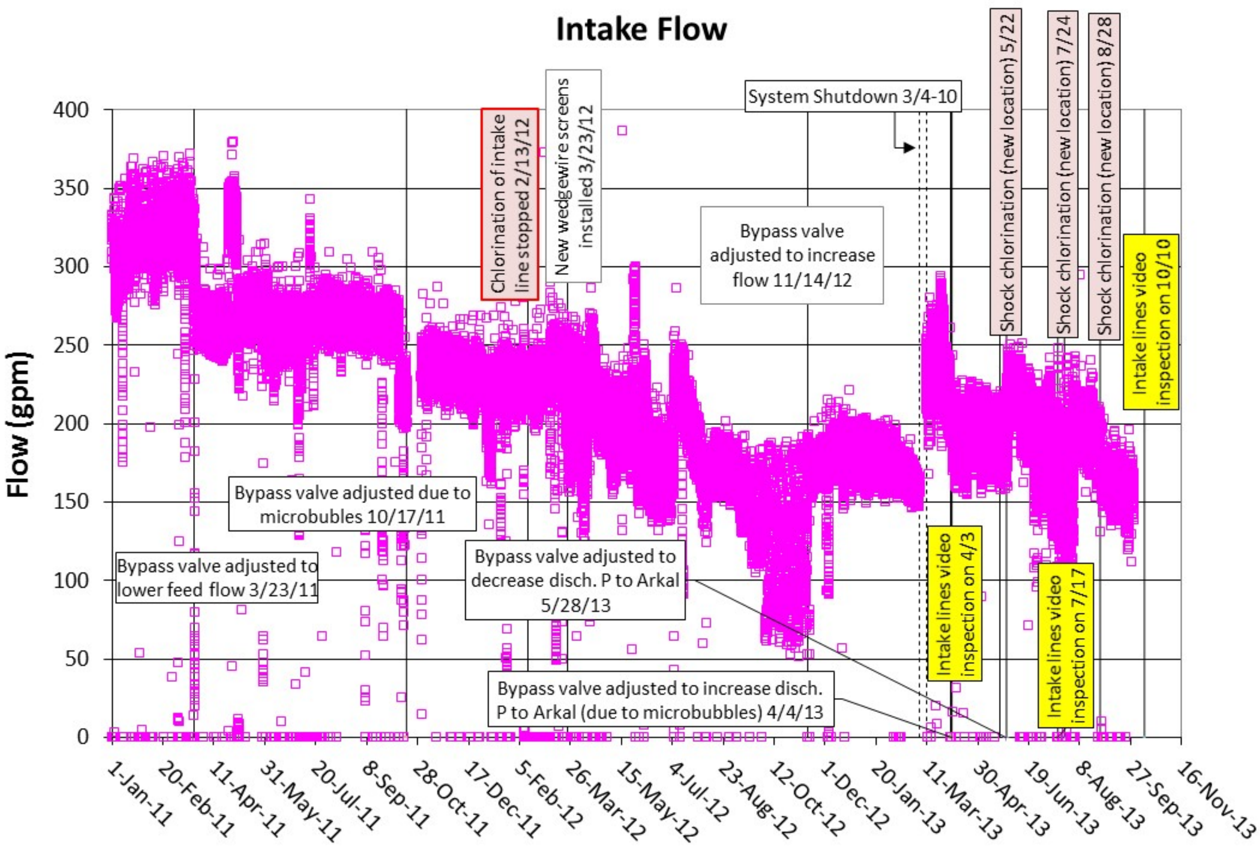
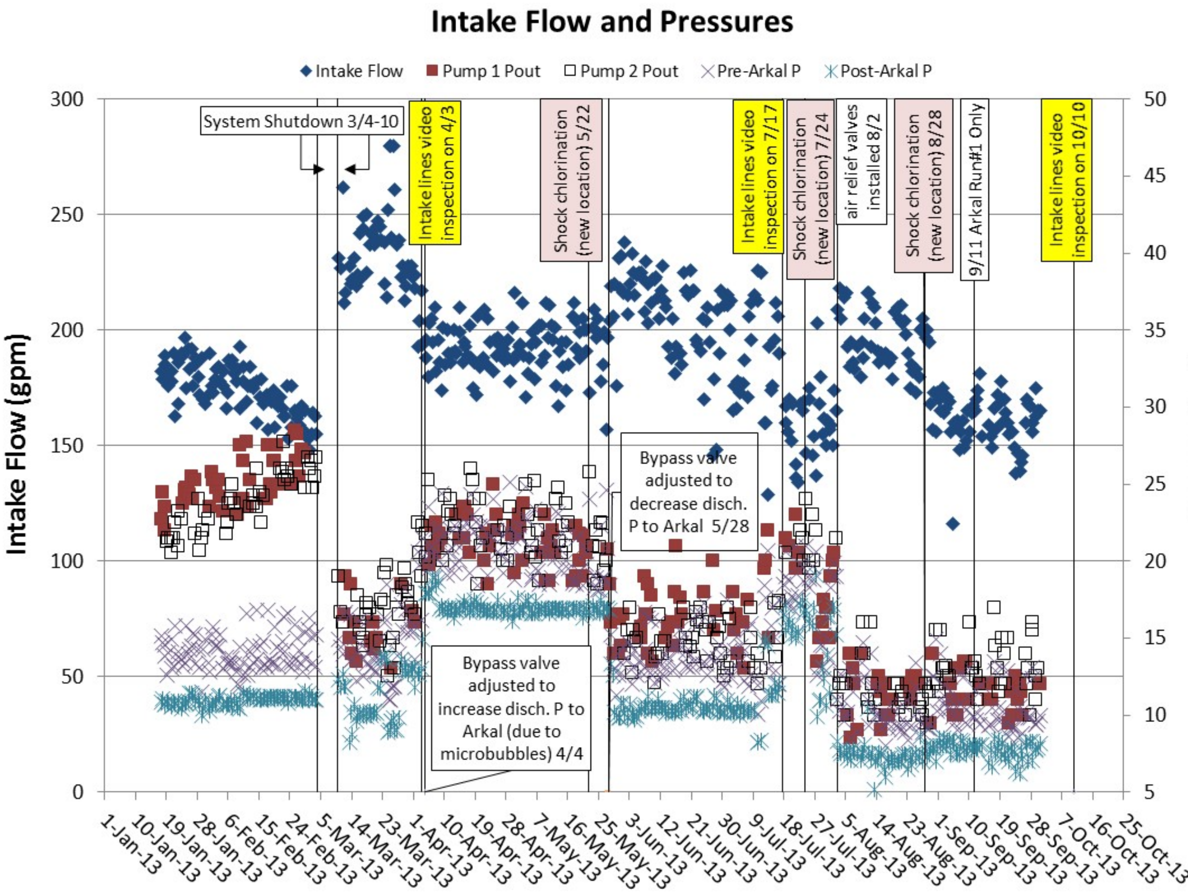


Figure 4-4 presents the daily measurements of (manually logged) of intake flow, discharge pressure for each pump (at forebay), and the pressure before and after the Arkal filters. Measurements were taken from January 2013 to the end of the project.

Figure 4-4: Daily Measurements for Intake Flow and Discharge Pressure



In summary:

- During the first year of operation (February 2011 to February 2012), periodic shock chlorination maintained in the intake lines free of mussel attachment. Frequency of intake lines shock chlorination varied between weekly to monthly and residual chlorine was between 8 and 10 mg/L.

- From February 2012 to September 2013, switching the intake lines every four (4) days without shock chlorination was effective in preventing biogrowth development on the suction side of the intake pumps, as shown in the pipeline video inspections performed throughout the project (April, July, and October 2013).

- Based on the three video inspections performed in 2013, the single line section of intake pipe from the west gate to the Arkal feed (Section C in Figure 4-1) experienced biogrowth (mussels attachment). This section of pipeline was shock chlorinated, but was not subject to the alternated normal/anoxic (reducing) regime due to pipeline layout. Shock chlorination began two months after the line was cleaned (May 22, 2012), so it is possible that once seeded, biogrowth was more difficult to inhibit by shock chlorination. Also, shock chlorination was performed on a monthly basis and thus might not have been frequent enough to prevent biogrowth accumulation on this intake line.

- In 2013, despite intake line cleanup (on discharge side of intake pumps) and bypass valve adjustments, the intake flow could not be re-established to values similar to the beginning of the project (250 gpm and higher). The cause is unclear.

4.2 Subsurface Intake Pilot

The subsurface intake pilot experienced operational challenges which were not resolvable. These included filtrate water pumping equipment which was not reliable and differential pressure measurement across the bed which appeared erroneous throughout the testing. These issues directly impacted the ability to assess the rate of clogging of the bed. Efforts were made to correct these issues over the course of the study, but were not adequately successful to generate meaningful data regarding bed clogging.

With regard to determination of the impingement and entrainment reduction, bed flow rates were insufficient to determine predation/organism fate. As such, the objectives of the subsurface intake pilot could not be achieved.

4.3 Arkal Disc Filter

4.3.1 Performance Evaluation

Shortly after the beginning of the study until the end of April 2012, the operation engaged three (3) filters, with a backwash differential setpoint at 3 psi and a 15 second backwash duration. When the feedwater quality worsened and the number of backwashes was too great to operate with only three filters, the 4th filter was put in service or changes were made to either the differential pressure setpoint for backwash (higher) or the backwash duration (shorter). For example, when the hydraulic load was approximately 75 gpm/filter during March 2012, the feedwater turbidity increased from a background value of approximately 0.5 NTU to 2-3 NTU and the three filters in operation were undergoing backwashing every three (3) minutes, causing the system to shut down. The system was maintained in operation by decreasing the hydraulic load per filter (adding the 4th filter), increasing the backwash differential pressure from7 and 10 psi and also decreasing the backwash duration down to 10 seconds, resulting in an average of one (1) backwash per hour.

From late April 2012 to January 2013, the number of operating filters was reduced to two (2) to optimize the number of filters in use. There were other episodes of high turbidity that occurred, such as the one at the end of May 2012 where the feedwater turbidity increased to values above 2 NTU and filters were backwashing every 2 to 5 minutes. Two more filters were put in service while maintaining the same backwash setpoint at 5 psi and backwash duration of 10 seconds, reducing the number of backwashes and maintaining the system in operation. Table 4-2 presents a summary of the Arkal filter operation from the beginning of the study to January 2013.

Table 4-2: Operation of Arkal filters from beginning of study to January 2013

Date	No. of Filters	Backwash Trigger dP (psi)	Backwash Duration (sec)	Operator Observations
1/11 to 8/11/11	3	3	15	Operating with 3 filters after 3/30 due to extensive backwashing with 2 filter operation from 1/11/ to 3/30
8/1/11 to 8/3/11	4	3	15	4 filters operating (unintentionally.) Changed to 3 filter operation.
8/3/11 to 3/5/12	3	3	15	Discussion between 8/17/12 and 4/17/12. Backwashing frequency correlated to poor water quality prohibited return to 2 filters until 5/9/12
3/6/12 to 3/13/12	3	10	10	On 3/6 high turbidity feed water; Arkal backwashing every 3 minute. Changed dP setting to 10 psi
3/14/12 to 3/17/12	3	10	15	Arkal backwash time returned to 15 second

Date	No. of Filters	Backwash Trigger dP (psi)	Backwash Duration (sec)	Operator Observations
3/18/12 to 4/7/12	3	7	15	Operator reported poor water quality with turbidity > 1 NTU; occasionally 3 to 5 NTU on 3/21. Filters backwashing every 3 minutes with 4 filters running; changed dP setting to 7 psi.
4/8/12 to 4/17/12	3	10	10	Backwash duration reset to 10 seconds; dP reset to 10 psi and 3 filters running.
4/18/12 to 4/19/12	3	5	10	Return to lower dP.
5/9/12 to 5/24/12	2	5	10	Return to fewer filters on duty.
5/25/2012	4	5	10	Filters backwashing every 2 to 5 minutes; changed to 4 filters. Windy day and high turbidity.
5/26/12 to 1/13	2	5	10	Switch back to 2 filters

From January 2013 to September 2013, Arkal filters were operated on a systematic schedule, in sets of 24 hour runs. For every run, changes were made to either the number of operating filters (from 2 to 4), the differential pressure setpoint (5 and 7 psi), or duration of backwash (8, 10, and 15 seconds). The purpose of those runs was to gather performance data over a wide array of operating conditions under various feed water quality (quantified by turbidity and AlgaeWatch data).

The followings were concluded:

- Number of backwashes increased with the decrease in the duration of backwash;
- For a given water quality and backwash settings (differential pressure and duration of backwash), the number of backwashes increased with the hydraulic load per filter (Table 4-3).

Table 4-3: Variation of Backwash Frequency with Hydraulic Load

Feed Turbidity (NTU)	Hydraulic Load (gpm/filter)	ΔP (psi)	BW Duration (sec)	Number of BW/filter/day
0.6	50	5	15	0.4
			8	1.3
0.7	95	5	15	1.8
			8	5.0

- Number of backwashes was lower for a higher differential pressure (Table 4-4)

Table 4-4: Variation of Backwash Frequency with Backwash Trigger ΔP

Feed Turbidity (NTU)	Hydraulic Load (gpm/filter)	BW Duration (sec)	ΔP (psi)	Number of BW/filter/day
0.7-0.8	95	15 sec	5 psi	1.8
			7 psi	1.1
		10 sec	5 psi	4.5
			7 psi	3.5

- Number of backwashes increased with higher feedwater turbidity. Turbidity alone is only a rough estimation of the water quality impacting the number of backwashes for Arkal filters; as such, there were inconsistencies in establishing a relationship between the number of backwashes and turbidity values. For example, extremely windy events resulted in a significant increase in the number of backwashes, whereas turbidity increased to only 2-4 NTU.

Table 4-5: Variation of Backwash Frequency with Feedwater Turbidity

Feed Turbidity (NTU)	Hydraulic Load (gpm/filter)	BW Duration (sec)	ΔP (psi)	Number of BW/filter/day
0.7	65	10	7	1.1
2.3*				56*
0.6	95	15	5	1.0
0.9				2.2
1				2.4
0.7	110	8	5	3.1
1.1				5.2

*Very windy conditions

- Possible red tide events were identified by an increase in chlorophyll-a in the intake water measured by an AlgaeWatch meter and verified by lab analysis. One such event likely occurred in mid-April 2013, when chlorophyll-a increased to 6-8 µg/L from values less than 2 µg/L during normal feedwater conditions (Table 4-6).

Table 4-6: Variation of Backwash Frequency with Feedwater Turbidity during Possible Red Tide Events

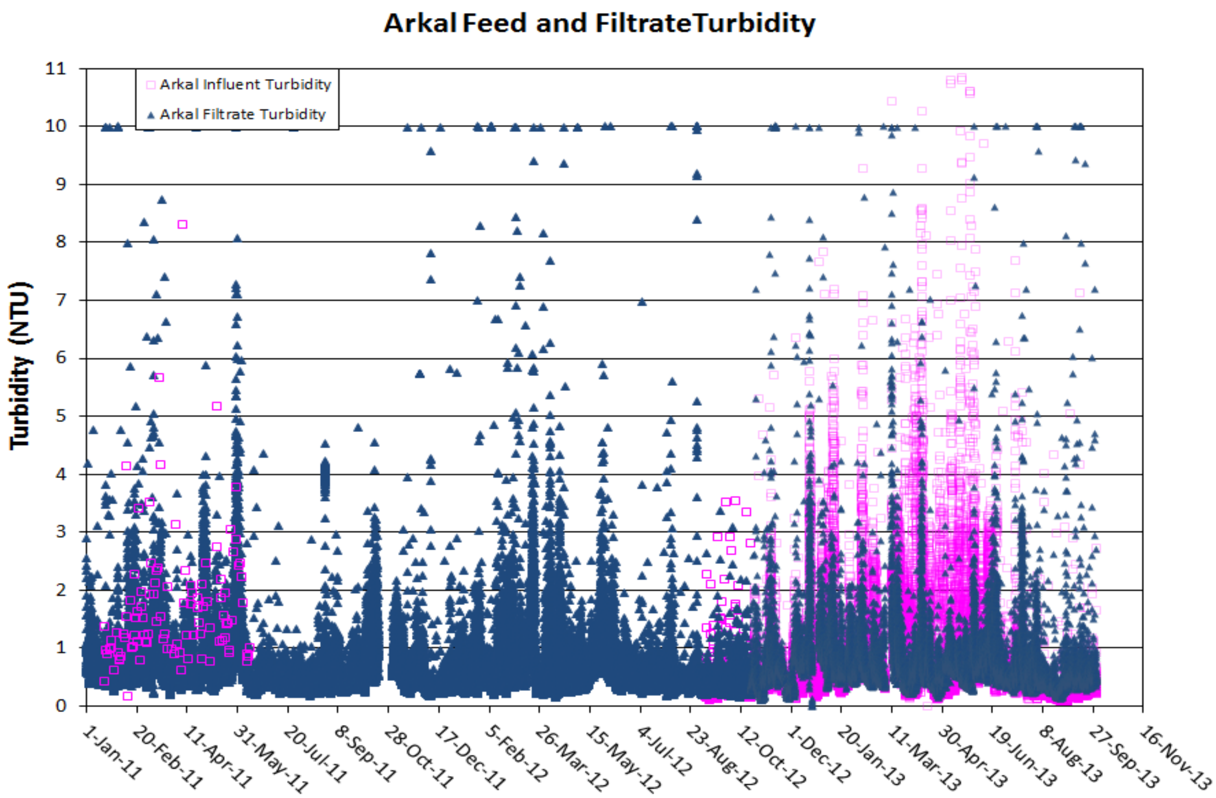
Feed Turbidity (NTU)	Hydraulic Load (gpm/filter)	BW Duration (sec)	ΔP (psi)	Number of BW/filter/day
0.43-2.48*	65	8	5	26*
2-2.5*	100	15	7	17.5*

*Likely red tide event

4.3.2 Filtrate water quality

Despite the previously mentioned correlation of high turbidity events to increased backwash frequency, the feed water and filtrate water turbidity were compared and consistently found to be essentially the same (Figure 4-5). There were a few spikes in the intake water turbidity (mainly end of April 2013 to June 2013), which were higher than the filtrate water; however, these events coincided both with calibration of the influent turbidity meter and also with the inlet tube feeding the influent turbidity meter getting clogged frequently.

Figure 4-5: Turbidity of the influent and filtrate water for Arkal filters



4.3.3 Biofouling of Arkal Filters

Arkal filters were opened for inspection eleven times during the study. From March 2012 to March 2013, biogrowth development was reported mainly on filters one and two, which were continually in service. Discs were either cleaned or replaced. During this period, shock chlorination was not active. After shock chlorination was resumed in May 2013, only minor biogrowth was noticed (Table 4-7).

Table 4-7: Dates and findings of Arkal filter inspections.

Date of Arkal Filters Inspection	Months Since last Inspection	Findings
6/1/11	4	One filter opened, discs were mainly clean
3/29/12 (Shock chlorination operated until Feb. 2012)	10	Mussels and sand found on filters #1, 2 and 3, discs were replaced for filter #1
4/20/12	1	Filters were clean
11/16/12	7	Significant biogrowth found on filter #1, and less on filter#2. Filters #3 and #4 were relatively clean. Mussels, barnacles and other biogrowth were observed on the feed pipeline to Arkal filters and to some extent, on the filtrate manifold as well.
2/6/13	3	Significant mussels loading inside filter#1, disc replaced. The other filters not inspected.
3/6/13	1	Filters#1 and #2 opened, some biogrowth/mussels accumulated on filter#1. During plant shutdown from 3/4/13 to 3/10/13, all discs were removed and acid cleaned/NaOCl cleaned.
4/17/13	1	Minor debris/biogrowth was found inside filters #1 and #2, rest were clean.
5/16/13 (Shock chlorination resumed 5/22/13)	1	Very little solids observed on any of the four filters.
6/10/13	1	Minor growth on filters #1 and #2, filters #3 and #4 were very clean
7/17/13	1	Minor growth on filters #1 and #2, filters #3 and #4 were very clean
8/29/13	1.5	Minor growth on filters #1 and #2, filters #3 and #4 were very clean
10/10/13	1.5	Minor growth on filters #1 and #2, filters #3 and #4 were very clean

There is general correlation between the incidence of mussels attachment in the Arkal filters and periods of shock chlorination. Following resumption of shock chlorination, the filters evidenced only minor mussels growth.

4.3.4 Osmotic Shock Procedure

Osmotic shock of the Arkal system is a process used for cleaning the discs by exposure to a very low TDS solution (RO permeate). Biogrowth can be reduced as cells are subject to the process of natural (direct) osmosis between the cells and RO permeate, which they cannot tolerate.

Osmotic shock was stopped from mid-August 2013 until the end of the project, in order to observe the impact on filter performance. Results for this eight week period show that the frequency of backwashes did not increase compared with the period when the osmotic shock was engaged. Also, on the inspection performed October 10, 2013, discs presented minor biogrowth, similar to findings of the past six months when osmotic shock was engaged.

4.4 Ultrafiltration System

4.4.1 Performance Evaluation

The performance of the UF filters and efficiencies of the backpulse and chemical cleanings are monitored based on the following parameters:

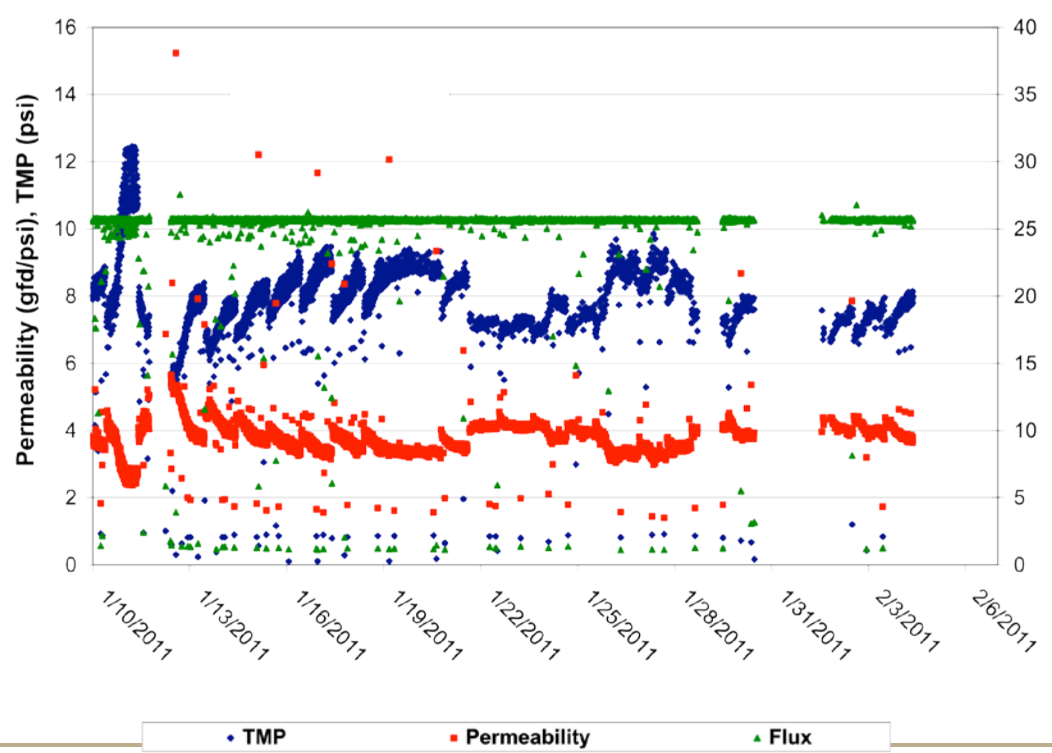
- Trans-membrane pressure (TMP)
- Temperature adjusted permeability
- Filtrate water turbidity
- Filtrate water quality and permeability following MC and CIP

Over the period of testing, three sets of UF modules were used, as follows:

- Set 1: 1/12/2011 to 4/19/2011
- Set 2: 4/20/011 to 11/15/20
- Set 3: 1/16/2012 to 9/30/2013

The UF system was the first put into service during the commissioning phase of the project in early November 2010 and was operated intermittently at reduced capacity. The system began the 21 day acceptance test on January 12, 2011 and lasted through February 4th, 2011. Figure 4-6 shows the performance of this 21 day test, where it maintained design flux with a daily maintenance clean. However, the permeability range (3.5-4.5 gfd/psi) was lower than expected based on experience at the El Segundo pilot testing, prior to this project. Stabilized permeability was approximately 8 gfd/psi in that testing.

Figure 4-6: UF System 21 Day Acceptance Test

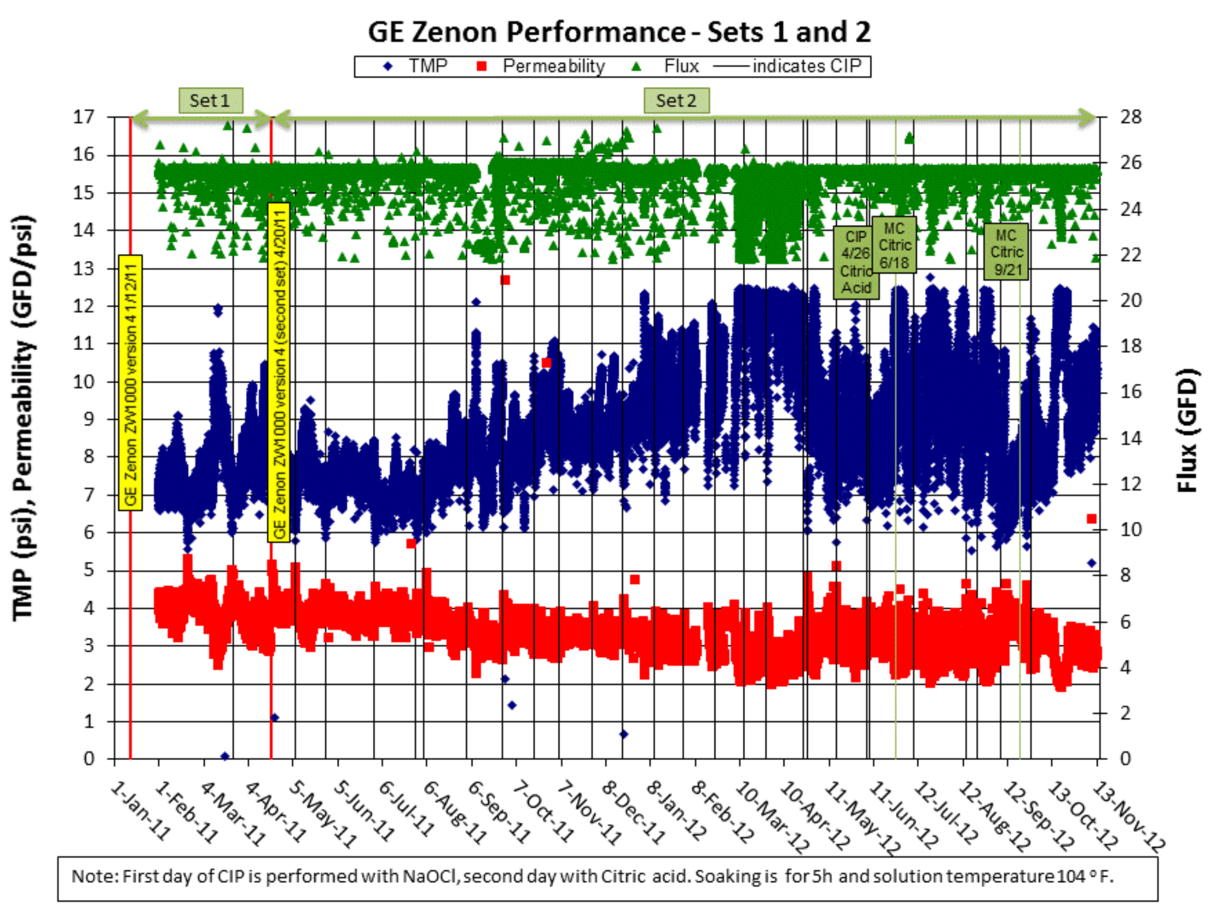


UF Membranes Set 1 (1/12/11 to 4/19/11) and Set 2 (4/20/11 to 11/15/12)

The system experienced increased TMP in mid-March 2011, and Maintenance Cleans (MC) frequency was increased to twice per day to extend run time between CIP events. This strategy proved effective at maintaining TMP below the terminal value of 12 psi, and the TMP decreased until the next CIP was performed on March 23rd and 24th. This CIP was effective at restoring permeability to previous levels. Discussions with GE took place regarding the lower than expected permeability values, and modules were replaced by GE on April 20th, 2011.

Figure 4-7 shows the system performance (flux, TMP and permeability) for the first two sets of membranes after the initial 21 day acceptance test for the first set.

Figure 4-7: UF Membranes Performance – Sets 1 and 2



Note: Vertical lines designate CIP events, unless noted otherwise.

As seen in Figure 4-7, performance of the second set of membrane was similar to the first set for the first 100 days (approximate) following installation (till beginning of August 2011), after which the TMP started to increase gradually from 7 psi to 12 psi in March-April 2012. During this period, as previously, MCs were performed twice a day and a CIP was performed every 21 days. The turbidity of the UF influent water remained below 0.4 NTU most of the time (thus, good feed water quality). The degree of fouling between MCs also increased, as reflected by the wider range of TMP oscillation, from 2 psi in the beginning of runs with Set 2 to 4 psi in April to August 2012.

Below is a list of notable events which occurred during this period and the lesson learned:

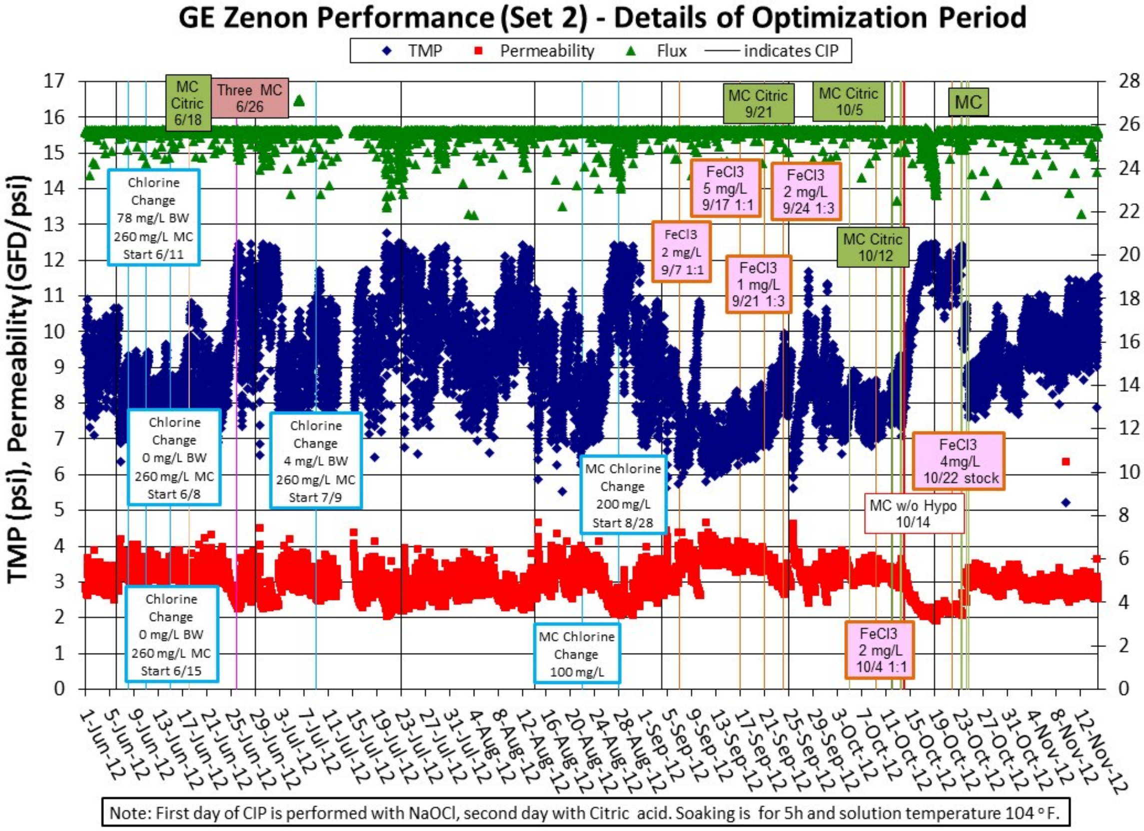
- The use of only one MC per day was found inadequate to achieve 21 day period between Ps;
- Sept. 7, 2011 – A CIP was performed without heat (heater was broken), and the cleaning was found ineffective. A significant improvement in the performance and recovery of permeability was noticed after the next CIP which was performed with heated water (Sept. 21, 2011);
- September 30 to October 15, 2011 –During an algal bloom event (as indicated by the increase of chlorophyll A in feedwater) the UF maintained design flux. However, TMP increased by 2 psi. GE recommended the use of a coagulant during poor water quality events;
- For a few days following January 9, 2012 multiple MCs (more than 2) per day were required to prevent the TMP from reaching the terminal value (12 psi). The feed water turbidity during this time was slightly higher than normal (still less than 2 NTU and lower than during an algal bloom);
- March - April, 2012 – a poor feed water quality event occurred, with turbidity values above 2 NTU most of the time and spikes of 5-6 NTU, caused rapid increase to terminal TMP (12 psi). The UF system was operated at reduced the filtrate flow during this period.
- April 16, 2012 – the existing 2-inch filtrate header was replaced with a 3-inch line. According to GE, the existing filtrate header was too small, causing too much friction loss and inefficient backwash, which in turn, manifested by reduced permeability. As a result of this change, the TMP was reduced by approximately two (2) psi.

Optimization Period

Since the permeability remained relatively low following the filtrate header modifications, operation optimization was performed from June 2012 to November 2012. Figure 4-8Ref340078339 illustrates the details of the optimization period. The optimization consisted of two phases:

- **Phase I** (from 6/8/12 to 8/28/12): variations to the chlorine dose in the backwash and maintenance cleans were assessed;
- **Phase II** (from 9/7/12 to 11/15/12): the addition of ferric chloride to the UF feed was assessed.

Figure 4-8: Details of Performance Optimization for Membrane Set 2



Note: Vertical lines designate CIP events, unless noted otherwise.

Prior to the optimization period, the chlorine dose in the backwash was 4 mg/L and in the MC water was 100 mg/L. Phase I's changes to chlorine dose in backwashes and maintenance cleans (MCs) are detailed below. There were six (6) optimization trials, during which the chlorine in the backwash varied from 0 to 78 mg/L while the chlorine in the MC varied from 100 to 260 mg/L. It was concluded that none of these regimes made a difference in TMP and permeability of the membranes.

- Chlorine Optimization 1: 6/8/2012 to 6/11/2012
  - Chlorine in BW was zero, and in MC was 260 mg/L
  - Results: No change in permeability

- Chlorine Optimization 2: 6/11/2012 to 6/15/2012
  - Chlorine in BW was 78 mg/L (intent was 25 mg/L), and in MC was 260 mg/L
  - Results: No change in permeability

- Chlorine Optimization 3: 6/15/2012 to 7/9/2012
  - Chlorine in BW was zero, and in MC was 260 mg/L

  - Results: No improvements in permeability. A sharp increase in TMP started on 6/24 until 7/2, which did not correlate with changes in any feedwater quality indicator

- Chlorine Optimization 4: 7/9/2012 to 8/22/2012
  - Chlorine in BW was 4 mg/L (historical value), and in MC was 260 mg/L
  - Results: No improvements in permeability, TMP remained high (9 to 12 psi)

- Chlorine Optimization 5: 8/22/2012 to 8/28/2012
  - Chlorine in BW was 4 mg/L, and in MC was 100 mg/L
  - Results: Decline in permeability

- Chlorine Optimization 6: 8/28/2012 to 9/6/2012
  - Chlorine in BW was 4 mg/L, and in MC was 200 mg/L
  - Results: Recovery in permeability to levels similar to Optimization 4

Phase II's changes are detailed below. Dosing of $FeCl_3$ was varied from 1 to 5 mg/L. Also different dilution of the stock solution (42% strength) was utilized, out of concern that a diluted solution of $FeCl_3$ may be less effective in coagulation due to formation of $Fe(OH)_3$. Per GE's recommendation, a weekly MC with citric acid was also implemented during this phase. It was concluded that addition of ferric chloride at 2 mg/L was very effective in reduction of TMP by approximately 3 psi, bringing it to levels similar to the beginning of the runs with this membrane set.

- Coagulant Optimization 1: 9/7/2012 to 9/17/2012
  - Dosing 2 mg/L at 50% dilution
  - Results: Significant improvements in permeability (approximately 4 gfd/psi)

- Coagulant Optimization 2: 9/17/2012 to 9/21/2012
  - Dosing 5 mg/L at 50% dilution
  - Results: Slight decline in permeability

- Coagulant Optimization 3: 9/21/2012 to 9/23/2012
  - Dosing 1 mg/L at 25% dilution
  - Results: Decline in permeability

- Coagulant Optimization 4: 9/24/2012 to 10/4/2012
  - Dosing 2 mg/L as $FeCl_3$ using 25% dilution of stock solution
  - Results: No recovery in permeability since previous optimization period (#3)

- Coagulant Optimization 5: 10/4/2012 to 10/22/2012
  - Dosing 2 mg/L as $FeCl_3$ using 50% dilution of stock solution
  - Results: No recovery in permeability since previous optimization period

- Coagulant Optimization 6: 10/22/2012 to 11/15/12
  - Dosing 4 mg/L as $FeCl_3$ using stock solution

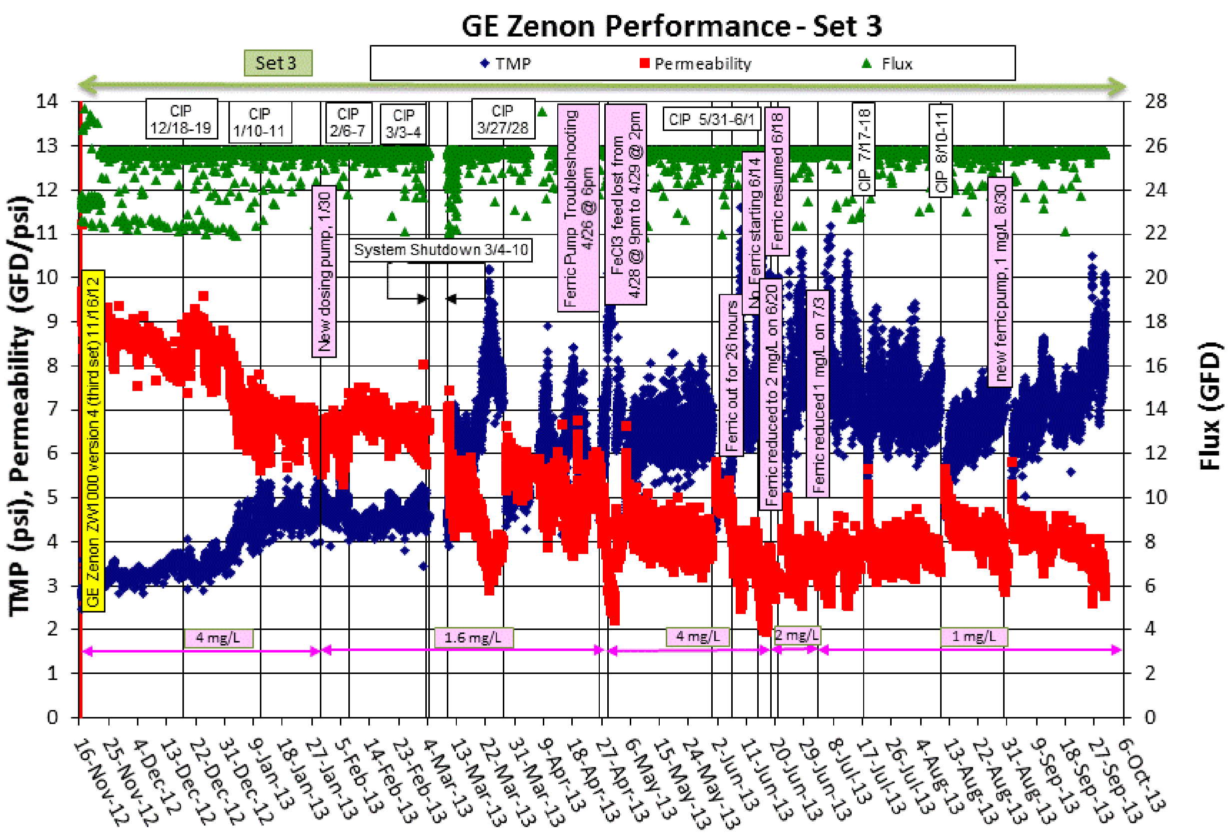
- o Results: Permeability steady at ~3.0 gfd/psi, which was slightly lower than for Coagulant Optimization #4 and #5.

A MC on October 14, 2012 performed without hypochlorite (due to an undetected leak in the NaOCl dosing pump) was followed by a decrease in the permeability from 3.5 to 2.0 gfd/psi. A CIP was performed on October 19 and 20, and four (4) more MCs were necessary before permeability was restored to ~3 gfd/psi.

UF Membrane Set 3 (11/30/2012 to 9/30/2013)

On November 16th, 2012, a new set of UF membrane was installed (Set 3). They were the same model as the previous sets, i.e. ZeeWeed ZW 1000, version 4, with a membrane surface area per module of 550 square feet. The filtrate manifold line was enlarged to 1.5 inch during this installation. Figure 4-9 presents the performance of this membrane set, along with the concentrations of ferric chloride addition.

Figure 4-9: UF Membranes Performance – Set 3



As presented in Figure 4-9, permeability at startup was 9 gfd/psi and remained at this level for several weeks. This permeability level was similar to the permeability experienced during pilot testing in EL Segundo and significantly higher than for UF membranes sets 1 and 2. Following this period, permeability began a decline to 8 - 8.5 gfd/psi through the end of 2013. In the first week of January 2013, permeability decreased sharply from slightly above 8 to below 7 gfd/psi, and remained relatively stable until system was shut down in March 2013. After the system restart on March 10, permeability continued to decline to approximately 3.5 gfd/psi in June 2013 and after approximately two months, it increased slightly to 4 gfd/psi where it stayed until end of the project. The variations in permeability did not correlate with changes in the dose of ferric chloride coagulant to the influent stream. To summarize the findings with the third membrane set:

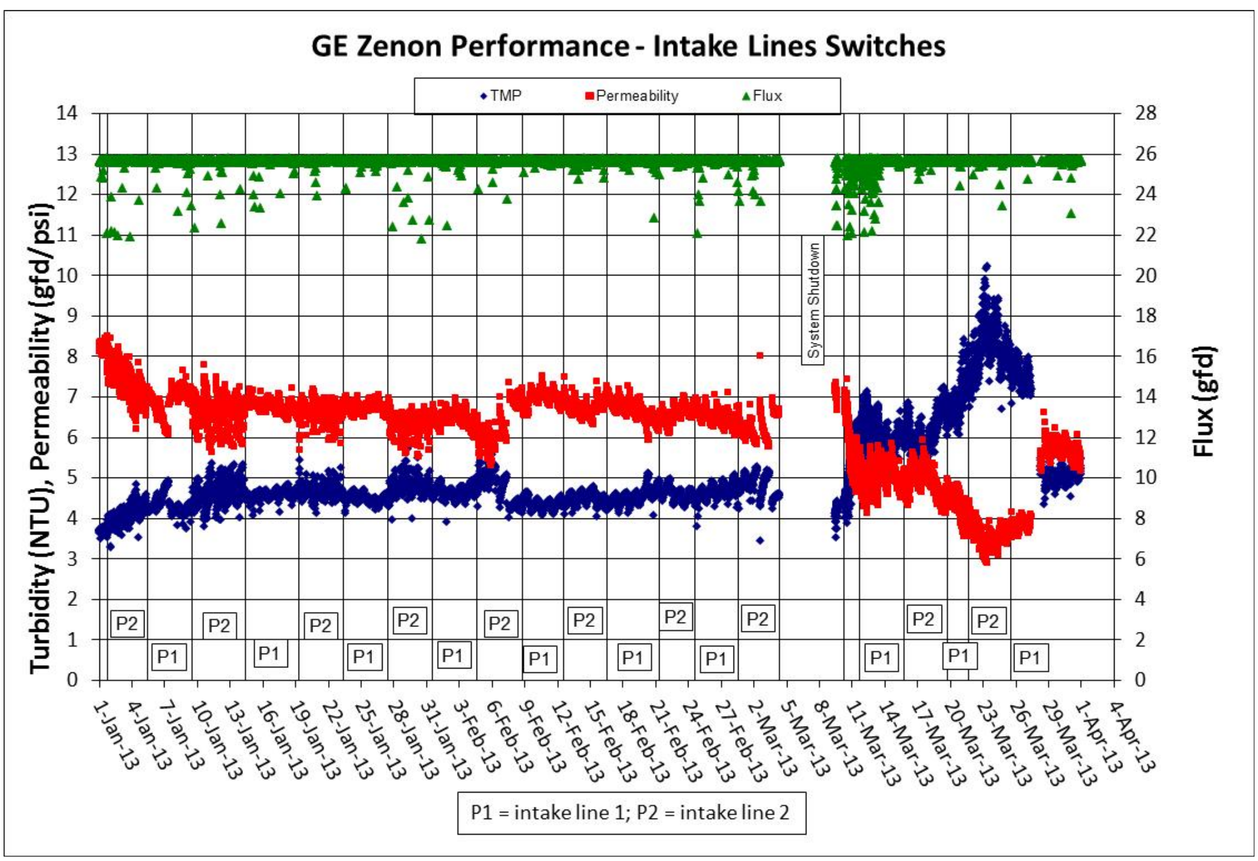
- A new ferric chloride dosing pump was installed January 30, 2013. A series of troubleshooting measures took place in the following months as the pump speed appeared too low (~7%), although the pump drawdown showed an average dosing of 4 mg/L. On April 29, 2013 it was observed that the drawdown test was not performed correctly and the actual ferric dose was likely close to 1.6 mg/L. On the same day, the pump speed was increased to 18-19% resulting in a dosing rate of 4 mg/L. Ferric chloride was reduced to 2 mg/L on June 20, 2013 and to 1 mg/L on July 3, 2013. It appeared that the permeability was not impacted by the reduction of ferric dose down to 1 mg/L.
- During operation with this membrane set, ferric was interrupted on few instances such as at the end of April 2013 for troubleshooting the dosing pump and mid-June 2013 purposely to observe the impact on permeability. In the absence of coagulant dosing, a sharp increase in TMP (reaching terminal TMP in 72 hours) was observed resulting in permeability drop, denoting that the operation benefits from the use of ferric chloride in the influent flow.
- Ferric chloride injection quill was found ~50% clogged on an inspection in April 2013 and regular (every 3 weeks) cleanings were performed to prevent clogging from that time to end of project.
- GE performed an audit on the UF system on April 8-10, 2013. Based on the field report:
    - Small stream of bubbles were observed from both Tank 1 (Module 5) and Tank 2 (Modules 3 and 5). Based on very good permeate turbidity and MIT results, no action was taken for fiber repairs;

      Note: Internal Control System calculations for MIT values were found incorrect later in August 2013.
    - Modules had adequate fiber slack, with no cracks and broken shrouds observed.
    - There was some ferric chloride sludge buildup at the top of each tank which would require manual removal.
- On August 23, 2013 significant air bubbling was found from tank 1 (Module 5) during an integrity test performed by GE, and LRV was 3.5. Fibers were repaired on August 26, 2013 and LRV increased to 4.5 (site specific value for a pass MIT value is 4.0).
- It appears that traces of ferric chloride were carried over and oxidized on the cartridge filters upstream of RO system. However, the UF filtrate was analyzed for total iron

multiple times from May to September 2013 and lab results showed non–detect (<0.0022 mg/L).

