West Basin Municipal Water District
Ocean Water Desalination Pilot Program
Final Comprehensive Report 2002-2009

FINAL

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Executive Summary

1.0 EXECUTIVE SUMMARY

The West Basin Municipal Water District (District) located in a coastal portion of Los Angeles County, CA, began assessing the feasibility of full-scale seawater desalination over ten years ago, as part of an interest in diversifying its water supply and reducing dependence on imported water. Initial feasibility studies indicated seawater desalination as a viable option for a local, drought-proof water supply for this water district. In 2002 the District embarked on the Ocean Water Pilot Study Program (pilot study), a multi-phase pilot study program which took place through mid-2009. The pilot study occurred at the El Segundo Power Generating Station in El Segundo, CA. The study siting took advantage of the power generating facility's existing seawater cooling intake and outfall infrastructure. Initial investigations included the use of Microfiltration (MF) as pretreatment to Reverse Osmosis (RO). Over the course of testing between 2002 -2009, the pilot program expanded to investigate various aspects of the seawater desalination process including pre-straining, ultrafiltration (UF) membrane pretreatment, ambient temperature ocean water versus warmed power plant ocean water discharge, latest-generation RO membrane evaluation, seasonal variations in source water characteristics, various aspects of water quality, and techniques for biogrowth control.

This report summarizes the extensive results of seven years of pilot testing on an open-intake Southern California Pacific Ocean feedwater source. A summary of optimized performance for three different MF/UF products is provided, along with data on several different RO membranes. Data on two different pre-straining technologies is presented along with their effect on the downstream Microfiltration process Seasonal feed water quality trends are provided, including data on harmful algal blooms, along with assessment of a novel strategy to control biofouling in the treatment process. Finished product water quality is also discussed.

The pilot study has been a key component of the District's overall Ocean Water Desalination Program, supporting the current implementation of a demonstration-scale facility (Redondo Beach, CA) and ultimately a full-scale ocean water desalination plant that is currently in the planning and development stages. Among other objectives, the demonstration-scale project will further validate the pilot test results with long-term operation using full-scale process equipment.

Overall, the pilot study was a tremendous success; demonstrating the viability of ocean water desalination for the District, advancing the understanding of the performance of several key process components on local ocean water conditions and resulting in a body of data not previously available. The study provided an opportunity to document the range of variability of ocean water quality, seasonally as well as year-to-year. The multi-year operation allowed exposure to variations in feed water quality and resulting operational challenges (e.g. algal blooms), which may not necessarily have occurred within a given 12-month period. Overall, results of the study show that membrane pretreatment followed by reverse osmosis effectively treated raw seawater to meet the District's potable water standards.

1.1 OBJECTIVES

The WBMWD Ocean Water Desalination Pilot Project had many specific objectives over various phases and seven years of testing. These objectives focused on several major technical aspects of the seawater desalination process including:

- Documentation of seasonal variations in source water and their impact on treatment performance.
- Evaluation of RO membrane pretreatment alternatives
- Comparison of power plant intake (ambient temperature) and outfall (warm) water sources
- Pre-strainer alternative evaluation
- Latest generation RO membrane evaluation
- Approaches to meet specific stringent product water quality objectives
- Novel biogrowth control techniques

Seasonal Variations in Source Water

The Pacific Ocean water off the coast of southern California can vary significantly with respect to temperature and water quality throughout the seasons. Both of these parameters affect the design and operations of a seawater desalination facility. Storm events and algal blooms can result in poor feedwater quality to the process equipment and variations in temperature have an affect on operating parameters and final product water quality. A project goal was to monitor the variations in seawater temperature and water quality over the course of the seasons and evaluate the affect on various process equipment and develop operating strategies for various times of the year.

Pretreatment Alternatives

The successful operation of any Seawater Reverse Osmosis System is dependent on proper pretreatment. Conventional seawater pretreatment has consisted of various steps and process configurations such as flocculation, coagulation, sedimentation, and media filtration to remove suspended particulate matter and reduce feedwater turbidity prior to the reverse osmosis membranes. Membrane pre-treatment offers the potential to eliminate some of the operational and filtrate quality issues and challenges associated with many conventional media filtration systems. Membrane pre-treatment utilizes a physical membrane barrier for reduction or removal of suspended material, in addition to providing log-reduction of bacteria and viruses.

One of the goals of this study was to evaluate the use of Microfiltration and Ultrafiltration membrane systems as pretreatment to the reverse osmosis membrane. Aspects of the evaluation included flux rate optimization, cleaning intervals, and filtrate water quality. As part of this study, various pre-straining options to the MF and UF system were also investigated. Pre-strainers are required ahead of MF and UF system to prevent membrane damage from particulate matter. The pre-straining systems evaluated included basket strainers, a backwashable disc filter, and a high rate granular media filter.

○ *Power Plant Seawater Intake and Outfall Testing*

The co-location of a seawater desalination facility with an existing power plant can potentially provide several advantages. This includes access to the substantial ocean water intake and outfall infrastructure used by the power plant for cooling. As such the co-location siting may offer the choice of operation on ambient temperature intake or warm power-plant discharge. Use of the higher temperature cooling water discharge as feedwater to the desalination facility, has been identified as a preference at other locations, citing operational advantages. A goal of this study was to determine the viability, advantages and disadvantages of treating this higher temperature cooling water compared to the ambient ocean water. While treating higher temperature seawater lowers the pressure required by the RO membrane, the higher temperature also increases salt passage through the membrane, impacting permeate quality. This may impact membrane selection and second-pass RO requirements. There is also a threat of increased potential for biogrowth within the treatment process and resulting membrane fouling. Complete understanding of these factors is essential for source selection of a full-scale facility.

○ *Seawater Reverse Osmosis Membrane Evaluation*

The seawater reverse osmosis system can be considered the heart of the desalination process. It is at this step in the process where the dissolved salts in the feedwater are removed and high quality RO permeate is produced. There are several manufacturers of SWRO membranes with variations in product specifications which affect the operations and product water quality. One of the goals of the study was to evaluate several different manufacturers SWRO membrane products available in the marketplace. The objectives included an evaluation of both permeate water quality and permeate flow rates, as well optimizing operating parameters and product water quality. A second pass reverse osmosis system was also pilot tested to develop additional data for full scale design.

○ *Approaches to meet specific stringent product water quality objectives*

While the product water quality requirements for a full-scale project will be driven largely by regulatory potable water limits, other aspects of water produced by oceanwater desalination are increasingly being recognized and becoming critical drivers of the final specification, with substantial impact to the treatment process design. These other water quality parameters include chloride, boron and bromide. While firm water quality limits for these constituents are not universal, nor have they been established for the District, a project goal was to gather data on treatment process approaches to accomplish stringent water quality goals, providing the engineering resource to meet the requirements should they be established.

○ *Biogrowth Control*

Biogrowth is often one of the major operational challenges associated with seawater desalination. Biogrowth can affect the entire process, from the intake pipe to the RO system. Effective control of biogrowth throughout the treatment process will help keep energy consumption and operating costs down. A pilot study goal was to examine various ways at controlling biogrowth throughout the process. This included the periodic use of chlorine in the pre-strainers and MF/UF systems and also the use of chloramines to prevent biofouling of the SWRO system.

Additionally the pilot study results are serving as a significant tool for the District; supporting full-scale planning efforts in the following areas:

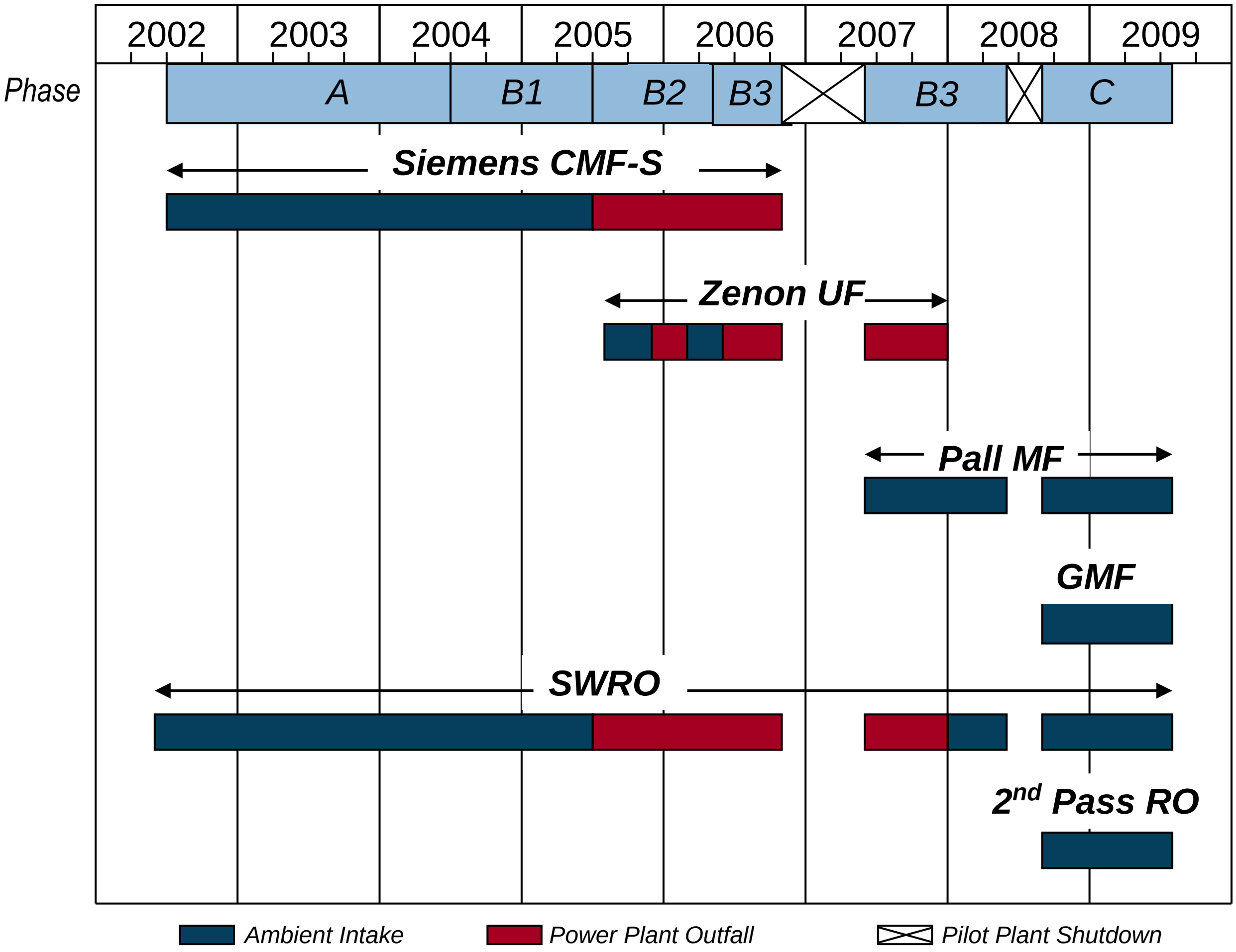
- Demonstrated sustainable operation of membrane pretreatment processes and established operability expectations
- Developed process design parameters and operational understanding to support capital and O&M cost estimating
- Feed and permeate water quality benchmarks
- Support to the environmental and permitting aspects of a larger facility
- Public outreach and education

Figure 1-1 Pilot Equipment Onsite at El Segundo Generating Station

1.2 PILOT TEST DESCRIPTION

A summary time-line of the tested processes are shown in Figure 1-2. The primary treatment processes of membrane filtration and reverse osmosis were common in all phases of the testing. However, various manufacturer’s products, upgrades, and variants of the testing work such as operation on ambient temperature raw seawater and heated power-plant effluent water were divided into “Phases” of work, which minimized variables in a given period and allowed focus on specific goals. The project began with a single microfiltration unit and reverse osmosis system and grew in subsequent phases to include prestraining devices, ultrafiltration and second-pass RO. Figure 1-3 provides a Process Flow Diagram (PFD) of the final configuration of the pilot facility.

Figure 1-2 Pilot Test Summary Timelines



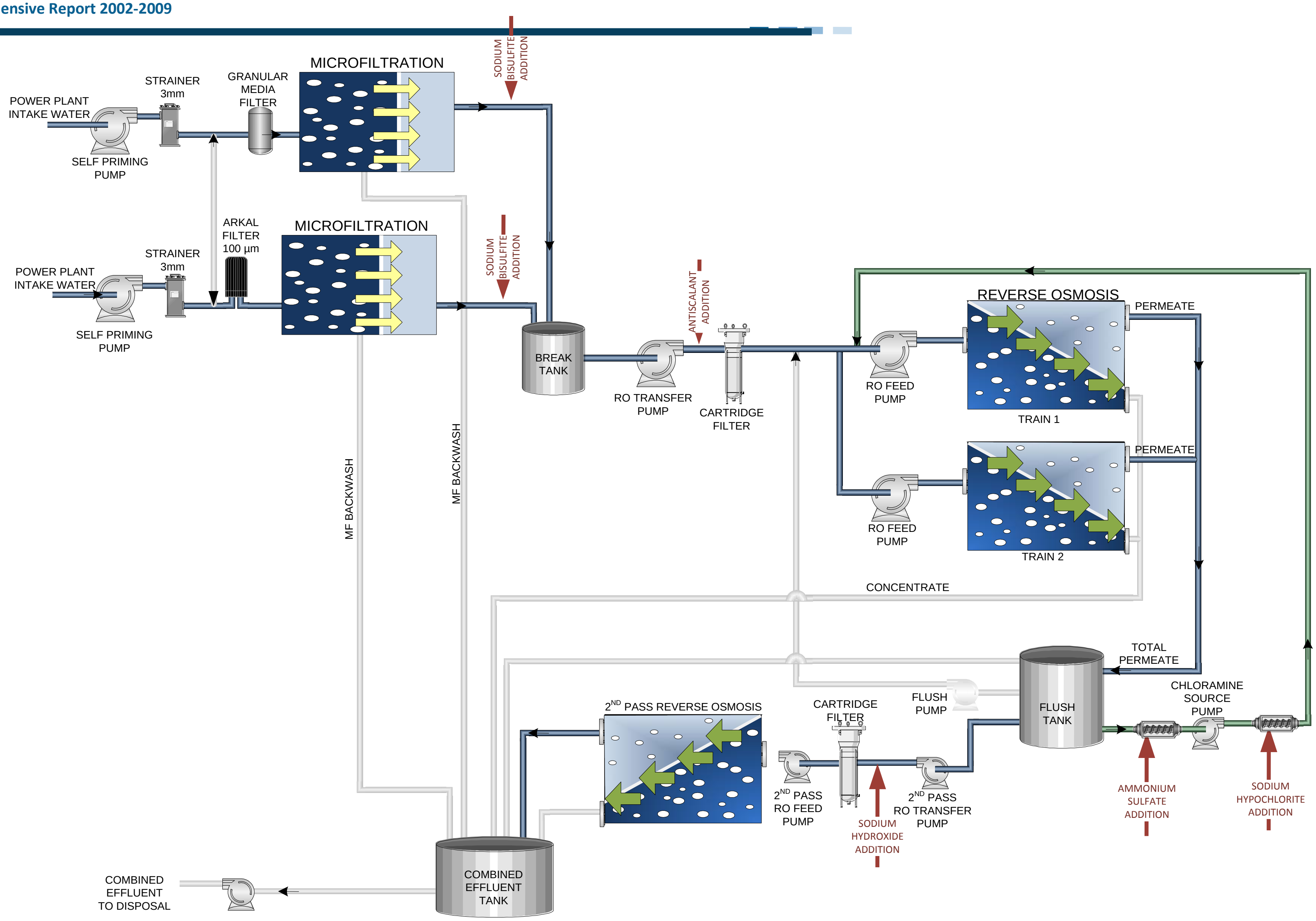


Figure 1-3 Process Flow Diagram

In order to successfully and repeatedly demonstrate the performance of the treatment system, testing protocols were established, and upgraded when necessary over the course of testing. The performance of each system was evaluated, documented, and changes and optimization were made, consistent with the goals of the Program. The results of the key tested parameters are discussed below.

1.3 RESULTS

1.3.1 Raw Water Characterization

Over the course of the pilot program, numerous source water quality parameters were analyzed and characterized. The salient observations are summarized below.

<u>Temperature</u>. The temperature of the raw ambient seawater varied with the seasons, ranging from 11°C in winter to 25°C in late summer. The average annual temperature was approximately 16°C The temperature typically increased up to 8°C above the ambient seawater temperatures across the power plant condenser, when the power plant was operational. However, being a “peaking” plant, the power facility was frequently in standby, resulting in much less increase in temperature during these periods.

<u>Salinity</u>. The average feedwater TDS was approximately 34,000 mg/L, with a low of 27,000 mg/L and a high of 39,000 mg/L.

<u>Turbidity</u>. The average turbidity of the raw water was consistent, with average values less than 2 NTU. This represents a relatively good quality for open intake source water (irrespective of algal content). Warm and ambient feed water turbidity did not differ significantly. However, elevated turbidity readings reaching 10 NTU were associated with periods of increased phytoplankton counts (algal blooms) and storm events.

Algal Blooms / TOC. The source water for the pilot test was Santa Monica Bay, open to the Pacific Ocean and subject to algal blooms and red tide events. Over the course of the Pilot, several algal blooms occurred of varying intensity and duration.

There was generally a measurable increase in seawater algae during the spring and summer months, with lower values in fall and winter. Other seasonal-induced variations included typical spring upwelling events, storm events and the associated nutrient runoff causing TOC increases of up to 3 mg/L over typical concentrations of 0.5 to 1.5 mg/L.

1.3.2 Intake System

The seawater delivered to the pilot plant was obtained from the power plant cooling loop, which uses an open ocean intake outfitted with a velocity cap. The desalination pilot drew source water from the ambient temperature intake facilities and warm water effluent for various periods during the study.

1.3.3 Pretreatment

One critical criterion for any successful open-intake ocean water desalination facility, is the capability of the pretreatment system to effectively and reliably remove suspended solids which would otherwise foul the RO membrane. During the course of the pilot, three membrane pretreatment systems were tested:

- Siemens Microfiltration (Submerged)
- GE Zenon ZW-1000 Ultrafiltration (Submerged)
- Pall Microza Microfiltration (Pressurized)

The membrane pretreatment piloting objectives included performance evaluation and demonstration of sustainable (stable) operating conditions on both ambient ocean water and warm water effluent; to observe cleaning frequency and effectiveness; to establish cleaning protocols; to measure the effect of variable seawater quality conditions on the performance of the pretreatment systems; and to demonstrate filtrate water quality through both analytical results and performance of downstream RO.

Siemens (Memcor CMF-S) Microfiltration.

The Siemens membrane pretreatment system, employing a PVDF microfiltration membrane, was the first system tested beginning in 2002 and continuing for four years. Over the course of testing, several generations of module design were assessed, which demonstrated development of the product's fiber robustness, permeability and module construction. Ultimately, sustainable operating parameters for the Siemens membrane pretreatment were established at a flux of 34 gfd, employing chlorinated backwashes and a 21-day cleaning interval. Heating of the cleaning solution was required to restore membrane permeability. During the most severe algal bloom events, it was necessary to reduce the operating flux by approximately 30% to maintain stable performance.

GE / Zenon ZW-1000

The Zenon ZW-1000 UF membrane pretreatment system was tested for two years beginning in 2005. While initial performance was poor (irrecoverable permeability and integrity loss), improvements in next-generation design of replacement membrane modules and prestrainer operation facilitated improved performance. A sustainable operating flux of 27.5 gfd was demonstrated with a 21-day cleaning frequency. A heated cleaning solution was shown to be beneficial in restoring membrane permeability based on seasonal variations in feedwater quality.

Pall Microza.

The Pall MF membrane pretreatment system operated two years starting in mid-2007. Over the course of testing, the system was capable of meeting a 30-day cleaning interval at a sustained flux rate of 70 gfd. However, a reduction in flux rate to 53 gfd was necessary for sustained operation required during times of algal blooms. A heated cleaning solution was a necessity in order to restore membrane permeability between runs.

The use of chlorine in some aspect of operation (backwash or chemical washing) was essential to control the rate of membrane fouling and to meet a minimum 21-day membrane cleaning frequency for all three systems.

During the course of Phase A testing, it became apparent that shell fragments were passing the 500 micron basket strainer and damaging the microfiltration fiber. The addition of the Arkal disc filter was effective in eliminating this problem. There were additional incidents of membrane integrity loss, which impacted the filtrate water quality. These were addressed improved module and/or fiber design in subsequent generation modules. Following these developments, all the membrane pretreatment systems reliably provided excellent quality filtrate

During this period of operation downstream of the disc strainer, the operating flux for each system was reduced approximately 30% during the most severe algal bloom (red tide) event to maintain stable performance (control losses in permeability). In an interest to investigate a generic alternative to the disc filter and potentially improve MF performance through severe algal bloom events, a high-rate deep-bed granular media filter (GMF) was tested.

Disc Filter and High-Rate Granular Media Filter.
During Phase C testing an Arkal backwashable disc filter and a high-rate deep-bed granular media filter (GMF) were tested in parallel, each with an identical Pall MF downstream (Figure 1-3). The MF performance indicated comparable capability of these two pre-filters to remove harmful shell fragments. However, the deep-bed high-rate GMF provided higher quality filtrate during periods of poor raw oceanwater quality (storm and algal bloom events). Testing showed that the GMF allowed more sustainable MF permeability and affected an increased MF cleaning interval compared to disc filtration during an algal bloom event.

1.3.4 Seawater Reverse Osmosis / Brackish Water (2nd Pass) Reverse Osmosis

Five reverse osmosis membrane manufacturers’ seawater RO membranes were tested during the pilot: Dow (Filmtec), Hydranautics, Koch, Toray and Saehan (CSM). The SWRO piloting objectives and benchmarks included evaluation and demonstration of sustainable (stable) operating conditions on both ambient and warm (effluent) ocean water; observe cleaning frequency; establish cleaning protocols; and compare salt rejection capability of key constituents, such as chloride and boron.

Extensive water quality and operating performance data provided important information for the confirmation of design parameters under a range of temperature and flux conditions. The RO membrane industry achieved substantial product development in the period of 2002 – 2009. Accordingly, several “next-generation” seawater reverse osmosis membranes were tested during the latter phase of pilot testing. Several of the best performing products had quite similar characteristics. At average temperature and salinity conditions they demonstrated the capability to produce permeate of <300 mg/L TDS, <1 mg/L boron and <100 mg/L chloride. Some specific products showed capability to achieve somewhat lower concentrations of specific constituents (e.g. chloride or boron). This performance suggests that at design conditions of high temperature, high feed salinity and a factor for age, these membranes should be capable of producing potable quality water in a single pass. However, if higher quality water is required to meet stricter chloride or boron goals (e.g. 100 mg/L Cl, 0.5 mg/L B), the use of a partial second-pass RO system is required. Second-pass RO testing (Figure 1-4) included data collection with pH adjustment for enhanced boron rejection.

As expected, testing on the warmer powerplant effluent water resulted in lower RO feed pressure requirements, but also higher permeate concentrations of TDS, boron and other constituents. However, more significantly, the elements were affected by biofouling to a greater extent on the warmer effluent water than on the colder influent water. While processing the warmer power plant outfall water is technically feasible, this performance highlighted the opportunity for development of additional biogrowth control strategies on this source.

Five distinct RO fouling events occurred throughout the testing. Permeability loss and increases in differential pressure were corrected with chemical cleanings using a heated high pH cleaning solution.

Figure 1-4 Second Pass RO System

1.3.5 Results of Algal Toxin Testing

The pilot was operated through several algal bloom events (red tide). Testing for domoic acid during these events indicated the ocean water contained domoic acid levels as high as 2 to 3 µg/L yet the SWRO permeate content was always below the detection limit of 0.002 µg/L. This demonstrated the RO treatment process to be an excellent barrier to this constituent.

1.3.6 Chloramines

Chloramines have been considered a candidate for biogrowth control in seawater RO systems, due to the membrane's tolerance for chloramine and the success of this strategy in reclaim water systems. However, an initial attempt to form chloramines directly in seawater (Phase A testing), by adding ammonia and chlorine, was unsuccessful due to the unintended formation of bromamines. During Phase C, the addition of pre-formed chloramines was demonstrated successfully, minimizing biofouling in the SWRO train. The SWRO membrane was tolerant to the 5-7 mg/l of intermittent chloramine dosing over several months with this method.

1.4 CONCLUSIONS

The West Basin Municipal Water District Pilot Program was a successful, multi-year ocean water desalination pilot program which developed a broad range of data, not previously available. Where operational or process challenges were encountered, they were addressed, supporting the development and planning of the demonstration and full-scale projects.

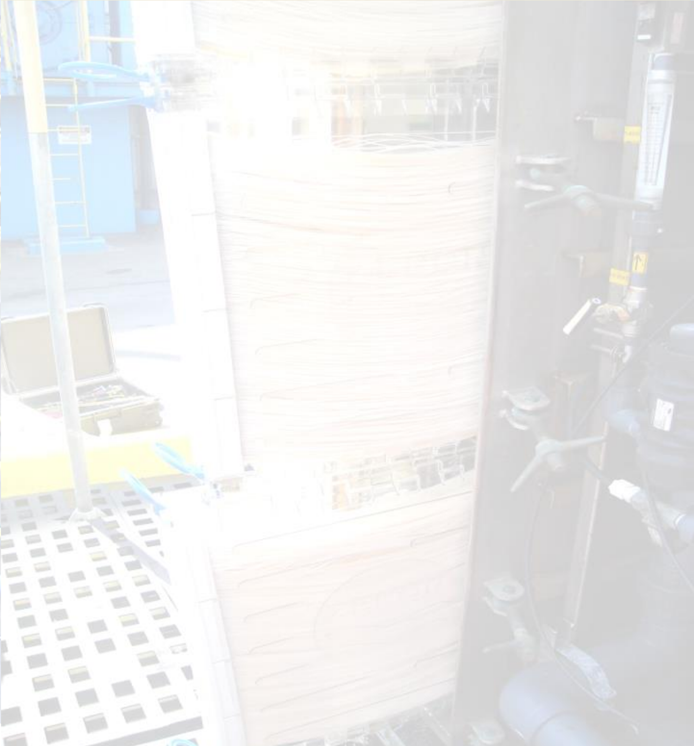
Specifically, the following conclusions can be drawn from this pilot study:

1. The study successfully established the feasibility of utilizing the membrane filtration pretreatment process for seawater reverse osmosis on an open intake. This was demonstrated on Pacific Ocean water taken from both a power plant intake and the warmer power plant post-condenser effluent sources.
2. The latest generation RO membranes demonstrated the capability of producing product water meeting drinking water regulations in a single-pass. The piloting also demonstrated the capabilities of a second-pass RO, should higher product quality standards be considered. Specifically the impact of pH adjustment on boron rejection was demonstrated.
3. Reverse Osmosis membranes operated effectively at 8 to 12 GFD flux on MF and UF filtrate.
4. Analyses for Domoic Acid in the RO permeate indicated non-detect (less than 0.002 μg/L) results, even when elevated concentrations (2-3 μg/L) existed in the raw feedwater due to substantial algae bloom events.
5. The Siemens CMF-S microfiltration system:
    a. Optimum MF operating conditions were determined to be:
        i. Flux = 34 GFD
        ii. Backwash Frequency = 20 minutes
        iii. Backwash with 20 mg/L NaOCl every backwash
        iv. CIP frequency of every 3 weeks
6. The Zenon ZW-1000 Ultrafiltration system:
    a. Optimum UF operating conditions were determined to be:
        i. Flux = 27.5 GFD
        ii. Backwash Frequency = 22 minutes
        iii. Backwash with 4 mg/L NaOCl every backwash
        iv. CIP frequency of every 3 weeks
7. The Pall Microza Microfiltration system:
    a. Optimum UF operating conditions were determined to be:
        i. Flux = 70 GFD
        ii. Backwash Frequency = 20 minutes
        iii. EFM with 350 mg/L NaOCl daily

    iv. CIP frequency of every 30 days

8. No relationship was found between RO operating flux and fouling in the range tested, 8 to 12 GFD.
9. A 100 micron Arkal disc filter was demonstrated to be effective removing these shell fragments.
10. A high-rate deep-bed granular media filter was demonstrated to enhance the performance of a Pall MF system during poor water quality conditions compared to an identical MF system operating with an Arkal disc filter.
11. Impacts of operation of the desalination process on a warm water (power plant effluent) source were documented relative to the ambient temperature feed source, including feed pressure, permeate quality and accelerated biofouling within the treatment process.
12. The viability of pre-formed chloramines as a biogrowth strategy for seawater RO was demonstrated.

Introduction



2.0 INTRODUCTION

The West Basin Municipal Water District began studying seawater desalination over ten years ago as part of diversifying their water supply to reduce dependence on imported water. Seawater desalination was seen as a viable option for a local, drought-proof water supply for this water district. As part of this investigation, a pilot study began in 2002 at the El Segundo Power Generating Station in El Segundo, CA. Initial investigations included the use of Microfiltration as pretreatment to Reverse Osmosis. Over the course of testing between 2002 -2009, the pilot program expanded to investigate various aspects of the seawater desalination process including pre-straining and MF/UF membrane pretreatment, SWRO membrane evaluation, seasonal variations in source water, various aspects of water quality, and techniques for biogrowth control.

This report summarizes the extensive results of seven years of pilot testing on an open-intake Southern California Pacific Ocean Water feedwater source. A summary of optimized performance for three different MF/UF manufacturers is provided, along with data on several different reverse osmosis membrane manufacturers. Data on two different pre-straining technologies is presented along with their effect on the downstream Microfiltration process Seasonal feed water quality trends are provided, including data on harmful algal blooms, along with strategies to control biofouling in the treatment process. Finished product water quality is also discussed.

As a result of the success of the pilot study, West Basin's Ocean Water Desalination Program is continuing on with a demonstration-scale seawater desalination project that will further validate the desalination process with full scale process equipment.

Project Goals

3.0 PROJECT GOALS

The WBMWD Ocean Water Desalination Pilot Project had many goals over the seven years of testing. The goals early on in the project were broad, and as more knowledge and insight was gained over the course of the study the goals became more specific, with the development of more concise objectives. The goals focused on several major technical aspects of the seawater desalination process including:

- Seasonal Variations in Source Water
- RO Membrane Pretreatment Alternatives
- SWRO Membrane Evaluation
- Power Plant Intake and Outfall Water Source
- Water Quality
- Biogrowth Control

3.1 Seasonal Variations in Source Water

The Pacific Ocean water off the coast of southern California can vary significantly with respect to temperature and water quality throughout the seasons. Both of these parameters affect the design and operations of a seawater desalination facility. Storm events and algal blooms can result in poor feedwater quality to the process equipment and variations in temperature have an affect on operating parameters and final product water quality. A project goal was to monitor the variations in seawater temperature and water quality over the course of the seasons and evaluate the affect on various process equipment and develop operating strategies for various times of the year.

3.2 Pretreatment Alternatives

The successful operation of any Seawater Reverse Osmosis System is dependent on proper pretreatment. Conventional seawater pretreatment has consisted of various steps and process configurations such as flocculation, coagulation, sedimentation, and media filtration to remove suspended particulate matter and reduce feedwater turbidity prior to the reverse osmosis membranes. Membrane pre-treatment offers the potential to eliminate some of the operational and filtrate quality issues and challenges associated with many conventional media filtration systems. Membrane pre-treatment utilizes a physical membrane barrier for reduction or removal of suspended material, in addition to providing log-reduction of bacteria and viruses.

One of the goals of this study was to evaluate the use of Microfiltration and Ultrafiltration membrane systems as pretreatment to the reverse osmosis membrane. Aspects of the evaluation included flux rate optimization, cleaning intervals, and filtrate water quality. As part of this study, various pre-straining options to the MF and UF system were also investigated. Pre-strainers are required ahead of MF and UF system to prevent membrane damage from particulate matter. The pre-straining systems evaluated included basket strainers, a backwashable disc filter, and a high rate granular media filter.

3.3 Seawater Reverse Osmosis Membrane Evaluation

The seawater reverse osmosis system can be considered the heart of the desalination process. It is at this step in the process where the dissolved salts in the feedwater are removed and high quality RO permeate is produced. There are several manufacturers of SWRO membranes with variations in product specifications which affect the operations and product water quality. One of the goals of the study was to evaluate several different manufacturers SWRO membrane products available in the marketplace. The objectives included an evaluation of both permeate water quality and permeate flow rates, as well optimizing operating parameters and product water quality. A second pass reverse osmosis system was also pilot tested to develop additional data for full scale design.

3.4 Power Plant Seawater Intake and Outfall Testing

The co-location of a seawater desalination facility with an existing power plant can have several advantages. One of the advantages is the availability of ocean water that has been used by a power plant for cooling purposes. Many coastal power plants use seawater in their once-through cooling systems, and this presents an opportunity for a desalination facility to use this higher temperature cooling water discharge as feedwater to the desalination facility, perhaps reducing full scale civil works, permitting requirements, and allowing for other operational advantages. A goal of this study was to determine the viability of treating this higher temperature cooling water compared to the ambient ocean water. While treating higher temperature seawater lowers the pressure required by the SWRO system, the higher temperatures can lead to an increased potential for biofouling. The higher temperature also has the effect of increasing salt passage across the reverse osmosis membrane, resulting in lower quality product water. Attention to these factors is essential for the design of a full scale facility.

3.5 Water Quality

Water quality of the incoming feedwater, RO concentrate discharge, and of the final RO product water are critical aspects in the design of a seawater desalination facility. The feedwater quality will often determine the level of pretreatment required before the SWRO system, and the desired product water quality will determine the design parameters for the SWRO system. One of the project goals was to gather long term data on the raw water, RO permeate, RO concentrate, and at other steps in the treatment process. Extensive water sampling was performed throughout the treatment process and laboratory analyses were conducted for a variety of constituents.

3.6 Biogrowth Control

Biogrowth is one of the major operational challenges associated with seawater desalination. Biogrowth affects then entire process, from the intake pipe to the SWRO system. Effective control of biogrowth throughout the treatment process will help keep energy consumption and operating costs down. A pilot study goal was to examine various ways at reducing biogrowth throughout the process. This included the periodic use of chlorine in the pre-strainers and MF/UF systems and also the use of chloramines to prevent biofouling of the SWRO system.

Pilot Study Approach And Description

4.0 PILOT STUDY APPROACH AND DESCRIPTION

The WBMWD Ocean Water Desalination Pilot Project operated from July 2002 to June 2009. The project was completed in several phases, each with its own set of specific testing objectives as described in the following sections.

4.1 Location

The pilot study was conducted in El Segundo, CA, located in west Los Angeles County. Figure 4-1 shows the general location of the pilot project.

Figure 4-1 Pilot Project Location Map

The pilot study was conducted on the grounds of the El Segundo Generating Station (ESGS), a power plant located at 301 Vista Del Mar in the city of El Segundo, CA. The ESGS is a natural gas-fired steam electric generating facility operating two conventional steam turbine units (Unit 3 and Unit 4) with a combined generating capacity of 670 MW. Units 1 and 2 have been retired from service as part of a repowering project. Figures 4-2 and 4-3 show the location of the ESGS and the location of the pilot plant within the power plant property.

Figure 4-2 Aerial View of Pilot Project Location

Figure 4-3 Aerial View of Pilot Project Location

The power plant uses a once-through-cooling process to provide condenser cooling water to the two generating units. The cooling water used in this process is Pacific Ocean water. The power plants' intake system utilizes a submerged ocean intake conduit 2,000 feet offshore at a depth of approximately 20 feet, and is fitted with a velocity cap to minimize entrainment of marine life. Prior to the power plant cooling loop, the raw seawater goes through traveling screens and is periodically dosed with chlorine to control biofouling in the cooling loop. Downstream of the traveling screens are four circulating water pumps, each rated at 69,200 gpm for a total facility capacity of 399 mgd. The cooling water is discharged through a single submerged outfall to the Pacific Ocean located approximately 2,100 feet from shore at a depth of 20 feet.

It is important to note that ESGS is a peaking facility, and does not operate at full capacity on a continuous basis and can be offline for long periods of time.

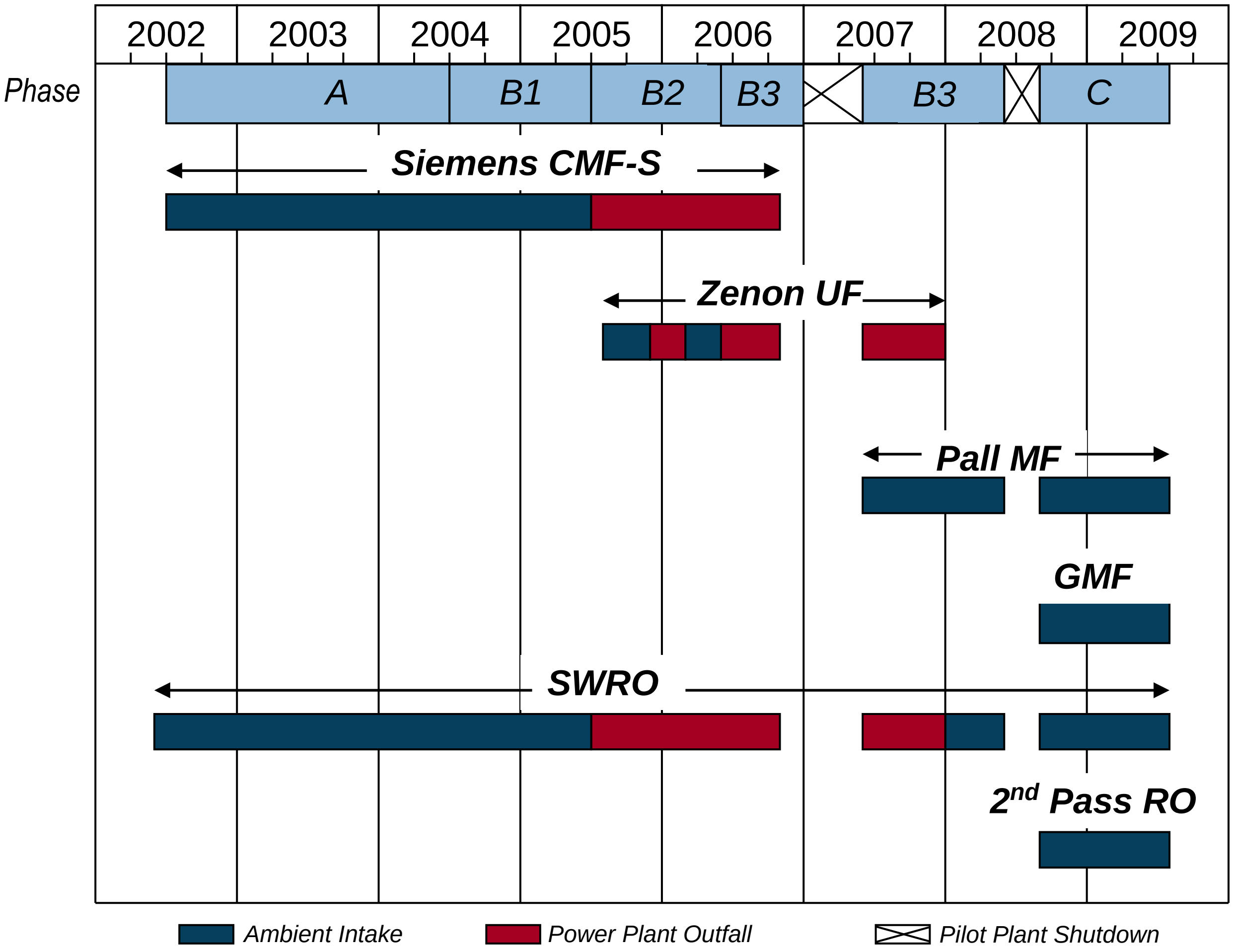
4.2 Process Description and Testing Objectives

The pilot equipment was located in between the two main generating buildings at the El Segundo Generating Station, in close proximity to the forebay where there is access to incoming seawater (Figure 4-4).

Figure 4-4 Photo of Seawater Desalination Pilot Equipment

Figure 4-5 shows the various phases of the pilot project, and the treatment processes that were operating at each phase, in addition to the water source (ambient ocean water or the warmer post-condenser power plant outfall water).

Figure 4-5 Pilot Project Timeline Graphic



4.2.1 Phase A Testing

The pilot testing began with Phase A, which lasted from June 2002 to June 2004. The main objectives of Phase A were:

- To determine the optimum membrane operating flux and cleaning interval for a MF membrane system operating on Southern California coastal seawater.
- Investigate cleaning formulations and techniques for removal of contaminants found in seawater which foul the MF membrane.
- Determine the optimum operating flux and cleaning interval for a seawater reverse osmosis system operating on MF filtrate.

- Assess RO permeate water quality related to drinking water standards.
- Investigate cleaning formulations and techniques for the removal of contaminants found in microfiltered seawater, which foul RO membrane
- Characterize the MF backwash and RO concentrate streams to develop data suitable for evaluation of waste stream disposal options
- Develop design and operating parameters based on the above gathered data to assess cost of large scale seawater desalination by MF/RO.

In order to meet the test objectives, a pilot plant was installed consisting of a Microfiltration System and a Reverse Osmosis System. The overall pilot treatment process is indicated in Figure 4-6, the Initial Process Flow Diagram. Originally, the first component of the pilot treatment process was a transfer pump which pulled seawater from the discharge side of the power plant circulation pumps. This transfer pump provided sufficient head for delivery of ocean water through an 800-micron duplex basket strainer to the microfiltration system. After processing by the MF system, the filtrate was directed to the 150 gallon covered Break Tank, which served as an equalization tank between the intermittent MF production and the continuous flow RO process. Prior to entry into the Break Tank, provision was made for chemical addition to the MF filtrate stream. The chemical metering pump was suitable for addition of either ammonium hydroxide or sodium bisulfite, for chloramine formation or dechlorination, respectively. Elimination of free chlorine is necessary to protect the polyamide RO membrane, which is subject to damage from exposure to strong oxidants. The RO membranes are, however, more tolerant of chloramines.

MF filtrate was pumped from the Break Tank by a booster pump to the RO system. The booster pump delivered RO feedwater through cartridge prefilters and provided sufficient suction pressure to the RO high pressure pump. Excess MF filtrate overflowed the Break Tank to the Waste Collection Tank. After processing through the RO system, both the RO permeate and RO concentrate streams were also sent to the Waste Collection Tank, where the combined streams were discharged by a transfer pump to the seawater intake forebay for eventual discharge to the ocean outfall.

The pilot process was modified in late of 2002 and is shown in Figure 4-7 below. The chlorine injection point was moved to the MF backwash, injection of ammonia in the MF filtrate was stopped, and SBS was dosed in the MF filtrate to neutralize any free chlorine.

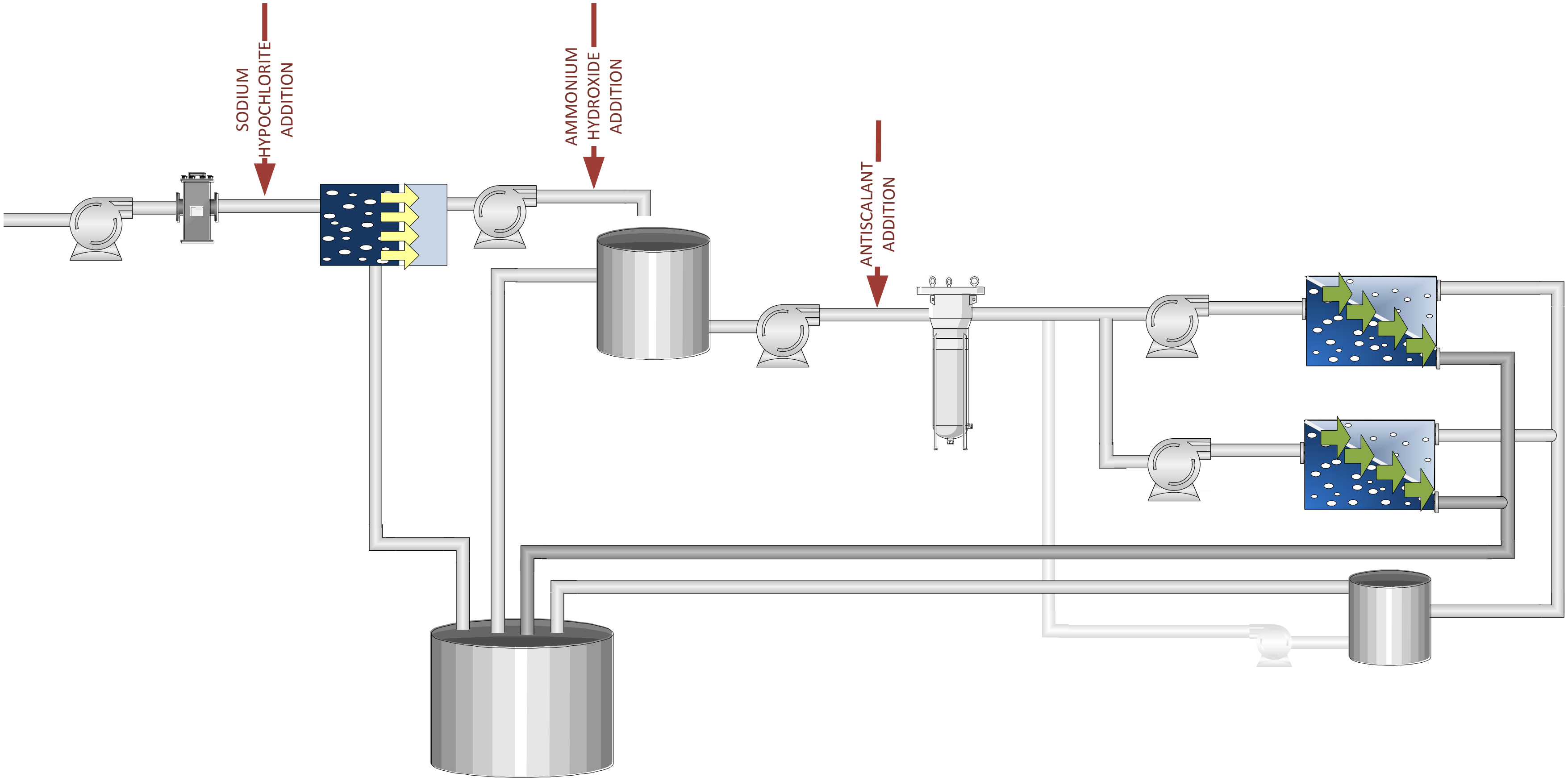
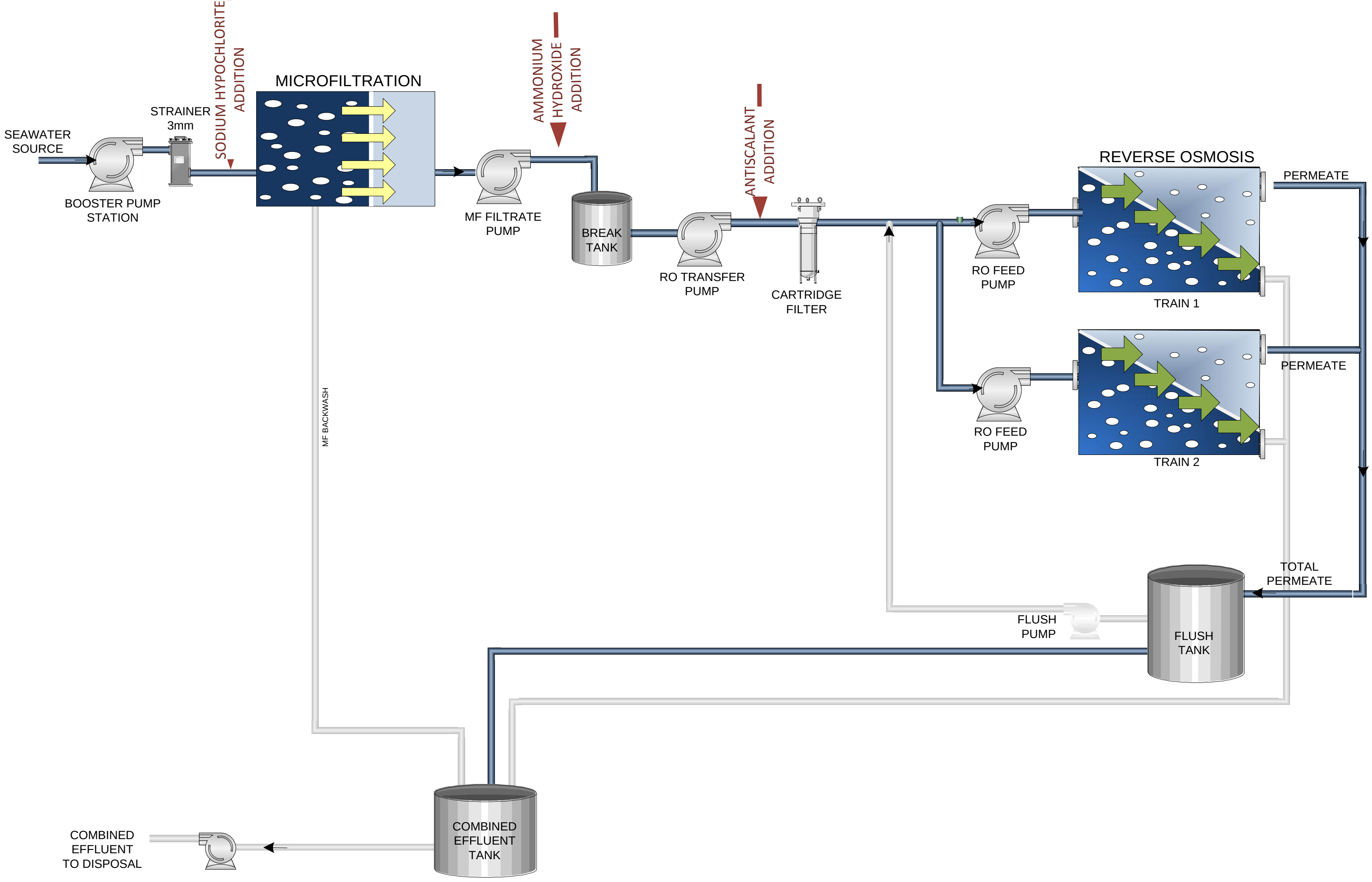


Figure 4-6   Initial Process Flow Diagram of the Pilot System, Phase A

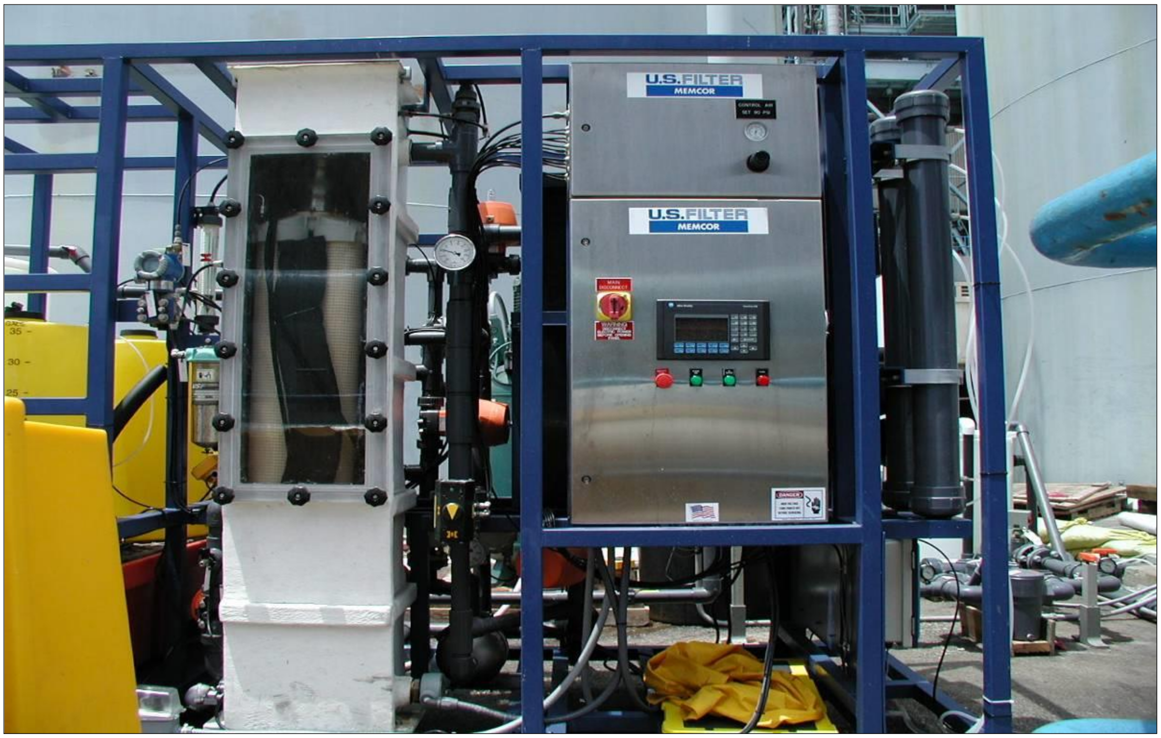
Figure 4-7 Revised Process Flow Diagram of the Pilot System, Phase A



4.2.1.1 Siemens CMF-S Microfiltration System

The MF system piloted in Phase A was a Siemens CMF-S system, utilizing 0.1 micron nominal pore size polyvinylidene fluoride (PVDF) hollow fiber membranes. The PVDF membrane chemistry has a high tolerance of chlorine and other oxidants, providing a wide range of options for the control of biological growth within the system and the prevention of membrane fouling due to organic matter. The CMF-S process consists of four modules submerged in a process tank. Suction is applied to the lumen of the fibers by the MF filtrate pump; drawing water though the walls of the fibers while particulate matter accumulates on the outside surface of the fibers. The CMF-S process includes periodic interruption of filtration for backwashing of the fibers. Following the filtration period, the fibers are backwashed by reversing the filtrate flow and introducing an air scour across the membranes outside surface. Subsequently, the process tank is drained and refilled, and the filtration process starts again. The pilot unit is shown in Figure 4-8.

Figure 4-8 Siemens CMF-S Microfiltration Pilot System



The CMF-S system was operated initially at the conditions indicated in Table 4-1. Over the course of operation the trans-membrane pressure (TMP) rises gradually due to fouling of the membrane fibers. The system is taken out of service when the TMP reaches the maximum limit value. At that time a Clean in Place (CIP) procedure is performed to remove the foulants from the fiber surface, which normal backwashing had been unable to remove. The period of operation from initial operation until maximum TMP is reached is the CIP interval. A goal of this pilot test is to determine the maximum flux and/or backwash interval which will allow a CIP interval of at least 21 days. Based on the CIP period achieved at the initial operating conditions, adjustments were made to the operating conditions of subsequent runs. The effectiveness of the CIP procedure was assessed by comparison of the post-CIP TMP value to the baseline. Modifications of the CIP procedure were made to improve CIP performance or eliminate steps where unnecessary.

Table 4-1 Initial MF Operating Conditions

Initial MF Operating Conditions	
Instantaneous Flux	21.5 gfd
Instantaneous Filtrate Flow	20 Gpm
Backwash interval	15 minutes
Maximum TMP	12 psi
Backwash chemical addition	None
NaOCl addition	Dose sufficient to maintain 1 mg/L free chlorine in the MF feed stream
Clean-in-place (CIP) cleaning procedure	Siemens standard two step Acid/Hypochlorite procedure as published in their operation literature.

In order to properly evaluate the performance of the MF system, operating data was collected both electronically and manually by the operators. The parameters in Table 2 were collected to monitor performance of the MF system.

Table 4-2 MF Operating Data Requirements

Data Collection for CMF-S System	
Filtrate Flow (gpm)	Backwash chemical requirements
TMP (psi)	Air flow (cfm)
Temperature (^{O}C)	MF feed turbidity (NTU)
pH	MF Filtrate turbidity (NTU)
Run Time (hours)	Chemical day tank level
Backwash frequency setpoint	Pressure decay test start pressure (psi)
Backwash flow (gpm)	Pressure decay test end pressure (psi)
Backwash flow duration (sec)	Pressure decay duration (sec)
Backwash pressure (psi)	Pressure decay test result (psi/min)

4.2.1.2 Seawater Reverse Osmosis System

The seawater reverse osmosis system consisted of two independent trains with one common booster pump mounted on one skid as seen in Figure 4-9. Antiscalant and acid addition points were located downstream of the common booster pump. Antiscalant addition equipment included a day tank and chemical metering pump. Dose adjustment was manual as the RO operation was continuous and maintained at flow setpoints. Initial operation did not include acid addition. A 10 micron cartridge filter followed antiscalant addition, providing mixing and a barrier to debris introduced at the break tank.

Following cartridge filtration the stream split to feed two identical RO units (Train 1 & Train 2). Each train consisted of a high pressure pump feeding two, four-inch diameter pressure vessels in series. Each vessel was capable of holding four elements in series. During this study a spacer assembly was used in the lead vessel to allow operation of seven elements in series, which is common for a full scale SWRO system. Concentrate flow was manually adjusted to the flow setpoint using the concentrate control valve. The RO units had positive-displacement high-pressure pumps. Therefore, permeate flow was manually adjusted to a setpoint using the high pressure pump recycle control valve. The RO system included ancillary cleaning and flush systems. Upon shutdown the RO system was automatically flushed with RO permeate.

Figure 4-9 Seawater Reverse Osmosis Pilot System

A primary objective of the RO testing in Phase A was the determination of the maximum operating flux which allowed operation for 30 days between chemical cleanings. The RO system was operated initially at the parameters indicated in Table 4-3. The conditions for initiating a chemical cleaning (CIP) of the membrane were as follows:

- A decline in Specific Flux of 20% from its initial value,
- An increase in Normalized Differential Pressure of 25%,
- Or upon 1,000 hours (41 days) of operation, which ever occurred first.

If the period of operation before cleaning exceeded 30 days, the operating conditions after the cleaning were adjusted by increasing the operating flux by 1 gfd. This adjustment of operating flux was to continue for subsequent runs up to 12 gfd. If the Specific Flux was very stable during a run, the operating flux of the subsequent run may be increased by more than 1 gfd.

If the period of operation between cleanings was less than 30 days, the same operating flux will be repeated for the following run. A cleaning period of less than 30 days for the second run will result in a decrease of operating flux by 1 gfd for the subsequent run, but not less than 8 gfd.

The initial cleaning formulation and technique were the generic procedure recommended by the membrane manufacturer for seawater desalination applications. Should this not be successful, variations in the formulation were to be tried. A successful cleaning was defined as one that recovers the Specific Flux to 95% of its initial stabilized value.