- A remarkable pattern in the permeability variation was noticed in connection with the intake line switching in January-February 2013. Figure 4-10 presents the UF membranes performance together with the intake line switching. The intake lines were switched approximately every four (4) days in order to keep them periodically anoxic, as a measure of preventing biogrowth development in the intake line in the absence of any chlorination. The intake line with the 1 mm screen was operated with intake pump #1 whereas the intake line with the 2 mm screen was operated with intake pump #2. From November 7, 2012 to December 24, 2012, only pump #1 was operating as the 2 mm screen was pulled out with the intent of being replaced with a 0.5 mm screen. There were installation problems with the 0.5 mm screen and the 2 mm screen was installed back on December 19, 2012. Line switching resumed on December 24, 2012. As observed from Figure 4-10, when intake line #2 was put online after December 24, 2012, the UF TMP variation was over a wider range than when intake line #1 was online, indicating that the fouling of UF membranes was more accelerated when intake line #2 was operating. Such wider variation of TMP when line #2 was online was observed consistently until mid-February 2013, after which the effect seemed to have been diminished. Investigations of differences in the water quality for the two intake lines included Total Organic Carbon (TOC) measurements and Fluorescence Excitation-Emission Matrix (FEEM). Intake samples were taken on February 19th. However the results showed no difference in water quality between the two intake lines with respect to the performed analyses (turbidity, FEEM, and TOC).

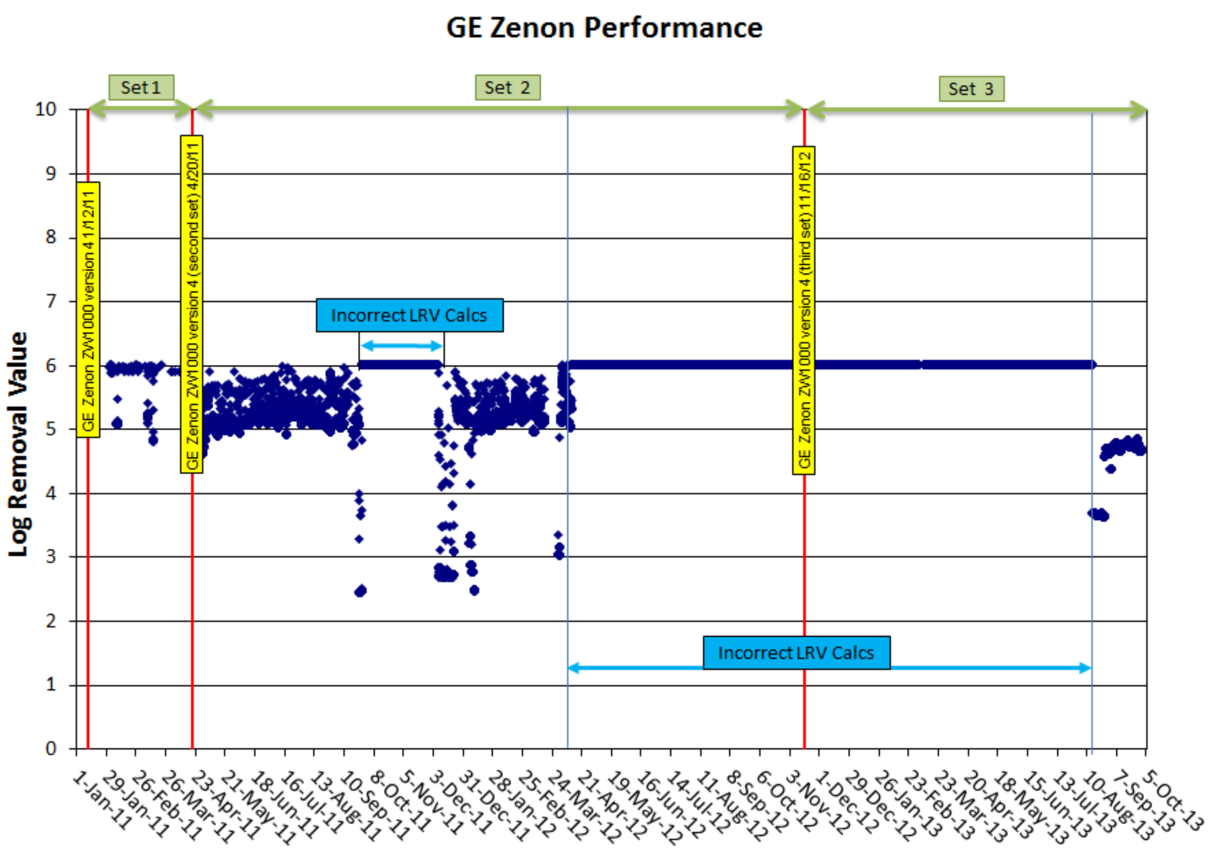
Figure 4-10: UF Membrane Performance and Intake Lines Switches



4.4.2 Membrane Integrity

Figure 4-11 shows the Log Removal Value (LRV), which is an indication of membrane fiber integrity. The start MIT pressure was between 9.6 and 9.7 psi, the end MIT pressure was between 9.2 to 9.4 psi. The pass value for LRV was 4.0, specific to this site. There was a change in LRV value when the modules were changed in April 20th, 2011, but the consistent values greater than 4 is an indication that the membrane fibers are intact. The MIT system was under several stages of repairs and automatization and in August 2013 it was discovered that calculations performed September-October 2011 and from April 2012 to August 2013 were incorrect. Calculations were corrected August 2013, and LRV was 3.5. Repairs were done to fibers and LRV went to 4.5 which was above the pass LRV for the site.

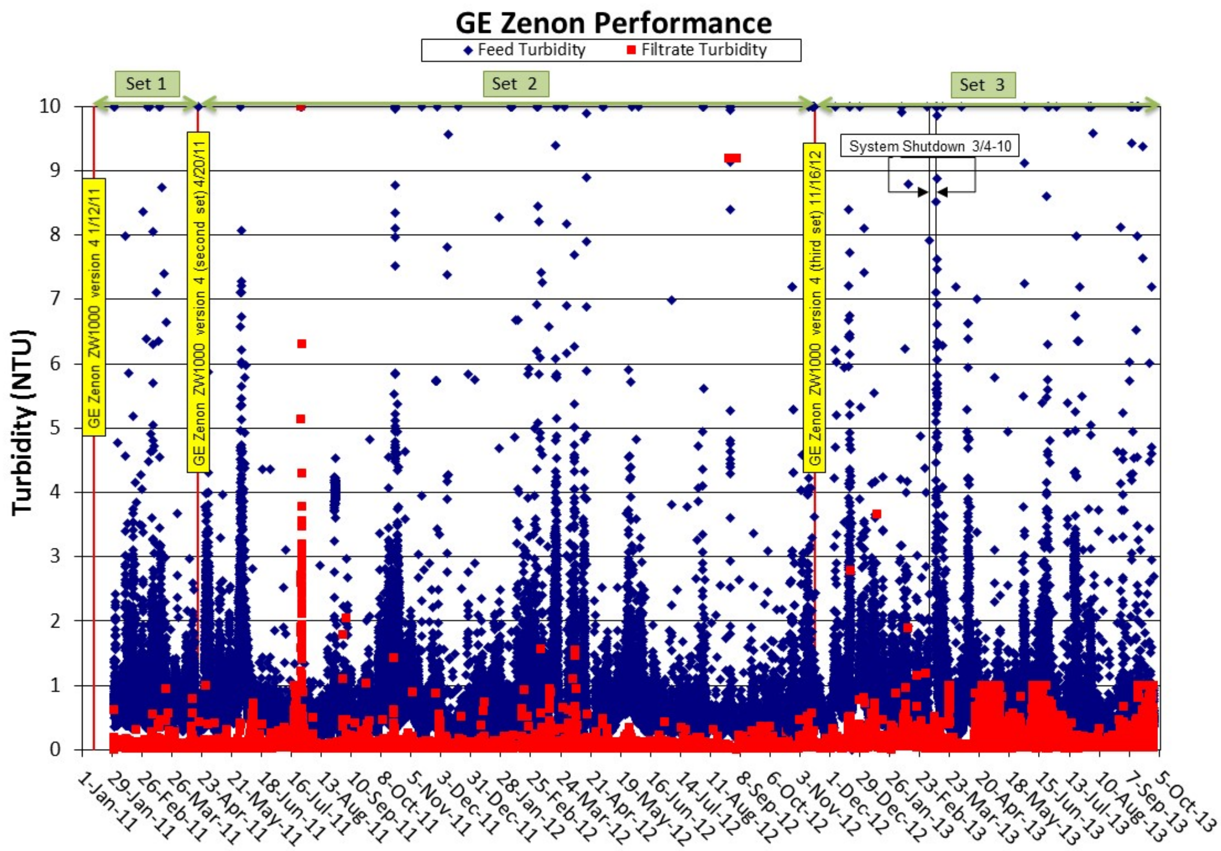
Figure 4-11: Log Removal Value for Membrane Integrity Testing



4.4.3 Filtrate Water Quality

Although the permeability of the membrane sets 1 and 2 was below expectations, the modules performed well with respect to filtrate water quality. Figure 4-12 shows the UF feed and filtrate turbidity. The filtrate turbidity for sets 1 and 2 was less than 0.07 NTU for 90% of the time and less than 0.09 NTU for 95% of the time. In the case of set 3, filtrate turbidity was higher likely due to the encountered fiber breakage, with values less than 0.16 NTU for 90% of the time and less than 0.25 NTU for 95% of the time.

Figure 4-12: Turbidity of UF Feed and UF Filtrate



To summarize UF membrane performance:

- For membrane sets 1 and 2, permeability begun at approx. 5.5-6 gfd/psi and stabilized at values around 3.5 gfd/psi for duration of study. Such levels are significantly below permeability levels observed during pilot study at El Segundo (approximately 8 gfd/psi). The longest period of operation for a membrane set was approximately 19 months (set 2);

- Membrane set 3 demonstrated higher initial permeability (9 gfd/psi) and the use of ferric chloride as coagulant in the feed water was beneficial in stabilizing the permeability. Concentration of ferric chloride in the feedwater varied from 1 to 4 mg/L and it appeared that 1 mg/L might be sufficient for periods of normal feed water quality. Dosing stock solution appeared more efficient than diluted solution. The coagulant helps stabilization of permeability but does not increase low permeability;

- Despite beneficial effect of ferric chloride addition, the membrane set 3 did experience periods of permeability loss and eventually stabilized at a permeability values of 3.5-4 gfd/psi.

- The most effective backwash regime was established at 4 mg/L NaOCl every 22 minutes for a duration of 30 seconds;

- Two Maintenance Cleans per day were necessary to prevent reaching terminal TMP. They were performed with a cleaning solution of 200 mg/L NaOCl heated at 104 degF (40 degC) and 30 minutes soak time;

- When ferric chlorite was added, one additional Maintenance Clean with 2% citric acid was performed every week to prevent ferric buildup on membranes fibers. The target pH for cleaning solution was 2 and hydrochloric acid was used to lower the pH to this value;

- A dual CIP was performed every 21 days, first with NaOCl and second with 2% citric acid. The procedure included a 5 hours soaking period in solution heated at 104 degF (40 degC);

- Membrane fiber integrity was excellent for sets 1 and 2. However, set 3 experienced fiber breakage;

- Filtrate water quality was excellent most of the time, with turbidity values below 0.2 NTU and occasional spikes typically correlated with fiber breakage.

4.5 Seawater Reverse Osmosis System (SWRO)

The first-pass RO primarily was operated at 50% recovery and a flux of 9 gfd. Operating performance confirmed these operating setpoints to support stable, sustainable operation. Over the course of OWDDF operation, seven sets of membranes from four (4) different manufacturers were tested in the first-pass RO. The membranes were classified into two groups: Group A – a higher salt rejection/lower permeability membrane (supplied by Toray, DOW and Hydranautics) and Group B - a lower salt rejection/higher permeability membrane (supplied by NanoH$_2$0 and Dow). The feed pressure for Group A membranes was in the range of 850-900 psi whereas the permeate total dissolved solids (TDS) ranged from 150 to 250 mg/L. The feed pressure for Group B membranes was in the range of 790-810 psi, however the permeate TDS was approximately 400 mg/L.

In addition to the project's key objectives, West Basin made the OWDDF RO operation available to two research studies to gather data. There were a Water Research Foundation (WRF) study on seawater desalination energy consumption and a study managed by MWH on verification of technologies claiming a reduction in the energy requirements for desalination. As such, additional sets of membrane were provided to the facility and the range of operating protocols was expanded to support these studies.

The discussion of first pass RO performance is divided by membrane sets, as follows:

- **Phase 1**: from January 31, 2011 to July 24, 2011 (**6 months**)
    - Toray, TM810F-400 (Group A)
    - Operating Setpoints: 9 gfd flux, 50% recovery
- **Phase 2**: from July 25, 2011 to August 28, 2012 (**13 months**)
    - Hydranautics, SWC-5 (Group A)
    - Operating Setpoints: 9 gfd flux, 50% recovery
- **Phase 3** (WRF study): from August 29, 2012 to October 29, 2012 (**2 months**)
    - Dow, hybrid arrangement: 2 of SW30XHR-400i and 5 of SW30XLE-400i (Group A)
    - Operating Setpoints: 7 to 9 gfd, 45 to 55% recovery
- **Phase 4a** (WRF study): from October 30, 2012 to November 15, 2012 (**15 days**)
    - NanoH$_2$0, SW400ES (Group B)
    - Operating Setpoints: 7 to 9 gfd, 45 to 55% recovery
- **Phase 4b** (WRF study): from November 16, 2012 to January 17, 2013 (**2 months**)
    - NanoH$_2$0, hybrid arrangement: 2 of SW400R and 5 of SW400ES (Group B)
    - Operating Setpoints: 7 to 9 gfd, 45 to 55% recovery
- **Phase 5a** (MWH study): from January18, 2013 to January 27, 2013 (**10 days**)

- Dow, SW30ULE-400i (Group B)
- Operating Setpoints: 7 to 9 gfd, 45 to 55% recovery

- **Phase 5b, 5c** (MWH study), and **5d** (baseline operation): from January 28, 2013 to September 23, 2013 (**8 months**)
  - DOW hybrid arrangement: 2 of SW30XLE-400i and 5 of SW30ULE-400i (Group B)
  - Operating Setpoints: 7 to 9 gfd, 45 to 55% recovery, and baseline operation at 9 gfd and 50% recovery
- **Phase 6:** from September 24, 2013 to October 31, 2013 (end of study) (**5 weeks**)
  - Second set of DOW, hybrid arrangement: 2 of SW30XLE-400i and 5 of SW30ULE-400i (Group B)
  - Operating Setpoints: 9 gfd and 50% recovery

4.5.1 Phase 1: Toray TM820F-400

The SWRO system was commissioned in January-February 2011 with Toray membranes, subsequently operated at setpoints of 9 gfd flux and 50% recovery. Figure 4-13 shows permeability of the membrane for six month period of Phase 1 operation. Permeability was stable for the first five months, until early June 2011, when a slight decline occurred. This decline coincided with an increase in seawater temperature by about 4 ^{o}C, and it is possible the equations of data normalization for temperature did not accurately compensate for the temperature increase. The temperature correction coefficient was provided by the manufacturer.

Figure 4-13: Permeability of Phase 1: Toray TM820F-400

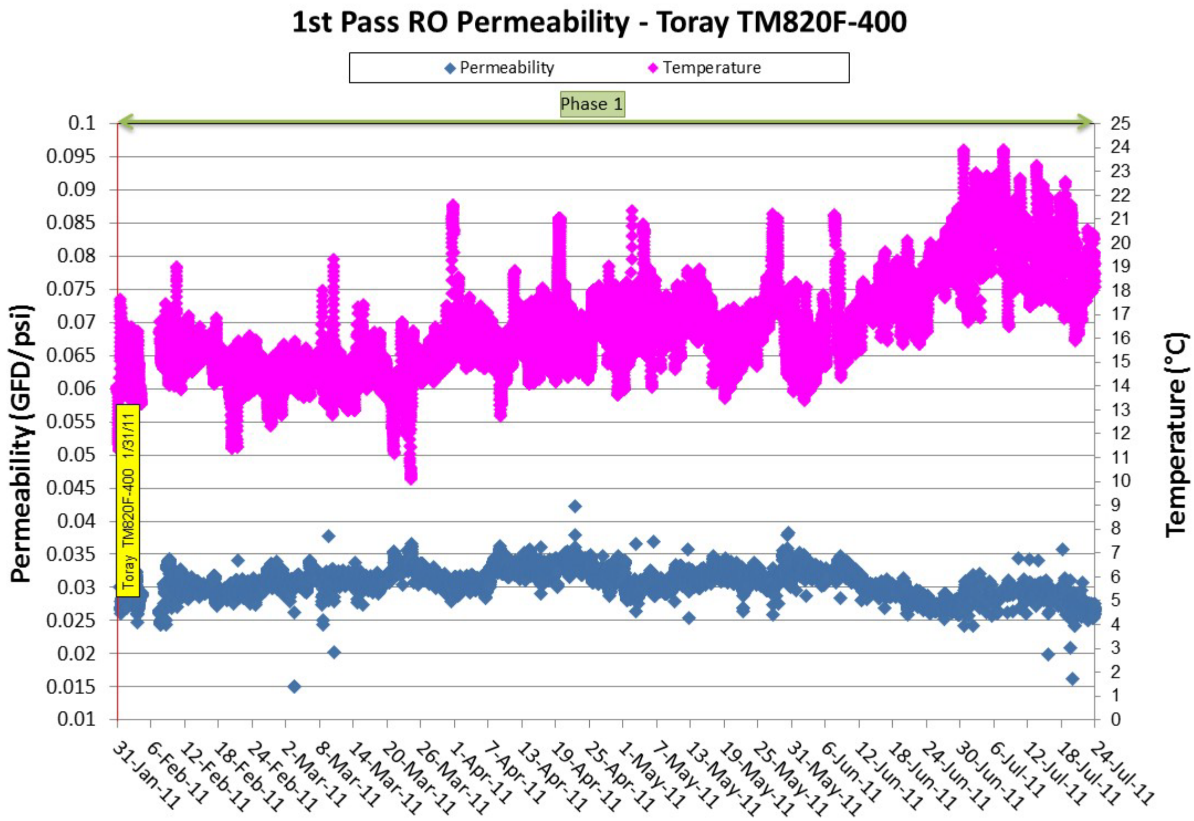


Figure 4-14 shows the differential pressure across the pretreatment 5 micron cartridge filters and RO membranes. Figure 4-15 provides oxidation/reduction potential (ORP) data for the feed stream and normalized permeate conductivity. The ORP was typically 500 mV when the chloramines were online from February 2011 through mid-April 2011. In mid-April 2011, problems with the sodium hypochlorite pump developed; chloramines were only being dosed intermittently, and typically at a dose from 1-3 mg/L, below the targeted 5 mg/L. The decreased use of chloramines coincided with an increase in cartridge filter differential pressure on several occasions, as well as a gradual increase in SWRO membrane differential pressure from mid-May 2011 through early June 2011 (Figure 4-15). When chloramine dosing was more consistent, starting in mid-June 2011 after pump repairs took place, the differential pressure across the SWRO membranes stabilized, and even started to decrease in late June 2011.

Figure 4-14: ΔP for Cartridge Filters and RO Membranes – Phase 1: Toray TM820F-400

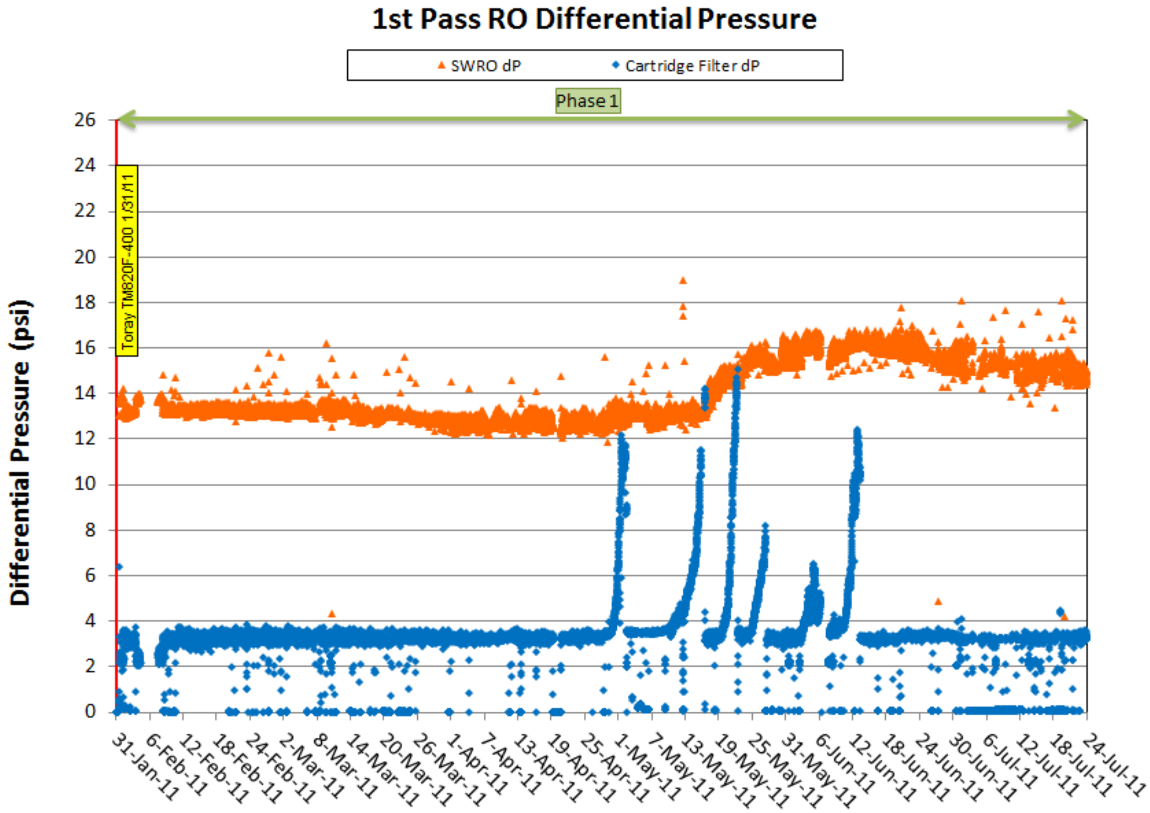
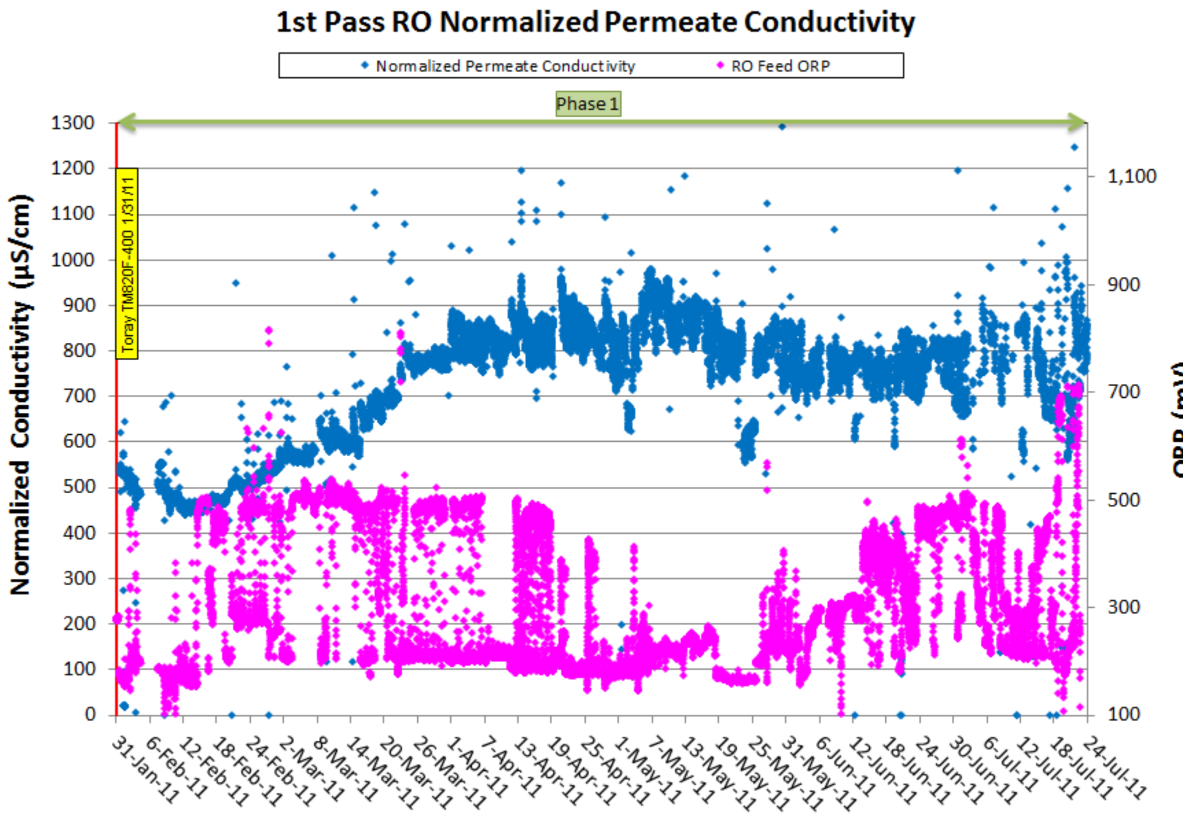


Figure 4-15 shows the normalized permeate conductivity and ORP of the RO feedwater for Toray membranes. The preformed chloramine system was undergoing commissioning during the same timeframe as the RO system, and consistent dosing of chloramines in the RO feedwater began in mid-February 2011. The elevated feedwater ORP in the 500 mV range is indicative of preformed chloramines in the RO feedwater. During this period, there was a significant increase in normalized permeate conductivity over time, from about 500 µS/cm immediately after commissioning to 850-900 µS/cm on mid-April until the end of July 2011.

Figure 4-15: Permeate Conductivity and Feed ORP– Phase 1: Toray TM820F-400



As part of the troubleshooting process, one SWRO element was removed from the system for analysis with a dye test and autopsy performed by an outside service provider (Avista Technologies). During a dye test, a purple colored dye solution is recirculated through the membrane element. Normally, the RO membrane will reject all the dye, and none of the dye can be found in the RO permeate. If there is damage to the RO membrane, the dye can penetrate the membrane and be detected on the RO permeate side of the membrane when the element is autopsied after the dye test. Depending on the nature of dye penetration to the permeate side of the element, the type of damage to the membrane can be determined.

The purple dye was observed on the back-side of the membrane and in the permeate carrier indicating there was damage to the membrane which caused the high permeate conductivity condition. The nature of this damage rules out any hydraulic issues with the system, and is more indicative of chemical attack to the membrane.

Based on the dye test and autopsy results, it was concluded that the flushing procedure of the RO train on shutdown was likely the main cause for the membrane chemical damage. Changes in the RO flushing sequence were made to include flushing the RO train with permeate water that has been dosed with sodium bisulfite to neutralize any chloramines present. It is believed that in the presence of bromides from seawater, chloramines can convert to bromochloramines over time, and oxidize the RO membrane.

Once these programming changes were in place, a single new element (Hydranautics SWC) was installed on July 7, 2011 into the lead position of the vessels and isolated from the rest of the elements with a solid membrane interconnector. The performance of this one element was monitored over a series of shutdowns and flushes for a period of two weeks to ensure no membrane damage is occurring. The rest of the elements were replaced on July 25, 2011.

In summary, Phase 1 operation demonstrated the benefit of preformed chloramine to prevent biogrowth. However, potential membrane damage when flushed was identified.

4.5.2 Phase 2 - Hydranautics SWC-5

On July 25, 2011, new membranes from Hydranautics (model SWC-5) were installed in the first-pass RO system. Four (4) CIPs were performed during this period, and are discussed in the following paragraphs. Chloramines were operating intermittently during this period, estimated to be 8% of total operating time. Challenges with the chloramine system are discussed in Section 4.7.

Figure 4-16 shows the normalized permeability of the 1st pass for the 13 months of operation with this membrane. The normalized permeability was relatively stable, varying within a narrow range, from 0.025 gfd/psi to 0.03 gfd/psi. With the decrease in feedwater temperature, the actual permeability of a membrane decreases as more feed pressure is required to produce the same permeate flow - however, the graph shows that the normalized permeability increased during the cold feedwater period. It is likely that this variation in permeability is a temperature effect (seawater temperature varied between 13 and 21°C), for which the normalization equation overcompensated, similar to the situation described above for Toray membranes. In this case, normalization equations were provided by Hydranautics.

Figure 4-16: Permeability of Phase 2: Hydranautics SWC-5

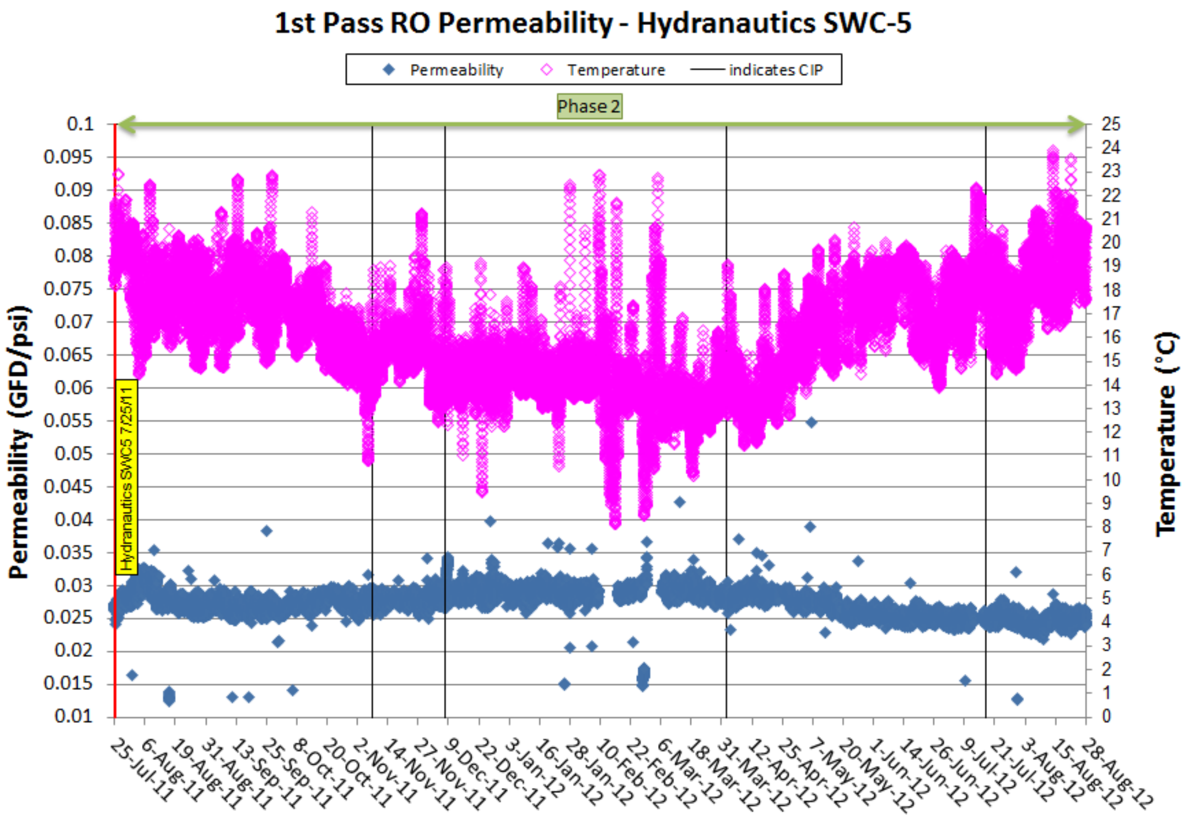


Figure 4-17 presents the differential pressure across the cartridge filters (CF) in the pretreatment system together with the differential pressure from the 1st Pass RO for Phase 2. For the first three months of operation, differential pressure across membranes was stable at 12-13 psi, after which it spiked to 19 psi. The differential pressure in the cartridge filters also spiked in that period from the normal 4 psi to almost 8 psi. Chloramines were not run since the beginning of October 2011, and it is believed that some biofouling had developed both in the cartridge filters and RO membranes. The CF were replaced and two CIPs were performed on November 11, 2011 and December 8, 2011. The second CIP (December 8, 2011) was performed because the first one reduced the differential pressure by only 2 psi. However, the second CIP on November 11, 2012 only reduced the differential pressure by an additional 1.5 psi, and as such, the baseline of 12-13 psi could not be reestablished.

Another spike in differential pressure both for CF (up to 9 psi) and RO (up to 23 psi) occurred at the end of March 2012. The presence of microbiological organisms was tested on March 18, 2012 using Millipore HPC total count samplers, and positives were identified in the sample pre and post CF as well as in the RO concentrate. The UF break tank which feeds the RO system was sterilized on March 28, 2012, by soaking the tank overnight in 100 mg/L NaOCl solution. CFs were replaced on March 23, and April 2, 2012. A third CIP was performed on the RO on April 2, 2012. Differential pressure in the RO was restored to about 17 psi; however, the differential pressure in the CF spiked on two more occasions immediately thereafter, leading to additional CF change outs (April 7 and April 20, 2012).

A fourth CIP occurred on July 18, 2012 in response to another increase in differential pressure for CF and RO membranes. Differential pressure was successfully restored to 14 psi after the cleaning. Prior to the CIP, the UF break tank was sterilized on July 12, 2012 using 100 mg/L sodium hypochlorite while the CFs were replaced multiple times (June 28, July 1, July 3, and July 3rd). It should be noted that in order to prevent the RO from being shut down due to high differential pressure in CF, on April 20, 2012, the CF change out was set at 4.5 psi. This value was very close the differential pressure encountered during normal operation.

Figure 4-17: ΔP for Cartridge Filters and RO Membranes – Phase 2: Hydranautics SWC-5

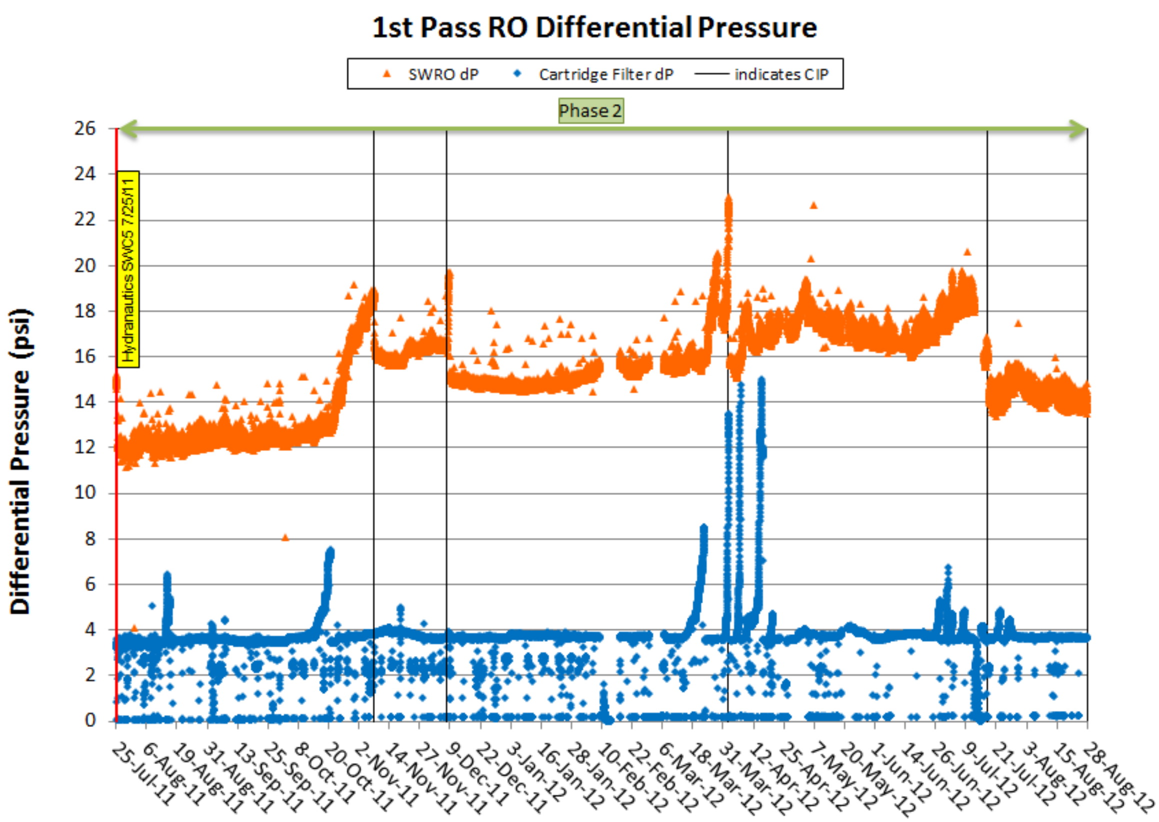
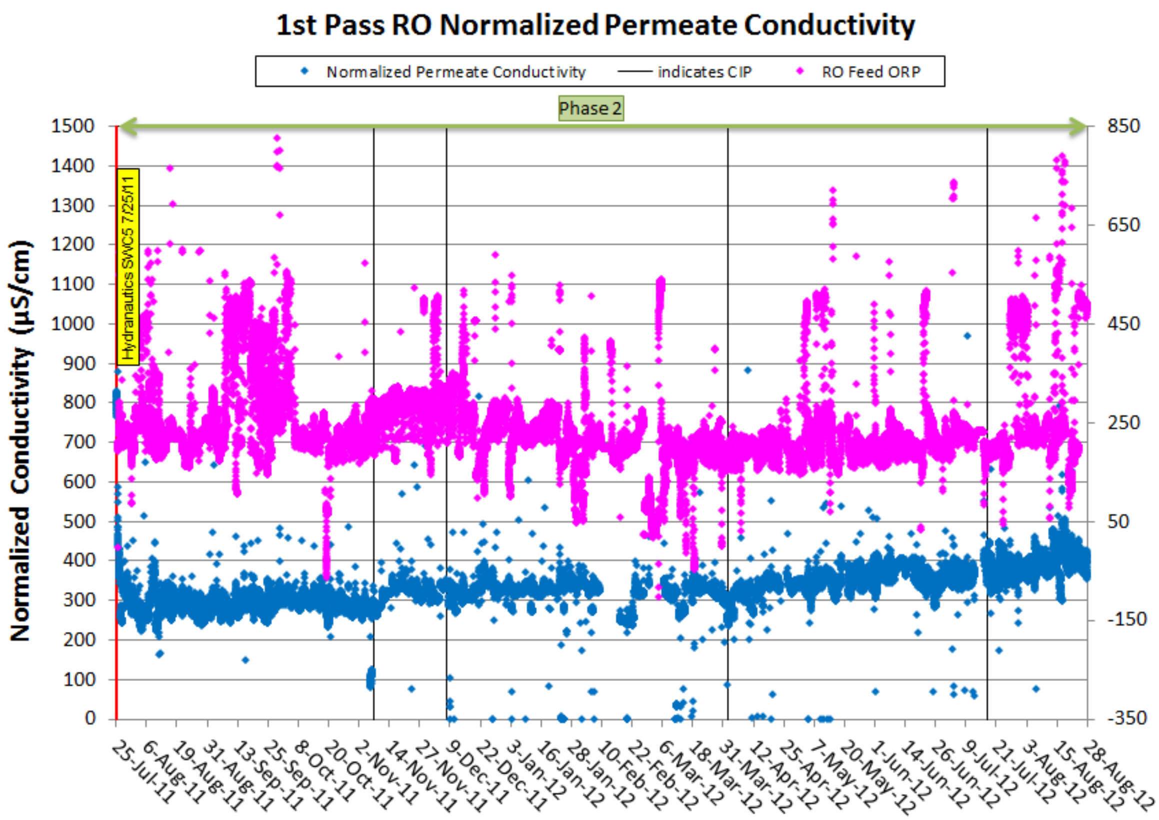


Figure 4-18 presents the normalized permeate conductivity and ORP of the feedwater. Permeate conductivity was about 300 μS/cm until November 11, 2011, when it stepped up to approximately 350 μS/cm. On this date, the intake line (1 mm screen) was chlorinated and it is possible that a slug of chlorine had reached the RO, oxidizing the membrane to a small extent. Another step up in permeate conductivity occurred at the end of April 2012, which was consistent with the increase in chloride, boron and bromide in the RO permeate. Around this time, the chloramine system was operating and the ORP in RO feed had spiked to values above

550 mV, denoting the presence of free chlorine in the RO feed line. While values above 550 mV shut down the RO system automatically, there is a chance that the membranes were exposed to free chlorine for a short period a time until the unit shuts down and flushes, as the ORP meter does not respond instantaneously to a spike in ORP.

RO flush sequence was modified on April 19, 2012, as high conductivity in the RO concentrate was measured at the end of the existing flushing sequence and it appeared that the flush water was preferentially going through ERD and bypassing the RO membrane system. In the new multi-step flush sequence, the ERD is flushed separately from the RO membranes.

Figure 4-18: Permeate Conductivity and Feed ORP– Phase 2: Hydranautics SWC-5



Another step up in permeate conductivity occurred in the beginning of June, 2012 when SBS dosing pump for UF filtrate was started (in manual mode) two minutes after the MC was performed, thus feed water with free chlorine was sent to RO system. Chloramines were off during this period.

On July 7, 2012, the MC for UF was performed manually, after the automatic MC aborted multiple times, with the SBS addition post MC also performed manually. Another ORP spike was observed in the RO feed, leading to further oxidation to the RO membranes and increased in permeate conductivity. Chloramines were also off during this period.

From July 30 to mid-August 2012, a series of events lead to ORP spikes in the RO feed water, resulting in additional increases in permeate conductivity. The spikes in ORP occurred in two distinctive situations: (1) post UF maintenance clean, when apparently not enough SBS solution has been dosed to neutralize the free chlorine used in the MC; (2) initiation of the chloramination system, when the injection point moved to the RO feed and appeared to deliver a slug of free chlorine to the RO membranes.

The overall increase in permeate conductivity due to oxidation events during the 13 months of operation with Hydranautics membranes resulted in a permeate conductivity increase from 300 μS/cm to over 500 μS/cm. Hydranautics membranes were replaced on August 29, 2012.

4.5.3 Phase 3 - Dow XHR/XLE Hybrid

On August 29, 2012, RO membranes in the 1st Pass RO were replaced with a hybrid arrangement of Dow membranes. The front two (2) elements were model SW30XHR-400i and the last five (5) elements were model SWOXLE-400i. The schedule of runs with these membranes is presented in Table 4-8. The purpose of this part of the study with Dow membranes was to collect data (feed pressure and water quality) for RO system operation at various setpoints to be used as guidance in an energy consumption model developed as part of a Water Research Foundation (WRF) project.

Table 4-8: Details of Runs with Dow XHR/XLE Hybrid

Run #	Run Name	Flux (gpd)	Recovery	Duration
1	Dow-Hyb1-Cond (conditioning)	9	50%	8 days
2	Dow-Hyb1-1	7	45%	24 hours
3	Dow-Hyb1-2	7	50%	24 hours
4	Dow-Hyb1-3	7	55%	24 hours
5	Dow-Hyb1-4	9	45%	24 hours
6	Dow-Hyb1-5	9	50%	24 hours
7	Dow-Hyb1-6	9	55%	24 hours
8	Dow-Hyb1-7	10	48%	24 hours
9	Dow-Hyb1-8	11	50%	24 hours
10	Dow-Hyb1-9	11	55%	24 hours
11	Dow-Hyb1-10 (repeat of run#2)	7	45%	24 hours
12	Dow-Hyb1-Demo (demonstration)	9	50%	5 weeks

Figure 4-19 presents the normalized permeability of the runs with Dow hybrid membranes and seawater temperature. In the first eight (8) days, membranes were conditioned at the historical setpoints of 9 gfd flux and 50% recovery at which the 1st Pass RO has run at up to this point. The demonstration period which lasted for 5 weeks (Run #12) was also run at the same historical setpoints. The normalized membrane permeability was stable for Runs 1, 6, and 12 (9 gfd and 50% recovery) and appears to vary with different setpoints for runs 2 to 5 and 7 to 11. However, it is believed that these variations were due to inability of the normalization equation to compensate for such a great variations in flux and recovery, as the permeability reverted to the initial value of about 0.025 gfd during the long term demonstration period.

The period from October 1, 2012 to October 29th, 2012 represents the last four weeks of the demonstration period constituting Run #12 (and last) with Dow hybrid membranes in Phase 3. The permeability was generally stable, with a small trend upward, most likely due to a decline in the seawater temperature of almost 5ºC. The permeability was very similar to the value predicted by the membrane projection software.

Figure 4-19: Permeability of Phase 3: Dow Hybrid XHR/XLE

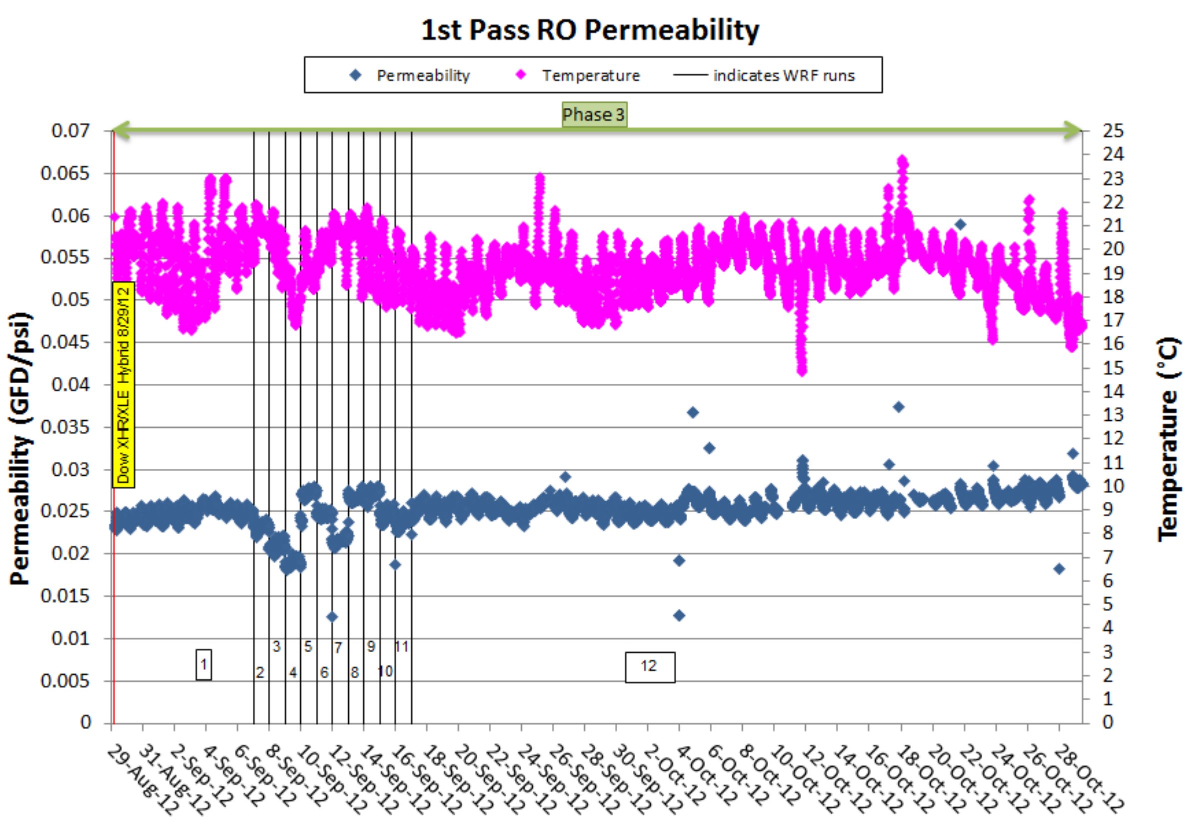
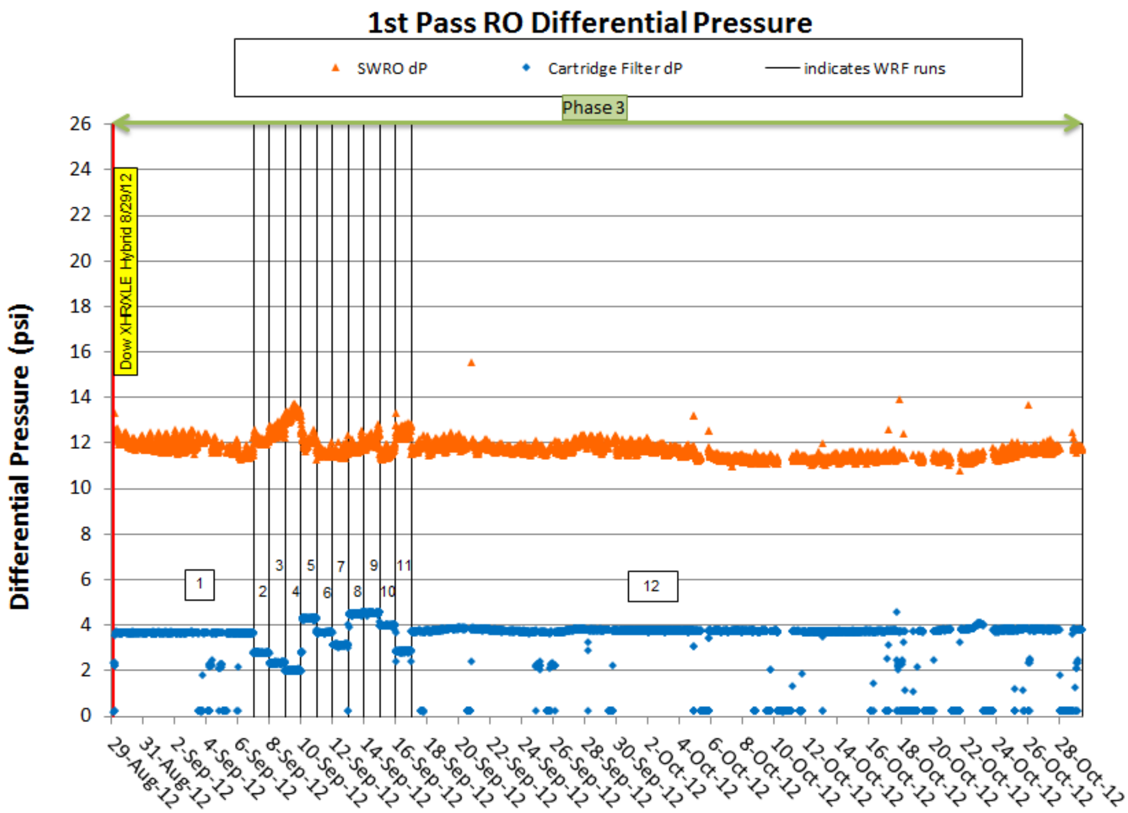


Figure 4-20 presents the differential pressure in the cartridge filters and across Dow membranes in Phase 3. Similar to the discussion for permeability, differential pressure was varying by only 1-2 psi for the runs with operating setpoints deviated far from the historical 9 gfd and 50% recovery. The variation in the differential pressure for the cartridge filters (which is not normalized) is explained by the different feed flows across the filters, which is the highest in Run #9 (85.6 gpm), followed by Run #8 (81.3 gpm), and Runs #5 and #10 (77.8 gpm): the higher the feedwater flow to the cartridge filters, the higher the differential pressure.

Figure 4-20: ΔP for Cartridge Filters and RO Membranes – Phase 3: Dow Hybrid XHR/XLE



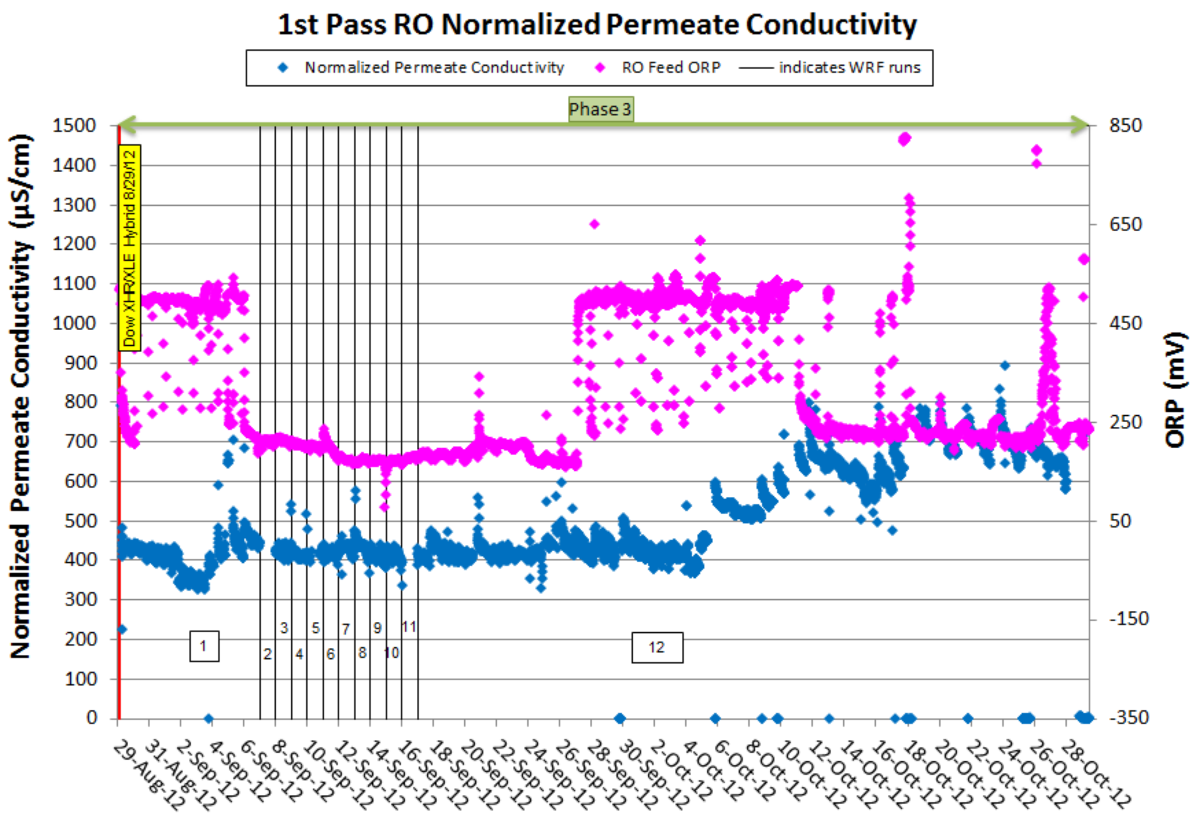
Permeate conductivity and ORP of the feedwater for Phase 3 are presented in Figure 4-21**.** The conductivity was between 425 to 450 µS/cm, except for a short period on September 2 to 4, 2012 when the permeate conductivity decreased to 350 µS/cm. Upon investigation of the conductivity decline during early September, it resulted that it was due to the conductivity meters which were re-calibrated in that period.

During October 6th to October 22nd, a series of overnight RO shutdowns caused by faultings of the UF drain pump resulted in an increase of the Dow membrane conductivity from ~400 µS/cm to ~750 µS/cm. Preformed chloramine dosing to the RO feed was in operation during this period, and with each overnight shutdown, the permeate conductivity was higher upon startup, suggesting that the membranes were becoming chemically oxidized with each shutdown. Upon detailed investigation, it was believed that the RO membrane flushing that occurs automatically after a shutdown (unless there is a power outage) was performed with chloraminated water due to problems in the SBS dosing system to the flush water, and likely bromo-chloramines were formed inside the feed-concentrate membrane channels. The bromo-chloramines are strong oxidants and could be formed in time (more than 4 hours) from reaction of chloramines in the flush water and bromide diffusing from the annular water present in the pressure vessels. The diffusion of the annular seawater/seawater concentrate from the annular area of the pressure vessels to the feed/concentrate channel of the membranes was demonstrated repeatedly by measuring the concentrate conductivity immediately after a shutdown (~1.4 mS/cm) and 14-18 hours later (~8 mS/cm).

From October 19, 2012 until the October 29, 2012 (end of Phase 3), investigations and troubleshooting took place to identify the cause of SBS dosing to the flush water not operating correctly. SBS dosing pumps were shown to draw down from the SBS solution tank; however, it appeared that no SBS was delivered to the flush water. Some re-piping was done (shortening the SBS dosing line by about 70 ft), the injection quill was replaced, and pressure sustaining valves were mounted. As of October 29, 2012 the SBS dosing system was successful in dechlorinating the RO permeate/city water, however there were still pending issues with the SBS duty/standby dosing pumps.

In light of the post shutdown oxidation scenario and lack of confidence in the robustness of the SBS dosing system to the flush water at the current time, it was decided to discontinue chloramination of the RO feed water, while the overall chloramination approach was reassessed. The valve supplying city water to the flush tank was closed since city water also contains chloramines. Historically, city water was used as a backup source for RO flushing water when not enough RO permeate was available. As these membranes were compromised, they were replaced on October 30, 2012 and testing proceeded to the next phase with membranes from NanoH_2O.

Figure 4-21: Permeate Conductivity and Feedwater ORP – Phase 3: Dow Hybrid XHR/XLE



4.5.4 Phase 4(a) and 4(b) – NanoH$_2$O SW400ES and SW400R/SW400ES Hybrid

RO Phase 4 commenced the operation of Group B membranes. Group B are high permeability membranes that operate at lower feed pressure relative to traditional membranes, but produce higher concentration permeate.

On October 30, 2013, Group B membranes from NanoH$_2$O were installed in the first pass RO. Operating conditions were varied during Phase 4 to generate data for the WRF research project.. Phase 4 was divided into two parts, Phase 4(a) and Phase 4(b):

- Phase 4(a): October 30, 2012 through November 13, 2012
  - Conventional arrangement: NanoH$_2$O Model SW400ES
  - Setpoints: 7 to 9 gfd, 45% to 55% recovery (Table 4-9)
- Phase 4(b): November 14, 2012 through January 17, 2013
  - Hybrid arrangement: 2 of NanoH2O Model SW400R and 5 of NanoH2O Model SW400ES
  - Setpoints: 7 to 9 gfd, 45 to 55 % recovery (Table 4-10)

Table 4-9: Run Setpoints and Actual Flows for Phase 4(a)

Run#	Run Name	Flux (gpd)	Recovery (%)	Feed Flow (gpm)	Average Feed/Concentrate Flow (gpm)
1	Nano-ES-Cond	9	50%	71.0	53.7
2	Nano-ES-1	7	40%	69.0	55.5
3	Nano-ES-2	7	45%	61.8	48.2
4	Nano-ES-3	9	45%	79.2	61.7
5	Nano-ES-4	11	50%	82.3	63.2
6	Nano-ES-5	9	55%	64.9	47.5
7	Nano-ES-6	11	55%	74.7	55.6
8	Nano-ES-7	12	51%	81.7	62.6

Table 4-10: Run Setpoints and Actual Flows for Phase 4(b)

Run#	Run Name	Flux (gpd)	Recovery (%)	Feed Flow (gpm)	Average Feed/Concentrate Flow (gpm)
9	Nano-Hyb-Cond	9	50 %	71.7	54.2
10	Nano-Hyb-1	7	40 %	69.0	55.5
11	Nano- Hyb -2	7	45 %	61.3	47.8
12	Nano- Hyb -3	7	50 %	55.3	41.8
13	Nano- Hyb -4	7	55 %	50.4	36.9
14	Nano- Hyb -5	9	45 %	79.7	62.1
15	Nano- Hyb -6	9	50 %	71.6	54.1
16	Nano- Hyb -7	9	55 %	65.2	47.7
17	Nano- Hyb -8	11	49 %	84.3	62.8
18	Nano- Hyb -9	11	50 %	85.1	63.7
19	Nano- Hyb -10	11	55 %	79.5	58.1
20	Nano- Hyb -11	11	50 %	83.8	62.4
21	Nano- Hyb -12	9	50 %	69.4	51.9

The preformed chloramine dosing system remained turned off for the duration of this phase.

Figure 4-22 presents the permeability of RO membranes in Phase 4 along with seawater temperature. Interestingly, the permeability of the hybrid configuration (Phase 4b) was slightly higher than the configuration using only high permeability membrane (Phase 4b), as seen comparing runs#1 and #9. This was opposite of our expectation from the membrane specifications.

The variability of the permeability values during the short-term runs is a function of the dramatically different operating conditions, not fouling or membrane damage.

This is confirmed, looking at the first and last runs (Run #9 and #21, respectively) in Phase 4(b) which were run at 9 gfd and 50% recovery and presented the same permeability of approximately 0.033 gfd/psi.

The preformed chloramine dosing system remained turned off for the duration of this phase.

Figure 4-22: Permeability of Phase 4 – NanoH$_2$O ES and R/ES Hybrid

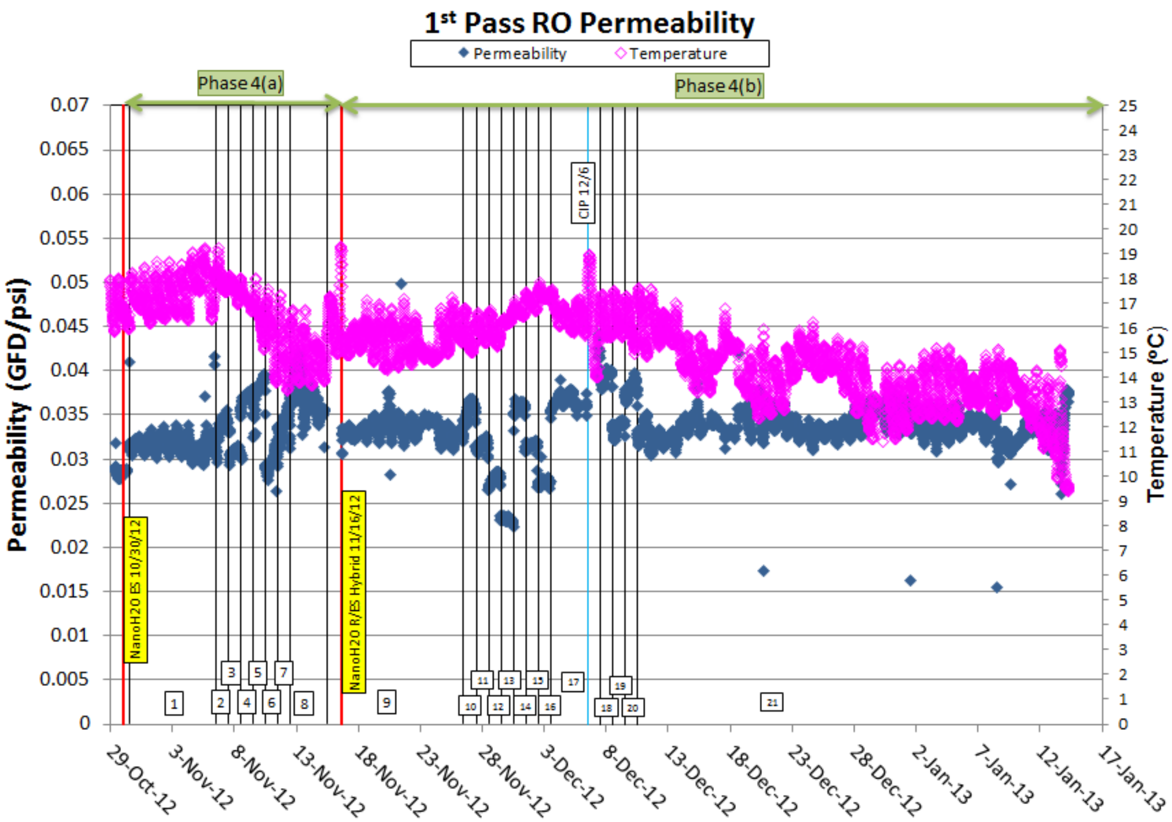
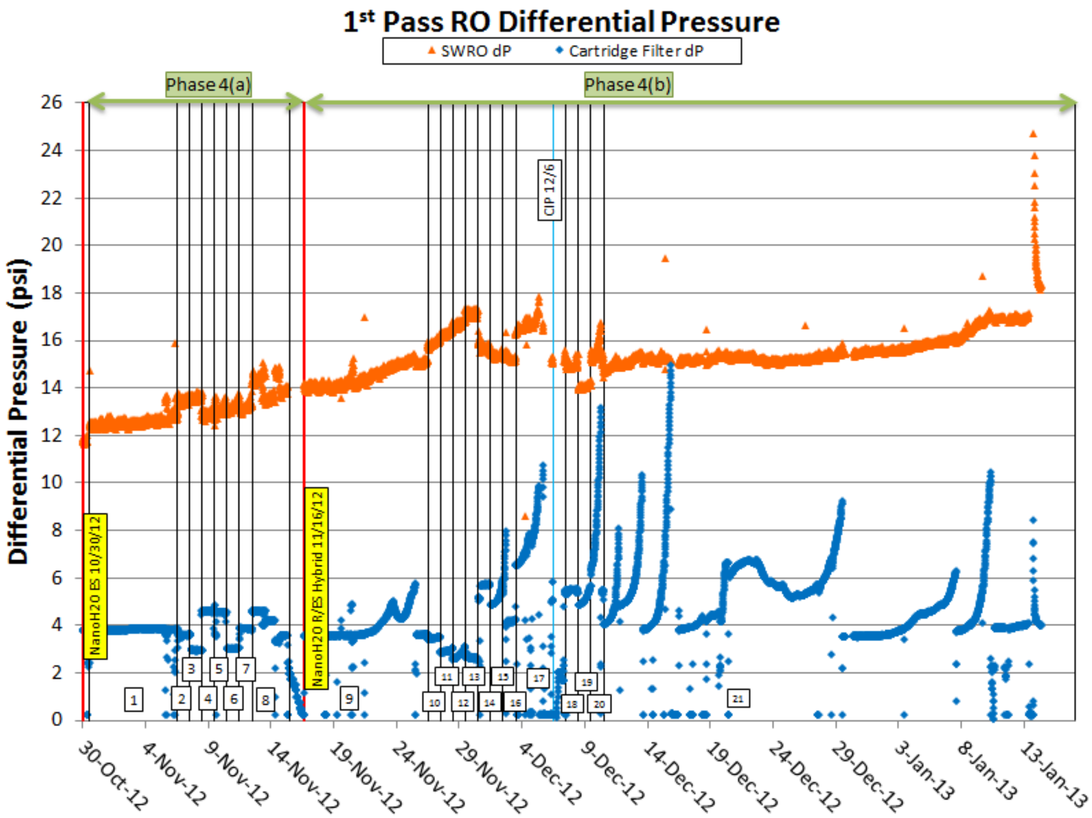


Figure 4-23 presents differential pressure across cartridge filters and RO membranes in Phase 4. The overall trend in phases 4a and 4b is a slight increase. Although some of the higher values in runs 10-20 are due to changes in operating conditions. A CIP was performed on December 12, 2012 using Avista P-111, under the same cleaning regime as previous cleanings. As observed during Run #17, an approximately 2 psi reduction in RO differential pressure was achieved with membrane cleaning. After the CIP, differential pressure remained stable for three weeks and then began a slow increase again (run 21).

CF differential pressure experienced several episodes of dramatic increase during Phase 4b, which was an indication of biofouling. Starting with November 22nd, 2012, fouling of cartridge filters occurred on numerous occasions, leading to frequent cartridge change out (November 25th, December 1st, 3rd, 7th, 10th, 11th, and 13th, 2012). Slime was observed inside the cartridge filter housing during change out. The cartridge filter housing and ancillary piping was sanitized on January 13th, 2013.

Figure 4-23: ΔP for Cartridge Filters and RO Membranes Phase 4 – NanoH$_2$O ES and R/ES Hybrid



Cartridge filters were replaced again on January 7, 2013 in response to a differential pressure increase, coincidental with a 1 psi differential pressure increase in the RO membranes. The spike and recovery in RO differential pressure, observed on January 13, 2013, appears to be an anomaly associated with RO feed pipeline cleaning activities (sanitization of pipes and cartridge filters housing between UF filtrate tank and RO membrane pressure vessels).

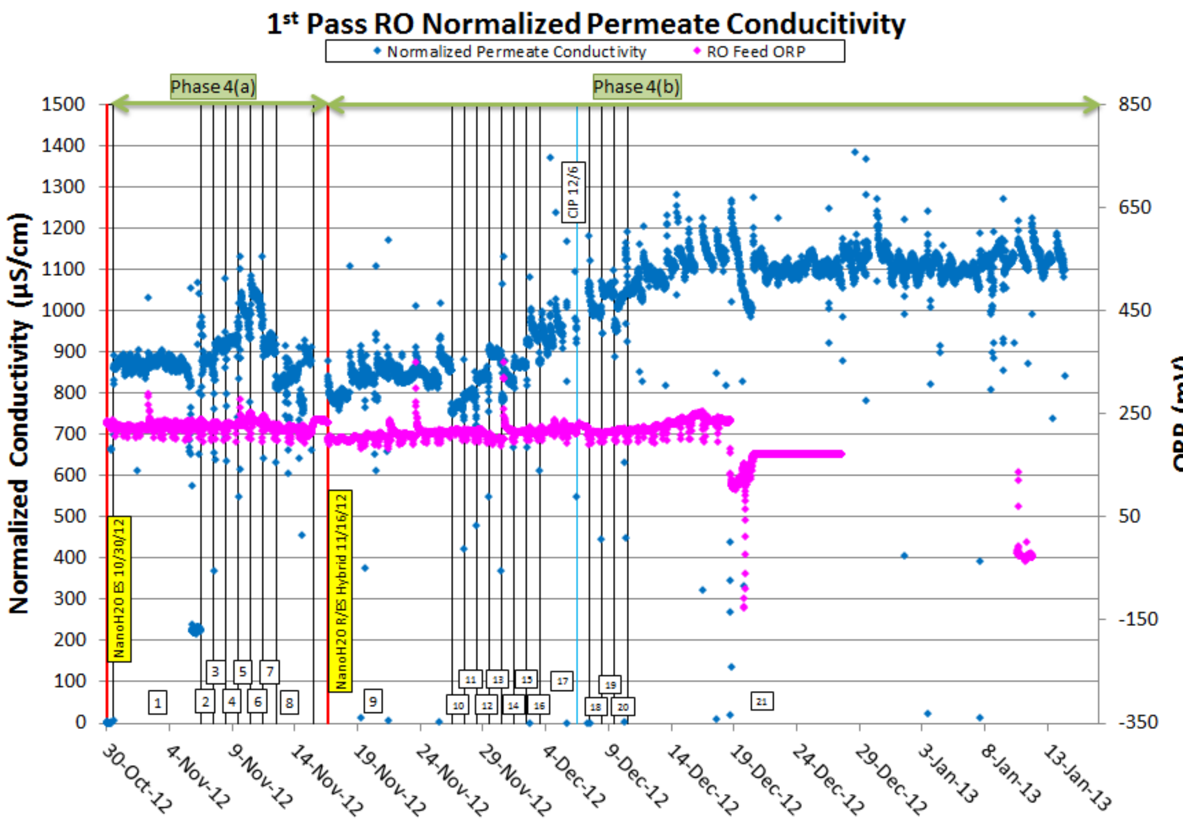
Figure 4-24 presents the first-pass RO normalized permeate conductivity along with ORP of the feed water for Phase 4 operation. A higher normalized permeate conductivity is expected for this grade of membrane (model NanoH$_2$O SW400ES), compared to the Phase 3 – Grade A membrane. However, comparing the performance with membrane projections and from discussion with NanoH$_2$O engineers, this conductivity was higher than expected by ~40%. Preformed Chloramines were not in use during Phase 4 operation.

Phase 4b runs 9 and 21 were at the same operating conditions (Table 4-9). Figure 4-24 indicates a significant increase in conductivity occurred between these runs and in the first days of run 21.

The majority of the increase happened in between Runs #16 and #20; however, it was difficult to pinpoint exactly when it took place, given that the operating setpoints varied during those runs, as indicated in Table 4-10.

A majority of the permeate conductivity increase appears to be due to the CIP event on December 6, 2012 as the runs immediately before and after (#17 and #18) were performed at identical operating setpoints and an increase in conductivity was evident. A slight increase also appears to have occurred at the beginning of run #21. Investigation of ORP measurement for the RO feed (1 min data) did not reveal presence of free chlorine at any time during those runs. Membranes were returned to NanoH$_2$O and Avista Technologies for analysis. The autopsy results indicated no evidence of oxidation. NanoH$_2$O membranes were replaced on January 18, 2013.

Figure 4-24: Permeate Conductivity and Feedwater ORP for Phase 4 – NanoH$_2$O ES and R/ES Hybrid



4.5.5 Phase 5(a) to 5(d) – DOW ULE and XLE/ULE Hybrid

Phase 5 commenced on January 18, 2013 with a new set of Dow membranes and was divided in four sub-phases, 5(a) to 5(d). Sub-phases 5(a) through 5(c) were part of a study conducted by MWH for a WateReuse Research Foundation project which compared the energy consumption of Dow membranes versus $NanoH_20$ membranes. Sub-phase 5(d) resumed operation at historical setpoints of 9 gfd flux and 50% recovery with a Dow hybrid XLE/ULE configuration.

- Phase 5(a): January 18, 2013 through January 27, 2013 (Table 4-7)
  - Dow, conventional arrangement: SW30ULE
  - Setpoints: 7 to 9 gfd, 45% to 55% recovery

Table 4-11. Run Setpoints for Phase 5(a)

Run#	Run Name	Flux (gpd)	Recovery (%)	Duration
1	Dow-ULE-Cond	9	45%	48 hours
2	Dow-ULE-1	7	40%	24 hours
3	Dow-ULE-2	7	45%	24 hours
4	Dow-ULE-3	7	50%	24 hours
5	Dow-ULE-4	7	55%	24 hours
6	Dow-ULE-5	9	50%	24 hours
7	Dow-ULE-6	9	55%	24 hours
8	Dow-ULE-7	11	50%	18 hours

- Phase 5(b): January 28, 2013 through February 6, 2013 (Table 4-12)
  - Dow, hybrid arrangement #2: 2 of SW30XLE and 5 of SW30ULE
  - Setpoints: 7 to 9 gfd, 45 to 55 % recovery

Table 4-12. Run Setpoints for Phase 5(b)

Run#	Run Name	Flux (gpd)	Recovery (%)	Duration
9	Dow-Hyb-Cond	9	45%	48 hours
10	Dow-Hyb -1	7	40%	24 hours
11	Dow-Hyb -2	7	45%	24 hours
12	Dow-Hyb -3	7	50%	24 hours
13	Dow-Hyb -4	7	55%	24 hours
14	Dow-Hyb -5	9	50%	24 hours
15	Dow-Hyb -6	9	55%	24 hours
16	Dow-Hyb -7	11	50%	18 hours

- Phase 5(c): February 19, 2013 through February 26, 2013
  - Dow, hybrid arrangement #2: 2 of SW30XLE and 5 of SW30ULE

- Setpoints: 7 to 9 gfd, 45 to 55 % recovery

The runs during this phase were repeats of runs # 9-13, 15 and 16 in Phase 5(b).

- Phase 5(d): February 27, 2013 to September 23, 2013
  - Dow, hybrid arrangement #2: 2 of SW30XLE and 5 of SW30ULE
  - Setpoints: 9 gfd, 50 % recovery

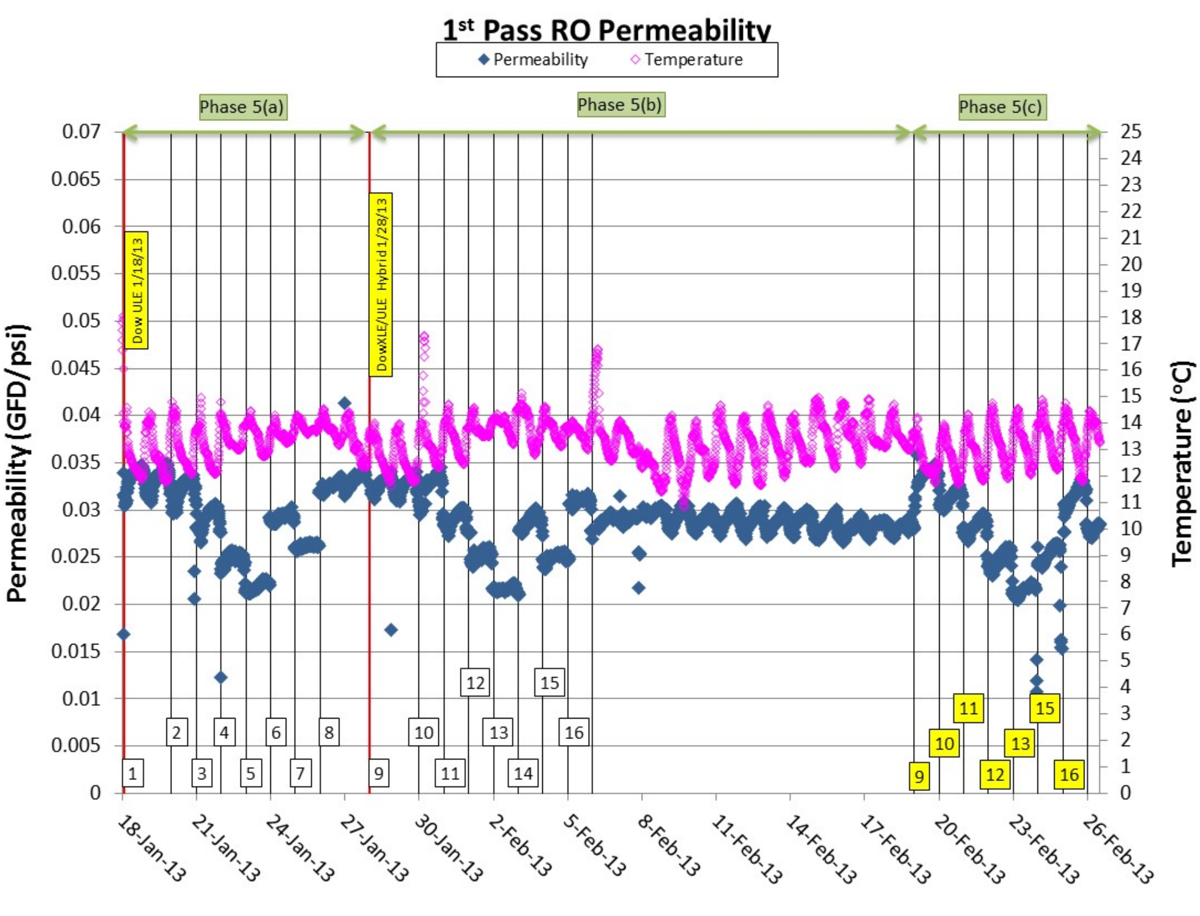
Permeability Analysis

Phase 5(a) – Dow ULE

Permeability of Dow ULE membranes (Figure 4-25) was similar to NanoH_2O R/ES Hybrid when operation at similar setpoints was considered (e.g. Run #21 with NanoH_2O R/ES Hybrid vs. Run #1 with Dow ULE). The step variations for various runs from #1 to #8 can be attributed to the inability of normalized equations to compensate for great variations in flux and recovery.

Phase 5(b) to 5(d) – Dow XLE/ULE Hybrid

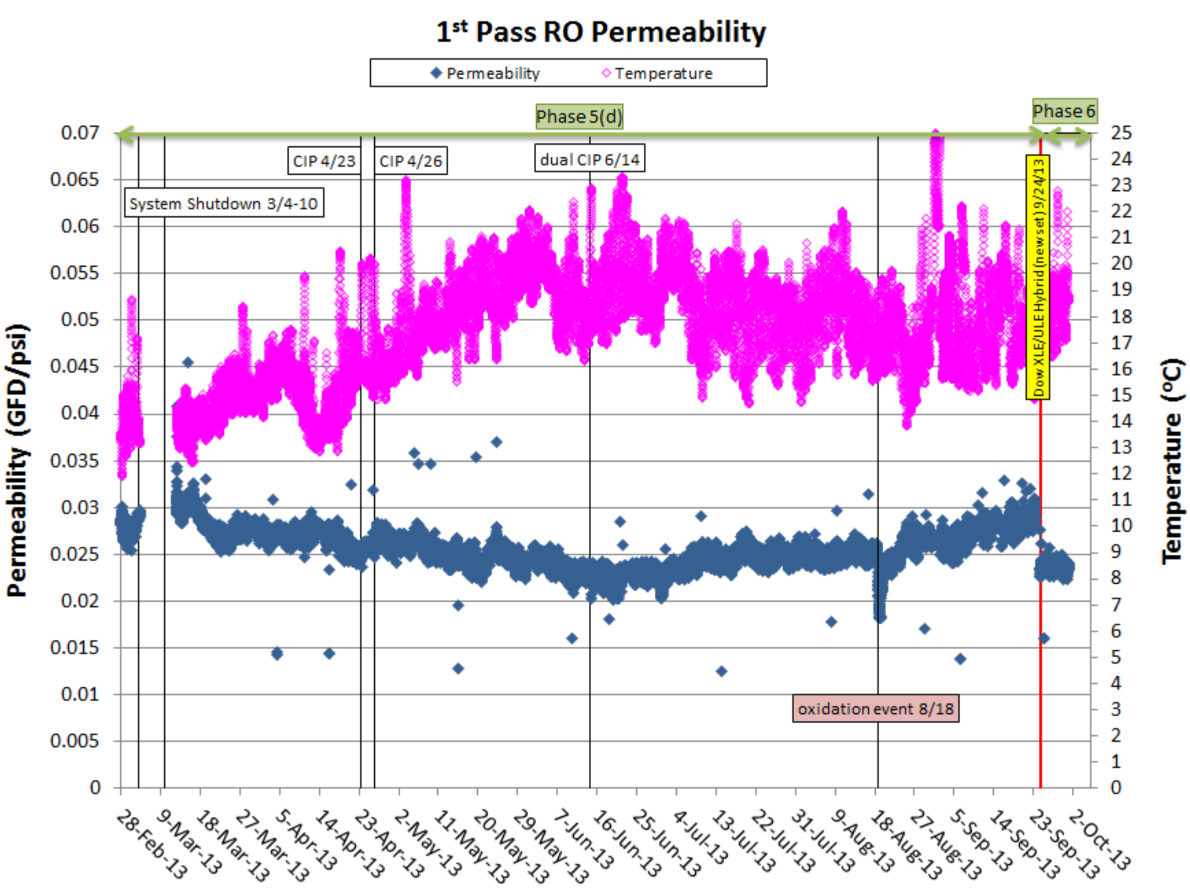
Figure 4-25: Permeability of Phase 5(a) to (c) – Dow ULE and XLE/ULE Hybrid



Permeability of the Dow XLE/ULE hybrid (referred as Dow Hybrid 2) was also similar to the NanoH$_2$O R/ES Hybrid and the Dow ULE membrane. Runs #9 to #13 and Runs #15 and #16 during Phase 5(c) were repeats of runs with the same conditions as during Phase 5(b). As observed from Figure 4-25, permeability replicated well for repeat runs in sub-phase 5(c).

During Phase 5(d) (Figure 4-26), the system was operated at historical setpoints of 9 gfd and 50% recovery. Permeability declined from March to July 2013, then remained stable until mid-August 2013 when an oxidation event occurred, compromising the membranes and resulting in a permeability increase. Despite the fact that the permeability values are normalized for temperature, it is believed that a majority of the decline in permeability observed from March 2013 to July 2013 can be attributed to changes in seawater temperature (seawater temperature increased by about 5^{O}C from March 2013 to July 2013).

Figure 4-26: Permeability of Phase 5(d) and 6– Dow XLE/ULE Hybrid



Differential Pressure Analysis

Phase 5(a) – Dow ULE

Differential pressure across Dow ULE membranes was approximately 12 psi when operating at historical settings of 9 gfd flux and 50% recovery (e.g. during run #1 and #9), which was similar to the starting differential pressure for NanoH$_2$O membranes. During operation with Dow ULE, differential pressure varied both in the cartridge filters and in the RO membranes in a step change, as a result of different recoveries the system operated at for Runs #1 through #8. During this period, there was no indication of RO membrane fouling.

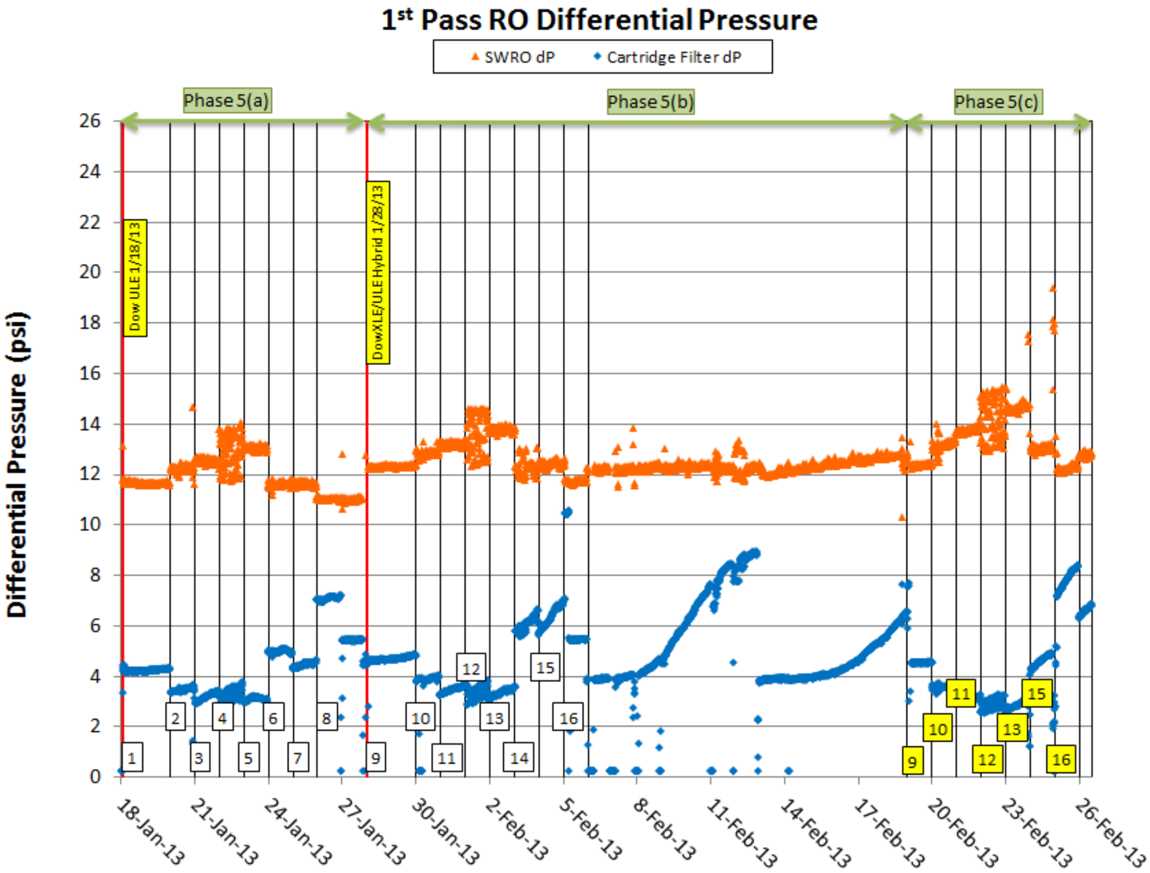
Phase 5(b) to 5(d) – Dow XLE/ULE Hybrid

Variations in cartridge filter differential pressure during this period were of two natures: a step variation due to different feed flows throughout the runs, and an exponential spike which was an indication of biofouling.

Exponential increases in cartridge filter differential pressure were observed on five occasions, and cartridge filters were replaced on February 5, 13, 27, and March 25, 2013. The RO membranes did not appear to accumulate significant fouling as the RO differential pressure remained between 12 to 14 psi. RO differential pressure was slightly higher during some of the runs due to the large variations in setpoints of operation.

During Phase 5(d), differential pressure escalated in the cartridge filters on several occasions, requiring frequent cartridge changeouts, even daily in June 2013. It is believed that there were two contributors to the frequent escalations in differential pressure: the main cause appears to be oxidized (particulate) iron. Ferric chloride was as coagulant in the UF filtrate during this period. Iron was present in trace amounts in the UF filtrate, likely due to some fiber breakage encountered in the UF membranes. Cartridge filters were tinted dark red at changeouts, which is indicative of oxidized iron deposition. A sample of cartridge filter was sent for analysis by SEM/EDXRF and results confirmed presence of iron (5% by weight vs. <0.5% for a clean sample). When the concentration of ferric chloride in UF influent was reduced from 4 mg/L to 2 mg/L in June 2013, frequency of cartridge filters changeout decreased from every 1.5 days to once a week and to once every two weeks when ferric chloride was reduced further to 1 mg/L in July 2013. It is possible that biofouling was also a contributor to the increase in differential pressure across cartridge filters.

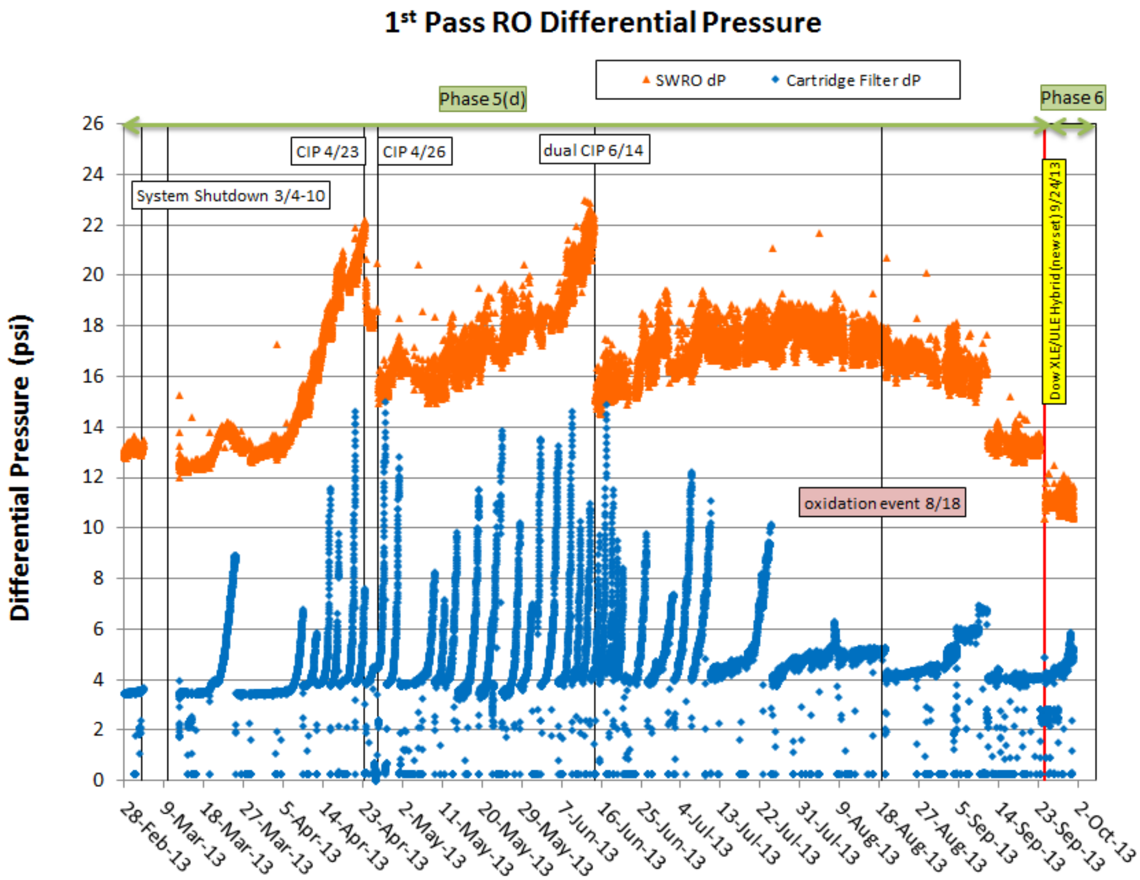
Figure 4-27: ΔP for Cartridge Filters and RO Membranes Phase 5(a) to (c) – Dow ULE and XLE/ULE Hybrid



In the RO system, there were two noteworthy spikes in differential pressure, one at the end of April 2013 and one mid-June 2013 (Figure 4-28), when differential pressure reached 22 psi (from a baseline of 12-13 psi). During these events, the feed water quality was poor as shown by high turbidity in the UF feed and filtrate (Figure 4-12) as well as higher levels of Chlorophyll-a in the intake water, suggesting possible red tide events occurring during this time. Two CIPs were performed on April 23, 2013 and April 26, 2013 with Avista P-111 (as before), which resulted in a reduction in differential pressure from 22 psi to 16 psi. Avista P-111 targets removal of silt and organic foulants such as colloidal silica, clays, organic color and bacterial slime, but not iron deposits. This suggest the fouling of RO membranes in late April 2013 was mainly biological in nature. Chloramines were not operating during this time (restarted August 2013).

The CIP performed on June 14, 2013 used dual solutions; Avista P-111 was used to target organics and the second was a low pH solution (~3) made of 2% citric acid and ammonium hydroxide. The low pH cleaning solution targeted iron deposits. After this CIP, differential pressure was reduced again from 22 psi to 16 psi.

Figure 4-28: ΔP for Cartridge Filters and RO Membranes Phase 5(d) and 6 – Dow XLE/ULE Hybrid



After an oxidation event which occurred on August 18, 2013, membranes were compromised and differential pressure decreased to approximately 13 psi.

Permeate Conductivity Analysis

Phase 5(a) – Dow ULE

The normalized RO permeate conductivity for Dow ULE membranes was approximately 800 µS/cm when runs were performed at historic setpoints of 9 gfd flux and 50% recovery (Run #1). Such values were very similar with the permeate conductivity for NanoH_2O ES and NanoH2O R/ES hybrid membrane sets when performance is compared across similar operation setpoints. During Runs #2 through #8, conductivity varied between 750 µS/cm and 940 µS/cm, most likely due to large variations in flux and recovery for these runs.

Phase 5(b) to 5(d) – Dow XLE/ULE Hybrid

The normalized RO permeate conductivity for Dow XLE/ULE Hybrid (Dow Hybrid 2) membranes was approximately 850 µS/cm when runs were performed at historic setpoints of 9 gfd flux and 50% recovery (Run #9). The values varied from 700 µS/cm to approximately 900 µS/cm for Runs #9 through #16, most likely due to large variations in flux and recovery for these runs (not adequately compensated by normalization equations, as discussed previously).