Table 4-3 Initial RO Operating Conditions

	Train 1	Train 2
Membrane manufacturer	Dow Filmtec	Hydranautics
Membrane Element Model	SW30-4040	SWC1-4040
Quantity of elements	7	7
Element active membrane area (ft2)	80	70
Total active membrane area (ft2)	560	490
Initial Permeate flow (gpm)	3.1	2.7
Initial Flux (gfd)	8	
RO recovery	50%	
Antiscalant Addition	3 mg/L PermTreat 191	
Clean-in-place (CIP) criteria	20% loss of initial Specific Flux or 25% increase in normalized Differential Pressure	
Clean-in-place (CIP) procedure	Membrane manufacturer's generic formulation and procedure	

In order to properly evaluate the performance of the RO Trains, operating data was collected both electronically and manually by the operators. The parameters in Table 4-4 were collected to monitor performance of the RO system.

Table 4-4 RO Operating Data Requirements

Data requirements common for both trains	Data requirements for each train
Run time (hours)	Feed Pressure (psi)
Cartridge Filter inlet pressure (psi)	Interstage pressure (psi)
Cartridge Filter outlet pressure (psi)	Concentrate Pressure (psi)
Temperature (^{O}C)	Total Permeate flow (gpm)
Feed Conductivity (□S/cm)	Bank 2 Permeate Flow (gpm)
Feed pH	Concentrate flow (gpm)
Antiscalant day tank level	Permeate Conductivity (□S/cm)
	Individual vessel permeate conductivity (□S/cm)

4.2.1.3 Sampling

In order to help assess the performance of the MF and RO Systems and to characterize the source water, product water, and waste streams, extensive sampling and laboratory analyses were carried out.

Table 4-5 outlines the water sampling and laboratory analyses for the initial Phase A testing period.

Table 4-5 Water Quality Parameters Phase A

Laboratory Analysis Frequency								
Parameter	**Raw Feed**	**MF Feed**	**MF Filtrate**	**MF Backwash**	**Break Tank Influent**	**RO Feed**	**RO Permeate**	**RO Conc.**
pH		Daily						
Turbidity (NTU)	Daily	Daily	Weekly	Weekly		Weekly		
TOC (mg/L)	Weekly	Weekly	Weekly	Weekly				
DOC (mg/L)		Weekly						
UV_{254} (cm^{-1})	Weekly	Weekly	Weekly					
Total Alkalinity (mg/L as $CaCO_3$)		Weekly	Weekly					
Total hardness (mg/L as $CaCO_3$)		Weekly	Weekly					
Calcium hardness (mg/L as $CaCO_3$)		Weekly	Weekly					
Manganese (mg/L)		Monthly						
Aluminum (mg/L)		Monthly						
TDS (mg/L)		Monthly	Monthly	Monthly				
Free chlorine residual (mg/L)		Daily	Daily	Daily	Daily	Daily	Weekly	Weekly
Total chlorine residual (mg/L)					Daily	Daily	Weekly	Weekly
Complete mineral analysis (constituents listed in Table 5A)						Monthly	Monthly	Monthly
Silt Density Index (15 min)						Weekly		
Total Heterotrophic Plate Count	Daily	Daily	Daily			Weekly		Weekly

Table 4-5A Mineral Analysis

Parameter	Units
TDS	mg/L
Alkalinity (as CaCO3)	mg/L
Bicarbonate (as CaCO3)	mg/L
Carbonate (as CaCO3)	mg/L
Hydroxide (as CaCO3)	mg/L
Sulfate	mg/L
Chloride	mg/L
Nitrate (as N)	mg/L
Nitrite (as N)	mg/L
Bromide	mg/L
Calcium	mg/L
Magnesium	mg/L
Hardness (as CaCO3)	mg/L
Ca Hardness (as CaCO3)	mg/L
Sodium	mg/L
Potassium	mg/L
Fluoride	mg/L
Strontium	mg/L
Barium	mg/L
Boron	mg/L
Silica	mg/L
Ammonia (as N)	mg/L

4.2.2 Phase B Testing

Phase B of pilot testing was designed to build on the accomplishments of Phase A and had several longer term objectives. The major objectives of Phase B were:

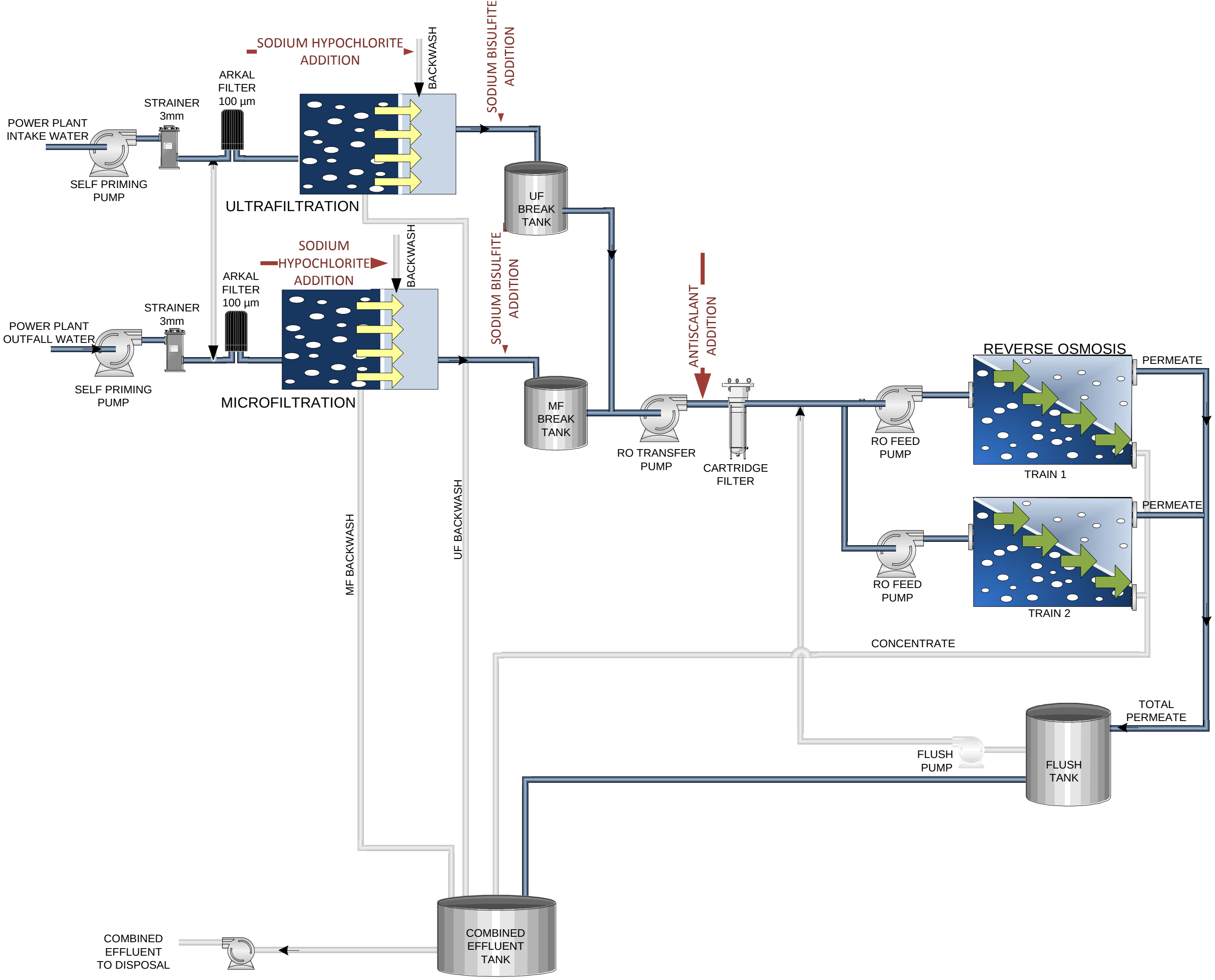
- Examine the use of the power plant warm water outfall as feedwater to the pilot plant.
- Investigate and optimize the use of Ultrafiltration as an alternative to Microfiltration for pretreatment to RO.
- Assess the performance of several "next generation" seawater reverse osmosis membranes
- Assess long term performance of two of the "next-generation" seawater reverse osmosis membranes.

In order to meet all the objectives, Phase B was further separated into three sub-Phases as follows:

- Phase B1 evaluated four "next-generation" or recently developed seawater RO membranes on microfiltered power plant influent water. Phase B1 lasted from June 2004 through June 2005.
- Phase B2 introduced the Zenon Ultrafiltration System, which was initially operated on power plant influent water. Phase B2 also evaluated MF performance and next-generation RO membranes on the warmer power plant effluent. Phase B2 lasted from July 2005 through May 2006.
- Phase B3 indentified two of the four next-generation RO membranes for longer term testing and evaluated the Siemens MF, Zenon UF and RO membranes on power plant effluent for an extended period of time. Phase B3 also introduced another microfiltration system manufacturer, Pall Corporation, into the pilot testing. Phase B3 lasted from June 2006 through May 2008.

Phase B used the existing Siemens CMF-S Microfiltration System and the existing Seawater Reverse Osmosis System in addition to the new Zenon Ultrafiltration System, which operated in parallel with the CMF-S system. Provisions were also made on site to withdraw seawater from the power plant outfall line, after it has been through the cooling loop, in order to test system performance at elevated feed temperatures. In Phase B3, the Siemens CMF-S MF unit was substituted with a Pall Microfiltration System. The process flow diagram is shown in Figure 4-10 below.

Figure 4-10 Process Flow Diagram of the Pilot System, Phase B



4.2.2.1 Siemens CMF-S Microfiltration System

Phase B of testing utilized the same CMF-S System that was used in Phase A. The primary goal of Phase B1 was to evaluate the operation of the next-generation SWRO membranes using MF pretreatment on influent water. This provided an opportunity to gain additional operating experience with the MF process at the optimum design parameters developed in Phase A. As such, the MF operating conditions were maintained as much as possible at the conditions listed in Table 4-6.

Table 4-6 CMF-S Initial Operating Conditions

Initial CMF-S Operating Conditions Phase B1	
Instantaneous Flux	34 gfd
Instantaneous filtrate flow	25.7 gpm
Backwash interval	20 minutes
Maximum TMP	12 psi
Backwash chemical addition	20 mg/l sodium hypochlorite in backwash
Clean-in-place (CIP) cleaning procedure	Siemens standard two step Acid/Hypochlorite procedure as published in their operation literature.

The objectives for testing the CMF-S System in Phase B2 and B3 entailed assessing the performance on warmer power plant effluent. The optimization process used in Phase A was followed for Phase B2 and B3.

The same operating MF data was collected throughout Phase B that was collected in Phase A.

4.2.2.2 Zenon ZW-1000 Ultrafiltration System

The Zenon ZW1000 consists of three cassettes, each with ZW1000 PVDF hollow fibers with a pore size of 0.02 µm. The Zenon system is also vacuum driven, consisting of a filtrate pump that draws water through the hollow fiber lumens. Particulate matter accumulates on the outside surface of the fiber and periodically, a reverse flow backwash procedure is utilized to remove the particulate matter. Air is also used in the backwash process to help scour the membranes. In addition to regular backwashes, the Zenon unit also utilizes Maintenance Cleans, where a chemical solution is introduced into the membrane tank and the membranes are soaked for 30 minutes. This is typically done daily, but can even be done multiple times a day. Like the Siemens CMF-S system, once the maximum TMP is reached the system is shut down and a Clean-In-Place is performed. The Zenon ZW-1000 Pilot unit is shown in Figure 4-11.

Figure 4-11 Zenon ZW-1000 Pilot Unit

The initial operating conditions are shown in Table 4-7. The optimization process was similar to the Siemens CMF-S system, with the goal being to determine the maximum flux and/or backwash interval which will allow a CIP interval of at least 21 days. Adjustments were made to the operating conditions of subsequent runs based on the CIP interval achieved at the previous operating parameters.

Table 4-7 Zenon Ultrafiltration Initial Operating Conditions.

Initial Zenon UF Operating Conditions	
Instantaneous Flux	24 GFD
Instantaneous filtrate flow	25 gpm
Backwash interval	25 minutes
Maximum TMP	13 psi
Backwash chemical addition	None
Maintenance Clean frequency / chemical addition	2x a day /100 mg/L chlorine soak for 30 minutes
Clean-in-place (Recovery Clean) cleaning procedure	5 hours soak/recirculate with 500 mg/L Citric Acid followed by 500 mg/L NaOCl soak/recirculate

Operating data was routinely collected both electronically and manually by the operators to properly evaluate the performance of the MF system. The data collected is shown in Table 4-8.

Table 4-8 Zenon UF Operating Data Requirements

Data Collection for Zenon Ultrafiltration System	
Filtrate Flow (gpm)	Air flow (cfm)
TMP (psi)	Maintenance Clean Frequency
Temperature (^{O}C)	Maintenance Clean Duration
pH	MF feed turbidity (NTU)
Run Time (hours)	MF Filtrate turbidity (NTU)
Backwash frequency setpoint	NH_4OH day tank level
Backwash flow (gpm)	Pressure decay test start pressure (psi)
Backwash flow duration (sec)	Pressure decay test end pressure (psi)
Backwash pressure (psi)	Pressure decay duration (sec)
Backwash chemical requirements	Pressure decay test result (psi/min)

4.2.2.3 Pall Microza Microfiltration System

In Phase B3 the Siemens CMF-S pilot unit was removed from the pilot site and the Pall MF pilot unit was installed in its place. The Pall Microza Microfiltration System is a pressurized, outside/in MF system utilizing PVDF Hollow Fiber membranes with a nominal pore size of 0.1 micron. Unlike the submerged vacuum driven process employed by the Siemens CMF-S and Zenon ZW-1000 systems, the Pall system pumps feedwater to the Hollow Fiber membrane under pressure. A portion of the feed stream exits the top of the module and is recirculated back to the feed tank. This is referred to as excess recirculation, and provides crossflow across the membrane to help keep foulants from building up on the membrane. A backwash pump periodically pumps filtrate through the fibers in the reverse direction to help remove foulants that have built up on the surface of the membrane. Like the Zenon Unit, the Pall System utilizes a maintenance type clean, which is called an Enhance Flux Maintenance (EFM). Typically once a day the system initiates an EFM, where a heated chlorine solution is recirculated through the membrane for 30 minutes to help remove foulants. Over time, the backwashes and EFMs become less effective at removing the foulants and the transmembrane pressure increases. When the maximum TMP of 40 psi is reached the system is shut down to undergo a Clean-In-Place. The Pall pilot system is shown below in Figure 4-12.

Figure 4-12   Pall Microfiltration System

The Pall system was started under the initial operating conditions shown in Table 4-9. The optimization process was very similar to both the Siemens and Zenon system, with the primary goal of the testing being to determine the maximum flux and/or backwash interval which will allow a CIP interval of at least 21 days. Adjustments were made to the operating conditions of subsequent runs based on the CIP interval achieved at the previous operating parameters.

Table 4-9   Pall Microfiltration Initial Operating Conditions.

Initial Pall MF Operating Conditions	
Instantaneous Flux	40 GFD
Instantaneous filtrate flow	30 gpm
Backwash interval	15 minutes
Maximum TMP	40 psi
Backwash chemical addition	None
EFM frequency/chemical	1 x a day /500 mg/L chlorine soak heated to 40 C for 30 minutes
Clean-in-place cleaning procedure	2 hour soak high pH 1% NaOH + 1000 ppm NaOCl followed by 1 hour low pH soak with 2% Citric Acid, each heated to 40 C

Operating data was routinely collected both electronically and manually by the operators to properly evaluate the performance of the MF system. The data collected is shown in Table 4-10.

Table 4-10 Pall Microfiltration Data Collection

Data Collection for Pall MF System	
Feed Flow (gpm)	Backwash flow duration (sec)
Filtrate Flow (gpm)	Backwash pressure (psi)
Excess Recirculation Flow (gpm)	Air flow (cfm)
Feed Pressure (psi)	Enhanced Flux Maintenance Frequency
Filtrate Pressure (psi)	Enhanced Flux Maintenance Duration
Excess Recirculation Pressure (psi)	MF feed turbidity (NTU)
TMP (psi)	MF Filtrate turbidity (NTU)
Temperature (^{O}C)	Pressure decay test start pressure (psi)
Run Time (hours)	Pressure decay test end pressure (psi)
Backwash frequency setpoint	Pressure decay duration (sec)
Backwash flow (gpm)	Pressure decay test result (psi/min)

4.2.2.4 Seawater Reverse Osmosis System

The primary goal for the SWRO testing in Phase B was the evaluation of several “next-generation” SWRO membrane elements, as substantial development had occurred in several manufacturers’ product lines in the period from the start of Phase A to the start of Phase B. Phases B1 and B2 consisted of testing four next-generation membranes on power plant influent and effluent water, respectively. The two membrane models considered to have demonstrated the best performance in Phases B1 and B2 were selected for long term operation in Phase B3. The initial operation conditions for the four next-generation SWRO elements are shown in Table 4-11.

Table 4-11 Initial RO Operating Conditions

Membrane Manufacturer	Dow Filmtec	Hydranautics	Toray	Koch
Membrane Element Model	SW30HRLE-4040	SWC4+ 4040	TM810	TFC-1820SS
Quantity of elements	7			
Element active membrane area (ft2)	80	70	73	73
Total active membrane area (ft2)	560	490	511	511
Initial Permeate flow (gpm)	4.7	4.1	4.3	4.3
Initial Flux (GFD)	12			
RO recovery	50%			
Antiscalant Addition	3 mg/L Nalco PermaTreat 191			
Clean-in-place (CIP) criteria	20% loss of initial Specific Flux or 25% increase in normalized Differential Pressure			
Clean-in-place (CIP) procedure	Membrane manufacturer’s generic formulation and procedure			

The same data collection and process optimization protocol that was used for the SWRO System in Phase A was also utilized in Phase B.

4.2.2.5 Sampling

In order to help assess the performance of the MF and RO Systems and to characterize the various streams, extensive sampling and laboratory analyses were carried out similar to Phase A, but with more analyses associated with permitting requirements.

The following tables summarize the water sampling and laboratory analyses for Phase B of testing.

Table 4-12 Water Quality Parameters Phase B

Laboratory Analysis Frequency-Phase B1							
Parameter	**MF Feed**	**MF Filtrate**	**MF Backwash**	**Break Tank Influent**	**RO Feed**	**RO Permeate**	**RO Conc.**
pH	Daily						
Turbidity (NTU)	Daily	Weekly	Weekly		Weekly		
TOC (mg/L)	Weekly	Weekly	Weekly				
DOC (mg/L)	Weekly						
UV_{254} (cm^{-1})	Weekly	Weekly					
Total Alkalinity (mg/L as $CaCO_3$)	Weekly	Weekly					
Total hardness (mg/L as $CaCO_3$)	Weekly	Weekly					
Calcium hardness (mg/L as $CaCO_3$)	Weekly	Weekly					
Manganese (mg/L)	Monthly						
TDS (mg/L)	Monthly	Monthly	Monthly				
Free chlorine residual (mg/L)	Daily	Daily	Daily	Daily	Daily	Weekly	Weekly
Total chlorine residual (mg/L)				Daily	Daily	Weekly	Weekly
Complete mineral analysis (constituents listed in Table 12A)					Weekly	Weekly	Weekly
Silt Density Index (15 min)					Weekly		
Modified Fouling Index (MFI)							
Total Heterotrophic Plate Count							
Total Coliform	Every other month	Every other month			Every other month	Every other month	Every other month
Fecal Coliform	Every other month	Every other month			Every other month	Every other month	Every other month
Enterococcus Bacteria	Every other month	Every other month			Every other month	Every other month	Every other month
Epifluorescence	Every other month	Every other month			Every other month	Every other month	Every other month

Parameter	Raw Feed	MF Feed	MF Filtrate	MF Backwash	UF Feed	UF Filtrate	UF Backwash	RO Feed	RO Permeate	RO Conc.
pH		Daily			Daily					
Turbidity (NTU)	Daily	Daily	Weekly	Weekly	Daily	Weekly	Weekly	Weekly		
TOC (mg/L)	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly			
DOC (mg/L)		Weekly			Weekly					
UV_{254} (cm^{-1})	Weekly	Weekly	Weekly		Weekly	Weekly				
Total Alkalinity (mg/L as $CaCO_3$)		Weekly	Weekly		Weekly	Weekly				
Total hardness (mg/L as $CaCO_3$)		Weekly	Weekly		Weekly	Weekly				
Calcium hardness (mg/L as $CaCO_3$)		Weekly	Weekly		Weekly	Weekly				
Manganese (mg/L)		Monthly			Monthly					
TDS (mg/L)		Monthly	Monthly	Monthly	Monthly	Monthly	Monthly			
Free chlorine residual (mg/L)		Daily	Daily	Daily	Daily	Daily	Daily	Daily	Weekly	Weekly
Total chlorine residual (mg/L)								Daily	Weekly	Weekly
Complete mineral analysis (constituents listed in Table 12A)								Weekly	Weekly	Weekly
Silt Density Index (15 min)								Weekly		
Modified Fouling Index (MFI)								Monthly		
Total Heterotrophic Plate Count										
Total Coliform	Every other month	Every other month	Every other month		Every other month	Every other month		Every other month	Every other month	Every other month
Fecal Coliform	Every other month	Every other month	Every other month		Every other month	Every other month		Every other month	Every other month	Every other month

Parameter	Raw Feed	MF Feed	MF Filtrate	MF Backwash	UF Feed	UF Filtrate	UF Backwash	RO Feed	RO Permeate	RO Conc.
Enterococcus Bacteria	Every other month	Every other month	Every other month		Every other month	Every other month		Every other month	Every other month	Every other month
Epifluorescence		Every other month	Every other month		Every other month	Every other month		Every other month	Every other month	Every other month

Laboratory Analysis Frequency-Phase B3										
Parameter	**Raw Feed**	**MF Feed**	**MF Filtrate**	**MF Back wash**	**UF Feed**	**UF Filtrate**	**UF Backwash**	**RO Feed**	**RO Permeate**	**RO Conc.**
pH		Daily			Daily					
Turbidity (NTU)		Daily	Weekly	Weekly	Daily	Weekly	Weekly	Weekly		
TOC (mg/L)		Weekly	Weekly	Weekly	Weekly	Weekly	Weekly			
DOC (mg/L)		Weekly			Weekly					
UV_{254} (cm^{-1})		Weekly	Weekly		Weekly	Weekly				
Total Alkalinity (mg/L as $CaCO_3$)		Weekly	Weekly		Weekly	Weekly				
Total hardness (mg/L as $CaCO_3$)		Weekly	Weekly		Weekly	Weekly				
Calcium hardness (mg/L as $CaCO_3$)		Weekly	Weekly		Weekly	Weekly				
Manganese (mg/L)		Monthly			Monthly					
TDS (mg/L)		Monthly	Monthly	Monthly	Monthly	Monthly	Monthly			
Free chlorine residual (mg/L)		Daily	Daily	Daily	Daily	Daily	Daily	Daily	Weekly	Weekly
Total chlorine residual (mg/L)								Daily	Weekly	Weekly
Complete mineral analysis (constituents listed in Table 3-12A)								Bi- weekly	Bi-weekly	Bi-weekly
Silt Density Index (15 min)								Weekly		
Modified Fouling Index (MFI)								Monthly		
Total Heterotrophic Plate Count										

Laboratory Analysis Frequency-Phase B3										
Parameter	**Raw Feed**	**MF Feed**	**MF Filtrate**	**MF Back wash**	**UF Feed**	**UF Filtrate**	**UF Backwash**	**RO Feed**	**RO Permeate**	**RO Conc.**
Total Coliform	Every other month	Every other month	Every other month		Every other month	Every other month		Every other month	Every other month	Every other month
Fecal Coliform	Every other month	Every other month	Every other month		Every other month	Every other month		Every other month	Every other month	Every other month
Enterococcus Bacteria	Every other month	Every other month	Every other month		Every other month	Every other month		Every other month	Every other month	Every other month
Epifluorescence		Every other month	Every other month		Every other month	Every other month		Every other month	Every other month	Every other month

Table 4-12A Mineral Analysis

Parameter	Units
TDS	mg/L
Alkalinity (as CaCO3)	mg/L
Bicarbonate (as CaCO3)	mg/L
Carbonate (as CaCO3)	mg/L
Hydroxide (as CaCO3)	mg/L
Sulfate	mg/L
Chloride	mg/L
Nitrate (as N)	mg/L
Nitrite (as N)	mg/L
Bromide	mg/L
Calcium	mg/L
Magnesium	mg/L
Hardness (as CaCO3)	mg/L
Ca Hardness (as CaCO3)	mg/L
Sodium	mg/L
Potassium	mg/L
Fluoride	mg/L
Strontium	mg/L
Barium	mg/L
Boron	mg/L
Silica	mg/L
Ammonia (as N)	mg/L

Table 4-13 Additional Water Quality Parameters

List	Phase		
	B1	B2	B3
Ocean Plan Metals (Raw Water, MF Filtrate, and RO Concentrate)	1x month	1x month	Once every 3 months
Ocean Plan Organics & Rads (Raw Water, MF Filtrate, and RO Concentrate)	once	once	Once every 6 months
Title 22 Organics & Rads (RO Permeate, per membrane)	once	once	Once every 6 months
CA UCMR (RO Permeate, per membrane)	once	once	twice
EPA UCMR (RO Permeate, per membrane)	once	once	twice
CA Action Levels (RO Permeate, per membrane)	once	once	Once every 6 months
EPA CCL List 1 and 2 (RO Permeate, per membrane)	once	once	twice

4.2.3 Phase C Testing

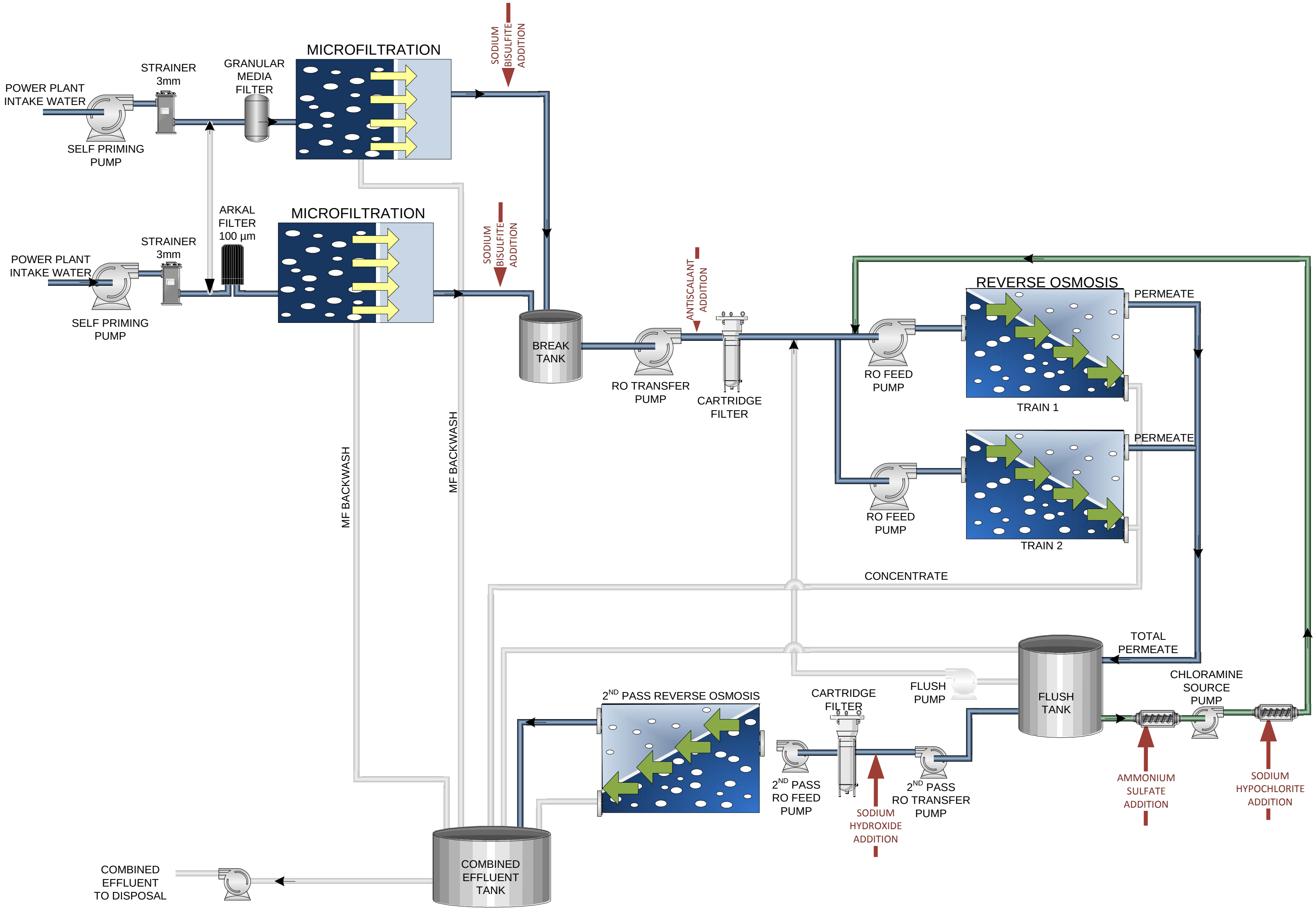
Phase C of testing lasted from September 2008 through June of 2009, and included the addition of several pieces of equipment to the pilot site. Phase C included operation of the Arkal disc filter with a liquid backwash, a new Granular Media Filter, two Pall Microfiltration Units in parallel, the existing Seawater Reverse Osmosis (SWRO) trains, a new Second Pass RO train, and the use of preformed chloramines for biofouling control. The feedwater source to the pilot was the raw water intake to the power plant (only), prior to the power plant cooling loop and discharge.

The major objectives for Phase C included:

- Optimization of the of the Arkal disc filter backwash process.
- Investigate the use of a High Rate Granular Media Filter as pretreatment to Microfiltration.
- Further optimization of the Pall MF System.
- Investigate the use of preformed chloramines to control biofouling.
- Asses the performance of high productivity SWRO membrane in conjunction with a 2nd Pass RO System.

The process flow diagram for Phase C is shown in Figure 4-13.

Figure 4-13 Process Flow Diagram Phase C



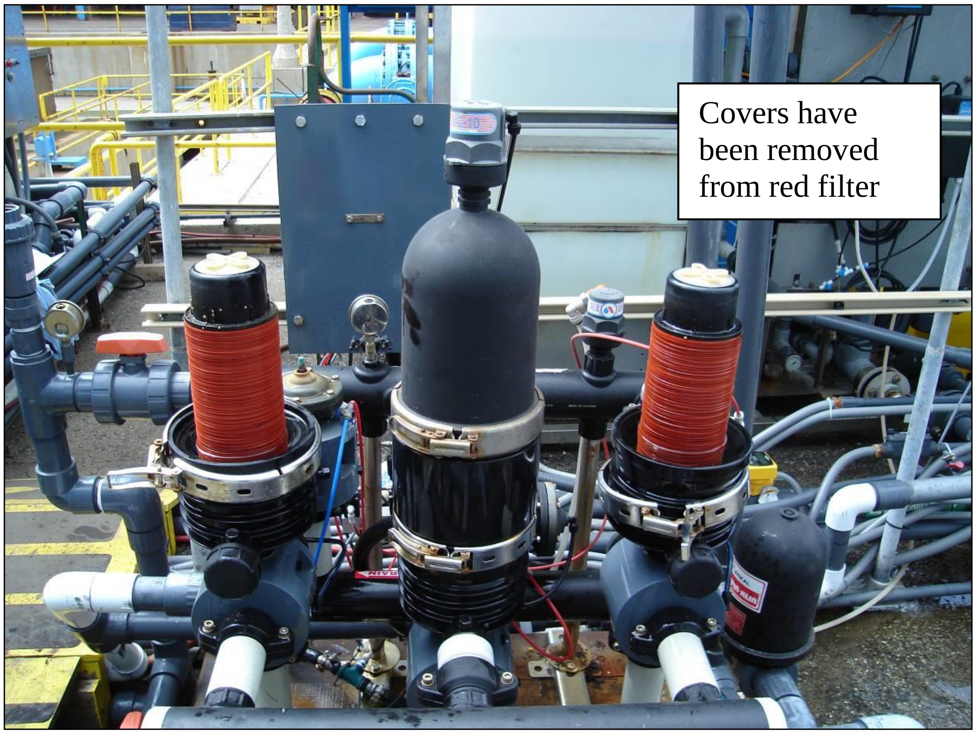
4.2.3.1 Arkal Disc Filter

The Arkal disc filter was used as a pre-strainer to the MF and UF systems to remove harmful particulate matter that could damage the membrane fiber, such as shell fragments.

During normal filtration mode seawater is fed in parallel through the two disc filter columns, and a small volume of filtrate is stored in a third empty housing. After a predetermined time, or on high differential pressure across the discs, a backwash sequence is automatically initiated.

During the backwash process on a small scale pilot system, air is fed under pressure into the housing containing the filtered backwash water. The backwash water is sent to the inside of one of the disc filters to start the backwash process. Inside the disc filter housing the compression spring holding the discs in place is released and the discs are then able to move freely. Tangential jets of the filtered backwash water are sent through the column of discs in the opposite direction through nozzles at the center of the spine. The discs spin free and clear, loosening the trapped solids which are flushed out through the drain. Unfiltered seawater is then sent through the clean disc for a brief period of time to collect another volume of filtered backwash water in the third housing, and then the backwash process is repeated on the second filter disc column. Larger scale Arkal systems utilize a water backwash only, not an air-assisted backwash, to clean the discs. The backwash sequence for the Arkal Filter was setup such that the backwash pump delivers 50 gpm at 60 psi to one of the columns for 20 seconds. After the first column is backwashed, the second column is backwashed in the same manner. The system then goes back online, utilizing both columns in parallel to filter the feedwater. The Arkal system is shown in Figure 4-14.

Figure 4-14 Arkal Disc Filter



Covers have been removed from red filter

The goal of this new phase of testing was to optimize the filtration rate and backwash sequence, test the efficacy of a new liquid backwash method, and to compare filtered water quality and operating performance to that of Granular Media Filter. The performance of the downstream Pall MF units acted as the primary indicator for prescreened water quality, in addition to Turbidity data and samples collected and analyzed for Heterotrophic Plate Count (HPC), E. Coli, Enterocci, and bacteria count via epifluorescence. Operating performance was based on efficiency of the water backwash with and without chlorine present in the backwash water, and the time between backwashes. By extending the time between backwashes, the overall recovery of this prescreening step can be maximized, resulting in reduced operating costs. The downstream Pall MF system was monitored closely, and the rate of decline in permeability of the MF system was compared to the second Pall MF system utilizing the GMF system as prescreening. For example, if the permeability of one Pall system is much more stable than that of the other Pall system, this would indicate that the prescreening methods may differ in the quality of water they produce.

The initial operating conditions for the Arkal Filter are shown in Table 4-14.

Table 4-14 Initial Arkal Operating Conditions

Initial Arkal Operating Conditions	
Filtration Rate	~35 gpm
Backwash interval	20 minutes
Backwash water volume	33 gallons
Backwash water flowrate	50 gpm
Backwash water pressure	55-60 psi
Backwash duration (per pod)	20 seconds
Backwash chemical addition	100 mg/L chlorine 2 x a week
Duration of Initial Operating Conditions	2 weeks

Initial optimization steps included extending the duration between backwashes in increments of 10 minutes every week. Manual data collection was per Table 4-15.

Table 4-15 Arkal Data Collection

Arkal Manual Data Recording	
Delta P (psi) across Arkal disc filter	1 x Daily
Filtrate flowrate (gpm)	1 x Daily
Feed water Turbidity	1 x Daily
Arkal Filtrate Turbidity	1 x Daily

4.2.3.2 High Rate Granular Media Filter

The goal of this testing was to determine the effectiveness of a high rate Granular Media Filter (GMF) as a pre-strainer to a hollow fiber Microfiltration System, and to optimize operating conditions for the GMF. The testing included optimizing the filtration rate and backwash sequence, and a comparison of the filtered water quality and operating performance to that of the Arkal Disc Filter. The performance of the downstream Pall MF units acted as the primary indicator for filtered water quality, in addition to Turbidity data and water samples analyzed for HPC, E. Coli, Enterocci and bacteria count via epifluorescence.

The GMF system is a high rate, deep bed, dual media granular media filter. There are two principal advantages of this filter design: (1) excellent solids holding capacity allowed by the deep bed design and (2) robust effluent water quality attributed to the dual media. Both of these factors are extremely important when treating seawater, as variations in feedwater quality will result in time periods (i.e. storm or algal bloom events) where the filters need to hold more solids while continuing to produce a consistent effluent quality. The media selection and depths were selected based upon the estimated clean bed headloss at a filtration rate of 20 gpm/sq.ft. and the project team’s desired water quality. Because the GMF’s role is primarily to serve as a pre-strainer, the established filtration rate for the concept tested in this study is substantially higher than in conventional drinking water applications. The GMF’s role is not to produce the water quality needed for the reverse osmosis system, but it is to protect the MF unit from shells and enhance MF performance. Because the effluent turbidity does not form the design basis for this high rate GMF, the backwash interval for the GMF was based on a 48 hour filtration run. Although this filtration cycle could have been longer (producing a larger unit filter run volume), the filtration run was limited to 48 hours due to concerns with biogrowth in the filter bed.

The GMF System was furnished with two identical filter columns, and could be operated in either alternating mode or simultaneous (parallel) mode. Each schedule 80 PVC column is 13 ft. tall, 20” in diameter (ID of 17.8”) and contains 30” of sand supporting 60” of anthracite media. The system was operated in alternating mode for the duration of this study with one filter column in service and the other in standby. When a filter column commences a backwash, the feedwater is diverted to the other filter column in order to maintain a constant supply of feedwater to the downstream MF system. The filters continue to alternate service duty between backwash cycles. At the end of a backwash cycle, the washwater was chlorinated to prevent biogrowth.

Table 4-16 Design Parameters of the High-Rate Granular Media Filter

Average Filtration Rate	40 gpm
Average Loading Rate	23 gpm/sq. ft.
Media Specifications	▪ 30" of Sand (d = 0.88 mm, U.C < 1.4) ▪ 60" of Anthracite (d = 1.65 mm, U.C. < 1.4)
Backwash Interval	48 hours
Backwash flowrate	25 gpm
Backwash Steps ▪ Drain Down ▪ Aeration ▪ Aeration with Backwash flow ▪ Backwash flow only ▪ Filter to waste	 ▪ 5 minutes ▪ 4 minutes @ 8.7 scfm ▪ 2 minutes @ 25 gpm ▪ 8 minutes @ 25 gpm ▪ 5 minutes @ 40 gpm
Backwash water volume per backwash	250 gallons

Figure 4-15 High Rate Granular Media Filter

The initial operating conditions for the GMF are shown in Table 4-17.

Table 4-17 High Rate GMF Initial Operating Conditions

Initial GMF Operating Conditions	
Operating Mode (Alternating or Simultaneous)	Alternating
Filtration rate/ Surface loading rate	35 gpm (20 gpm/sq ft)
Backwash interval	Every 8 hours
Backwash flowrate	25 gpm
Duration of Initial Operating Conditions	2 weeks

Initial optimization steps included extending the duration between backwashes in increments of two hours every week.

Data collection for the GMF System was per Table 4-18.

Table 4-18 High Rate GMF Data Collection

GMF Data Recording	
Filter Column Inlet Pressure (psig)	Time since backwash (hours)
Filter Column Outlet Pressure (psig)	Feed water Turbidity (NTU)
Filtrate flowrate (gpm)	Filter Column Outlet Turbidity (NTU)
Temperature (°C)	Filter Column in Operation (A or B)

4.2.3.3 Pall Microfiltration Systems

For Phase C the pilot plant was configured with two Pall Microfiltration systems in parallel. The goal for this phase of testing with the Pall MF units was to compare operating performance in order to determine the effect of the two different pre-straining technologies used in front of the MF units. Unit 1 was fed with Arkal disc filter prefiltered seawater, and Unit 2 was fed with high rate granular media filter prefiltered seawater. Both Pall units were to be operated under identical conditions in order to help asses the water quality out of each upstream prefiltration process.

The Pall systems were started at the conditions listed below in Table 4-19. These conditions were based on previous testing of the Pall system at this site, and were considered somewhat conservative for the initial run.

Table 4-19 Pall MF Units Initial Operating Conditions

Initial MF Operating Conditions for Pall 1 and 2	
Instantaneous Flux	40 GFD
Instantaneous filtrate flow	30 gpm
Maximum TMP	43.5 psi
Recovery	92-93%
Backwash interval	15-20 minutes
Backwash chemical addition	None
EFM	1 x daily
EFM chemical addition	500 mg/L chlorine, heated to 40 C
Clean-in-place cleaning procedure	1% NaOH solution with 1,000 mg/l NaOCl, heated to 40 C, 2 hr recirc Followed by 2% citric acid solution heated to 40 C, 1 hr recirc

Initial optimization steps were to entail increasing the flux rate by ~10% after every CIP. Data collection for Phase C was the same that was used in Phase B.

4.2.3.4 Seawater Reverse Osmosis System

A goal for Phase C testing for the Reverse Osmosis System was to investigate the use of higher productivity SWRO membrane used in conjunction with a 2nd Pass RO System. Previous seawater RO membrane testing had focused on the highest rejection RO membranes in the market. These membranes were tested to determine if drinking water quality could be reached in a single pass system. While drinking water standards were achievable with a single pass, it may be desirable to produce water with lower levels of chloride and boron. In order to achieve this goal, a partial second pass RO system was tested in Phase C. In conjunction with testing a second pass RO system, an alternative 1st Pass SWRO membrane was investigated. The alternative 1st Pass SWRO membrane tested was the SWC5 product from Hydranautics. While this membrane does not have the higher salt rejection characteristics as previous membranes tested, the permeability of this membrane is higher, which will lower the energy requirements of the 1st Pass SWRO. By operating the SWC5 in tandem with the second pass RO, final water quality and energy requirements can be further evaluated.

In addition to testing a new 1st Pass SWRO membrane and a partial 2nd Pass RO system, the use of preformed chloramines was also examined in this phase of the study. Preformed chloramines were to be examined as a method to control biofouling, first in one of the SWRO trains, and then in one of the upstream prescreening and Microfiltration systems.

In order to safely startup the new chloramine addition system, old out of service RO elements were loaded into RO 1 and 2. This enabled the operators to work out any mechanical issues with the chloramine dosing system without the risk of oxidizing a new set of RO membranes. Once the chloramine dosing was stable, the SWC5 membranes were loaded into Train 1 and Train 2. Chloramines were dosed only in the feed of Train 1, to test the effectiveness of reducing biofouling against Train 2, the control. Table 20 shows the initial operating conditions for RO Trains 1 and 2.

Table 4-20 Initial 1st Pass RO Operating Conditions

Initial RO Operating Conditions	
Membrane Element Model	Hydranautics SWC5-4040
Qty of elements per Train	7
Element active membrane area (ft2)	85
Total active membrane area (ft2)	595
Initial Flux (GFD)	9
Initial Permeate flow (gpm)	3.7
Initial Concentrate flow (gpm)	3.7
RO recovery	50%
Antiscalant Addition	3 mg/L Nalco PermaTreat 191
Clean-in-place (CIP) criteria	20% loss of initial Specific Flux or 25% increase in normalized Differential Pressure
Clean-in-place (CIP) procedure	2% Citric Acid followed by 2% Avista P111

Data collection for Phase C was the same as in Phase B, with the addition of measuring chloramine concentrations for Train 1.

4.2.3.5 2nd Pass Reverse Osmosis

As mentioned above, a 2nd Pass RO system was evaluated to help determine final permeate quality and optimize operating conditions. This data is necessary for the full scale design and for determining final water quality. The system was equipped with seven 2.5" diameter membranes in series, caustic addition to the feed line to test boron rejection at various pH levels, and a concentrate recycle stream to allow operation at high recoveries. Routine samples were collected for ionic constituent analysis, similar to RO Trains 1 and 2. The 2nd Pass RO Unit is shown in Figure 16.

Figure 4-16 Second Pass RO

Table 4-21 Initial Second Pass RO Operating Conditions

Initial Second Pass RO Operating Conditions	
Membrane Element Model	Hydranautics ESPA2-2540
Qty of elements	7
Element active membrane area (ft2)	28
Total active membrane area (ft2)	196
Initial Flux (GFD)	25
Initial Permeate flow (gpm)	3.5
Initial Concentrate flow (gpm)	0.62
Initial Recycle flow (gpm)	0.5
RO recovery	85%
Feed pH (with caustic addition)	9

Initial optimization steps will entail changing the pH of the feedwater to test the effect on boron rejection. The system will run for 30 days at a feed pH of 9, and then the feed pH will be increased to 9.5 and 10.0, each for a 30 day run.

Data collection was per Table 22.

Table 4-22 Second Pass RO Data Collection

2nd Pass RO Data Recording	
Cartridge Filter Inlet Pressure	Permeate flowrate
Cartridge Filter Outlet Pressure	Concentrate flowrate
Feedwater Conductivity	Recycle flowrate
Feedwater Temperature	Permeate conductivity
Feedwater pH	Permeate pH
Feed Pressure	Concentrate pH
Concentrate Pressure	Vessel 1 -7 Permeate Conductivities

4.2.4 Preformed Chloramine Dosing

In Phase A pilot testing , the use of chloramines was piloted in an effort to control biofouling. The method used in an attempt to form chloramines resulted in the formation of bromamines due to the natural presence of bromine in seawater, and the bromamines oxidized the RO membranes. Recent laboratory studies by West Basin have shown that if chloramines are preformed before coming in contact with seawater, bromamine formation can be avoided, and a chloramine residual can remain in the seawater which should provide some form of biological control. A goal of Phase C testing was to implement the laboratory work on the pilot scale. The method for forming the chloramines involves injecting ammonia sulfate into a carrier water line, and then injecting sodium hypochlorite downstream of the ammonia. SWRO permeate is used as the carrier water to make the chloramine solution. Two injection points for the chloramines were installed in the new equipment layout, with one injection point located on the discharge of cold water pump to control biogrowth in the RO pretreatment, and the other injection point in the feed line to SWRO Train 1.

Table 23 shows the initial setup for the chemical dosing.

Table 4-23 Initial Chloramine Dosing

Initial Chloramine Dosing Setup	
Carrier Water Pump	Flowrate: 0.2 gph of SWRO permeate
Ammonia Sulfate Injection Pump	Flowrate: 0.2 gph of 2% (NH3)SO4
Chlorine Injection Pump	Flowrate: 0.2 gph of 1.5% NaOCl
Chloramine Injection Point	RO Train 1 Feed
Chloramine dose	7 mg/l

4.2.5 Phase C Sampling

Sampling

In order to help assess the performance of the process equipment and to characterize the various streams, extensive sampling and laboratory analyses were carried out per the document TM-1 Sampling Plan.

The following tables summarize the water sampling and laboratory analyses for Phase C of testing.

Table 4-24 Phase C Routine Sampling

Parameter	Raw Water	Arkal Filtrate	Arkal Back-wash	GMF Filtrate	GMF Back-wash	Pall 1 Filtrate	Pall 1 Back-wash	Pall 2 Filtrate	Pall 2 Back-wash	RO Feed Pre-Chloram	RO Feed Post Chloram	RO 1 Perm	RO 1 Conc
E. Coli	**D**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**D**	**M**
Enterocci	**W**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**
HPC	**D**	**2x a week**	**2x a week**	**2x a week**	**2x a week**	**2x a week**	**2x a week**	**2x a week**	**2x a week**	**2x a week**	**2x a week**	**2x a week**	**2x a week**
EPI DBC for VBNC	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Turbidity	**C**	**D**	**W**	**D**	**W**	**C**	**W**	**C**	**W**				
Conductivity										**C**		**C**	**C**
On-Line Relative Fluorescence	**C**												
TOC	**W**											**W**	**W**
Conventional Emerging Contaminants	**M**											**M**	
TDS	**W**											**W**	**M**
Major Anions (Cl, SO4, Alk)	**W**											**W**	**M**
Minor Anions (Br, F, NO3 & NO2)	**M**											**M**	**M**
Major Cations (Ca, Mg, Na & K)	**M**											**M**	**M**
Minor Cations (Sr, Ba)	**M**											**M**	**M**
Silica & Boron	**W**											**W**	**M**
Ammonia	**M**											**M**	**M**
Temperature						**C**						**C**	
pH	**D**										**D**	**D**	
Color												**W**	
Chlorophyll a	**W**												
Proportional counter (Gross Alpha/beta/photons) (EPA 900*****)	**W**											**M**	
Odor-Threshold	**M**											**M**	
Radio active substance (EPA 900*****)													**M**

Table 4-25 Phase C Drinking Water Parameters Sampling

Parameter	Raw Water	Arkal Filtrate	Arkal Back-wash	GMF Filtrate	GMF Back-wash	Pall 1 Filtrate	Pall 1 Back-wash	Pall 2 Filtrate	Pall 2 Back-wash	RO Feed Pre-Chloram	RO Feed Post Chloram	RO 1 Perm	RO 1 Conc.
Asbestos	**SA**											**SA**	
TCDD	**SA**											**SA**	
ICP - MS (Trace metals)	**A**											**A**	
AAS (Mercury)	**Q**											**SA**	
Perchlorate	**SA**											**SA**	
Colorimetric/RFA	**SA**											**SA**	
GC/ECD (pesticides)	**A**											**SA**	
GC/ECD (Herbicides)	**SA**											**SA**	
GC/MS SIM (NDMEA, NDMA, NDPA)	**SA**											**SA**	
GC/MS (VOCs)	**A**											**SA**	
GC/MS (TBA, 1,2,3 TCP)	**SA**											**SA**	
GC/MS (SOCs)	**A**											**SA**	
GC/MS (RDX and TNT)	**SA**											**SA**	
HPLC(Carbamates)	**SA**											**SA**	
HPLC/PCD (Glyphosate)	**SA**											**SA**	
GC/MS (Endothall)	**SA**											**SA**	
GC/MS (Diquat)	**SA**											**SA**	
Carbon disulfide	**SA**											**SA**	
Emanation (Radium 226)	**Q**											**Q**	
Proportional counter (Radium 228)	**Q**											**Q**	
Scintillation counter (Strontium-90)	**Q**											**Q**	
Proportional counter (Tritium)	**Q**											**Q**	

Parameter	Raw Water	Arkal Filtrate	Arkal Back-wash	GMF Filtrate	GMF Back-wash	Pall 1 Filtrate	Pall 1 Back-wash	Pall 2 Filtrate	Pall 2 Back-wash	RO Feed Pre-Chloram	RO Feed Post Chloram	RO 1 Perm	RO 1 Conc.
Colorimetric method (Foaming agent)	**SA**											**SA**	
GC/ECD (Formaldehyde)	**SA**											**SA**	

Table 4-26 Phase C Ocean Plan Parameters Sampling

Parameter	Raw Water	Arkal Filtrate	Arkal Back-wash	GMF Filtrate	GMF Back-wash	Pall 1 Filtrate	Pall 1 Back-wash	Pall 2 Filtrate	Pall 2 Back-wash	RO Feed Pre-Chloram	RO Feed Post Chloram	RO 1 Perm	RO 1 Conc.
Acute and chronic toxicity	**Q**												**Q**
Dibenzo-Dioxin	**Q**												**Q**
Trace metals	**SA**												**Q**
Mercury	**Q**												**Q**
Pthalates; base, neutral and acid extractable compounds; PAHs;PCBs; triazine; and pesticides	**Q**												**Q**
VOCs	**Q**												**Q**
Radio active substance	**Q**												**Q**
Tributyltin	**Q**												**Q**
Chromium (VI)	**Q**												**Q**
Residual chlorine	**Q**												**Q**
Cyanide	**Q**												**Q**

Sampling Key	
D	Daily (5 times a week)
W	Weekly
M	Monthly
Q	Quarterly
SA	Semi-Annual
A	Annual

Source Water Characterization

5.0 Source Water Characterization

5.1 Introduction

The source water for the pilot project, and ultimately the proposed full scale seawater desalination facility, is Pacific Ocean water, specifically from Santa Monica Bay. The water quality of Santa Monica Bay has been the subject of many investigations in recent decades, many of which focused on the discharge from Hyperion Wastewater Treatment Plant. The Hyperion Wastewater Treatment Plant underwent significant improvements in the 1980's and 1990's, resulting in full secondary treatment of all wastewater before being discharged through the 5 mile outfall line. These upgrades drastically improved the water quality in Santa Monica Bay. Other discharges into the bay include runoff from Ballona Creek watershed via Ballona Creek and the Malibu Creek watershed via Malibu Creek. The Ballona Creek is an urban storm drainage channel for the Los Angeles area, where Malilbu Creek drains a mostly undeveloped watershed. The approximate location of the Hyperion 5 mile outfall and the locations of Malibu Creek discharge, Ballona Creek discharge, and the seawater desalination pilot plant are shown in Figure 5-1.

Figure 5-1 Map of Santa Monica Bay

The quality of the source water used to feed a seawater desalination facility has a profound affect on both the design and operations of the facility. The parameters which have the greatest impact on the design and operation of a seawater desalination facility include turbidity, temperature, concentrations of dissolved ionic species, and levels of biomass present in the feedwater. These parameters can affect the fouling rate, operating pressure, and finished water quality of the desalination facility. As described in the previous section extensive water quality analyses were performed in order to fully characterize the source water.

Turbidity of the feedwater is a measure of how cloudy the water is, and is quantified by the water's ability to transmit light. The more light that is able to pass through the water, the lower the turbidity. In seawater, the turbidity is typically a function of how much suspended material and particulate matter is present in the water, often in the form of silt, biomass, or decaying organic matter. If a water sample is high in particulate matter, more light will be scattered by the particles and light will not transmit completely through the water sample, resulting in higher levels of turbidity. This particulate matter can be detrimental to both the pre-screening equipment and the hollow fiber MF/UF membranes used for pretreatment to the RO membranes. The presence of particulate matter can lead to plugging or fouling of the MF/UF membranes and can have a direct impact on the operating efficiency of the facility in terms of potential increase in cleaning chemicals, increase in power consumption, or decrease in capacity. As such, it was very important to quantify these parameters in the source water.

The temperature of the feedwater to a seawater desalination facility directly impacts both the RO permeate quality (salt passage) and the RO feed pressure required to produce the required flows. One important aspect of RO membranes is their response to changes in feed water temperature. When the temperature of the feedwater is elevated, salt passage through the membrane increases resulting in increased levels of individual ions, such as chloride and boron, and in increase in overall TDS in the RO permeate. The permeability of the membrane also increases with elevations in feedwater temperature (although at a different rate than salt passage), resulting in less operating pressure required to achieve the same flux. Temperature was monitored for both naturally occurring diurnal and seasonal variations as well as variations from power plant operations when the pilot plant was operated on the warmer power plant outfall water.

The concentration of total dissolved solids (TDS) in the source water also directly impacts the operating pressure of the RO system and RO permeate quality. High TDS levels require greater feed pressure to the RO system in order to overcome high osmotic pressure, and also result in higher levels of TDS in the RO permeate. In order to develop proper design parameters, it is important to account for any variations in salinity in the source water that may occur from other sources such as nearby rivers or other discharges.

The level of biomass in the source water can also greatly impact the seawater desalination facility. Biomass, typically in the form of phytoplankton and marine bacteria, can foul the MF/UF membranes. Marine bacteria not removed by the MF/UF process can then foul the downstream RO membranes, leading to increased operating costs. It is important to understand the seasonal changes in biomass levels, brought about by upwelling events or storms, and the subsequent affects on the seawater desalination facility.

5.2 Source Water Quality Results

5.2.1 Turbidity

The turbidity of the raw water to the pilot facility was measured consistently throughout the course of the testing period. Samples were collected of both the ambient power plant intake water and the warmer power plant outfall water, depending on the testing phase. Samples were collected after the primary basket strainer but before the disc filter / granular media filter. The 3 mm basket strainer simply kept out large pieces of debris and did not screen out the small particles that account for the turbidity. Table 5-1 is a summary table of the turbidity values throughout the testing period

Table 5-1 Summary of Feedwater Turbidity

Phase	Average (NTU)	Standard Deviation	Minimum (NTU)	Maximum (NTU)	95th Percentile
A (6/02 – 5/04)	1.28	0.92	0.13	6.46	3.37
B1 (6/04– 6/05)	1.25	0.82	0.23	3.77	3.18
B2 Ambient (7/05 – 5/06)	2.28	2.08	0.24	10.60	6.86
B2 Warm (7/05 – 5/06)	1.82	1.36	0.19	9.70	4.51
B3 Ambient (6/06 – 3/08)	2.10	1.62	0.54	10.0	5.72
B3 Warm (6/06 – 3/08)	1.57	1.26	0.28	10.0	3.35
C (9/08 – 6/09)	1.38	1.03	0.42	6.16	3.18

The average turbidity of the raw water was consistent over the seven year period of testing, with average values ranging from 1.25 – 2.28 NTU. Both the average and the maximum values can be considered very good quality for an open intake source water as feedwater to a seawater desalination facility.

The following graphs show the turbidity values for the entire period of testing and for each phase across the specific time period for that phase of testing. Typical causes for elevated levels of turbidity were either from storm events with rough seas or from algal blooms with increased levels of biomass. Figures 5-5 and 5-7 show the turbidity of both the raw ambient intake water and power plant outfall water over the same time period. It is noteworthy that there is not a significant difference in the turbidity levels on these two water sources across the same time frame.