Figure 4-29: Permeate Conductivity and Feedwater ORP for Phase 5(a) to (c) – Dow ULE and XLE/ULE Hybrid

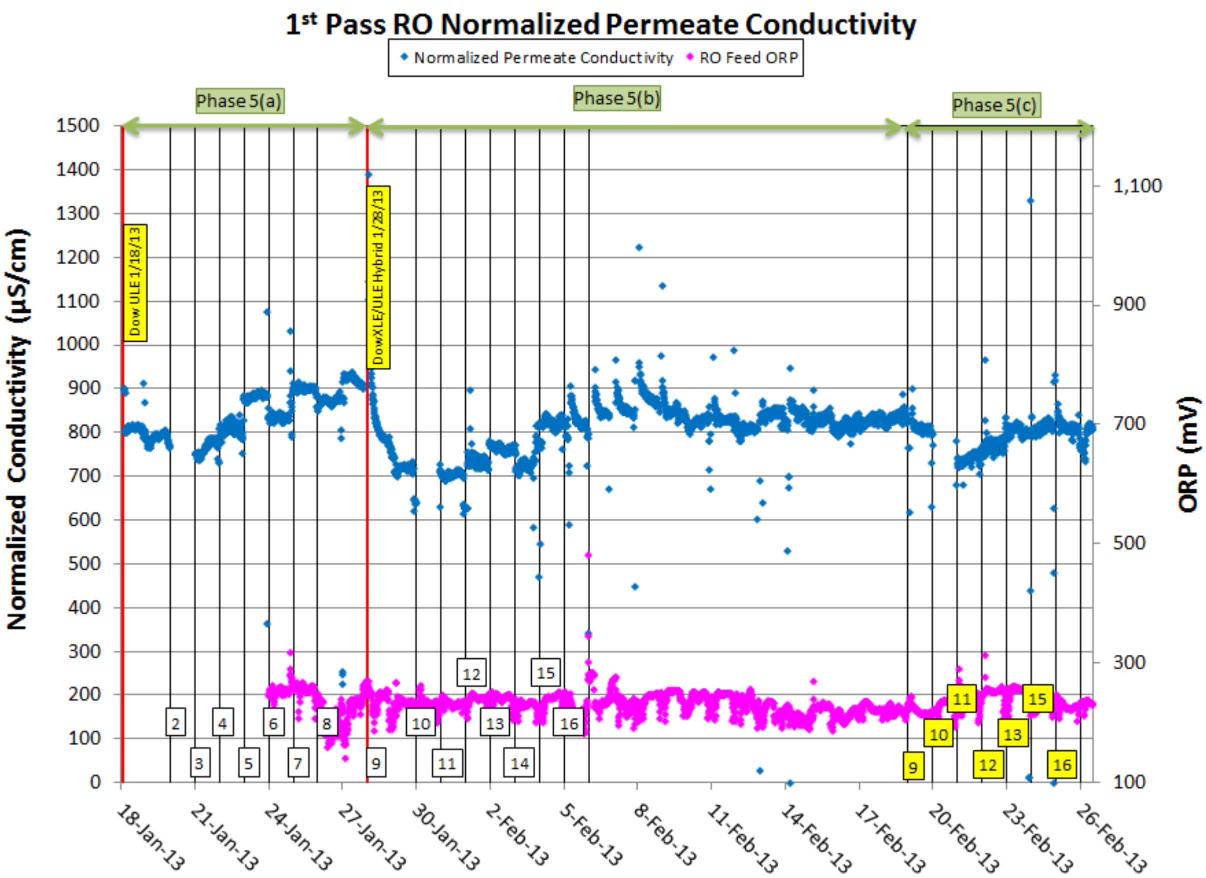
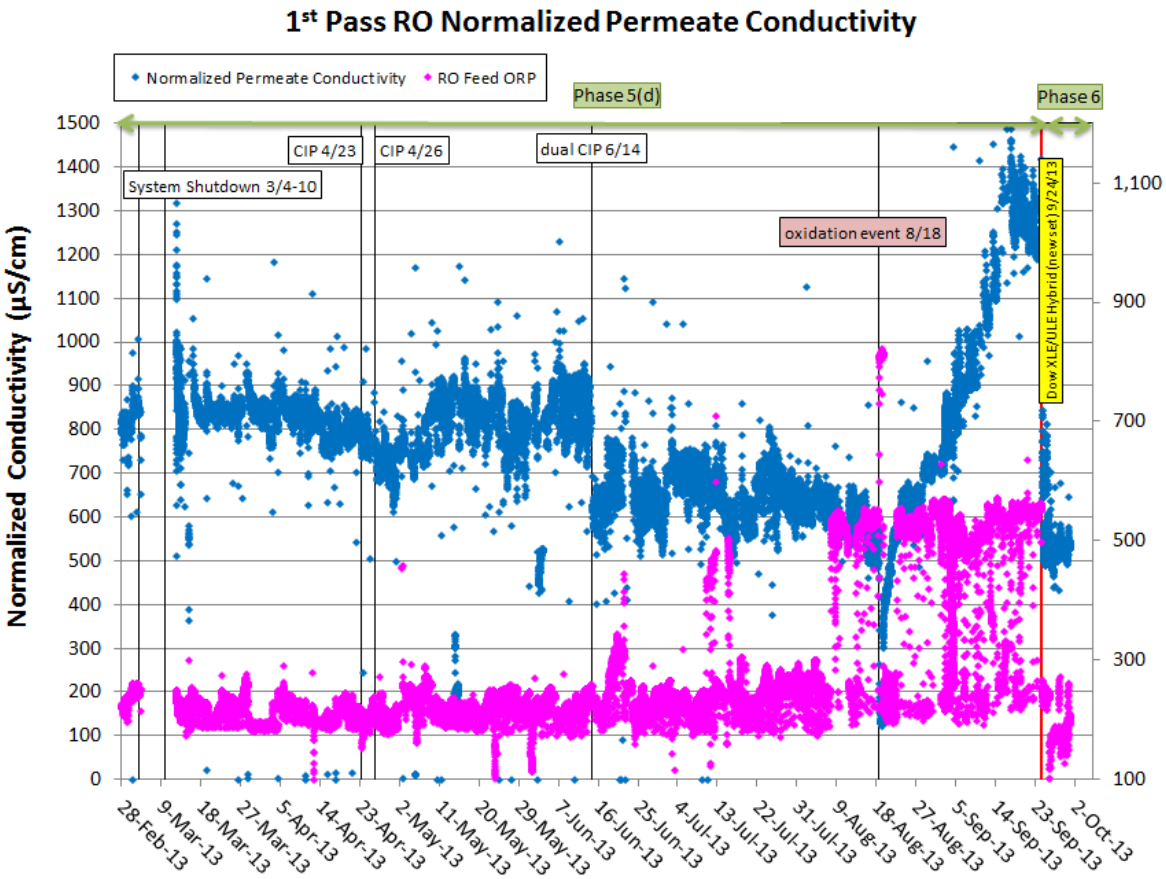


Figure 4-30 presents the normalized conductivity of the permeate for Phase 5(d). The spike in RO permeate conductivity observed on March 12, 2013 was related to the system startup after the general shutdown period for intake pipeline cleanup and modifications. From system restart in March 2013 to the second CIP on June 14 2013, conductivity was fairly constant, varying between 800 µS/cm and 900 µS/cm. Following the CIP on June 14, 2013, conductivity stepped down significantly and varied between 600 µS/cm to 700 µS/cm until the oxidation event in August 2013. Such behavior after a CIP event is atypical for RO membranes, which normally observe a slight increase in permeate conductivity (decrease of rejection). Other parameters did not vary significantly in this period (permeability, differential pressure).

An oxidation event occurred on August 18, 2013 when the chloramine system was restarted (August 16, 2013) and the ammonia pump was air locked, thus free chlorine was dosed to the RO feed. The ORP meter located on the RO feed had been inadvertently taken off-line at the time. The initial response of the membrane was that the rejection actually improved for a short period of time after which permeate conductivity increased to 1,300 µS/cm .

Figure 4-30: Permeate Conductivity and Feedwater ORP for Phase 5(d) and 6 – Dow XLE/ULE Hybrid



4.5.6 Phase 6 – Second set of Dow XLE/ULE Hybrid

A second set of Dow XLE/ULE hybrid was installed on September 24, 2013. There were some issues at startup, the system experienced high conductivity in the permeate which in turn, required a high feed pressure in the second pass RO, causing repeated shutdowns. It appeared that the iLEC interlocking mechanism was dis-engaged between some elements in the 1st Pass RO. Pressure vessels were opened and membrane elements re-loaded which fixed the issue.

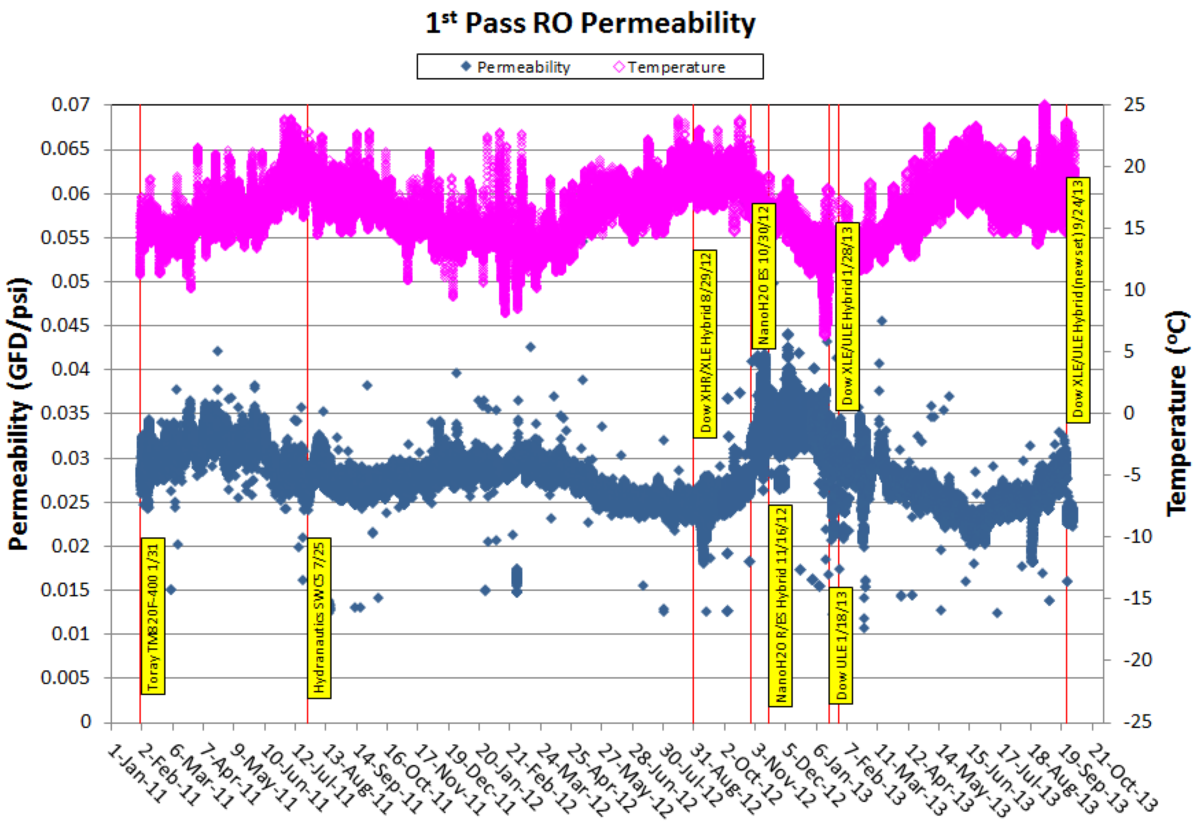
Although the period of operation with this new set of membranes was limited due to the end of the project, it appeared that permeability and differential pressure were similar to previous set of Dow membranes (~0.025 gfd/psi and 11-12 psi, respectively), see Figure 4-26 and Figure 4-28. The normalized conductivity of the permeate was approximately 550 µS/cm, similar to values observed after CIP cleaning on June 14, 2013 for the previous set of Dow membranes, but lower than the startup permeate conductivity with the previous set. A longer period of operation would have been necessary for a full comparison of this membrane set with the previous analyzed in Phase 5 (b) to (d).

4.5.7 Overall Membrane Performance for 1st Pass RO

To summarize performance of the 1st Pass RO:

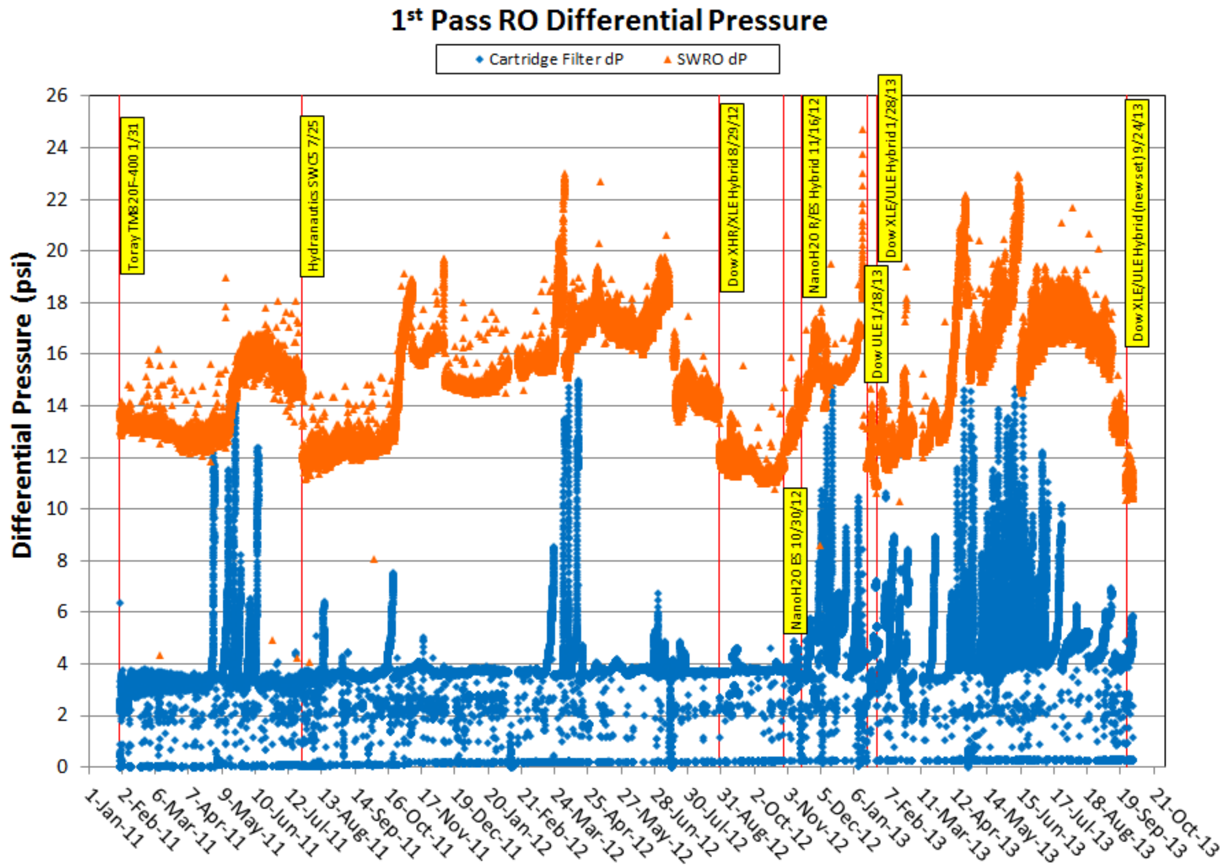
- Seven (7) different membrane sets from four (4) different manufacturers were tested; They can be classified in two general categories:
    - Grade A: Higher salt rejection/lower permeability:
        - Toray TM820F, Hydranutics SWC-5, and Dow SW30XHR/XLE hybrid (2+5)
    - Grade B: Lower salt rejection/higher permeability:
        - NanoH_2O SW400ES, NanoH_2O SW400R/ES hybrid (2+5), Dow SW30ULE, and Dow SW30XLE/ULE hybrid (2+5)
- Feed pressure varied between 790 psi (NanoH_2O ES) and 900 psi (Dow XLE/ULE hybrid); the startup feed pressures were very similar to the estimated values based on manufacturer's projections, except for the second set of Dow XLE/ULE.
- When compared at similar operating setpoints (9 gfd and 50% recovery), feedwater temperature and membrane age, permeability was highest for Grade A membranes: NanoH_2O ES and R/ES hybrid configuration (0.032 – 0.035 gfd/psi), followed by the group of Toray TMG820F, Dow ULE, and Dow XLE/ULE hybrid, with similar permeabilities (0.03 gfd/psi). The lowest permeability was observed from Grade B membranes: Hydranutics SWC-5 and Dow XHR/XLE hybrid (0.025-0.027 gfd/psi) (see Figure 4-31). This was expected based on the membranes data sheets provided by manufacturers, as well as from the membrane projections run for each membrane set.

Figure 4-31: Permeability of all RO Membranes 1st Pass



- Figure 4-32shows the differential pressure across all membranes used in this study. When comparing the startup periods, all membrane sets presented similar values (12-13 psi) (Figure 4-32);

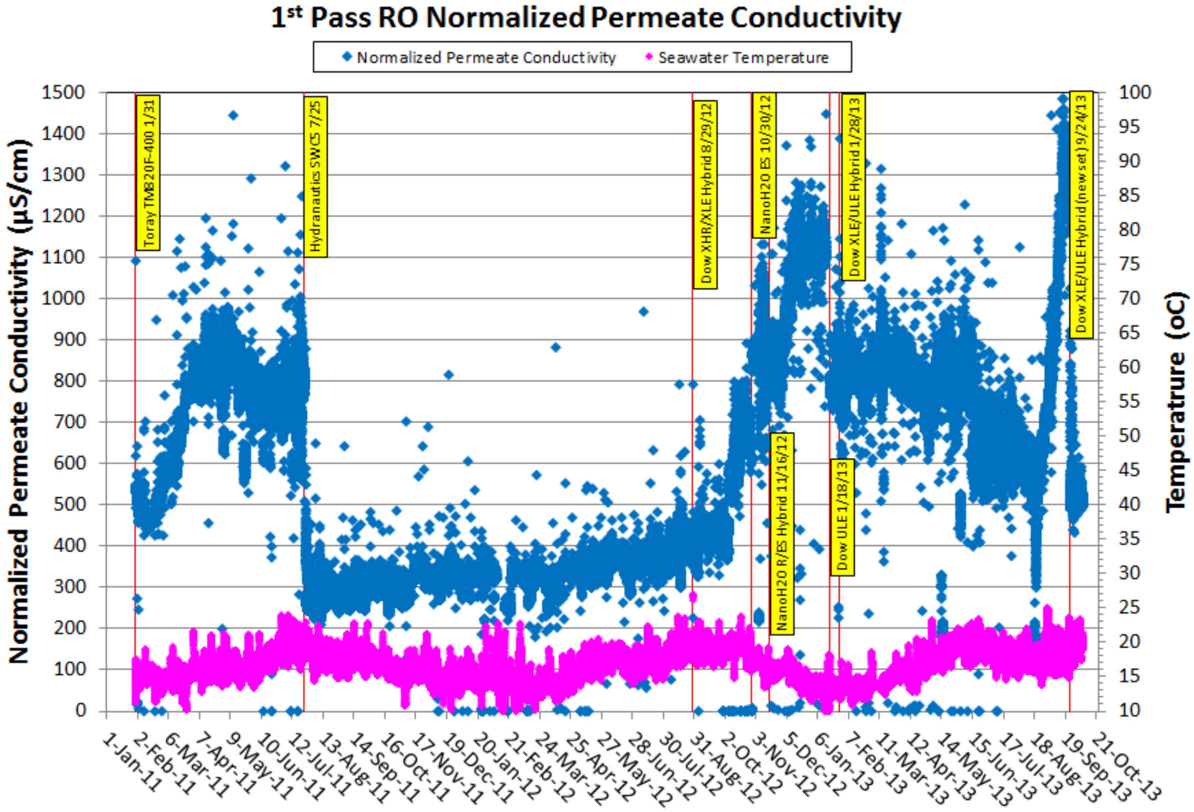
Figure 4-32: Differential Pressure for Cartridge Filters and RO Membranes 1st Pass



- Figure 4-33 presents the permeate conductivity for the three membrane sets used in the study. The normalized permeate conductivity was lowest for Hydranautics SWC-5 and Dow XHR/XLE (300-400 µS/cm), followed by Toray TM820F and second set of Dow XLE/ULE hybrid (500 µS/cm). The highest permeate conductivity was observed for NanoH$_2$O membranes and Dow ULE (800 µS/cm). This is generally inline with what was anticipated for the membranes respective class; however, it was observed that for NanoH$_2$O membranes (both ES and R/ES hybrid) as well as for Dow ULE and XLE/ULE hybrid set 1, the conductivity of the permeate was significantly higher than projected;

- Details of permeate water quality are presented in Section 5;

Figure 4-33: Permeate Conductivity and feed ORP for all RO Membranes 1st Pass



- From an operational standpoint, the Dow iLEC system for membrane inter-coupling was found challenging during membrane loading in the pressure vessels; special handling tools were required and membranes could easily unlock during loading; all Dow seawater membranes were equipped with this type on interconnectors.

- Several chemical oxidation events resulted in membrane sets being compromised; oxidation events were in three distinctive circumstances:

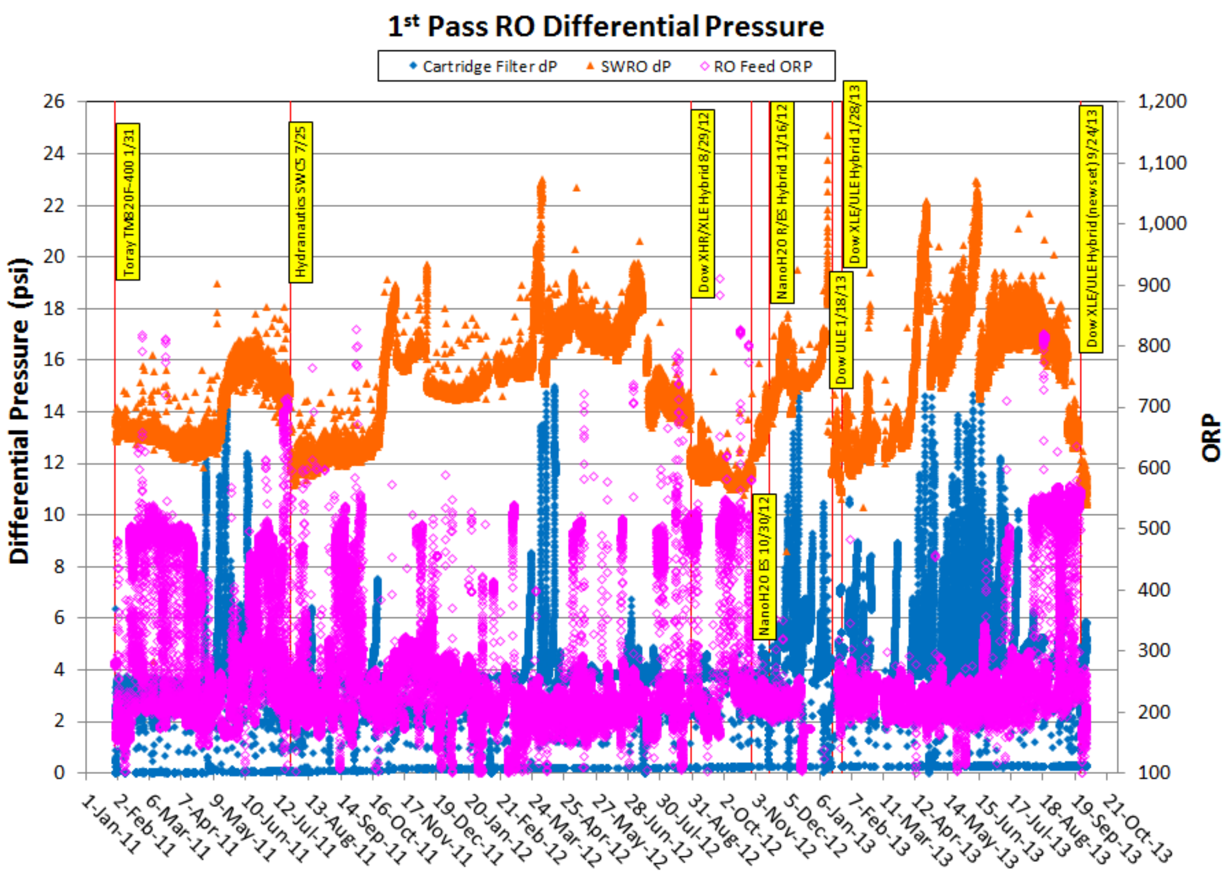
  - Direct exposure to free chlorine carried over in the UF filtrate following a maintenance clean when the SBS pump were in manual mode and remained off;

  - Direct exposure to free chlorine when chloramines were dosed to the RO feed and the ammonia metering pump faltered; the ORP meter did not appear to offer sufficient protection to the RO system at the selected alarm setpoint;

- Likely exposure to strong oxidants such as bromo-chloramines formed when the RO system was shut down for periods longer than 2-3 hours and flushing water contained chloramines; it is believed that bromo-chloramines were formed by the reaction of chloramines in the flush water with bromides diffusing from the annular space of the pressure vessels into the feed/concentrate channel of membrane elements.

- The chloramine system operated for approximately 17% of the study; during those times, it appeared that the increase in the differential pressure across RO membrane elements as well as in the cartridge filters was reduced relative to periods when chloramines were not being dosed (Figure 4-34, ORP values above 500 mV denote chloramine presence). A detailed discussion on chloramines is presented in Section 4.7.

Figure 4-34: Differential Pressure across RO membranes and cartridge filters together with feed water ORP



- A total of eight (8) CIPs were performed to the 1st Pass RO. Cleanings were performed initially with Avista P-112 then switched to Avista P-111, which appeared more efficient in achieving a reduction loss in differential pressure caused by biogrowth. In two instances, repeated CIPs needed to be performed in order to reduce the differential pressure. One dual CIP was performed with both Avista P-111 and 2% citric acid topped with ammonium hydroxide, as fouling with traces of precipitated iron from UF filtrate was a possibility. This particular CIP regime was found effective. Since many new membrane sets were tested with and without chloramines during the 32 months of study, an average frequency of CIPs is not relevant. General membrane fouling (loss of permeability) was minimal during the study. The most significant fouling observed was increase in differential pressure due to biogrowth.

4.5.8 Performance of Energy Recovery Device

The first pass RO system was equipped with a PX energy recovery device (ERD) provided by ERI™. The efficiency of energy recovery device (ERD) used in this study was evaluated using the equation below provided by ERI™:

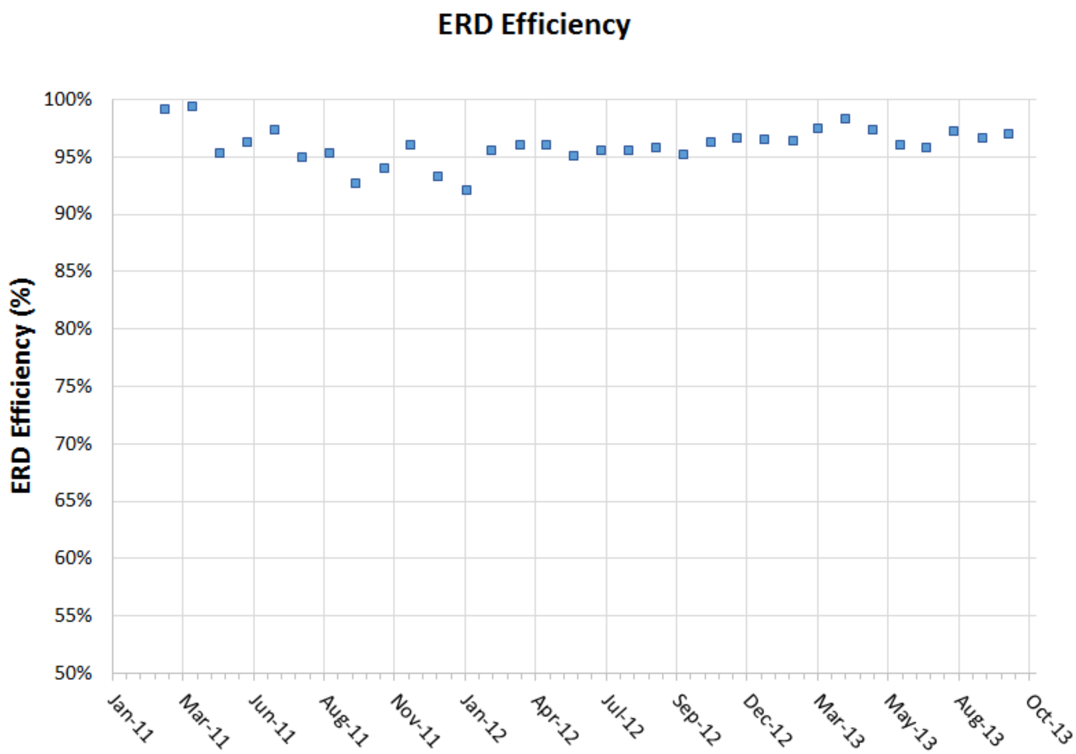
$$\eta = \frac{(\text{Flow x Pressure})_{\text{high pressure OUT}} + (\text{Flow x Pressure})_{\text{low pressure OUT}}}{(\text{Flow x Pressure})_{\text{high pressure IN}} + (\text{Flow x Pressure})_{\text{low pressure IN}}}$$

Figure 4-35 presents the monthly averages of the efficiency. As anticipated, the efficiency was high (mainly above 95%), with small variations around the average value, likely due to the following reasons:

- First pass RO was operated at different recoveries during the WRF and MWH studies (thus different flow balance across ERD)
- Fluctuations due to data collection method: most of data was collected online by the data logger every 15 minutes, but some data was manually collected at a frequency of once per day.

An operational challenge occurred when some debris from the RO pressure vessels entered the device and prevented it from spinning. The debris were pieces of plastic from a broken thrust cone used in the pressure vessels, which likely was subject to water hammer upon system startup with a new membrane set. The ERD was dismantled, the debris was removed and the device was returned to service.

Figure 4-35: Efficiency of Energy Recovery Device



4.6 Second Pass Reverse Osmosis System

Three second-pass RO membrane sets were used from January 2011 to September 30, 2013: Toray TMG10 and Dow BW30-4040. The discussion on membrane performance will be divided per membrane set, as follows:

- **Phase 1**: from January 2011 to August 28, 2012
  - Toray model TMG10
  - Operating Setpoints: 16 to 18 gfd and 90% recovery, feed pH of 10.2
- **Phase 2**: from August 29, 2012 to September 23, 2013
  - Dow model BW30-4040
  - Operating Setpoint: 15.8 to 21 gfd and 90% recovery, feed pH of 10.2
- **Phase 3**: from September 24, 2013 to end of study
  - Second Dow model BW30-4040
  - Operating Setpoint: 18 gfd and 90% recovery, feed pH of 10.2

4.6.1 Phase 1: Toray TMG10

Figure 4-36 shows the permeability of the second-pass RO for Toray membranes. The permeability increased from February 2011 to mid-April 2011, after which it remained stable until July 24, 2011. A step up in permeability occurred on July 25, 2011 when Toray membranes in the first-pass were replaced with Hydranautics membranes. This is explained by the decrease in feed water conductivity to the second-pass RO (Hydranautics membrane had a higher rejection) which was apparently not fully compensated for in the permeability calculations (Figure 4-38).

Figure 4-36: Permeability for 2nd Pass RO: Phase I – Toray TMG10

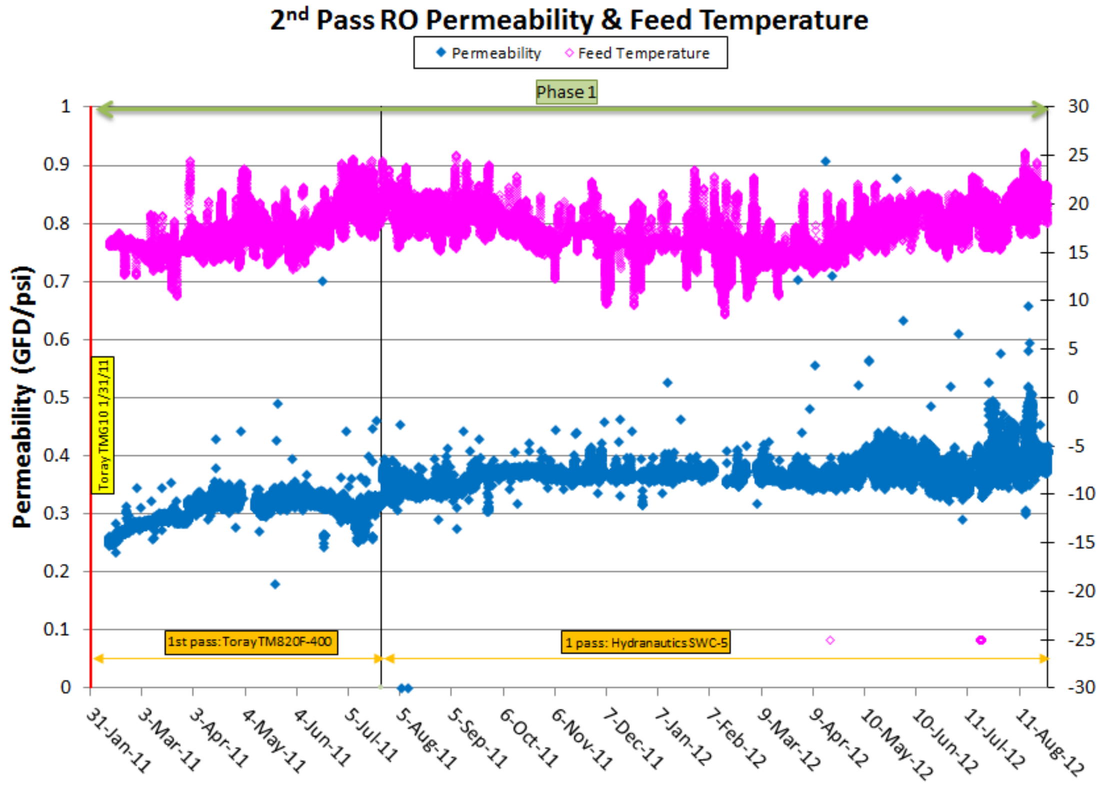


Figure 4-37: Feed Conductivity and Pressure for 2nd Pass RO: Phase I – Toray TMG10

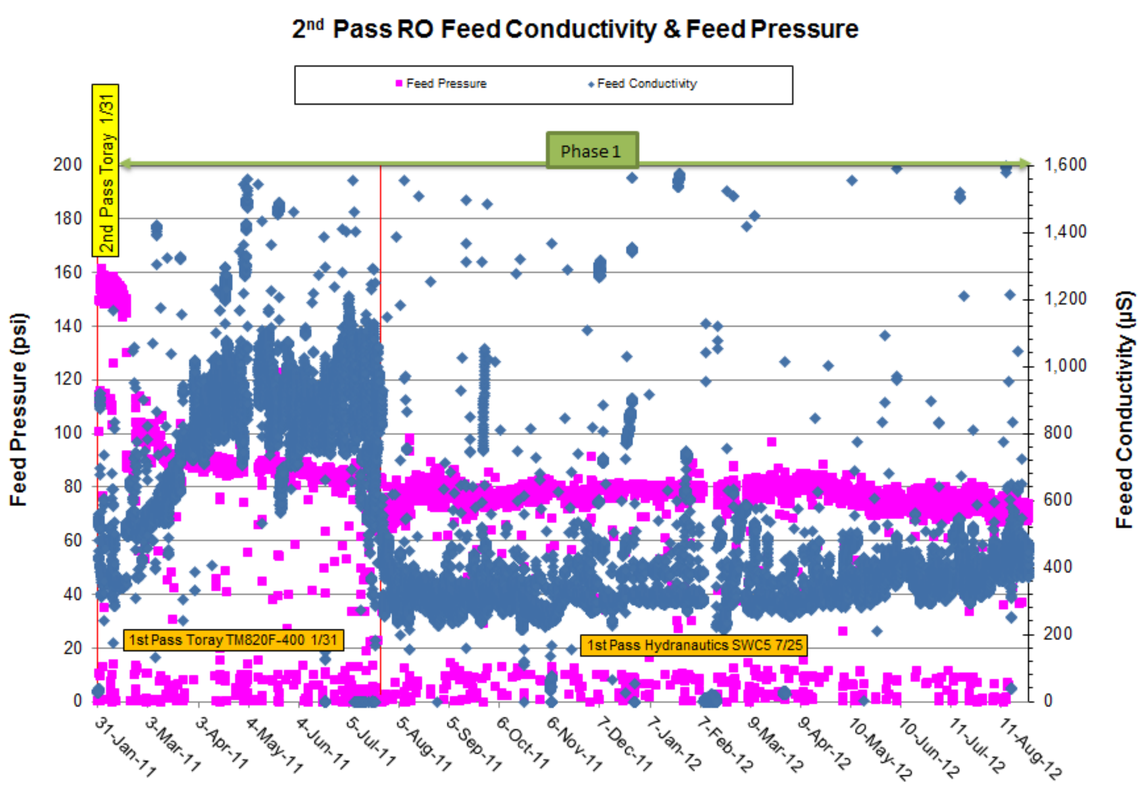


Figure 4-38 presents the differential pressure across the membranes in the second-pass. Toray membranes' differential pressure was stable at around 27 psi when the feed flow was 20 gpm and increased to about 30 psi with the increase in feed flow to 22 gpm. No cleaning was performed for this membrane set.

Figure 4-38: Differential Pressure and Feed Flow for 2nd Pass RO: Phase 1 – Toray TMG10

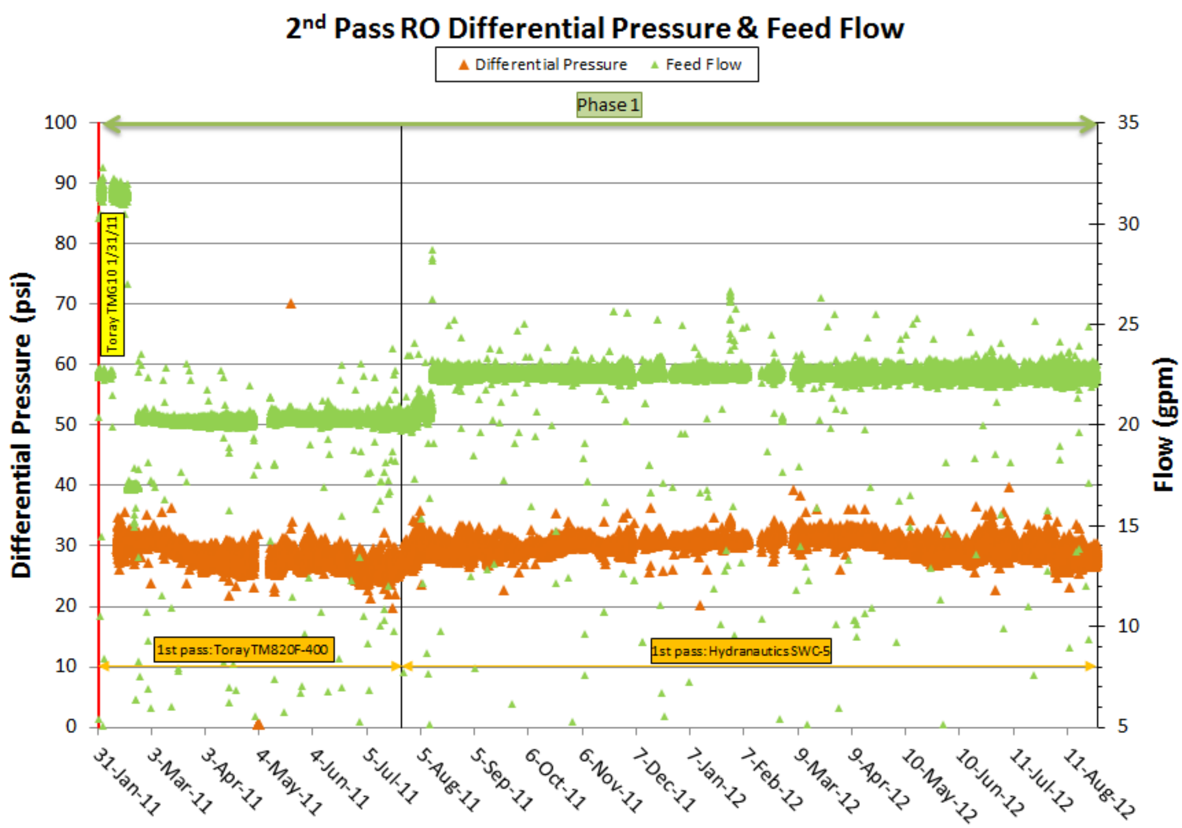
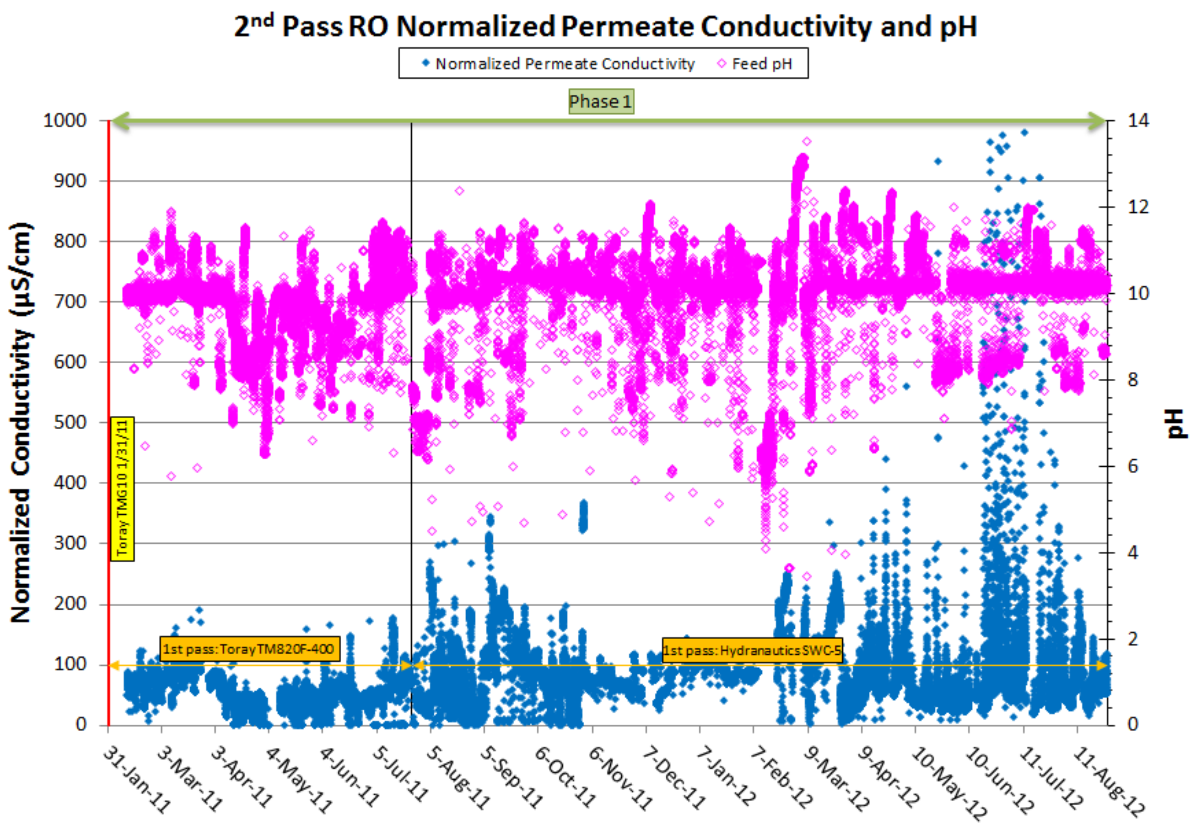


Figure 4-39 shows the permeate conductivity and feed pH. The increasing trend in normalized permeate conductivity for the Toray membrane in the first month after commissioning is either due to the increasing SWRO permeate conductivity (despite normalization), which is the feed water to the second-pass RO, or to potential oxidation of the membranes in the second-pass, coincidental with the oxidation of membranes in the first-pass (occurred from beginning of March 2011, as shown in Figure 4-37). Fluctuations of the permeate conductivity values was a chronic issue. The permeate conductivity probe was frequently cleaned and calibrated; however, it is believed that it malfunctioned due to entrained air. Readings with the Myron L handheld meter from April to November 2011 showed a relatively stable trend, with permeate conductivity values around 100 µS/cm. When membranes in the 1st pass were replaced with Hydranautics SWC-5 on July 25, 2011, they provided a much lower feed conductivity to the second-pass (down to 300 µS/cm); however, the conductivity in the second-pass permeate remained elevated after July 25, 2011. This suggests that the second-pass Toray membranes were exposed to oxidant in March 2011 along with the membranes in the 1st pass.

Figure 4-39: Permeate Conductivity and Feed pH for 2nd Pass RO: Phase 1 – Toray TMG10



The online conductivity probe was replaced on March 2012 and relocated to a different position on the permeate pipeline (July 17, 2012); however, the large fluctuation in the readings continued. Toray membranes' TMG10 was replaced with the DOW BW30-4040 on August 29, 2012.

4.6.2 Phase 2 and 3: Dow BW30-4040

The first set of Dow BW30-4040 membranes was installed on August 29, 2012 (Phase 2) and a second set installed towards the end of the project, on September 24, 2013 (Phase 3). Permeability of Dow membranes was significantly lower than for Toray membranes (approximately half) (Figure 4-40). These membranes are high rejection – low productivity, and as such, they operated at a higher feed pressure than the Toray membranes.

The recovery of the 2nd Pass RO was maintained at 90%; however, the flux varied as follows below:

1. From January 1 to 13, 2013:
   - 16 gfd (historical setpoint)

2. From February 13 to 18, 2013:
    - 20.2 gfd, 22 gfd and 23.7 gfd. The system run at each of these fluxes for 48 hours as part of WRF Energy Model study.
3. From February 18, 2013 to end of Phase 2 (September 23, 2013):
    - 20.2 gfd to 23.7 gfd attempting to narrow the variation of feed pH band which appeared to be sensitive with the feed flow. Starting with March 13th, 2013, the operating flux was established at 22.4 gfd (28 gpm permeate flow).
4. From September 24, 2013 to end of project (Phase 3):
    - 20 gfd (25 gpm permeate flow)

Figure 4-40 presents the permeability of second-pass RO membranes together with the second-pass feed water temperature for Phases 2 and 3. For Phase 2, permeability was very steady during most of the period, (~0.16 gfd/psi). Starting with July 24, 2013, a drop in permeability and differential pressure was observed. It was believed that calcium carbonate scaling occurred in the second stage of the second-pass, creating an unbalanced flux between the first and second stage. Likely the first stage permeate flow increased to maintained the setpoint of 28 gpm whereas the second stage feed flow was reduced, which explained the drop in differential pressure and increase in feed pressure (thus permeability decrease). The second stage of the second-pass was cleaned with 2 % citric acid on August 8, 2013. As a result, differential pressure went back to similar values of 35 psi whereas permeability increased to values somewhat higher than the startup permeability. Ten days after the CIP, on August 18, 2013 an oxidation event occurred in the first-pass affecting the second-pass as well, since membranes were exposed to free chlorine present in the first pass permeate. Oxidation manifested in a gradual permeability increase and the permeate conductivity increased significantly. As this set of membranes was compromised, they were replaced with same model on September 24, 2013.

Figure 4-40: Permeability of second-pass RO: Phases 2 and 3 – Dow BW30-4040

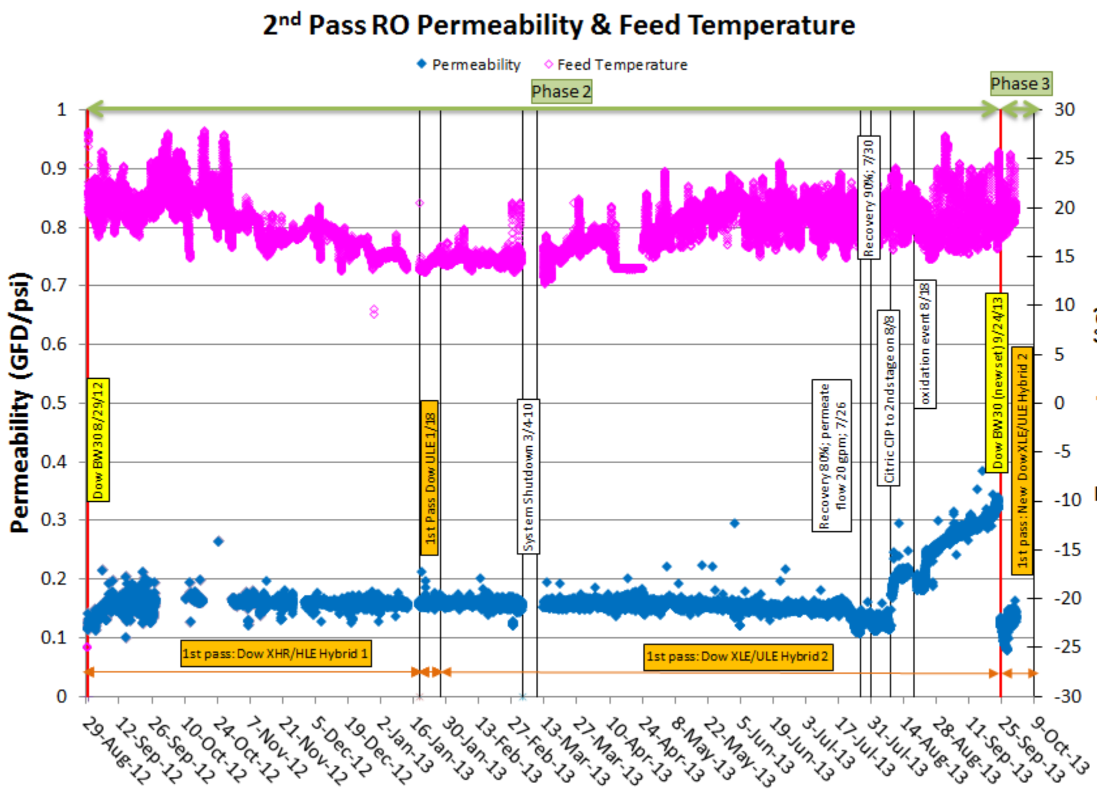


Figure 4-41: Differential Pressure for second-pass: Phases 2 and 3 – Dow BW30-4040

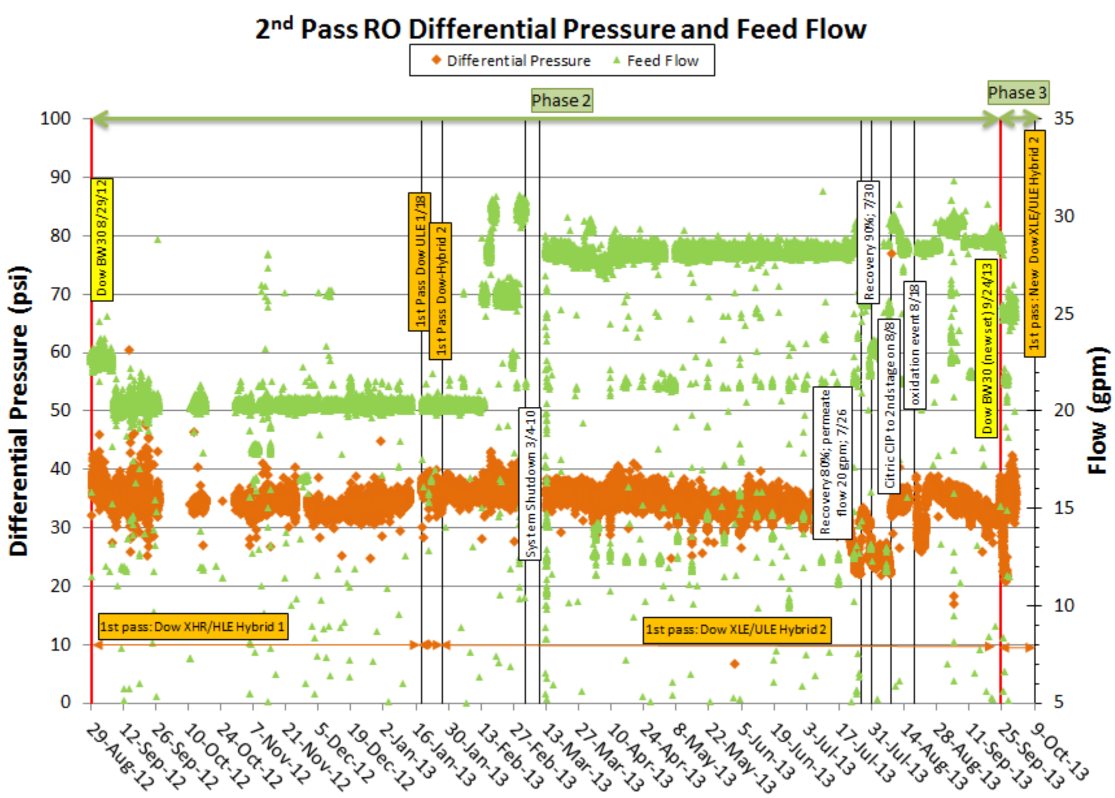
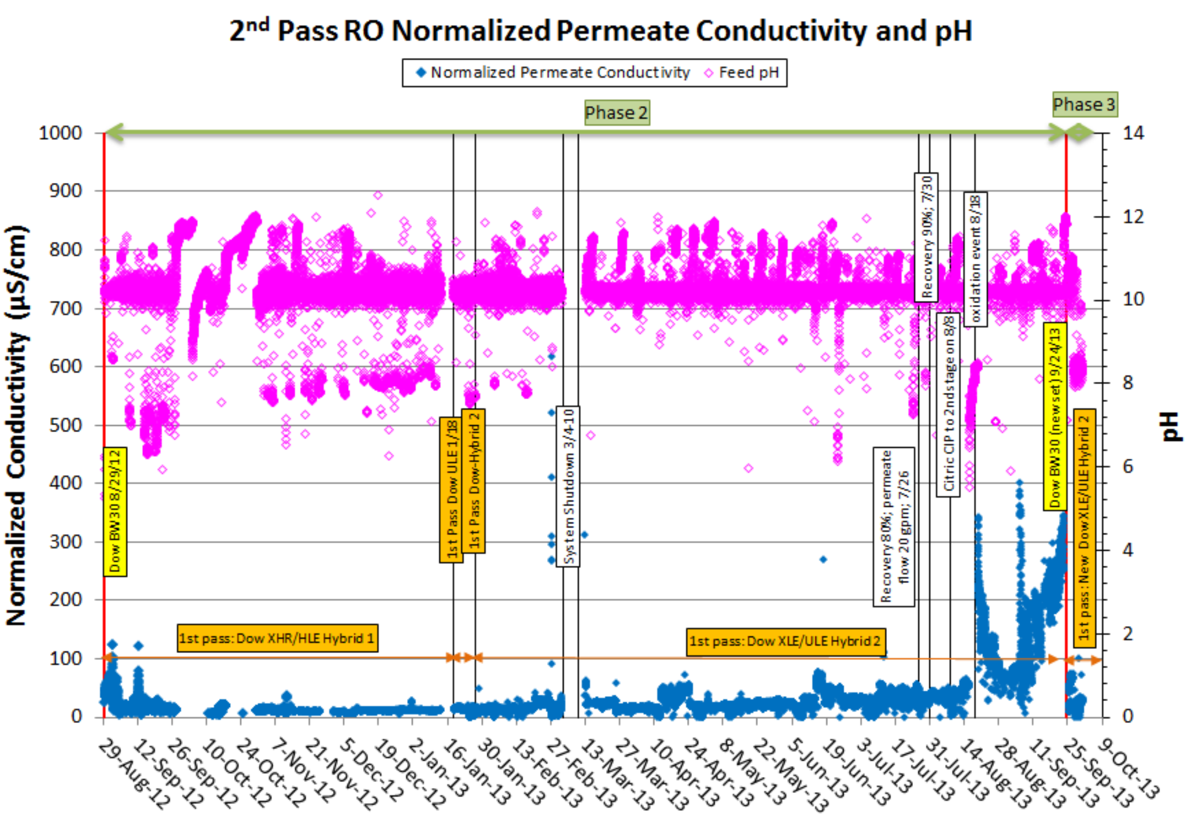


Figure 4-42 presents the normalized permeate conductivity for the second-pass for Phases 2 and 3, together with feed pH. The permeate conductivity values were steady and low, with variations between 7 µS/cm and 50 µS/cm, depending on feed conductivity (i.e. 1st pass permeate, tail end). Controlling feed pH was challenging, which averaged 10.2, but varied by almost one pH unit. Feed pH was found to vary less at higher flow rates. For example, at 28 gpm the pH only varied between 10.0 and 10.4. As discussed above, conductivity increased greatly after the oxidation event when the membranes were compromised.

Figure 4-42: Permeate Conductivity for second-pass: Phases 2 and 3 – Dow BW30-4040



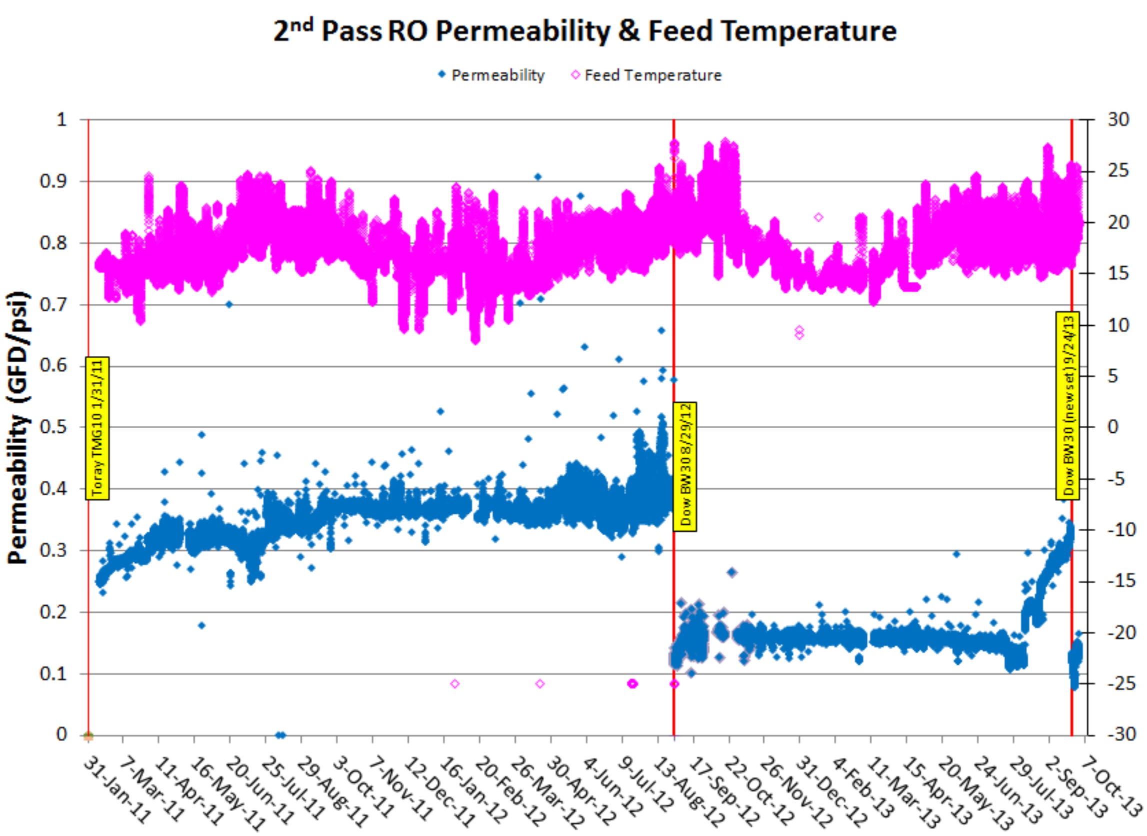
4.6.3 Overall membrane performance for second-pass RO:

- Comparing membrane performance for the three membrane sets:
    - For the same operating setpoints, Dow membranes required at a higher feed pressure (180-200 psi) than Toray membranes (70-90 psi). The feed pressure was very similar to the projected values obtained from projection software. Permeability of Dow BW30-4040 membranes was significantly lower (approximately half) than for the Toray TMG10 (Figure 4-43);

- o Differential pressure feed-concentrate was slightly lower for Toray membranes, approximately 30 psi versus 35 psi for Dow membranes (Figure 4-44);

- o Permeate conductivity for Toray membranes (~50 µS/cm) was higher than for Dow membranes (< 20 µS/cm) (Figure 4-45). This has relevance for the size of the 2nd pass required to meet certain targets for final water quality.

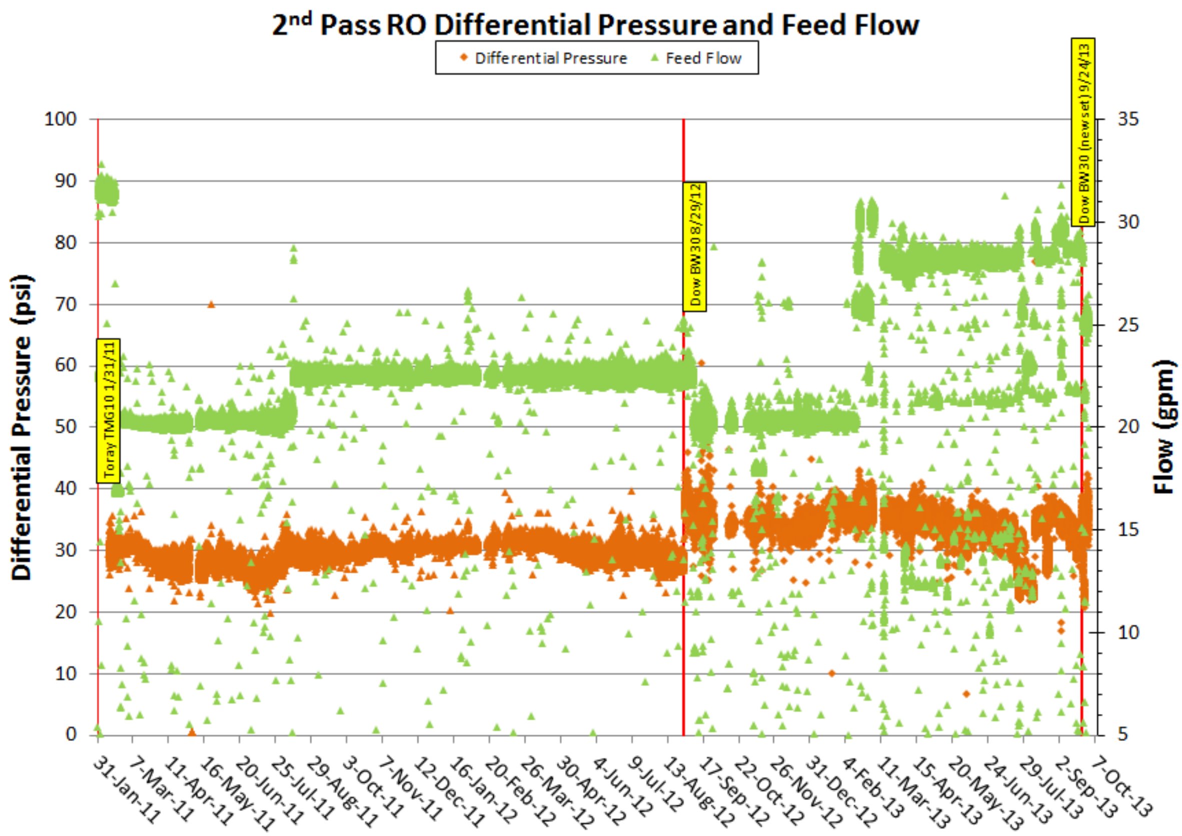
Figure 4-43: Permeability comparison for all membranes in 2nd Pass RO



- Regardless of the type of membrane used in the second-pass, water quality was excellent and as a blend with RO permeate from 1st Pass RO, met or exceeded project water quality goals. Details of water quality are presented in Section 5;

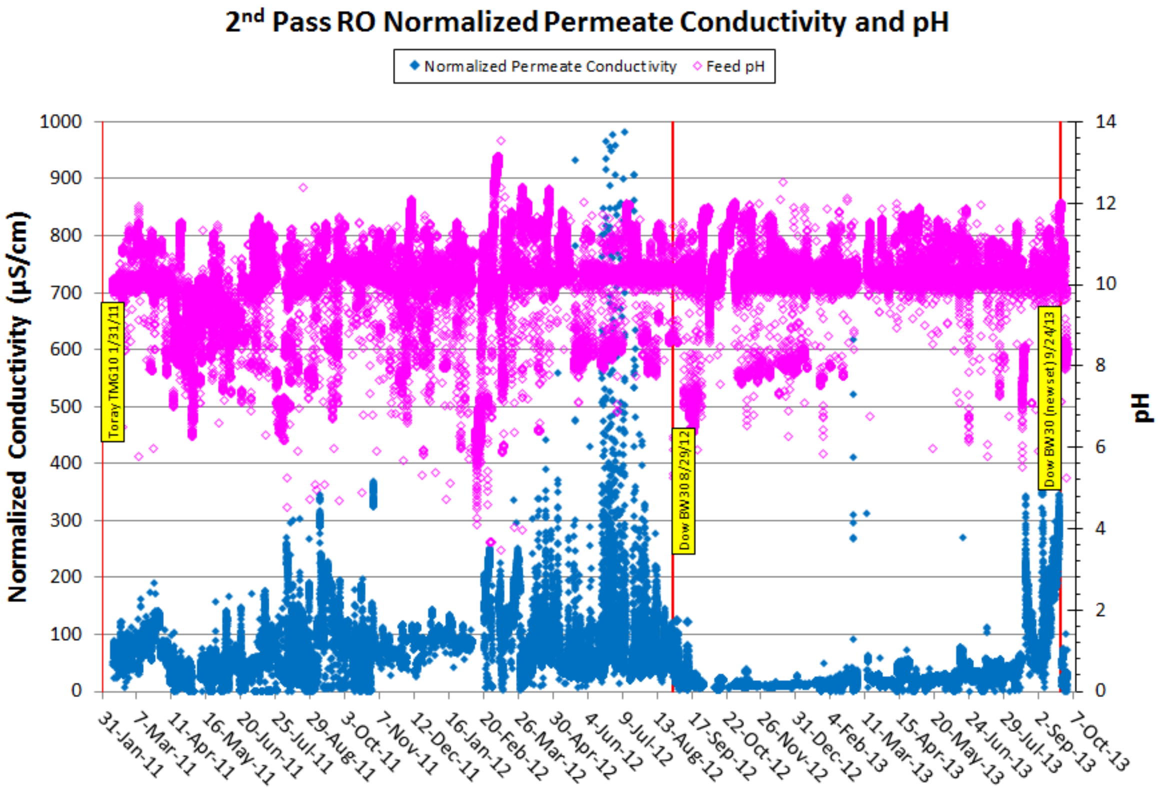
- One CIP was performed for the second-pass RO, and only to the second stage, in Phase 2. It is believed that a second-pass RO feed pH excursion resulted in precipitation of $CaCO_3$. A solution of 2% citric acid solution successfully restored performance;

Figure 4-44: Differential pressure comparison for all membranes in 2nd Pass RO



- Two membrane chemical oxidation events occurred, one in March 2011 and one in August 2013. They were in connection to events occurring in the 1st Pass RO (improper flushing and free chlorine presence in RO feed due to a faulting ammonia metering pump).

Figure 4-45: Permeate conductivity comparison for all membranes in second-pass RO



P
ost-treatment

An important part of the seawater desalination demonstration project involved educating the public about the treatment process by providing visitors access to a reliable supply of product water from the demonstration plant. This was accomplished by way of a visitors' tasting station that immediately followed a bench-top post treatment process at a flowrate of approximately 0.3 gpm.

Considering the fact that samples of product water from the demonstration desalination plant was provided for taste testing by the public, an additional disinfection process was included. An additional objective for the post-treatment process was to replicate a full-scale corrosion control strategy. A bench-top post treatment system was utilized for accomplishing both of these objectives. For the purposes of the demonstration phase, UV was utilized to achieve disinfection goals given its ease of application at the scale of the tasting station. Another aspect of the post treatment system involved the use of limestone chips to accomplish corrosion control objectives.

The combined permeate from the RO treatment was subjected to a 100 mJ/cm^2 dose of UV in a small point of entry unit. Corrosion control for the demonstration plant tasting station was accomplished by adding CO_2 to the UV treated RO permeate water, then running the water through a column of limestone ($CaCO_3$) chips. Adjustment of the addition of CO_2 was necessary to attain hardness targets for the product water, but pH was determined automatically through equilibration with the $CaCO_3$. The post treatment in the tasting station successfully added hardness and alkalinity to the desalinated water, provided drinking water at a pH suitable for consumption, and produced high quality drinking water that compared favorably to conventional sources.

4.7 Power consumption for RO system

Power consumption for the RO system (both first and second pass) was evaluated for one representative of each of the two membrane classes used in the first pass RO:

- Dow SW30XHR/XLE hybrid (2+5), representative of the Grade A: high salt rejection/low permeability class, and
- NanoH$_2$O SW400R/ES hybrid (2+5), representative of the Grade B: low rejection/high permeability class.

The RO membranes in the second pass were Dow BW30-4040. In this analysis, both membrane sets in the first pass were operated at nearly identical setpoints and the feedwater quality and temperature were also very similar (Table 4-13). Second pass RO was operated at 90% recovery and a flux of approx. 14 gfd. As indicated in Table 4-13, Dow XHR/XLE operated at a higher feed pressure than NanoH$_2$O R/ES (871 psi vs. 800 psi), however the TDS and Boron in the permeate water was lower for Dow XHR/XLE. This was reflected in a lower operating pressure for the second pass with Dow XHR/XLE membranes in the first pass than with NanoH$_2$O R/ES in the first pass (130 psi for Dow vs. 149 psi for NanoH$_2$O), since the RO permeate of the first pass served as feedwater to the second pass RO. Power consumption was calculated based on field readings of current and voltage for the high pressure pump and ERD booster pump in the first pass RO and feed pump for the second pass RO. Specific energy consumption (SEC) was calculated in each case by dividing the power consumption by the kilo-gallons of RO permeate produced.

The bypass represents the percentage of the first pass RO permeate flow which can bypass the second pass RO in order to meet same final permeate water quality. The water quality goal considered for this analysis was a boron concentration of 0.5 mg/L. Since rejection of boron by NanoH$_2$O R/ES membranes is significantly lower than for Dow XHR/XLE membranes (permeate concentration of 1.5 mg/L for NanoH$_2$O and 0.8 for Dow), a system equipped with NanoH$_2$O membranes in the first pass requires a significantly larger second pass than a system equipped with Dow XHR/XLE membranes in the first pass.

Table 4-13 Operating Conditions and Specific Energy Consumption

1st Pass Memb.	Op. Conditions			1st Pass RO		2nd Pass RO[4]		Bypass[5]	SEC[6]	
	T_{sw}[1]	Flux	R^2	P_{pump}	B_{perm}[3]	P_{Pump}	B_{perm}[3]		1st Pass[7]	2nd Pass
	°C	gfd	%	psi	mg/L	psi	mg/L	%	kWh/kgal	
Dow XHR/XLE	16.8	9.1	49%	871	0.8	130	0.2	53%	9.8	2.1
Nano R/ES	16.1	9.0	49%	800	1.5	149	0.096	21%	9.3	2.4

1) Seawater temperature
2) First Pass RO Recovery
3) Boron concentration in permeate
4) Second Pass membranes were Dow BW30-4040, and operated at flux of 14 gfd and 90% recovery
5) Percentage of 1st pass permeate flow bypassing 2nd pass RO, required for final water quality goal B = 0.5 mg/L
6) Specific Energy Consumption per kgal of RO permeate (1st pass or 2nd pass)
7) SEC for 1st pass includes the power consumption for ERD Booster Pump

SEC values indicated in Table 4-13 were used to estimate the total energy consumption for SWRO for producing same amount of total RO permeate (1,000 gph) at a given water quality (B = 0.5 mg/L) with the two different sets of membranes in the first pass RO. Results are presented in Table 4-14. Although the energy required for first-pass RO with Dow XHR/XLE membranes is higher than for NanoH_2O R/ES, a larger second pass is required for NanoH_2O membranes, thus a larger consumption of energy associated with the second pass. The total balance of energy for both RO passes shows that the use of Dow XHR/XLE membranes in the first pass results in approximately 9% savings in energy consumption comparing with the use of NanoH_2O R/ES membranes.

Table 4-14 Comparison of Energy Consumption for First Pass, Second Pass and Total RO System

1st Pass Memb.	Final Perm	Boron	Perm. 1st Pass	Perm. 2nd Pass	Energy 1st Pass	Energy 2nd Pass	Energy Total
	gph	mg/L	gph	gph	kW	kW	kW
Dow XHR/XLE	1000	0.5	1049	442	10.25	0.91	11.16
Nano R/ES	1000	0.5	1085	769	10.05	1.88	11.93

Note: As table 4-13 reflects a 1,000 gph case, the kW values indicated are equal to kWh/kgal final product.

4.8 Pre-formed chloramines

Seawater pilot testing at the El Segundo facility demonstrated that preformed chloramines were able to prevent biofouling while avoiding the harmful reactions that oxidize modern seawater reverse osmosis (RO) membranes. As such, chloramines were implemented at the demonstration facility to investigate potential scale up issues that arise with preformed chloramines for biofouling control. Previous studies of chloramine generation had established that off-gassing, dissipation, and instability of concentrated chloramine solutions make it infeasible to effectively transport or store chloramine solutions. As a result, the Demonstration Facility generated chloramines on-site, using RO permeate as a carrier water and continuous in-line addition of sodium hypochlorite and ammonium sulfate.

Testing of the preformed chloramine system demonstrated 1) the generation of stable monochloramines, 2) the successful use of in-line ORP monitoring to indicate the formation of safe chloramines (< 600 mV) or an aggressive oxidant, and 3) the formation of an aggressive oxidant in chloraminated seawater left in RO membranes for more than a few hours without adequate flushing and dechlorination. These findings were hampered by several operational issues, including startup issues with the pumps installed for preformed chloramine chemical feeds (ammonium sulfate and sodium hypochlorite), RO membrane oxidation events, and mechanical malfunctions during the shutdown flush sequence SBS pumping. The system was left inactive for several periods in order to resolve the operational issues and avoid potential impacts to special testing. Investigation of appropriate safeguard measures (flush sequence and addition of SBS) for shutdowns was ongoing during the third quarter of 2013, until the end of the demonstration project. Overall, more continuous runtime and additional testing were needed to reach formal conclusions about the viability of onsite chloramine generation and use with SWRO.

<u>Startup Challenges</u>

The preformed chloramine system started up in conjunction with the SWRO system. Initial operation proved to be very sporadic, and eventually the issue was determined to be a problematic ammonium sulfate dosing pump. After several iterations of attempted repairs of the Seepex pumps, including replacing several stators with various materials, the pumps were replaced with Prominent dosing pumps. Figure 4-46 shows the chemical concentrations of both ammonia and chlorine in the carrier water before and after dosing pump replacement, respectively. After pump replacement, the formation of chloramines was stable. This is also evident in Figure 4-47, which shows several UV-vis scans of preformed chloramine samples. Note the consistent and strong peak at a wavelength of 243, which is indicative of monochloramine (NH_2Cl).

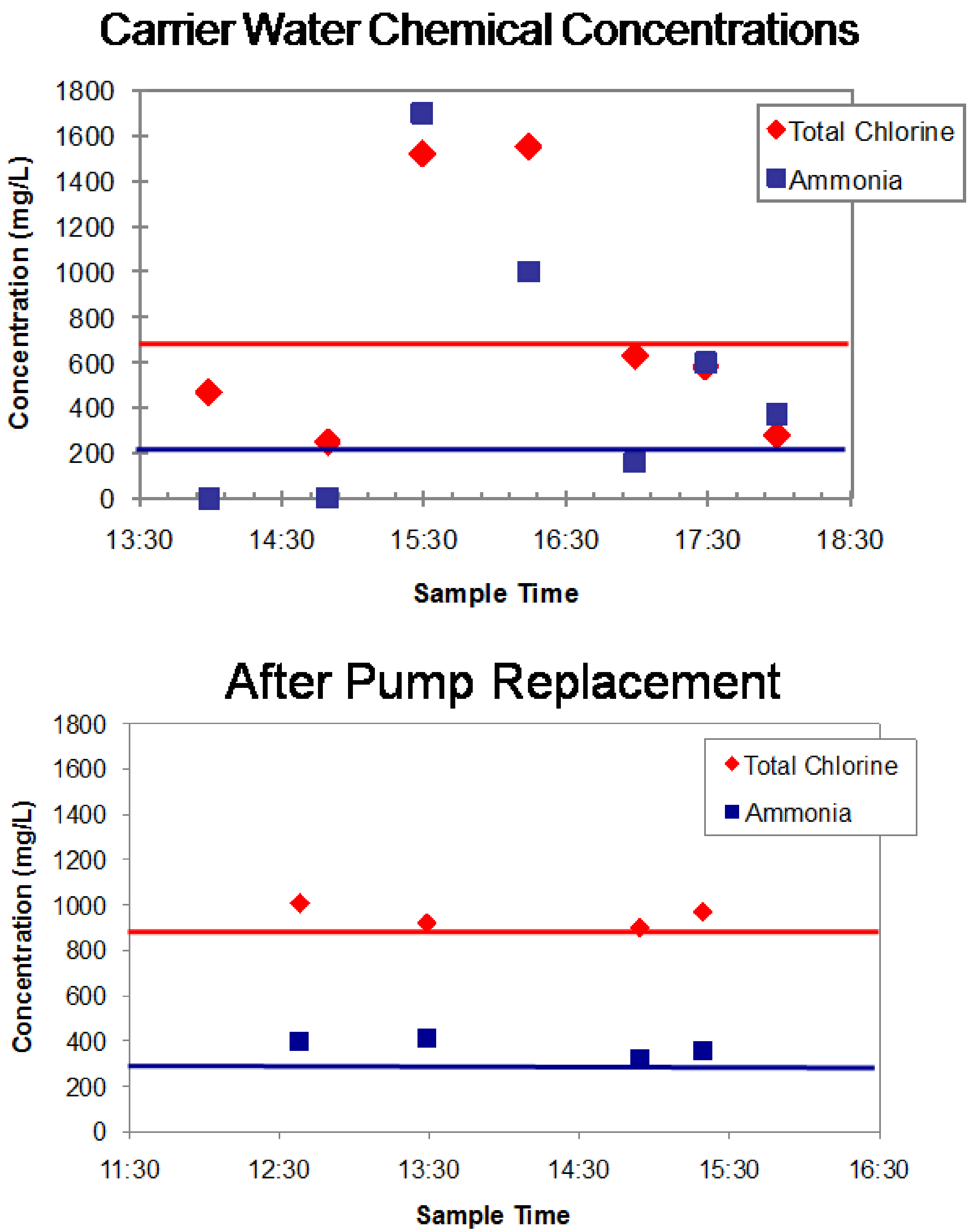


Figure 4-46: Chlorine and Ammonia Concentrations

Total chlorine and ammonia measurements indicate startup issues with the chemical feed dosing to the preformed chloramines. Values from January 18, 2011 are indicative of pumping issues, whereas values from February 11, 2011 are more stable after pumps were replaced.

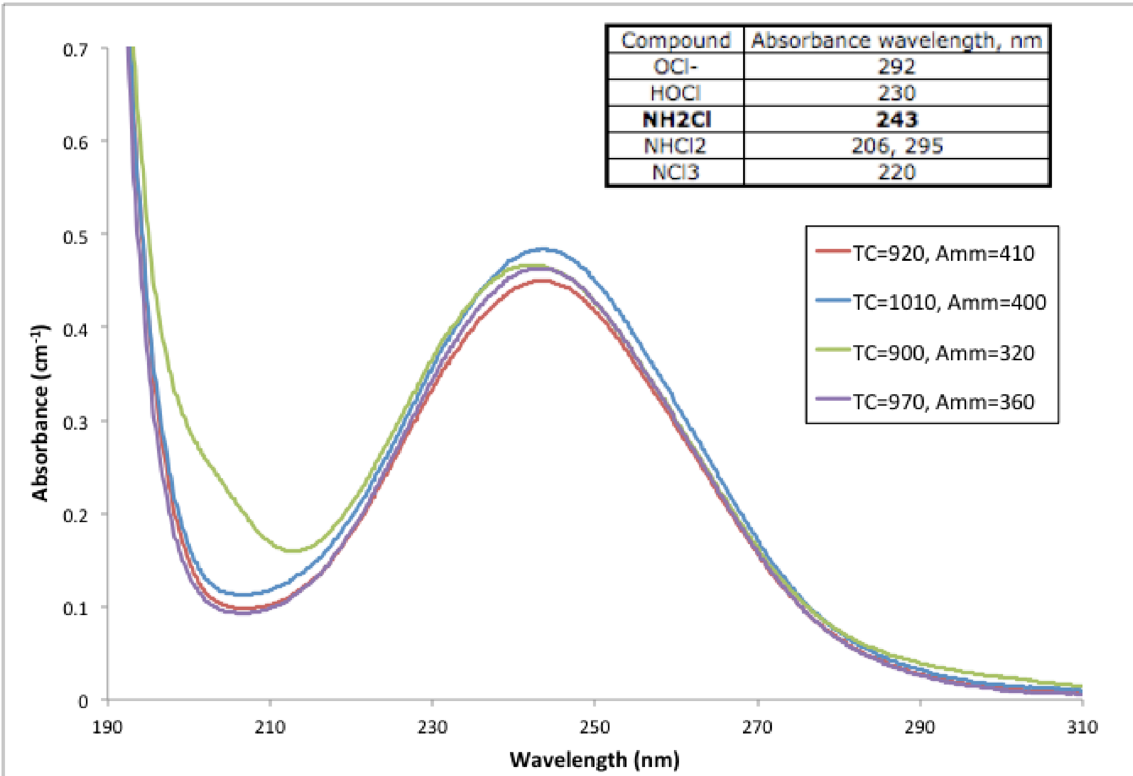


Figure 4-47: Absorbance of Preformed Chloramines

In order to help safeguard the RO membranes from oxidation damage in the event of a chloramine system upset, experiments were run to determine the high ORP level at which the RO unit should be shut down. Figure 4-48 shows the ORP value at various chlorine residual concentrations for both free chlorine and chloramines. The results show that chloramine residuals as high as 7 mg/L in raw seawater do not result in an ORP level above 600 mV, where very low doses of free chlorine (less than 1mg/L) yield ORP values in excess of 700 mV. These results show that a high ORP setpoint for the SWRO system is appropriate at 600 mV.

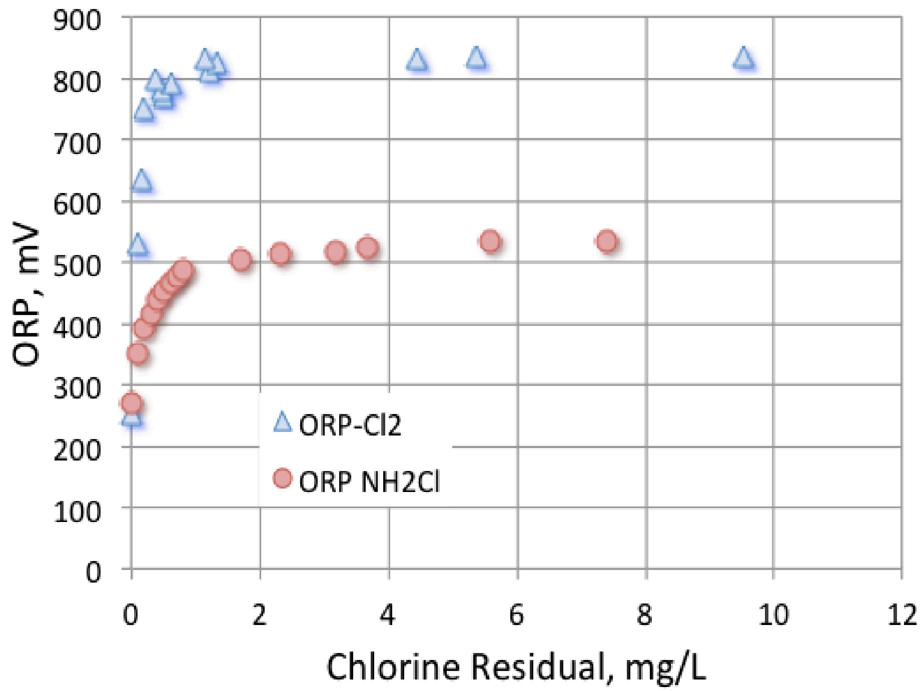
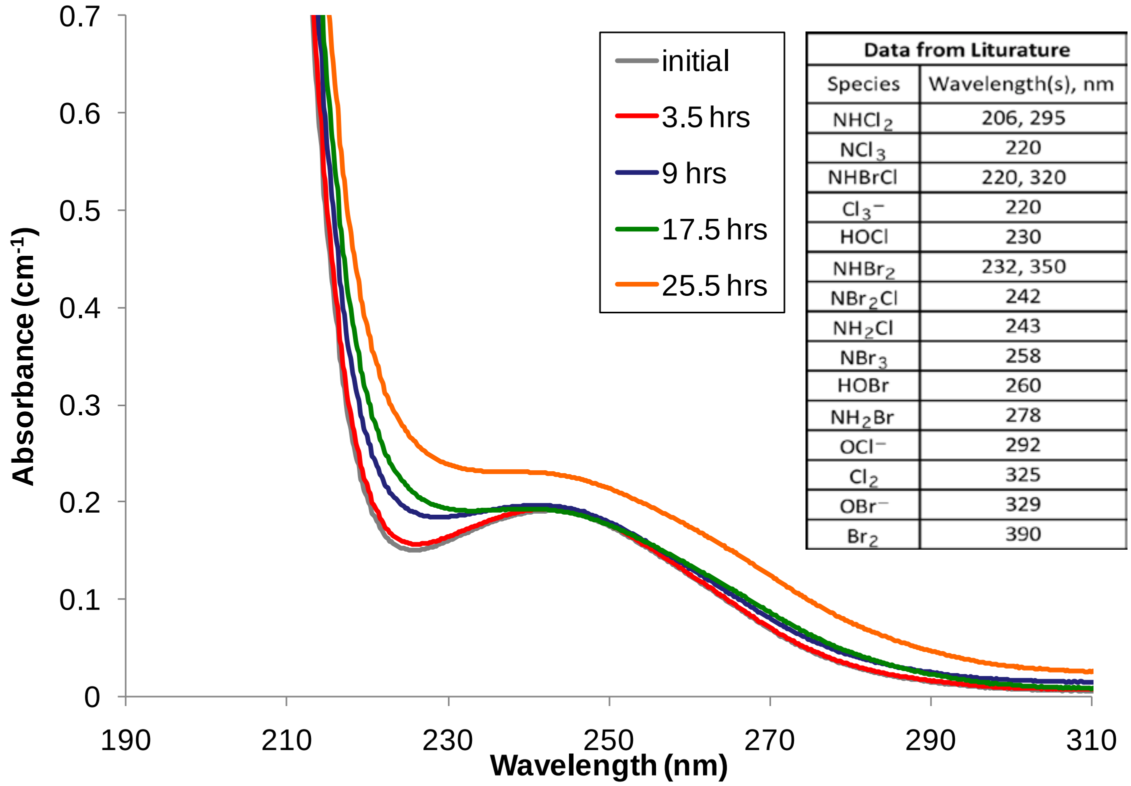


Figure 4-48: ORP values associated with seawater dosed with chlorine (blue triangles) and preformed chloramines (red circles)

Another concern with the use of preformed chloramines is the possibility to develop an aggressive residual over time. As the chloramines slowly react with the high concentrations of bromide in seawater, bromochloramine can develop which is a strong enough oxidant that it could potentially damage an RO membrane. This can be problematic at a facility that is not adequately flushed with dechlorinated RO permeate prior to shutdowns. Chloraminated seawater that is contained and allowed to react in the RO unit for more than 4 to 9 hours may develop an aggressive residual that could oxidize the membrane. Experiments were conducted where the UV-vis spectra of chloraminated seawater was observed over time to quantify when these reactions begin to occur. Figure 4-49 shows the resulting scans and it was determined that very little decay occurs in the first 3.5 hours, and that the RO system should be able to tolerate short-term shutdowns before harmful decay byproducts start to form.



Data from Liturature

Species	Wavelength(s), nm
$NHCl_2$	206, 295
NCl_3	220
NHBrCl	220, 320
Cl_3^-	220
HOCl	230
$NHBr_2$	232, 350
NBr_2Cl	242
NH_2Cl	243
NBr_3	258
HOBr	260
NH_2Br	278
OCl^-	292
Cl_2	325
OBr^-	329
Br_2	390

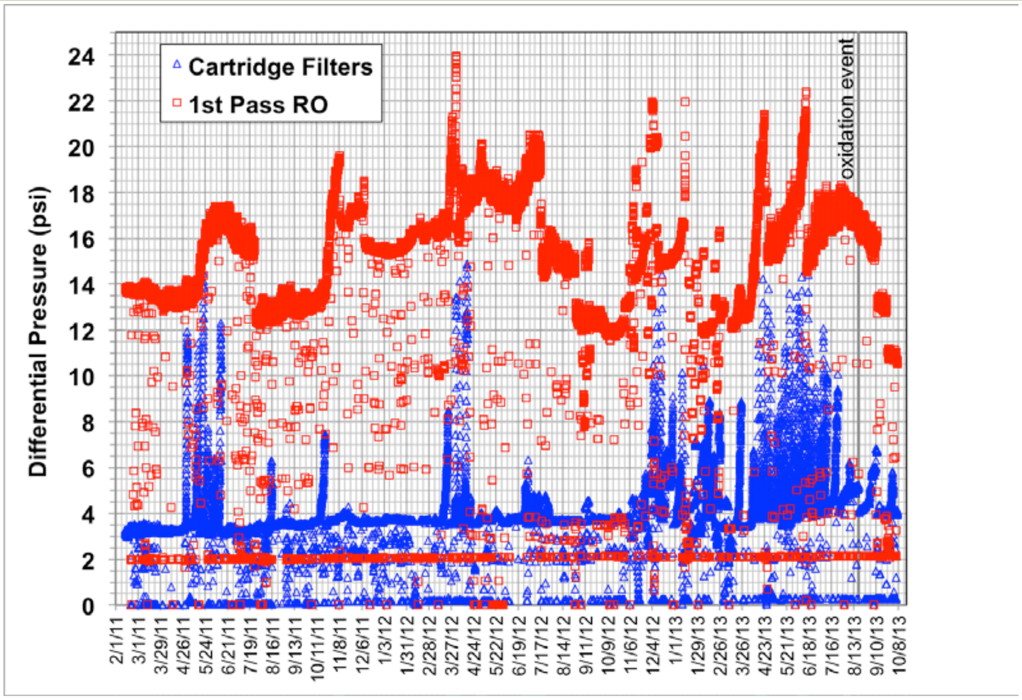
Figure 4-49: Decay of chloramines in seawater over a 25.5 hour period using UV-vis absorbance measurements

System Inactivity and Biofouling

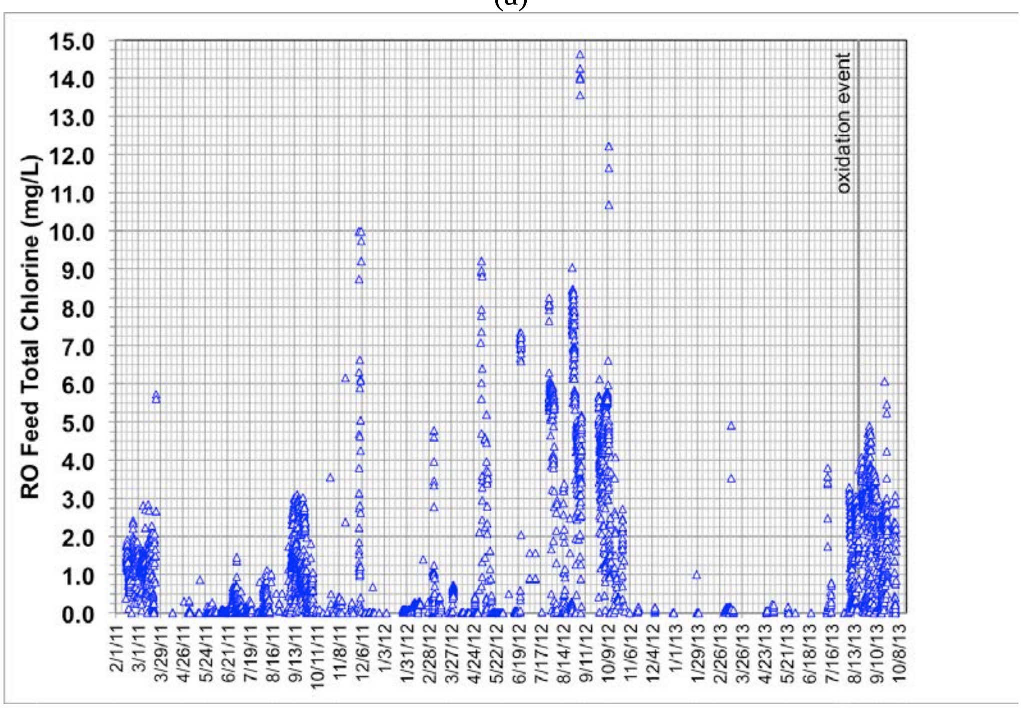
As shown in Figure 4-50(b), the preformed chloramine system was operated sporadically and infrequently, which made long-term demonstration of the preformed chloramine system infeasible. Issues related to the aquarium testing led to long periods of chloramine inactivity and mechanical issues caused unstable (off/on) operation in the brief windows that chloramines could run. The chemical dosing pumps continued to be an issue and the sodium hypochlorite pumps were eventually replaced as well. As a result of these mechanical issues, the chloramine system required careful oversight to ensure proper doses of chemical and the appropriate chlorine-to-ammonia ratio was maintained in the chloramine line. Following a chlorine leak in early 2012, the preformed chloramine dosing location was moved from the ocean intake to the RO feed. Considering the major difference in carrier water flow (1.5 - 1.9 gpm v. 0.4 - 0.7 gpm), it was operationally challenging to get the chemical feed pumps to consistently operate at the low flow required for dosing preformed chloramines at the RO feed. The feed was again changed to dose preformed chloramines ahead of the UF, in order to increase the carrier water flow and chemical feed rates.

Increases in differential pressure in the cartridge filters and RO membranes may provide an indication of biofouling. The project results for chloramines with respect to differential pressure are summarized in Figure 4-50, with differential pressure measured in the cartridge filters and in the 1st pass RO membranes provided in Figure 4-50(a) and RO feed total chlorine level in Figure 4-50(b). There were several long periods when chloramines were not fed to the system (Figure

4-50(b)) due to the aquarium and energy optimization studies, thus it is difficult to draw firm conclusions on the effectiveness of the chloramines to protect of the system against biogrowth and biofouling concerns. However, it appears that the most extensive increases in differential pressure observed in Figure 4-50 correlate with periods when the chloramine system was not operational. Although it is believed there may be additional factors beyond a lack of chloramine contributing to the increases in differential pressure observed on the cartridge filters, (e.g., ferric was added in the UF feed in the middle of the project in an attempt to improve the performance of the UF pretreatment to the RO), these observations suggest that preformed chloramines may help prevent biofouling.



(a)



(b)

Figure 4-50: RO Differential Pressure and Chlorine Concentration

Project results over the life of the project for (a) Differential Pressure and (b) RO feed chloramines. Hourly median values plotted, which were determined based on 1-minute and 15-minute data. Oxidation event on 8/19/2013 caused by inadvertently turning off the high ORP alarm on the RO feed.

System Shutdown Sequence

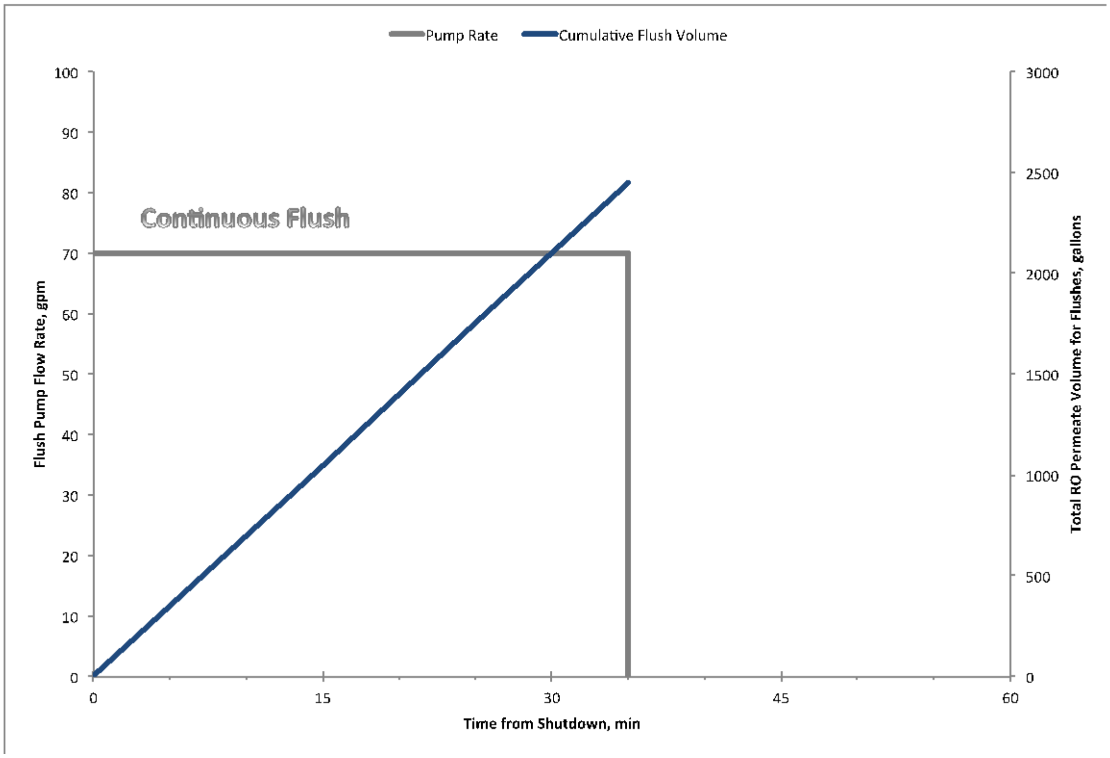
A series of unplanned overnight system shutdowns resulted in membrane oxidation in September 2012. The sodium bisulfite (SBS) pump failed during the flush initiated with the emergency shutdown, leaving a chloramine residual in the RO membranes, which slowly reacted with the high concentrations of bromide that remained in the pressure vessels. Membrane oxidation from chloraminated seawater does not occur during the time scales allowed during continuous operation (i.e., minutes), however the overnight shutdown provided sufficient time (> 9 h) for reactions to take place that transform the chloramine (see Figure 4-49) to what is speculated to be a strong oxidant. This transformation resulted in compromised membrane performance, as measured by increasing conductivity in the RO permeate.