Figure 5-2 Phase Cumulative Feedwater Turbidity (file: Sampling Rev A May 19 06)

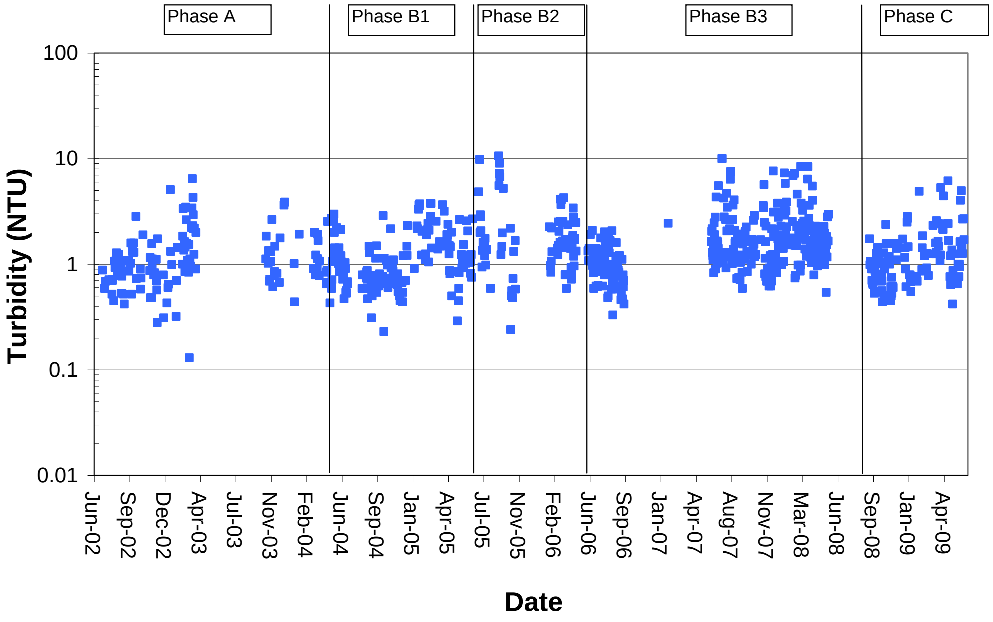


Figure 5-3 Phase A Raw Water Turbidity (file: Sampling Rev A May 19 06)

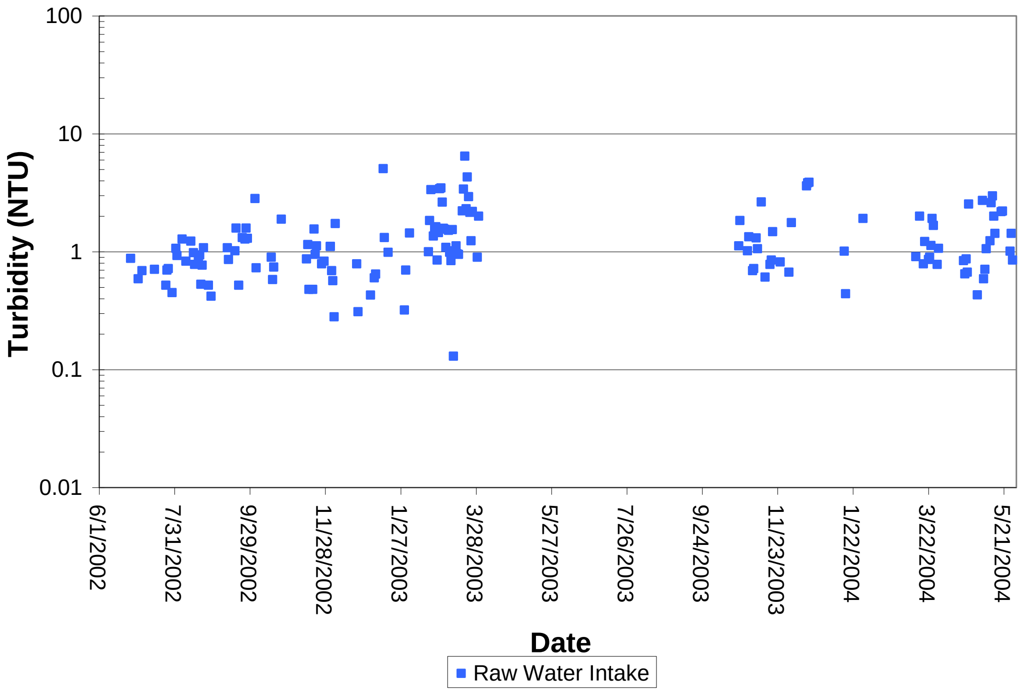


Figure 5-4 Phase B1 Raw Water Turbidity (file: Sampling Rev A May 19 06)

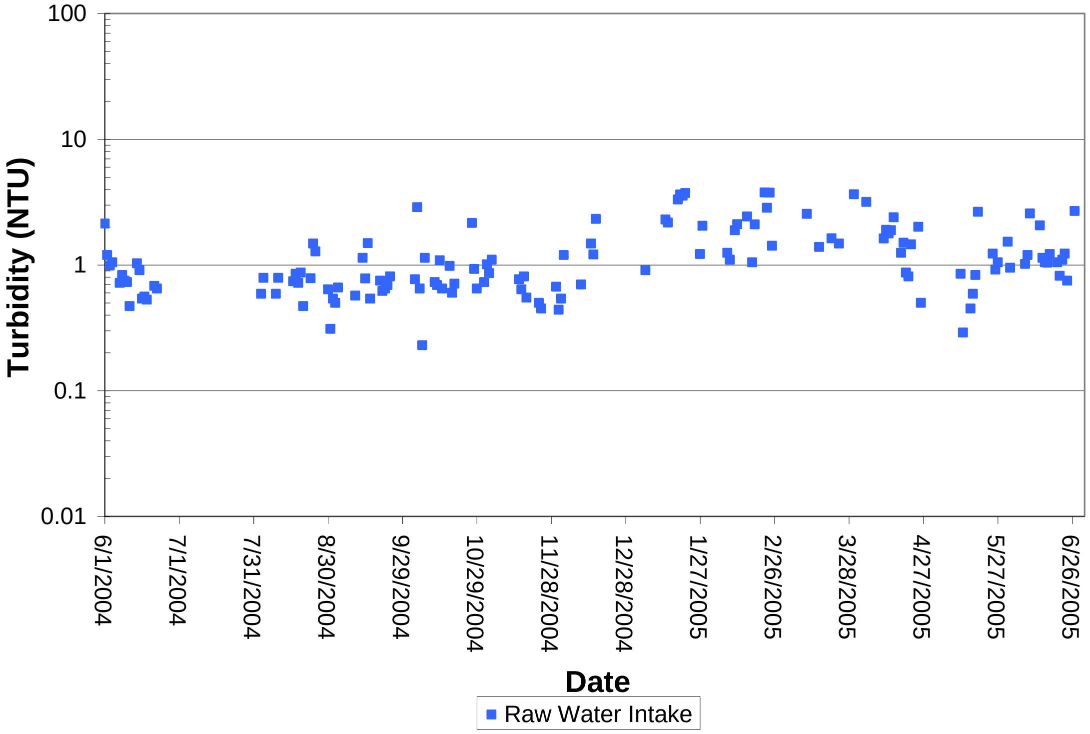


Figure 5-5 Phase B2 Raw Water Turbidity (file: Sampling Rev A May 19 06)

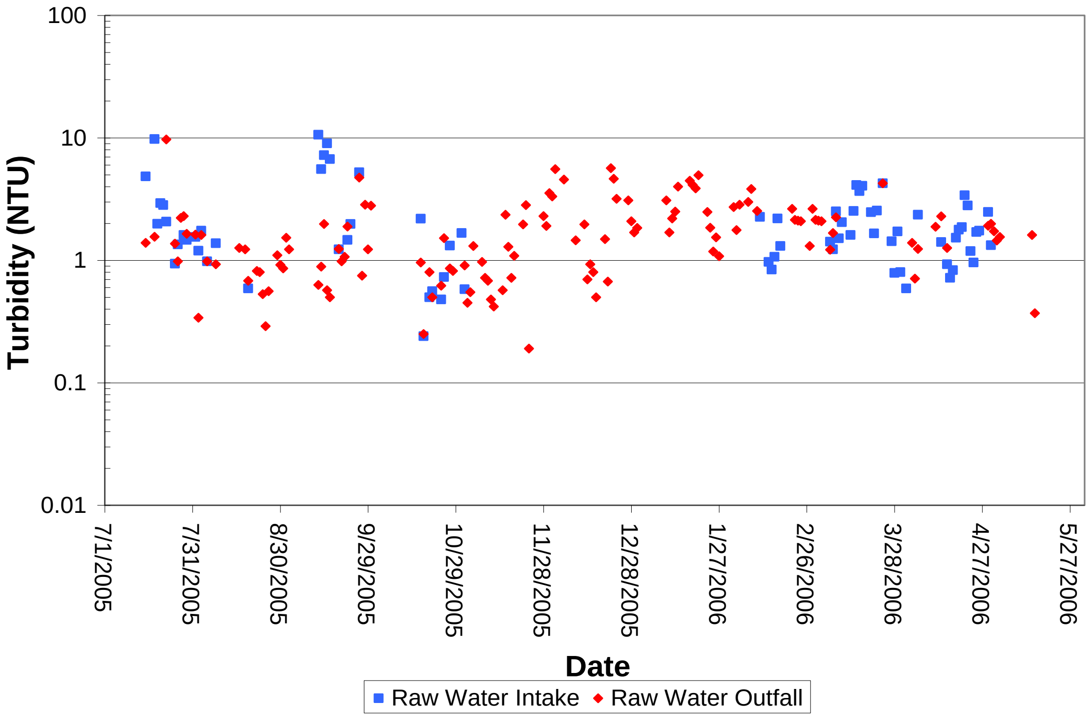


Figure 5-6 Phase B3 Raw Water Turbidity

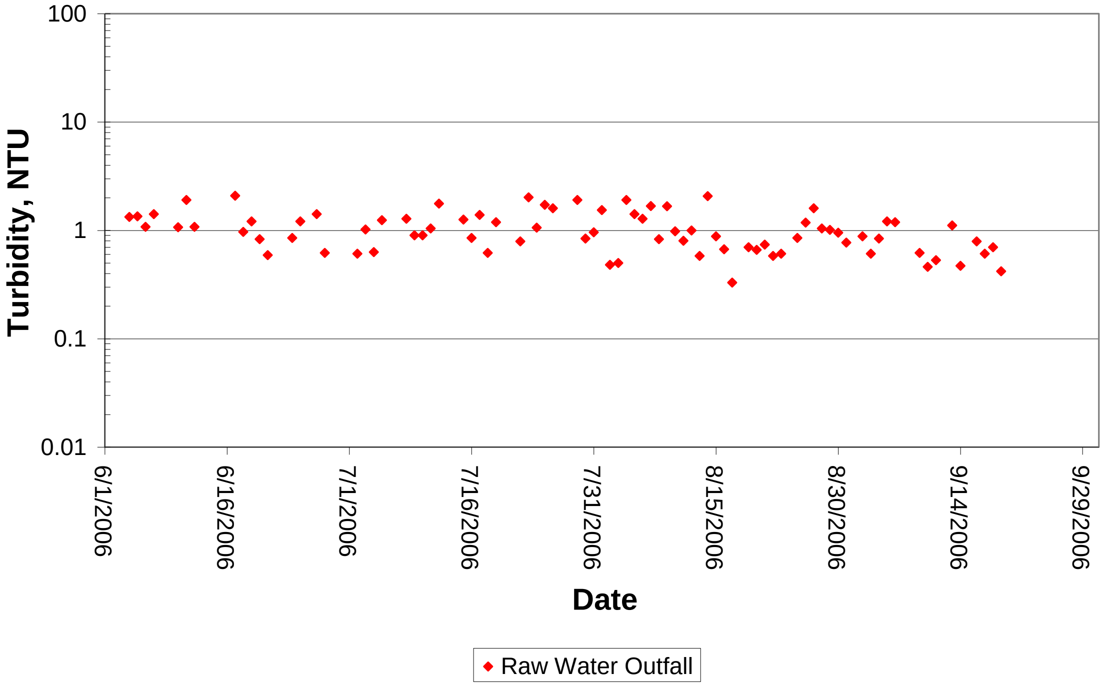


Figure 5-7 Phase B3 Raw Water Turbidity

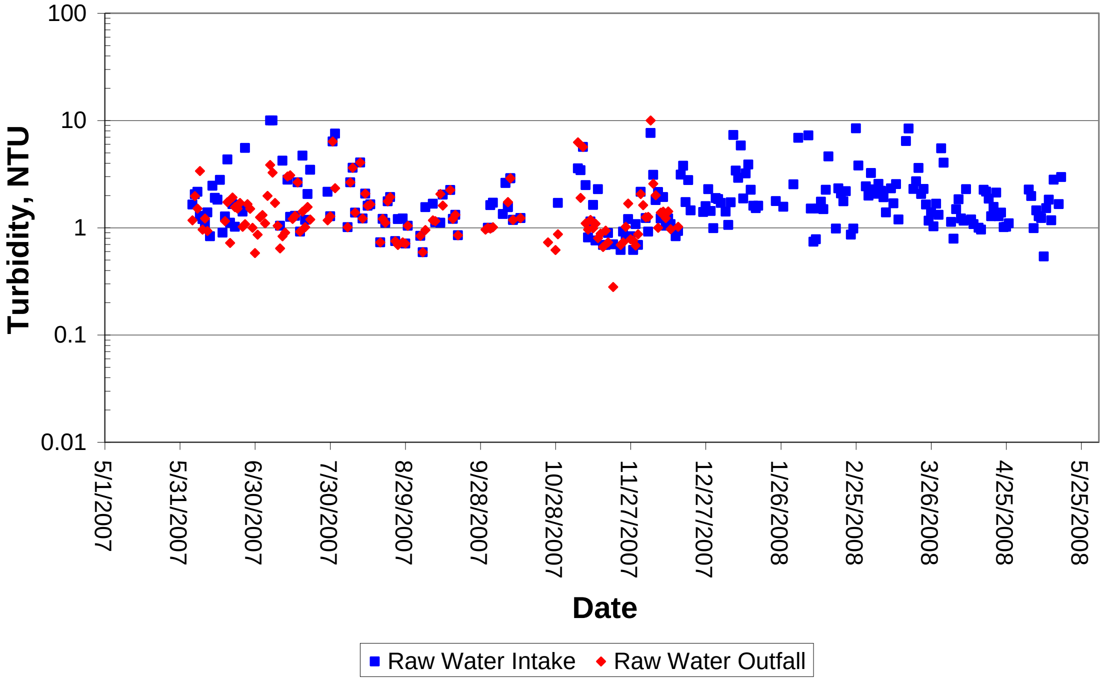
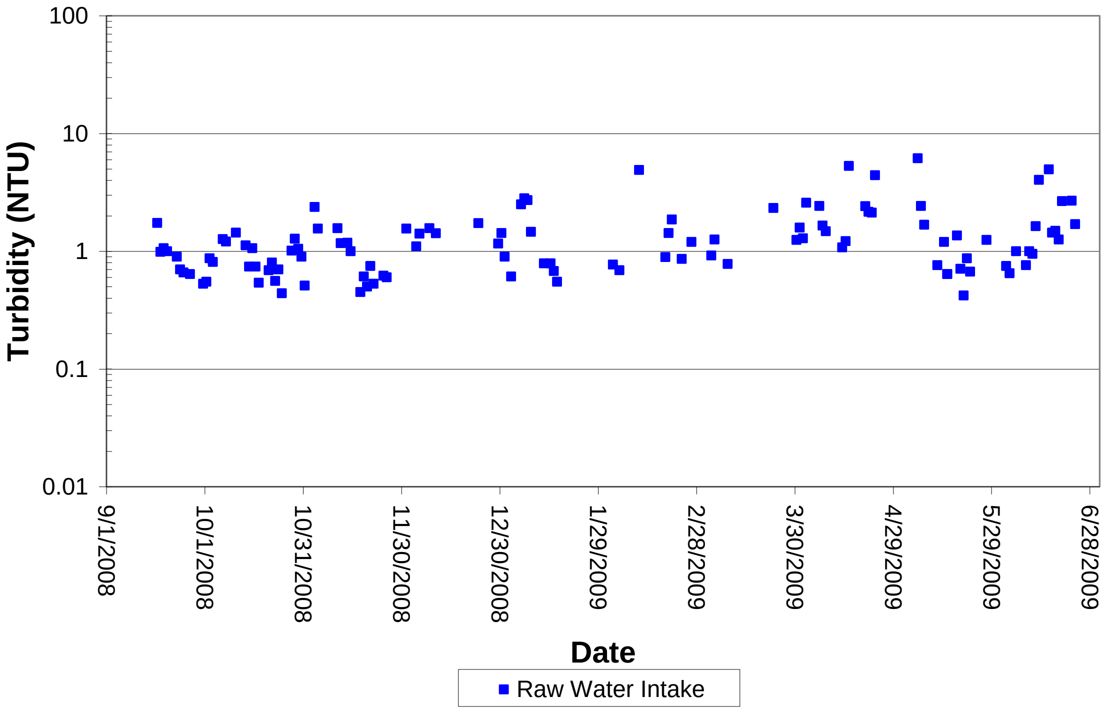


Figure 5-8 Phase C Raw Water Turbidity



5.2.2 Temperature

The temperature of the feedwater to the pilot plant was also monitored consistently throughout the testing and a summary is shown in Table 5-2. The ambient intake water temperature fluctuated seasonally between a minimum of 11.4°C and a maximum of 24.4°C across the entire period, with an average temperature of 16.0°C. The warmer power plant outfall water experienced a minimum temperature of 13.1°C and a maximum temperature of 36.8°C. The average temperature of the warm water outfall was 21.5°C.

Table 5-2 Summary of Feedwater Temperature

Phase	Average Temperature (°C)	Minimum Temperature (°C)	Maximum Temperature (°C)	95th% (°C)
A	16.0	11.4	20.5	19.3
B1	17.1	12.2	24.4	21.1
B2 Ambient	16.7	12.4	23.6	20.5
B2 Warm	21.2	13.1	32.5	26.1
B3 Ambient	15.4	12.0	20.3	19.1
B3 Warm	22.1	14.6	36.8	32.7
C	15.3	12.4	19.6	18.3

There are distinct seasonal trends seen in Figure 5-9 for the ambient intake water (shown in blue), with minimum temperatures occurring typically in February and March and maximum temperatures occurring in July to September. Also evident in Figures 24-26 is that there are periods of time when the warm water outfall temperature is very close to the ambient intake temperature. This is due to the fact that the El Segundo Power Plant is a peaking plant and does not generate electricity continuously throughout the year. When the power plant is operational, especially in the summer months when electricity demand is high, the temperature of the water can become quite elevated for weeks at a time. When the power plant was in operation the effluent would generally be approximately 8°C higher than the ambient intake. It should be noted that the temperature *did not* reach the maximum acceptable operating temperatures of the RO membranes of 40 - 45 °C (manufacturer specific).

Figure 5-9 Temperature of Ambient Intake and Warm Water

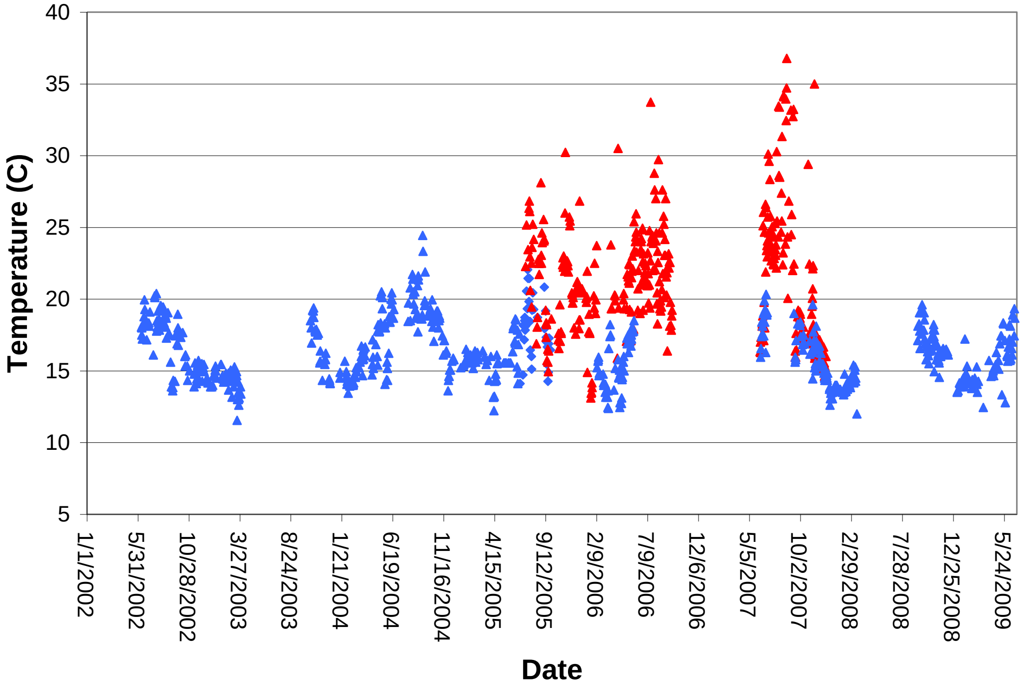


Figure 5-10 Phase B2 Temperature of Ambient Intake and Warm Water Outfall

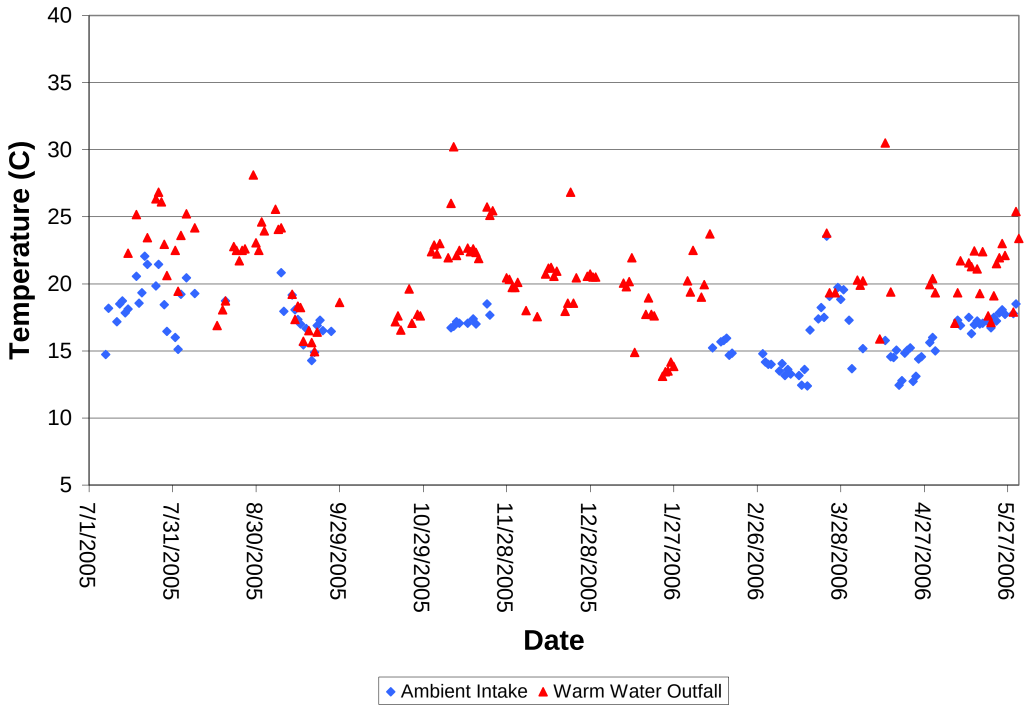
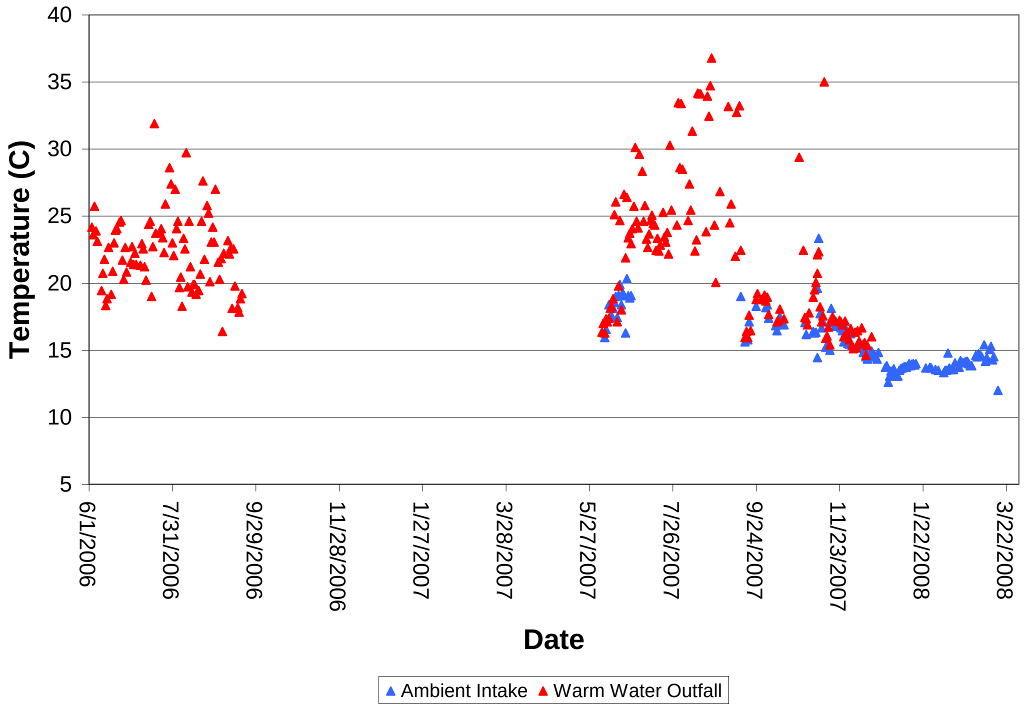


Figure 5-11 Phase B3 Temperature of Ambient Intake and Warm Water Outfall



5.2.3 Total Dissolved Solids

Tables 5-3 through 5-7 show the average total dissolved solids and average concentrations of individual ions for each phase of testing. The average TDS value across the entire testing period was approximately 34,000 mg/l with very little fluctuation. Therefore, the design of a reverse osmosis system can be based on treating this high level of salinity continuously, without needing special considerations for treating much lower TDS levels at various times of the year. These results are consistent with the lack of any nearby rivers emptying into the ocean in close proximity to the pilot site. The closest major contributor of incoming low TDS water is Ballona Creek, an urban storm drainage channel for the Los Angeles area located approximately 4 miles north of the pilot facility as depicted previously in Figure 5-1. The discharge from this channel, even at times of significant rainfall, is not sufficient to greatly impact the TDS levels of the source water to the pilot plant. Substantial water sampling did take place at the pilot plant during the winter of 2008-2009 to help quantify the effects of stormwater runoff at the pilot plant, and the results of that study are included in Appendix X of this report.

Table 5-3 Phase A Summary of Feedwater Total Dissolved Solids

Parameter	Method	Raw Water Average (mg/l)	Standard Deviation	Minimum (mg/l)	Maximum (mg/l)
TDS	SM 2540C	35,000	1,420	32,000	38,000
pH	SM 4500-H+ B	8.1	0.1	7.8	8.4
Alkalinity (as CaCO3)	SM 2320B	114	4	107	121
Bicarbonate (as CaCO3)	SM 4500-CO2 D	112	4	106	120
Carbonate (as CaCO3)	SM 4500-CO2 D	1	0.4	0.6	2.8
Hydroxide (as CaCO3)	SM 4500-CO2 D	0	0.0	0.0	0.1
Sulfate	EPA 300.0	2,531	84	2,230	2,650
Chloride	EPA 300.0	18,974	523	18,000	20,100
Nitrate (as N)	EPA 300.0	<25	NA	NA	NA
Nitrite (as N)	EPA 300.0	<25	NA	NA	NA
Bromide	EPA 300.0	63	9	52	91
Calcium	EPA 200.8	400	31	343	506
Magnesium	EPA 200.8	1,316	94	1,120	1,620
Hardness (as CaCO3)	SM 2340B	6,255	762	3,340	7,935
Ca Hardness (as CaCO3)	SM 2340B	999	77	856	1,263
Sodium	EPA 200.8	10,815	768	8,880	13,100
Potassium	EPA 200.8	391	76	41	478
Fluoride	SM 4500-F	0.94	0.07	0.84	1.10

Parameter	Method	Raw Water Average (mg/l)	Standard Deviation	Minimum (mg/l)	Maximum (mg/l)
	C				
Strontium	EPA 200.8	7.6	0.4	6.4	8.1
Barium	EPA 200.8	<0.025	NA	NA	NA
Boron	EPA 200.8	3.6	0.6	3.0	6.5
Silica	EPA 200.8	<10	NA	NA	NA
Ammonia (as N)	SM 4500-NH3 F	<0.1	NA	NA	NA
TOC	SM 5310C	1.12	0.3	0.7	2.3

Table 5-4 Phase B1 Summary of Feedwater Total Dissolved Solids

Parameter	Method	Raw Water Average (mg/l)	Standard Deviation	Minimum (mg/l)	Maximum (mg/l)
TDS	SM 2540C	33,000	2,432	27,000	36,000
pH	SM 4500-H+ B	8.0	0.2	7.4	8.2
Alkalinity (as CaCO3)	SM 2320B	110	3	99	113
Bicarbonate (as CaCO3)	SM 4500-CO2 D	109	3	98	112
Carbonate (as CaCO3)	SM 4500-CO2 D	1.1	0.4	0.3	1.7
Hydroxide (as CaCO3)	SM 4500-CO2 D	0.05	0.0	0.0	0.1
Sulfate	EPA 300.0	2,594	92	2,450	2,860
Chloride	EPA 300.0	19,137	641	18,000	20,800
Nitrate (as N)	EPA 300.0	<25	NA	NA	NA
Nitrite (as N)	EPA 300.0	<25	NA	NA	NA
Bromide	EPA 300.0	57	6	49	67
Calcium	EPA 200.8	392	17	352	419
Magnesium	EPA 200.8	1,248	64	1,140	1,420
Hardness (as CaCO3)	SM 2340B	6,119	291	5,573	6,864
Ca Hardness (as CaCO3)	SM 2340B	978	43	879	1,046
Sodium	EPA 200.8	10,245	500	9,500	11,600
Potassium	EPA 200.8	385	24	346	443
Fluoride	SM 4500-F C	0.90	0.02	0.86	0.93
Strontium	EPA 200.8	6.9	0.3	6.2	7.2
Barium	EPA 200.8	<0.025	NA	NA	NA

Parameter	Method	Raw Water Average (mg/l)	Standard Deviation	Minimum (mg/l)	Maximum (mg/l)
Boron	EPA 200.8	3.5	0.3	2.6	3.8
Silica	EPA 200.8	<10	NA	NA	NA
Ammonia (as N)	SM 4500-NH3 F	<0.1	NA	NA	NA
TOC	SM 5310C	0.88	0.1	0.6	1.1

Table 5-5 Phase B2 Summary of Feedwater Total Dissolved Solids

Parameter	Method	Raw Water Average (mg/l)	Standard Deviation	Minimum (mg/l)	Maximum (mg/l)
TDS	SM 2540C	33,000	2,538	28,000	37,000
pH	SM 4500-H+ B	7.9	0.2	7.2	8.1
Alkalinity (as CaCO3)	SM 2320B	112	2.6	108	120
Bicarbonate (as CaCO3)	SM 4500-CO2 D	111	2.6	107	120
Carbonate (as CaCO3)	SM 4500-CO2 D	0.9	0.3	0.2	1.3
Hydroxide (as CaCO3)	SM 4500-CO2 D	0.05	0.01	0.03	0.06
Sulfate	EPA 300.0	2,579	92	2,410	2,830
Chloride	EPA 300.0	19,377	831	17,700	20,900
Nitrate (as N)	EPA 300.0	<25	NA	NA	NA
Nitrite (as N)	EPA 300.0	<25	NA	NA	NA
Bromide	EPA 300.0	57	6.6	45	69
Calcium	EPA 200.8	384	17.5	351	414
Magnesium	EPA 200.8	1,262	96	1,110	1,400
Hardness (as CaCO3)	SM 2340B	6,155	430	5,487	6,743
Ca Hardness (as CaCO3)	SM 2340B	958	44	876	1,034
Sodium	EPA 200.8	10,576	554	9,360	11,600
Potassium	EPA 200.8	392	25.7	337	435
Fluoride	SM 4500-F C	0.91	0.03	0.86	0.95
Strontium	EPA 200.8	7.3	0.1	7.2	7.7
Barium	EPA 200.8	<0.025	NA	NA	NA
Boron	EPA 200.8	3.5	0.3	3.0	4.0
Silica	EPA 200.8	<10	NA	NA	NA
Ammonia (as N)	SM 4500-NH3 F	<0.1	NA	NA	NA
TOC	SM 5310C	1.11	0.4	0.8	2.4

Table 5-6 Phase B3 Summary of Feedwater Total Dissolved Solids

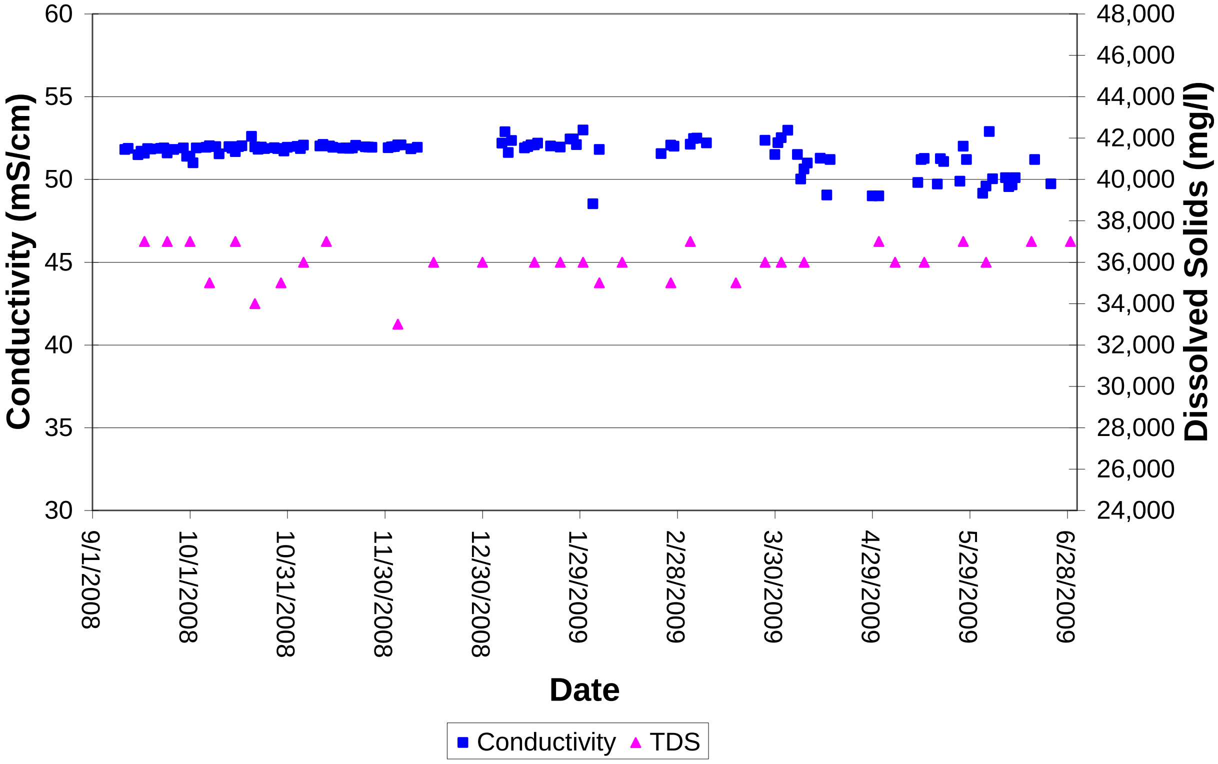
Parameter	Method	Raw Water Average (mg/l)	Standard Deviation	Minimum (mg/l)	Maximum (mg/l)
TDS	SM 2540C	35,605	2,168	30,000	39,000
pH	SM 4500-H+ B	8.0	0.2	7.6	8.2
Alkalinity (as CaCO3)	SM 2320B	115	4	111	130
Bicarbonate (as CaCO3)	SM 4500-CO2 D	114	4	110	129
Carbonate (as CaCO3)	SM 4500-CO2 D	1.2	0.4	0.4	1.7
Hydroxide (as CaCO3)	SM 4500-CO2 D	0.06	0.02	0.02	0.08
Sulfate	EPA 300.0	2,602	187	2,410	3,350
Chloride	EPA 300.0	18,895	646	17,500	19,800
Nitrate (as N)	EPA 300.0	<25	NA	NA	NA
Nitrite (as N)	EPA 300.0	<25	NA	NA	NA
Bromide	EPA 300.0	63	8	54	89
Calcium	EPA 200.8	389	25	347	432
Magnesium	EPA 200.8	1,227	77	1,100	1,380
Hardness (as CaCO3)	SM 2340B	6,026	366	5,431	6,749
Ca Hardness (as CaCO3)	SM 2340B	972	61	866	1,079
Sodium	EPA 200.8	10,095	651	9,040	11,400
Potassium	EPA 200.8	376	24	342	421
Fluoride	SM 4500-F C	0.91	0.06	0.83	1.10
Strontium	EPA 200.8	7.7	1.1	6.5	10.8
Barium	EPA 200.8	0.006	0.0001	0.005	0.007
Boron	EPA 200.8	3.6	0.4	3.1	4.5
Silica	EPA 200.8	<10	NA	NA	NA
Ammonia (as N)	SM 4500-NH3 F	<0.1	NA	NA	NA
TOC	SM 5310C	2.5	1.0	0.7	3.7

Table 5-7 Phase C Summary of Feedwater Total Dissolved Solids

Parameter	Method	Raw Water Average (mg/l)	Standard Deviation	Minimum (mg/l)	Maximum (mg/l)
TDS	SM 2540C	35,933	870	33,000	37,000
pH	SM 4500-H+ B	7.9	0.2	7.4	8.3
Alkalinity (as CaCO3)	SM 2320B	112	1	109	114
Sulfate	EPA 300.0	2,613	110	2,380	2,900
Chloride	EPA 300.0	19,408	395	18,500	21,100
Nitrate (as N)	EPA 300.0	<25	NA	NA	NA
Nitrite (as N)	EPA 300.0	<25	NA	NA	NA
Bromide	EPA 300.0	62	4	53	68
Calcium	EPA 200.8	398	12	362	418
Magnesium	EPA 200.8	1,222	44	1,150	1,320
Hardness (as CaCO3)	SM 2340B	6,027	196	5,640	6,447
Ca Hardness (as CaCO3)	SM 2340B	995	30	904	1,044
Sodium	EPA 200.8	10,024	356	9,600	11,100
Potassium	EPA 200.8	374	16	335	401
Fluoride	SM 4500-F C	0.9	0.05	0.8	1.0
Strontium	EPA 200.8	6.2	0.16	6.1	7.9
Barium	EPA 200.8	0.006	0.0001	0.006	0.007
Boron	EPA 200.8	3.4	0.3	3.0	4.3
Silica	EPA 200.8	<10	NA	NA	NA
Ammonia (as N)	SM 4500-NH3 F	<0.1	NA	NA	NA
TOC	SM 5310C	0.74	0.16	0.3	1.0
Color	SM 2120B	4.5	0.8	3.0	5.0

The conductivity of the feedwater was also measured in the field both continuously with a conductivity meter on the SWRO Train and daily with a handheld conductivity meter. Figure 5-12 below is a plot of conductivity vs total dissolved solids of the feedwater as measured in the lab during Phase C. The conductivity is consistently between 49 and 52 mS/cm and the TDS is consistently between 33,000 and 37,000 mg/l (lab error is approximate 10% on TDS analyses). This daily field measurement helps to confirm the consistent levels of dissolved ions in the feedwater.

Figure 5-12 Phase C Feedwater Conductivity and Total Dissolved Solids



5.2.4 Total Organic Carbon

Table 5-8 shows a summary of the Total Organic Carbon analyses performed over the course of the pilot on both the ambient intake and power plant outfall.

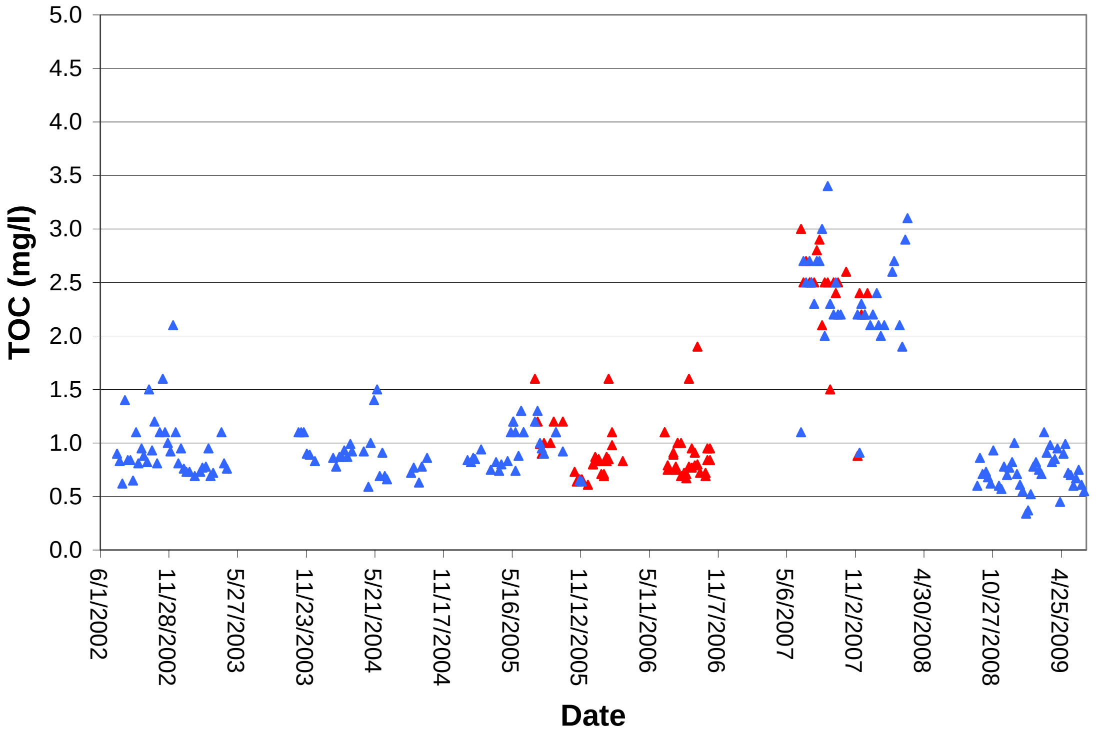
Table 5-8 Summary of Feedwater Total Organic Carbon

Phase	Average TOC (mg/l)	Standard Deviation	Minimum TOC (mg/l)	Maximum TOC (mg/l)	95th Percentile
A (6/02 – 5/04)	0.95	0.27	0.59	2.10	1.50
B1 (6/04– 6/05)	0.87	0.18	0.63	1.30	1.19
B2 Ambient (7/05 – 5/06)	0.98	0.22	0.64	1.3	1.3

Phase	Average TOC (mg/l)	Standard Deviation	Minimum TOC (mg/l)	Maximum TOC (mg/l)	95th Percentile
B2 Warm (7/05 – 5/06)	0.92	0.24	0.61	1.6	1.2
B3 Ambient (6/06 – 3/08)	2.34	0.5	.91	3.4	3.05
B3 Warm (6/06 – 3/08)	1.76	0.83	0.69	3.0	2.82
C (9/08 – 6/09)	0.73	0.17	0.34	1.10	0.99

Figure 5-13 shows the data in graphical form for the entire testing period. The data set for Phase B-3 from mid 2006 to early 2008 is elevated compared to the rest of the data.

Figure 5-13 Total Organic Carbon of Seawater

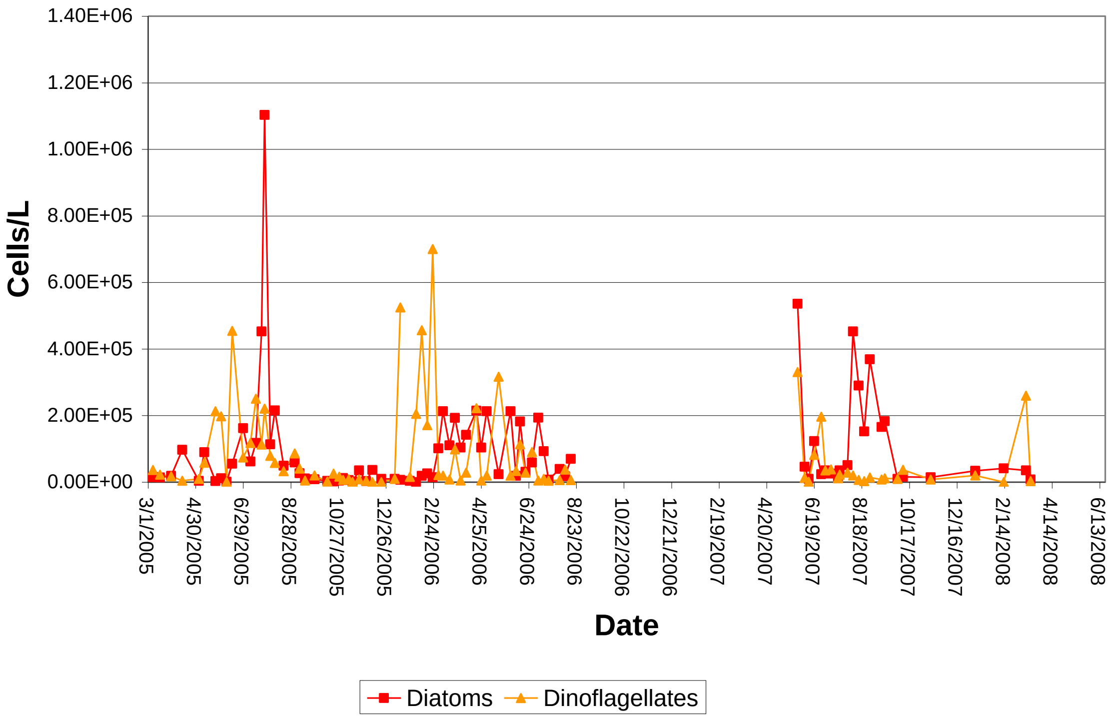


5.3 Algal Blooms

The level of biomass present in the feedwater can also greatly impact the performance of a seawater desalination facility. Increased levels of phytoplankton and marine bacteria can lead to fouling across the entire treatment train, including pre-straining filters, MF/UF membranes, and the SWRO membranes. In addition to fouling, certain types of algae are responsible for the release of toxins into the ocean water such as domoic acid and saxitoxin. These toxins can accumulate in shellfish, and can lead to illness in humans when shellfish contaminated with toxins are ingested. *(Note: A separate study showing removal of various algal toxins by SWRO membrane was conducted in conjunction with the University of Southern California and is included in Appendix X)*

Water samples were collected and analyzed for various species of algae and the toxin domoic acid by the University of Southern California (USC) throughout Phase B of testing. The abundance of algae, specifically diatoms and dinoflagellates, at different times of the year is shown in Figure 5-14. This graph shows that there is typically a larger amount of algae present in the spring and summer months, with lower amounts in the fall and winter. Storm events in the winter months can also trigger algal blooms due to increased levels of nutrients from storm runoff.

Figure 5-14 Phytoplankton Counts



Another tool for monitoring the presence of algal biomass present in the source water is satellite imagery. The Southern California Coastal Ocean Observing System provides access to various types of data regarding ocean water quality on their website at http://www.sccoos.org/data/modis/modis_regions.php?r=3. The satellite images below depict concentrations of chlorophyll-a, a photosynthetic pigment found in phytoplankton, in the ocean water.

Figure 5-15 is taken in on May 18th 2005 and shows a wide area of ocean with elevated levels of chlorophyll-a. This matches up with the elevated cell counts seen in Figure 5-14 at this same time frame. Figure 5-16 also shows elevated levels of chlorophyll-a in June 2007, but isolated more along the coastline, again correlating to high cell counts. Figure 5-17 is satellite imagery from November 2007 shows low levels of chlorophyll-a present in Santa Monica Bay, consistent with the low phytoplankton counts shown in Figure 5-14 for that same time period. These images show the seasonal, and sometimes sporadic, fluctuations in biomass for this source water.

Figure 5-15 Satellite Imagery, May 18, 2005

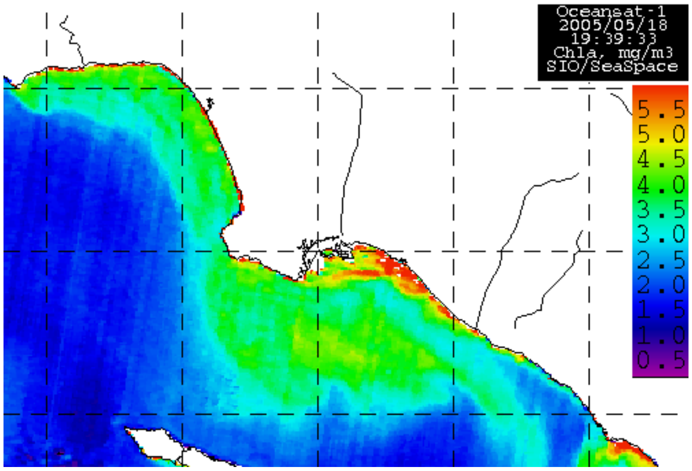


Figure 5-16 Satellite Imagery, June 19, 2007 (two columns?)

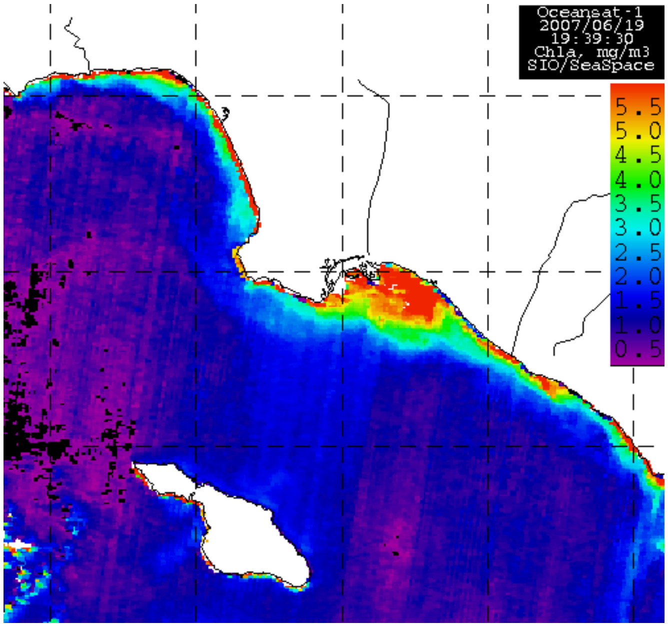
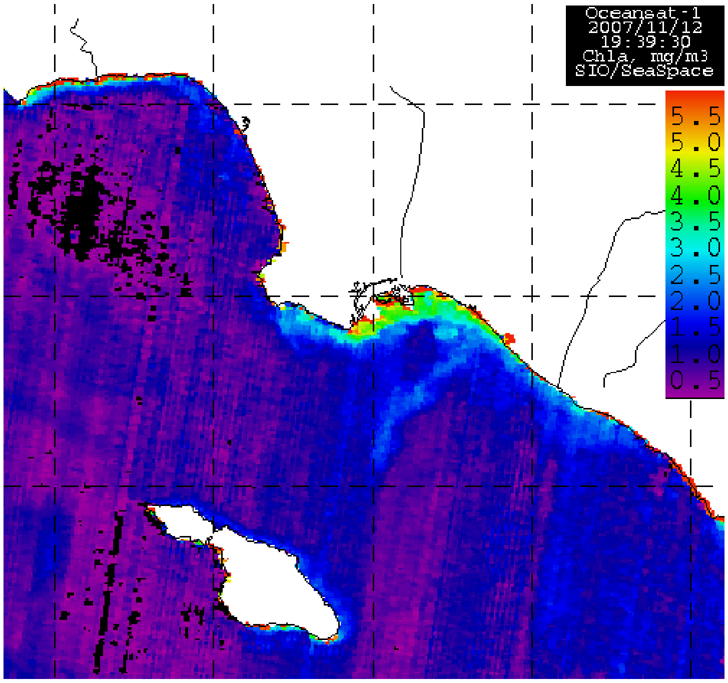


Figure 5-17 Satellite Imagery, November 12, 2007

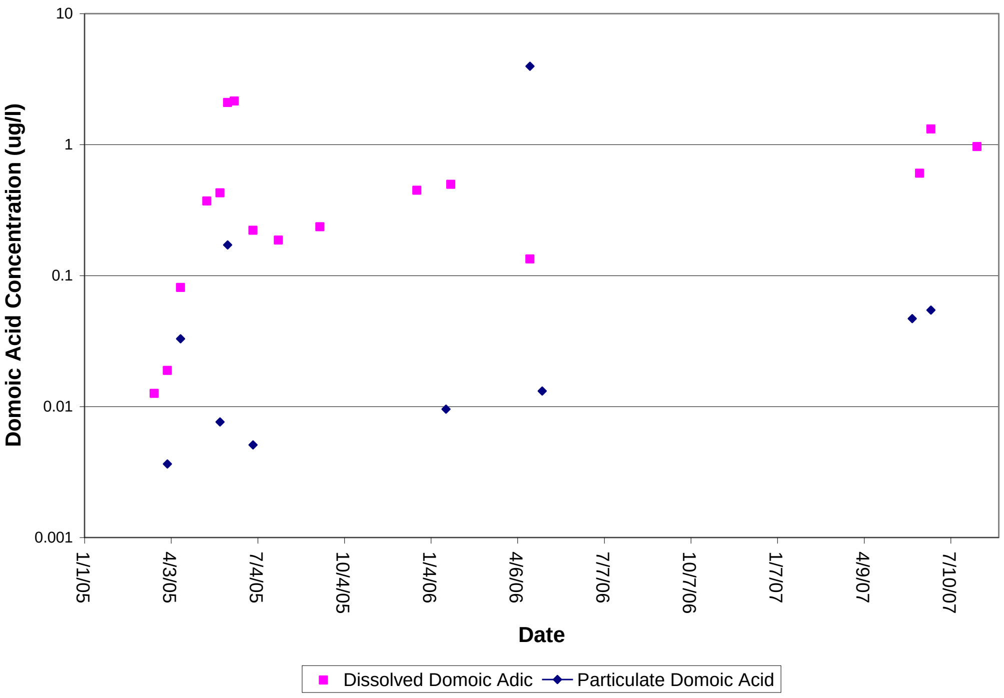


5.3.1.1 Algal Toxins

Another important water quality aspect of ocean water desalination has to do with the presence of algal toxins in the ocean water. One such toxin produced by the marine diatom Pseudonitschia is domoic acid, which can cause Amnesic Shellfish Poisoning (ASP) in humans and has been responsible for the death of marine mammals such as sea lions and seals along the southern California coast. This toxin accumulates in shellfish and small fish such as sardines and anchovies, that when consumed by humans and sea mammals can result in ASP.

As part of the pilot study, samples of raw water and RO permeate were collected regularly and analyzed for the presence of domoic acid by the University of Southern California. Figure 58 shows levels of particulate and dissolved domoic acid present the raw ocean water for Phase B of testing. Not once during Phase A or Phase B of testing did domoic acid appear in RO permeate. This is to be expected since the molecular weight of domoic acid (311) is large enough to be rejected by the RO membrane.

Figure 5-18 Domoic Acid Levels in Ocean water 2005 - 2007



Treatment Process Evaluation

6.0 Treatment Process Evaluation

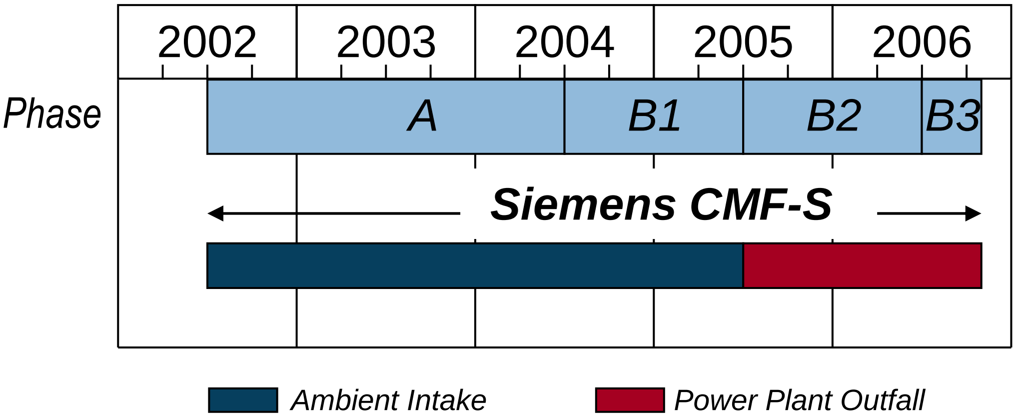
6.1 Introduction

The following sections review the performance of each of the different treatment processes tested at the pilot site. The review is organized in a chronological order, then by treatment process.

6.2 CMF-S Microfiltration System

The CMF-S system was operated from 2002 to 2006, on both ambient intake and powerplant outfall water per the schedule shown in Figure 6-1.

Figure 6-1 Testing Summary Graphic of Siemens CMF-S Microfiltration System



6.2.1 Operations / Optimization Phase A

The Siemens CMF-S system operation was initiated in June 2002, with the first month used as an equipment commissioning period. A summary description of the tested parameters for each "Trial" one through five are contained in Tables 6-1 and 6-2. The testing is divided between different test "trials" and "runs." A trial is defined here as a significant process change. A run is simply operation between chemical cleaning events, module replacements or operational changes.