To prevent such oxidation events, the RO membranes must be protected with multiple barriers during a shutdown when chloramines may be exposed to high bromide concentrations for an extended period of time (i.e., >3.5 hours). The project team pursued two strategies for shutdowns:

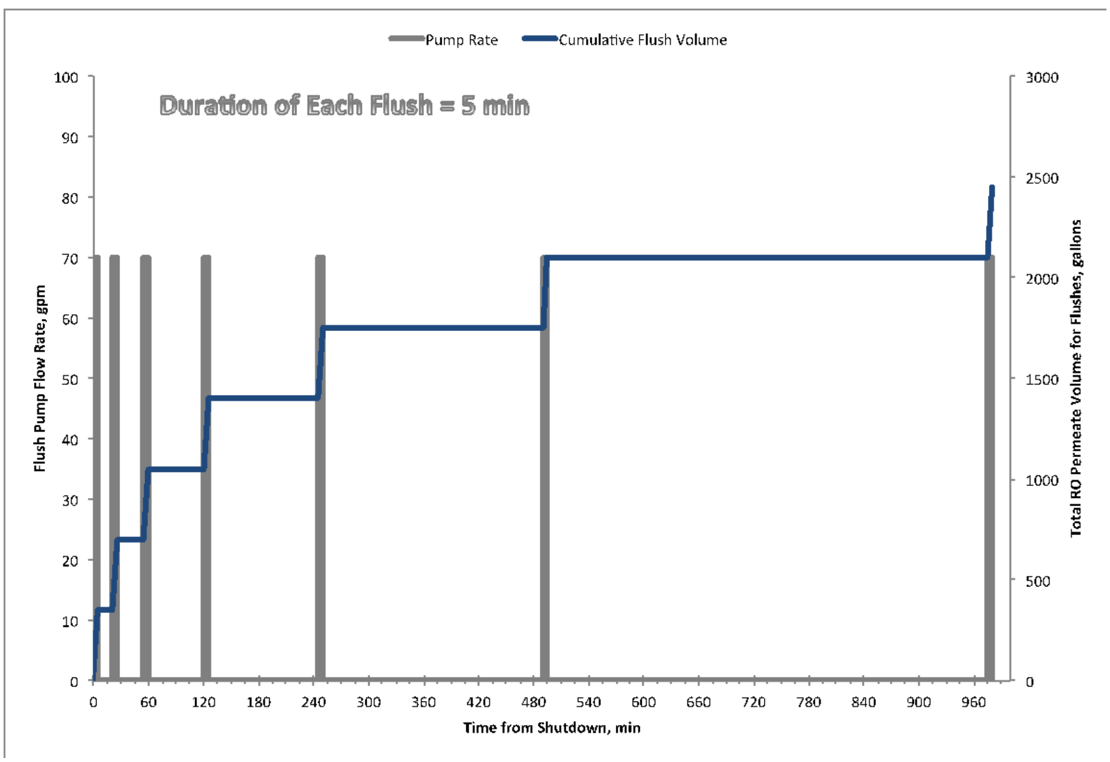
1. Reduce the concentration of bromide in the pressure vessels by flushing with RO permeate and;

2. Eliminate the chloramine residual by dosing sodium bisulfite (SBS) to the RO permeate flush water

Unfortunately, even with the above steps in place, membrane oxidation occurred. First, the SBS was not being added due to some mechanical malfunctions with its chemical feed system. It would seem that this issue could be easily addressed with redundant SBS pumps for the full-scale facility since shutdowns are relatively brief and infrequent. These two pumps would add double the amount of SBS required to ensure that an adequate amount is always present to eliminate the chloramine residual even in the event that one pump failed. Additionally, despite the use of RO permeate for the flush sequence, conductivity was found to increase during an overnight shutdown, due to seawater within the annular space between the RO elements and RO vessels. A modified flush programming sequence, illustrated in Figure 4-51(b), was proposed to provide time for mixing between the RO permeate and “trapped” seawater in the RO vessels.



A)



B)

Figure 4-51: (a) Current continuous RO flush approach (b) Staggered RO flush approach

The flush sequence for system shutdowns was re-evaluated, modified to include a series of increasing flush stages over an approximately 8-hour period, as well as redundant SBS pumping, and tested during the third quarter of 2013. A review of existing data from past chloramine/bromamine bench work and membrane oxidation at the pilot plant was completed. An initial test of the modified system of flushing the pressure vessels with RO permeate was conducted on March 27, 2013, and results are shown in Figure 4-52. Based on the positive preliminary test results and fixes to the SBS chemical feed system, including a redundant SBS dosing system, the preformed chloramines were restarted in the UF feed during Q3 2013.

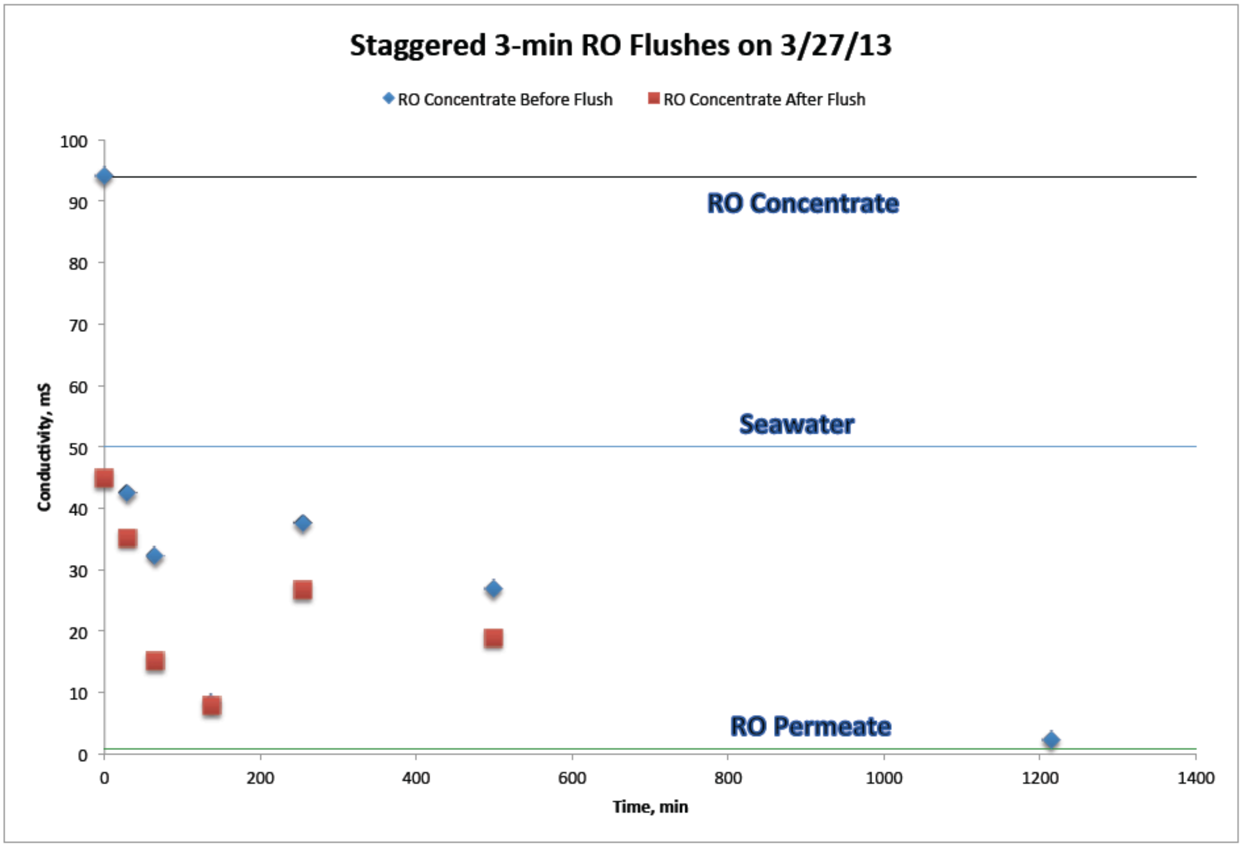
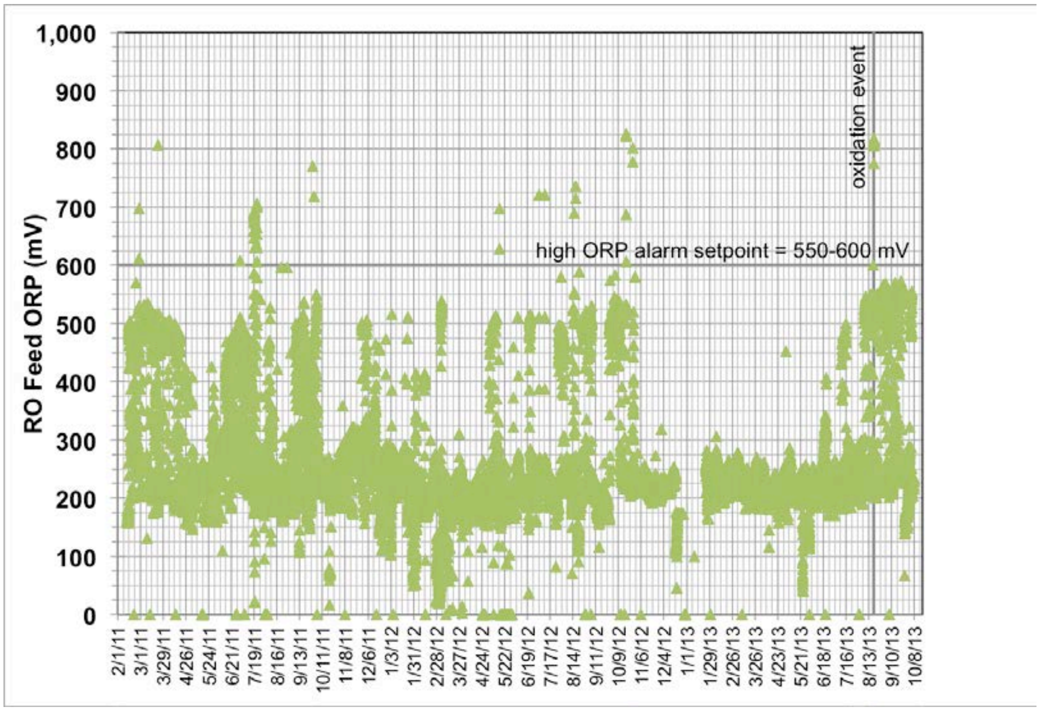
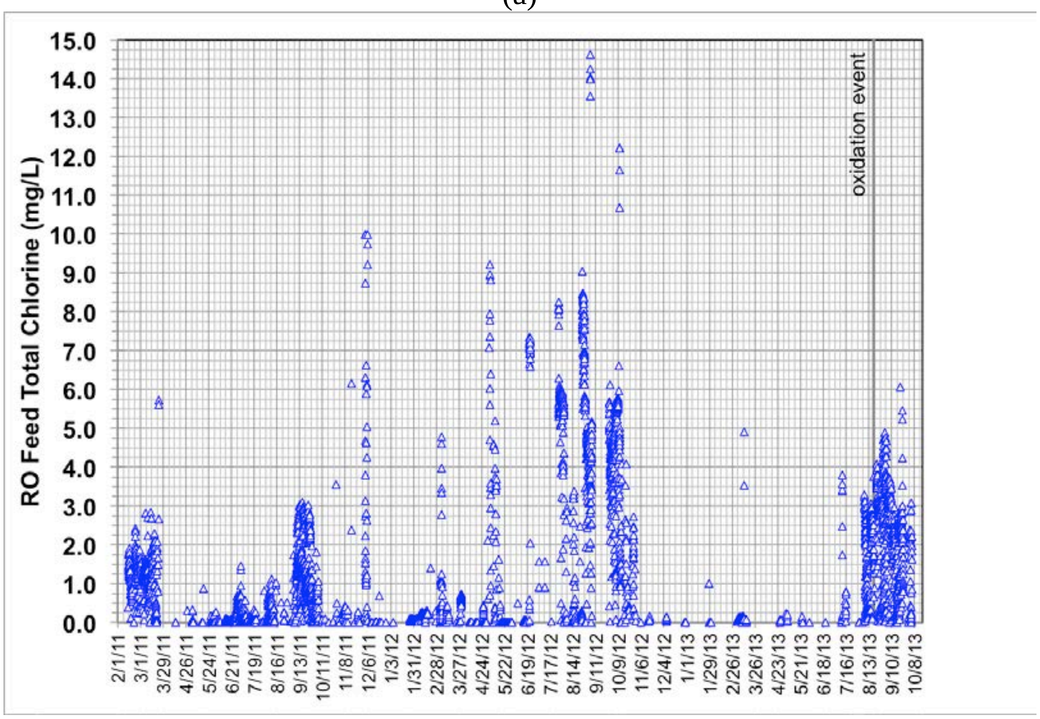


Figure 4-52: Results of RO Flush Test

Despite the revised shutdown measures, another membrane oxidation event occurred on 8/19/2013. The RO feed ORP alarm had been disabled and the ammonia feed pump experienced air lock while continuing to pump, hence the pump failure alarm did not activate either. A comparison of ORP levels shown in Figure 4-53(a) and total chlorine levels shown in Figure 4-53(b) indicates that prior to the revised shutdown steps implemented in Q3 of 2013, there were occasional events where the RO membranes were exposed to free chlorine (indicated by ORP levels > 600 mV). It is significant that other than the oxidation event caused by failure to activate the high ORP alarm in the RO feed on 8/19/2013, there were no experiences where ORP exceeded 600 mV in the RO feed after the staggered flush and dual SBS chemical feed pumps were implemented in Q3 2013.



(a)



(b)

Figure 4-53: RO Feed ORP and Chlorine Concentration

Project results over the life of the project for (a) ORP and (b) RO feed chloramines. Hourly median values plotted, which were determined based on 1-minute and 15-minute data. Oxidation event on 8/19/2013 caused by inadvertently turning off the high ORP alarm on the RO feed.

After the oxidation event in mid-August, several short-term tests were conducted to evaluate the effectiveness of the shutdown procedures. Testing was conducted with the following four conditions A, B, C, and D in September and October 2013.

A – Staggered Flush with SBS pumps on
B – Constant Flush with SBS pumps on
C – Staggered Flush with SBS pumps off
D – Constant Flush with SBS pumps off

Results for Test Conditions A, B, and C showed the absence of a chloramine residual after an overnight shutdown, whereas the Test Condition D result showed the presence of a chloramine residual after an overnight shutdown, a condition destructive to the RO membranes. The results suggest that the strategy of the staggered flush combined with redundant SBS pumps is effective for mitigating the exposure of the RO membranes to free chlorine at unexpected shutdowns.

Representative Results for Test Conditions A, B, C, and D for total chlorine levels after shutdown are summarized in Figure 4-54. It is observed that for three of the four shutdown test conditions total chlorine was not present within 71 minutes of shutdown, the exception being the test condition with constant flush with SBS pumps turned off. Conductivity levels after shutdown comparing constant flush to staggered flush are summarized in Figure 4-55, with the staggered flush resulting in lower conductivity levels and conditions less likely to result in oxidation issues at shutdown. The staggered flush sequence with redundant SBS dosing is the most promising approach for shutdown sequences. However, the catastrophic impact of an ineffective or insufficient flush requires such a process to be fail safe. Under the condition of a power failure, backup power and sufficient flush water volume for all trains would be required to protect the membranes. It is recommended that further development of flush sequences and redundancy would need to be addressed prior to full scale implementation.

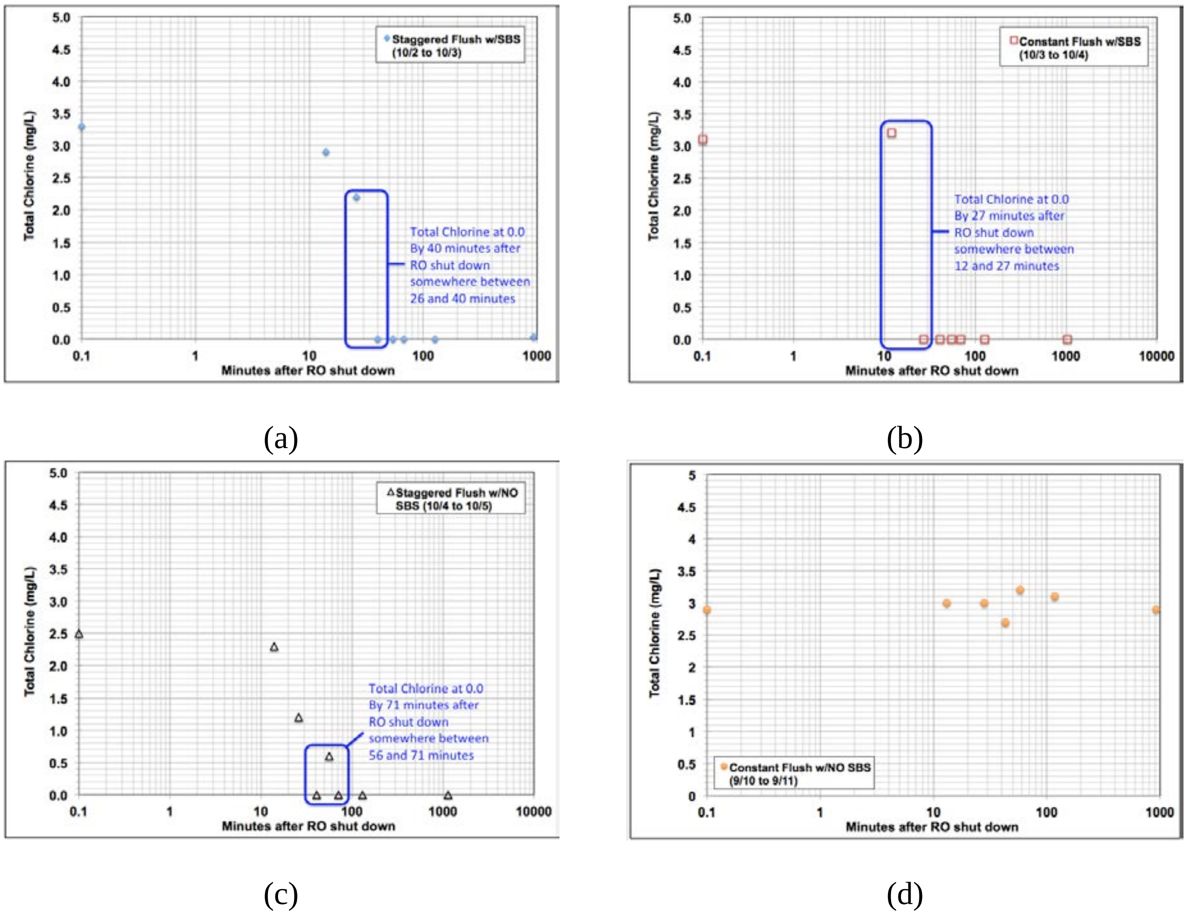


Figure 4-54: Shutdown Testing Results for Total Chlorine after Shutdown

(a) Staggered Flush with SBS, (b) Constant Flush with SBS, (c) Staggered Flush with SBS Pumps Off, (d) Constant Flush with SBS Pumps Off. Total chlorine levels in three of four cases were at zero within 71 minutes after shutdown with the exception of (d) the constant flush with SBS pumps off where chlorine residual was present after the overnight shutdown.

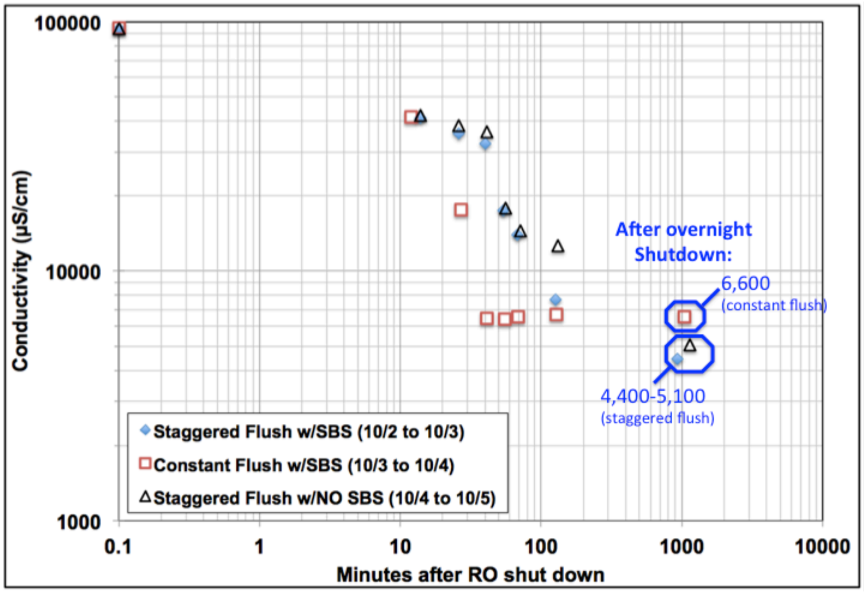


Figure 4-55: Shutdown Testing Results for Conductivity after Shutdown

(a) Staggered Flush (b) Constant Flush. Staggered flush resulted in lower conductivity after 16 hour shutdown.

5.0 WATER SAMPLING AND ANALYSIS

This section provides a detailed discussion of the water quality data generated from November 2010 through September 2013, including all results from OWDDF water quality monitoring. The water assessment defines the water quality requirements to meet the NPDES waste discharge requirements, Ocean Plan regulations, drinking water regulations, as well as some key water quality parameters. It also interprets the collected data to provide water quality predictions for future full-scale ultrafiltration (UF)/reverse osmosis (RO) seawater desalination process implications. A total of fifteen monitoring locations, listed below, were used in assessing the water quality throughout the desalination treatment train.

Sampling locations:

1. Raw water
2. Pre-screen filtrate
3. Pre-screen wash
4. UF filtrate
5. UF wash
6. RO feed
7. Combined 1st pass RO permeate
    a. 1st pass RO permeate lead-end elements
    b. 1st pass RO permeate tail-end elements
8. 1st pass RO concentrate
9. 2nd pass RO permeate
10. 2nd pass RO concentrate
11. Combined RO permeates (feed to tasting station)
12. Corrosion control effluent
13. Effluent tank inlet
14. Reconstituted ocean water discharge
15. Receiving water

Many water quality parameters are required to be monitored according to the California Ocean Plan. These parameters are generally analyzed in the raw water, 1st pass RO concentrate, reconstituted ocean water discharge, and the receiving water. Parameters associated with drinking water regulations, as well as contaminants of emerging concern are typically monitored in the raw water and the combined 1st pass RO permeate. Additional constituents required for NPDES compliance (beyond Ocean Plan constituents) and some other key water quality parameters monitored on a routine basis are analyzed from sample locations throughout the treatment train, at various frequencies. The schematics shown in Figure 5-16 and Figure 5-17 provide process flow diagrams of the 1st pass RO and 2nd pass RO treatment processes, which are helpful in analyzing the data.

Membranes were replaced for the ultrafiltration (UF) and reverse osmosis (RO) first and second-pass systems several times throughout the water quality monitoring program at the OWDDF. The various phases of membrane use for each system are defined, as follows.

UF
Phase 1: 1/12/11 – 4/19/11, GE Zenon ZW1000 version 4
Phase 2: 4/20/11 – 11/15/12, GE Zenon ZW1000 version 4 (second set)
Phase 3: 11/16/12 – 9/30/13, GE Zenon ZW1000 version 4 (third set)

RO 1st Pass
Phase 1: 1/31/11 – 7/24/11, Toray TM810F-400
Phase 2: 7/25/11 – 8/28/12, Hydranautics SWC5
Phase 3: 8/29/12 – 10/29/12, Dow XHR/XLE Hybrid
Phase 4a: 10/30/12 – 11/15/12, NanoH2O ES
Phase 4b: 11/16/12 – 1/17/13, NanoH2O R/ES Hybrid
Phase 5a: 1/18/13 – 1/27/13, Dow ULE
Phase 5b thru 5d: 1/28/13 – 9/23/13, Dow XLE/ULE Hybrid
Phase 6: 9/24/13 – 9/30/13, Dow XLE/ULE Hybrid (new set)

RO 2nd Pass
Phase 1: 1/31/11 – 8/28/12, Toray TMG10
Phase 2: 8/29/12 – 9/23/13, Dow BW30
Phase 3: 9/24/13 – 9/30/13, Dow BW30 (new set)

The first pass RO membranes were first replaced during the 3rd quarter of 2011, after exhibiting signs of damage that resulted in diminished treatment performance evidenced by poor water quality data in the RO permeates. Following the membrane replacement in July 2011, implementation of the full water assessment and monitoring program for the OWDDF resumed. Annual monitoring of water quality parameters with drinking water regulations was completed in August 2011, after having been postponed during quarters 1 and 2 of 2011, and again in February 2012, according to the original routine water quality monitoring schedule. First and second pass RO membranes were replaced in conjunction with a special WateReuse Foundation (WRF) energy consumption study in August 2012. poor water quality data and another drop in treatment performance indicated that the 1st pass RO membranes experienced oxidation damage. The 1st pass membranes were again replaced as part of the WRF study in late October 2012, mid-November 2012, early January 2013, mid-January 2013, and in late January 2013. One final first pass membrane change was made in late September 2013, for the final days of the monitoring program.

Second pass RO membranes were replaced twice, in late August 2012 and again in late September 2013 for the final days of the monitoring program.

All available water quality data from November 2010 through September 2013 are presented in the following sections.

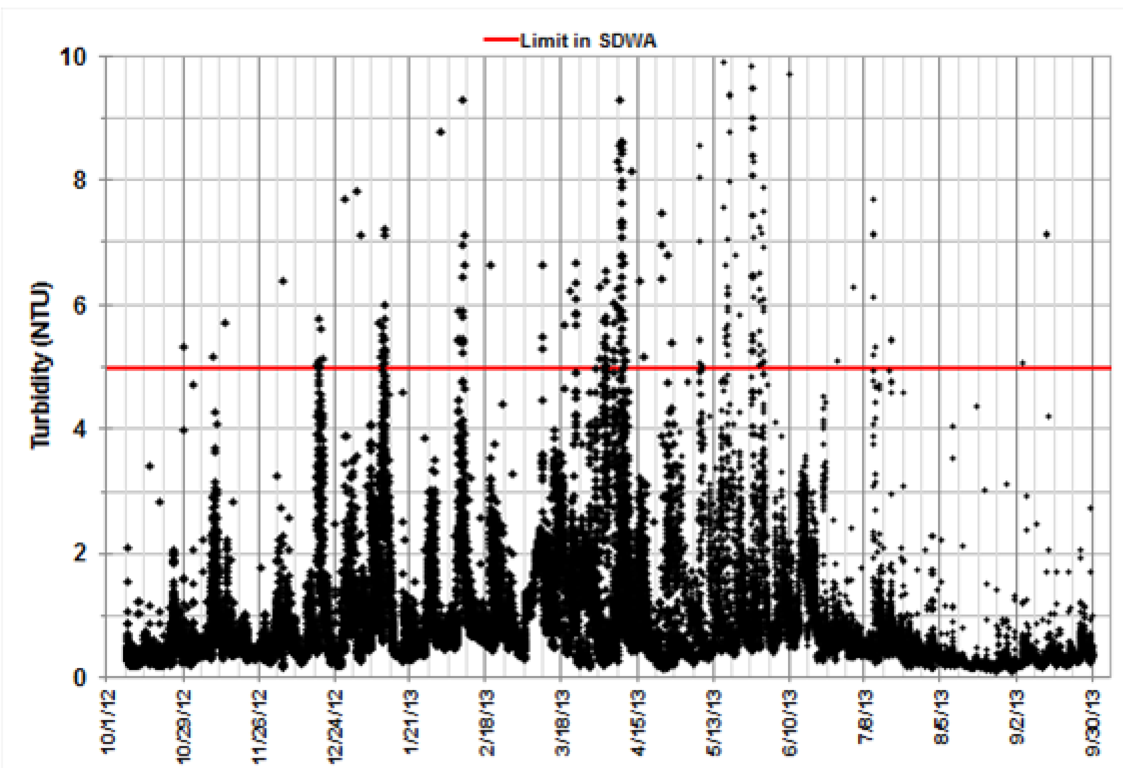
5.1 Water Analysis Summary

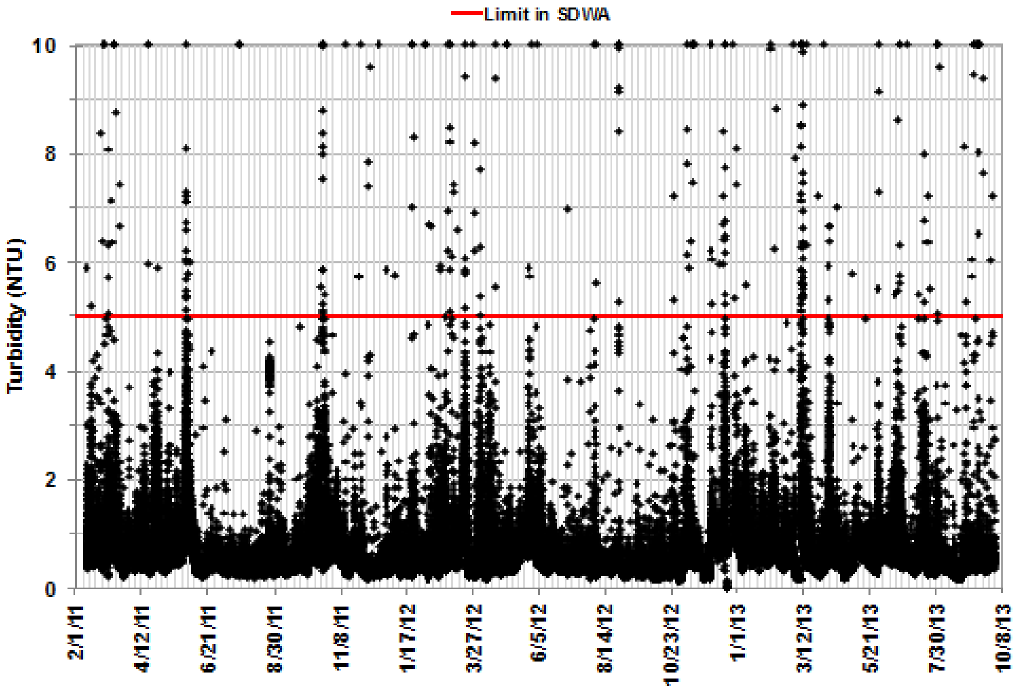
The water assessment defines the water quality requirements to meet the NPDES waste discharge requirements, Ocean Plan regulations, SDWA drinking water regulations, as well as some key water quality parameters.

The water quality monitoring program was initiated in November 2010 with NPDES waste discharge monitoring only. The Ocean Water Desalination Demonstration Facility (OWDDF) was fully commissioned and turned over to West Basin Municipal Water District (WBMWD) in late February 2011, at which point monitoring for the complete scope of water quality parameters was started. This report provides a summary of all available OWDDF water quality data from November 2010 through September 2013.

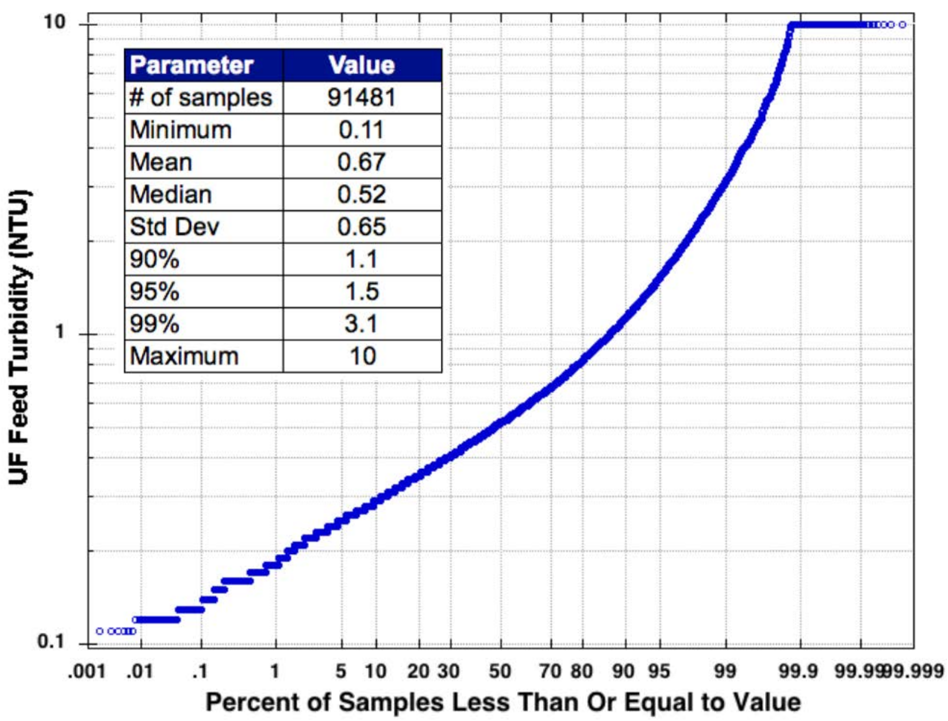
Turbidity in the raw ocean water is shown in Figure 5-1. Turbidity is also monitored continuously in the UF feed, as shown in Figure 5-2. Turbidity in the UF filtrate is shown in Figure 5-3. Another continuously monitored parameter, specific conductance (referred to as conductivity in this report), is measured in the RO feed, as shown in Figure 5-4,. TDS in the source ocean water is shown in Figure 5-5. TOC in the source ocean water is shown in Figure 5-6. The combined 1st pass RO conductivity is shown in Figure 5-7. The combined 1st pass RO TOC is shown in Figure 5-8.

Figure 5-1: Raw water turbidities, monitored continuously





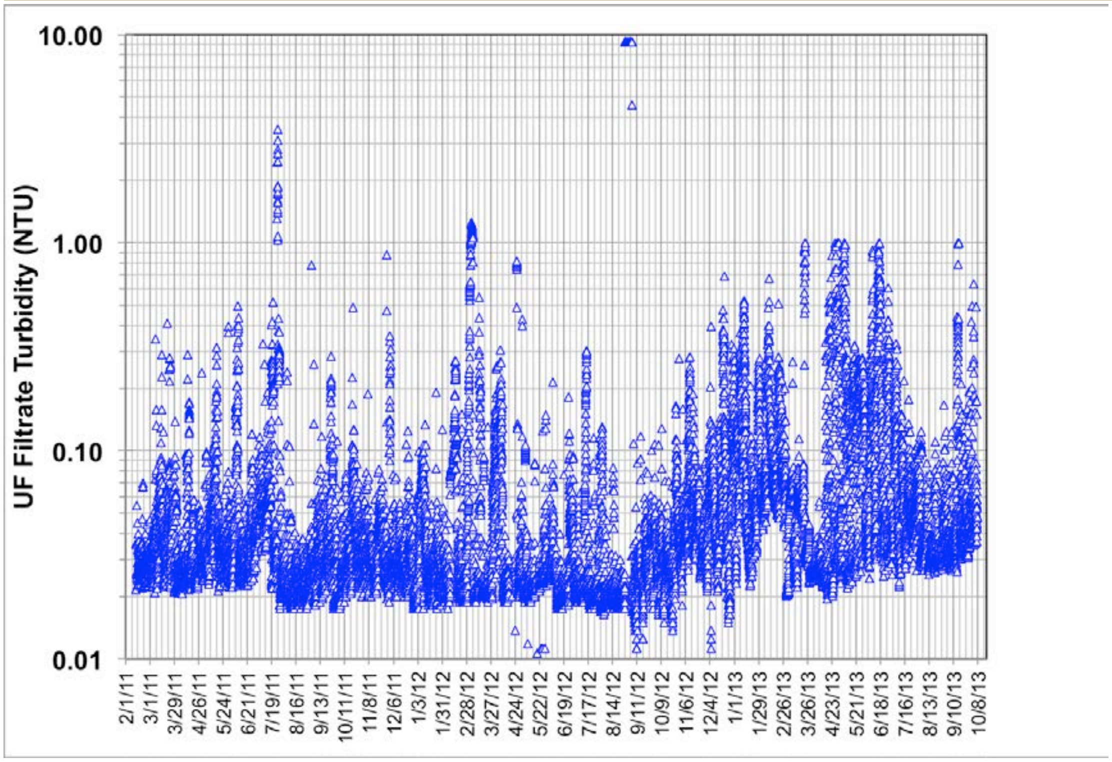
(a)



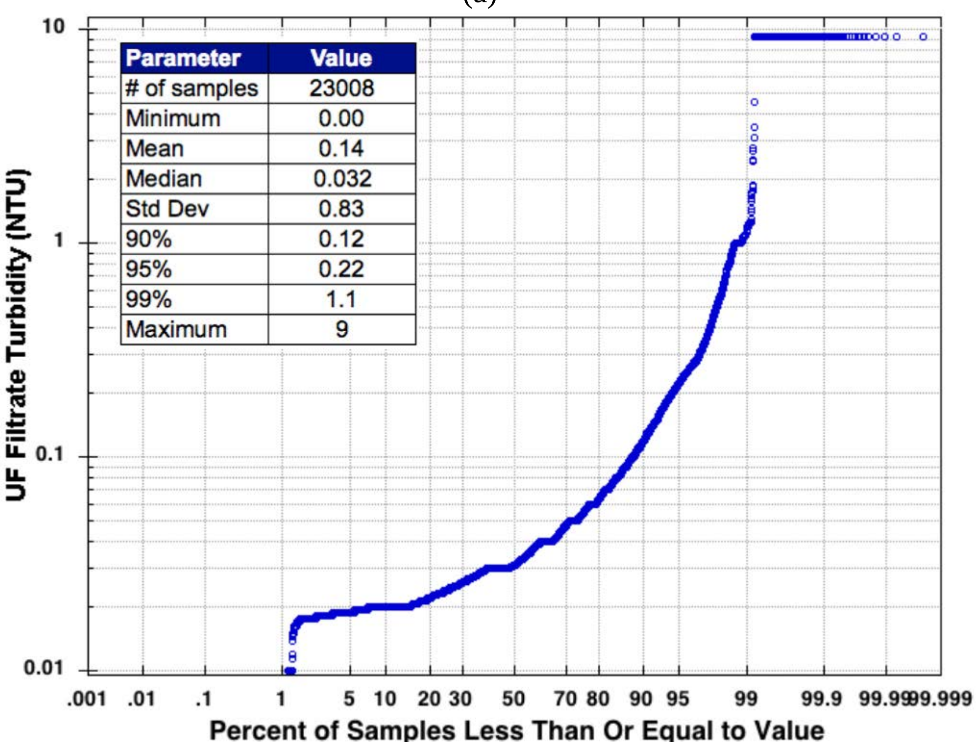
(b)

Figure 5-2: UF feed turbidities

(a) monitored continuously (b) probability plot of hourly median data with statistics inset



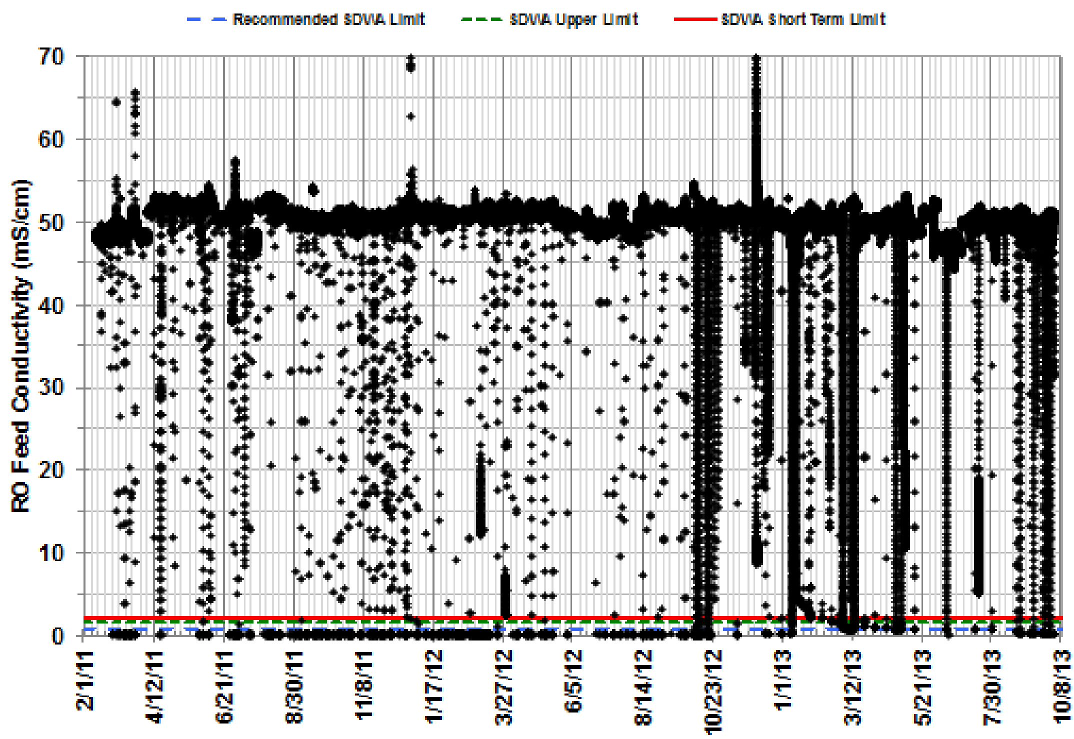
(a)



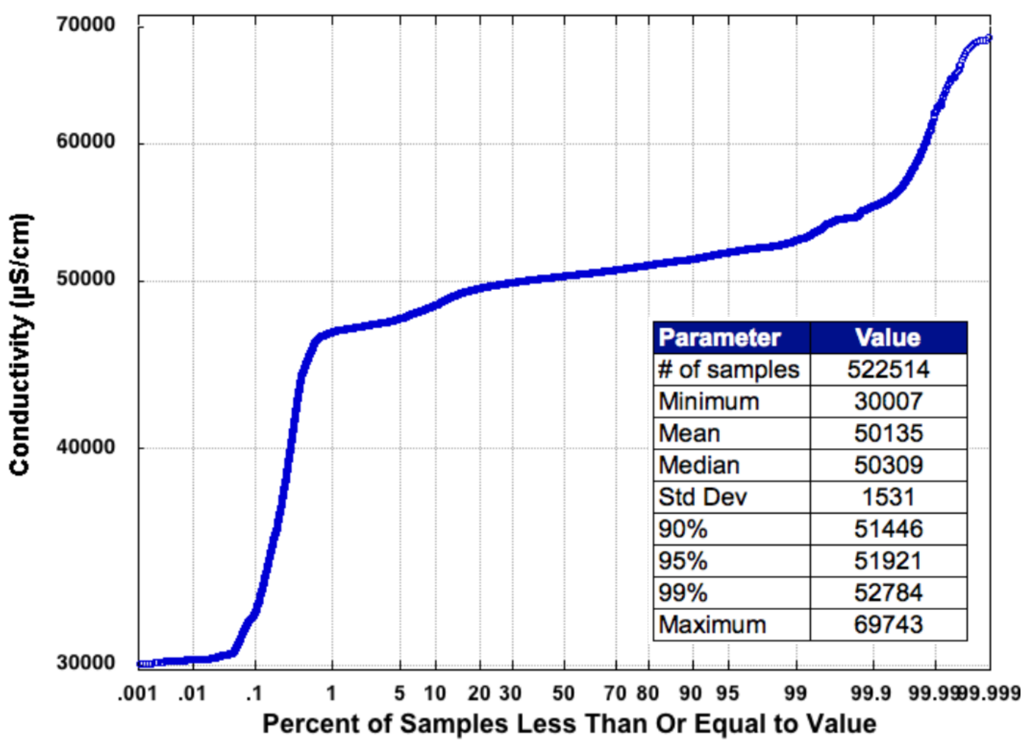
Parameter	Value
# of samples	23008
Minimum	0.00
Mean	0.14
Median	0.032
Std Dev	0.83
90%	0.12
95%	0.22
99%	1.1
Maximum	9

(b)

Figure 5-3: UF Filtrate turbidities, hourly medians determined based on continuous 1-minute and 15-minute data (a) Time Series (b) Probability Plot with summary statistics inset

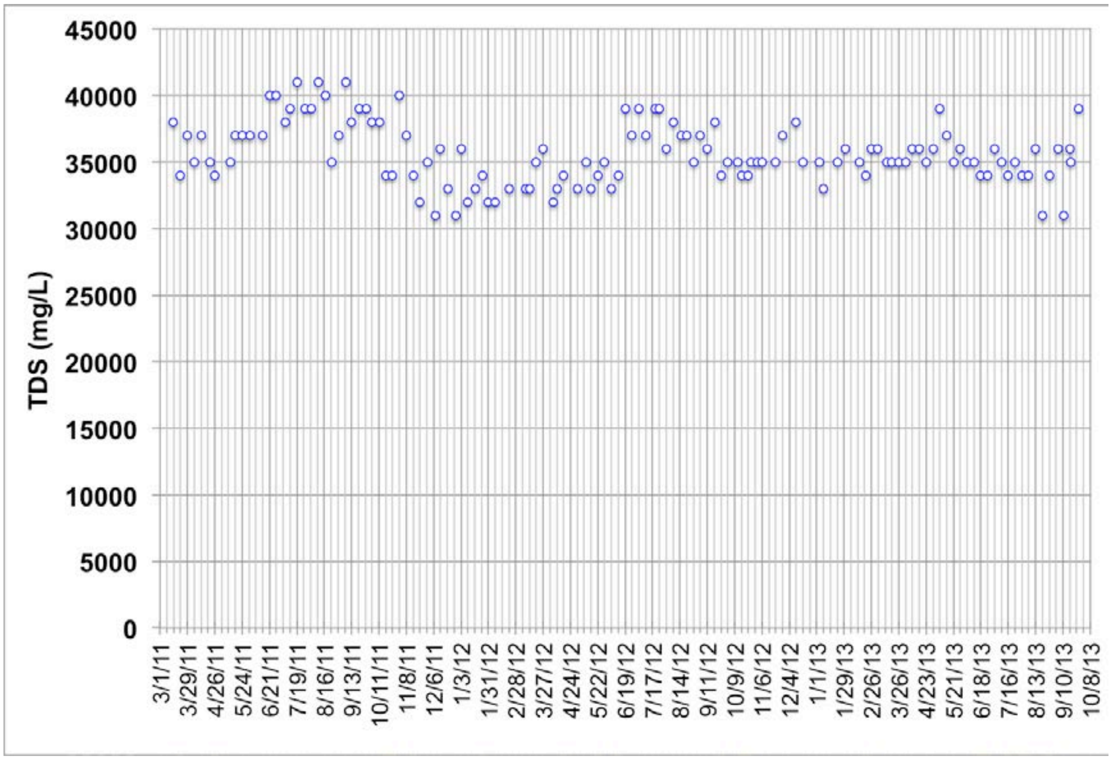


(a)

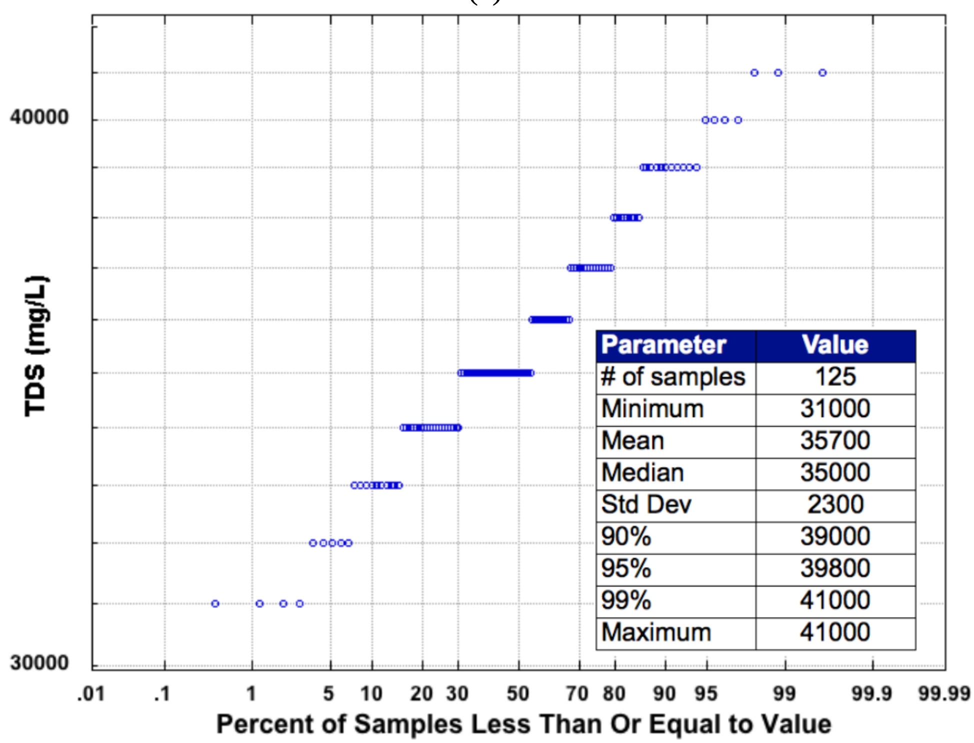


(b)