Table 6-1 Phase A MF Testing Trials

MF Testing Trials	Process Description
MF I	Continuous chlorination in MF feed water
MF II	Operation without chlorination
MF III	Operation with no chlorine in the feed but with chlorination of backwash
MF IV	Redesigned MF module (Generation B), operation with chlorination of backwash
MF V	Arkal 130 µm filter in front of MF, operation with chlorination of backwash and with Generation B MF module

Table 6-2 Details of Phase A Siemens CMF-S Microfiltration Runs

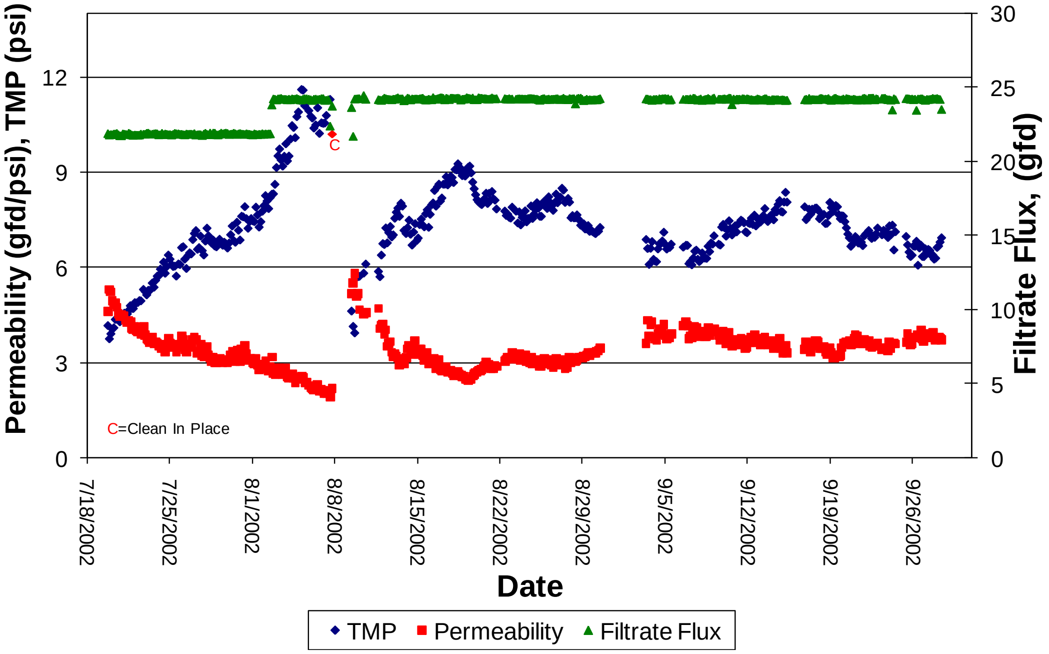
Trial	Run #	Dates	MF Run Hours	Total Filtrate Flow, gpm	Per Module Filtrate Flow, gpm	Flux GFD	Target Feed Chlorination (ppm)	Backwash Frequency,min	Comments
MF I	MF 1	7/19/02-8/8/02	525-951	20	5	21.5	1	15	Unit run continuously between 525 (7/19) and 951 (8/7) hrs
	MF 2	8/9/02-9/28/02	965-1853	22	5.5	23.6	1	15	Stable performance
MF II	MF 3	10/3/02-10/8/02		22	5.5	23.6	0	15	Ran <1 week before CIP
	MF 4	10/10/02-10/17/02		22	5.5	23.6	0	15	Ran <1 week before CIP
MF III	MF 5	10/22/02-11/4/02	2263-	22	5.5	23.6	10 in every backwash	15	Ran ~10 days before CIP required
	MF 6	11/7/02-11/26/02	2648-2860	22	5.5	23.6	40 in every backwash	15	Stable performance
	MF 7	11/26/02-12/19/02	2868-3357	22	5.5	23.6	25 in every backwash	15	Stable, No CIP before this run
	MF 8	12/23/02-1/9/03	3382-3600	24	6	25.8	25 in every backwash	15	1 problematic module replaced, added rinse to protect RO CIP 12/26 request by USF to wet new module
	MF 9	1/9/03-1/24/03	3600-3820?	24	6	25.8	25 in every backwash	15	1/9 CIP replaced header assembly oring. 1/15 Replaced a second original module that had a crack in the potting. SDI now 2.4- RO Membranes replaced
	MF 10	1/24/03-2/5/03	3820?-4028	24	6	25.8	25 in every backwash	15	Heater broken-CIP not very effective before this run
	MF 11	2/5/03-2/21/03	4028-4242	24	6	25.8	25 in every backwash	15	Heater broken-CIP not very effective before this run. Electrical problem shutdown 2/11-2/13
	MF 12	2/21/03-3/6/03	4242-4513	24	6	25.8	25 in every backwash	15	In advertant daily mini CIP with chlorine improved performance
	MF 13	3/6/03-3/11/03	4513-4623	24	6	25.8	25 in every backwash	15	
	MF 14	3/12/03-4/3/03	4650-5100		6		40 in every backwash	15	Various flows
MF IV	MF 15	10/22/03-11/13/03	5380-5723	18	4.5	23.6	20 in every BW	15	**Restart with Redesigned membranes (new module design), increasing permeability**
	MF 16	1/15/04-03/10/04	5840-6296	26	6.5	34	20 in every BW	15	Post run CIP performed, over 120 pins added to the four modules. Majority of run w/o Arkal filter due to installation problems
MF V	MF 17	03/10/04-5/17/04	6296-7110	26	6.5	34	20 in every BW	20	**Modules Replaced 5/28/04**
	MF 18	6/8/2004-	7314-	26	6.5	34	20 in every BW	20	CIP after very short run-modules reconditioned

6.2.2 Permeability of Original CMF-S Module Design

6.2.3 Trial I-Continuous Prechlorination

MF runs 1 and 2 were performed with continuous chlorination in the feedwater as indicated in Table 6-2. Chlorine was dosed into the feedwater of the MF system and ammonium hydroxide was dosed into the MF filtrate in an effort to form chloramines prior to the RO membranes as shown in Figure 6, the initial process flow diagram for Phase A. The initial MF run at 21.5 GFD experienced steady fouling over the course of the three week run, but the CIP performed was successful in restoring permeability as indicated in Figure 6-2. For run 2, the flux was increased to 24 GFD. This 24 GFD run with continuous chlorination lasted over 6 weeks without requiring a chemical cleaning. The continuous chlorination was discontinued following MF Trial I as this method of chloramine formation resulted in oxidation of the RO membranes. The formation of chloramines is discussed in detail in Section 5.8

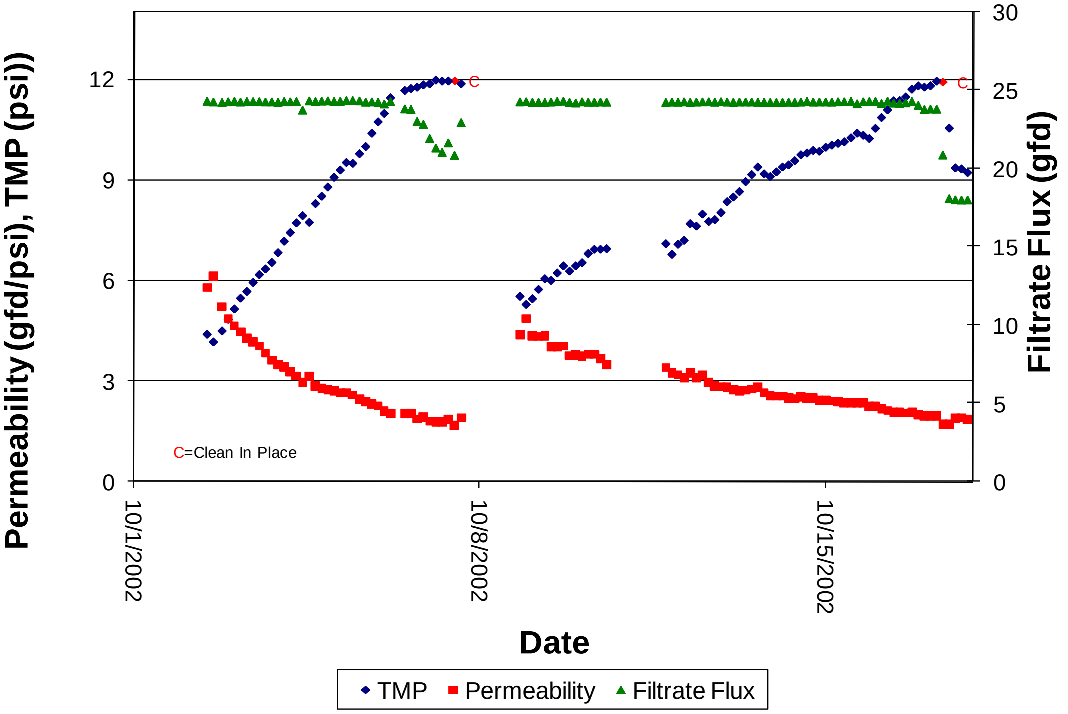
Figure 6-2 Performance of Microfiltration System with Continuous Prechlorination (MF Trial I)



6.2.4 Trial II-No Chlorination

Once prechlorination was discontinued, attempts were made to compare the operational impacts of chlorination versus non-chlorinated feedwater in Trial II. Rapid fouling was observed in two consecutive runs as shown in Figure 6-3. Note that neither of the Trial II runs lasted more than ten days before reaching terminal TMP. Operation at 24 GFD was unsuccessful without chlorinating the feedwater and these runs demonstrated how beneficial the oxidant is to the stable performance of microfiltration membrane process on this feed source.

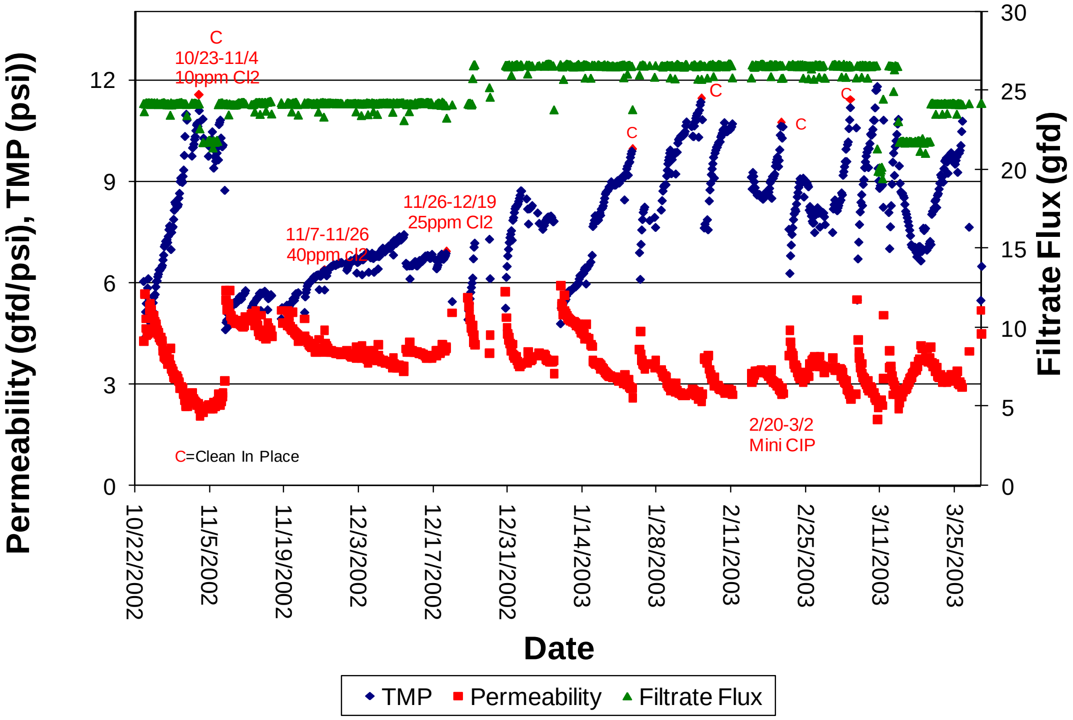
Figure 6-3 Performance of Microfiltration System with No Chlorination (MF Trial II)



6.2.5 Trial III-Chlorinated Backwashes

In Trial III, chlorinated backwashes of the MF system were utilized to try to gain the benefit of chlorine without subsequently damaging the RO membranes. For run 5, 10 mg/l of NaOCl was added in every MF backwash and again rapid fouling was observed as depicted in Figure 6-4. A stable run condition was finally achieved in run 6 by increasing the dose to 40 mg/L NaOCl in every backwash. After run 6, a CIP was not performed, and the chlorination was decreased from 40 to 25 mg/L NaOCl for every backwash in run 7. The MF operated for an additional month without requiring a shut down for a chemical clean in place (CIP).

Figure 6-4 Performance of Microfiltration System with Chlorinated Backwashes (MF Trial III)



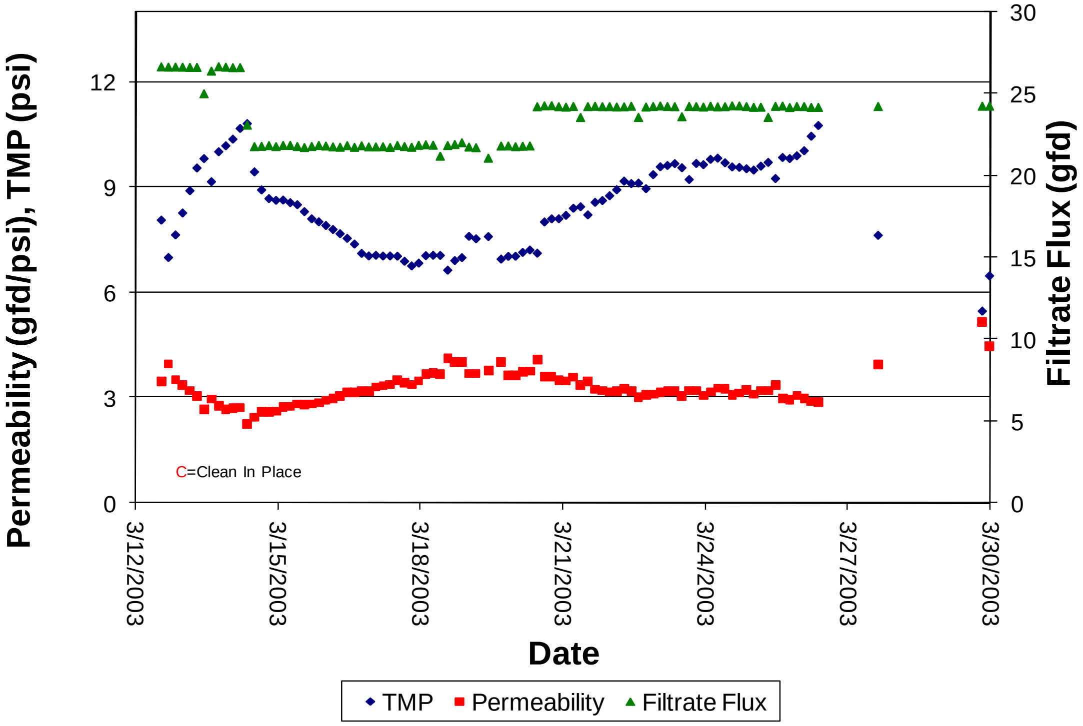
The filtrate flow was then increased from 22 gpm to 24 gpm for run #8, corresponding to a flux increase from 24 to 25.8 GFD. Numerous attempts failed to demonstrate a run time longer than the 21 day goal at this flux before a CIP was required. This was compounded by the fact that the CMF-S clean-in-place (CIP) heater was disabled for a period of time and the cleanings done to start runs #10 and #11 did not effectively restore membrane permeability.

Run #13 was started with a fully heated CIP. However, this run had a very short run time. Two things were now evident:

1. A filtrate flux of 25.8 GFD was not sustainable with these original CMF-S membranes
2. The membranes had been fouled to the point that the normal heated CIP process did not restore the permeability to a “fully clean” condition or approximately 6 GFD/psi.

During run #14, the filtrate flow and hence the flux rates were varied as shown in Figure 6-5.

Figure 6-5 Microfiltration Run #14 Performance



The run was started with a filtrate flux of ~25.8 GFD and demonstrated rapid fouling, similar to the previous runs. Dropping the flux down to ~22 GFD resulted in an improvement in permeability. Subsequently, the flux was increased to ~24 GFD and the fouling rate increased. Close examination of this data reveals that the acceptable filtrate flux on this water is 22 GFD to 24 GFD with these original CMF-S membranes with this feedwater quality.

6.2.6 Cleaning Effectiveness

Examination of Figure 6-4 shows that the “clean” or post “Clean-In-Place” microfiltration permeability’s had declined since January 23, 2003. This is a sign of an ineffective CIP procedure. The problem was initiated when the CMF-S heater failed, and the two subsequent cleanings were performed with cold water on January 23 and February 5, 2003. These cleanings were not effective as shown in Figure 33. The clean permeability’s are only 4 GFD/psi after the cold water cleanings, whereas with previous heated CIP’s, the clean permeability’s were consistently ~6 GFD/psi.

At the completion of run 14, an enhanced CIP process was undertaken in an attempt to restore the clean permeability of the membranes to ~6 GFD/psi. Hydrochloric acid was utilized in addition to the normal citric acid and chlorine. This enhanced process showed improvement, but failed to fully restore the membranes. The data in Figures 33 and 34 demonstrates that the heated CIP was effective at restoring the membrane permeability and it was not until the CMF-S heater failed that the membranes were fouled to the point that not even an enhanced CIP process could restore them. This indicates each CIP solution must be heated to be effective.

Table 6-3 Effective Microfiltration Cleaning Procedure

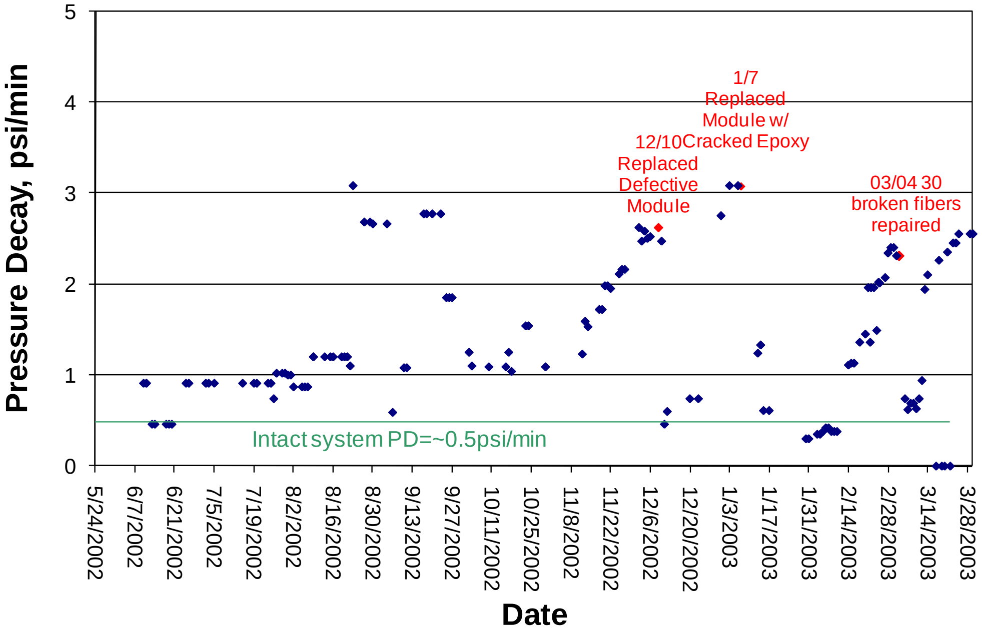
Step	Chemical	Temperature (ºC)	Procedure
1	2% Citric Acid	36 - 38	Perform reverse filtration until membrane cell is filled with MF Filtrate. Add chemicals, heat solution and aerate every 2 minutes. Perform filtrate recirculation for 30 minutes. Repeat 5 minute aeration/5 minute soak cycles 9 times.
2	400 – 600 mg/L chlorine	20	

6.2.7 Siemens PVDF Membrane Module Integrity-Original CMF-S Modules (MF Trials I-III)

The Siemens CMF-S unit utilized for this study contains four S10V PVDF modules. Over the course of trials I - III, two of these modules required replacement. The first was replaced on December 10, 2002 due to numerous fiber breakage events, and the second on January 7, 2003 after it developed a crack in the epoxy that isolated the feed from the filtrate water. Furthermore, one of the replacement modules demonstrated fiber breakage events as well.

Broken fibers were easily detected during the pressure decay test (PDT). During the PDT, the unit was isolated and the lumen (filtrate) side of the modules was drained. Air was then injected to the lumen at 15 psi, and then a valve on the feed side is opened to atmosphere. Intact wetted fibers retain the air pressure as the pressure decay rate across an intact fiber is diffusion controlled. Broken fibers pass air at a drastically greater rate than normal diffusion, resulting in a rapid pressure decay rate. The intact Siemens system with no fiber breaks displays a PDT rate of $\leq$ 0.5 psi/minute. To quantify the broken fiber problems observed during this study, on March 4, 2003, a pressure decay was performed on the system resulting in a decay rate of ~2.3psi/minute. Thereafter, between 30 and 35 fibers were isolated on one of the four modules in the system. Each original CMF-S module contained ~14,500 Fibers. Figure 36 demonstrates that the unit has had broken fibers over most of trials I - III of the study. Figure 6-6 displays air passage during a pressure decay test through the crack that developed in the module epoxy.

Figure 6-6 Siemens Microfiltration Unit Pressure Decay Test Results Phase A testing



Siemens sent the problematic modules to the manufacturing facility Australia for autopsy to determine the cause of the fiber breakage and epoxy failures. The results from the analysis of the module with the cracked epoxy can be summarized as follows:

A. The epoxy crack was likely a manufacturing problem resulting from an incorrect epoxy mixing or curing procedure.
B. When the flow distribution screen was removed from the end of the module, particles were found covering 20 mm of the fibers at the bottom. The particles consisted of sand and broken shell fragments that apparently passed through both the 800 µm coarse strainer and the standard 500 µm strainer on the CMF-S unit. It was noted that a number of broken fibers were punctured by what appeared to be sharp objects. It is possible that the broken shell fragments are a cause for some of the fiber breakage problems. A 130 µm Arkal filter replaced the original 500 µm strainer in front of the MF to alleviate this problem.
C. Twenty four fibers were analyzed for fiber break extension or fiber strength. The fiber strength had decreased by 20 - 40%. SEM photographs showed that other broken fibers that had sheared appeared to have been stretched before failure (Figures 6-8, 6-9).

Figure 6-7 Air Bubbles Emitted from the Cracked Epoxy During the Pressure Decay Test

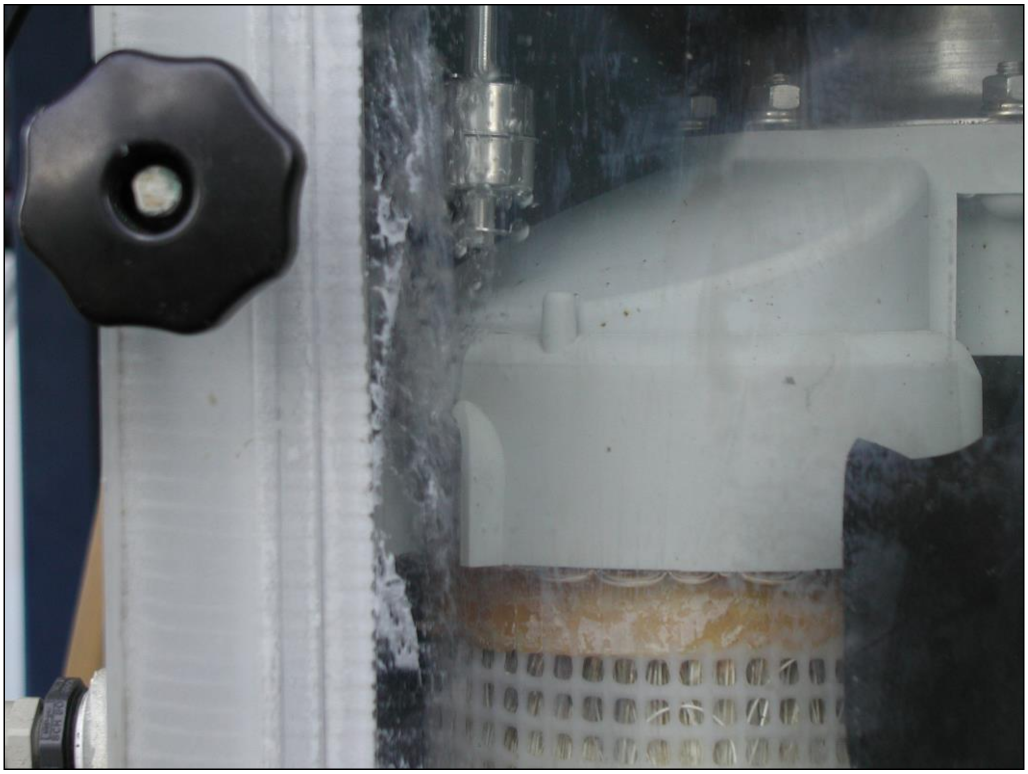
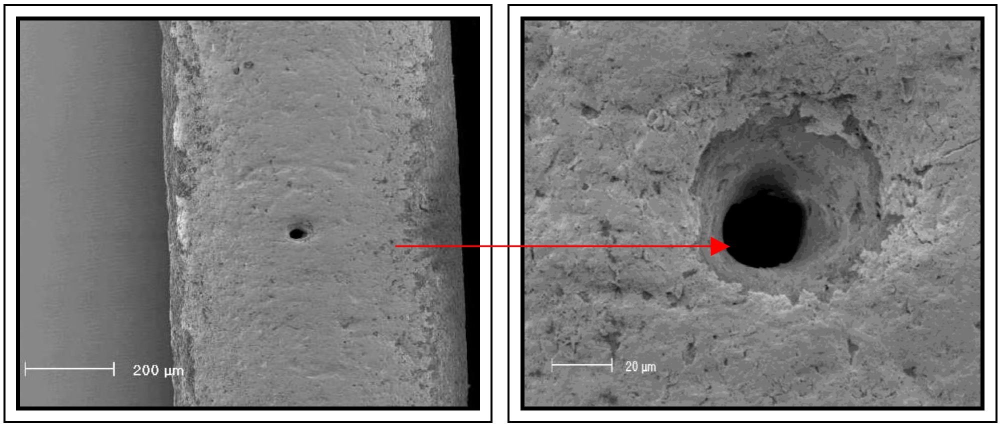
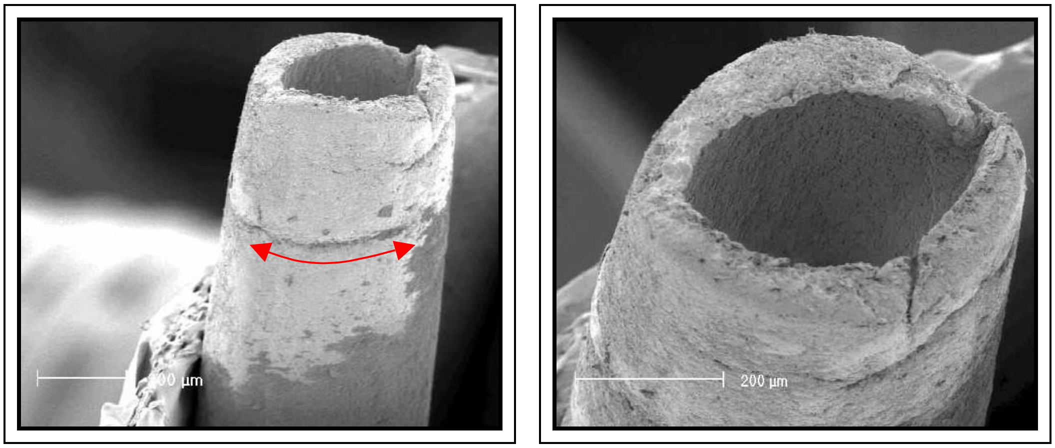


Figure 6-8 SEM photographs of a Hole in a CMF-S Module Fiber



A hole in fibre found 490mm from the top. A closer look at the hole shows it appears to have been caused by a sharp object, or by something wearing into the fibre



Broken fibre found 350mm (fibre 2) from the bottom. The fibre has been bent and the surface appears stretched.

Figure 6-9 Sheared CMF-S Fiber Shows Evidence of Stretch Failure

The fiber stretching, and the fact that three of the six modules displayed no epoxy problems and very little fiber breakage problems, provided evidence of a module manufacturing problem. Siemens recognized that there were some design and manufacturing issues with their PVDF modules, and they notified West Basin that their module underwent a substantial redesign including:

1. Larger fiber (diameter and wall thickness)
2. Smaller number of fibers in module (different packing density)
3. Reduced fiber area per module

This newly designed S10V module is referred to as Generation B, and Table 6-4 describes its features.

Table 6-4 Siemens CMF-S Module Comparison

Parameter	Original S10V Module Generation A	Redesigned S10V Module Generation B
Fiber Outside Diameter, µm	650	800
Fiber Inside Diameter, µm	390	500
Number of Fibers per Module	14,500	9,600
Module Active membrane Area, m^2	31.1	25.3

6.2.8 Trial IV-Redesigned CMF-S Modules Without Arkal Filter

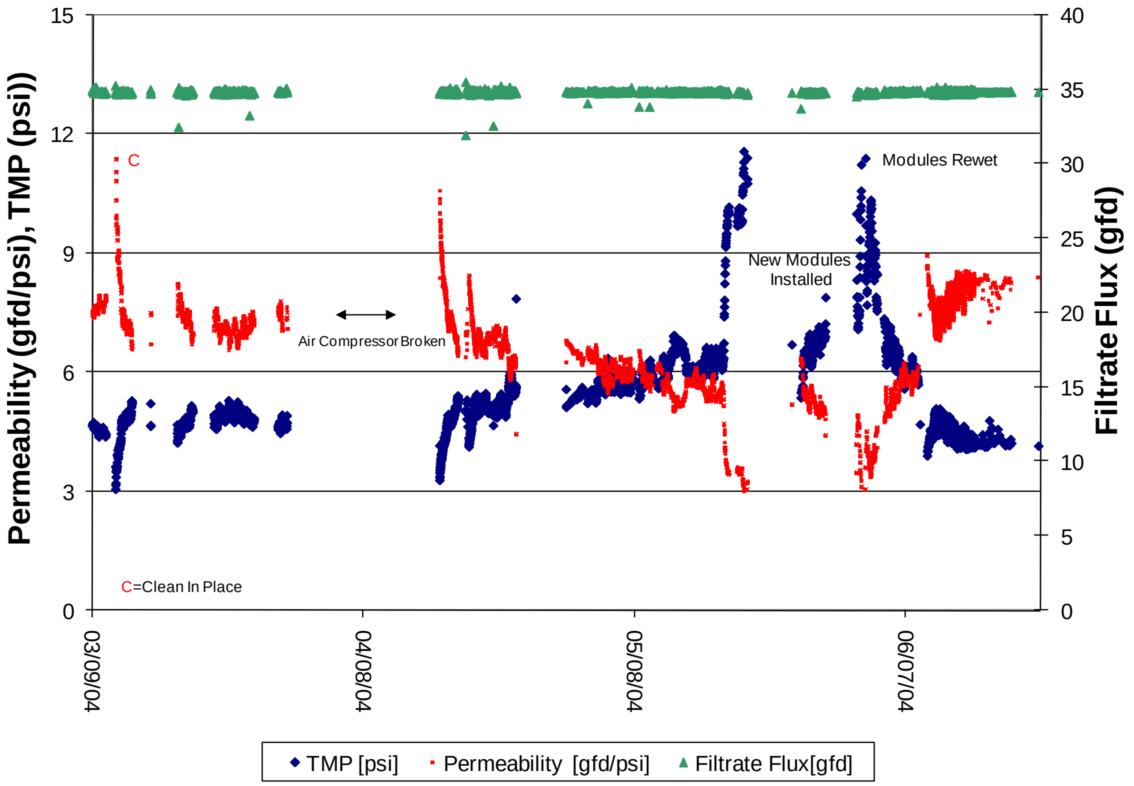
In October 2003 the trials commenced with the new, improved Siemens CMF-S module, which we refer to as Generation B. The new modules had fewer, larger fibers, and were considered by Siemens to be more efficient and would be able to run at a higher flux rate and maintain permeability. For run 15 the redesigned modules were operated for eight weeks at the same 24 GFD flux rate as the "original" Siemens modules. No permeability decline (fouling) was observed. For run 16 the flux was then increased to 34 GFD and the system stabilized after some initial fouling. Figure 6-10 shows the performance of these two runs.

Figure 6-10 Performance of Redesigned MF modules (MF Trial IV)

6.2.9 Trial V-Performance of New Modules with the Arkal Spin Klin Filter as Pretreatment

In an effort to reduce the amount of shell fragments and other particulate matter from damaging the membrane fibers, an Arkal Spin Klin Disc Filter with 130 µm filters was put online on March 10, 2004. Run 17 was started with the flux rate set at 34 GFD, and the backwash frequency of the Siemens CMF-S unit was reduced from every 15 to every 20 minutes. Figure 6-11 shows that one run was performed at these conditions and accumulated 33 days of run time before reaching terminal TMP.

Figure 6-11 Performance of Redesigned Modules with Arkal Filter (Trial V)

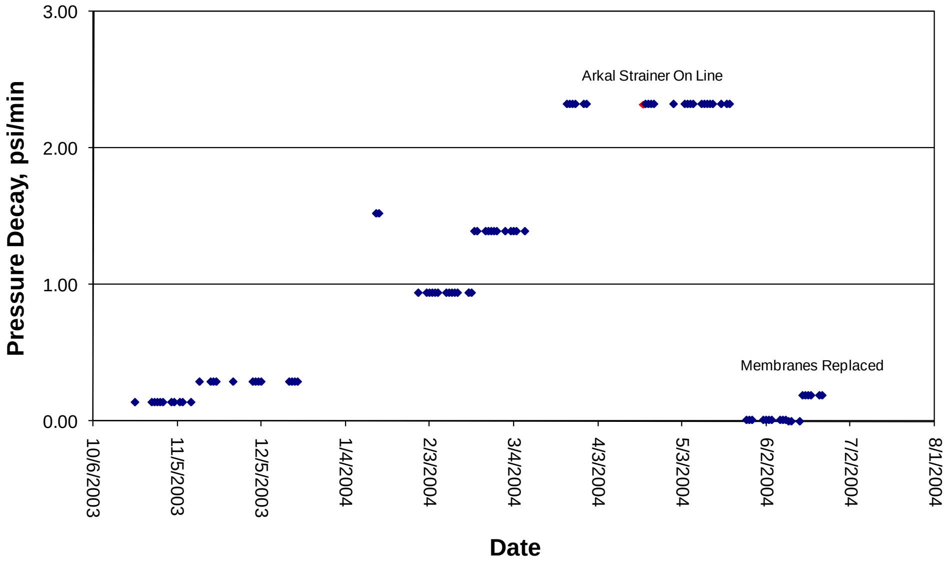


6.2.10 New Redesigned Siemens PVDF Membrane Module Integrity Problems

The Generation B modules also experienced fiber integrity problems. Figure 6-12 shows the pressure decay test values increasing since installation in October 2003 up to a value of approximately 2.4 psi/min through May 2004. These modules were operated without the benefit of the 130μm Arkal filter for several months and showed an increasing trend in PDT values. Once the Arkal filters were installed in mid March, the PDT values, although elevated, did not continue to increase.

All four Generation B modules were replaced on May 28, 2004 for continued testing with the 130μm Arkal filter.

Figure 6-12 PDT Results of Redesigned CMF-S Modules



6.2.11 Optimized Siemens CMF-S Microfiltration Parameters for Phase A

Table 6-5 shows the optimized Siemens CMF-S Run Parameters for Phase A. These run parameters where met while meeting the criteria for a minimum 21 day run with a Clean In Place program that restored permeability.

The high rate of fiber breakage experienced throughout Phase A of the testing, is concerning, and this will be addressed later in the report.

Table 6-5 Optimized Siemens CMF-S Microfiltration Run Parameters Phase A

Parameter	Value
Filtrate Flow per module (gpm)*	6.5
Filtrate Flux (gfd)*	34
Filtration time between backwashes (min)	20
Recovery	93%
Backwash Parameters	
Air scour Rate (SCFM/module)	7
Air scour Duration (seconds)	30
Backpulse Rate (gpm/module)	9.9
Air Scour + backpulse Duration (seconds)	15
Additional Feed to Drain Volume (gal)	~25
Rinse Duration (seconds)	15
Refill Duration (seconds)	~35
Backwash chlorination (mg/L)*	20

*Optimized Parameters. Non optimized parameters recommended by Siemens.

6.2.12 Operations / Optimization Phase B

Phase B consisted of three separate sub-phases, B1, B2 and B3. Each of the phases will be reviewed separately.

6.2.13 MF Permeability Phase B1

Table 6-6 summarizes the runs in Phase B1.

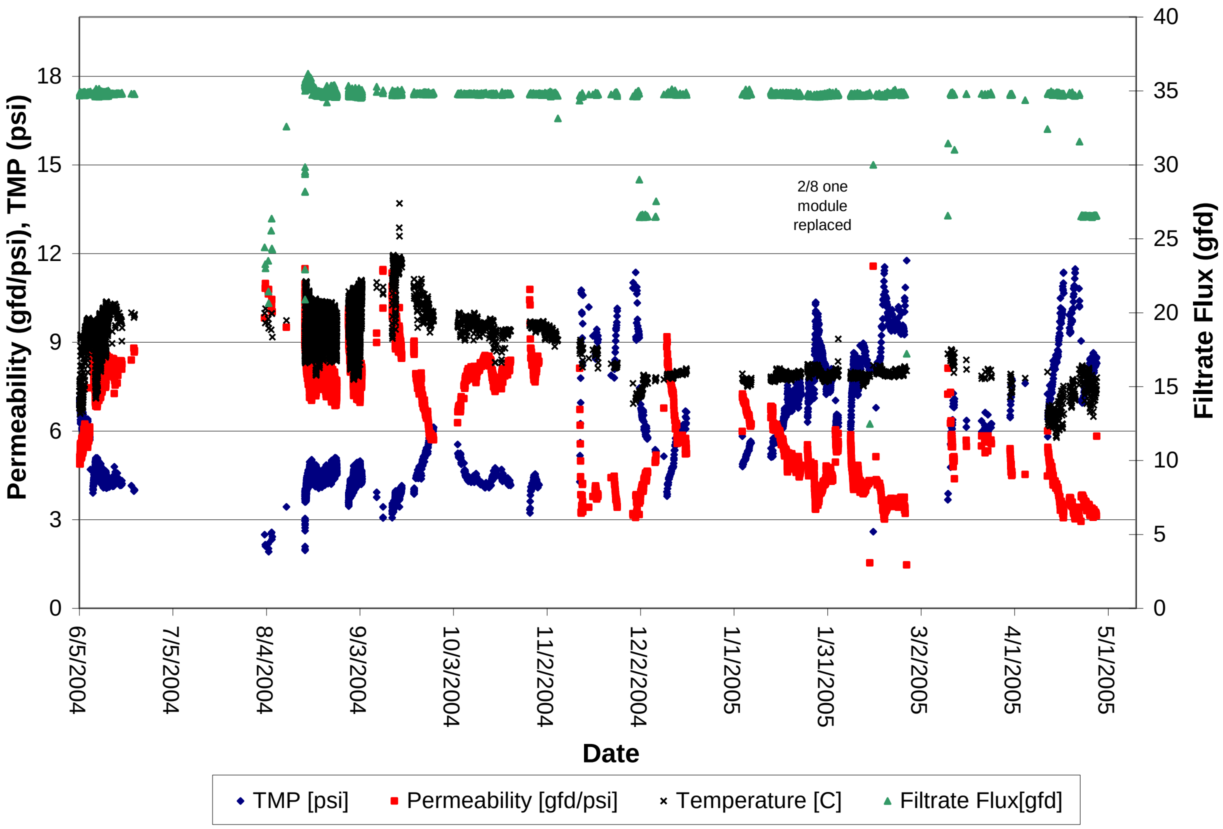
Table 6-6 Details of Phase B1 Siemens CMF-S Runs

Feedwater Source: Influent Water

Run #	Dates	Flux (GFD)	Backwash Chlorination (mg/l)	Backwash Frequency	Comments
MF 18	6/8/04 – 9/10/04	34	20 in every backwash tank	~ 20 minutes	New Generation "B" modules, Set 2 Arkal 130 micron
MF 19	9/10/04 – 12/10/04	34	20 in every backwash tank	~ 20 minutes	Several fibers were pinned 9/20/04
MF 20	12/10/04 – 3/10/05	34	20 in every backwash tank	~ 20 minutes	1/15/05 2 pins in one module 2/8/05 Same module replaced due to damage
MF 21a	3/10/05 – 4/27/05	34	20 in every backwash tank	~ 20 minutes	
MF 21b	4/27/05 – 6/6/05	34	20 in every backwash tank	~ 20 minutes	New MF pilot unit installed 4/27/05. Continued operation with previous membrane set
MF 22	6/6/05 – 7/18/05	24.5, 20.5	20 in every backwash tank	~ 20 minutes	Severe Red Tide Event in Late May / Early June

Figure 6-12 shows that the operating flux of 34 GFD was sustainable for the goal period of 21 days before a CIP was required on influent water several times over the course of a year. One module was replaced in February 2005 due to fiber integrity problems. These results confirmed the Phase A optimized operating parameters for influent operation.

Figure 6-12 CMF-S Performance June 2004 – May 2005



6.2.14 Phase B-2

The Phase B-2 MF operation was defined by the shift of feedwater source from power plant influent to the warmer post-condenser effluent. Table 6-7 summarizes the runs in Phase B-2.

Table 6-7 Details of Phase B2 Siemens CMF-S Runs

Feedwater Source: Post Condenser Effluent

Run #	Dates	Flux (GFD)	Backwash Chlorination (mg/l)	Backwash Frequency (min)	Comments
MF 22	7/18/05 – 9/5/05	20.5	20 in every backwash tank	~ 20 minutes	Continuation of Run 22, but on effluent sourcewater
MF 23	9/6/05 – 9/16/05	34	20 in every backwash tank	~ 20 minutes	
MF 24	9/18/05 – 9/23/05	27, 34	20 in every backwash tank	~ 20 minutes	9/23 all modules replaced due to fiber integrity issues. Generation "B", Set 3
MF 25	9/26/05 – 10/1/05	34, 27	20 in every backwash tank	~ 20 minutes	Prefiltration tightened from 130 to 100 micron
MF 26	10/19/05 – 11/23/05	27, 32	20 in every backwash tank	~ 20 minutes	November 30th, Prefiltration tightened from 100 micron to 40 micron
MF 27	12/9/05 – 12/31/05	31-32	20 in every backwash tank	~ 20 minutes	Generation "C", Set 1, of modules installed
MF 28	1/5/06 – 1/27/06	34	20 in every backwash tank	~ 20 minutes	Irreversible fouling of MF modules on 1/26
MF 29	1/31/06 – 3/6/06	34, 19	20 in every backwash tank	~ 20 minutes	Fouling problems continued – Feb 10th, operation reverted to Influent source until June, due to Effluent feed pump failure
MF 30	N/A	N/A	N/A	N/A	Fouling problems continued
MF 31	4/1/06 – 4/15/06	28	20 in every backwash tank	~ 20 minutes	Set 2 of Generation "C" modules installed due to fouling issues. 40 micron proved too tight to allow for sufficient feed flow to the MF unit, so 70 micron disks were installed 4/17/06
MF 32	4/29/06 – 6/8/06	28	20 in every backwash tank	~ 20 minutes	

In Phase B-2, Siemens introduced another version of their S10V module that was even thicker than the previous two versions and was designed to be less prone to fiber breakage. We refer to this third generation of product as Generation C. Table 6-8 summarizes the characteristics of each generation. Membrane material remained PVDF and nominal pore size remained 0.1 micron for each generation. This new Generation C fiber was first installed in December 2005, mid-way through Phase B-2.

Table 6-8 Summary of Siemens CMF-S Modules Tested

Parameter	Generation A	Generation B	Generation C
Fiber outside diameter, micron	650	800	1000
Fiber inside diameter, micron	390	500	530
Approximate # of fibers per module	14,500	9,600	7,400
Surface area per module, sq. ft.	335	272	262
Permeate flow per module, gpd	8040	9248	8908

In late May 2005 the onset of a severe algal bloom (red tide) began. As seen in Figure 6-13, the flux rate was reduced in order to maintain operation of the unit. The MF unit was able to operate during this event at a reduced flux rate of approximately 20-24 GFD, approximately 30% less than previous operating flux rates. As the algal bloom conditions subsided in August, the flux rate was able to be increased back to previous values. During this period of testing, on July 18 2005, the feedwater source was switched to the warmer power plant effluent, marking the beginning of Phase B-2.

Figure 6-13 CMF-S Performance May 2005 – September 2005

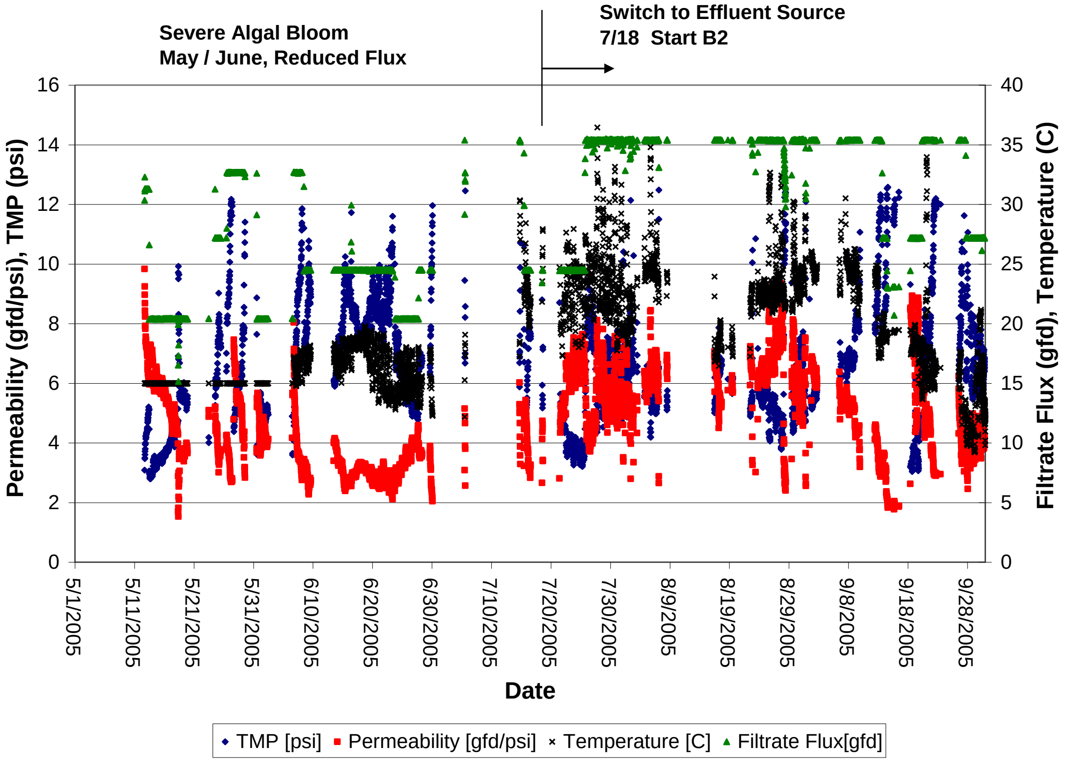
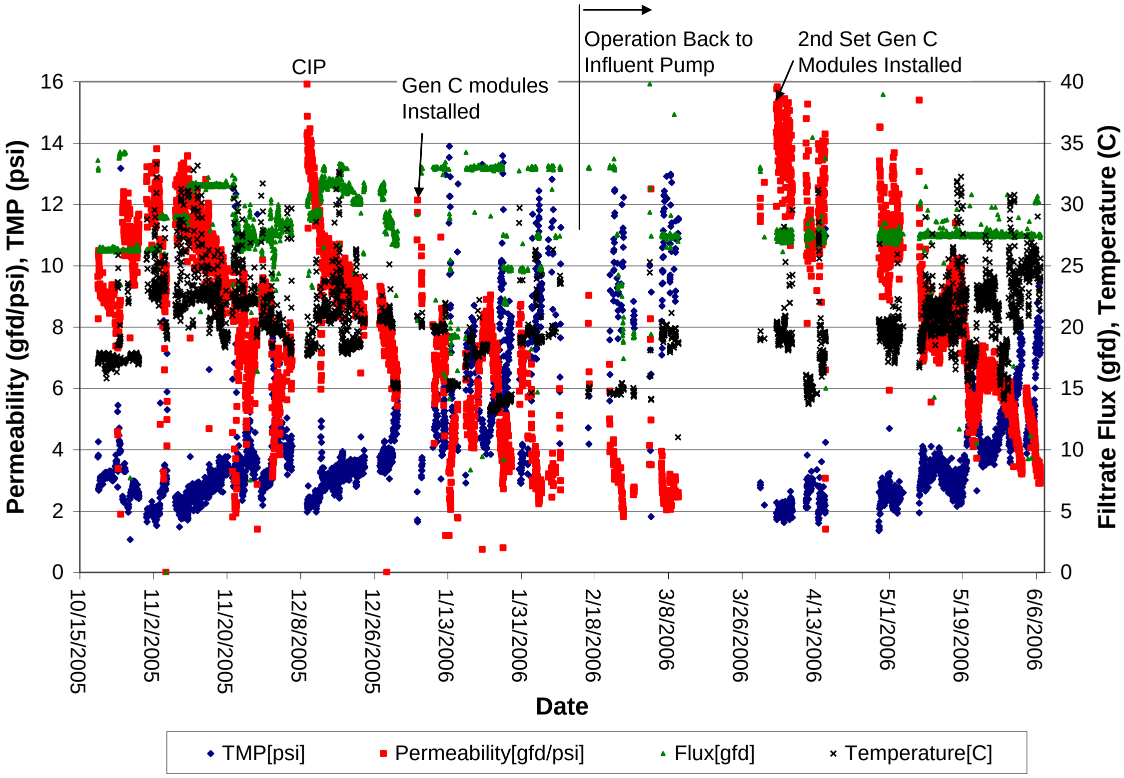


Figure 6-14 shows the performance of the MF unit from October 2005 to May 2006 (balance of Phase B-2), with feedwater continuing from power plant effluent. The MF unit experienced integrity issues during this time period and several different Arkal prescreen filter disc sizes were utilized in an effort to keep shell particles and other debris from damaging the membrane fibers. MF flux rates varied from 19 to 34 GFD during this period, with one episode of irreversible fouling occurring in January/February on a newly installed set of Generation C modules, resulting in the need to reduce the operating flux to 19 GFD. The irreversible aspect of this fouling was a unique event in the entire Phase A and B operation. The operating personnel reported the water in the MF basin had an unusual yellow color during this period. An autopsy analysis of an MF module by the membrane manufacturer indicated the presence of organics and biological matter on the membrane surface, but was not able to provide a more specific cause of the permeability loss. Lab scale cleaning trials on the fibers indicated the best recovery when cleaning was performed with 0.5% sodium percarbonate (40˚C) followed by 0.05% H_2SO_4 (40˚C). This information was retained for implementation at the pilot, should a similar event occur. Operational issues with the effluent feed pump resulted in reverting operation back to influent water from February 10th until early June 2006.

Figure 6-14 CMF-S Performance October 2005 – May 2006



6.2.14.1 Phase B-3

With regard to the Siemens CMF-S MF operation, Phase B-3 was a continuation of B-2 testing, demonstrating performance of the MF on the warm post-condenser effluent water. Table 6-8 shows the details of the Siemens runs.

Table 6-8 Details of Phase B3 Siemens CMF-S MF Runs

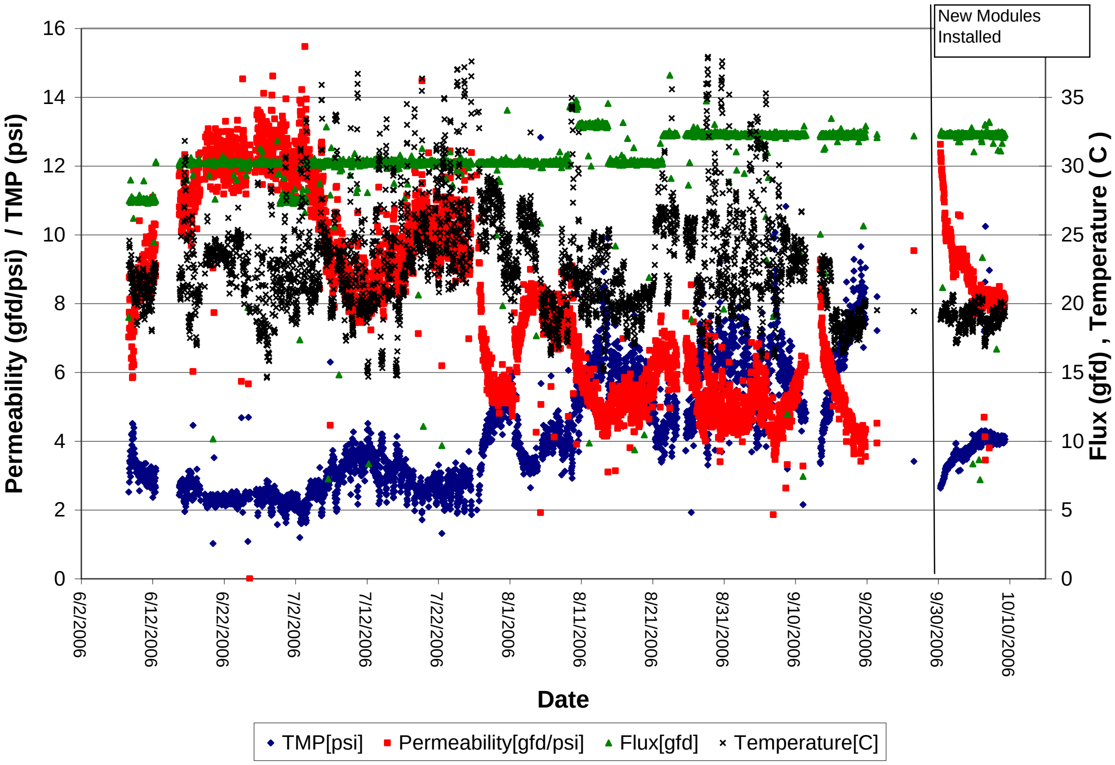
Feedwater Source: Post Condenser Effluent

Run #	Dates	Flux (GFD)	Backwash Chlorination (mg/l)	Backwash Frequency (min)	Comments
MF 33	6/9/06 – 9/20/06	30-34	50 for 2 weeks, then 20 in every backwash tank	~ 20 minutes	Very long and stable run, although MF membrane integrity issues developed.
MF 34	10/1/06 – 10/9/06	32	20 in every backwash tank	~ 20 minutes	New modules installed, Generation "C", Set 3. Run stopped short due to equipment relocation

Figure 6-15 displays the last of the run time for the CMF-S unit. The unit experienced a very long run time during this period of time with flux range of 32-34 GFD. During run #33 the CMF-S maintained 30 GFD for two months without requiring a CIP. Subsequently, in late August 2006, the flux rate was increased to 34 GFD and the unit maintained this for another month, again, without requiring a CIP.

Integrity issues developed towards the end of run 33, but this can be attributed to an operational error with the Arkal prescreening system, when raw ocean water containing shell fragments and other debris was inadvertently bypassed around the Arkal filter and made its way into the membrane tank. This shows the importance of proper prescreening prior to the MF system.

Figure 6-15 CMF-S Performance June 2006 – October 2006



6.2.15 Filtrate Water Quality

The MF pretreatment is utilized to condition the raw ocean water such that it is suitable for spiral wound reverse osmosis membranes. This involves particulate matter removal that is monitored through turbidity measurement and silt density index (SDI). Spiral wound reverse osmosis membranes operate best when the RO feed water has turbidity less than 1 NTU and SDI less than 5.

6.2.16 Phase A CMF-S Filtrate Quality

6.2.16.1 Turbidity and SDI

The raw ocean water and MF filtrate turbidities were measured once per day at the test site. The incoming ocean water turbidity averaged ~1NTU, with peak values of ~5NTU. Per Figures 6-16 and 6-17, the MF filtrate turbidity averaged 0.05NTU and typically was <0.1NTU, suitable for RO despite the module and fiber integrity problems.

Figure 6-16 Feed Water and MF Filtrate Turbidity-MF Trials I – III

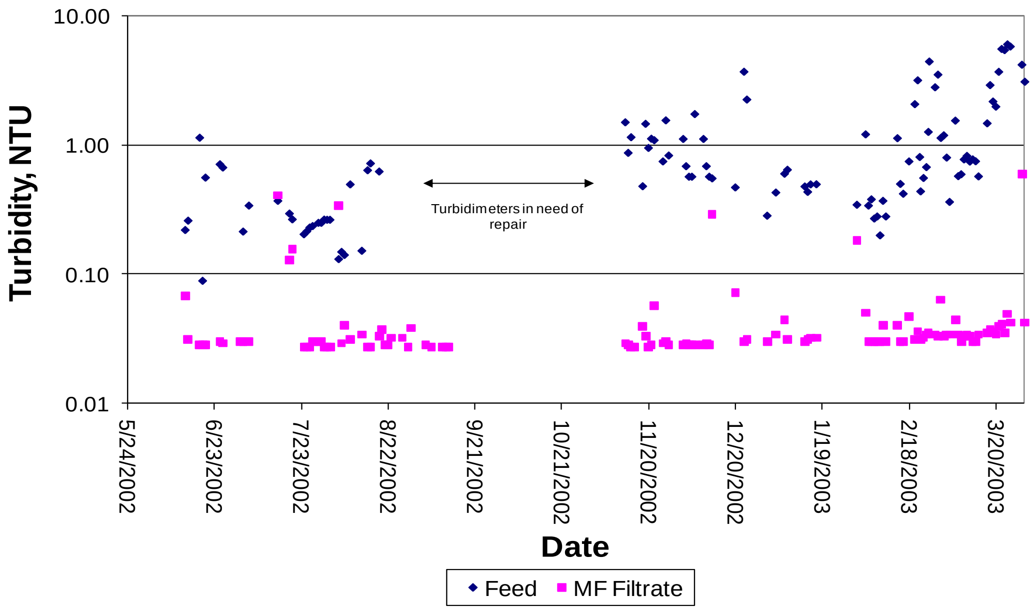
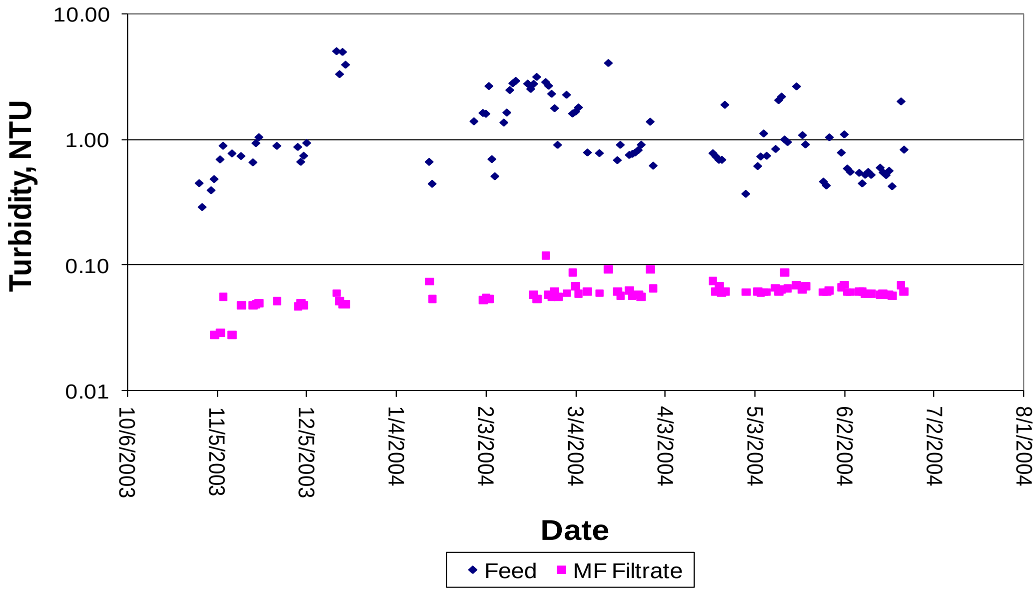


Figure 6-17 Feed Water and MF Filtrate Turbidity-MF Trials IV & V

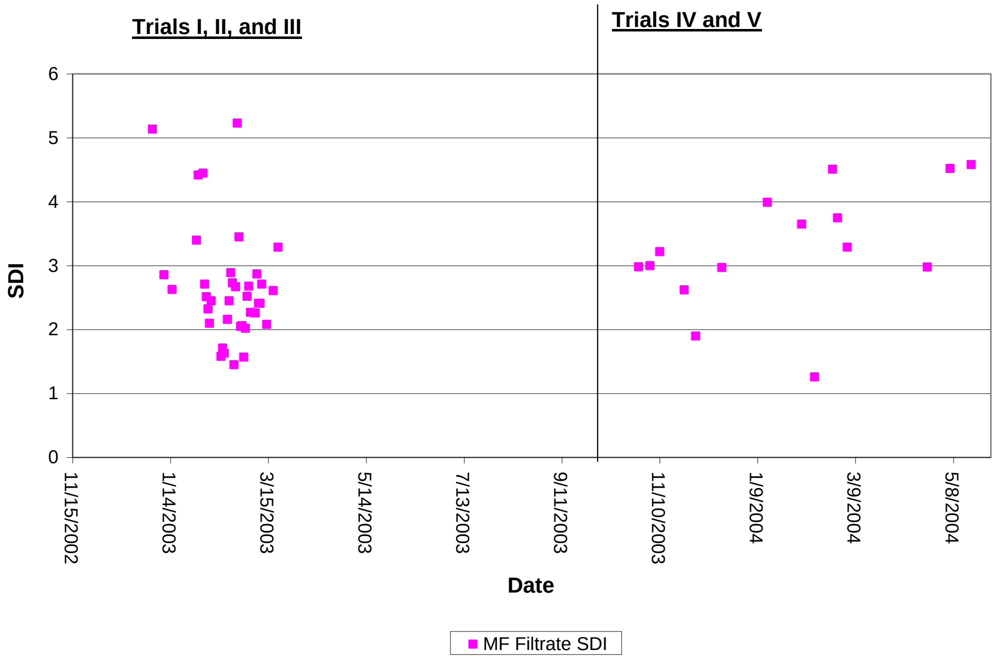


The silt density index, or SDI_{15} is a popular method for determining feed water quality in RO applications. It is based on the time difference required to filter an initial volume of water through a 0.45 µm filter pad at a feed pressure of 30 psig, and again after fifteen minutes of continuous filtration. Colloidal and suspended matter clogs the filter pad resulting in increasing SDI_{15} values.

It is important for the feed water to the spiral RO membranes to have an SDI_{15} less than 5, according to manufacturer recommendations. An SDI_{15} greater than 5 represents water that poses an increased risk to RO membrane fouling/permeability decline and differential pressure increase.

The SDI_{15} analysis of the raw ocean water was attempted on a few occasions and was immeasurable, clogging the SDI pad significantly within 5 minutes and almost completely by the fifteen-minute mark. The CMF-S system proved to be effective at SDI_{15} reduction, typically producing water with an SDI_{15} between 2 and 3. Figure 6-18 shows the RO Feed SDI_{15}.

Figure 6-18 CMF-S System Pressure Decay Results and Filtrate SDI MF Trials I - III



6.2.16.2 Phase A CMF-S Filtrate Laboratory Data

Weekly water quality analysis demonstrated that the microfiltration system provided a slight removal of TOC (approximately 10% removal). As expected, inorganic constituents were unaffected as seen in Tables 6-9 and 6-10.

Table 6-9 Siemens CMF-S Feed Water Quality Phase A

CMF-S Feed			**MF Testing Trials I-III**		**MF Testing Trials IV, V**	
Parameter	**Units**	**DL**	**Average**	**Std Dev**	**Average**	**Std Dev**
UV 254	abs/cm	0.005	.010	0.003	0.013	0.003
Alkalinity (as CaCO3)	mg/L	2	115	2.1	109	1.3
Calcium	mg/L	25	407	29	389	22
Magnesium	mg/L	25	1335	103	1236	68
Hardness (as CaCO3)	mg/l	200	6515	473	6061	313
Sodium	mg/L	25	10963	733	10285	528
Potassium	mg/L	25	404	32	394	26
TOC	mg/L	0.5	0.95	0.3	.93	0.1
DOC	mg/L	0.5	0.67	0.12	0.60	0.11

Table 6-10 Siemens CMF-S Filtrate Water Quality Phase A

CMF-S Filtrate			**MF Testing Trials I-III**		**MF Testing Trials IV, V**	
Parameter	**Units**	**DL**	**Average**	**Std Dev**	**Average**	**Std Dev**
UV 254	abs/cm	0.005	Non Detect		Non Detect	
Alkalinity (as CaCO3)	mg/L	2	115	6	109	4
Calcium	mg/L	25	406	33	393	21
Magnesium	mg/L	25	1338	105	1257	90
Hardness (as CaCO3)	mg/l	200	6525	491	6157	409
Sodium	mg/L	25	10920	808	10449	737
Potassium	mg/L	25	405	37	399	41
TOC	mg/L	0.5	0.87	.18	0.84	.11

The backwash effluent was sampled weekly for TOC and monthly for turbidity to characterize this waste stream. Results are listed in Table 6-11 below.

Table 6-11 Microfiltration Backwash Effluent Stream Characterization

CMF-S Backwash			MF Testing Trials I-III		MF Testing Trials IV, V	
Parameter	Units	DL	Average	Std Dev	Average	Std Dev
TOC	mg/L	0.5	1.00	0.37	1.06	0.27
Turbidity	NTU	0.1	7.6	3.5	11.3	8.6

6.2.17 Phase B CMF-S Filtrate Quality

6.2.17.1 Turbidity and SDI

In Phase B, the MF filtrate in general was again typically less than 0.1 NTU as seen in Figure 6-19.

Figure 6-19 Phase B Siemens CMF-S Turbidity

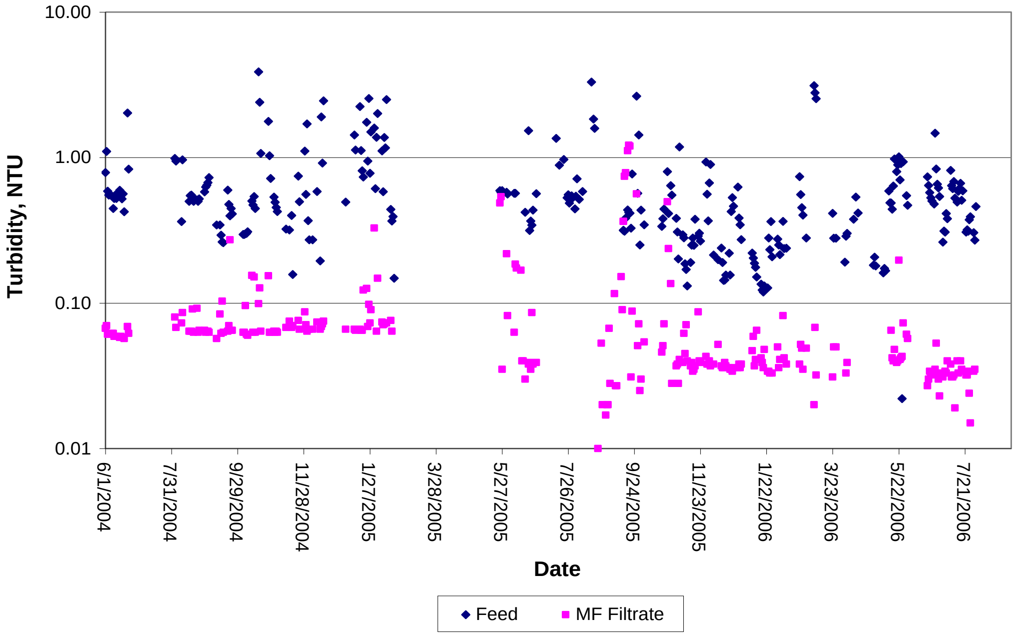


Figure 6-20 shows the integrity of the MF fibers during phase B with various grades of prescreening. Note that the major fiber integrity issues in August of 2005 correspond with the highest filtrate turbidity values as depicted in Figure 6-19.

Figure 6-20 Phase B CMF-S Pressure Decay Test Results

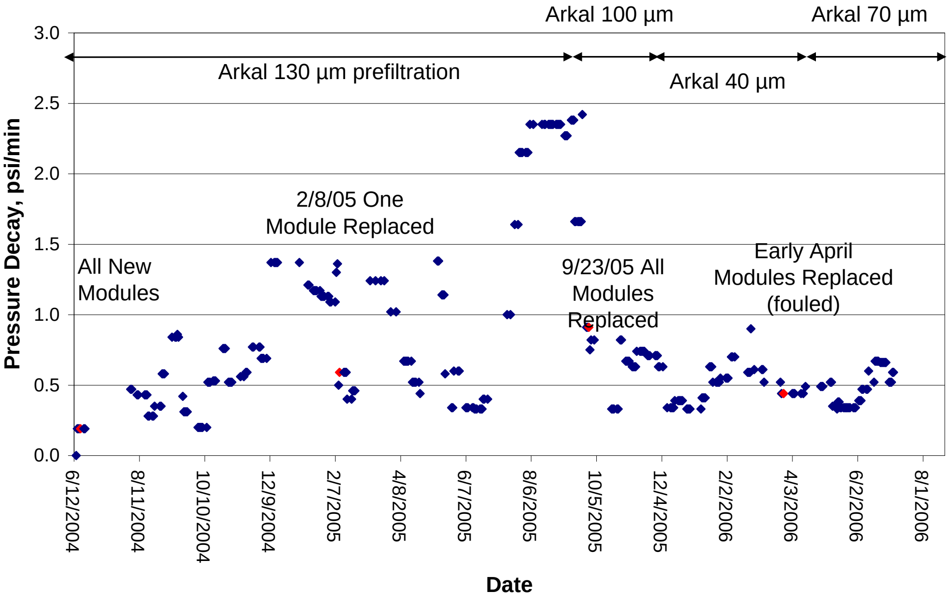
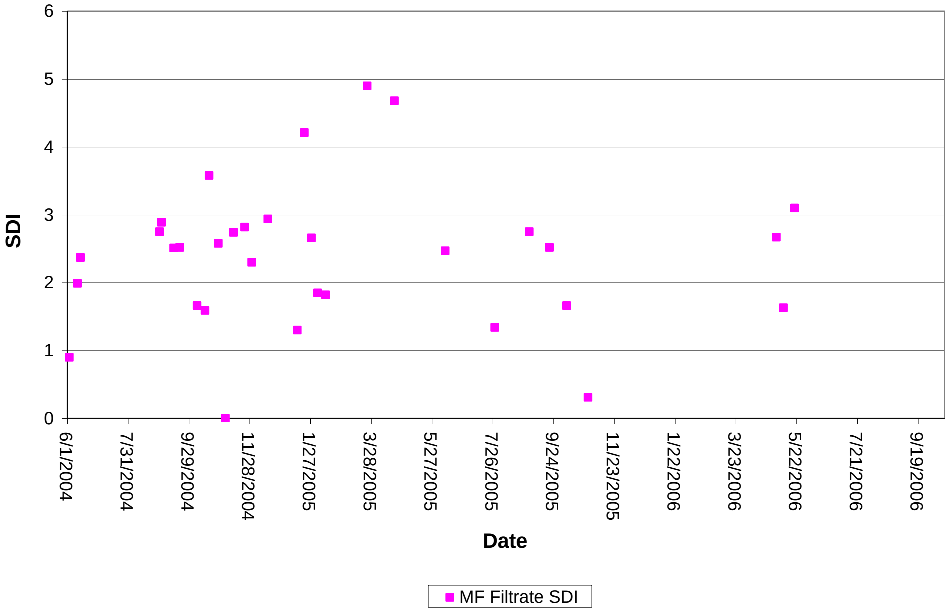


Figure 6-21 shows the CMF-S filtrate SDI values for Phase B. In general, the SDI values for the CMF-S system were below 3, with only three measurements in the 4 to 5 range during this period testing.

Figure 6-21 Phase B CMF-S PDT and SDI Values



6.2.17.2 Phase B CMF-S Filtrate Laboratory Data

Tables 6-12 and 6-13 show detailed water quality of both the CMF-S feed and filtrate water quality respectively. Like the Phase A testing, the CMF-S system demonstrated approximately 10% removal of TOC, and no removal of inorganic constituents.

Table 6-12 CMF-S feed water quality January 2005 – October 2006

CMF-S Feed			Phase B1		Phase B2		Phase B3	
Parameter	**Units**	**DL**	**Average**	**Std Dev**	**Average**	**Std Dev**	**Average**	**Std Dev**
UV 254	abs/cm	0.01	0.013	0.003	0.016	0.007	0.014	0.004
Alkalinity (as CaCO3)	mg/L	2	113	4.5	113	4.0	113	1.2
Calcium	mg/L	25	386	18	377	25	387	14
Magnesium	mg/L	25	1245	52	1254	95	1190	65
Sodium	mg/L	25	10237	414	10422	716	9830	602
Potassium	mg/L	25	372	17	390	32	373	17
TOC	mg/L	0.5	0.99	0.24	0.93	0.20	0.85	0.13
DOC	mg/L	0.5	0.65	0.12	0.63	0.12	0.70	0.07

Table 6-13 CMF-S filtrate water quality January 2005 – October 2006

CMF-S Filtrate			Phase B1		Phase B2		Phase B3	
Parameter	**Units**	**DL**	**Average**	**Std Dev**	**Average**	**Std Dev**	**Average**	**Std Dev**
UV 254	abs/cm	0.01	Typically ND		Typically ND		Typically ND	
Alkalinity (as CaCO3)	mg/L	2	113	4.9	113	3.9	113	1.1
Calcium	mg/L	25	386	24	378	25	390	17
Magnesium	mg/L	25	1249	66	1264	94	1203	80
Sodium	mg/L	25	10303	508	10509	683	9941	675
Potassium	mg/L	25	373	23	390	28	377	20
TOC	mg/L	0.5	0.85	0.15	0.87	0.16	0.76	0.18

6.2.18 CMF-S MF Summary

The Siemens CMF-S system underwent a total of approximately four years of testing. Similar performance with regards to sustainable flux rate and filtrate water quality were observed on both the power plant influent and post condenser effluent water sources. 34 GFD was

determined to be the optimum flux for both water sources, and filtrate quality was consistently acceptable as feed to the Reverse Osmosis units. Fiber damage did occur during Phase B testing and pre-filter rating of 70 micron or less was found to be effective at preventing damage. The optimized CMF-S operating parameters are included in Table 6-14.
Chlorination of the backwash was found to be vital to maintain the performance achieved.

At the end of Phase B1 and into Phase B2 a severe algal bloom occurred that required the operating flux to be reduced by approximately 30% in order to maintain stable operation and a reasonable period between chemical cleanings.

Three generations of MF modules were trialed during Phase A and B. The most recent module, Generation C, had the thickest fiber and lowest surface area of all the modules tested, but was least affected by fiber breakage issues. The one fiber breakage incident that did occur with the Generation C modules was believed to be the result of an operational error with the Arkal prescreening unit. The generation C module with the 70 µm Arkal prefilter demonstrated acceptable integrity and would be suitable for full scale design consideration.

A successful CIP protocol was found to be:

- 2% citric acid recirculation/aeration at 36 – 38˚C followed by
- 400 to 600 mg/L NaOCL recirculation at 20 - 22˚C

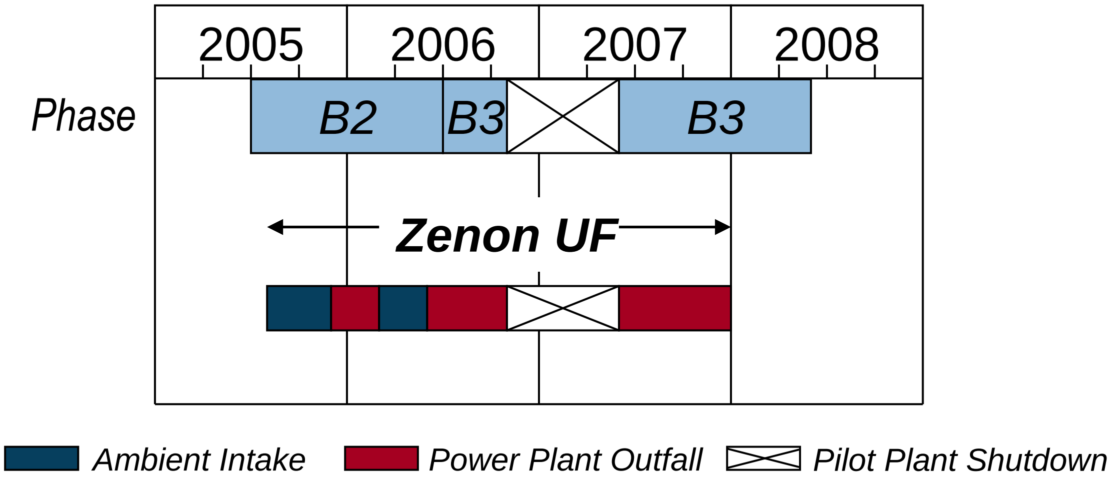
Table 6-14 Optimized CMF-S Parameters

Parameter	Value
Filtrate Flux (gfd)	34
Filtration time between backwashes (min)	20
Recovery	93%
Backwash Parameters	
Air scour Rate (SCFM/module)	7
Air scour Duration (seconds)	30
Backpulse Rate (gpm/module)	9.9
Air Scour + Backpulse Duration (seconds)	15
Refill Duration (seconds)	~35
Backwash chlorination (mg/L)	20

6.3 Zenon ZW1000 Ultrafiltration System

The Zenon ZW1000 system was operated from 2005 to 2008, on both ambient intake and powerplant outfall water per the schedule shown in Figure 6-22.

Figure 6-22 Testing Summary Graphic of Zenon ZW1000 Ultrafiltration System



6.3.1 Operations/Optimization Phase B-2 and B-3

Phase B-2 included the addition of a Zenon ZW1000 Ultrafiltration (UF) system to the site in May of 2005. The unit was operated on both power plant influent (Phase B-2) and effluent (Phase B-3) with various operating strategies.

Table 6-15 summarizes the UF unit run conditions during the Phase B testing period:

Table 6-15 Details of Zenon ZW1000 UF System Runs

Phase B-2 Summary **Feed Source is Power Plant Influent**

Run	Dates	Flux (GFD)	Backwash Frequency (min)	# of NaOCl MC per day	NaOCl concentration (mg/l)	# of Citric Acid MC per week	Citric Acid concentration (g/l)	Comments
UF 1	4/15/05 – 5/20/05	23.5	25	3	100	1	0.5	Unit commissioned in April and May with 500 sq ft ZW1000 modules with a nominal pore size of 0.02 micron. Material is PVDF.
UF2	5/20/05 – 7/4/05	20.1	28	3	100	1	0.5	Late May/ Early June Red Tide Event started.
UF 3	7/4/05 – 7/26/05	20.1-16	28	1	100	1	0.5	Red tide required flux reduction to maintain adequate runtime.
UF 4	7/27/05 – 8/8/05	18	28	2	100	1	0.5	Power plant operating issues resulted in short run.
UF 5	9/14/05 – 9/26/05	18	28	2	100	1	0.5	Equipment shut down midway through run 5 for overall pilot upgrades.
UF 6	11/7/05 – 11/23/05	18	28	2	100	1	0.5	Zenon unit switched to power plant effluent during this run.

Feed Source switched to Effluent water Nov 23, 2005

UF 6	11/23/05 – 11/30/05	18	28	2	100	1	0.5	Fiber breakage occurred in mid/late November, later attributed to manufacturer defect.
UF 7	12/2/05 – 1/03/06	18	28	2	100	1	0.5	New 500 sq ft ZW-1000 modules installed. Changed Arkal disk filter from 130 micron to 40 micron.

Run	Dates	Flux (GFD)	Backwash Frequency (min)	# of NaOCl MC* per day	NaOCl concentration (mg/l)	# of Citric Acid MC* per week	Citric Acid concentration (g/l)	Comments
UF 8	1/11/06 – 1/31/06	19	28	2	100	1	0.5	CIP study showed heating CIP solutions to 35-40ºC to be more effective.
Feed Source returned to Influent water Feb. 10, 2006								
UF 9	2/1/06 – 2/20/06	19	28	2	100	1	0.5	Runs 8-10 did not quite reach full 21-day run target.
UF 10	3/1/06 – 3/30/06	19	28	2	100	1	0.5	
UF 11	3/30/06 – 5/5/06	14	34	1	100	0	N/A	Flux reduced to ensure 21 day run time between cleanings. Arkal filters loosened to 100 micron.
UF 12	5/10/06 – 5/31/06	14	34	1	100	0	N/A	

Note: Use of citric acid maintenance cleans were stopped after run 10

Phase B-3 Summary   Feed Source is Effluent wate

rRun	Dates	Flux (GFD)	Backwash Frequency (min)	# of NaOCl MC* per day	NaOCl concentration in MC (mg/l)	NaOCl used in backwash	NaOCl backwash concentration (mg/L)	Comments
UF 13	6/2/06 – 8/9/06	14	34	1	100	No	N/A	Effluent supply pump restored. Run lasted greater than 60 days with no CIP.
UF 14	8/10/06 – 9/25/06	14-18	34	1	100	No	N/A	Flux increased after extended run time at 14 GFD.
UF 15	9/26/06 – 10/15/06	16	34	1	100	Yes	Experimental	Experimental hypochlorite dosing in backwash started in addition to the existing daily hypochlorite maintenance clean. .
Equipment relocation, down for 6 months								
UF 16	5/10/07 – 6/19/07	20-25	22-24	1 @ 110ºF	100	Yes	2 mg/l In every backwash tank	New unit with 600 sq ft. ZW-1000 modules installed, nominal pore size remains 0.02 micron. Break-in run.
UF 17	6/20/07-7/22/07	25-27.5	22	1 @ 110ºF	100	Yes	2 mg/l In every backwash tank	Increase of flux during this period.
UF 18	7/25/07-8/16/07	27.5	22	1 @ 110ºF	100	Yes	2 mg/l In every backwash tank	Demonstration of 27.5 GFD sustainable for 21 days.

rRun	Dates	Flux (GFD)	Backwash Frequency (min)	# of NaOCl MC* per day	NaOCl concentration in MC (mg/l)	NaOCl used in backwash	NaOCl backwash concentration (mg/L)	Comments
UF 19	8/17/07-11/29/07	27.5-30	22	1 @ 110ºF	350	Yes	4 mg/l In backwash tank	Increase in chlorine concentrate in both the backwash and Maintenance cleans. Very stable run at 27.5 GFD with little increase in TMP for over 30 days.
UF 20	11/30/07 - 12/16/07	33	24	1 @ 110ºF	350	No	NA	Last run of Zenon trial.

6.3.2 Zenon ZW1000 UF Permeability

As shown in the summary Table 6-15, early testing in 2005 and 2006 of the Zenon unit on both influent and effluent streams resulted in a sustainable flux rate 16-18 GFD. Figure 6-23 shows the details of operation between May 2005 and September 2005. The Zenon system was brought online during the first severe red tide event, making it difficult to achieve long run times during the first two months of operation and resulting in a reduction of operating flux. Per figure 6-22, runs 2 and 3 (May 20, 2005 through July 27, 2005) consisted of operation at 20 gfd, and operation at this flux rate did not provide the target 21 days of operation before a CIP was required. The flux was therefore lowered to 18 gfd with run 5 starting on 9/14/05. Unfortunately, run 5 was halted after two weeks of operation as the pilot plant was shut down for overall pilot system upgrades.

Figure 6-23 Zenon Operating Performance May 2005 – September 2005

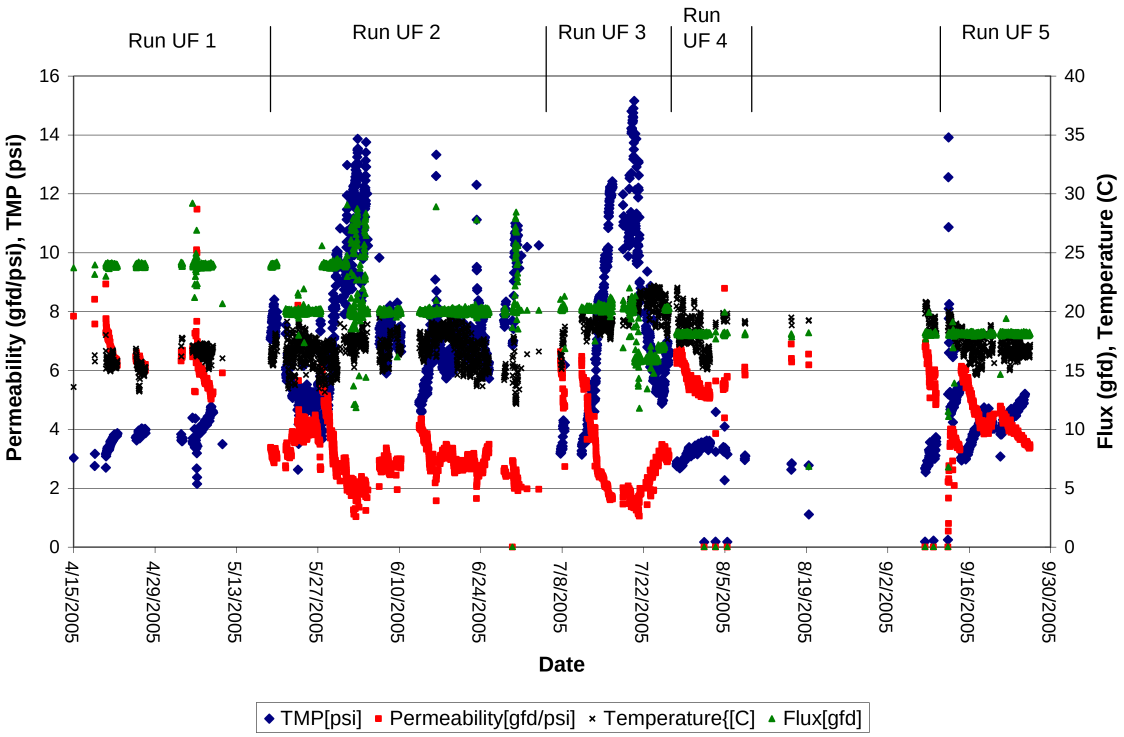


Figure 6-24 details the continued Phase B-2 operation from November 2005 to March 2006. The unit was switched from power plant influent to power plant effluent during run 6 on November 23, 2005 due to site operational requirements.

Prior to switching to the effluent source, the membrane cassettes began to experience fiber integrity problems as shown in the Pressure Decay Test in Figure 6-24. The cassettes were replaced at the end of run 6, and the new cassettes were used for the start of run 7. For the start of run 7, the Arkal filter size was tightened to 40 micron as it was unclear if the integrity problems were from suspended particles in the feedwater. The damaged membrane cassettes were sent back to Zenon for evaluation and it was determined that several of the fibers had been sheared as the result of manufacturing defect, and not from particulate matter in the feedwater.

At the conclusion of run 7 a CIP was performed with little success at restoring permeability. Subsequently, Zenon personnel came to the site at the end of January and performed CIP experiments. Their testing indicated that heating the CIP solutions was beneficial for the CIP (previous cleans were not heated). The CIP protocol used for the remainder of this test period consisted of:

- 500 mg/L NaOCl followed by
- 2% Citric Acid
- Each of these solutions heated to 35º to 40ºC and have a contact time of 6 hours with the membranes

Run 9 began on February 1st, and on February 10th the sourcewater was switched back to influent water. Neither run 9 or 10 were able to achieve the target continuous run time of 21 days at 19 GFD.

Figure 6-24 Zenon Operating Performance November 2005 – March 2006

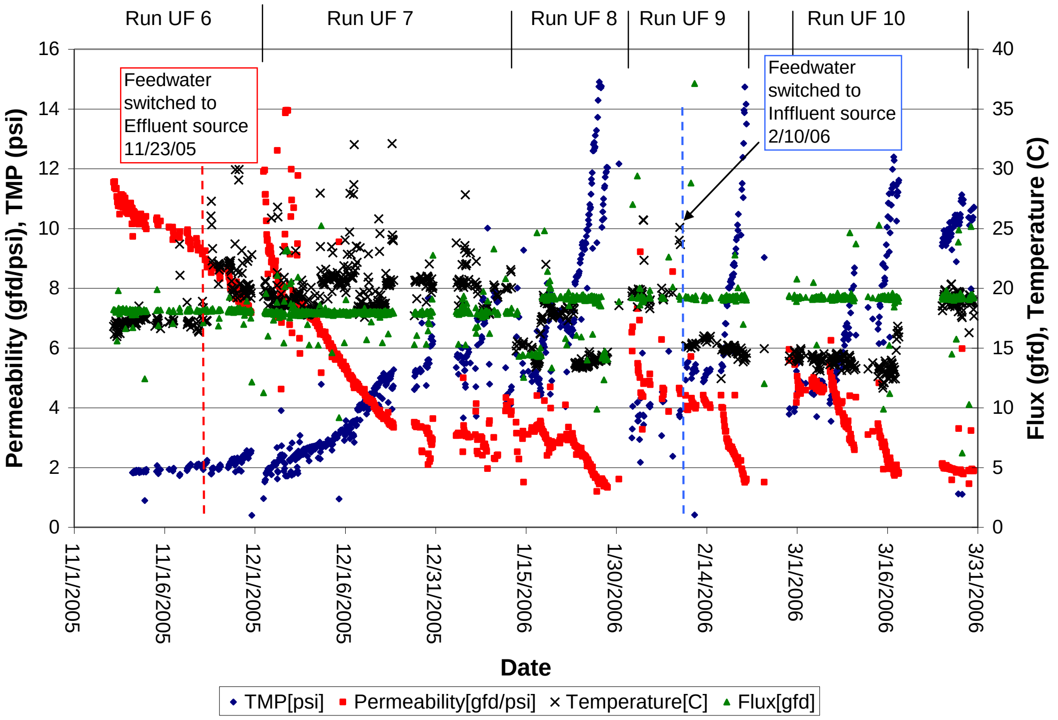
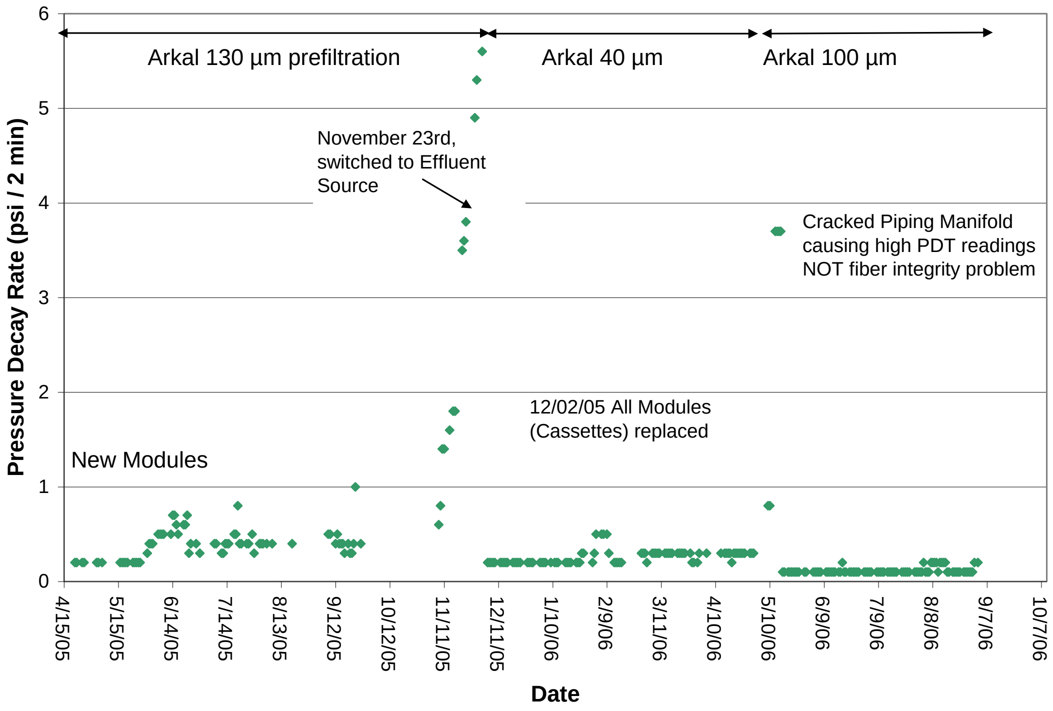
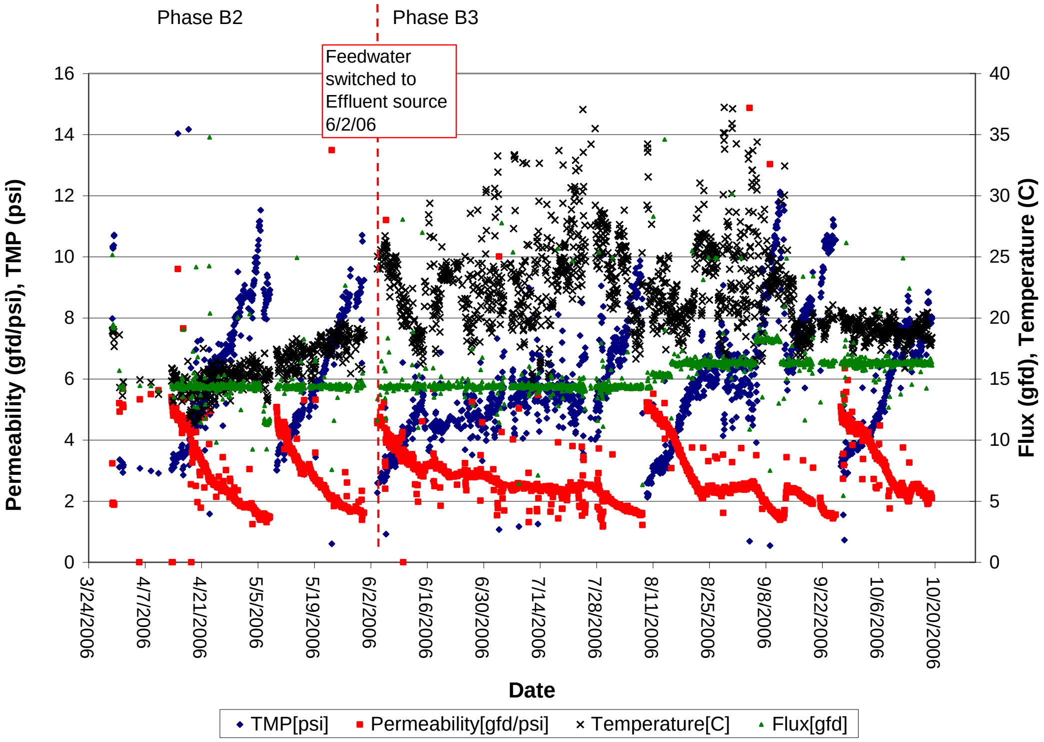


Figure 6-25 Zenon Pressure Decay Test Data



Detailed operating performance for April 2006 to October 2006 is shown in Figure 6-26. Flux rate was reduced from 19 GFD to 14 GFD for a period of this testing, resulting in extended run times between cleanings. Phase B3 started in early June, with the feedwater source switching to the warmer effluent water for run 13. Run 13 exceeded 60 days of run time, indicating a flux of 14 GFD was too low as the target CIP frequency was 21 days. The flux was raised to 16 GFD in runs 14 and 15. It is noteworthy that with the new heated CIP procedure, there is improvement in the consistency of the post CIP permeability after each CIP, but permeability returns to only ~ 5.8 gfd/psi.

Figure 6-26 Zenon Operating Performance April 2006 to October 2006

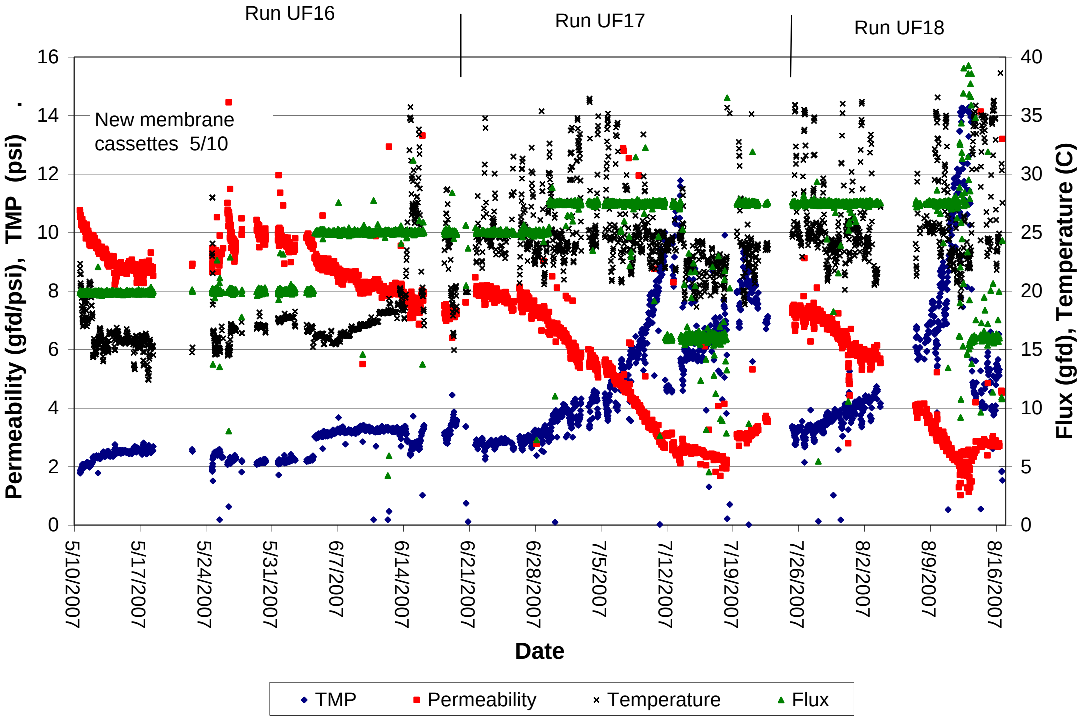


During run 15, experiments were run with the introduction of chlorinated backwashes, as was successfully done for the Siemens CMF-S unit, in addition to the daily hypochlorite maintenance clean. This brief experimentation period proved beneficial in maintaining permeability. The pilot equipment was shut down after run 15 for relocation.

In May of 2007, as part of the pilot equipment relocation effort, an upgraded Zenon Pilot system was installed at the site. The new unit utilized a total of three 600 sq. ft. ZW-1000 membrane cassettes, which was an updated design over the previous 500 sq. ft. cassettes. The membrane material remained PVDF with a nominal pore size of 0.02 micron. Several changes in operating strategy were implemented with this new round of testing in an effort to bring the flux rate up to a value that was more competitive with the previous Siemens MF system. The most significant changes included the use of chlorine in every backwash in addition to the use of heated, chlorinated maintenance cleans once a day.

The Zenon unit was operated on effluent water during this phase B3. Figure 57 shows the details of this time period. Per Figure 6-27, the changes provided a drastic improvement in performance with operation at 25 - 27.5 GFD

Figure 6-27 Zenon Performance June 2007 – September 2007



The Zenon unit was restarted up in late May 2007, with Run 16 considered a "break-in" period. Run 17 and 18 were operated under the following conditions, with adjustments to flux rates made periodically:

Instantaneous Flux Rate : 25 – 27.5 GFD
Recovery : ~93%
Backwash Frequency : ~22 minutes
Backwash Type : Chlorinated backwash (20 mg/l in backwash volume, which corresponds to ~ 2 mg/L in membrane tank) with air scouring
Daily Maintenance Clean : 100 mg/l chlorine solution in membrane tank heated to 40 C, 30 minute soak

Run 17 ran for 7 days at 25 GFD before the flux was increased to 27.5 GFD, where it ran for 14 more days before approaching terminal TMP. In order to maintain sufficient flow to the RO units a CIP could not be scheduled at that time, so the flux was then reduced to 16 GFD and the unit ran for 6 more days. A CIP was then scheduled, and unit ran for 3 more days at the previous setpoint of 27.5 GFD before being shutdown for CIP.

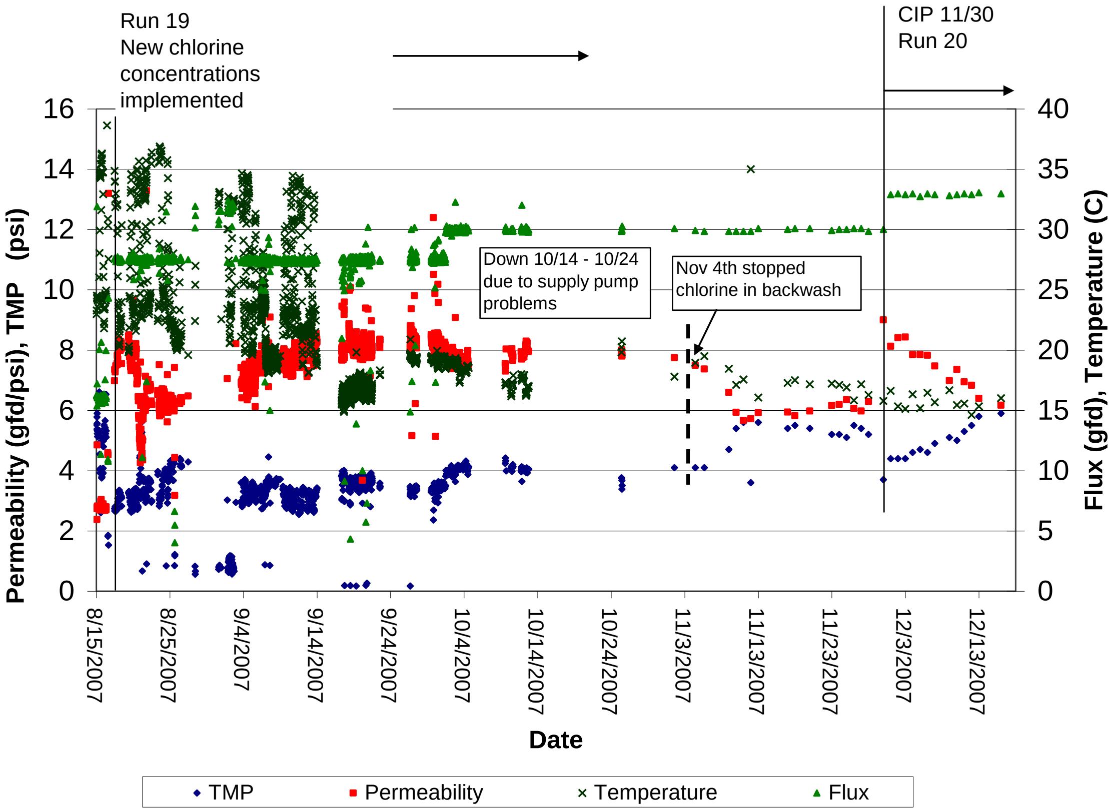
Run 18 was started with a flux rate of 27.5 GFD, and ran at that flux rate for 20 days before reaching terminal TMP, 1 day short of the 21 day goal. A CIP was scheduled, and the unit was operated at a reduced flux of 16 GFD for two days to maintain flow to the downstream RO units before the CIP could take place.

A slightly more aggressive cleaning procedure was used during this period of testing, which consisted of 500 ppm NaOCl solution followed by a 2% citric acid solution suppressed to pH 2.1 with hydrochloric acid. Both cleaning solutions were heated to 40°C and allowed to soak for 5 hours. (Note: previous CIP step did not entail use of hydrochloric acid, but had longer soak times of 6 hours for each step.)

The three CIPs that were performed after runs 16, 17 and 18 resulted in post CIP permeability values of 8.0, 7.8 and 8.1 gfd/psi, respectively. This is a great improvement over the previous post CIP values of 5.8 gfd/psi, and is most likely attributed to the more effective maintenance cleans and backwashes that were performed with the new operating strategy.

Figure 6-28 shows the complete performance for Run 19 and 20. Run 19 started on Aug 18th with the flux rate remaining 27.5 GFD to test out using increased chlorine concentrations in the backwash and maintenance clean. The chlorine concentration used in the backwash was increased to 40 mg/l in the backwash water, which equates to approximately 4 mg/l in the membrane tank. Also, the chlorine concentration in the daily maintenance clean was increased from 100 mg/l to 350 mg/l, and heating to 40°C was continued. These changes resulted in very stable performance throughout September and October, although run time was not consistent. The flux rate was raised to 30 GFD on October 2nd. On November 4th, operating with chlorinated backwashes was halted to test the effect. Over the course of the following few days the TMP showed a steady increase, but leveled off after 1 week of operation. The TMP remained very stable for the remaining two weeks of operation for Run 19.

Figure 6-28 Zenon Performance June 2007 – September 2007



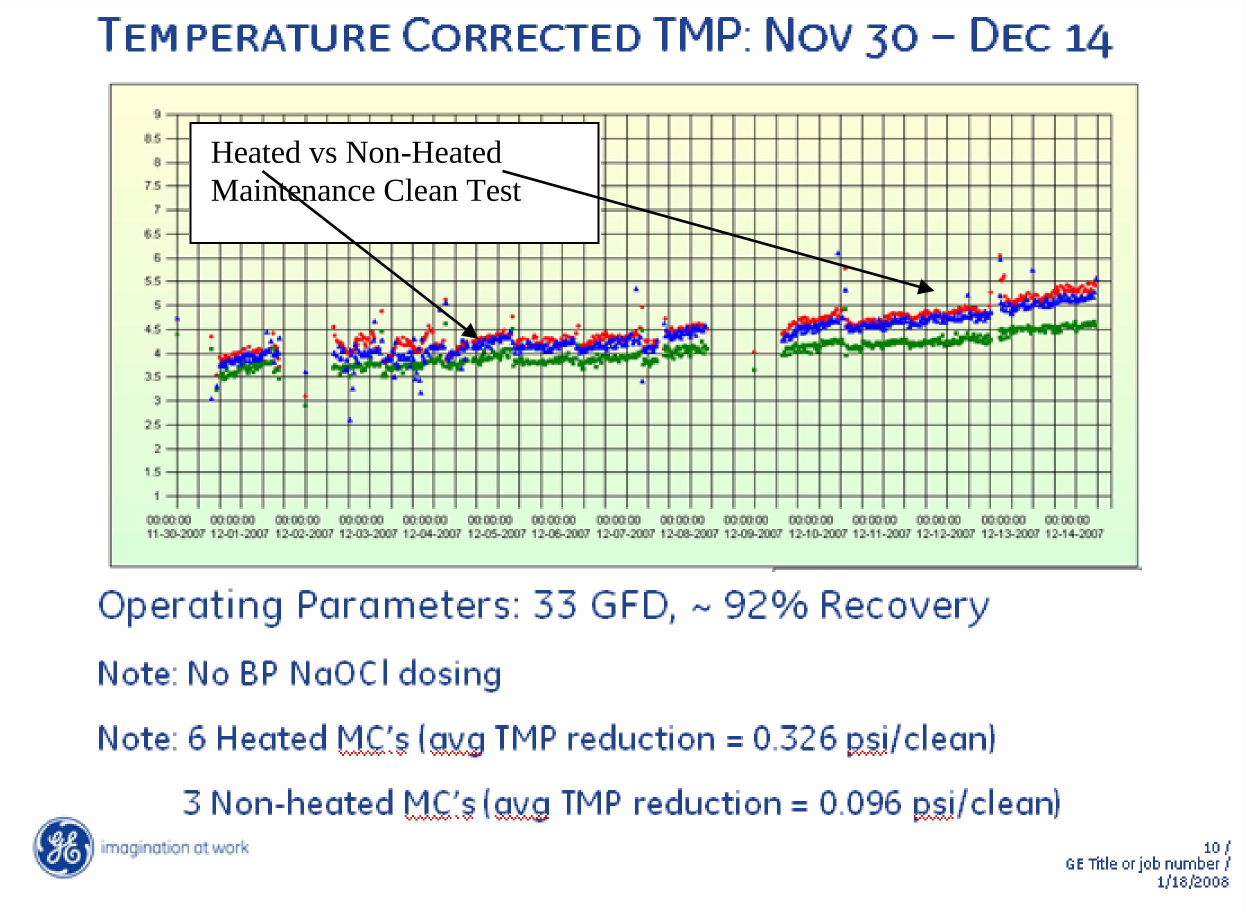
A CIP utilizing the same procedure for runs 16-18 was performed on November 29/30th , not because of high TMP, but in order to have one more full run at new operating conditions. Post-CIP permeability returned to 8 GFD/psi.

Run 20 began on December 1st and is the last run for the Zenon unit for this testing program. For Zenon's final run the flux rate was increased to 33 GFD and the effects of non-heated daily maintenance cleans were evaluated. The unit continued to run without chlorinated backwashes as well. The only chlorine being used was the 350 mg/l in the once daily maintenance cleans. Figure 6-29 shows the detailed performance during the 15 day period. During the first six days of operation there was a slight overall increase in TMP while operating with the heated maintenance cleans. The use of heat in the daily maintenance cleans was then stopped. The subsequent several days showed a larger increase in TMP when operating with no heated maintenance cleans, but not as great as one might expect. This brief test shows that further investigation into non heated maintenance cleans is in order, and trials should be performed on the demonstration scale system. There may be times during a suitable feedwater condition when the system can operate without the use of heated maintenance cleans, thus reducing operating costs of a full scale system. Further work at the demonstration plant should be done to help quantify such conditions.

The Zenon unit operated under the following conditions for Run 20:

Instantaneous Flux Rate: 33 GFD
Permeate Flowrate: 41 gpm
Recovery: ~92%
Backwash Frequency : ~24 minutes
Backwash Type: No Chlorinated backwash, with air scouring
Daily Maintenance Clean: 350 mg/l chlorine solution, with trials of heated to 40 C and non heated, 30 minute soak.

Figure 6-29 Maintenance Clean Trials



TEMPERATURE CORRECTED TMP: NOV 30 – DEC 14

Operating Parameters: 33 GFD, ~ 92% Recovery

Note: No BP NaOCl dosing

Note: 6 Heated MC's (avg TMP reduction = 0.326 psi/clean)

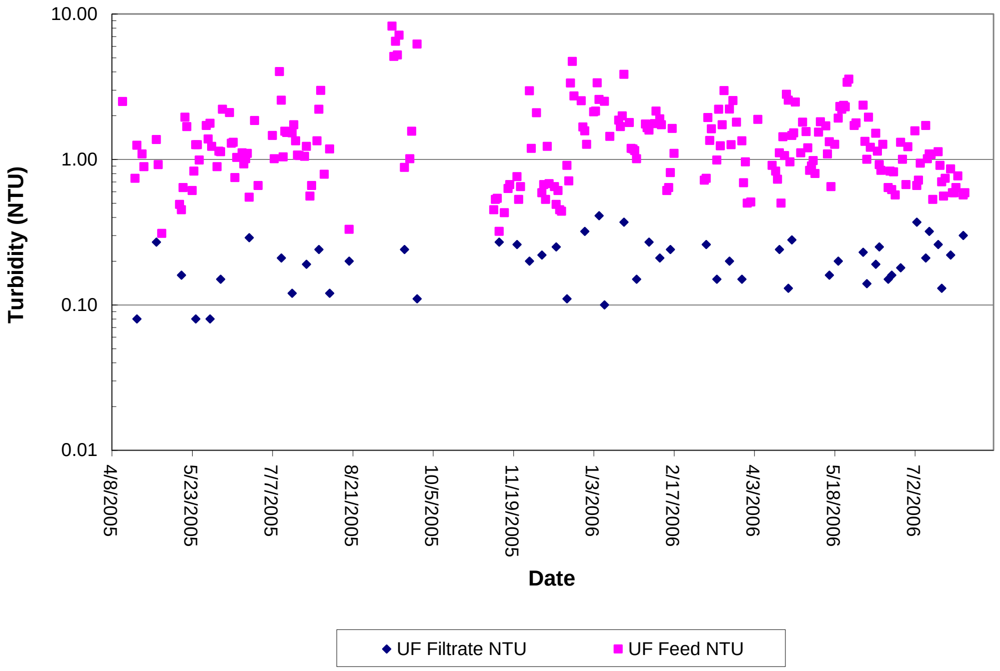
3 Non-heated MC's (avg TMP reduction = 0.096 psi/clean)

6.3.3 ZW1000 UF Water Quality

6.3.3.1 Turbidity and SDI

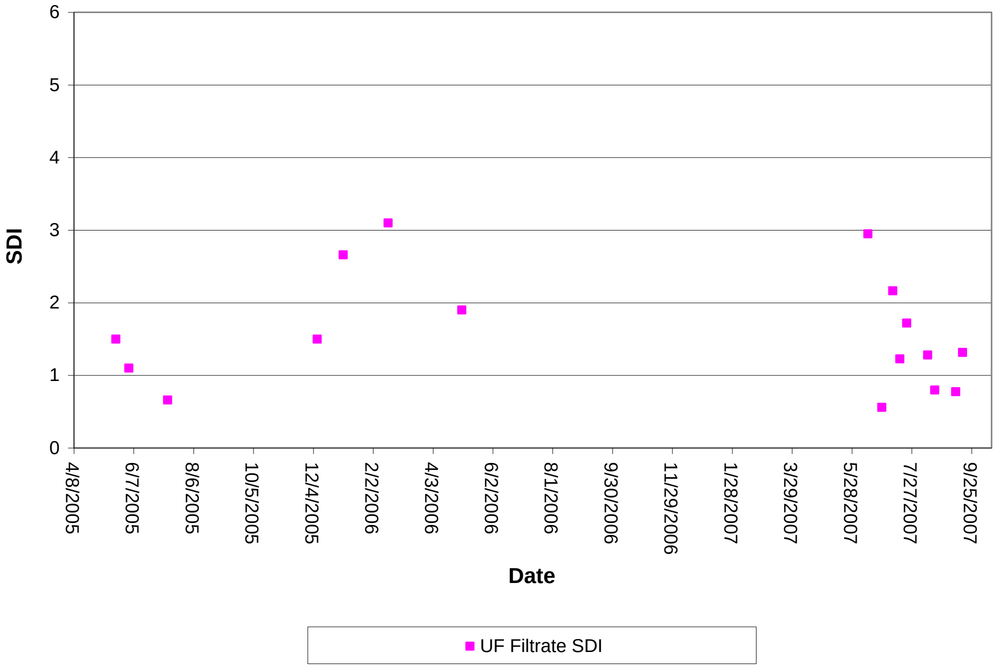
Figure 6-30 displays the feed and filtrate turbidity of the Zenon UF unit in 2005 and 2006. These values are from the onsite hand-held meter, as the online instruments suffered from extensive maintenance issues.

Figure 6-30 Zenon UF Turbidity



The data shown in Figure 6-31 shows the SDI of the UF filtrate was consistently acceptable as feed to the RO system (less than 5)

Figure 6-31 Zenon UF Silt Density Index



6.3.3.2 Laboratory Data

Tables 6-16 and 6-17 show detailed water quality of both the Zenon feed and filtrate water quality respectively. On average, the Zenon system also demonstrated approximately 10% removal of TOC.

Table 6-16 Zenon feed water quality June 2005 – July 2007

Zenon ZW 1000 Feed			Phase B2		Phase B3	
Parameter	**Units**	**DL**	**Average**	**Std Dev**	**Average**	**Std Dev**
UV 254	abs/cm	0.01	0.014	0.005	0.018	0.009
Alkalinity (as CaCO3)	mg/L	2	113	1.9	114	1.2
Calcium	mg/L	25	377	27	391	24
Magnesium	mg/L	25	1263	111	1206	70
Sodium	mg/L	25	10407	826	9955	652
Potassium	mg/L	25	389	31	377	22
TOC	mg/L	0.5	0.94	0.24	1.43	0.85
DOC	mg/L	0.5	0.59	0.06	0.97	0.36

Table 6-17 Zenon filtrate water quality June 2005 – July 2007

Zenon ZW 1000 Filtrate			Phase B2		Phase B3	
Parameter	**Units**	**DL**	**Average**	**Std Dev**	**Average**	**Std Dev**
UV 254	abs/cm	0.01	Typically ND	NA	Typically ND	NA
Alkalinity (as CaCO3)	mg/L	2	113	2.1	113	5.2
Calcium	mg/L	25	381	22	394	23.9
Magnesium	mg/L	25	1272	97	1213	72.7
Sodium	mg/L	25	10514	700	10042	721.1
Potassium	mg/L	25	399	32	379	22.9
TOC	mg/L	0.5	0.86	0.17	1.3	0.83

6.3.4 ZW1000 UF Summary

The Zenon ZW1000 system was tested on both power plant influent and effluent for a period of approximately two years. Similar performance with regards to sustainable flux rate and filtrate water quality were observed on both the power plant influent and post condenser effluent water sources. The final period of testing with the 600 ft^2 membrane, from June 2007 to December 2007, produced the most favorable results with respect to sustainable flux rate. The use of chlorinated backwashes in every backwash combined with daily heated chlorinated maintenance clean has resulted in a sustainable flux rate of 27.5 GFD. Other successful operational parameters are listed in Table 6-18 below.

Membrane integrity was very good on the Zenon system. The use of a pre-filter rating of 100 micron or less was effective at protecting the UF membrane from damage due to particulates, including shell fragments. UF Filtrate quality was excellent throughout the testing period, as indicated by turbidity, filtrate SDI and ultimately downstream RO performance.

A successful CIP protocol for the ZW1000 on this water was found to be:

- 2% citric acid with hydrochloric acid added to pH 2.1, heated to 40˚C with 5 hour contact time, followed by
- 500 mg/L NaOCL recirculation at 40˚C with 5 hour contact time

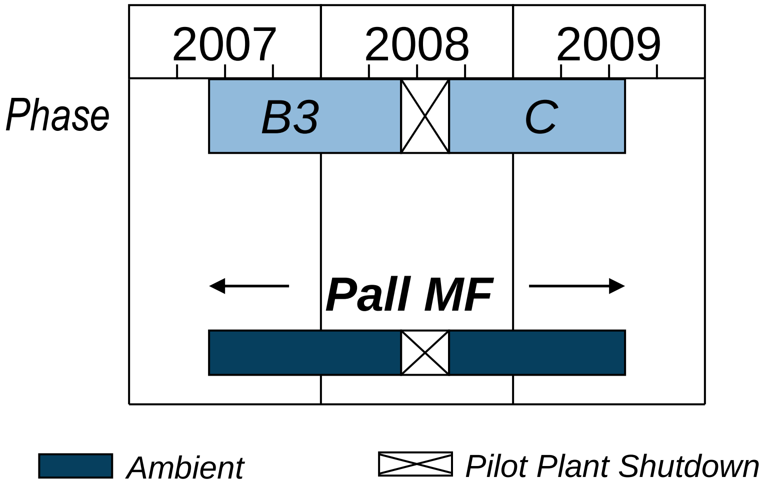
Table 6-18 Optimized Zenon ZW1000 Operating Parameters

Parameter	Value
Filtrate Flux (gfd)	27.5
Filtration time between backwashes (min)	22
Recovery	93%
Backwash Parameters	
Air scour Rate (SCFM/module)	3
Air scour Duration (seconds)	30
Backpulse Rate (gpm/module)	8.7
Backpulse Duration (seconds)	30
Refill Duration (seconds)	~50
Backwash chlorination (mg/L)	2
Maintenance Clean Frequency	1/day
Maintenance Clean Chlorination (mg/L)	100
Maintenance Clean Duration (min)	30

6.4 Pall Microfiltration System

The Pall Microza Microfiltration system was operated from 2007 to 2009, on ambient intake water only per the schedule shown in Figure 6-32.

Figure 6-32 Testing Summary Graphic of Pall Microfiltration



6.4.1 Operations / Optimization Phase B-3 (June 07 – April 08)

The following table summarizes the Pall MF unit run conditions for Phase B-3.