Figure 5-4: RO feed conductivity (a) monitored continuously (not normalized), with SDWA limits indicated (b) Probability plot with values <30,000 and >70,000 excluded with statistics inset

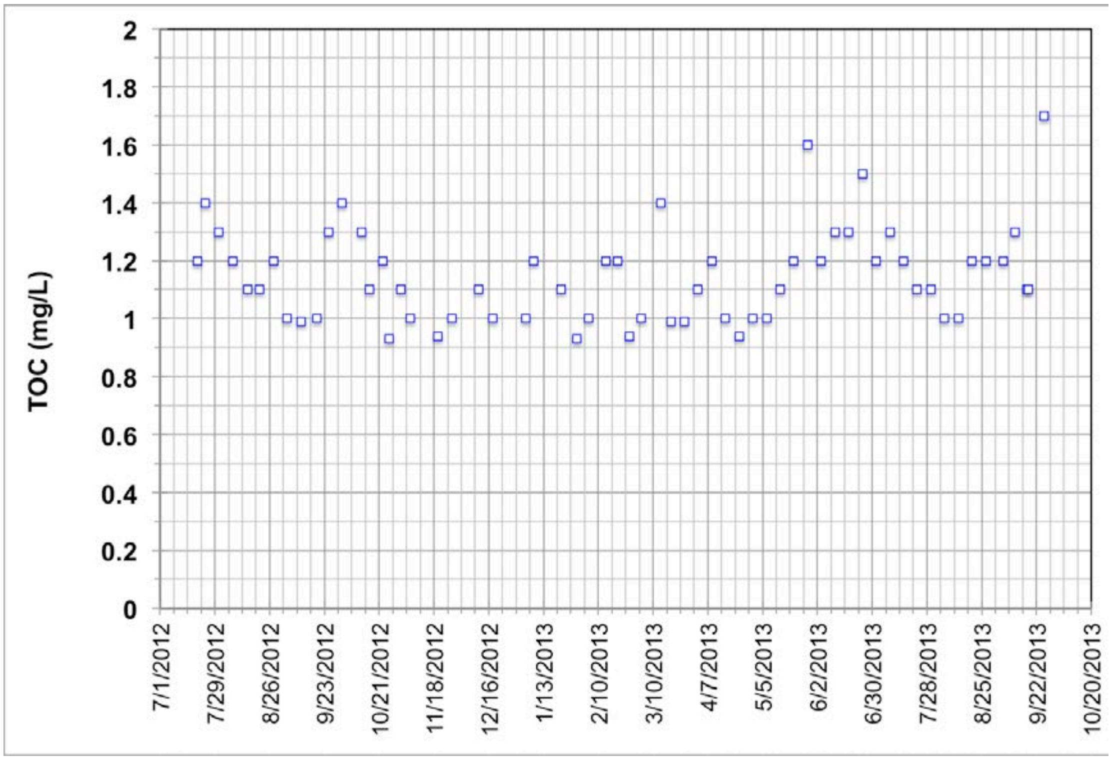


(a)

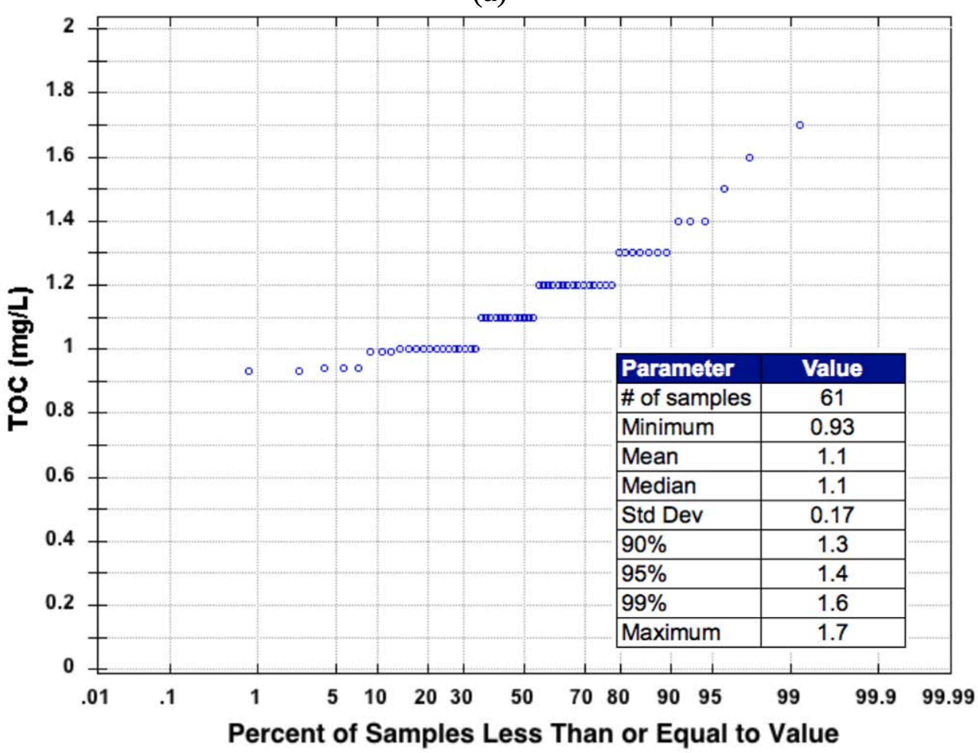


(b)

Figure 5-5: Source ocean water TDS (a) Grab samples collected weekly (b) Probability plot with with statistics inset



(a)



Parameter	Value
# of samples	61
Minimum	0.93
Mean	1.1
Median	1.1
Std Dev	0.17
90%	1.3
95%	1.4
99%	1.6
Maximum	1.7

(b)

Figure 5-6: Source ocean water TOC (a) Grab samples collected weekly (b) Probability plot with statistics inset

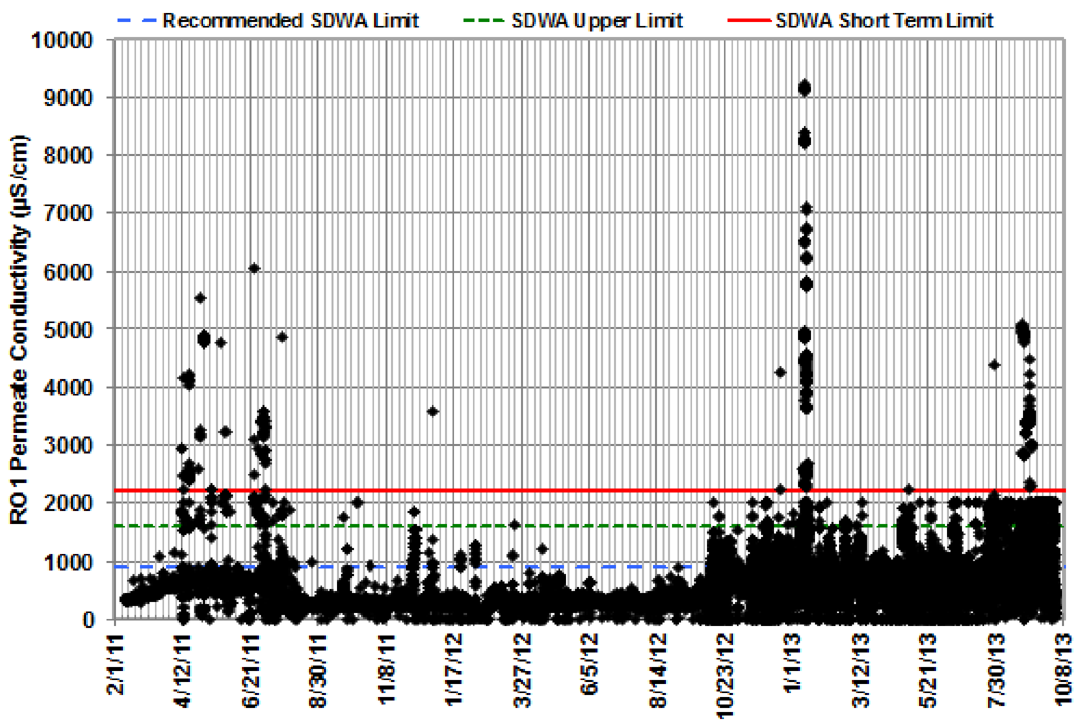


Figure 5-7: First pass combined RO permeate conductivity, monitored continuous, with SDWA limits indicated

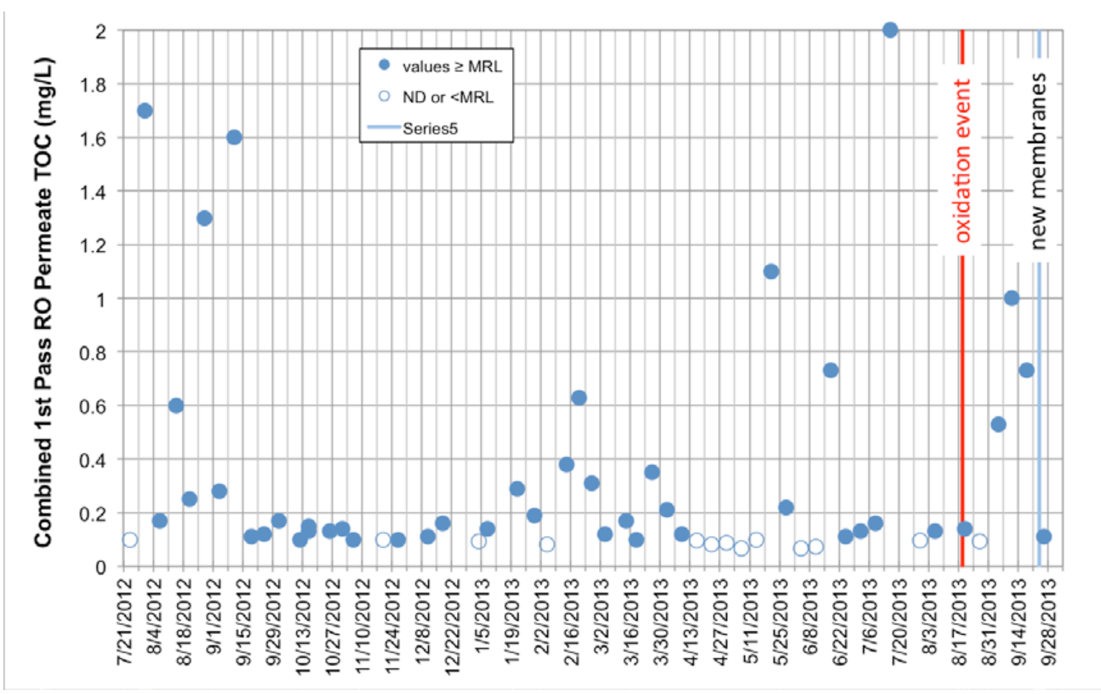


Figure 5-8: Combined 1st pass RO Permeate TOC

Figure 5-9 presents the chlorophyll-a in the ocean water measured both by the lab as well as with the online meter (AlgaeWatch) located just upstream of Arkal filters. Figure 5-10 presents details of the measurements performed in 2013. The lab detects of chlorophyll-a correlated well with spikes in the online data measured by the AlgaeWatch meter. These detects of chlorophyll-a above the background values in seawater likely are indicative of a red tide events.

Figure 5-9: Chlorophyll-a Concentration in ocean water

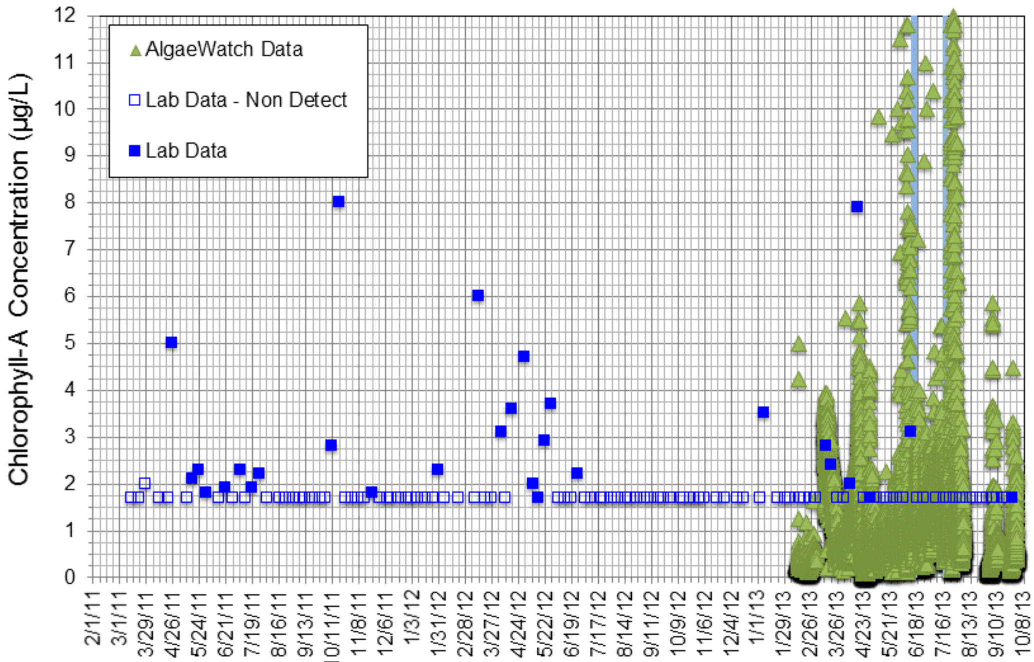
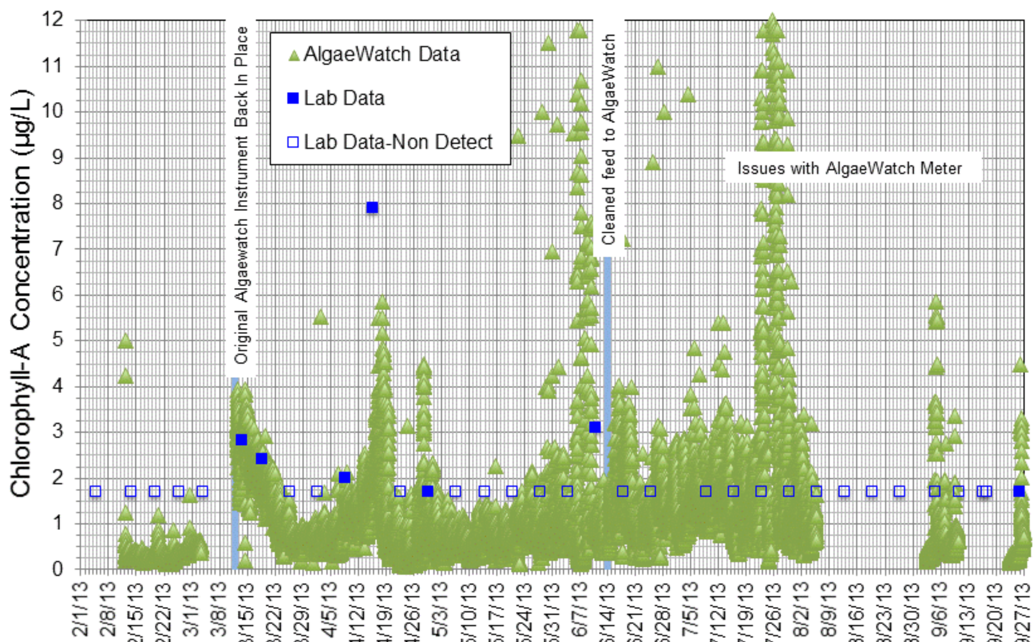


Figure 5-10: Details of Chlorophyll-a Concentration for 2013



Measurements of constituents with primary or secondary MCLs under the Safe Drinking Water Act (SDWA) and unregulated constituents with health-based advisory levels in California called Notification Levels (NLs) are summarized in for the combined RO permeate after partial 2nd pass RO. All constituents with primary and secondary MCLs or NLs were reduced to levels lower than regulatory limits or NLs at all times. The water quality objectives for boron, bromide, and chloride were consistently met in the combined RO permeate after partial 2nd pass RO.

Table 5-1 Summary of water quality compared to SDWA for Combined RO Permeate after Partial 2nd Pass RO

Chemicals with Limits in Drinking Water Regulations				Chemicals with Exceedances of Limits in Drinking Water Regulations			
Name	***Type***	***No. of Constituents***	***No. of Constituents Reported***	***No. of Constituents***	***List of Constituents***	***No. of Observance***	***No. of Exceedance***
Inorganic Chemicals	Primary MCLs	17	17	0	N/A	N/A	N/A
Organic Chemicals	Primary MCLs	60	60	0	N/A	N/A	N/A
Various Types of Chemicals	Secondary MCLs[2]	18	18	0	N/A	N/A	N/A
Radionuclides	Primary MCLs	7	7	0	N/A	N/A	N/A
Various Types of Chemicals	NLs	31	31	0	N/A	N/A	N/A

A full set of data for constituents measured for evaluation with respect to the SDWA over 2010-2013 is provided in the Appendix. The rejection of TDS through the combined 1st pass RO membranes is shown in Figure 5-11. The TDS removal exceeds 99% in all cases, with the exception of a few short periods when NanoH$_2$O Conventional SW400ES, NanoH$_2$O Hybrid SW400R/SW400ES, and Dow Hybrid SW30XLE/SW30ULE membranes were in place during the energy optimization studies and immediately following the oxidation event on 8/19/2013 discussed above.

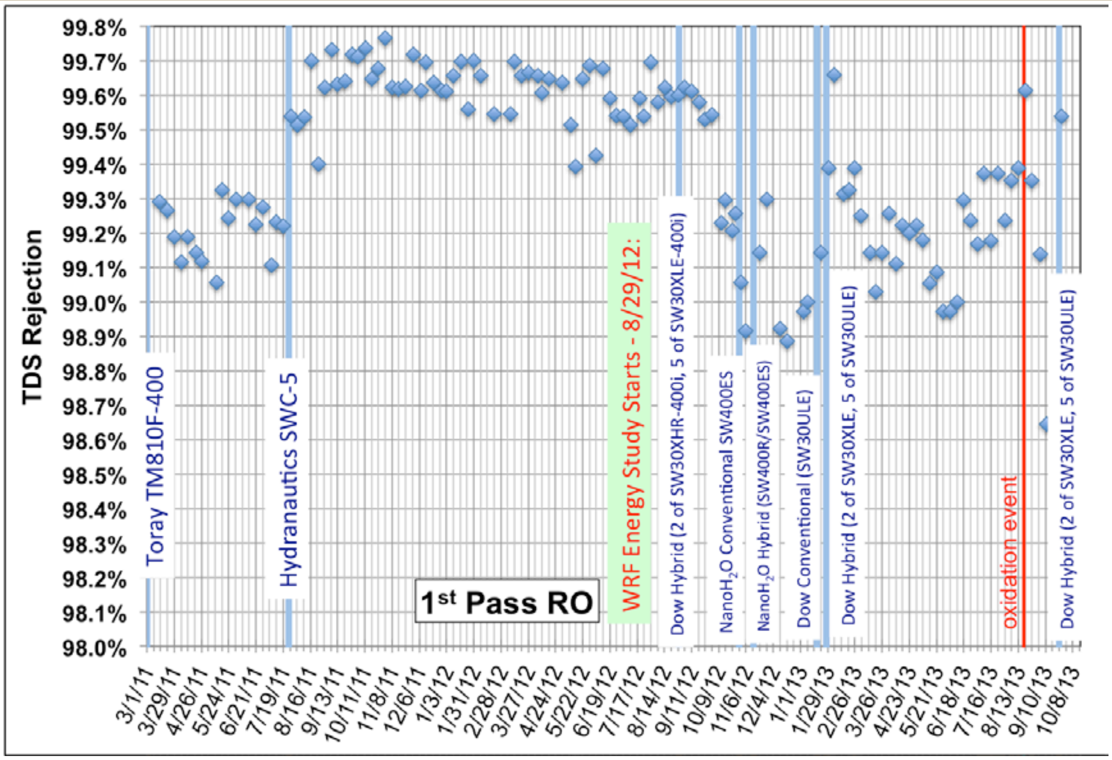


Figure 5-11: Rejection of TDS through the combined 1st pass RO membranes

Table 5-2 summarizes water quality data collected for the Ocean Plan constituents from the raw water, 1st pass RO concentrate, reconstituted ocean water discharge, and the receiving water, respectively. There were exceedances of the Ocean Plan limits for copper, ammonia, beta/photon emitters adjusted for K-40 benzidine, NDMA, TCDD Equivalents, bis (2-ethylhexyl), lead, nickel, beryllium and zinc since the monitoring program began. No other constituents monitored at any of the specified sampling locations were in exceedance of Ocean Plan limits.

The beta/photon emitters exceedances occurred in 1st pass RO concentrate, and reconstituted ocean water discharge. Investigation of the analytical method for determining beta/photon emitters revealed that the K-40 adjustment is based on an approximation of K-40 photons calculated using a correction factor in conjunction with a measurement of total potassium. Pacific Ocean marine waters off the California coast have been found to contain gross beta levels that exceed the Ocean Plan limit of 50 pCi/L (CDM 2010). In order to gain a more thorough understanding of the beta/photon emitters, each sample that was in exceedence of 50 pCi/L was analyzed with a full gamma scan, to provide a more complete understanding of the contribution of K-40 to the ocean water sample. While beta/photon emitters adjusted for K40 were detected at levels exceeding Ocean Plan limits in the raw ocean water, in the RO concentrate, and in the reconstituted ocean water discharge, a subsequent gamma isotope scan of these locations for beta/photon emitters showed the presence of only naturally occurring K40 at detectable levels. This demonstrates that the exceedances were associated with analytical error in the gross beta method and/or inaccuracies in the estimate of K40 as a fraction of inorganic potassium and do not indicate the presence of beta/photon emitters.

Benzidine and NDMA showed up at detectable levels only in the raw ocean water in the Nov. 2011 sampling but they were non-detect in the 1st pass RO concentrate and in the reconstituted ocean water. This suggests that the raw ocean water detection may be a consequence of laboratory error. Bis (2-ethylhexyl) phthalate was detected in two samples from the 1st pass RO concentrate at a level that exceeded the Ocean Plan 30-day average limit of 3.5 µg/L. This compound is commonly detected in association with laboratory contamination. There were two exceedences of this limit in samples collected from the reconstituted ocean water discharge, however upon rerunning these samples, the analytical lab found both to be either below the method detection limit (MDL) or non-detect (ND). There was one exceedance of this compound in the receiving water. The fact that it was not measured at detectable levels in the source ocean water is further evidence supporting laboratory contamination.

There were four exceedances of copper in the source ocean water, seven exceedances of copper in the 1st pass RO concentrate, 25 exceedances of copper in the reconstituted ocean water discharge, and two exceedances of copper in the receiving water before any dilution credits were factored in. The source ocean water samples were collected on-shore, downstream of the intake screens, while the receiving water samples, representing the ambient water condition, were collected offshore at a depth of approximately 5 feet below the water surface directly above the facility outfall.

The first copper exceedance in the source water was reported in August 2011 at the time when the Cook Legacy screens were in use, which was the same as the concentration reported for the receiving water sample (i.e. the ambient condition). Two subsequent copper exceedances of the source ocean water samples had concentrations above those measured in the receiving water samples (i.e. the ambient condition) between February and August 2012. This suggests that the elevated source ocean water copper levels relative to the ambient condition may have been related to the intake screens[1]. The first instance (2/21/2012) was concurrent with the use of the Cook Legacy wedge wire intake screens[1]. Prior to this sampling event, structural failure and severe macrofouling had been reported[1]. The deteriorating screens could have elevated copper concentrations in the source ocean water above the receiving water concentration. A similar exceedance (i.e. above the Ocean Plan limit and above the ambient water copper concentration) was observed in August 2012 after the Cook Legacy screen had been replaced by the Johnson Z-Alloy screens. It is noted that a subsequent source water and receiving water sampling event conducted in February 2013, at which time the Johnson Z-Alloy intake screen remained in use, showed that copper concentrations in samples from both locations were comparable and below the Ocean Plan limit. The final copper exceedance in the source water was detected in samples collected in August 2013, at which time a Johnson Z-Alloy screen and a Hendricks tee screen were in alternate use[1]. The February and August 2012 type of exceedances, i.e. copper concentrations in the source water were above the receiving water concentrations, were not observed in this case. It is noted that copper concentrations in all discharges were within the discharge limit because a 10:1 dilution credit was given to the Ocean Water Desalination Demonstration Facility (OWDDF). However, whether such a dilution credit would be given to the full-scale desalination facility is presently unknown at this time.

There was a single exceedance of lead, nickel, and zinc (out of more than 45 samples each) in the reconstituted ocean water discharge, while none was observed in the 1st pass RO concentrate. The fact that a) these exceedences were all measured from the same sampling event (2/21/12), b) the exceedence values were more than 10 times the average values measured for these compounds, and c) the duplicate sample collected on that same day was below the limit, suggests that this exceedence may be attributable to laboratory contamination, though it could also result from deterioration of metal components in the

[1] The demonstration facility had experimented with three different copper-nickel (Cu-Ni) alloy wedge wire screens to evaluate their corrosion and antifouling characteristics. Two of them were made of 90-10 Cu-Ni alloys (i.e. Cook Legacy and Johnson Z-Alloy) and one was made of 70-30 Cu-Ni alloy (Hendricks Tee screen). The Cook Legacy screens were installed in October 2010. Signs of corrosion of the Cook Legacy screens were reported in late 2010 and cathodic protection using zinc anode was subsequently installed to reduce the corrosion rate. The use of cathodic protection was reported to have impaired the screens' antifouling property allowing macrofouling to occur. Severe macrofouling had caused structural failure of these screens which were removed in January and March 2012, respectively. They were replaced by the Johnson Z-Alloy installed at the end of March 2012. A Hendricks screen was installed to replace one of the Johnson Z-Alloy screens in March 2013.

plant. There was a single exceedance of ammonia in the 1st pass RO concentrate and 9 exceedances in the reconstituted ocean water discharge, suggesting that it may be necessary to breakpoint chlorinate to remove ammonia if sufficient dilution credit is not received at the full-scale and the chloramines are put in place to control biofouling at the full-scale. Breakpoint chlorination was not needed at the demonstration-scale because of the dilution credit received in the NPDES permit for the facility discharge.

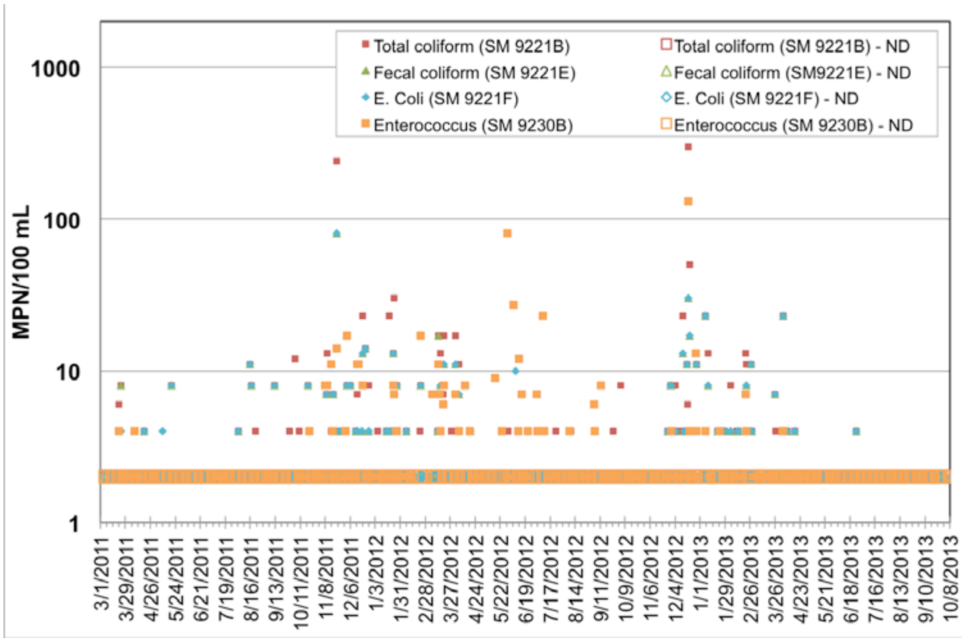
Table 5-2 Summary of water quality compared to Ocean Plan for (a) raw ocean water, (b) 1st pass RO concentrate, (c) reconstituted ocean water discharge, and (d) receiving water

Chemicals with Limits in Ocean Plan			Chemicals with Exceedances of Limits in Ocean Plan			
Name	***No. of Constituents***	***No. of Constituents Reported***	***No. of Constituents***	***List of Constituents***	***No. of Observance***	***No. of Exceedance***
(a) RAW OCEAN WATER QUALITY						
Protection of Marine Aquatic Life	25	25	2	Copper	6	4
				Gross Alpha Particle (excluding radon and uranium)	27	1
				Beta/photon emitters (adjusted for K40)	22	11*
				Ammonia	10	1
Protection of Human Health-Noncarcinogens	20	20	0	N/A	N/A	N/A
Protection of Human Health-Carcinogens	42	42	2	Benzidine	10	1
				N-nitrosodimethylamine	10	1
(b) 1st PASS RO CONCENTRATE WATER QUALITY						
Protection of Marine Aquatic Life	25	25	3	Copper	10	6
				Ammonia	10	1
				Beta/photon emitters (adjusted for K40)	21	10*
Protection of Human Health-Noncarcinogens	20	20	0	N/A	N/A	N/A
Protection of Human Health-Carcinogens	42	42	1	bis(2-ethylhexyl) phthalate	10	2
(c) RECONSTITUTED OCEAN WATER DISCHARGE WATER QUALITY						
Protection of Marine Aquatic Life	25	25	4	Copper	28	15
				Lead	26	1
				Ammonia	26	8
				Beta/photon emitters (adjusted for K40)	9	3*
Protection of Human Health-Noncarcinogens	20	20	0	N/A	N/A	N/A
Protection of Human Health-Carcinogens	42	42	2	Beryllium	16	1
				bis(2-ethylhexyl) phthalate	25	2**
(d) RECEIVING WATER QUALITY						
Protection of Marine Aquatic Life	25	25	3	Copper	13	2
				Zinc	12	2
				Beta/photon emitters (adjusted for K40)	7	2
Protection of Human Health-Noncarcinogens	20	20	0	N/A	N/A	N/A
Protection of Human Health-Carcinogens	42	42	1	bis(2-ethylhexyl) phthalate	13	1

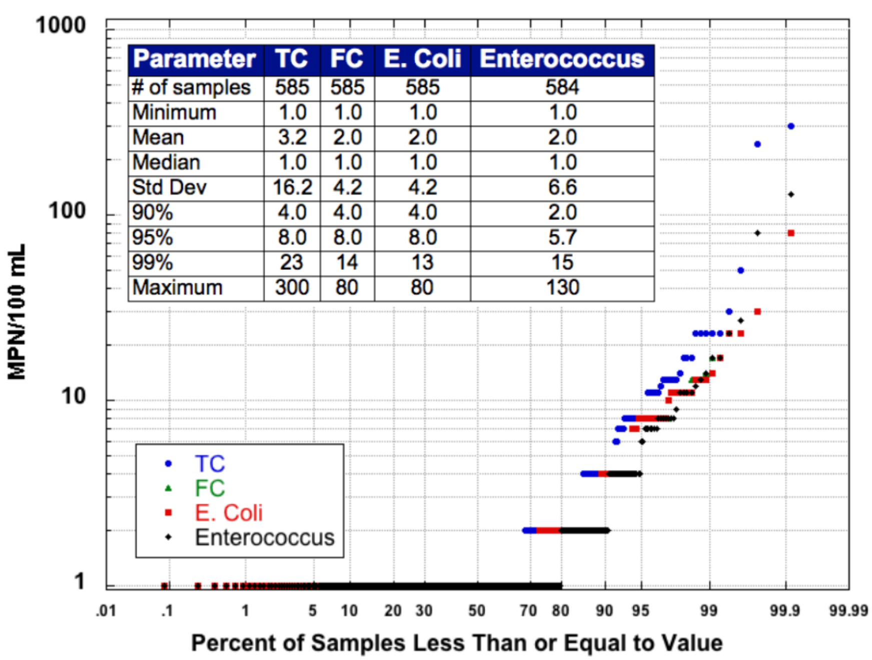
* While beta/photon emitters adjusted for K40 were detected at levels exceeding Ocean Plan limits in the raw ocean water and the RO concentrate, a subsequent gamma isotope scan of these locations for beta/photon emitters showed the presence of only naturally occurring K40 at detectable levels. This demonstrates that the exceedances were associated with analytical error in the gross beta method and/or inaccuracies in the estimate of K40 as a fraction of inorganic potassium and do not indicate the presence of beta/photon emitters

**Both exceedances of the Ocean Plan limit were rerun with nondetect results and attributed to laboratory contamination in the lab report.

Overall, bacteriological parameters were either non-detect or reported at low levels that don't present health concerns. Bacteriological results for the source ocean water are shown in Figure 5-12. Data collected for total coliform (TC), fecal coliform (FC), E. coli (EC), and Enterococcus over 2011-13 are summarized in Figure 5-12(a), with a probability plot with statistical results inset shown in Figure 5-12(b). It is observed that 99% of the TC data is < 23 MPN/100 mL, 99% of the FC data is < 14 MPN/100 mL, 99% of the EC data is < 13 MPN/100 mL, and 99% of the Enterococcus data is < 15 MPN/100 mL. All bacteriological results were below detection in daily sampling (weekdays) in the combined 1st pass RO permeate. A comparison of TC data from storm events is shown in Figure 5-13. There may be some evidence that TC levels increase after storms, but it is not consistent in all cases and as stated above, the overall quality of the source ocean water was not indicative of health concerns either with or without storm events during the course of testing.



(a)



Parameter	TC	FC	E. Coli	Enterococcus
# of samples	585	585	585	584
Minimum	1.0	1.0	1.0	1.0
Mean	3.2	2.0	2.0	2.0
Median	1.0	1.0	1.0	1.0
Std Dev	16.2	4.2	4.2	6.6
90%	4.0	4.0	4.0	2.0
95%	8.0	8.0	8.0	5.7
99%	23	14	13	15
Maximum	300	80	80	130

(b)

Figure 5-12: Bacteriological Results in the Source Ocean Water (a) Time Series (b) Probability Plot

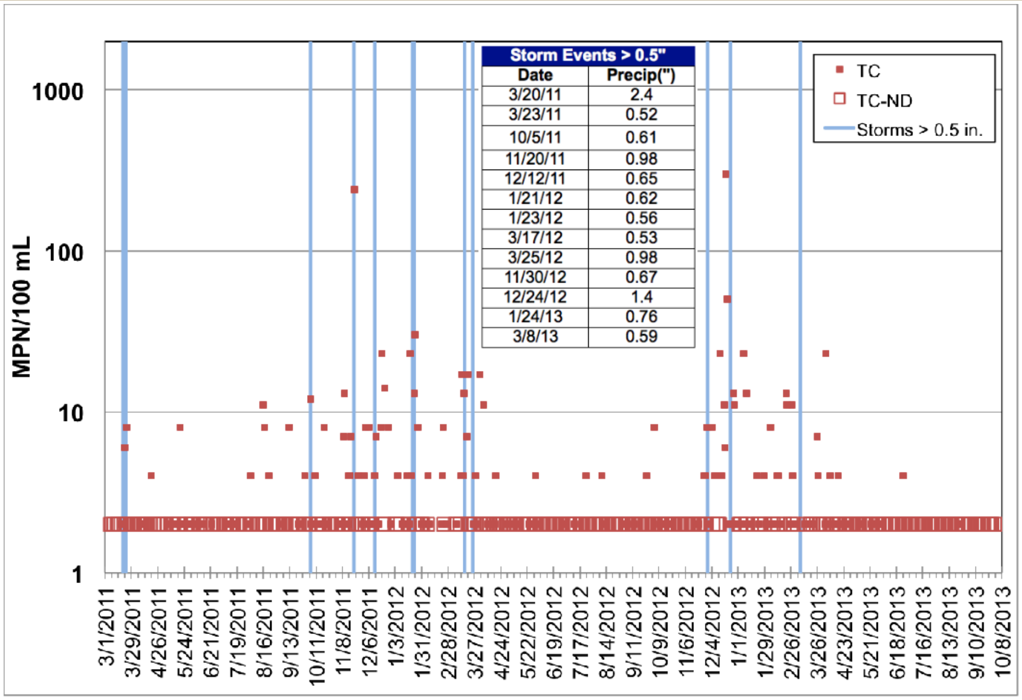


Figure 5-13: TC Results with Storms > 0.5 in. annotated on the plot

In terms of process control, the main water quality parameters that are indicative of RO process performance are chloride, bromide, and boron. The results over the life of the project from 2011-2013 are summarized in Table 5-3. The schematics shown in Figure 5-16 and Figure 5-17 provide process flow diagrams of the 1st pass RO and 2nd pass RO treatment processes, which are helpful in interpreting the data presented in Table 5-3. As shown in Table 5-3, the average boron level in the combined RO permeate out of the plant after partial 2nd pass RO was 0.36 mg/L and met the water quality objective of 0.5 mg/L and the CDPH NL of 1 mg/L. The average chloride and bromide levels in the combined RO permeate after partial 2nd pass RO were 19 and 0.092 mg/L, respectively, meeting the water quality objectives.

The chloride, bromide, and boron results are broken down by type of membrane in Table 5-4. For example, for the Hydranautics SWC5, the average chloride, bromide, and boron levels in the combined 1st pass RO permeate were 64, 0.28, and 0.74 mg/L, respectively. For the same membranes, the average chloride, bromide, and boron levels in the combined RO permeate after the partial 2nd pass RO were 14, 0.068, and 0.48, respectively. The boron results are summarized in Figure 5-14. The combined 1st pass RO permeate boron concentrations and combined RO permeate after partial 2nd pass RO are shown, with periods where the RO membranes were compromised denoted in Figure 5-14 by red dashed boxes. Boron rejection by the 2nd pass RO membranes is summarized in Figure 5-15, along with 2nd pass RO feed pH. The 2nd pass RO rejection of boron was consistently above 80% after the 2nd pass RO membranes were replaced in late August 2012, with boron rejection greater than 90% observed for much of 2013, until the oxidation event on 8/18/2013. After the 1st pass RO and 2nd pass RO membranes were replaced in late September 2013, the boron rejection returned to a level greater than 90%. The first set of 2nd pass RO membranes were in place from the outset of the project until late August 2012, with the lower 2nd pass RO boron rejection experienced during that time frame indicative that the membranes were compromised.

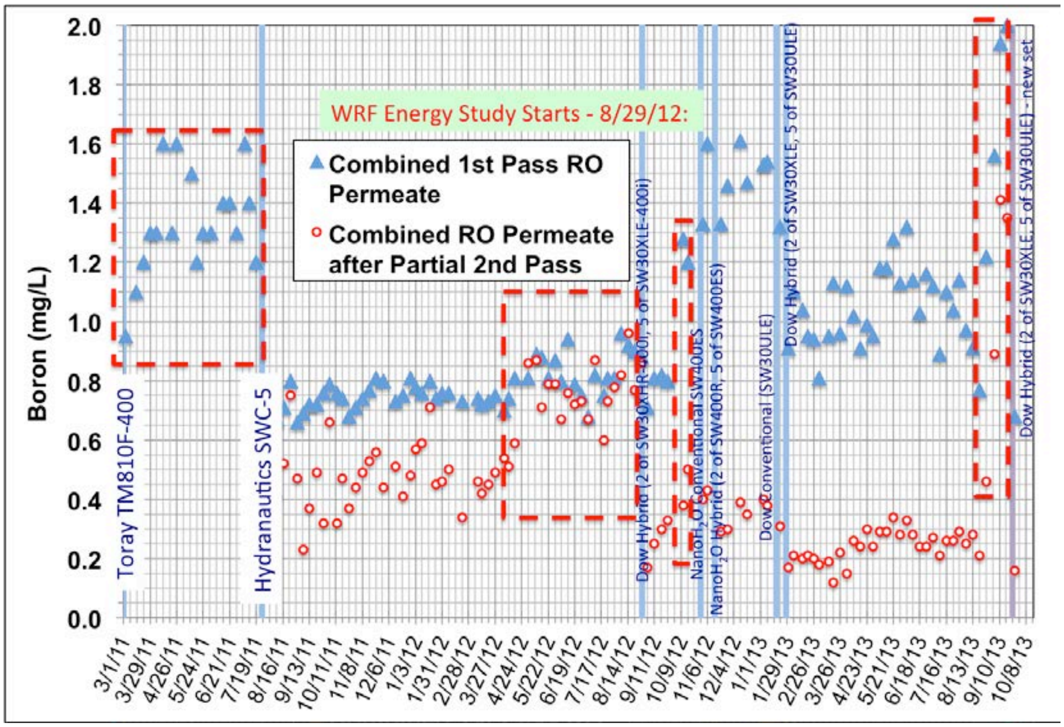


Figure 5-14: Boron results for combined 1st pass RO permeate and combined RO permeate after partial 2nd pass RO. Red dashed boxes indicate periods when the RO membranes were compromised.

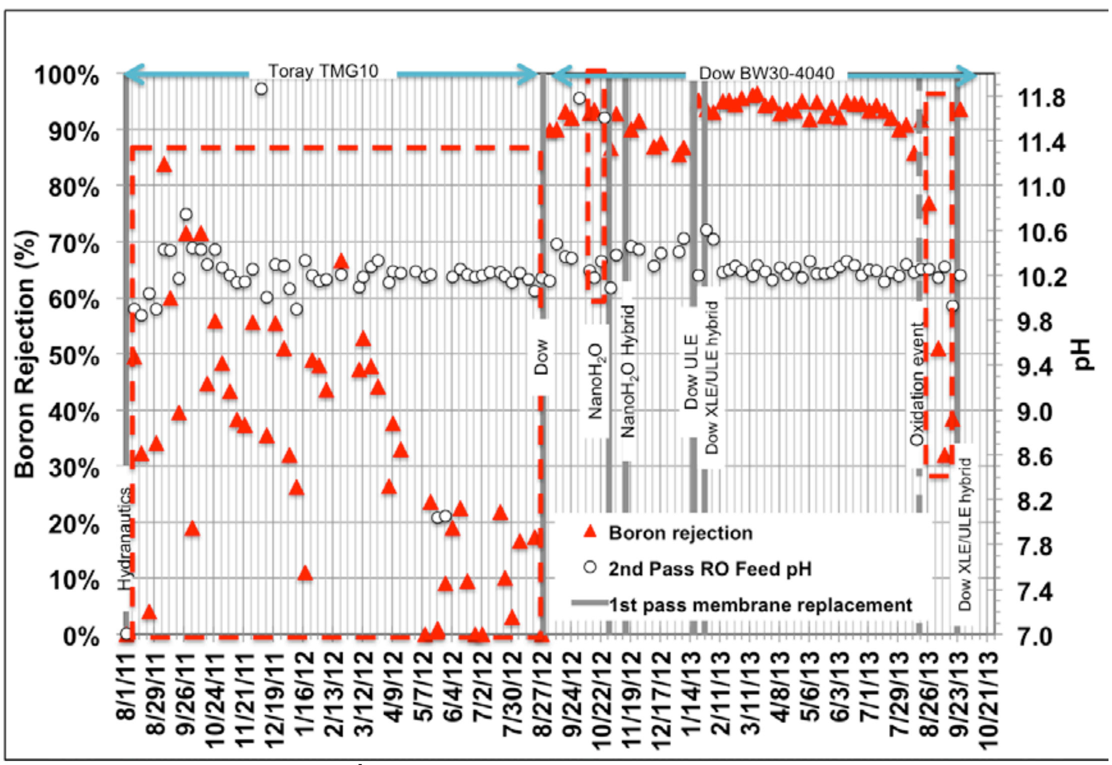


Figure 5-15: Boron Rejection for 2nd Pass RO. Red dashed boxes indicate periods when the 1st pass RO or 2nd pass RO membranes were compromised.

Table 5-3 Overall Water Quality

Summary of process control water quality indicators (a) raw ocean water, (b) 1st pass RO permeate lead end element, (c) 1st pass RO permeate tail end element, (d) calculated combined 1st pass RO permeate, (e) measured combined 1st pass RO permeate, (f) 2nd pass RO permeate, and (g) combined RO permeate. Values in (d) and (g) are calculated, not measureda

Constituent	Units	Average	Standard Deviation	Median	Minimum	Maximum	No. of Observations
(a) RAW OCEAN WATER QUALITY							
Chloride	mg/L	20548	1497	20100	15700	26800	122
Bromide	mg/L	68	5.5	68	55	79	34
Boron	mg/L	4.7	0.26	4.7	4.0	5.3	127
(b) 1st PASS RO PERMEATE LEAD END ELEMENT WATER QUALITY							
Chloride	mg/L	40	12	37	25	90	76
Bromide	mg/L	0.20	0.10	0.18	0.11	0.90	76
Boron	mg/L	0.45	0.09	0.43	0.29	0.76	76
(c) 1st PASS RO PERMEATE TAIL END ELEMENT WATER QUALITY[1]							
Chloride	mg/L	175	93	181	70	388	75
Bromide	mg/L	0.79	0.42	0.8	0.31	1.6	75
Boron	mg/L	1.3	0.39	1.2	0.80	2.3	75
(d) CALCULATED 1st PASS RO COMBINED PERMEATE WATER QUALITY							
Chloride	mg/L	123	60	121	54.5	257	75
Bromide	mg/L	0.56	0.29	0.50	0.10	1.1	75
Boron	mg/L	0.95	0.26	0.82	0.60	1.6	75
(e) MEASURED 1st PASS RO COMBINED PERMEATE WATER QUALITY							
Chloride	mg/L	177	43	178	58.8	254	38
Bromide	mg/L	0.80	0.18	0.81	0.36	1.1	38
Boron	mg/L	1.1	0.25	1.1	0.60	1.6	36
(f) 2nd PASS RO PERMEATE WATER QUALITY							
Chloride	mg/L	3.9	1.6	3.9	1.6	11	77
Bromide	mg/L	0.027	0.034	0.021	0.0066	0.23	77
Boron	mg/L	0.29	0.23	0.17	0.046	0.95	77
(g) CALCULATED COMBINED RO PERMEATE WATER QUALITY							
Chloride	mg/L	19	5	17	9.0	34	75
Bromide	mg/L	0.092	0.033	0.080	0.050	0.21	74
Boron	mg/L	0.36	0.14	0.33	0.12	0.75	75

[a]Excludes RO performance data from periods when RO membranes were believed to be compromised.