Table 6-19 Pall Microza MF Operating Conditions

Run #	Dates	Filtrate Flow (gpm)	Flux (GFD)	Backwash chlorination (mg/l)	Backwash Frequency (min)	Comments
MF-0	6/4/07 to 7/10/07	30	40	No chlorine in backwash	~15	Break-in period. Stable performance for 30 days
MF-1	7/11/07 to 8/21/07	33, 36	44, 48	No chlorine in backwash	~20	Stable performance for 30 days
MF-2	8/22/07 to 8/31/07	30, 33	40, 44	No chlorine in backwash	~20	Short Run with NO XR and NO RF
MF-3	9/5/07 to 11/1/07	35, 37	47, 50	No chlorine in backwash	~15	XR and RF re-instated, stable performance under these conditions
MF-4	11/2/07 to 12/1/07	37	50	No chlorine in backwash	~15	Stable performance for 30 days

Run #	Dates	Filtrate Flow (gpm)	Flux (GFD)	Backwash chlorination (mg/l)	Backwash Frequency (min)	Comments
MF-5	12/6/07 to 2/22/08	20, 41	26, 55	No chlorine in backwash	~15-20	Mechanical problems required period of operation at conservative flux with no EFM
MF-6	2/23/08 to 4/2/08	37	50	No chlorine in backwash	~15	Stable run with EFM extended to every other day

The Pall system was started up in May 2007 with one old module that was installed simply to commission the system. On June 4th two new modules were installed and the system began operation. The unit achieved a run time of 36 days for this initial break-in run. The flux rate was maintained at 40 GFD for this run.

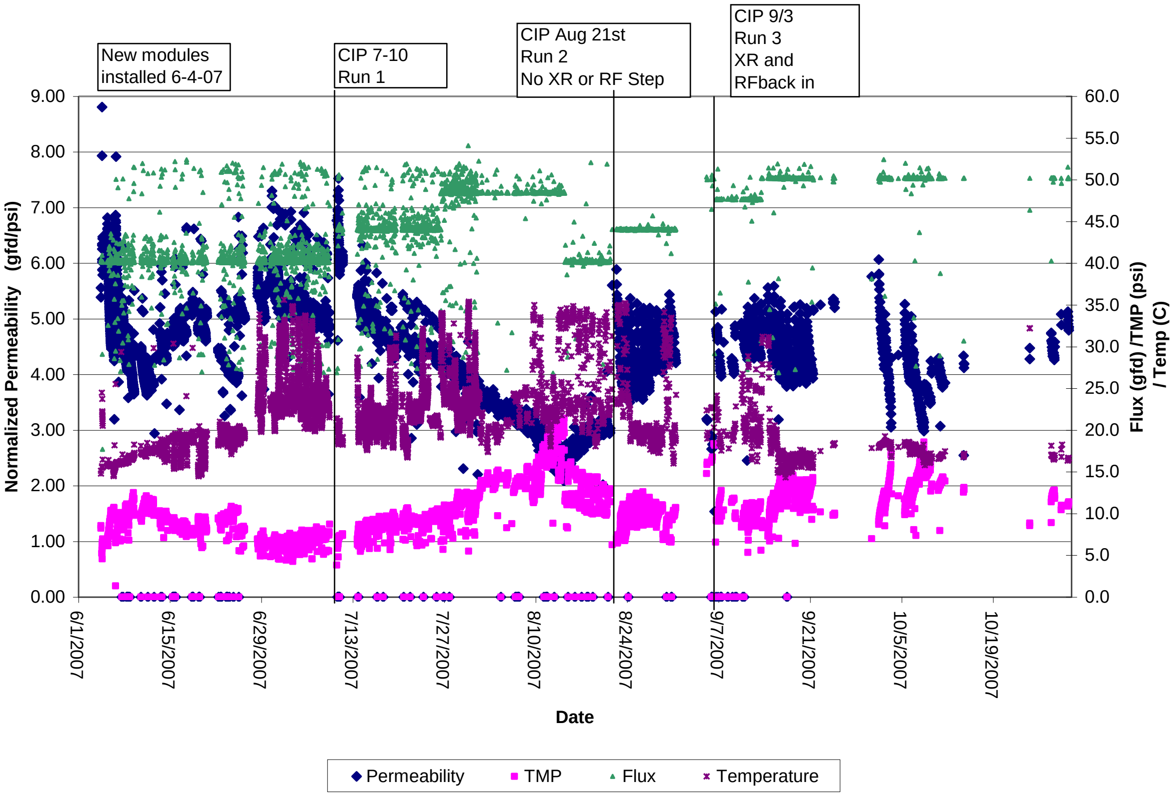
A CIP was performed on July 10th, and the unit was started back up at flux rate of 44 GFD for the beginning of Run 1. After approximately two weeks of run time at an acceptable flux rate decline, the flux was increased to 48.5 GFD on July 26th. The unit continued to run at this flux rate for 19 days with a steady increase in TMP as shown in Figures 1 and 2 below. On August 14th the flux was reduced to 40 GFD in order to maintain run time without reaching terminal TMP before a CIP could be scheduled. The unit ran quite well over the next week, actually improving in permeability at the reduced flux, until a CIP was implemented on August 21st.

Run 2 started with different operating conditions than Run 1, namely with no XR (excess recirculation) or RF (reverse flush) step, at 44 GFD. This mode of operation was only used for approximately 2 weeks before stopping. It was decided that is was more beneficial to test a higher flux rate than to remove operating steps at this time. Thus, another CIP was performed on September 3rd, and the unit was put back in operation with the XR and RF steps in place. The flux was 48.5 GFD for the first 8 days of run 3, and then the flux was increased to 50 GFD.

The standard CIP procedure consisted of a high pH 1% NaOH + 1000ppm NaOCl solution soak for 2 hours followed by a low pH 2% citric acid solution soak for 1 hour, both heated to 40ºC.

Figure 6-33 shows the performance for Runs 1-3.

Figure 6-33 Pall Microfiltration Performance June to October 2007



Run 4 started on November 2nd, and over the course of the next two weeks the permeability dropped. It was discovered on Nov 15th that the heater for the EFMs had tripped, so this most likely had an effect on permeability and caused an increase in TMP. After the heater was fixed, the system ran until the end of November at varying flux rates between 40-50 GFD to try to maintain run time until the next scheduled CIP in early December.

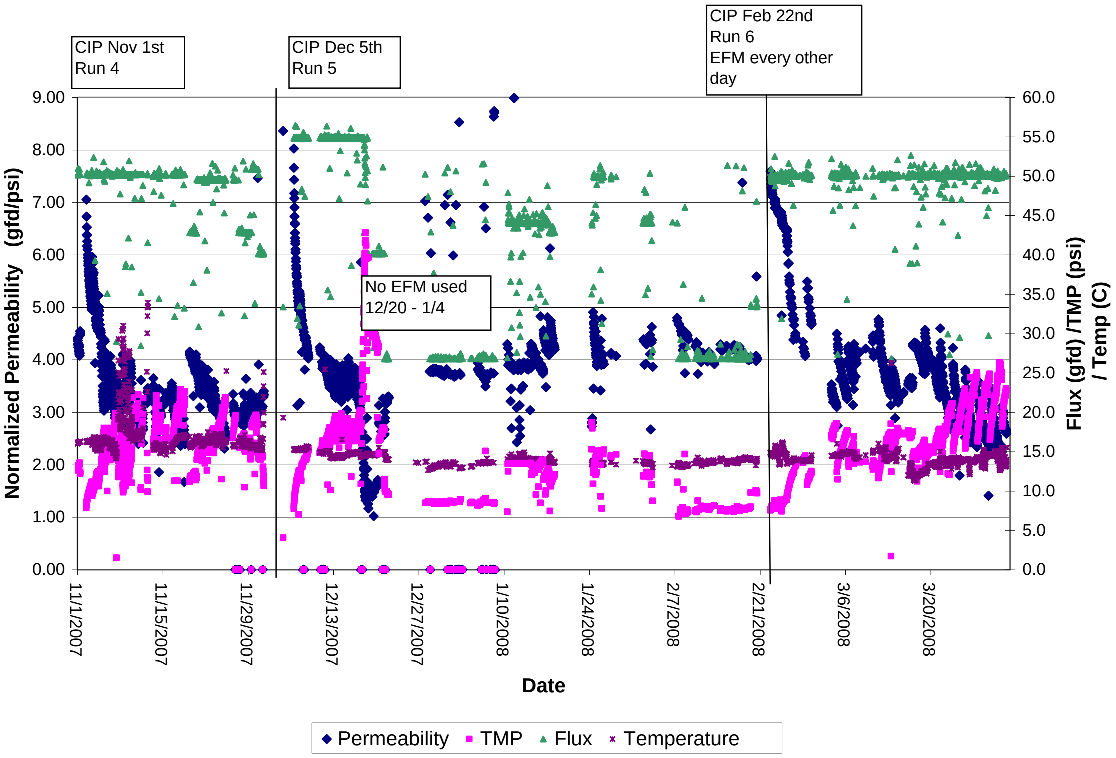
Run 5 started on December 6th following a standard CIP. The flux was raised to 55 GFD for the start of this run, and the rate of flux decline was acceptable for the first 11 days of run time. On December 17th, the unit failed to initiate the daily EFM and terminal TMP was reached. This scenario was not confirmed until December 20th, at which time the EFM cycle was removed from the programming sequence and the flux was reduced to 27 GFD in order to maintain feedwater to the RO units. The unit ran from Dec 20th to Jan 4th with no EFM cycle at this reduced flux of 27 GFD with the exception of 4 days of downtime due to a problem with the unit's air compressor. The TMP remained very stable during this time period of reduced flux and no EFMs. The unit was operated only intermittently for the rest of January due to software problems, mechanical issues, as well as shutdowns by the power plant due to their maintenance schedule. On February 7th the unit was started back up at the reduced flux of 27 GFD with no

EFM cycle. The system showed stable performance with virtually flat TMP over the course of the next two weeks, until the software problem was resolved and a standard CIP was initiated in order to start a new run under normal operating conditions.

Run 6 started on February 22nd 2008 at 50 GFD, with heated EFMs being performed every other day as opposed to every day in previous runs. By extending the operating time between EFMs, operating costs associated with chemicals and the energy to heat the EFM water are reduced. The system ran quite well with very little down time during this run. The only downtime was associated with the cold water feed pump losing suction due to clogging of the basket strainer.

Figure 6-34 shows the MF performance for Runs 4-6.

Figure 6-34 Pall Microfiltration Performance November 2007 - March 2008



Run 7 started on April 2nd at 50 GFD, with heated EFMs being performed every other day (as was done in Run 6) and also with the excess recirculation mode (XR) disabled. By eliminating the XR mode, additional energy savings can be realized by not pumping the additional 10% of the flow across the membrane surface. However, in some instances, the elimination of XR may lead to increased fouling and higher TMP, which can offset the energy savings realized by eliminating the XR.

The system ran well for the first week, with a gradual increase in TMP occurring over the two day period, and then dropping after the scheduled EFM. The system experienced a computer malfunction on April 10th, and a Pall technician came to the site on the 11th to restart the system. When the system was restarted, an incorrect flow setpoint was entered, and the system operated at a reduced flux of 44 GFD for four days until the correct flow setpoint was re-entered on the 15th. When the system was restarted at 50 GFD the TMP climbed rapidly, and the system reached terminal TMP of 40 psi on April 16th. A manual heated EFM was initiated after the system reached terminal TMP, and the TMP dropped to 13 psi. The system was put back into normal operation after the manual EFM. The system operated as expected for the next four days with a steady increase in TMP over that time, but on April 20th the heater for the EFM water failed, and a non-heated EFM was performed, resulting in virtually no reduction in TMP after the EFM (31 psi reduced to 29 psi TMP after the EFM). The system reached terminal TMP 24 hours later on April 21st. After discovering the heater electrical outlet had failed, the outlet used for the heater was switched and a manual EFM was initiated. This heated EFM was successful in reducing the TMP from 40 psi to 28 psi. In an effort to maintain runtime until a full CIP could be performed, the setpoints on the system were changed to a more conservative mode of operation. EFMs were initiated on a daily basis as had been done in all but one of the previous runs, and the flux was reduced to 37.5 GFD. Over the course of the next week, the permeability actually started to increase and the TMP decreased, indicating that this conservative mode of operation was a bit too conservative, and the system most likely could have continued to operate at a higher flux with just the daily EFMs being utilized. The system was shut down on April 30th for a full standard CIP.

Run 8 started on May 1st at 50 GFD, with heated EFMs reinstated every day and XR reinstated as well. The system experienced a rapid rise in TMP upon startup, and after only 4 days of run time reached terminal TMP. Since performing a full CIP every several days is quite impractical on a full scale system, a manual EFM was initiated on May 5th in an attempt to restore performance. This EFM produced only moderate results, and the next day terminal TMP was reached again. A manual EFM was initiated again on May 6th, but with additional chlorine added to the EFM solution to bring the concentration up to approximately 1250 mg/l. This EFM was more successful in cleaning the membranes, and the operation remained stable for the next week, although steep inclines in the TMP occurred daily. The TMP climbed higher during May 13 -15th, coming close to terminal TMP but stopping just short at 38 psi. The TMP dropped over the course of the next couple of days until the system was shut down on May 17th, due to the scheduled construction at the site in June and July.

Figure 6-35 shows this performance.

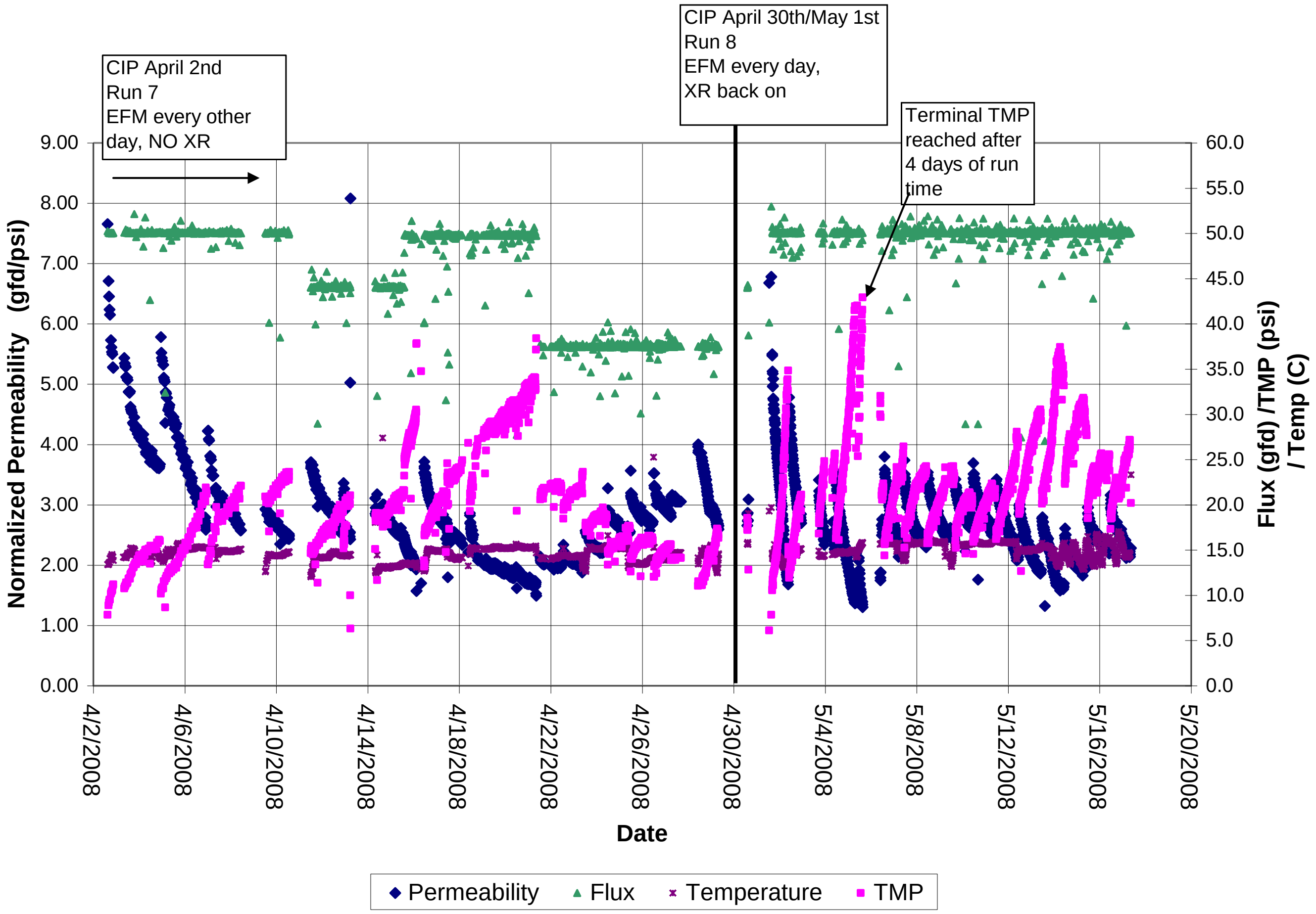


Figure 6-35 Pall Microfiltration Performance April - May 2008

6.4.2 Operations / Optimization Phase C (Sept. 08 – June 09)

Phase C operation began in September 2008 and entailed operating two Pall MF units in parallel, each being fed with a different prescreening unit, as described in Section 3. Pall 1 was fed seawater filtered through a 100 micron Arkal disc filter and Pall 2 was fed seawater filtered through a high-rate granular media filter.

Table 6-20 summarizes the various runs and their operating conditions in Phase C.

Table 6-20 Pall Microza MF Units 1 and 2 Operating Conditions Phase C

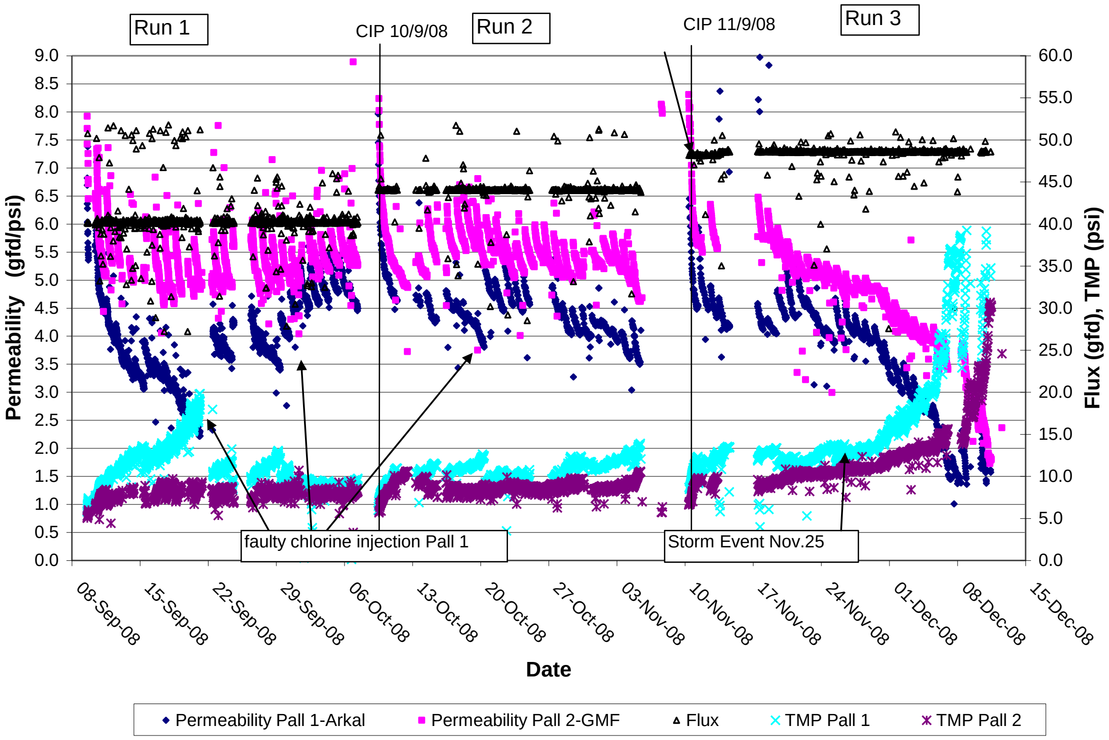
Run #	# of Days	Flux Rate (GFD)	Backwash Frequency (minutes)	EFM Details
1 (9/9/08-10/7/08)	28	40	20	Daily, 500 mg/l Sodium Hypochlorite, Heated to 35° C
2 (10/9/08-11/5/08)	27	44	20	Daily, 500 mg/l Sodium Hypochlorite, Heated to 35° C
3 (11/10/0/-12/11/08)	31	48.5	20	Daily, 500 mg/l Sodium Hypochlorite, Heated to 35° C
4 (12/16/08-1/20/09)	35	52-37	20	Daily, 500 mg/l Sodium Hypochlorite, Heated to 35° C
5 (1/22/09-2/24/09)	33	55	20	Daily, 500 mg/l Sodium Hypochlorite, Heated to 35° C
6 (2/25/09-3/24/09)	27	65	20	Daily, 350 mg/l Sodium Hypochlorite, Heated to 35° C
7 (3/26/09-4/26/09)	30	70	20	Daily, 350 mg/l Sodium Hypochlorite, Heated to 35° C
8 (4/29/09-5/28/09)	31	54	20	Daily, 350 mg/l Sodium Hypochlorite, Heated to 35° C
9 (6/1/09-6/26/09)	26	70	20	Daily, 350 mg/l Sodium Hypochlorite, Heated to 35° C

Figure 6-36 shows the performance of Pall 1 and Pall 2 for the period of September 08 through December 08. Pall 1 experienced a drop in permeability upon startup where Pall 2 maintained permeability. It was discovered that the chlorine dosing pump that doses chlorine into the EFM water was faulty on Pall 1, and when this was remedied in late October the performance improved. The pump experienced periodic upsets in Run 2 as well and is scheduled for rebuild.

The TMP for both units remained quite low during Runs 1 and 2, except for the equipment malfunction mentioned above. Pall 2, being fed with slightly less turbid water, has a slightly average lower TMP of about 2 psi than Pall 1 during Runs 1 and 2.

Run 3 started on November 10, and the TMP for both Pall 1 and 2 remained quite flat for the first 3 weeks of the run. On November 25th there was a storm event in the Los Angeles area resulting in over 0.5” of rain in 24 hours at Los Angeles International Airport. Several days after the storm event an increase in biomass was noticed in the feedwater and around December 1st the TMP of both Pall 1 and 2 started to increase. Over the course of the next week, Pall 1 TMP increased more rapidly than Pall 2, suggesting that the GMF unit ahead of Pall 2 was removing more of the biomass from the feedwater resulting in less fouling of Pall 2. Pall 1 reached terminal TMP on December 8th and again on December 10th, while Pall 2 did not reach terminal TMP during this time. The largest TMP reached by Pall 2 during this time was 30 psi on December 12th, after which both units were shut down on to perform a CIP. The standard CIP performed following Run 3 was successful in restoring permeability to both units.

Figure 6-36 Pall Microfiltration Performance September – December 2008



As seen in Figure 6-37, Run 4 started in mid December and ran 35 days until January 20th, although run time was sporadic due to the clogging of the basket strainers in the forebay. The flowrate through Pall 1 and 2 was decreased in early January from 52 to 37 GFD in an effort to alleviate the basket strainer problem and improve run time, not because of high TMP requiring a decrease in flux rate. This was effective in maintaining run time and there was very little rise in TMP at this decreased flux rate. There was a drop in Pall 2 permeability at the end of Run 4 which was most likely caused by a malfunction in the EFM process, such as the chlorine dosing pump losing prime.

Run 5 has very little run time for Pall 2, as the unit was down awaiting replacement of the touch screen computer controller. Pall 1 performed well during Run 5, with a flux rate of 55 GFD and little rise in TMP over the course of the run

Figure 6-37 Pall Microfiltration Performance December 2008 – March 2009

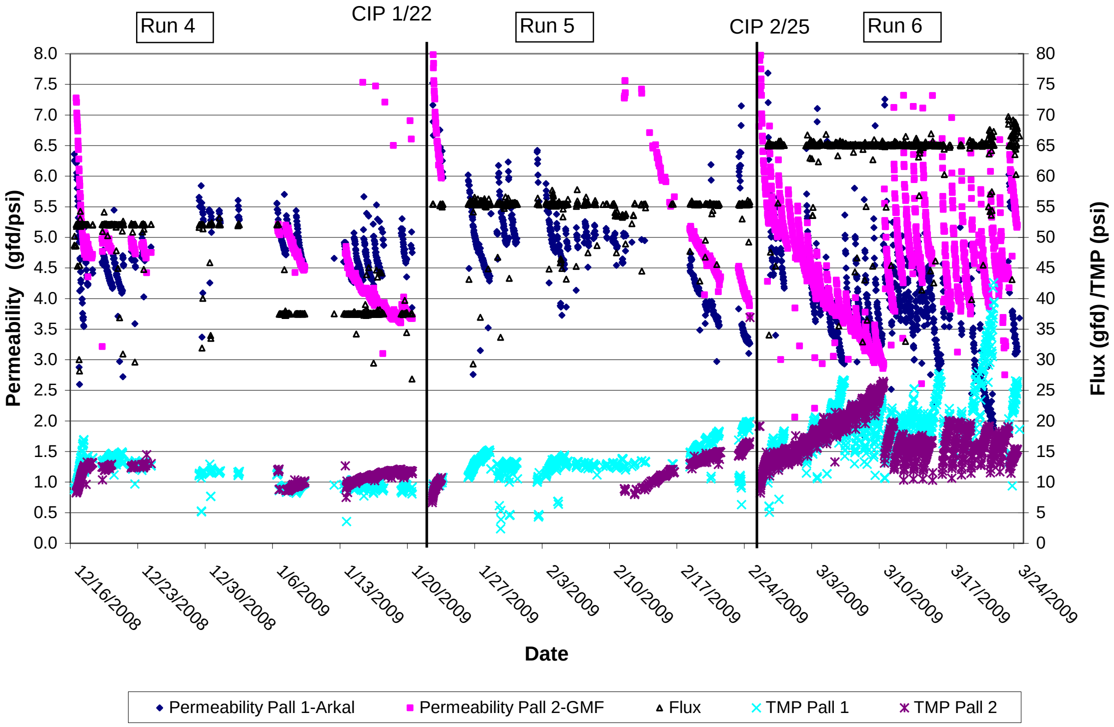


Figure 6-38 shows the detailed performance of Run 6 which occurred from February 25th to March 24th 2009. Noteworthy during this run was the importance of the use of fresh chlorine at the pilot site for the EFM sequences. In early March fresh chlorine obtained from the main WB Recycling Facility chlorine storage unit was brought to the pilot site in 5 gallon containers to restock the supply at the site. The chlorine tank for Pall 1 was refilled on March 7th with the fresh chlorine and noticeable difference in EFM effectiveness was seen. The chlorine tank for Pall 2 was refilled with fresh chlorine on March 10th, and again a noticeable difference in EFM effectiveness was observed. This is outlined in Figure 6-36. This shows the importance of using fresh, potent chlorine in the EFM process. The EFMs were very effective for the remainder of the run using the fresh chlorine. It became part of the standard procedure to obtain fresh chlorine from the WBRF to replenish the stock at the pilot site, rather than ordering many small containers of chlorine and allow them to sit for many weeks before being used. One other noteworthy aspect of Run 6 is regarding the performance of Pall 1 toward the end of the run. In mid March the level transmitter on Pall 1 feed tank began to lose calibration. This affected the draining of the feed tank of seawater prior to an EFM, and resulted in cold seawater still being present in the tank when the hot EFM water was added to the feed tank. The resulting EFM solution was then cooler and had a lower concentration of chlorine in it. This happened a few times toward the end of Run 6, most notably on March 15th and March 22nd as outlined in Figure 10. This shows the importance of heated EFMs Run 6 can be considered a very good run for the Pall units, as they operated at 65 GFD with an acceptable rise in TMP between EFM sequences (when operating as designed). The 30 day run time in between CIPs was easily achieved without the need for a CIP.

Figure 6-38 Detailed Operations for Run 6

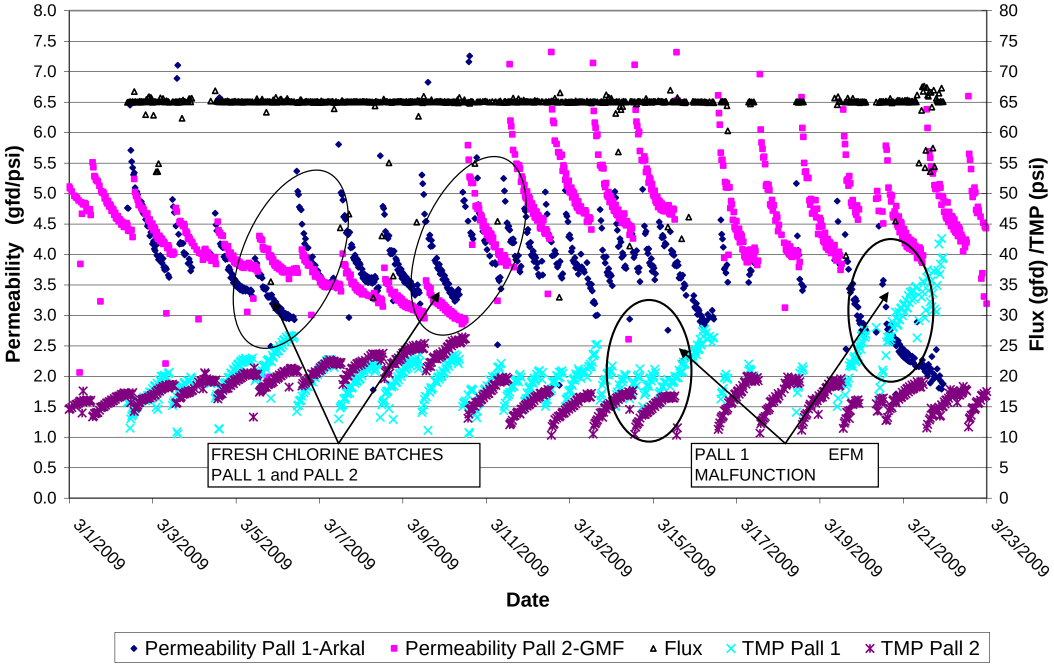


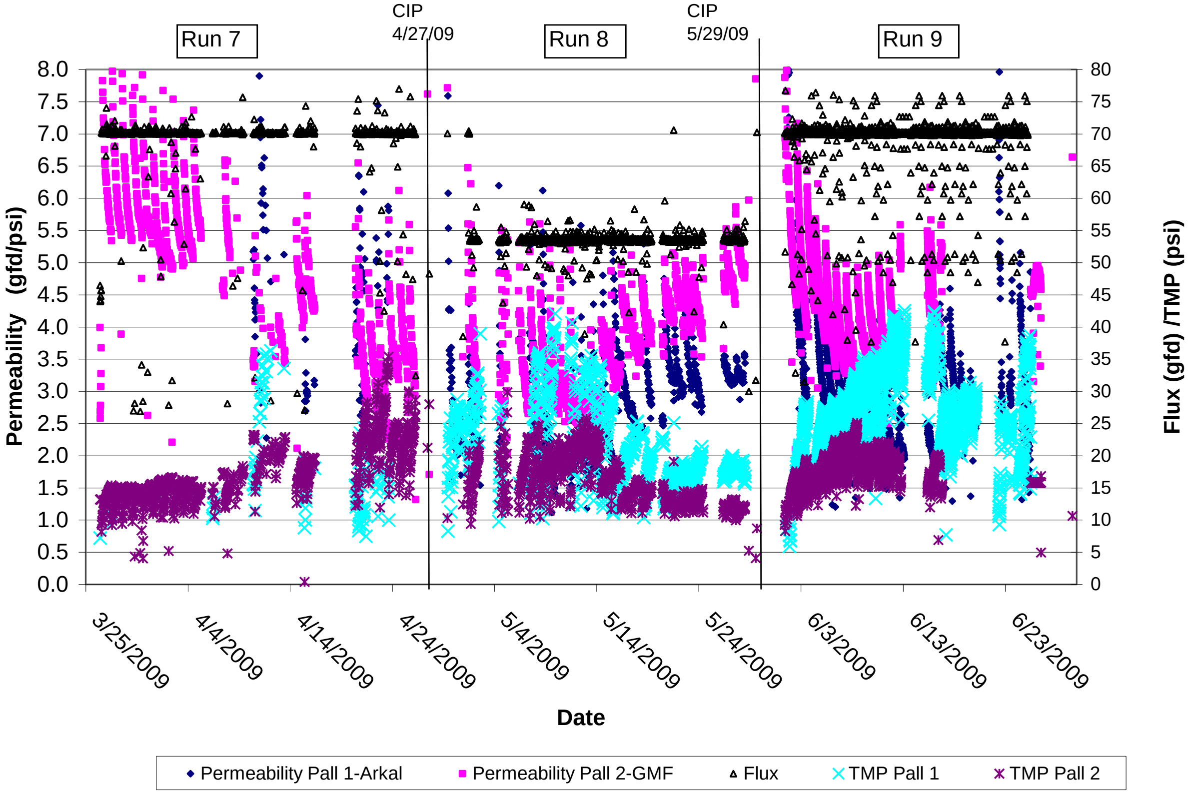
Figure 6-37 shows the performance of both MF systems from March through June 2009, which completed Phase C of testing. Run 7 started on March 26th and at a flux rate of 70 GFD. Pall 1 was offline for majority of Run 7 due to mechanical difficulties, but Pall 2 ran well for with very little increase in TMP over the course of the first three weeks. On April 21st the TMP started to climb at a faster rate over the course of a day in between EFMs. The TMP reached as high as 35 psi over the course of the next five days before the unit was shut down for a scheduled cleaning on day 30.

Prior to starting Run 8, it was evident that an algal bloom was in effect based on the rapid increase in TMP and pressure differentials of the upstream granular media filter, as well as visual observations of the source water. As such, Run 8 was started with a conservative flux rate of 53 GFD for both Pall 1 and 2. During this run a substantial difference in performance was seen between Pall 1 and 2. Even at the reduced flux, Pall 1 TMP still increased at a rapid rate, where

Pall 2 TMP increase was modest. After approximately 2 weeks of run time the TMP on each Pall unit began to decrease, likely as a result of the algal bloom subsiding. Both systems were maintained at 53 GFD for the remainder of the run until the next scheduled CIP on May 29th.

Run 9 started on June 1st with the flux set back to 70 GFD, since the algal bloom had shown signs of subsiding. Once again the Pall 1 TMP increased at a faster rate, and reached terminal TMP on June 16th. A manual EFM was initiated June 17th, but with additional chlorine added to the EFM solution to bring the concentration up to approximately 1250 mg/l. This sufficiently cleaned the membrane to allow for continued operation at 70 GFD for the remaining 9 days of run time until the testing was finished.

Figure 6-37 Pall Microfiltration Performance March 2009 – June 2009

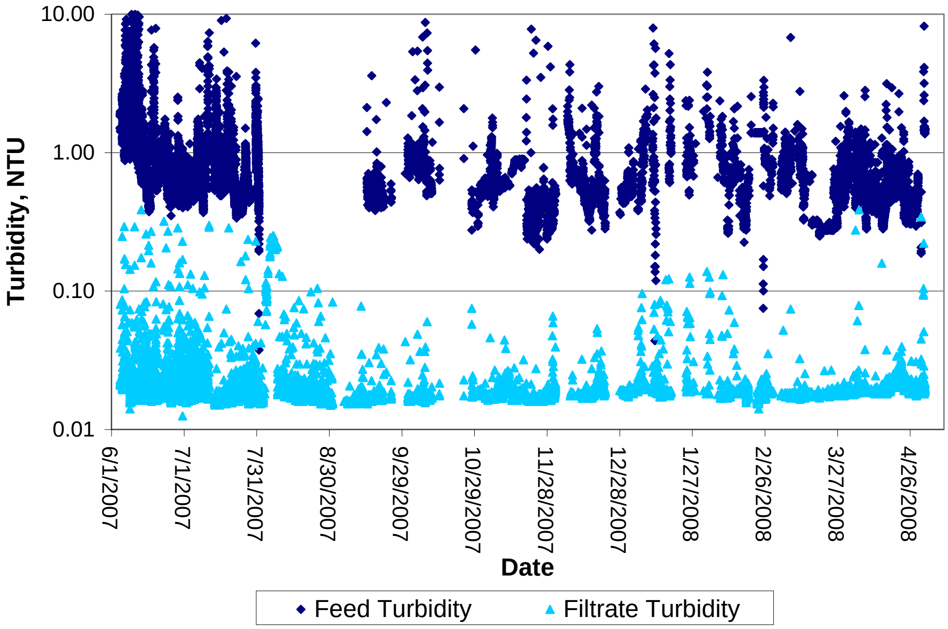


6.4.3 Filtrate Water Quality

6.4.3.1 Turbidity and SDI

Per Figure 6-38 below, the Pall unit consistently produced filtrate with turbidity less than 0.1 NTU, with typical values close to 0.02 NTU. The Pall MF modules have shown no signs of integrity breaches, indicated by Pressure Decay Test values of 0.2 psi/min that were conducted manually throughout Phase B-3.

Figure 6-38 Phase B-3 Pall MF Feed and Filtrate Turbidity



Feed and filtrate turbidity values in Phase C for both Pall 1 and Pall 2 are shown in Figures 6-39 and 6-40 The turbidimeter used to measure both feed and filtrate turbidity was handheld meter, and not the more sensitive online meter that was used to measure the filtrate in Phase B-3. The difference in feed water quality to each Pall unit as a result of different pre-screening equipment upstream is evident from Figures 69 and 70 below. This is discussed further in the Granular Media Filter performance section.

Figure 6-39 Phase C Pall-1 Feed and Filtrate Turbidity

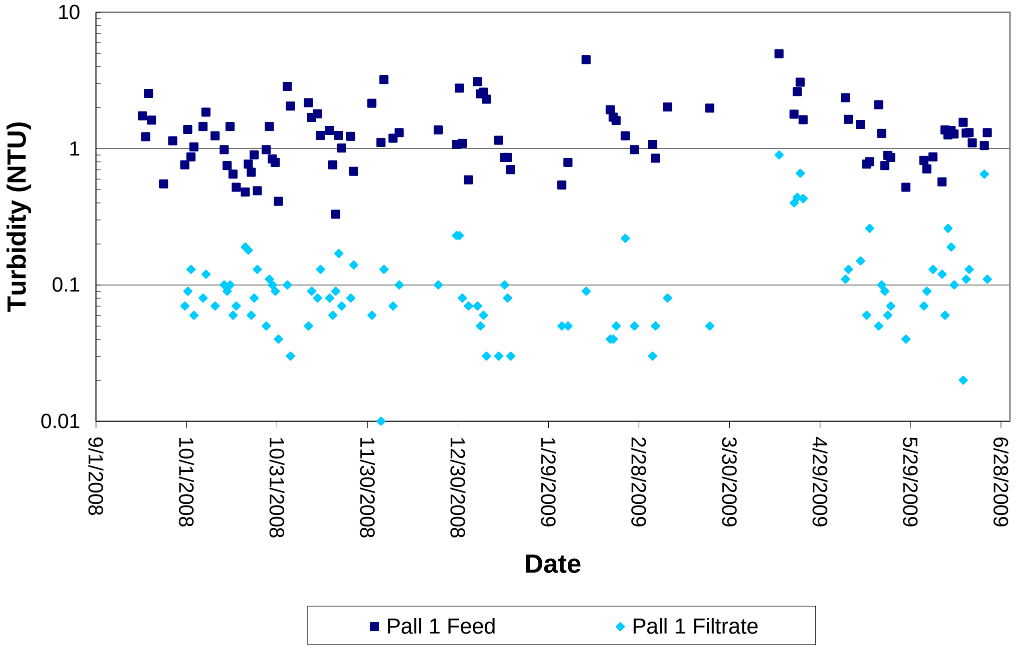
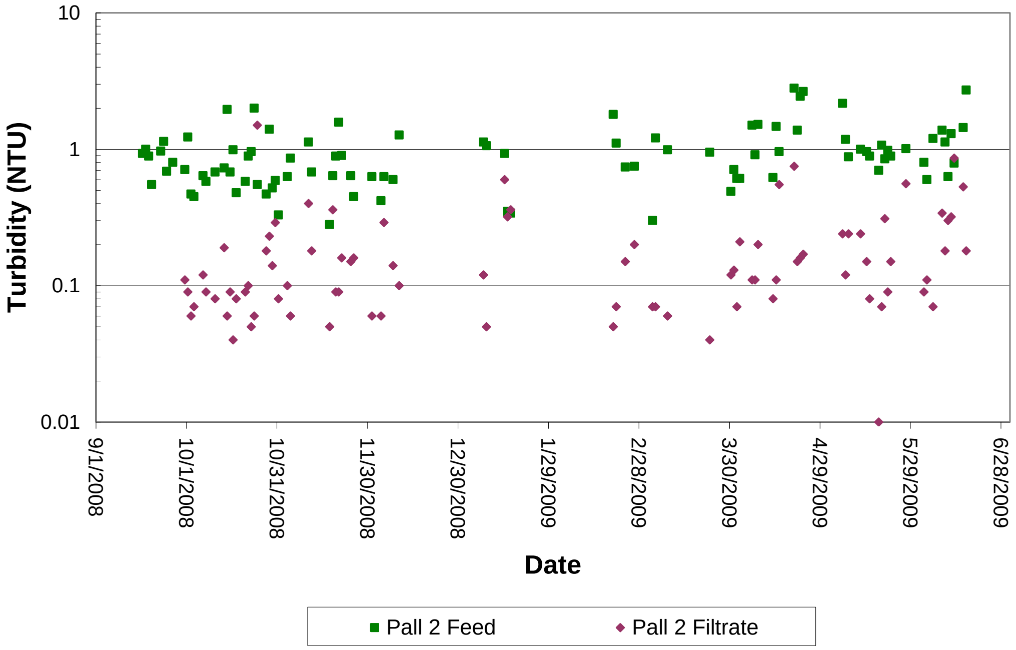
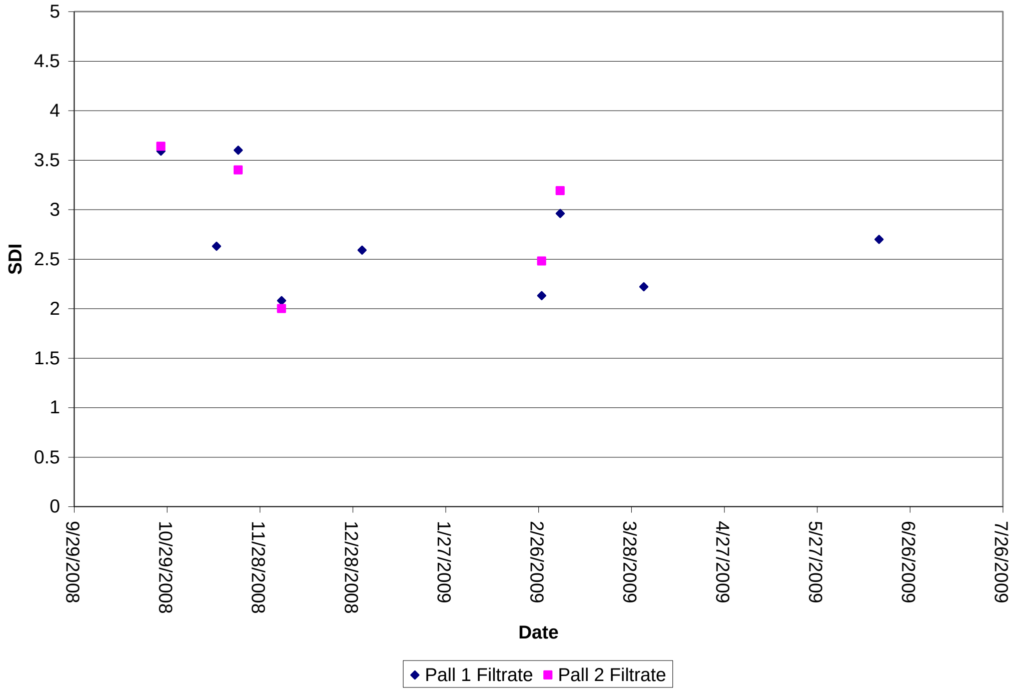


Figure 6-40 Phase C Pall-2 Feed and Filtrate Turbidity



SDI values were also measured for both Pall 1 and Pall 2 filtrate streams. Per Figure 6-41, the majority of these values were below 3 with several measurements at 3.6, indicating suitable quality to be used as feed to the RO.

Figure 6-41 Phase C Pall 1 and 2 Filtrate SDI



6.4.3.2 Laboratory Data

Tables 6-21 through 6-23 show detailed water quality of both the Pall MF feed and filtrate water quality. On average, the Pall system also demonstrated approximately 10% removal of TOC.

Table 6-21 Pall Water Quality Phase B-3

			Feed		Filtrate	
Parameter	**Units**	**DL**	**Average**	**Std Dev**	**Average**	**Std Dev**
UV 254	abs/cm	0.01	0.013	0.004	0.013	0.004
Alkalinity (as CaCO3)	mg/L	2	114	4	114	4
Calcium	mg/L	25	390	26	386	26
Magnesium	mg/L	25	1,217	84	1,219	71
Sodium	mg/L	25	10,013	718	9,756	1,664
Potassium	mg/L	25	376	24	375	21
TOC	mg/L	0.5	2.3	0.5	2.3	0.5

Table 6-22 Pall 1 Water Quality Phase C

Parameter	Units	DL	Pall 1 Feed Average	Pall 1 Feed Std Dev	Pall 1 Filtrate Average	Pall 1 Filtrate Std Dev
TOC	mg/l	0.01	0.74	0.17	0.69	0.19

Table 6-23 Pall 2 Water Quality Phase C

Parameter	Units	DL	Pall 2 Feed Average	Pall 2 Feed Std Dev	Pall 2 Filtrate Average	Pall 2 Filtrate Std Dev
TOC	mg/l	0.01	0.70	0.17	0.66	0.20

6.4.4 Pall Microza MF Summary

The Pall Microza MF system performed very well with respect to both permeability and water quality. The maximum sustainable flux rate for a 30 day cleaning frequency was 70 GFD, but a reduction in flux rate can be required during times of algal blooms. The filtrate turbidity was consistently close to 0.02 NTU, and SDI less than 3, which is considered very good quality as feed to the RO system. Membrane integrity has also remained stable with the 100 micron Arkal Disc filter as prescreening. Pressure Decay Values for the Pall module have consistently been approximately 0.2 psi/min, indicating negligible fiber breakage, if any. The use of heat and a fresh supply of chlorine is critical to effective EFMs. It was shown that the frequency of EFMs time can be extended if feedwater quality is high, thereby reducing operating costs of a full scale system.

A successful CIP protocol for the Pall Microza MF system on this water was found to be:

- High pH 1% NaOH + 1000ppm NaOCl solution soak at 40ºC for 2 hours followed by
- Low pH 2% citric acid solution soak at 40ºC for 1 hour

Table 6-24 Optimized Pall Microza MF Operating Parameters

Parameter	Value
Filtrate Flux (gfd)	70
Filtration time between backwashes (min)	20
Recovery	95%
Backwash Parameters	
Air Scour Duration(seconds)	60
Air Scour Rate (SCFM/module)	3
Air scour – Reverse Flush flowrate (gpm/module)	8
Reverse Flush Duration (seconds)	30
Reverse Flush flowrate (gpm/module)	18
Enhanced Flux Maintenance (EFM) Frequency	1/day
EFM Chlorination (mg/L)	350
Maintenance Clean Duration (min)	30

6.5 Granular Media Filtration System and Arkal Disc Filter

6.5.1 Introduction

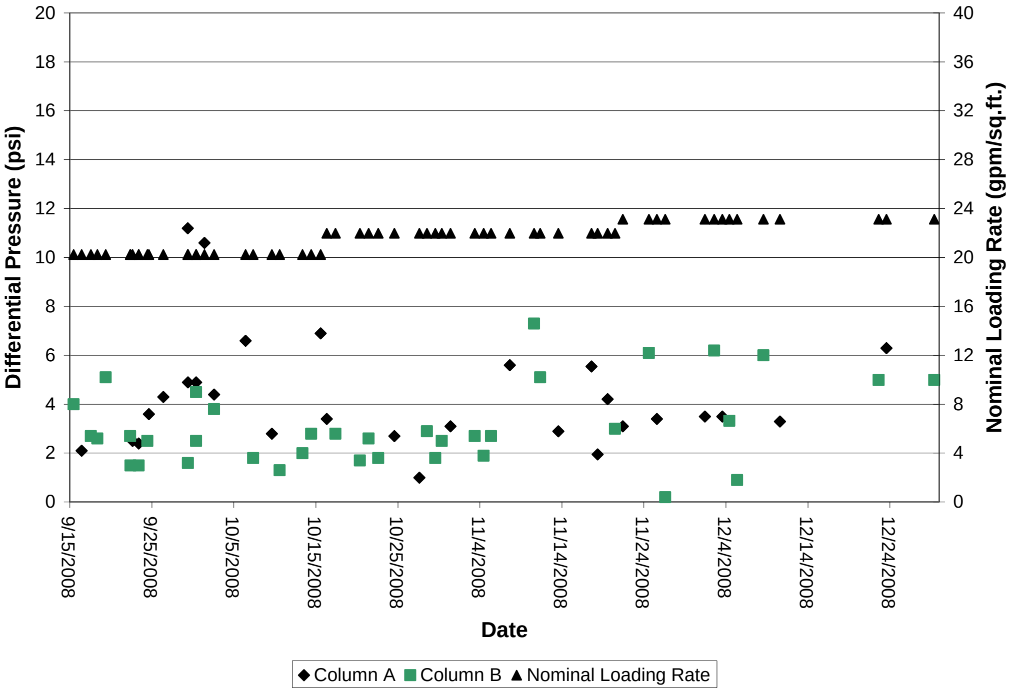
As outlined in Section 3, the goal for testing the Granular Media Filtration (GMF) system was to determine the effectiveness of a high rate Granular Media Filter (GMF) as a pre-strainer to a hollow fiber Microfiltration System, and to optimize operating conditions for the GMF. The testing included optimizing the filtration rate and backwash sequence, and a comparison of the filtered water quality and operating performance to that of the Arkal Disc Filter

To evaluate the GMF concept, two pilot trains were operated with identical microfiltration (MF) systems operating downstream of the pre-straining processes. The high rate GMF and disc filter processes were operated in parallel on the raw ocean water that was pre-screened with a 3 mm basket strainer. This configuration allowed for direct performance comparison of the GMF / MF combination in parallel with the Arkal disc filter / MF combination under identical raw feed water quality conditions.

6.5.2 GMF Operating Data

The granular media filter started up in September 2008, but the initial filter columns lacked digital pressure sensors for continuous differential pressure (DP) measurement across the filter bed. As such, manual DP recordings were performed once a day per column for the first few months of operation, and the data is shown in Figure 6-42 below. Typical DP increase ranged from 2 to 8 psi over the 48 hour run time on each filter column with a loading rate between 20 - 24 gpm/ sq. ft.

Figure 6-42 GMF Manual Differential Pressure September – December 2008



In early January 2009, online pressure sensors were installed and DP across the filter columns could then be measured continuously during the course of a 48 hour run. The rise in DP during a filter run could then be tracked more accurately, as shown in Figure 6-43. There is some scatter in the data in late January and late February caused by insufficient feed flow to the GMF (due to problems with the forebay pump). During March, the DP was routinely between 4 – 8 psi at a loading rate of 24 gpm/sq. ft.

Figure 6-43 GMF Differential Pressure January – March 2009

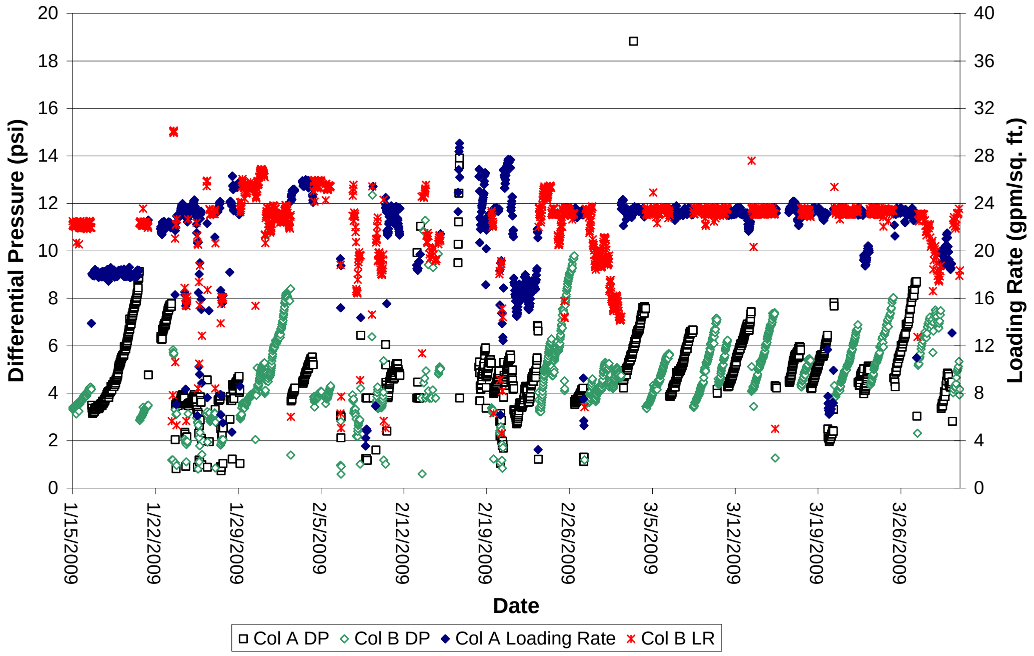
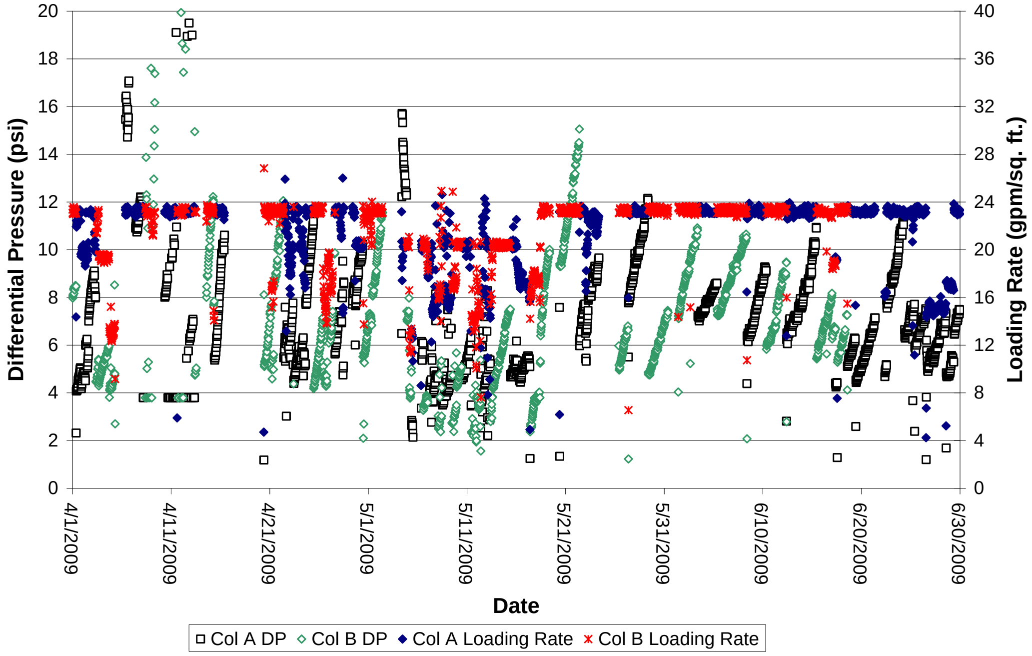


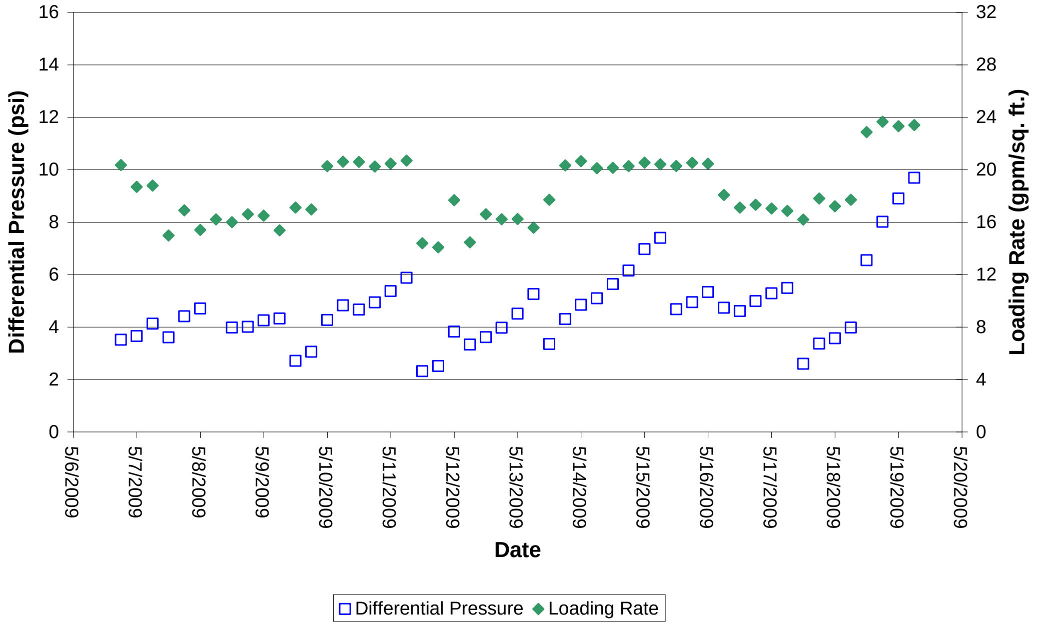
Figure 6-44 shows the GMF performance from April through the end of the study in June 2009. In late April an algal bloom developed, and the DP across the filter columns increased to 12 psi due to an increased solids loading attributed to the increase in biomass. This differential pressure was considered excessive for terminal headloss and needed to be balanced against filter bed runtime, filtrate quality, and backwash frequency. Therefore, in mid May, a trial was conducted to incrementally test decreased of 16 gpm/sf and 20 gpm/sf and monitor the DP during the algal bloom. These summary results are shown in Figure 6-45.

Figure 6-44 GMF Differential Pressure April – June 2009



At the lower loading rates the DP across the filter bed is significantly reduced, showing this is a viable operating strategy during times of algal blooms. After the algal bloom subsided, the loading rate was returned to the original value of 24 gpm/sq. ft. The starting DP values did not come back to the low starting value of 4 psi as seen in March, but the overall increase in DP over the course of a 48 hour run was still acceptable.

Figure 6-45 GMF Differential Pressure at Varying Loading Rates During Algal Bloom



Figures 6-46 and 6-47 show turbidity of the raw feed and GMF filtrate throughout Phase C of the study. The average turbidity of the GMF filtrate was approximately 0.3 NTU. In February and April the turbidity of the GMF filtrate exceeded 1 NTU during times of elevated raw water turbidity.

Figure 6-46 GMF Feed and Filtrate Turbidity January – March 2009

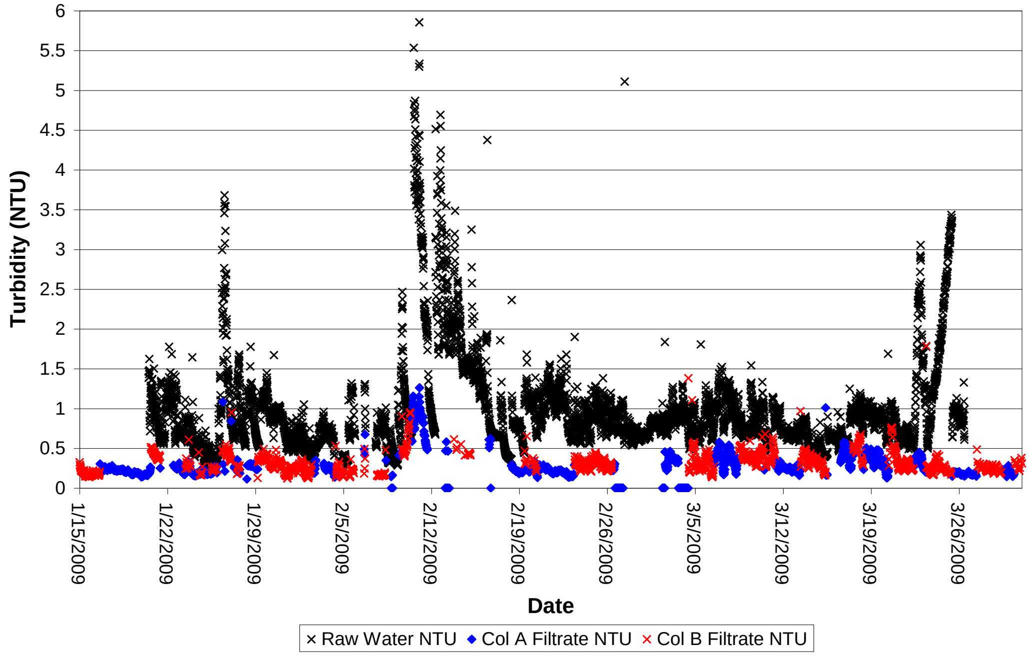
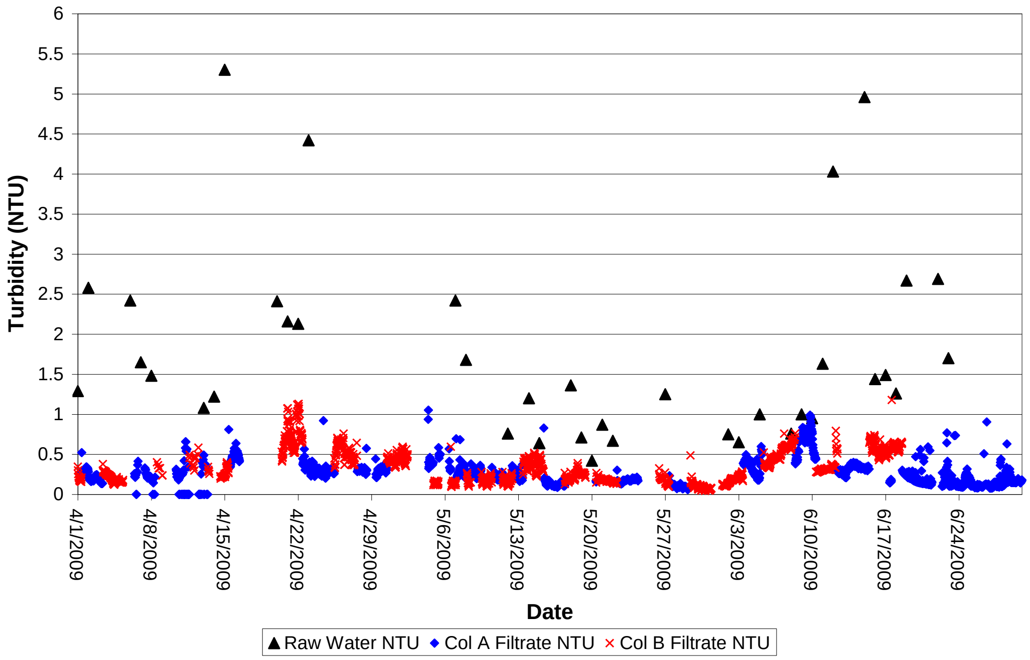


Figure 6-47 GMF Feed and Filtrate Turbidity April – June 2009



6.5.3 Arkal Operating Data

As mentioned in Section 3, the 100 micron Arkal Disc Filter system was upgraded to use a liquid backwash for Phase C. Figure 6-48 shows the operating performance from September 2008 through June 2009. The differential pressure across the filter was monitored while the cycle time between backwashes was increased incrementally. The differential pressure across the Arkal system stayed below 5 psi with increasing cycle times until December 2008 when it exceeded 10 psi. The differential pressure decreased in late January and remained below 5 psi through April at extended cycle times up to 80 minutes, but at lower filtration rates.

Figure 6-48 Arkal Performance

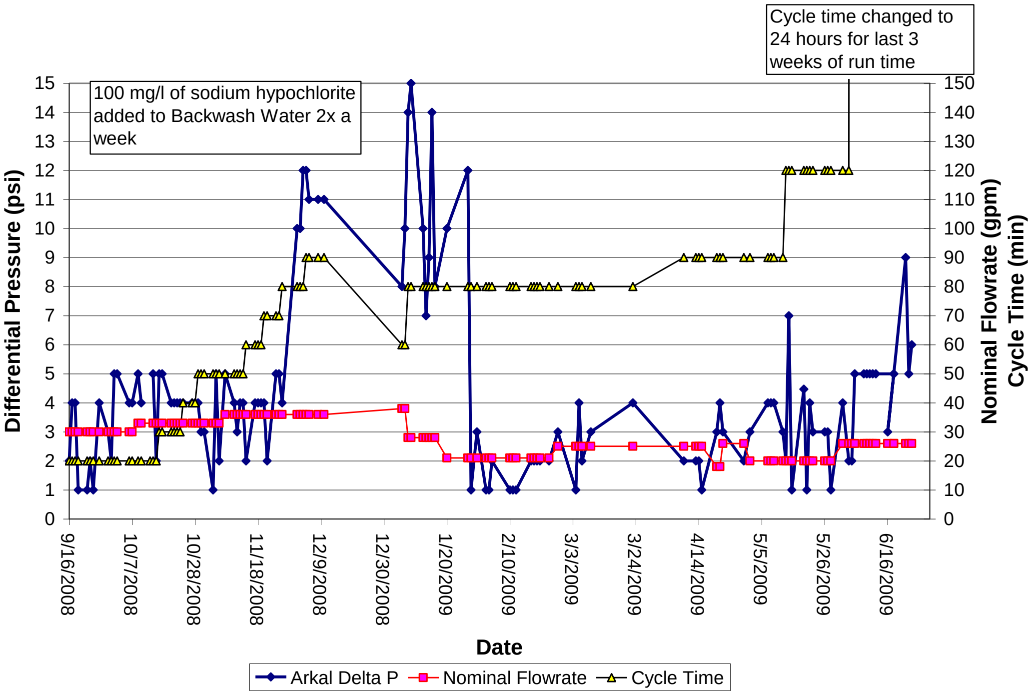
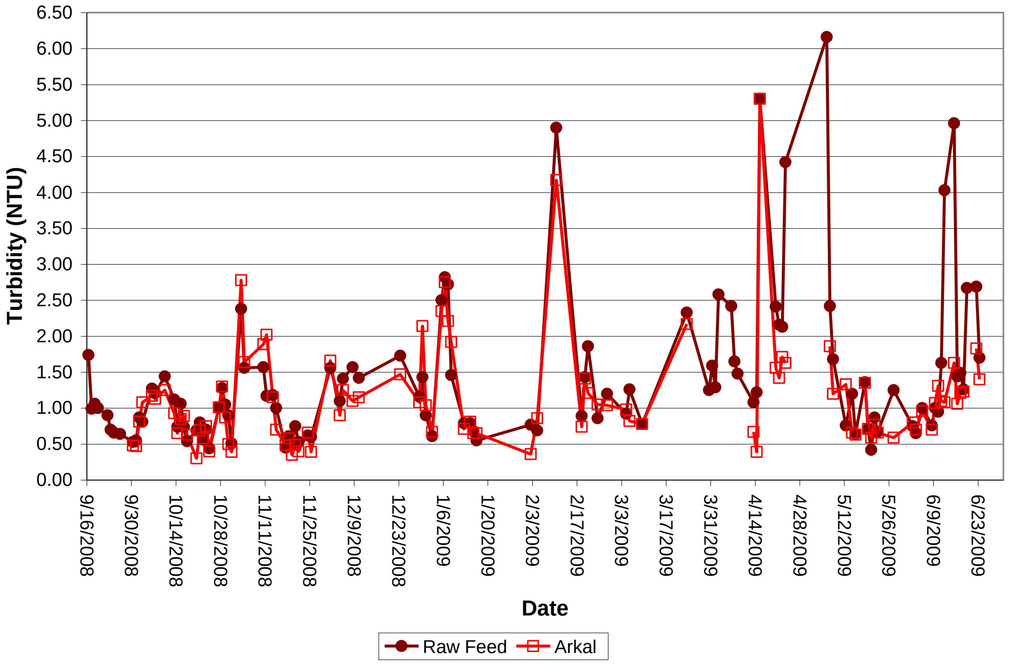


Figure 6-49 below shows the turbidity of both the raw water and Arkal filtrate for Phase C. The raw feed and Arkal filtrate turbidity values are very similar over the entire period, indicating that the 100 micron disc filter does very little to reduce turbidity.

Figure 6-49 Raw Feed and Arkal Filtrate Turbidity



In previous phases of testing the Arkal filter was not equipped with a liquid backwash and periodic dosing of chlorine was not used. During these periods the discs experienced biofouling and had to be routinely removed and soaked in chlorine. Figure 80 below is a photograph of such biofouling that occurred in May 2006. In addition to growth on the discs, mussels, barnacles and other shells grew inside the disc filter housings and had to be periodically removed by hand. Figure 6-50 shows shells that were removed from the disc housing in August 2006. It is noteworthy that during Phase C the discs remained free of biofouling and shell growth and did not have to be removed for chlorine soaking at all. The use of liquid backwashing with periodic chlorine addition to the backwash water was beneficial in this respect.

Figure 6-50 Photo of Arkal Disc Filter Biofouling

Figure 6-51 Photo of Shells Removed from Arkal Disc Filter Housing

6.5.4 Comparison of downstream performance of MF systems

The performance of the downstream Pall microfiltration systems was used as a major indicator of the water quality produced by both the GMF and Arkal pre-strainers. The two Pall systems were operated under identical conditions, with Pall 1 being fed the filtrate from the disc filter and Pall 2 being fed the filtrate from the GMF. Any difference in the transmembrane pressure (TMP) of the Pall systems indicates a difference in the feedwater quality to each Pall system. A less dramatic rise in TMP over the course of a run corresponds to a higher quality feedwater.

The following data gives an indication of the varying raw water quality throughout the testing period and how both MF systems behave during typical periods and challenging periods, such as during a storm event or algal bloom. For each specific period, data for MF performance is shown followed by corresponding data on water quality produced by the upstream GMF and disc filter systems.

Figure 6-51 shows the performance of both MF systems during a two-week period from October 10th – 24th, 2008 immediately following a membrane cleaning. The operating flux for each of the MF systems was constant at 44 GFD. The TMP for both systems was similar during this period with either identical values or a slightly higher TMP (e.g. 2 or 3 psi) for Pall 1. This performance can be considered normal operation, as the feedwater quality was not impaired during this time.

Figure 6-51 Pall 1 and 2 TMP During Normal Operation

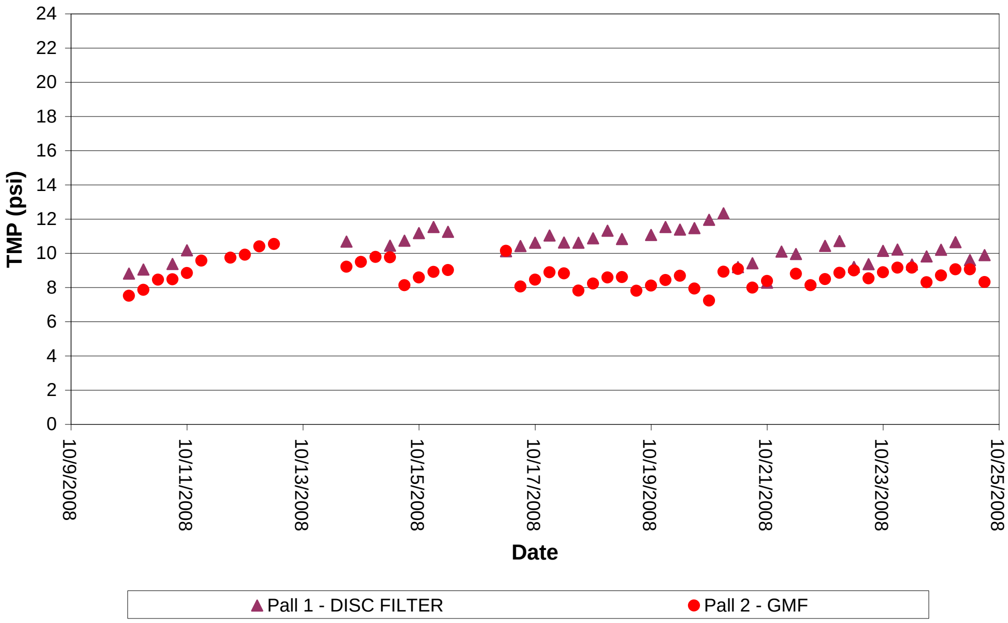


Figure 6-52 shows the raw seawater turbidity as well as the filtrate turbidity from both the GMF and Arkal disc filter systems over the same time period shown in Figure 5. Feedwater turbidity ranged from 0.5 – 1.5 NTU and biological activity was minimal in this timeframe, representing a period of good feedwater quality. The disc filter system filtrate generally followed the same trend as the raw water values with little turbidity removal (e.g. 0.1 NTU), if at all. The GMF system filtrate on the other hand was consistently around 0.3 NTU. This data indicates that a major portion of the particulate matter contributing to the raw water turbidity was less than 100 micron but greater than the 20-30 micron filtering ability of the GMF.

Figure 6-52 Turbidity During Normal Operation

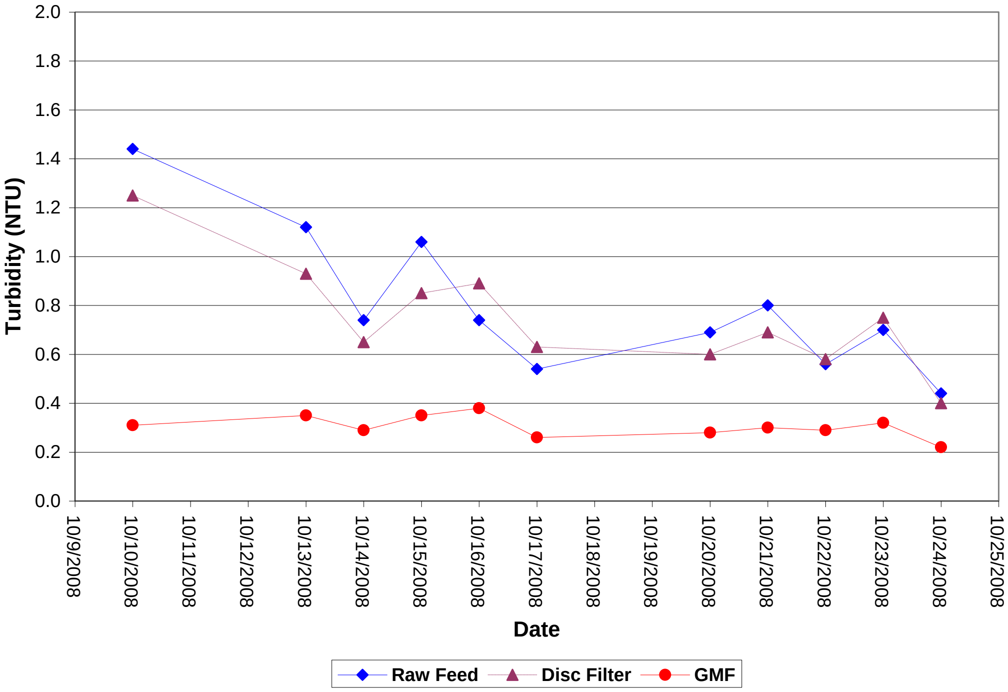


Figure 6-53 shows the performance of both MF systems at constant flux rate of 48 GFD from November 10th to December 14th 2008 where a storm event occurred halfway through the run. On November 25th (day 15) a significant rain storm occurred in the Los Angeles area which resulted in what is believed to be a significant amount of urban runoff into the waters in close proximity to the pilot equipment. These storm events produce runoff that provides nutrients that can result in an algal bloom and generally increases the potential for biological activity in the seawater. This is evident in Figure 84, where in the two-week period following the rain event the TMP on both microfiltration systems increased steadily. However, the Pall 1 – Disc Filter TMP rose more rapidly than the Pall 2 – GMF TMP, and reached a terminal TMP of 40 psi on December 8th that requires the unit to be shutdown for a cleaning. The Pall 2 – GMF system ran for 3 more days and reached a TMP of 30 psi before both units were shut down for a cleaning. Although the Pall 2 – GMF system did not ever reach the terminal TMP of 40 psi, the project team estimates that this unit had another 3 days of run time available prior to reaching terminal TMP.

Figure 6-53 Pall 1 and 2 TMP During Storm Event

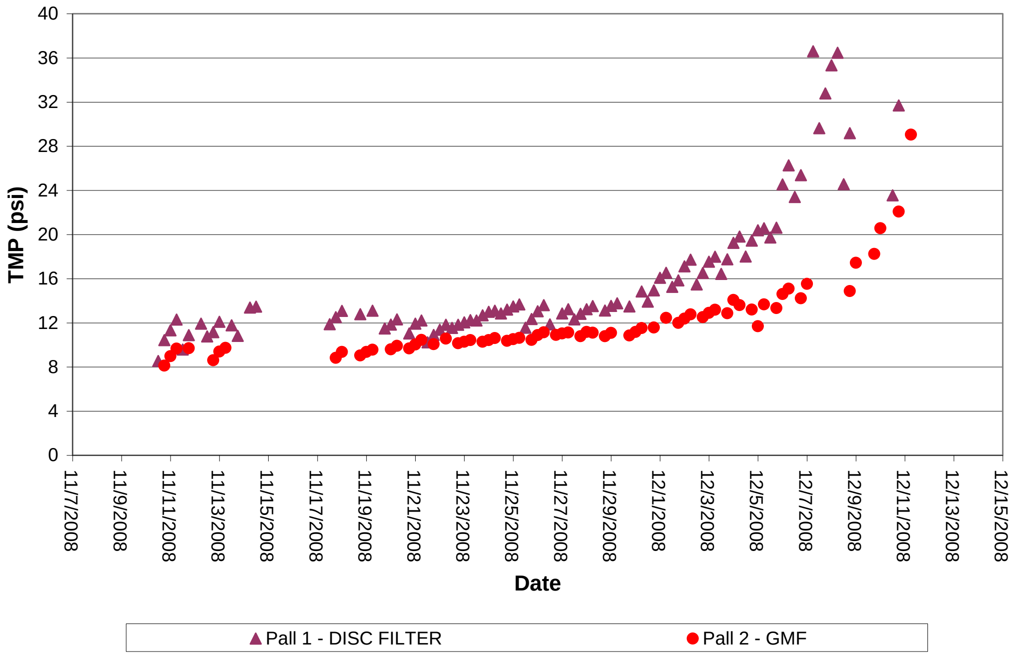


Figure 6-54 shows the turbidity of the raw water, disc filter filtrate and GMF filtrate during this period. The raw water turbidity was around 1 NTU for the first few days of operation and then drops to around 0.5 to 0.6 NTU for several more days. The storm event at day 15 was quite evident, as the raw water turbidity increases sharply after that point. The filtration performance was similar to that seen in Figure 6-52, where the disc filter filtrate turbidity closely follows the raw water turbidity and the GMF filtrate was consistently around 0.3 NTU. Most noteworthy about this data is how the TMP for both Pall 1 and 2 were quite similar during the beginning and middle of this run when turbidity levels were varying, but after the storm event when turbidity levels increased again, a greater difference in TMP was observed. This data indicates that turbidity values alone are not always a good indicator of downstream microfiltration system performance.

Figure 6-54 Turbidity During a Storm Event

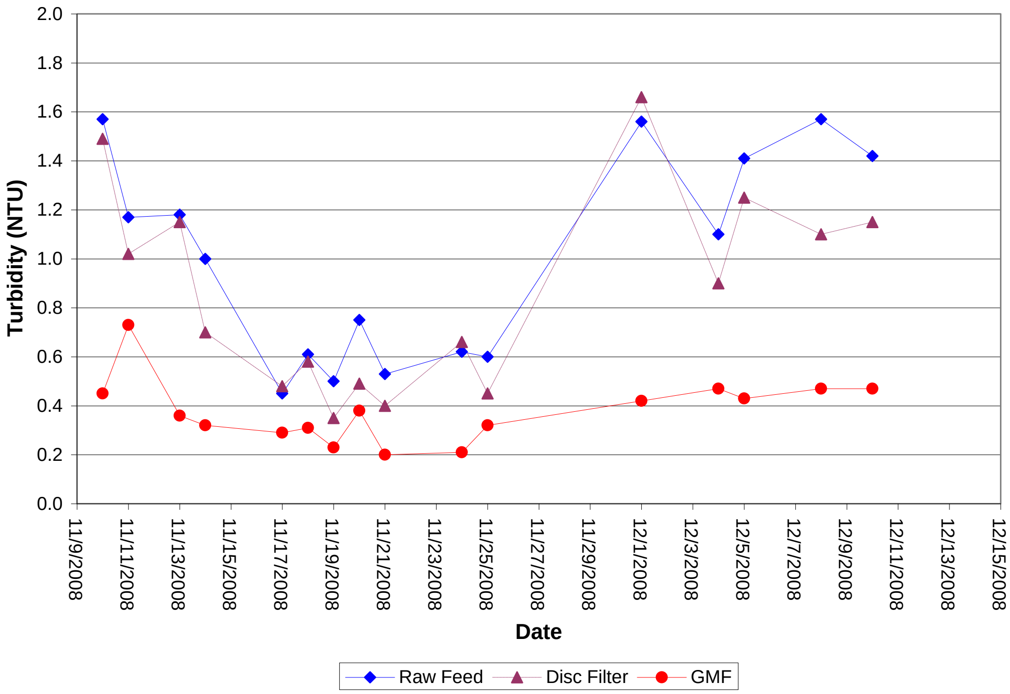


Figure 6-55 displays the performance of both MF systems from May 7th to May 23rd 2009 during the same algal bloom described in the GMF discussions previously. The Pall 1 – Disc Filter TMP was consistently higher than the Pall 2 – GMF TMP throughout this period of increased biomass loading and approached terminal TMP on several occasions. The flux rate of both MF systems was dropped at the onset of the algal bloom from 70 GFD to 53 GFD in order to maintain runtime on the Pall 1 MF. It is evident from the data that the Pall 2- GMF system flux could have maintained a higher value without approaching the terminal TMP in the established run time. Towards the end of this testing period, the Pall 1- Disc Filter TMP remained higher than the Pall 2 – GMF TMP even though the algal bloom had begun to subside. Regardless, after the bloom subsided, the TMP values on both systems had dropped significantly indicating that the flux rate on both systems could be again increased. These results indicate that extended MF run times can be achieved during algal blooms using the high-rate GMF. These results also indicate that a higher flux rate is more sustainable downstream of the high-rate GMF than the disc filter system during an algal bloom event.

Both of these factors indicate that for a full scale system design with a disc filter pre-strainer, the full scale microfiltration system would either be forced to operate at a reduced capacity in order to maintain run time and water production; or, additional microfiltration membrane area would need to be installed to make up for the necessary reduced operating flux in order to maintain full design-capacity water production during an algal bloom. For a full scale system design with a GMF pre-strainer, the negative effects of an algal bloom are much less, and the full scale microfiltration system would be capable of operating at a higher reduced capacity in order to maintain water production, or would require less additional microfiltration membrane area to maintain full design-capacity water production.

Figure 6-55 TMP Algal Bloom

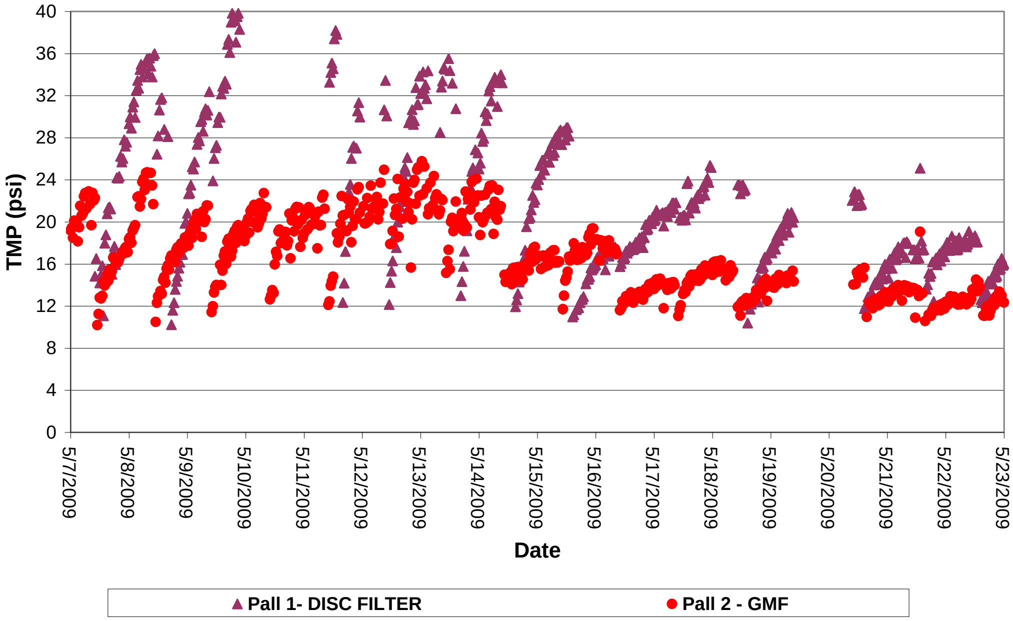
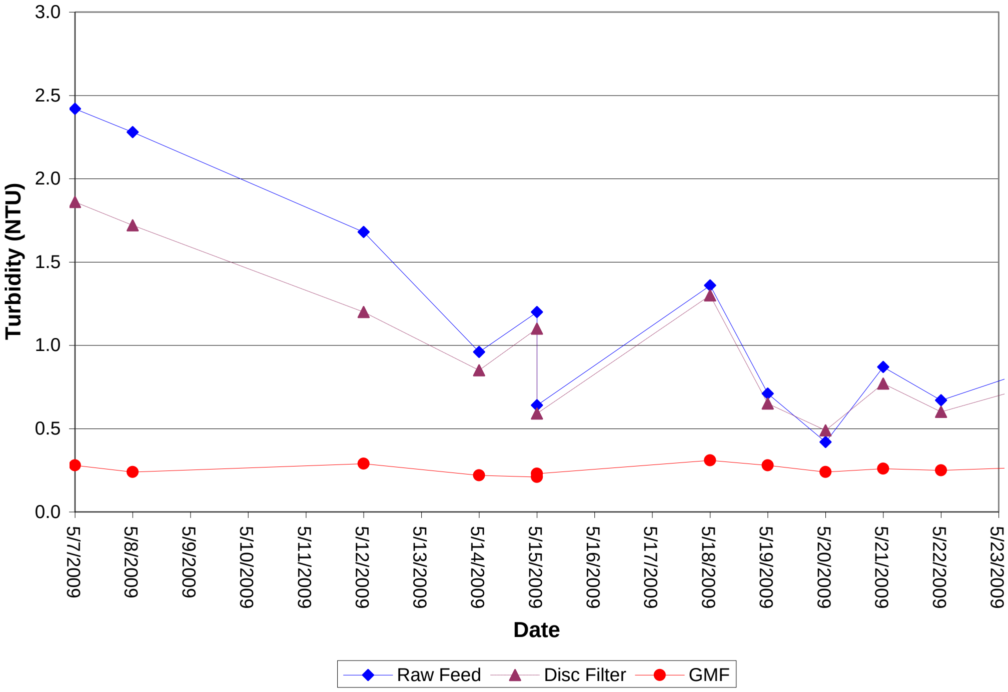


Figure 6-56 shows the turbidity of the raw water, disc filter filtrate and GMF filtrate during this period. At the beginning of the run the turbidity values were elevated, and as the bloom subsided the turbidity values dropped. Again the disc filter filtrate turbidity was varying with the raw water turbidity while the GMF filtrate was consistently around 0.3 NTU.

Figure 6-56 Turbidity Algal Bloom



In order to fully evaluate the use of either a high-rate GMF or disc filter system as a pre-strainer to an MF system, many factors must be considered and used in a life-cycle analysis to determine which operating scenario would result in the lowest total water cost. These factors include:

- Total footprint (pre-strainer + MF systems)
- Total capital cost (pre-strainer + MF systems)
- Total operating costs (power, chemicals, staffing for pre-strainer + MF systems)
- Robustness during challenging feedwater quality (pre-strainer + MF systems)
- Backwash volume and residuals handling

There are three principal advantages offered by the high-rate GMF as a pre-strainer:

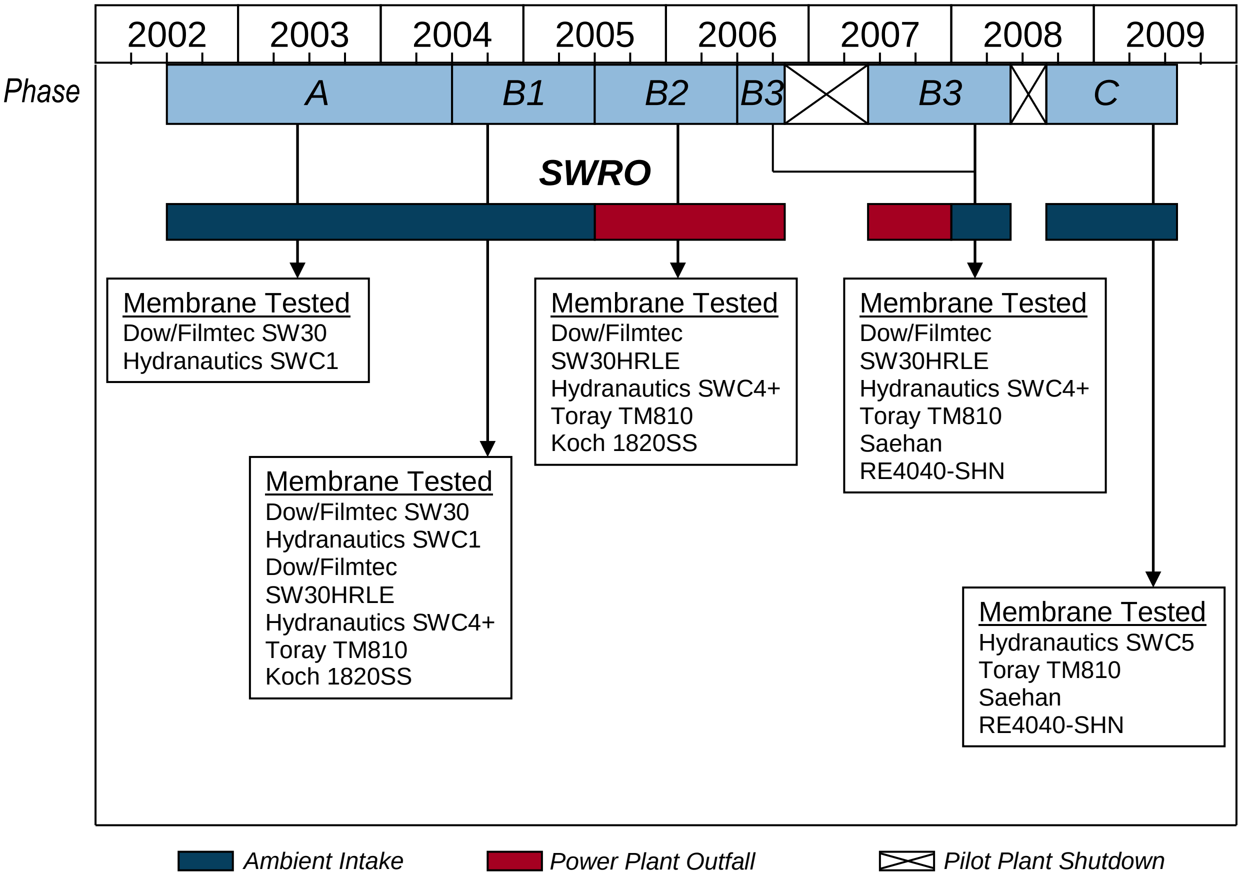
(1) Less membrane area required for the MF system
(2) Fewer MF standby trains required for poor feedwater conditions
(3) Reduced power and chemical consumption on the MF system and less operator attention

The above advantages will continue to be evaluated by West Basin MWD as the seawater desalination program advances towards a full-scale facility and a thorough life-cycle analysis is performed.

6.6 Seawater Reverse Osmosis System

The Seawater Reverse Osmosis system was operated for the duration of the study from 2002 to 2009, on both ambient intake water and power plant outfall per the schedule shown in Figure 6-57.

Figure 6-57 Testing Summary Graphic of SWRO System



6.6.1 Phase A Permeability / Permeate Quality

All Phase A testing of the RO utilized a microfiltered feed water source. Phase A of the RO Testing can be grouped into the following trials:

Table 6-25 Phase A RO Testing Trials

RO Testing Trial	Details
RO I	Operation with ammonium hydroxide addition pretreatment in an attempt to form chloramines, subsequent sodium bisulfite pretreatment -RO membranes oxidized
RO II	SBS pretreatment, operation at 8 GFD
RO III	SBS pretreatment, operation at 9 GFD
RO IV	SBS pretreatment, operation at 11 GFD

Table 6-26 Details of Each Phase A Reverse Osmosis Run

Trial	Run #	Dates	MF Filtrate Chemical	RO Feed Antiscalant ppm	Hydranautics Flux, GFD	Hydranautics Recovery	Filmtec Flux, GFD	Filmtec Recovery	Notes
RO I	RO 1	7/15/02-9/6/02	1ppm NH4OH	3	8	50	8	50	RO Membranes show signs of oxidation
	RO 2	9/1/02-9/28/02	1.5ppm NH4OH	3	8	50	8	50	Adjusted NH4OH dose-RO membranes continue to degrade
	RO 3	9/29/02-10/23/02	none	3	8	50	8	50	Rapid MF fouling
	RO 4	*10/23/02-11/24/02*	*1ppm SBS*	3	*8*	*50*	*8*	*50*	Memcor chlorinated b/w oxidizing RO
	RO 5	11/25/02-12/16/02	2-3ppm SBS	3	8	50	8	50	Increase SBS
	RO 6	12/17/02-1/15/03	2-3ppm SBS	3	8	50	8	50	Both RO pumps repaired, recycle modification
RO II	RO 7	1/15/03-3/9/03	2-3ppm SBS	3	8	50	8	50	1/15-Replaced both HYD and FT RO membranes
RO III	RO 8	3/9/03-4/3/03	3ppm SBS	3	9	50	9	50	Increased RO Flux
	RO 9A	10/21/03 - 11/19/03	3ppm SBS	3	9	50	9	50	Installed RO feed pump VFD
		11/19/03-1/15/04	3ppm SBS	3	9	50	9	50	Infrequent operation to MF/feed flow problems **CIP 12/5**
	RO 9B	1/30/04 - 2/18/04	3ppm SBS	3	9	50	9	50	
RO IV	RO 10	2/18/04 - 6/10	3ppm SBS	3	11	50	11	50	Increased RO Flux

The original pretreatment process, an attempt to create chloramines in ocean water, damaged the RO membranes in RO trial I. In many MF/RO membrane facilities operating on wastewater, chlorine is added to the feed water to enhance the membrane performance. Ammonia, naturally occurring or added to the wastewater, combines with the chlorine to form chloramines. The intent is to have a combined oxidant that would decrease the fouling rate of both the MF and RO processes. This chloramination followed by MF and subsequently RO process has been used successfully on many wastewater reclamation facilities including the 20 MGD West Basin Water Recycling Plant. The ammonia reacts with free chlorine or HOCl to form chloramines.

However, two items complicate the formation of chloramine on ocean water. First, ammonia is not present is ocean water and thus must be added. Second, the presence of bromide (Br-) in ocean water interferes with the reactions. The Pacific Ocean water source used in this study has around 64 mg/L of Br-. Br- substitutes for Cl- such that the chlorine addition to ocean water actually produces hypobromous acid (HOBr) instead of HOCl. This is discussed further in Section 6.8

As depicted in Figures 6-57 and 6-58, this chlorination, MF, ammonia addition, RO process failed to protect the RO membranes from oxidation. The specific flux and permeate conductivity of the Dow membranes started rising almost immediately. The Hydranautics membranes proved to be more resistant, but after ~100 days of operation it was clear that the salt passage or permeate conductivity of this membrane was rising as well. On September 1, 2002 the NH4OH addition rate was increased 50% to 1.5 mg/L in an effort to ensure that excess ammonia was present and prevent the presence of free chlorine. This did not alleviate the problem and the permeate conductivity continued to rise. In response to the RO deterioration, on October 3, the continuous chlorination in front of the MF was discontinued. Subsequently, attempts were made to run without any chlorine in the process and rapid MF fouling was observed (MF Trial II). Chlorine in the 20 - 40 mg/L range was then utilized in the MF backwash, which is an intermittent operation. An additional “rinse” step was added to the MF backwash to ensure no chlorine carryover to the RO. This, combined with the addition of sodium bisulfite in front of the RO, was utilized in the remainder of the trials.

Figure 6-57 Increasing Permeability of RO Membranes due to Oxidation (RO Trial I)

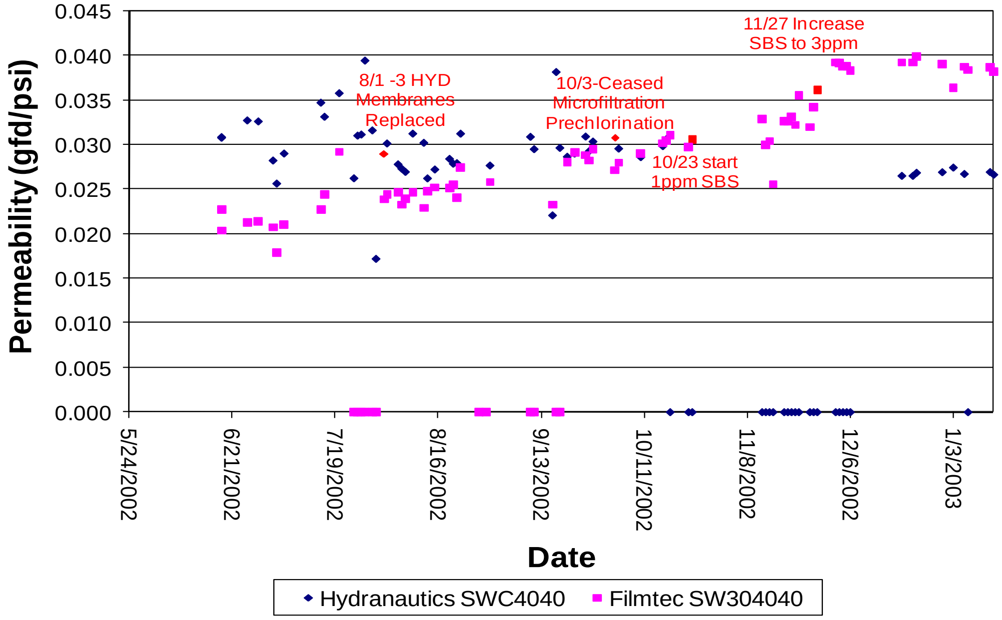
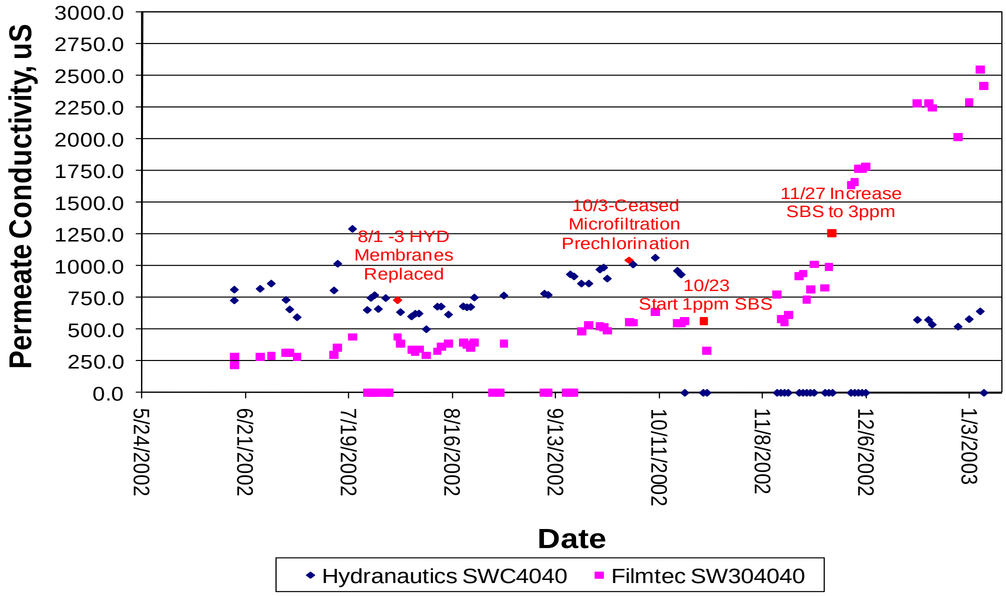


Figure 6-58 Increasing Permeate Conductivity of RO Membranes due to Oxidation (RO Trial I)



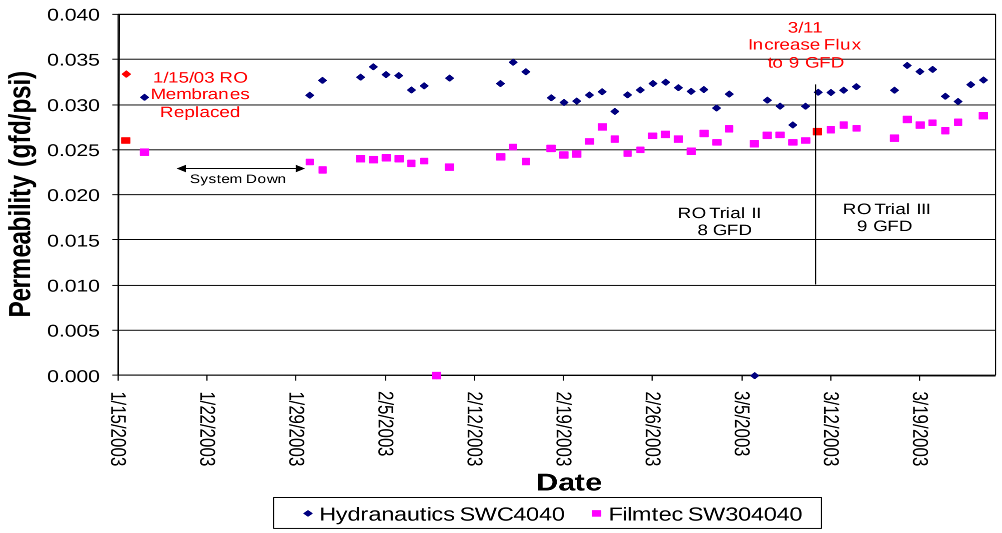
From October through December 2002, the RO was run with the damaged membranes in an attempt to find a pretreatment strategy that would allow the MF to maintain reasonable flux rates and run times without further RO oxidation. The RO membranes were replaced on January 15, 2003 and trial II of the RO testing commenced on MF Filtrate water with 3 mg/L sodium bisulfite protecting the RO. This was continued for the remainder of the trials. Note that the use of sodium bisulfite for reduction of trace free chlorine is a distinctly different approach to the continuous chlorination/dechlorination approach that has been found to result in RO biofouling.

6.6.1.1 RO Permeability

Like the MF and UF, the RO system is run at constant flux and thus if the membrane fouls, the pressure required to maintain throughput rises. The membrane permeability is monitored by the calculation of specific flux which is the operating flux divided by the temperature corrected net driving pressure. This way, changes in the membrane properties due to fouling can be observed regardless of changes in the operating conditions (e.g. temperature, flux, etc.)

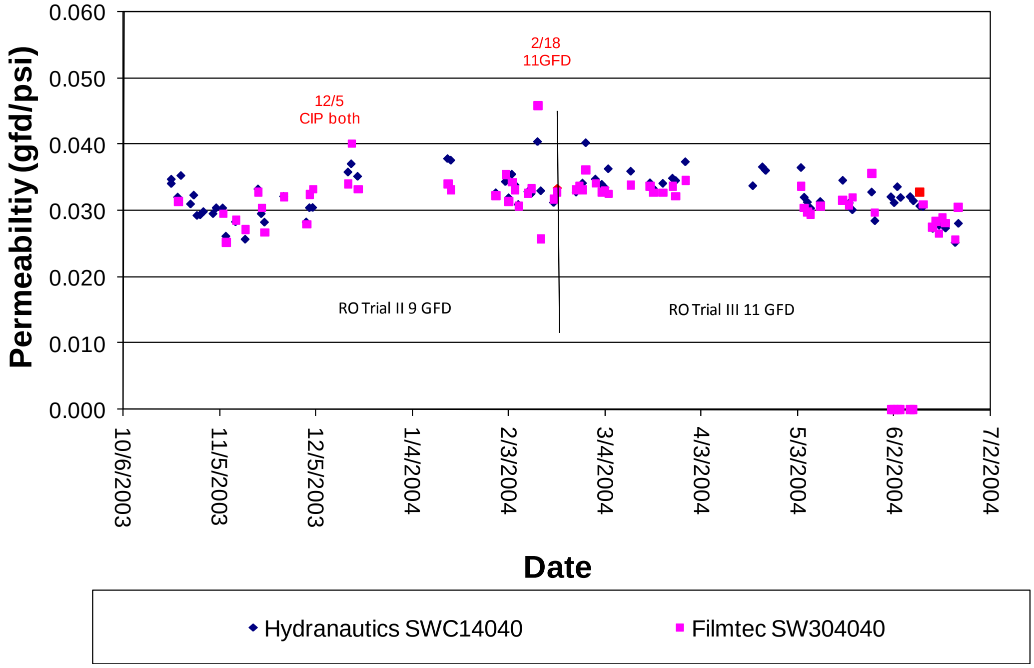
Figure 6-59 displays that the permeability of the Hydranautics membrane was fairly stable following the replacement of the RO membranes (RO trial II). Dow membranes, on the other hand, showed a slight increase in specific flux and as will be discussed in the next section, permeate conductivity as well. These trends are consistent with membrane oxidation. However, the Hydranautics membranes did not show these signs of oxidation, and these membranes were running side by side on the same feed water. It is possible that small amounts of chlorine (or bromine), not reduced by the sodium bisulfite, reached the RO system, and the Hydranautics membranes may be more resistant to oxidation. Likewise, examination of Figures 88 and 89 above, which display the results of the Trial I testing of the RO membranes oxidized by the chlorine followed by ammonia addition (failed chloramination) process, reveal that the Dow membranes experienced deterioration, presumably from oxidation, much faster than the Hydranautics membranes. RO Trial III commenced in March 2003 operating at 9 GFD.

Figure 6-59 Reverse Osmosis Membrane Permeability Trial II and Beginning of Trial III



Between April and October 2003, the trials were halted to make mechanical changes to the RO system, namely moving the high pressure pumps to a separate skid and the addition of variable frequency drives. This is discussed further in Process and Equipment Challenges. Testing was resumed in October 2003. A drop in permeability was immediately observed and the membranes were cleaned on December 5, 2003. The permeability decline was probably due to bacteriological growth in the RO membranes during the period of shutdown. For most of the shutdown, the membranes were periodically run and then flushed with RO permeate water. However, the RO retrofit occurred over a period of 2 months in the summertime, the power to the unit was out, and thus the membranes could not be flushed. After cleaning, the permeability was restored to pre-shutdown values and operated at 9 GFD flux. The flux was increased to 11 GFD on February 18, 2004. Comparison of the permeability between January 15, 2003 and June 2, 2004 in Figure 6-60 demonstrated that both the Hydranautics and Dow membranes did not decrease in permeability over the course of the testing. Thus, no significant fouling was observed on these RO membranes over approximately 3100 hours of testing at 11 GFD.

Figure 6-60 Reverse Osmosis Membrane Permeability End of Trial III



On June 10, 2004, the RO flux rate was increased to 12 GFD. Further testing was required at this flux rate, and at the end of Phase A, the optimized RO run parameters were as follows:

Table 6-27 Optimized RO Parameters Phase A Testing

Parameter	Value
RO Operating Flux (gfd)*	8 - 11
Recovery	50%
Sodium Bisulfite Dose (mg/L)*	3
Antiscalant Dose (mg/L)	3

**Optimized Parameters.*

6.6.2 RO Permeate Quality

Over the course of the Phase A testing, two sets of RO membranes from each RO manufacturer were tested, and for each set, the Dow SW30-4040 initially produced water of significantly better quality (lower concentration of most constituents) than the Hydranautics SWC-4040. RO Permeate quality was continuously measured via conductivity and biweekly samples were taken for individual analysis.

6.6.2.1 Conductivity

Figure 6-61 demonstrates that the conductivity produced by the Dow membrane was initially significantly lower than that of Hydranautics. However, during trial II, the conductivity of Dow permeate rose and the Hydranautics permeate conductivity gradually declined. By the beginning of Trial III of the RO testing, the two membranes were producing water with similar conductivity. At the end of Trial IV of the testing, each membrane was producing permeate water of about 550 µS at a flux of 11 GFD and 18°C feedwater temperature.

Figure 6-61 Reverse Osmosis Membrane Conductivity Trials II and Beginning of Trial III

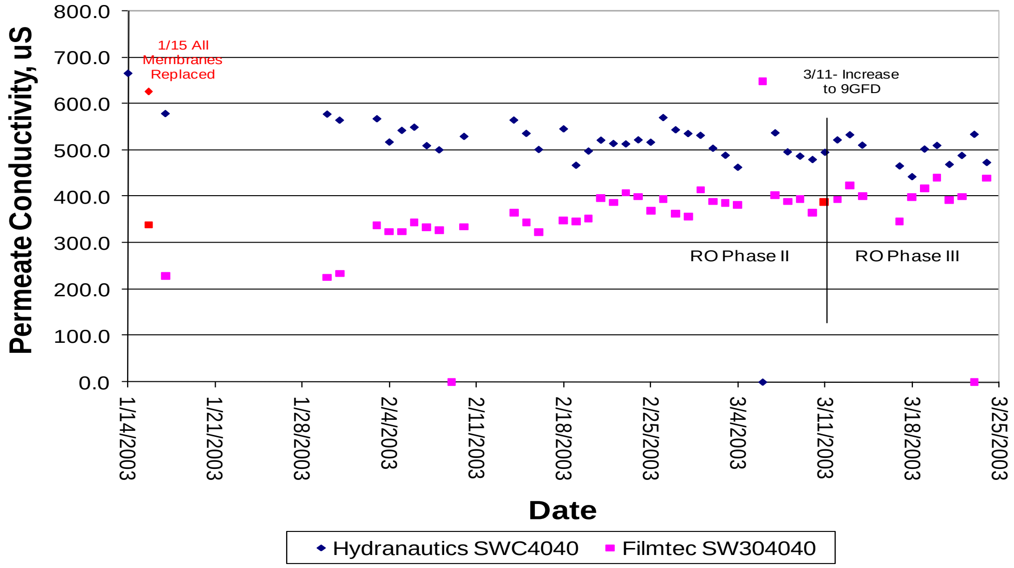
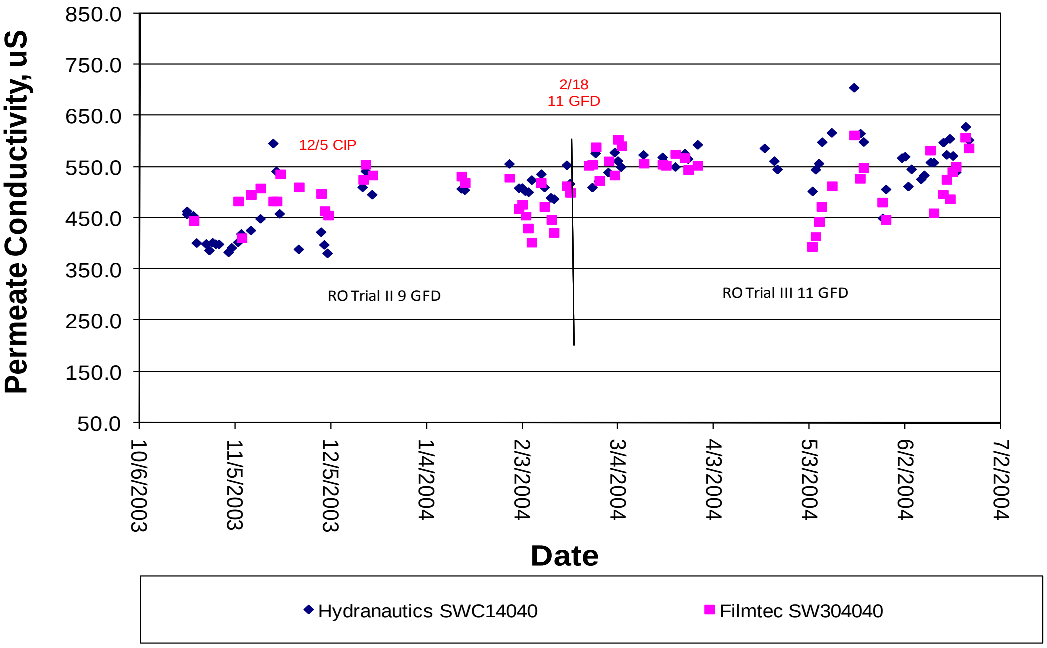


Figure 6-62 Reverse Osmosis Membrane Conductivity End of Trials III and Trial IV



6.6.2.2 Individual Ion Analyses

Tables 6-28 – 6-30 summarize the average results of the laboratory analysis performed on the RO streams for each trial of the Phase A testing. The following were evident:

1. For each Trial (flux), each RO membrane produced permeate of TDS < 300 mg/L. Note that this treatment process did not include stabilization of the RO permeate which would be necessary for distribution of potable water.

2. For both Boron and TDS, the Dow membrane initially produced water substantially lower concentration than the Hydranautics membrane. The Dow membrane continued to produce lower concentration, but the gap between the two membranes lessened as the testing progressed. Boron levels were constantly below 1.5 mg/L and 1.0 mg/L for Hydranautics and Dow, respectively.

Table 6-28 Average RO Membrane Water Quality for Trial II (8 GFD)

	SAMPLE ID					
	RO Feed	Permeate		Concentrate		
		Train 1	Train 2	Train 1	Train 2	
Parameter		**HYD**	**DOW**	**HYD**	**DOW**	**Units**
TDS	34750	230	150	69000	67000	mg/L
Lab pH*	8.1	6.9	6.5	7.9	7.9	UNITS
Alkalinity (as CaCO3)	115	<2	<2	212	214	mg/L
Bicarbonate (as CaCO3)	114	<2	<2	210	212	mg/L
Carbonate (as CaCO3)	1.3	<0.1	<0.1	1.5	1.6	mg/L
Hydroxide (as CaCO3)	0.06	<0.01	<0.01	0.04	0.04	mg/L
Sulfate	2533	<10	<10	5538	5463	mg/L
Chloride	18875	111	70	35325	34975	mg/L
Nitrate (as N)	<25	<0.5	<0.5	<25	<25	mg/L
Nitrite (as N)	<25	<0.5	<0.5	<25	<25	mg/L
Bromide	63	<0.25	<0.25	<100	<100	mg/L
Calcium	395	0.6	1.1	739	724	mg/L
Magnesium	1360	2.0	2.6	2504	2460	mg/L
Hardness (as CaCO3)	6586	9.4	13.1	12156	11937	mg/L
Ca Hardness (as CaCO3)	986	1.5	2.8	1846	1807	mg/L
Sodium	11175	77	46	20600	20400	mg/L
Potassium	398	2.7	1.9	779	756	mg/L
Fluoride	0.9	<0.1	<0.1	1.2	1.2	mg/L
Strontium	7.6	0.011	0.018	14.6	14.5	mg/L
Barium	<0.025	<0.025	<0.025	<0.025	<0.025	mg/L
Boron	3.7	1.2	0.6	6.6	6.9	mg/L
Silica	<10	<10	<10	<10	<10	mg/L
Ammonia (as N)	<0.1	<0.1	<0.1	<0.1	<0.1	mg/L
TOC	0.9	<0.5	<0.5	1.7	1.7	mg/L

Notes: Ave temperature 22C, Four samples
Maximum TDS: 290 HYD, 160 Dow
Maximum Boron: 1.3 HYD, 0.7 Dow

Table 6-29 Average RO Membrane Water Quality for Trial III (9 GFD)

	SAMPLE ID					
	RO Feed	Permeate		Concentrate		
		Train 1	Train 2	Train 1	Train 2	
Parameter		**HYD**	**DOW**	**HYD**	**DOW**	**Units**
TDS	34167	185	178	64667	64667	mg/L
Lab pH*	8.0	6.6	6.6	7.8	7.8	UNITS
Alkalinity (as CaCO3)	112	<2	<2	205	205	mg/L
Bicarbonate (as CaCO3)	111	<2	<2	204	204	mg/L
Carbonate (as CaCO3)	1.1	<0.1	<0.1	1.2	1.3	mg/L
Hydroxide (as CaCO3)	0.05	<0.01	<0.01	0.03	0.03	mg/L
Sulfate	2538	<10	<10	5265	5160	mg/L
Chloride	18967	100	95	35050	33950	mg/L
Nitrate (as N)	<25	<0.5	<0.5	<200	<200	mg/L
Nitrite (as N)	<25	<0.5	<0.5	<200	<200	mg/L
Bromide	66	<0.25	<0.25	<100	<100	mg/L
Calcium	378	0.6	0.9	718	724	mg/L
Magnesium	1260	1.5	2.4	2410	2457	mg/L
Hardness (as CaCO3)	6133	7.1	11.2	11716	11925	mg/L
Ca Hardness (as CaCO3)	944	1.4	2.2	1792	1808	mg/L
Sodium	10383	68	63	19867	20133	mg/L
Potassium	384	2.3	2.3	719	743	mg/L
Fluoride	1.0	<0.1	<0.1	1.3	1.3	mg/L
Strontium	7.6	0.01	0.02	14	14	mg/L
Barium	<0.025	<0.010	<0.010	<0.025	<0.025	mg/L
Boron	3.5	1.1	0.8	6.6	6.6	mg/L
Silica	<10	<1	<1	<10	<10	mg/L
Ammonia (as N)	<0.1	<0.1	<0.1	<0.1	<0.1	mg/L
TOC	0.9	<0.5	<0.5	2.2	2.1	mg/L

Notes: Ave temperature 22C, Five samples
Maximum TDS: 240 HYD, 230 Dow
Maximum Boron: 1.2 HYD, 1.0 Dow

Table 6-30 Average RO Membrane Water Quality for Trial IV (11 GFD)

	SAMPLE ID					
	RO Feed	Permeate		Concentrate		
		Train 1	Train 2	Train 1	Train 2	
Parameter		**HYD**	**DOW**	**HYD**	**DOW**	**Units**
TDS	34800	200	160	71400	68600	mg/L
Lab pH*	8.0	7.1	6.8	7.7	7.8	UNITS
Alkalinity (as CaCO3)	108	<2	<2	205	205	mg/L
Bicarbonate (as CaCO3)	107	<2	<2	204	204	mg/L
Carbonate (as CaCO3)	1.0	<0.1	<0.1	1	1	mg/L
Hydroxide (as CaCO3)	0.0	<0.01	<0.01	0	0	mg/L
Sulfate	2492	<10	<10	5370	5276	mg/L
Chloride	18580	112.8	93.1	35000	34460	mg/L
Nitrate (as N)	<25	<0.5	<0.5	<200	<200	mg/L
Nitrite (as N)	<25	<0.5	<0.5	<200	<200	mg/L
Bromide	58	<0.25	<0.25	<100	<100	mg/L
Calcium	409	<0.5	0.6	790	779	mg/L
Magnesium	1304	1.0	1.3	2514	2498	mg/L
Hardness (as CaCO3)	6392	4.3	6.4	12326	12231	mg/L
Ca Hardness (as CaCO3)	1021	<1.2	1.5	1974	1945	mg/L
Sodium	10480	75.2	57.3	20240	20040	mg/L
Potassium	418	2.7	2.1	792	784	mg/L
Fluoride	0.9	<0.1	<0.1	1.3	1.3	mg/L
Strontium	7.6	0.0	0.0	14.8	14.6	mg/L
Barium	<0.025	<0.010	<0.010	<0.025	<0.025	mg/L
Boron	3.2	1.1	0.8	5.8	6.0	mg/L
Silica	<10	<1	<1	<10	<10	mg/L
Ammonia (as N)	<0.1	<0.1	<0.1	<0.1	<0.1	mg/L
TOC	1.2	<0.5	<0.5	2.5	2.2	mg/L

Notes: Ave temperature 21C, Five samples
Maximum TDS: 220 HYD, 190 Dow
Maximum Boron: 1.2 HYD, 0.9 Dow

6.6.3 Phase B Permeability / Permeate Quality

Phase B provided valuable data on several next generation RO membranes as well as operating data on the power plant effluent.