Table 5-4 Water Quality by Phase/Membrane Type

Summary of process control water quality indicators (a) raw ocean water, (b) 1st pass RO permeate lead end element, (c) 1st pass RO permeate tail end element, (d) calculated combined 1st pass RO permeate, (e) measured combined 1st pass RO permeate, (f) 2nd pass RO permeate, and (g) combined RO permeate. Values in (d) and (f) are calculated, not measured. Each of the RO water quality summary sections are subdivided into phases, based on the various membrane types used.a

Constituent	Units	Average	Standard Deviation	Median	Minimum	Maximum	No. of Observations
(a) RAW OCEAN WATER QUALITY							
Chloride	mg/L	20548	1497	20100	15700	26800	122
Bromide	mg/L	68	5.5	68	55	79	34
Boron	mg/L	4.7	0.26	4.7	4.0	5.3	127

Constituent	Units	Average	Standard Deviation	Median	Minimum	Maximum	No. of Observations
(b) 1st PASS RO PERMEATE LEAD END ELEMENT WATER QUALITY							
PHASE 1: 1/31/11 - 7/24/11 Toray TM810F-400							
Chloride	mg/L	NA	NA	NA	NA	NA	NA
Bromide	mg/L	NA	NA	NA	NA	NA	NA
Boron	mg/L	NA	NA	NA	NA	NA	NA
PHASE 2: 7/25/11 - 8/28/12 Hydranautics SWC5							
Chloride	mg/L	32	6.5	31	25	65	33
Bromide	mg/L	0.14	0.031	0.13	0.11	0.29	33
Boron	mg/L	0.42	0.054	0.41	0.32	0.66	33
PHASE 3: 8/29/12 - 10/29/12 Dow XRH/XLE Hybrid							
Chloride	mg/L	41	10	44	27	48	4
Bromide	mg/L	0.1875	0.04	0.2	0.13	0.22	4
Boron	mg/L	0.42	0.09	0.45	0.29	0.5	4
PHASE 4a: 10/30/12 - 11/15/12 NanoH2O ES							
Chloride	mg/L	61	10	61	54	68	2
Bromide	mg/L	0.28	0.042	0.28	0.25	0.31	2
Boron	mg/L	0.69	0.11	0.68	0.61	0.76	2
PHASE 4b: 11/16/12 - 1/17/13 NanoH2O R/ES Hybrid							
Chloride	mg/L	47	4.5	47	40	53	6
Bromide	mg/L	0.35	0.27	0.23	0.23	0.90	6
Boron	mg/L	0.49	0.051	0.50	0.40	0.55	6
PHASE 5a: 1/18/13 - 1/27/13 Dow ULE							
Chloride	mg/L	NA	NA	89.9	89.9	89.9	1
Bromide	mg/L	NA	NA	0.40	0.40	0.40	1
Boron	mg/L	NA	NA	0.71	0.71	0.71	1
PHASE 5b thru 5d: 1/28/13 - 9/23/13 Dow XLE/ULE Hybrid							
Chloride	mg/L	45	8	46	33	62	29
Bromide	mg/L	0.22	0.039	0.22	0.16	0.29	29
Boron	mg/L	0.46	0.078	0.45	0.30	0.63	29
PHASE 6: 9/24/13 - 9/30/13 Dow XLE/ULE Hybrid (new set)							
Chloride	mg/L	NA	NA	40.3	40.3	40.3	1
Bromide	mg/L	NA	NA	0.19	0.19	0.19	1
Boron	mg/L	NA	NA	0.31	0.31	0.31	1
(c) 1st PASS RO PERMEATE TAIL END ELEMENT WATER QUALITY[1]							
PHASE 1: 1/31/11 - 7/24/11 Toray TM810F-400							
Chloride	mg/L	NA	NA	NA	NA	NA	NA
Bromide	mg/L	NA	NA	NA	NA	NA	NA
Boron	mg/L	NA	NA	NA	NA	NA	NA
PHASE 2: 7/25/11 - 8/28/12 Hydranautics SWC5							
Chloride	mg/L	83	7.0	83	70	96	32
Bromide	mg/L	0.36	0.028	0.36	0.31	0.42	32
Boron	mg/L	0.92	0.052	0.92	0.80	1.0	32
PHASE 3: 8/29/12 - 10/29/12 Dow XRH/XLE Hybrid							
Chloride	mg/L	151	36	151	119	184	4
Bromide	mg/L	0.67	0.14	0.68	0.53	0.80	4
Boron	mg/L	1.2	0.23	1.3	0.94	1.4	4
PHASE 4a: 10/30/12 - 11/15/12 NanoH2O ES							
Chloride	mg/L	312	17	312	300	324	2
Bromide	mg/L	1.4	0.21	1.3	1.2	1.5	2
Boron	mg/L	2.0	0.28	2.0	1.8	2.2	2
PHASE 4b: 11/16/12 - 1/17/13 NanoH2O R/ES Hybrid							
Chloride	mg/L	336	41	330	290	388	6
Bromide	mg/L	1.5	0.15	1.5	1.3	1.6	6
Boron	mg/L	2.1	0.12	2.1	2.0	2.3	6
PHASE 5a: 1/18/13 - 1/27/13 Dow ULE							
Chloride	mg/L	NA	NA	276	276	276	1

Constituent	Units	Average	Standard Deviation	Median	Minimum	Maximum	No. of Observations
Bromide	mg/L	NA	NA	1.2	1.2	1.2	1
Boron	mg/L	NA	NA	1.7	1.7	1.7	1
PHASE 5b thru 5d: 1/28/13 - 9/23/13 Dow XLE/ULE Hybrid							
Chloride	mg/L	235	40	230	160	330	29
Bromide	mg/L	1.1	0.17	1.1	0.78	1.4	29
Boron	mg/L	1.4	0.16	1.4	1.1	1.8	29
PHASE 6: 9/24/13 - 9/30/13 Dow XLE/ULE Hybrid (new set)							
Chloride	mg/L	NA	NA	146	146	146	1
Bromide	mg/L	NA	NA	0.68	0.68	0.68	1
Boron	mg/L	NA	NA	0.86	0.86	0.86	1
(d) CALCULATED 1st PASS RO COMBINED PERMEATE WATER QUALITY							
PHASE 1: 1/31/11 - 7/24/11 Toray TM810F-400							
Chloride	mg/L	NA	NA	NA	NA	NA	NA
Bromide	mg/L	NA	NA	NA	NA	NA	NA
Boron	mg/L	NA	NA	NA	NA	NA	NA
PHASE 2: 7/25/11 - 8/28/12 Hydranautics SWC5							
Chloride	mg/L	64	5.3	65	55	73	32
Bromide	mg/L	0.28	0.025	0.28	0.24	0.36	32
Boron	mg/L	0.74	0.047	0.74	0.60	0.81	32
PHASE 3: 8/29/12 - 10/29/12 Dow XRH/XLE Hybrid							
Chloride	mg/L	91	6.3	90	86	100	4
Bromide	mg/L	0.41	0.024	0.41	0.38	0.44	4
Boron	mg/L	0.79	0.051	0.81	0.71	0.82	4
PHASE 4a: 10/30/12 - 11/15/12 NanoH2O ES							
Chloride	mg/L	221	25	221	204	239	2
Bromide	mg/L	0.92	0.12	0.91	0.83	1.0	2
Boron	mg/L	1.5	0.19	1.5	1.3	1.6	2
PHASE 4b: 11/16/12 - 1/17/13 NanoH2O R/ES Hybrid							
Chloride	mg/L	223	28	219	184	257	6
Bromide	mg/L	1.0	0.075	1.1	0.91	1.1	6
Boron	mg/L	1.5	0.095	1.5	1.3	1.6	6
PHASE 5a: 1/18/13 - 1/27/13 Dow ULE							
Chloride	mg/L	NA	NA	204	204	204	1
Bromide	mg/L	NA	NA	0.89	0.89	0.89	1
Boron	mg/L	NA	NA	1.3	1.3	1.3	1
PHASE 5b thru 5d: 1/28/13 - 9/23/13 Dow XLE/ULE Hybrid							
Chloride	mg/L	162	25	157	121	223	29
Bromide	mg/L	0.74	0.17	0.76	0.10	1.0	29
Boron	mg/L	1.0	0.12	1.0	0.81	1.3	29
PHASE 6: 9/24/13 - 9/30/13 Dow XLE/ULE Hybrid (new set)							
Chloride	mg/L	NA	NA	107	107	107	1
Bromide	mg/L	NA	NA	0.50	0.50	0.50	1
Boron	mg/L	NA	NA	0.68	0.68	0.68	1
(e) MEASURED 1st PASS RO COMBINED PERMEATE WATER QUALITY							
PHASE 1: 1/31/11 - 7/24/11 Toray TM810F-400							
Chloride	mg/L	NA	NA	NA	NA	NA	NA
Bromide	mg/L	NA	NA	NA	NA	NA	NA
Boron	mg/L	NA	NA	NA	NA	NA	NA
PHASE 2: 7/25/11 - 8/28/12 Hydranautics SWC5							
Chloride	mg/L	NA	NA	59	59	59	1
Bromide	mg/L	NA	NA	0.36	0.36	0.36	1
Boron	mg/L	NA	NA	0.60	0.60	0.60	1
PHASE 3: 8/29/12 - 10/29/12 Dow XRH/XLE Hybrid							
Chloride	mg/L	NA	NA	NA	NA	NA	0
Bromide	mg/L	NA	NA	NA	NA	NA	0

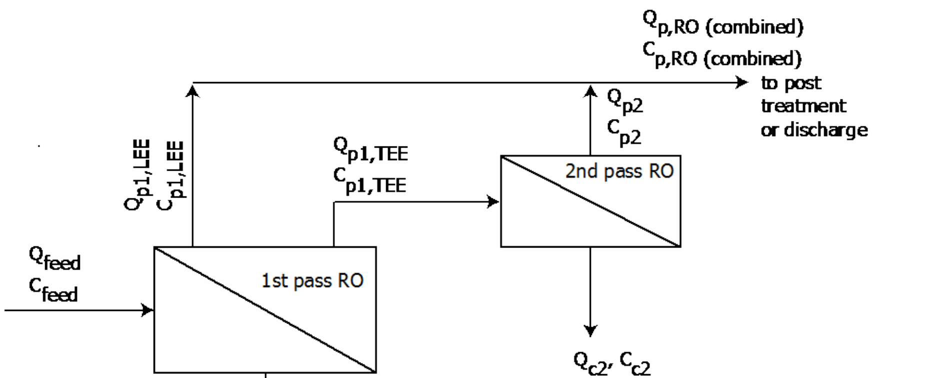
Constituent	Units	Average	Standard Deviation	Median	Minimum	Maximum	No. of Observations
Boron	mg/L	NA	NA	NA	NA	NA	0
PHASE 4a: 10/30/12 - 11/15/12 NanoH2O ES							
Chloride	mg/L	NA	NA	236	236	236	1
Bromide	mg/L	NA	NA	1.0	1.0	1.0	1
Boron	mg/L	NA	NA	1.6	1.6	1.6	1
PHASE 4b: 11/16/12 - 1/17/13 NanoH2O R/ES Hybrid							
Chloride	mg/L	225	25	225	194	254	6
Bromide	mg/L	1.0	0.096	1.0	0.84	1.1	6
Boron	mg/L	1.5	0.041	1.5	1.5	1.6	6
PHASE 5a: 1/18/13 - 1/27/13 Dow ULE							
Chloride	mg/L	NA	NA	NA	NA	NA	0
Bromide	mg/L	NA	NA	NA	NA	NA	0
Boron	mg/L	NA	NA	NA	NA	NA	0
PHASE 5b thru 5d: 1/28/13 - 9/23/13 Dow XLE/ULE Hybrid							
Chloride	mg/L	172	31	172	110	230	29
Bromide	mg/L	0.78	0.13	0.79	0.54	1.1	29
Boron	mg/L	1.1	0.14	1.1	0.82	1.3	27
PHASE 6: 9/24/13 - 9/30/13 Dow XLE/ULE Hybrid (new set)							
Chloride	mg/L	NA	NA	103	103	103	1
Bromide	mg/L	NA	NA	0.47	0.47	0.47	1
Boron	mg/L	NA	NA	0.63	0.63	0.63	1
(f) 2nd PASS RO PERMEATE WATER QUALITY							
PHASE 1: 1/31/11 - 8/28/12 Toray TMG10							
Chloride	mg/L	4.0	0.73	4.0	2.1	5.2	32
Bromide	mg/L	0.025	0.025	0.021	0.013	0.16	32
Boron	mg/L	0.52	0.18	0.5	0.14	0.95	32
PHASE 2: 8/29/12 - 9/23/13 Dow BW30							
Chloride	mg/L	3.8	2.0	3.2	1.6	11	44
Bromide	mg/L	0.025	0.026	0.019	0.0066	0.17	44
Boron	mg/L	0.12	0.068	0.10	0.046	0.32	44
PHASE 3: 9/24/13 - 9/30/13 Dow BW30 (new set)							
Chloride	mg/L	NA	NA	4.2	4.2	4.2	1
Bromide	mg/L	NA	NA	0.23	0.23	0.23	1
Boron	mg/L	NA	NA	0.055	0.055	0.055	1
(g) CALCULATED COMBINED RO PERMEATE WATER QUALITY							
PHASE 1: 1/31/11 - 7/24/11 Toray TM810F-400							
Chloride	mg/L	NA	NA	NA	NA	NA	NA
Bromide	mg/L	NA	NA	NA	NA	NA	NA
Boron	mg/L	NA	NA	NA	NA	NA	NA
PHASE 2: 7/25/11 - 8/28/12 Hydranautics SWC5							
Chloride	mg/L	14	1.3	14	12	17	32
Bromide	mg/L	0.068	0.021	0.060	0.05	0.15	32
Boron	mg/L	0.48	0.11	0.47	0.23	0.75	32
PHASE 3: 8/29/12 - 10/29/12 Dow XRH/XLE Hybrid							
Chloride	mg/L	21	7.6	23	12	28	4
Bromide	mg/L	0.10	0.033	0.10	0.060	0.13	4
Boron	mg/L	0.26	0.070	0.28	0.17	0.33	4
PHASE 4a: 10/30/12 - 11/15/12 NanoH2O ES							
Chloride	mg/L	30	5.7	30	26	34	2
Bromide	mg/L	0.14	0.028	0.14	0.12	0.16	2
Boron	mg/L	0.42	0.021	0.42	0.40	0.43	2
PHASE 4b: 11/16/12 - 1/17/13 NanoH2O R/ES Hybrid							
Chloride	mg/L	22	1.8	22	21	25	6
Bromide	mg/L	0.11	0.0089	0.12	0.10	0.12	5
Boron	mg/L	0.35	0.047	0.37	0.29	0.40	6
PHASE 5a: 1/18/13 - 1/27/13 Dow ULE							

Constituent	Units	Average	Standard Deviation	Median	Minimum	Maximum	No. of Observations
Chloride	mg/L	NA	NA	29	29	29	1
Bromide	mg/L	NA	NA	0.16	0.16	0.16	1
Boron	mg/L	NA	NA	0.31	0.31	0.31	1
PHASE 5b thru 5d: 1/28/13 - 9/23/13 Dow XLE/ULE Hybrid							
Chloride	mg/L	21	4.8	22	9.0	28	29
Bromide	mg/L	0.10	0.024	0.11	0.050	0.14	29
Boron	mg/L	0.24	0.052	0.24	0.12	0.34	29
PHASE 6: 9/24/13 - 9/30/13 Dow XLE/ULE Hybrid (new set)							
Chloride	mg/L	NA	NA	19	19	19	1
Bromide	mg/L	NA	NA	0.21	0.21	0.21	1
Boron	mg/L	NA	NA	0.16	0.16	0.16	1

[1]Ideal WQ objectives at the DDF were 0.5 mg/L boron, 0.3 mg/L bromide, and 100 mg/L chloride in the treated water. Plant was operated to achieve these targets, with boron controlling most, if not all of the time.

[a]Excludes RO performance data from periods when RO membranes were believed to be compromised.

Figure 5-16: Schematic of RO Treatment Process



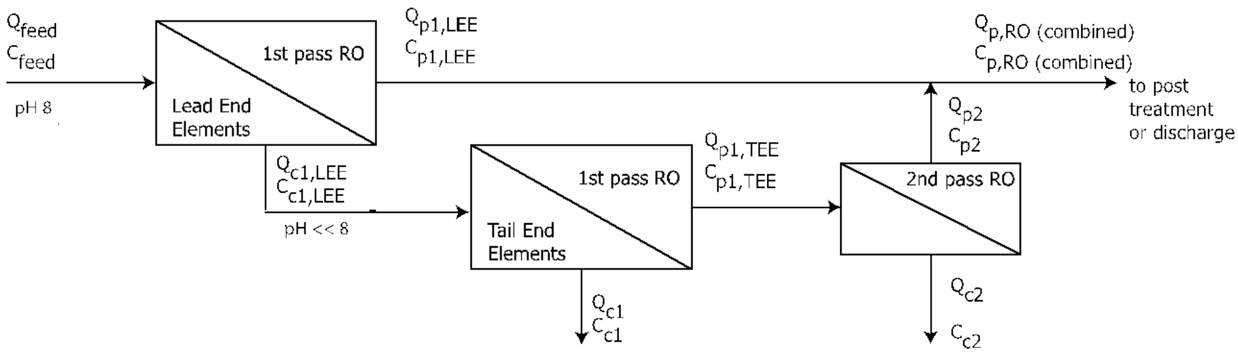
$$Q_{p,RO\ (combined)} = Q_{p1,LEE} + Q_{p2}$$

$$C_{p,RO\ (combined)} = \frac{Q_{p1,LEE}\, C_{p1,LEE} + Q_{p2}\, C_{p2}}{Q_{p,RO\ (combined)}}$$

$$Q_{p1,RO\ (combined)} = Q_{p1,LEE} + Q_{p1,TEE}$$

$$C_{p1,RO\ (combined)} = \frac{Q_{p1,LEE}\, C_{p1,LEE} + Q_{p1,TEE}\, C_{p1,TEE}}{Q_{p1,RO\ (combined)}}$$

Figure 5-17: More Detailed of Schematic of RO Treatment Process



Combined 1st pass RO Permeate:

$$Q_{p1,RO\ (combined)} = Q_{p1,LEE} + Q_{p1,TEE}$$

$$C_{p1,RO\ (combined)} = \frac{Q_{p1,LEE}\,C_{p1,LEE} + Q_{p1,TEE}\,C_{p1,TEE}}{Q_{p1,RO\ (combined)}}$$

Combined RO Permeate:

$$Q_{p,RO\ (combined)} = Q_{p1,LEE} + Q_{p2}$$

$$C_{p,RO\ (combined)} = \frac{Q_{p1,LEE}\,C_{p1,LEE} + Q_{p2}\,C_{p2}}{Q_{p,RO\ (combined)}}$$

Key:

p = permeate	1 = 1st pass RO
c = concentrate	2 = 2nd pass RO
LEE = lead end elements	Q = Flow
TEE = tail end elements	C = Concentration

5.2 Emerging Contaminants

In order to better characterize the occurrence and fate of contaminants of emerging concern (CECs) in the desalination treatment process, eight CEC compounds were selected for more rigorous monitoring (10 samples analyzed per year) in the raw water and combined 1st pass RO permeate. The following CECs are included in the OWDDF water assessment:

Estradiol	Gemfibrozil
Triclosan	DEET
Caffeine	Iopromide
N-Nitrosodimethylamine (NDMA)	Oxybenzone

Table 5-5 summarizes the CEC results from monitoring in both the raw water and combined 1st pass RO permeate. A complete summary of results from CEC monitoring in the raw water and those from the combined 1st pass RO permeate are presented in the appendix (Tables A-7 and A-8) including the sampling frequency, reporting limit, and dilution factor.

Table 5-5: Summary of emerging contaminants measured in (a) raw ocean water and (b) 1st pass combined RO permeate

Constituent	Units	Average	Standard Deviation	Median	Minimum	Maximum	No. of ND	No. of Observations
(a) RAW OCEAN WATER QUALITY								
Estradiol	ng/L	NA	NA	ND	ND	ND	24	24
Triclosan	ng/L	NA	NA	ND	ND	9.4	16	24
Caffeine	ng/L	NA	NA	2.9	ND	4.8	6	24
N-Nitrosodimethylamine (NDMA)	ng/L	NA	NA	ND	ND	<2.0	18	24
Gemfibrozil	ng/L	NA	NA	1.2	ND	1.4	1	24
DEET	ng/L	NA	NA	ND	ND	2.4	13	24
Iopromide	ng/L	NA	NA	ND	ND	<5.0	21	24
Oxybenzone	ng/L	NA	NA	3	ND	11	10	23
(b) 1st PASS COMBINED RO PERMEATE WATER QUALITY								
Estradiol	ng/L	NA	NA	ND	ND	ND	24	24
Triclosan	ng/L	NA	NA	ND	ND	18	19	24
Caffeine	ng/L	NA	NA	ND	ND	6.1	12	24
N-Nitrosodimethylamine (NDMA)	ng/L	NA	NA	ND	ND	3.5	16	24
Gemfibrozil	ng/L	NA	NA	ND	ND	<1.0	21	24
DEET	ng/L	NA	NA	ND	ND	1.4	16	24
Iopromide	ng/L	NA	NA	ND	ND	ND	24	24
Oxybenzone	ng/L	NA	NA	1.3	ND	7.2	10	23

Of the eight CECs monitored in the raw water and combined 1st pass RO permeate, two (estradiol and iopromide) were not detected above the reporting limit in either the raw water or the 1st pass RO permeate. NDMA was not detected above the reporting limit in the raw water, but found to be slightly above the reporting limit in 2 of 24 samples in the combined 1st pass RO permeate. Gemfibrozil was not detected above the reporting limit in the combined 1st pass RO permeate, but was detected with a maximum value of 1.4 ng/L in the raw water. Median values were found to be nondetect in 5 of the 8 CECs in the raw water and 7 of the 8 CECs in the combined 1st pass RO permeate. The exception was oxybenzone (sunscreen), detected at very low median level of 1.3 ng/L near the reporting limit of 1 ng/L.

5.3 Additional Sampling for NPDES Compliance

The OWDDF's NPDES permit requires monitoring of constituents regulated according to the Ocean Plan (Tables A-1 to A-4), as well as a select list of additional water quality parameters. All of the water quality parameters monitored in compliance with the NPDES permit are sampled both in the reconstituted ocean water discharge and the receiving water.

Beyond the required NPDES sampling locations, many of the constituents sampled for NPDES compliance are also monitored from sampling locations throughout the OWDDF treatment process to support process performance data generation as part of the OWDDF comprehensive water quality assessment. Sampling locations and frequencies vary, according to the individual constituent and potential treatment process implications.

The results of additional monitoring for NPDES compliance are summarized in Table 5-6 (complete data are presented in Tables A-8 to A-19). Data tables in the appendix (Tables A-8 to A-19) present each of the additional constituents monitored for NPDES compliance that were measured at various locations, along with details of sampling frequency, reporting limit, dilution factor, and reported values.

Table 5-6 Summary of additional constituents monitored for NPDES compliance

Parameters	Units	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
Raw Water										
Total coliform	MPN/100 mL	NA	NA	ND	ND	300	2	398	585	Daily
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	80	2	430	585	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	80	2	429	585	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	2400	10	461	585	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	130	1 ; 2	466	584	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	97	10	533	584	
HPC	CFU/mL	NA	NA	1	ND	240	1	257	585	
Gross Alpha Particle (excluding radon and uranium)	pCi/L	NA	NA	1.4	ND	16	-	3	27	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	156	93	130	40	380	-	0	22	
Chlorophyll a	ug/L	NA	NA	ND	ND	8.0	2	94	123	Weekly
Pre-screen Filtrate										
Total coliform	MPN/100 mL	NA	NA	ND	ND	8	2	21	28	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	4	2	22	28	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	4	2	22	28	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	31	10	22	28	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	4	1	23	28	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	10	10	25	28	
HPC	CFU/mL	NA	NA	1	ND	370	1	72	251	2x Week

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
Pre-screen Wash										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	28	28	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	28	28	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	28	28	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	41	10	23	28	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	4	1	24	28	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	51	10	25	28	
HPC	CFU/mL	NA	NA	7	ND	1700	1	32	241	2x Week
Total Suspended Solids (TSS)	mg/L	NA	NA	19	ND	44	5	1	27	Monthly
Turbidity	NTU	NA	NA	0.79	ND	24	0.1	19	124	Weekly

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
UF Filtrate										
Phase 1: 1/12/11 – 4/19/11 GE Zenon ZW1000 version 4										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	10	10	1	2	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	2	2	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
HPC	CFU/mL	NA	NA	ND	ND	1	1	8	10	2x Week
Phase 2: 4/20/11 – 11/15/12 GE Zenon ZW1000 version 4 (second set)										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	16	16	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	16	16	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	16	16	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	16	16	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	16	16	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	16	16	
HPC	CFU/mL	NA	NA	ND	ND	170	1	110	150	2x Week
Phase 3: 11/16/12 – 9/30/13 GE Zenon ZW1000 version 4 (third set)										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	10	10	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	10	10	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	10	10	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	10	10	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	10	10	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	10	10	
HPC	CFU/mL	NA	NA	ND	ND	67	1	72	91	2x Week

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
UF Wash										
Phase 1: 1/12/11 – 4/19/11 GE Zenon ZW1000 version 4										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	2	2	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
HPC	CFU/mL	59	90	18	4	280	1	0	10	2x Week
Biochemical Oxygen Demand, 5-day @ 20ºC (BOD)	mg/L	NA	NA	ND	ND	<2.0	2	1	2	Monthly
Total Suspended Solids (TSS)	mg/L	40	2.8	40	38	42	5	0	2	
Turbidity	NTU	4.2	4.1	3.9	0.030	8.8	0.1	0	4	Weekly
Phase 2: 4/20/11 – 11/15/12 GE Zenon ZW1000 version 4 (second set)										
Total coliform	MPN/100 mL	NA	NA	30	ND	50	2	5	16	Monthly
Fecal coliform	MPN/100 mL	NA	NA	30	ND	50	2	6	16	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	30	ND	30	2	6	16	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	117	ND	590	10	5	16	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	98.5	ND	170	1	7	16	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	30	10	11	16	
HPC	CFU/mL	NA	NA	43.5	ND	5700	1	3	148	2x Week
Biochemical Oxygen Demand, 5-day @ 20ºC (BOD)	mg/L	NA	NA	3.8	ND	6.8	2	2	15	Monthly
Total Suspended Solids (TSS)	mg/L	NA	NA	38	ND	110	5	1	15	
Turbidity	NTU	NA	NA	3.9	ND	29	0.1	2	79	Weekly

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
UF Wash										
Phase 3: 11/16/12 – 9/30/13 GE Zenon ZW1000 version 4 (third set)										
Total coliform	MPN/100 mL	NA	NA	3	ND	14	2	2	10	Monthly
Fecal coliform	MPN/100 mL	NA	NA	3	ND	14	2	2	10	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	3	ND	14	2	2	10	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	15	ND	720	10	3	10	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	2	ND	8	1	4	10	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	10	ND	31	10	2	10	
HPC	CFU/mL	6.5	6.4	3.8	2.4	23	2	0	10	2x Week
Biochemical Oxygen Demand, 5-day @ 20ºC (BOD)	mg/L	92	74	65	2.4	220	5	0	10	Monthly
Total Suspended Solids (TSS)	mg/L	NA	NA	28	ND	2200	1	8	91	
Turbidity	NTU	3.5	2.6	3	0.72	16	0.1	0	43	Weekly

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
RO1 Permeate										
PHASE 1: 1/31/11 - 7/24/11 Toray TM810F-400										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	82	82	Daily
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	82	82	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	82	82	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	82	82	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	2	2	Monthly
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
HPC	CFU/mL	NA	NA	1	ND	5700	1	13	35	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	0.3	0.42	0.3	0.0	0.6	-	0	2	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	NA	NA	ND	ND	ND	-	2	2	

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
RO1 Permeate										
PHASE 2: 7/25/11 - 8/28/12 Hydranautics SWC5										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	245	245	Daily
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	245	245	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	245	245	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	245	245	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	13	13	Monthly
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	13	13	
HPC	CFU/mL	NA	NA	1.0	ND	56.0	1	44	101	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	0.2	0.16	0.2	0.0	0.5	-	0	13	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	0.6	0.31	0.6	0.1	1.3	-	0	13	
PHASE 3: 8/29/12 - 10/29/12 Dow XRH/XLE Hybrid										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	42	42	Daily
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	42	42	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	42	42	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	42	42	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	2	2	Monthly
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
HPC	CFU/mL	NA	NA	ND	ND	11.0	1	13	17	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	0.6	0.48	0.6	0.2	0.9	-	0	2	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	0.4	0.45	0.4	0.1	0.8	-	0	2	

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
RO1 Permeate										
PHASE 4a: 10/30/12 - 11/15/12 NanoH2O ES										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	13	13	Daily
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	13	13	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	13	13	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	13	13	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	1	1	Monthly
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	1	1	
HPC	CFU/mL	NA	NA	ND	ND	2.0	1	3	5	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	NA	NA	NA	1.6	1.6	-	0	1	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	NA	NA	NA	3.0	3.0	-	0	1	
PHASE 4b: 11/16/12 - 1/17/13 NanoH2O R/ES Hybrid										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	34	34	Daily
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	34	34	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	34	34	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	34	34	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	2	2	Monthly
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
HPC	CFU/mL	NA	NA	12.0	ND	35.0	1	2	11	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	NA	NA	NA	0	0	-	0	1	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	NA	NA	NA	1.7	1.7	-	0	1	

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
RO1 Permeate										
PHASE 5a: 1/18/13 - 1/27/13 Dow ULE										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	5	5	Daily
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	5	5	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	5	5	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	5	5	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	NA	NA	NA	1	0	0	Monthly
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	NA	NA	NA	10	0	0	
HPC	CFU/mL	NA	NA	NA	ND	3	1	1	2	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	NA	NA	NA	NA	NA	-	0	0	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	NA	NA	NA	NA	NA	-	0	0	
PHASE 5b thru 5d: 1/28/13 - 9/23/13 Dow XLE/ULE Hybrid										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	148	148	Daily
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	148	148	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	148	148	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	148	148	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	7	7	Monthly
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	7	7	
HPC	CFU/mL	NA	NA	9	ND	77	1	14	68	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	1.1	1.34	0.6	0.3	4.0	-	0	7	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	0.8	0.49	0.9	0.2	1.3	-	0	7	

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
RO1 Permeate										
PHASE 6: 9/24/13 - 9/30/13 Dow XLE/ULE Hybrid (new set)										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	4	4	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	4	4	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	4	4	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	4	4	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	NA	ND	ND	1	1	1	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	NA	ND	ND	10	1	1	
HPC	CFU/mL	NA	NA	ND	ND	ND	1	2	2	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	NA	NA	NA	0.84	0.84	-	0	1	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	NA	NA	NA	NA	NA	-	0	0	

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
RO1 Concentrate										
PHASE 1: 1/31/11 - 7/24/11 Toray TM810F-400										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	2	2	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
HPC	CFU/mL	NA	NA	8.5	ND	5700	1	6	34	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	3.0	1.4	3.0	2	4.0	NA	0	2	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	1250	354	1250	1000	1500	NA	0	2	

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
RO1 Concentrate										
PHASE 2: 7/25/11 - 8/28/12 Hydranautics SWC5										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	13	13	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	13	13	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	13	13	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	13	13	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	13	13	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	13	13	
HPC	CFU/mL	NA	NA	29	1	5700	1	4	100	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	NA	NA	2.6	0.44	8.7	-	2	13	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	659	905	465	-120	3200	-	0	13	
PHASE 3: 8/29/12 - 10/29/12 Dow XRH/XLE Hybrid										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	2	2	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
HPC	CFU/mL	NA	NA	93	1	3100	1	1	17	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	5.1	5.5	5.1	1.22	9.02	-	0	2	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	-220	764	-220	-760	320	-	0	2	

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
RO1 Concentrate										
PHASE 4a: 10/30/12 - 11/15/12 NanoH2O ES										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	1	1	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	1	1	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	1	1	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	1	1	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	1	1	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	1	1	
HPC	CFU/mL	174	168	140	29	460	1	0	5	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	1.5	NA	1.5	1.5	1.5	-	0	1	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	-650	NA	-650	-650	-650	-	0	1	
PHASE 4b: 11/16/12 - 1/17/13 NanoH2O R/ES Hybrid										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	2	2	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	2	2	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	2	2	
HPC	CFU/mL	NA	NA	56	4	5700	1	1	12	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	1.1	1.4	1.1	0.11	2.0	-	0	2	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	-135	148	-135	-240	-30	-	0	2	

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
RO1 Concentrate										
PHASE 5a: 1/18/13 - 1/27/13 Dow ULE										
HPC	CFU/mL	40	35	40	15	64	1	0	2	2x Week
PHASE 5b thru 5d: 1/28/13 - 9/23/13 Dow XLE/ULE Hybrid										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	7	7	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	7	7	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	7	7	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	7	7	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	7	7	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	7	7	
HPC	CFU/mL	NA	NA	31	1	2700	1	3	64	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	NA	NA	0.88	0.15	2.6	-	1	7	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	-59	77	-43	-160	11	-	0	4	
PHASE 6: 9/24/13 - 9/30/13 Dow XLE/ULE Hybrid (new set)										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	1	1	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	1	1	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	1	1	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	1	1	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	1	1	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	1	1	
HPC	CFU/mL	183	223	183	25	340	1	0	2	2x Week
Gross Alpha Particle (excluding radon and uranium)	pCi/L	0.22	NA	0.22	0.22	0.22	NA	0	1	Monthly
Beta/photon emitters (adjusted for K40)	pCi/L	NA	NA	NA	NA	NA	NA	0	0	

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
2nd Pass RO Permeate										
PHASE 1: 1/31/11 - 8/28/12 Toray TMG10										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	321	321	Daily
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	321	321	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	321	321	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	321	321	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	15	15	Monthly
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	15	15	
HPC	CFU/mL	2.43	3.96	1	1	25	1	88	132	2x Week
PHASE 2: 8/29/12 - 9/23/13 Dow BW30										
Total coliform	MPN/100 mL	NA	NA	ND	ND	4	2	214	215	Daily
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	215	215	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	215	215	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	215	215	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	10	10	Monthly
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	10	10	
HPC	CFU/mL	10.8	20.7	2.0	1.0	88	1	54	90	2x Week
PHASE 3: 9/24/13 - 9/30/13 Dow BW30 (new set)										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	4	4	Daily
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	4	4	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	4	4	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	4	4	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	NA	ND	ND	1	1	1	Monthly
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	NA	ND	ND	10	1	1	
HPC	CFU/mL	NA	NA	ND	ND	1	1	1	2	2x Week

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
2nd Pass RO Concentrate										
PHASE 1: 1/31/11 - 8/28/12 Toray TMG10										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	15	15	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	15	15	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	15	15	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	15	15	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	15	15	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	15	15	
HPC	CFU/mL	153	552	52	1.0	5700	1	6	133	2x Week
PHASE 2: 8/29/12 - 9/23/13 Dow BW30										
Total coliform	MPN/100 mL	NA	NA	ND	ND	12	2	10	11	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	11	11	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	11	11	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	11	11	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	11	11	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	11	11	
HPC	CFU/mL	NA	NA	29	ND	5700	1	17	94	2x Week
PHASE 3: 9/24/13 - 9/30/13 Dow BW30 (new set)										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	1	1	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	1	1	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	1	1	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	1	1	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	ND	1	1	1	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	ND	10	1	1	
HPC	CFU/mL	NA	NA	ND	ND	ND	1	2	2	2x Week

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
Corrosion Control Effluent										
Total coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	27	27	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	ND	2	27	27	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	ND	2	27	27	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	ND	10	27	27	
HPC	CFU/mL	NA	NA	38	ND	5700	1	72	118	Week

Table 5-6 (continued) Summary of additional constituents monitored for NPDES compliance

Parameters	Unit	Mean	Standard Deviation	Median	Minimum	Maximum	Reporting Limit	No. of Non-Detects (ND)	No. of Observations	Sampling Frequency
Reconstituted Ocean Water Discharge										
Total coliform	MPN/100 mL	NA	NA	ND	ND	8	2	33	39	Monthly
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	4	2	36	39	
E. Coli (SM 9221F)	MPN/100 mL	NA	NA	ND	ND	4	2	36	39	
E. Coli (Colilert-18 (SM 9223B))	MPN/100 mL	NA	NA	ND	ND	41	10	34	39	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	ND	ND	7	1	27	39	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	10	10	33	39	
Biochemical Oxygen Demand, 5-day @ 20ºC (BOD); composite sample	mg/L	2.19	1.91	<2.0	<2.0	8.2	2	0	38	
Total Suspended Solids (TSS); composite sample	mg/L	NA	NA	13	ND	50	5	7	38	
Oil and Grease	mg/L	NA	NA	ND	ND	2	5	26	39	
Settleable Solids	mg/L	NA	NA	ND	ND	0.7	0.1	36	37	
Turbidity	NTU	1.0	0.71	0.76	0.15	2.4	0.1	0	18	Quarterly
Receiving Water										
Total coliform	MPN/100 mL	NA	NA	ND	ND	2	2	7	12	Semiannual
Fecal coliform	MPN/100 mL	NA	NA	ND	ND	2	2	7	12	
Enterococcus (SM 9230B)	MPN/100 mL	NA	NA	<1	ND	12	1	6	12	
Enterococcus (Enterolert)	MPN/100 mL	NA	NA	ND	ND	52	10	10	12	
Biochemical Oxygen Demand, 5-day @ 20ºC (BOD); composite sample	MPN/100 mL	NA	NA	ND	<2.0	<2.0	2	1	12	
Total Suspended Solids (TSS); composite sample	MPN/100 mL	NA	NA	16	ND	29	5	2	12	
Oil and Grease	CFU/mL	NA	NA	ND	ND	ND	5	13	13	
Settleable Solids	pCi/L	NA	NA	ND	ND	ND	0.1	12	12	
Turbidity	pCi/L	0.66	0.32	0.78	0.15	1.2	0.1	0	13	

5.4 Routine Sampling Parameters

Another aspect of the water assessment includes routine sampling for a number of water quality parameters indicative of process performance. Routine sampling parameters monitored in the raw water, as well as the RO permeates and concentrates include major and minor cations, major and minor anions, total organic carbon (TOC), total dissolved solids (TDS), and chlorophyll a. These constituents are summarized in the Appendix: Routine Monitoring Parameters, along with results for the tasting station and for copper. Key constituents for desalination process performance evaluation include boron, chloride, and bromide, presented in the water analysis summary section above.

Additionally, a number of routine water quality parameters are monitored from the pre-screen and UF wash sample locations, in order to better characterize the sludge from the desalination process. Results of sludge parameter routine monitoring, including sludge pH and % solids, sludge TCLP metals and organics, and chemical oxygen demand are presented the Appendix (Tables A-21 and A-22).

5.5 Special sampling

Special mineral sampling was conducted on February 5, May 7, and August 6, 2013. The purpose of the sampling was to more fully characterize the performance of the 1st pass RO and 2nd pass RO processes. The results of the special mineral sampling are shown in Table 5-7, Table 5-8, and Table 5-9. The results of the special mineral sampling demonstrate the effectiveness of the treatment process in meeting water quality objectives for boron, bromide and chloride They also demonstrate the effective removal across the treatment train of major and minor anions, as well as TDS, TOC, and conductivity.

Table 5-7 Results of Special Mineral Sampling Conducted on February 5, 2013 (1st Pass RO Membranes: Dow XLE/ULE Hybrid; 2nd Pass RO Membranes: Dow BW30)

	Item	Units	Raw Ocean Water	1st PASS RO				2nd PASS RO		Combined Permeate (Feed to Tasting Station)	Tasting Station Outlet
				LEE Permeate	TEE Permeate	Combined Permeate	Concentrate	Permeate	Concentrate		
LAB	B	mg/L	5.3	0.33	1.6	1.1	11	0.11	17	0.29	0.11
	Cl	mg/L	20000	33	280	176	46000	4.4	2980	16	19
	Br	mg/L	66	0.16	1.3	0.85	160	0.026	13	0.08	0.11
	Na	mg/L	12000	22	170	110	26000	5.1	2100	14	17
	Ca	mg/L	410	0.173	0.253	0.224	942	ND	2.6	ND	0.2
	Mg	mg/L	1330	0.528	0.748	0.662	3060	ND	7.88	0.23	0.11
	K	mg/L	500	1	8.9	5.7	1100	0.3	110	0.92	0.36
	SO_4	mg/L	2700	0.61	1.1	0.86	6100	ND	11	ND	ND
	alky	mg/L	120	2.9	3.4	3.4	260	6.7	150	5.1	9.9
	TDS	mg/L	34000	61	460	290	85000	15	4800	34	43
	TOC	mg/L	1	-	-	<0.1	2	<0.1	0.13	-	-
FIELD	pH	-	8.31	8.3	8.39	6.96	7.98	10.67	11.3	10.2	10.42
	Temp	ºC	14.4	15.1	15.3	13.9	-	15.7	-	15.2	15.4
	Conductivity	µS/cm	49950	117	666	449	-	38.7	-	70.8	128

Table 5-8 Results of Special Mineral Sampling Conducted on May 7, 2013 (1st Pass RO Membranes: Dow XLE/ULE Hybrid; 2nd Pass RO Membranes: Dow BW30)

	Item	Units	Raw Ocean Water	1st PASS RO				2nd PASS RO		Combined Permeate (Feed to Tasting Station)	Tasting Station Effluent
				LEE Permeate	TEE Permeate	Combined Permeate	Con-centrate	Perm-eate	Con-centrate		
LAB	B	mg/L	4.8	0.51	1.6	1.2	8.8	0.13	16	0.29	0.21
	Cl	mg/L	20800	62.1	298	216	43400	4.26	3220	29.8	29.4
	Br	mg/L	78	0.29	1.3	0.95	150	0.024	14	0.13	0.05
	Na	mg/L	11000	35	170	120	22000	4.7	1800	18	17
	Ca	mg/L	370	0.251	0.251	0.279	787	ND	2.57	0.10	2.8
	Mg	mg/L	1150	0.75	0.733	0.822	2450	ND	7.55	0.32	
	K	mg/L	390	1.4	8.6	5.6	810	0.22	110	0.82	
	SO_4	mg/L	2500	1.2	1.2	1.2	5400	ND	12	0.48	
	alky	mg/L	120	2.9	3.9	3.4	250	5.8	150	4.4	
	TDS	mg/L	39000	99	460	320	76000	13	4700	53	
	TOC	mg/L	1.0	-	-	-	1.9	<0.10	<0.10	-	-
FIELD	pH	-	7.86	8.61	8.11	7.35	7.73	10.45	10.89	9.51	8.07 / 7.84 (Weck)
	Temp	°C	18.3	18.2	18.3	18.9	-	18.7	-	19.1	20.1
	Cond.	µS/cm	50610	209	899	658	-	35.2	-	105	112

Table 5-9 Results of Special Mineral Sampling Conducted on August 6, 2013 (1st Pass RO Membranes: Dow XLE/ULE Hybrid; 2nd Pass RO Membranes: Dow BW30)

	Item	Units	Raw Ocean Water	1st PASS RO				2nd PASS RO		Combined Permeate (Feed to Tasting Station)	Tasting Station Effluent
				LEE Permeate	TEE Permeate	Combined Permeate	Conc-entrate	Perm-eate	Conc-entrate		
LAB	B	mg/L	4.7	0.43	1.3	0.950	8.8	0.12	14	0.24	0.18
	Cl	mg/L	23000	46	200	130	43000	8.3	2400	24	25
	Br	mg/L	64	0.210	0.810	0.74	130	0.058	0.096	0.120	0.14
	Na	mg/L	10000	27	120	80	22000	8.6	1400	16	17
	Ca	mg/L	366	0.162	0.244	0.210	780	<0.100	2.42	0.06	4.90
	Mg	mg/L	1180	0.477	0.735	0.628	2500	<0.100	6.97	0.20	0.34
	K	mg/L	510	1.1	5.4	3.6	1000	0.33	67	0.63	0.67
	SO_4	mg/L	3000	0.68	1.2	0.99	6200	ND	13	0.29	0.48
	alky	mg/L	120	2.6	3.1	5.0	250	8.8	130	8.1	19
	TDS	mg/L	34000	80	320	220	76000	19	3600	48	56
	TOC	mg/L	1.0	-	-	0.13	2.2	<0.10	0.10	-	-
FIELD	pH	-	7.73	7.76	7.32	7.27	7.55	10.44	10.75	10.11	10.03/ 7.84 (Weck)
	Temp	ºC	19.2	19.2	19.3	19.1	-	19.3	-	19.2	20.6
	Cond.	µS/cm	49600	166	701	360	-	66.7	-	101	122

6.0 CONCLUSIONS AND RECOMMENDATIONS

Operation of the OWDDF successfully demonstrated operation of the desalination process, yielding the following conclusions and recommendations.

- Three different wedgewire screen sizes were tested in this study: 0.5 mm, 1 mm, and 2 mm. Over the course of testing three materials where operated, Cook Legacy CuNi 90/10-7700, Johnson Z-Alloy and Hendricks Cu/Ni 90/10-7600. Results of this testing is provided in West Basin's Intake Biofouling and Corrosion Study.

- Shock Chlorination of intake lines was used successfully in maintaining the lines clear of biological attachment and a steady intake flow for the period of use. The recommended regimen is every 3-4 days for two (2) hours at 8 to 10 mg/L residual chlorine.

- Arkal filters (100 um) were successful in preventing fiber breakage in the UF system downstream for the first two set of UF membranes (22 months). While fiber breaks were experienced with the third membrane set there is no indication they were associated with particulates or shell fragments. It is possible the fiber breaks were present when the modules were initially installed. During normal feedwater quality (turbidity < 2 NTU), operation at a hydraulic load of 100 to 125 gpm/filter was sustainable, however this needed to be decreased to 65-80 gpm/filter during high turbidity feedwater. The Arkal filter model used in this study was 4" Galaxy, suitable to reduced flow rates at OWDDF. However, in a full scale design the 12" Galaxy Super Flow Systems should be considered. Spare capacity should be included to reduce the hydraulic load during events which result in degradation of the intake water quality, such as red tides. The necessity of backwash pumps should be reconsidered in a full scale design system if the feed pressure is be sufficient for direct backwash. Also, Arkal filtrate should be considered for backwash water; OWDDF used UF filtrate for backwash due to space limitations which restricted the addition of another tank.

- The GE-Zenon ZW-1000 UF system operated at a design flux set point of 25.5 gfd. It stabilized at significantly lower permeability (3.5 gfd/psi) than anticipated based on pilot results from El Segundo. This may have been a function of the current product performance or the site specific water quality differences between the Redondo Beach and El Segundo sites. A full scale design using this membrane should consider permeabilities of 3.5 gfd/psi or lower, as this study did not test UF membranes for the average membrane life. The longest period of operation with one membrane set was 1.6 years. A coagulant (ferric chloride) proved beneficial in stabilizing permeability and it is recommended for full scale design at 1 to 4 mg/L as $FeCl_3$, with the larger concentration considered for degraded seawater quality (e.g. during red tides).

- First pass RO system operated successfully at 50% recovery and average flux of 9 gfd. With the exception of oxidation events, all SWRO membranes sets delivered water quality which met the water quality goals (Boron ≤0.5 mg/L; Bromide ≤0.3 mg/L; Chloride ≤100 mg/L) when partly blended with the permeate from the second pass RO. The ultimate selection of membranes in a full scale design for the first pass RO and second pass RO is dictated by the lifecycle analysis of membranes capital and operational costs. Among operating costs, energy consumption plays a very important role. As discussed in the section *Power Consumption for SWRO system*, a SWRO membrane from the lower rejection/higher permeability class (such as NanoH_2O SWRO membranes) presents advantage in the energy consumption for the first pass, however it would require a larger second pass RO and a slightly larger intake and pretreatment system, impacting negatively the overall energy consumption for the plant.

Although different in salt rejection and permeability, both the Toray TMG10 and Dow BW30 membrane models used in the second pass RO were successful in achieving the water quality goals for the project. Recovery was maintained at 90% whereas two flux setpoints were considered, 16 gfd and 22.4 gfd, both allowing a stable operation. In a full scale design, the size of the second pass RO will be dictated by a series of factors, such as the temperature and water quality of the first pass RO permeate, the final water quality goals and the type of membranes used in the second pass.

- First pass RO system was equipped with an isobaric energy recovery device (ERD) provided by ERI. The ERD maintained a high efficiency (~95%) for the entire duration of the study. Such units are largely used in existing SWRO plants and they are recommended for consideration in the full scale plant design.

- Calculations of Specific Energy Consumption (SEC) for this study showed values between 9.3 and 9.8 kWh/kgal first pass permeate for first pass RO and between 2.1 and 2.4 kWh/kgal second pass permeate for second pass RO.

- The use of pre-formed chloramines in the RO feedwater, while showing benefit for biogrowth control in the cartridge filters and RO membranes, posed operational risks on the membrane elements in terms of potential for chemical oxidation. When the RO system was shut down for longer than a few hours, membranes were chemically damaged by a strong oxidant formed by reaction of chloramines with bromides present in seawater trapped in the annular space of the pressure vessels. Such shutdown events would require flushing with de-chloraminated RO permeate water. A staggered flush sequence with redundant SBS dosing is the most promising approach for shutdown sequences. However, the catastrophic impact of an ineffective or insufficient flush requires such a process to be fail safe. Under the condition of a power failure, backup power and sufficient flush water volume for all trains would be required to protect the membranes. It is recommended that further development of flush sequences and redundancy would need to be addressed prior to full scale implementation.