Table 6-31 lists the operating parameters of the RO membranes during the Phase B period of testing:

Table 6-31 Details of Each Phase B RO Run

Phase B1 Summary *Feed Source is Power Plant Influent*

Run #	Dates	Pretreatment Chemical	Antiscalant mg/L	Membrane A	Membrane A Flux (GFD) / % Recovery	Membrane B	Membrane B Flux (GFD) / % Recovery	Comments
RO11	6/10/04 to 11/16/04	3 mg/L SBS	3	Hydranautics SWC1-4040 Set B	12 GFD / 50%	Dow SW30-4040 Set B	12 GFD / 50%	Flux increased from 11 to 12 GFD to investigate performance at higher flux.
RO12	11/17/04 to 12/10/04	3 mg/L SBS	3	Hydranautics SWC1-4040 Set B	8 GFD / 50%	Dow SW30-4040 Set B	8 GFD / 50%	Flux reduced back to 8 GFD to compare performance vs. previous runs.
RO13	12/17/04 to 2/24/05	3 mg/L SBS	3	None	NA	Toray TM810	10, 12 GFD / 50%	Begin testing of next generation RO membranes
RO14	2/25/05 to 4/27/05	3 mg/L SBS	3	None	NA	Koch 1820SS	10, 12 GFD / 50%	
RO15	5/15/05 to 7/17/05	3 mg/L SBS	3	Dow SW30HRLE-4040	10, 12 GFD / 50%	Hydranautics SWC4+ 4040	10, 12 GFD / 50%	Red Tide event started in late May/ Early June. RO membranes experienced fouling

Phase B2 Summary -*Feed Source is Power Plant Effluent*

Run #	Dates	Pretreatment Chemical	Antiscalant (mg/L)	Membrane A	Membrane A Flux (GFD) / % Recovery	Membrane B	Membrane B Flux (GFD) / % Recovery	Notes
RO16	7/18/05 to 12/5/05	3 mg/L SBS	3	Dow SW30HR LE-4040	10,12 GFD / 50%	Hydranautics SWC4+ 4040	10,12 GFD / 50%	
RO17	12/06/05 to 5/20/06	3 mg/L SBS	3	Toray TM810	12 GFD / 50%	Koch 1820SS	10,12 GFD / 50%	Operation reverted to Influent water Feb 10th due to feed pump issues. RO Fouling occurred in mid March, coinciding with another algae bloom.

Phase B3 Summary - *Feed Source is Power Plant Effluent*

Run #	Dates	Pretreatment Chemical	Antiscalant (mg/L)	Membrane A	Membrane A Flux (GFD) / % Recovery	Membrane B	Membrane B Flux (GFD) / % Recovery	Notes
RO18	5/23/06 to 8/1/06	3 mg/L SBS	3	Dow SW30HR LE-4040	12 GFD / 50%	Toray TM810 Set B	12 GFD / 50%	Dow SW30HRLE -4040 and Toray TM810 selected for further testing
RO19	8-1-06 to 10-15-06	3 mg/L SBS	3	Dow SW30HR LE-4040 Set B	12 GFD / 50%	Toray TM810 Set B	12 GFD / 50%	RO HP Pump failure required new set of Dow membranes to be installed. Biofouling of Toray membranes experienced, CIP restored performance
RO2	6/11/07 to 9/24/07	3 mg/L SBS	3	Dow SW30HR LE-4040 Set B	12 GFD / 50%	Hydranautics SWC4+ 4040	12 GFD / 50%	Hydranautics installed for further evaluation based on possible need for higher chloride and boron removal. Biofouling experienced for both trains.

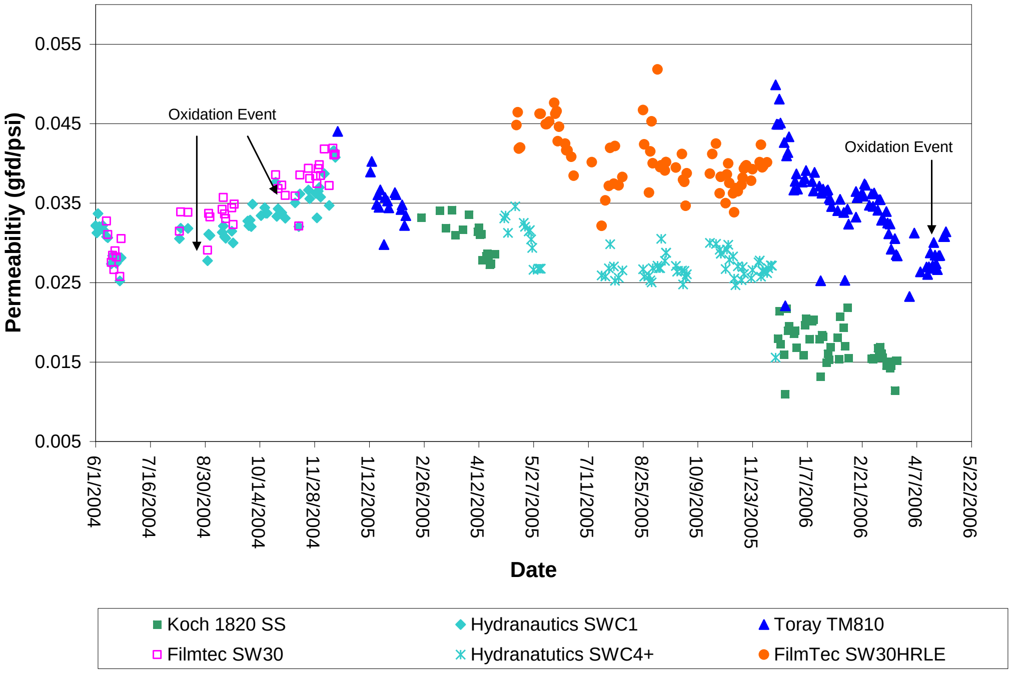
Run #	Dates	Pretreatment Chemical	Antiscalant (mg/L)	Membrane A	Membrane A Flux (GFD) / % Recovery	Membrane B	Membrane B Flux (GFD) / % Recovery	Notes
RO21	9/25/07 to 11/7/07	3 ppm SBS	3	Dow SW30HR LE-4040 Set B	9 GFD / 50%	Hydranautics SWC4+ 4040	9 -10 GFD / 50%	Both sets of elements went through CIPs
RO22	11/8/07 to 1/14/08	0-3 ppm SBS	3	Dow SW30HR LE-4040 Set B	8 – 9 GFD / 50%	Hydranautics SWC4+ 4040	8 -9 GFD / 50%	Fouling continued, elements cleaned again in January
RO23	1/20/08 to 2/18/08	3 ppm SBS	3	Dow SW30HR LE-4040 Set B	8 – 9 GFD / 50%	Hydranautics SWC4+ 4040	8 -9 GFD / 50%	Mechanical problems resulted in very little run time for Run 23

Phase B3 Summary - *Feed Source is Power Plant Influent*

Run #	Dates	Pretreatment Chemical	Antiscalant (mg/L)	Membrane A	Membrane A Flux (GFD) / % Recovery	Membrane B	Membrane B Flux (GFD) / % Recovery	Notes
RO24	3/11/08 to 5/17/08	3 mg/L SBS	3	Saehan RE 4040-SHN	9 GFD / 50%	Toray TM810	9 GFD / 50%	Saehan and Toray installed for further testing

Figure 6-63 displays the permeability of all membranes tested in Phases B1 and B2. June 2004 through November 2004 consisted of further evaluation of the Dow SW30-4040 and Hydranautics SWC1-4040 membrane at a flux rate of 12 GFD to compare performance at previous flux rates of 8, 9 and 11. Unfortunately, an operational upset with the sodium bisulfite pump caused free chlorine to come in contact with both sets of membranes, resulting in membrane oxidation in early August. This is shown by the increase in permeability for these two membranes.

Figure 6-63 Phase B1 and B2 RO Permeability



The Toray TM810 next generation RO membrane was tested at both 10 and 12 GFD from December 2004 to February 2005 to collect data on power plant influent water. The Toray membrane showed strong performance with respect to both permeability and permeate quality.

In March and April 2005, data was collected on the Koch 1820SS membrane on influent water. Average permeability was slightly lower than Toray and Dow, and average permeate concentrations were higher than all other next-generation membranes. This membrane had a comparatively poor performance.

In May – July 17, 2005, the next generation Dow (Filmtec) SW30HRLE and Hydranautics SWC4+ membranes were operated in parallel on influent water pretreated by microfiltration. On July 18th, the feed water source was switched to effluent water to start Phase B2, and these membranes remained operating on effluent water until December 2005. During this period of testing, a severe Red Tide event occurred that started at the end of May and persisted at varying intensities through mid August. Both sets of membranes experienced permeability loss during this time frame, and it is possible that dissolved organics present as the result of the algae bloom passed through the MF membrane and fouled the RO membrane.

In December of 2005, the Toray TM810 and Koch 1820SS membranes were reinserted into the system for continued testing on Phase B-2 power plant effluent. The Toray membranes started up with higher permeability and higher conductivity than when operated in Phase B-1, and after substantial troubleshooting, two elements were replaced in the tail end of the system. Overall permeability and permeate conductivity returned to previous (Phase B-1) values when the new membranes were installed. The Koch membranes started up with lower permeability than when operated in Phase B-1. This could possibly be due to biogrowth occurring in the membranes as they were in storage for 6 months. On February 10th 2006, operation reverted back to influent water operation due to a malfunction of the effluent water supply pump. In mid March both sets of membranes experienced a loss in permeability. This event coincided with an algae bloom, confirmed by elevated levels of domoic acid present in the feedwater as well as by satellite imagery of the Santa Monica Bay source water.

An offsite cleaning trial was performed on the Koch membranes, which is discussed further below. Separately, in an effort to eliminate the presence of biogrowth, the MF/RO break tank was cleaned with a sodium hypochlorite solution. Upon restarting the Toray membranes, some residual chlorine was present in the feedwater, which oxidized the Toray membranes.

Phase B3 began in June 2006 with new sets of the Dow SW30HRLE membrane and the Toray TM810 membrane. The high permeability and high boron rejection characteristics of these two membranes warranted their selection for further long term study.

The Toray TM810 and Dow SW30HRLE membranes were operated from June 2006 to October 2006 on power plant effluent. A high pressure feed pump seal failure leaked oil into the feed water resulted in damage to the first set of Dow membranes, so a second set was installed and started up in August of 2006. Figure 48 shows the performance of the Toray membrane from August 2006 to early October 2006 before the entire pilot operation was shut down and relocated. The Toray membranes started to show signs of fouling in August 2006, and the trend continued in September. It was discovered that the MF/RO break tank had experienced biogrowth which was the most likely contributor to the biofouling in the RO Trains. A membrane cleaning consisting of a 2% citric acid cleaning solution (pH ~2) heated to 35 – 38 ºC followed by a caustic cleaning solution with 2% Avista P111 membrane cleaner (pH ~ 10.5) heated to 35 – 38 ºC was successful in restoring performance. This data is displayed in Figure 6-64.

Figure 6-64 Toray TM810 Permeability August 2006 – October 2006

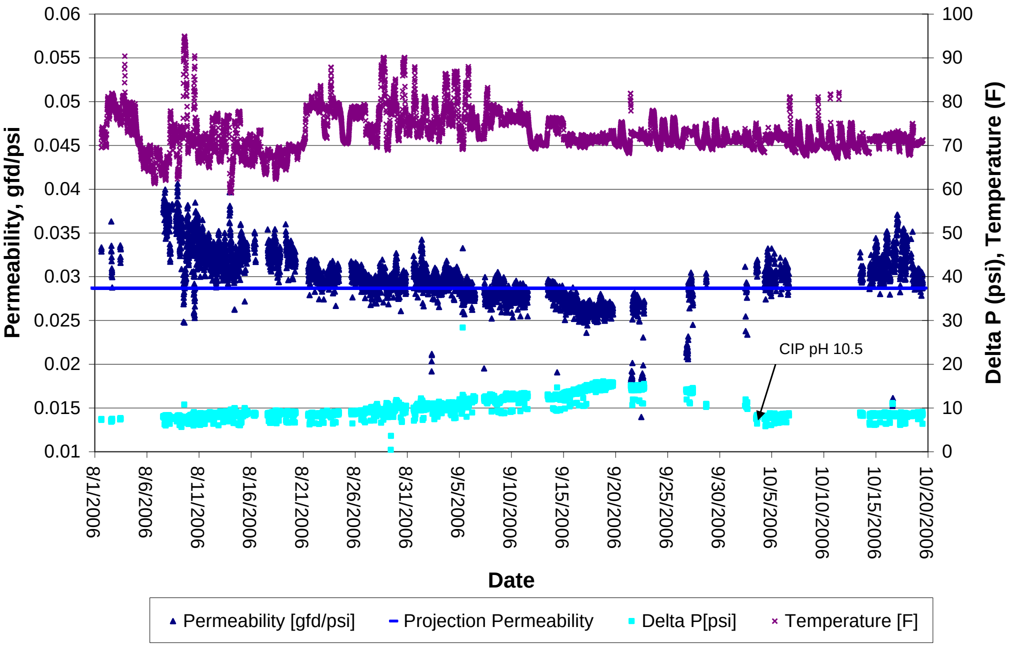
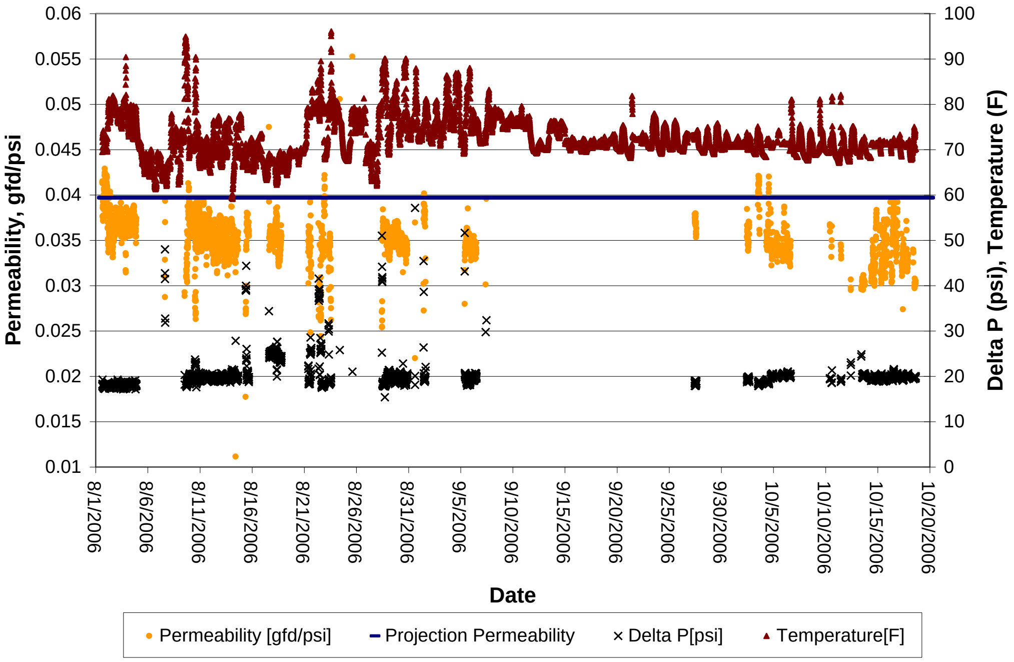


Figure 6-65 illustrates the Dow SW30HRLE membrane operation from August to October 2006. Mechanical issues as discussed in the Process and Equipment Challenges Section of this document limited the run time during this period, but a loss in permeability was witnessed for the Dow membranes.

Figure 6-65 Dow SW30HRLE Permeability August 2006 – October 2006



Phase B3 restarted in June 2007 with a new set of Hydranautics SWC4+ membrane to further evaluate the low TDS permeate quality seen in previous testing, along with the previous set of Dow SW30HRLE membrane. When the Dow RO membranes were brought back on line in June 07 the permeability declined. In early September 2007, a CIP was performed consisting of a 2% citric acid cleaning step (pH ~2) heated to 35 – 38 ºC followed by a caustic cleaning step with 2% Avista P111 membrane cleaner (pH ~ 10.5) heated to 35 – 38 ºC. This is the same cleaning procedure that was used successfully on the Toray membranes in September 2006, however it had no effect on restoring permeability for the Dow SW30HRLE.

Permeability started to decline more thereafter, and a visual inspection of the membranes in early September confirmed the presence of biogrowth in both sets of RO membranes SW30HRLE and Hydranautics SWC4+. Based on the poor results of the previous cleaning formulation at a pH of 10.5, a different cleaning formulation was trialed at the end of September. Avista P112 is a commercial membrane cleaning product used to clean biofouling from RO membranes. In late September 2007 a 2% solution of P112 was used with the addition of NaOH to bring the pH of the cleaning solution up to 12, and the solution was heated to 30-35ºC (Temperature guidelines for each membrane manufacturer at high pH were followed). This formulation had encouraging results, as the pressure drop across both RO trains decreased and the permeability of each RO train increased. The Hydranautics membrane showed a larger increase in permeability than the Dow membranes, but initial data for the Dow membranes suggests that more foulant may be able to be removed with another cleaning step.

Figures 6-66 and 6-67 show the performance from June 2007 through February 2008 of both the Dow and Hydranautics membranes.

Figure 6-66 Dow SW30HRLE Permeability June 2007 – February 2008

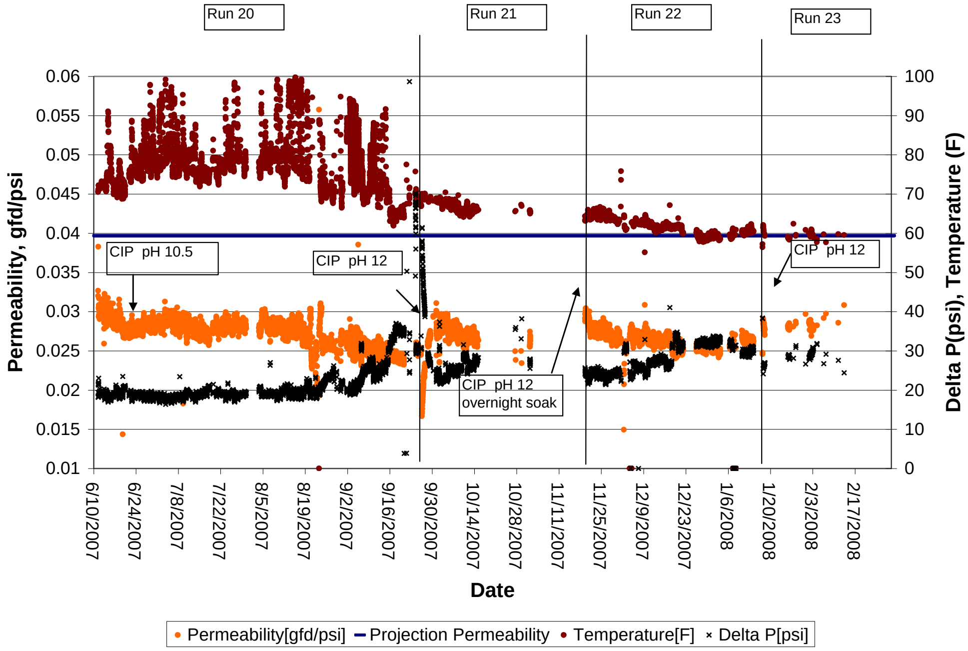
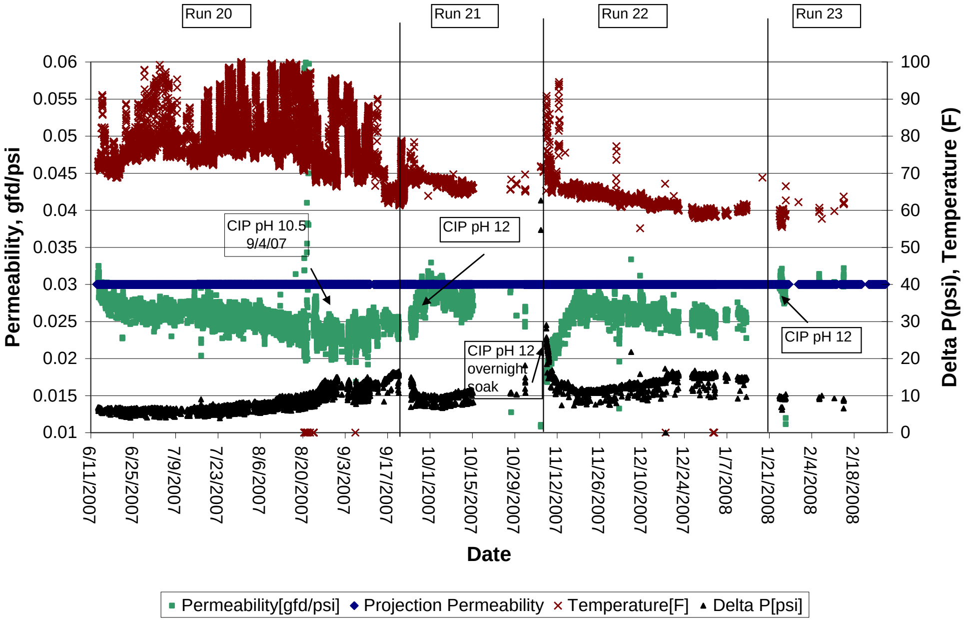


Figure 6-67 Hydranautics SWC4+ Permeability June 2007 – February 2008



The Filmtec and Hydranautics membranes were removed from the RO Trains in mid February 2008, and the Saehan RE 4040-SHN and Toray TM810 were installed in Train 1 and 2, respectively. Run 24 marks the start of testing for both the Saehan and Toray elements. Only ambient intake water was used as feedwater to the RO membranes for further testing in order to compare the propensity for biofouling on the ambient intake versus the warmer power plant outfall.

The Toray elements started up with permeability as expected from the manufacturer projections and from previous testing. A slight drop in permeability occurred over the first week of operation, but stabilized over the next two months. The Saehan elements also started up as expected, but have shown a larger decrease in permeability. One noteworthy aspect of the Saehan performance is the step changes that occur in permeability. These step changes occurred whenever the feed pressure approached 1,000 psi, indicating there may be some issues with element construction. Figure 6-68 shows this performance.

Figure 6-68 Saehan RE 4040-SHN Permeability March – May 2008

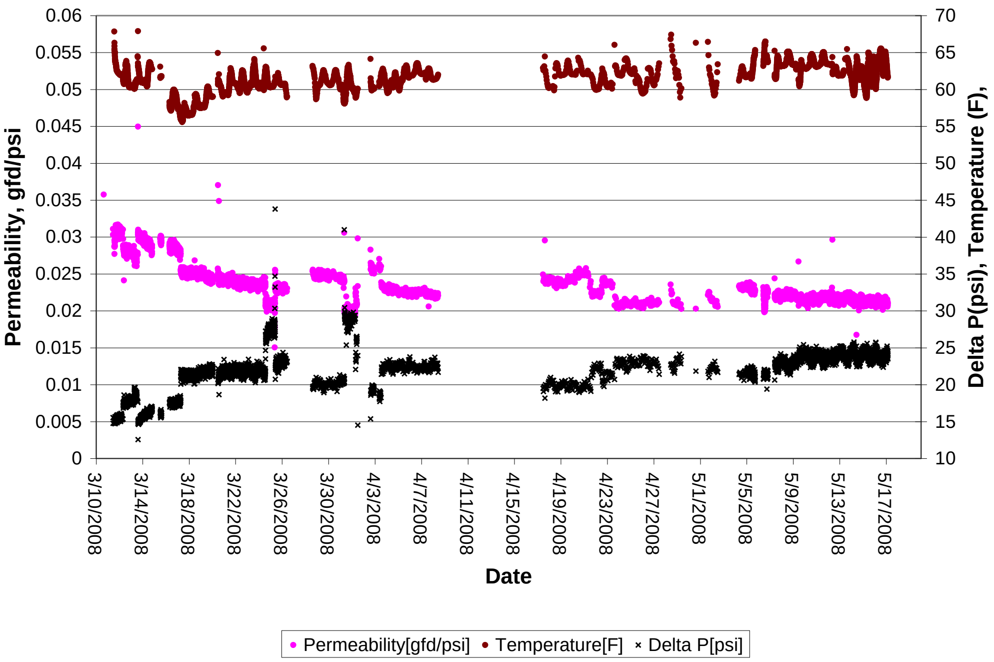
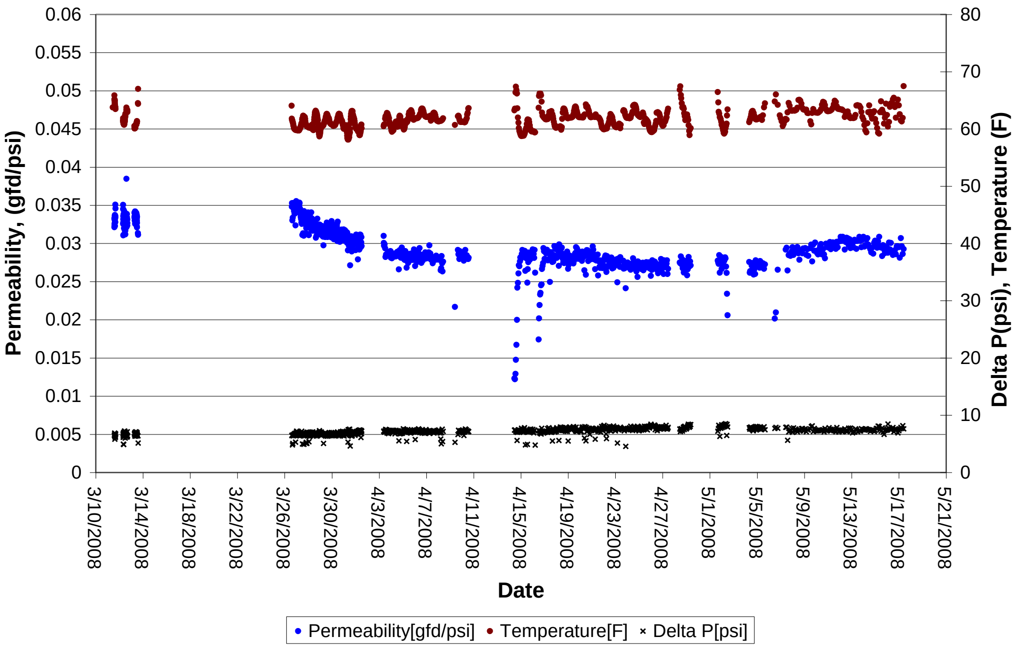


Figure 6-67 Toray TM810 Permeability March – May 2008



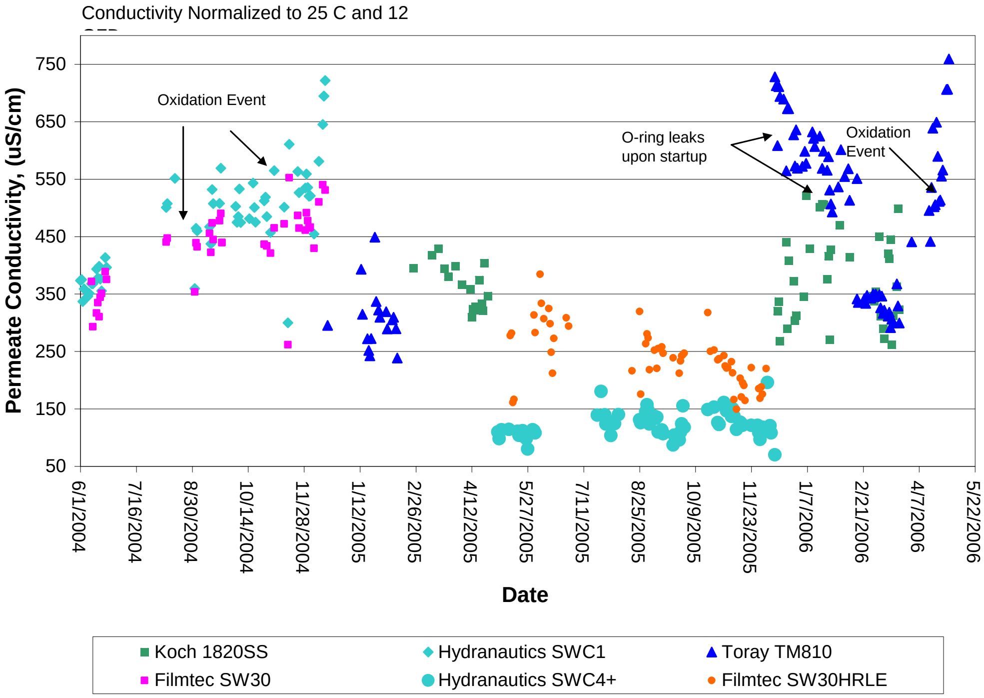
6.6.4 RO Permeate Water Quality

The permeate conductivity for each of the next-generation RO membranes tested is displayed below in Figure 6-68. The graph shows that the Hydranautics SWC4+ showed the lowest permeate conductivity of all membranes tested, followed by the Dow (Filmtec) SW30HRLE and Toray TM810 respectively. The Koch 1820SS membrane showed the highest permeate conductivity (lowest salt rejection) of the next generation RO membranes.

It should be noted that there were two operational upsets previously mentioned that resulted in oxidation of the Dow SW30-4040 and Hydranautics SWC1-4040 in the summer of 2004, and another in the spring of 2006 that oxidized the Koch 1820SS and Toray TM810 membranes. The high conductivity for each of these membranes (greater than 450 µS/cm) can be seen in Figure 100.

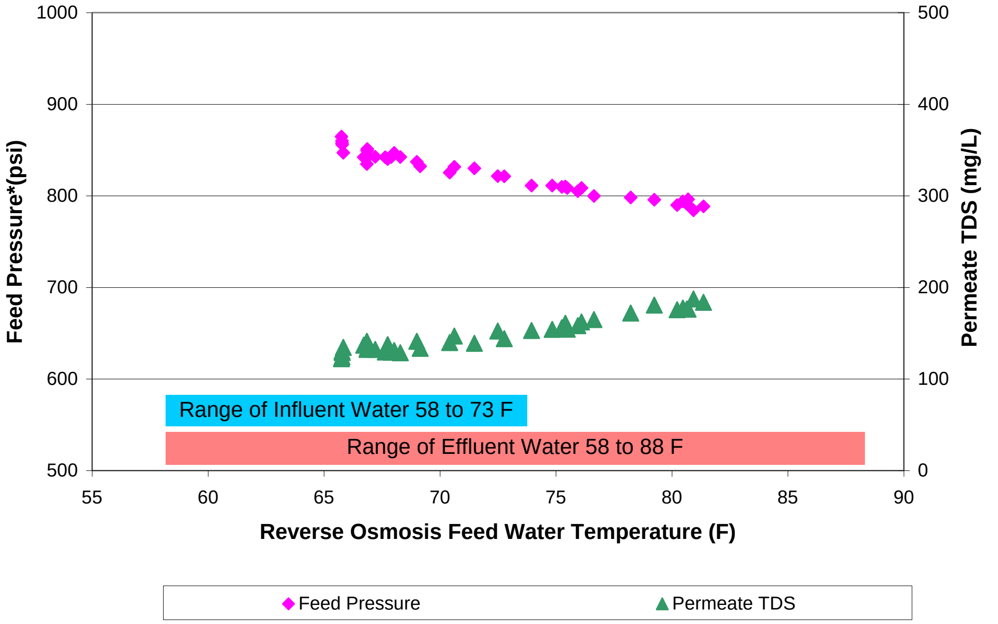
Another noteworthy point relates to the re-installation of the Toray and Koch membranes in December 2005. After substantial troubleshooting involving o-ring leaks with the Toray membrane, two new elements were installed on February 16, 2006 and permeate conductivity returned to the values seen in previous testing.

Figure 6-68 Summary of RO Conductivity



One important aspect of RO membranes is their response to changes in feed water temperature. When the temperature of the feedwater is elevated, salt passage through the membrane increases resulting in an increased overall TDS concentration in the RO permeate. This higher salt passage at elevated temperatures will result in elevated levels of individual ions such as chloride and boron. The permeability of the membrane also increases with elevations in feedwater temperature (although at a different rate than salt passage), resulting in less operating pressure required to achieve the same flux. Figure 6-69 shows a window of operation for the Dow SW30HRLE membrane as the temperature increased. Note the decrease in feed pressure required to maintain a constant flux and the increase in permeate TDS concentration. This window only shows the response to a temperature band of 65-80ºF. The actual operating window (as noted on the Figure) extends to a greater temperature range. This results in a greater range of feed pressure, permeate TDS and individual ion concentrations. Measured permeate boron and chloride concentrations as a function of temperature are displayed in Figures 6-70 and 6-71, respectively.

Figure 6-69 Temperature Effects on RO Membrane



*Feed Pressure Normalized to 10 GFD, Not Normalized for Temperature, SW30HRLE Membrane

Figure 6-70 Permeate Boron Concentration vs. Temperature at 12 gfd

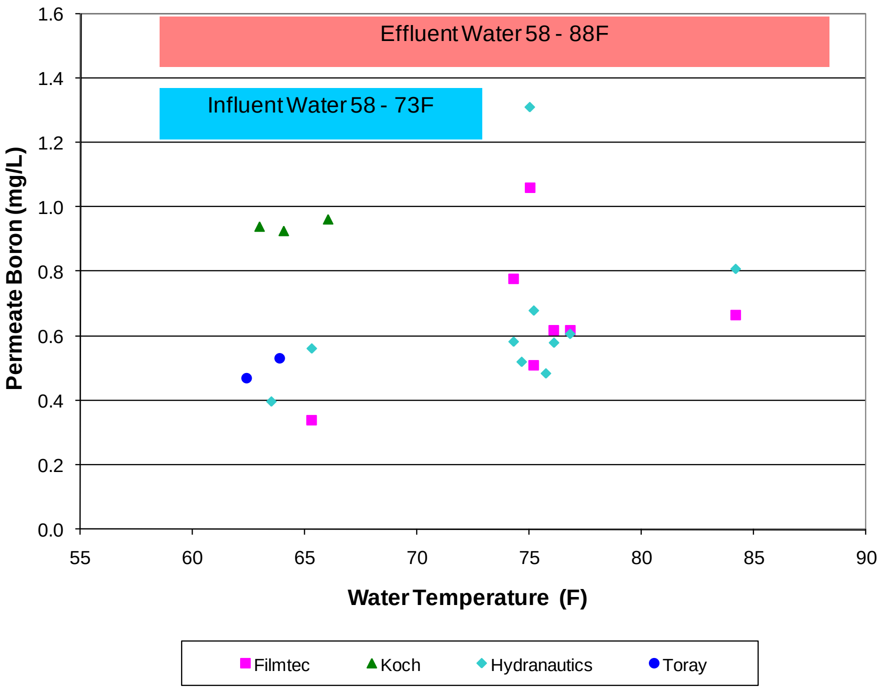
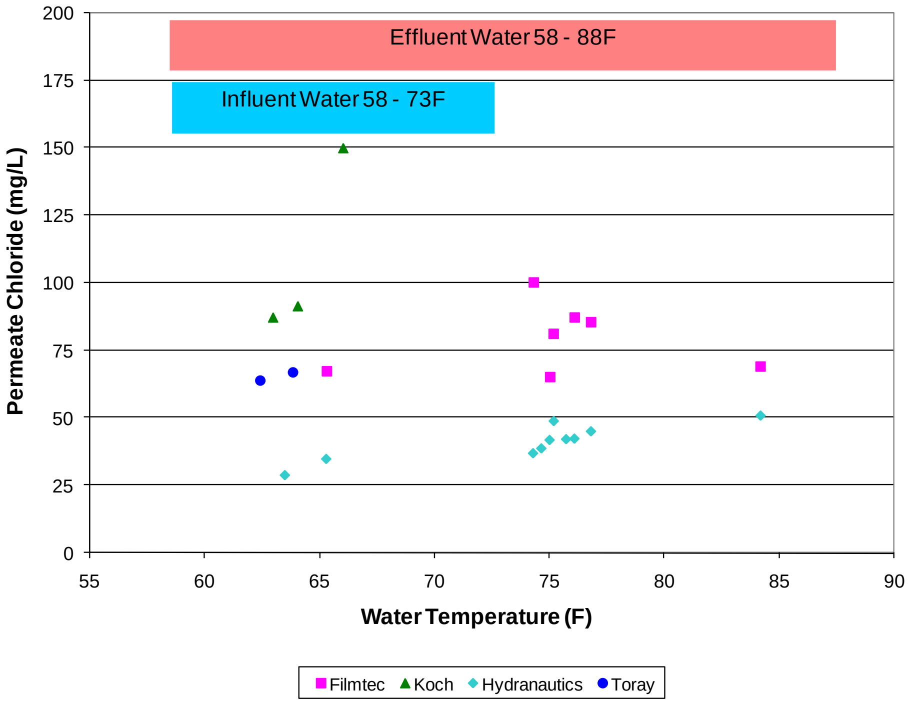


Figure 6-71 Permeate Chloride Concentration vs. Temperature at 12 gfd



Figures 6-72 and 6-73 illustrate the Dow and Hydranautics performance from June – September 2007 with respect to both raw and normalized conductivity (normalized for flow and temperature variations). The temperature of the post condenser effluent water varied greatly when the power plant was operating, with temperatures reaching 100ºF at times. When the temperature of the feedwater is elevated, salt passage through the membrane increased resulting in an increased overall raw conductivity values as seen in the figures. These raw values were then normalized to account for fluctuations in temperature in order to properly trend the conductivity of the RO permeate.

Figure 6-72 Dow SW30HRLE Permeate Conductivity June 2007 – February 2008

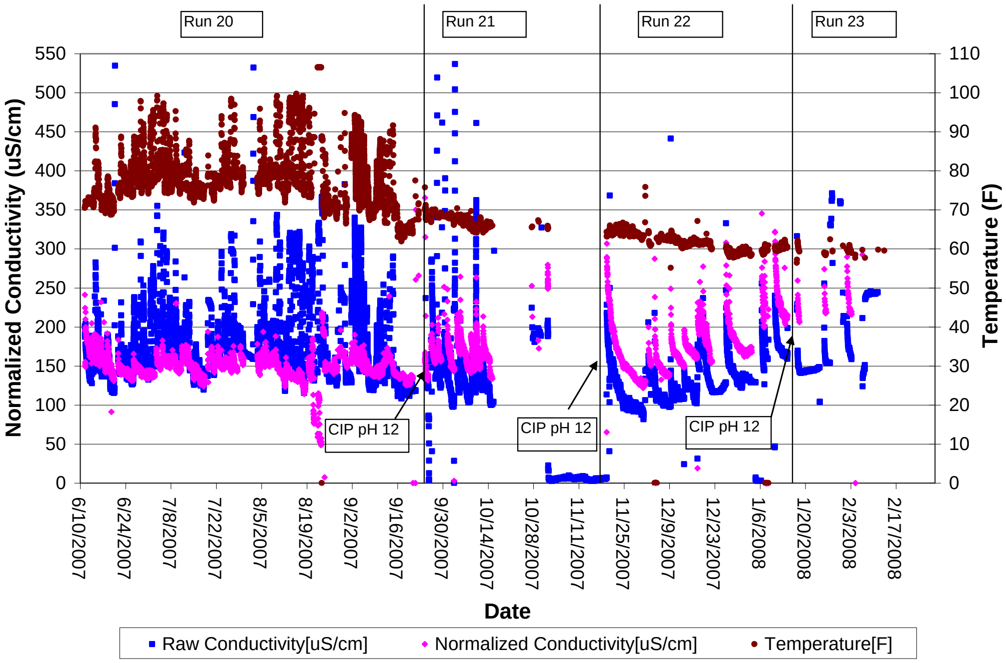
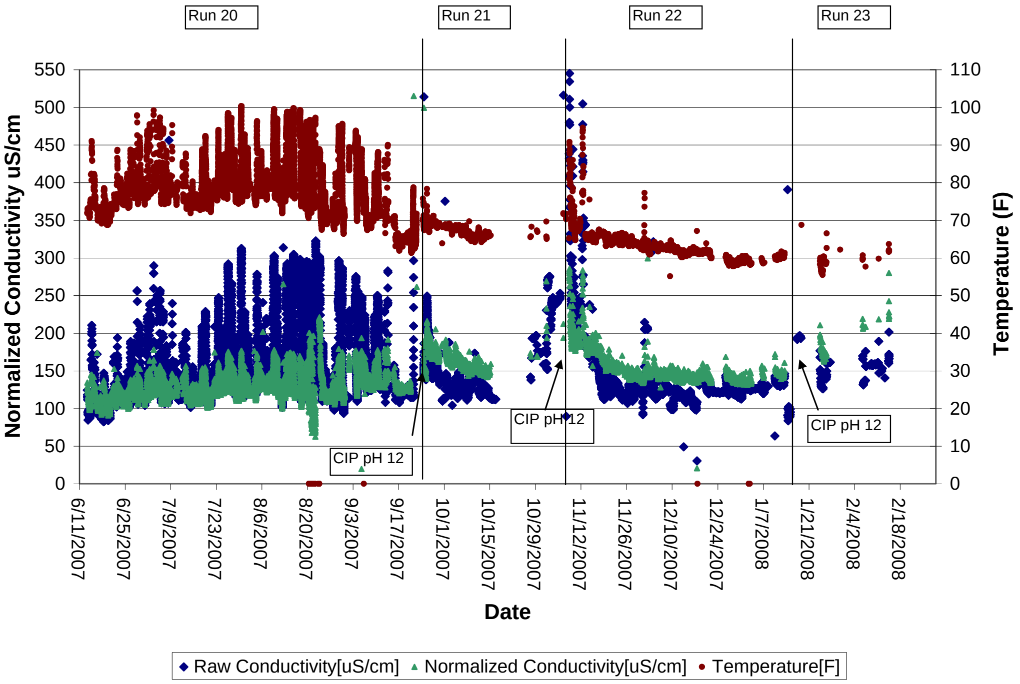


Figure 6-73 SWC4+ Permeate Conductivity June 07 – February 08



During Run 22, the Filmtec membranes were started and stopped several times over the course of the run. Spikes in conductivity are present upon startup, and then the conductivity gradually comes down over time, although not to a normal level. These spikes are out of the ordinary, and an examination of vessel conductivity in Table 6-32 confirms the increasing trend in conductivity in the second vessel. A check for o-ring leaks confirmed a breach which resulted in the high conductivity, and is not attributed to membrane damage.

Table 6-32 Conductivity Profiles

		SW30HRLE		**SWC4+**	
Date	**Feed (µS/cm)**	**Vessel 1 (µS/cm)**	**Vessel 2 (µS/cm)**	**Vessel 1 (µS/cm)**	**Vessel 2 (µS/cm)**
11/25/07	47.59	52.7	149.2	76.8	161.2
12/9/07	45.82	66.82	193.2	72.5	142.6
12/26/07	51.45	128.5	273.3	95.1	192.3
12/30/07	49.66	100.3	171.3	82.5	165.5
1/6/08	50.17	90.0	**354.85**	87.8	188.8

Several attempts were made to correct for the o-ring leak, but unfortunately the problem could not be fixed before the testing was concluded for the Filmtec and Hydranautics membrane in mid February.

Water samples were collected throughout the period of testing for detailed analyses. The flux rate of the RO membranes were varied to 8, 10, and 12 GFD to obtain data on permeate water quality at these different flux rates. At each flux rate, two sets of samples were collected and the average data is shown in Tables 64 and 65 below. The TDS, chloride, and boron concentrations are also compared to the manufacturers’ projected performance at those conditions.

Table 6-33 Filmtec SW30HRLE Average Water Quality June 2007 – August 2007

	Filmtec 8 GFD Ave Temp 25.2ºC			Filmtec 10 GFD Ave Temp 28.3ºC			Filmtec 12 GFD Ave Temp 22.2ºC			
Parameter	**RO Feed**	**RO Permeate**	**Projected Permeate**	**RO Feed**	**RO Permeate**	**Projected Permeate**	**RO Feed**	**RO Permeate**	**Projected Permeate**	**Units**
TDS	37000	107	262	38500	105	260	36000	64	139	mg/L
Lab pH*	8.1	7.1		8.2	7.1		8.2	7.3		UNITS
Alkalinity (as CaCO3)	113	<2		115	<2		116	<2		mg/L
Bicarbonate (as CaCO3)	112	<2		113	<2		114	<2		mg/L
Carbonate (as CaCO3)	1.3	<0.1		1.5	<0.1		1.7	<0.1		mg/L
Hydroxide (as CaCO3)	0.06	<0.01		0.071	<0.01		0.08	<0.01		mg/L
Sulfate	2580	2.5		2590	2.5		2630	2.5		mg/L
Chloride	19450	60.2	153	19100	61	152	19350	38.3	81	mg/L
Nitrate (as N)	<25	<0.1		<25	<0.1		<25	<0.1		mg/L
Nitrite (as N)	<25	<0.1		<25	<0.1		<25	<0.1		mg/L
Bromide	67	<0.2		58	<0.2		61	<0.2		mg/L
Calcium	422	0.29		419	0.24		416	0.2		mg/L
Magnesium	1335	0.94		1355	0.83		1240	0.6		mg/L
Hardness (as CaCO3)	6551	4.6		6626	4		6144	3.2		mg/L
Ca Hardness (as CaCO3)	1054	0.7		1046	0.6		1038	0.5		mg/L
Sodium	11000	38.7		11100	38		10300	22.7		mg/L
Potassium	409	1.51		416	1.5		392	0.9		mg/L
Fluoride	0.85	<0.1		1	<0.1		0.9	<0.1		mg/L
Strontium				8	0.0048					mg/L
Barium	<0.025	<0.010		<0.025	<0.010		<0.025	<0.010		mg/L
Boron	4	0.6	0.92	3.9	0.63	0.87	4.1	0.35	0.59	mg/L
Silica	<10	<1		<10	<1		<10	<1		mg/L
Ammonia (as N)	<0.1	<0.1		<0.1	<0.1		<0.1	<0.1		mg/L
TOC	3.4	<0.5		3	<0.5		3	<0.5		mg/L

Table 6-34 Hydranautics SWC4+ Average Water Quality June 2007 – Aug 2007

	Hydranautics 8 GFD Ave Temp 25.2ºC			Hydranautics 10 GFD Ave Temp 28.3ºC			Hydranautics 12 GFD Ave Temp 22.2ºC			
Parameter	**RO Feed**	**RO Permeate**	**Projected Permeate**	**RO Feed**	**RO Permeate**	**Projected Permeate**	**RO Feed**	**RO Permeate**	**Projected Permeate**	**Units**
TDS	37000	91	194	38500	91	169	36000	58	111	mg/L
Lab pH*	8.1	6.3		8.2	6.3		8.2	6.4		UNITS
Alkalinity (as CaCO3)	113	<2		115	<2		116	<2		mg/L
Bicarbonate (as CaCO3)	112	<2		113	<2		114	<2		mg/L
Carbonate (as CaCO3)	1.3	<0.1		1.5	<0.1		1.7	<0.1		mg/L
Hydroxide (as CaCO3)	0.06	<0.01		0.071	<0.01		0.08	<0.01		mg/L
Sulfate	2580	<2		2590	<2		2630	<2		mg/L
Chloride	19450	51	113	19100	49	99	19350	31	65	mg/L
Nitrate (as N)	<25	<0.1		<25	<0.1		<25	<0.1		mg/L
Nitrite (as N)	<25	<0.1		<25	<0.1		<25	<0.1		mg/L
Bromide	67	<0.2		58	<0.2		61	<0.2		mg/L
Calcium	422	0.12		419	0.13		416	0.1		mg/L
Magnesium	1335	0.39		1355	0.32		1240	0.3		mg/L
Hardness (as CaCO3)	6551	1.9		6626	1.5		6144	1.6		mg/L
Ca Hardness (as CaCO3)	1054	0.3		1046	0.3		1038	0.7		mg/L
Sodium	11000	32		11100	31		10300	18.4		mg/L
Potassium	409	1.49		416	1.4		392	0.8		mg/L
Fluoride	0.85	<0.1		1	<0.1		0.9	<0.1		mg/L
Strontium				8	0.0023					mg/L
Barium	<0.025	<0.010		<0.025	<0.010		<0.025	<0.010		mg/L
Boron	4	0.63	0.57	3.9	0.67	0.49	4.1	0.29	0.35	mg/L
Silica	<10	<1		<10	<1		<10	<1		mg/L
Ammonia (as N)	<0.1	<0.1		<0.1	<0.1		<0.1	<0.1		mg/L
TOC	3.4	<0.5		3	<0.5		3	<0.5		mg/L

In mid March, the Filmtec and Hydranautics membranes were removed from the RO Trains and the Saehan RE 4040-SHN and Toray TM810 were installed in Train 1 and 2, respectively.

The start-up conductivity values for both the Saehan and Toray membranes were acceptable, and over time the permeate conductivity for the Toray membrane continued to come down to ~ 250 uS/cm as seen in Figures 6-74 and 6-75.

In the month of May there was an operational upset related to the use of elevated concentrations of chlorine in the Pall MF EFM cycle. As described in the MF section, on May 6th a manual EFM was initiated with a higher than normal concentration of chlorine of ~ 1250 mg/l. Upon restarting the MF system, some of the chlorine carried over to the MF permeate and into the break tank. The RO trains were undergoing routine sampling approximately 2 hours after the EFM, and a chlorine concentration of 0.3 mg/l was found in the feedwater. The RO trains were immediately flushed with RO permeate with SBS added to neutralize any free chlorine present. The break tanks were also dosed with SBS and drained. The MF system continued to run overnight before the RO trains were started in the next morning after confirming no chlorine was present in the RO feed water via the Hach test kit.

While the Saehan membrane did not show an increase in permeability after the chlorine event, over the course of the next several days the membranes did show an increase in conductivity (Figure 6-74). This is likely due to the brief exposure to chlorine. The Toray membrane did not experience any negative effects from the brief exposure to chlorine.

Figure 6-74 Saehan RE 4040-SHN Permeate Conductivity March – May 2008

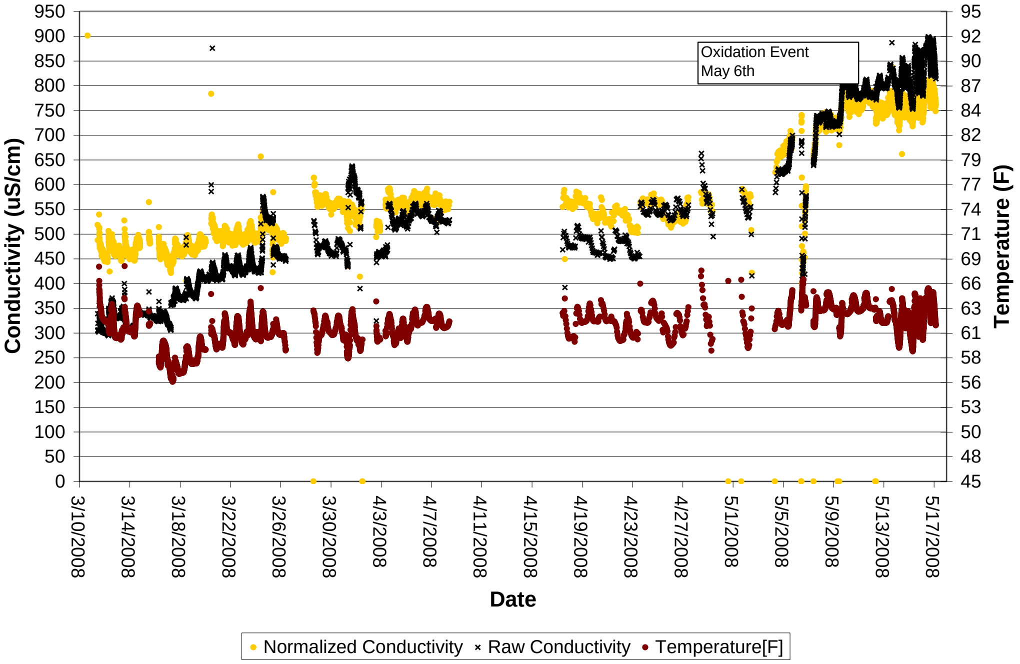
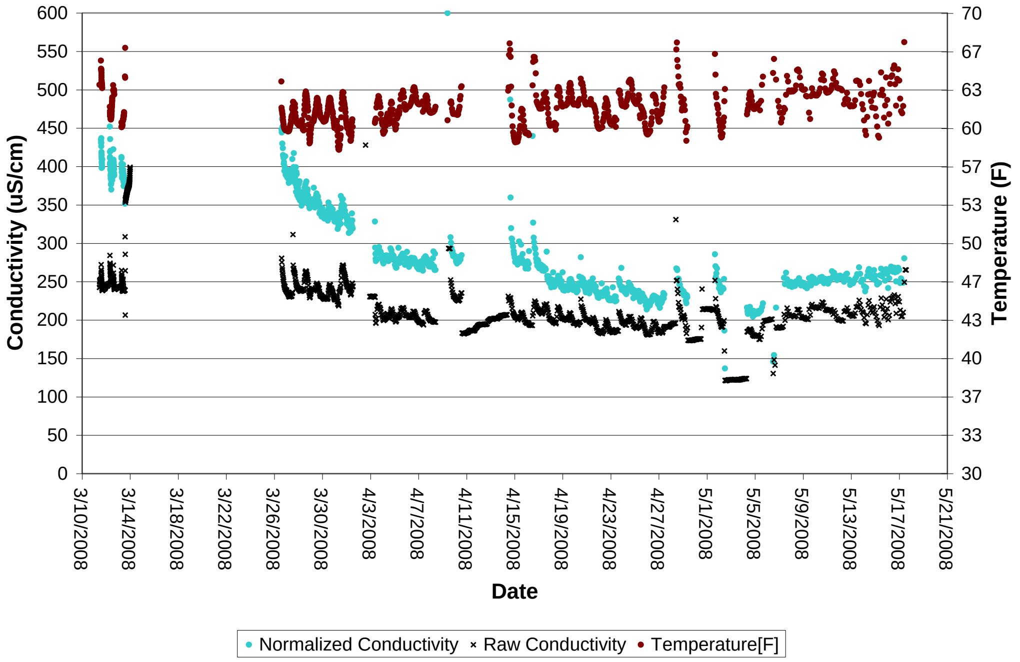


Figure 6-75 Toray TM810 Permeate Conductivity March – May 2008



6.6.5 Phase C Permeability / Permeate Quality

The SWRO Trains 1 and 2 were started up in September 2008 with the previous Toray and Saehan membranes installed that had been tested in the Spring of 2008. Part of the startup of the SWRO Trains included the startup of the new preformed chloramine system, which was designed to pre-form chloramines inline, and then dose 5-7 ppm of chloramine into the feed line to SWRO Train 1. Once the chloramine dosing system was working properly, new Hydranautics SWC5 SWRO membranes were to be loaded into the trains for a side by side comparison of membranes treated with and without chloramine in the feedwater to help control biofouling.

The original design for producing preformed chloramines consisted of injecting ammonium sulfate into a carrier water line, and then injecting sodium hypochlorite downstream of the ammonia. SWRO permeate was used as the carrier water to make the chloramine solution. The original chloramine dosing system did not work as planned, as it appears there was insufficient mixing in the dosing line to create a consistent solution of chloramines when ammonium sulfate and sodium hypochlorite were mixed together in the carrier water line. This is discussed further in Section 5.8

The performance for the both the Saehan and Toray membrane is shown in Figures 6-76 to 6-79. It is likely that a strong solution of sodium hypochlorite came in contact with the Toray membranes and oxidized the thin film membrane. This is evident by an increase in permeability as well as in increase in permeate conductivity after a chloramine dosing trial in late September.

Figure 6-76 Saehan RE 4040-SHN Permeability September – November 2008

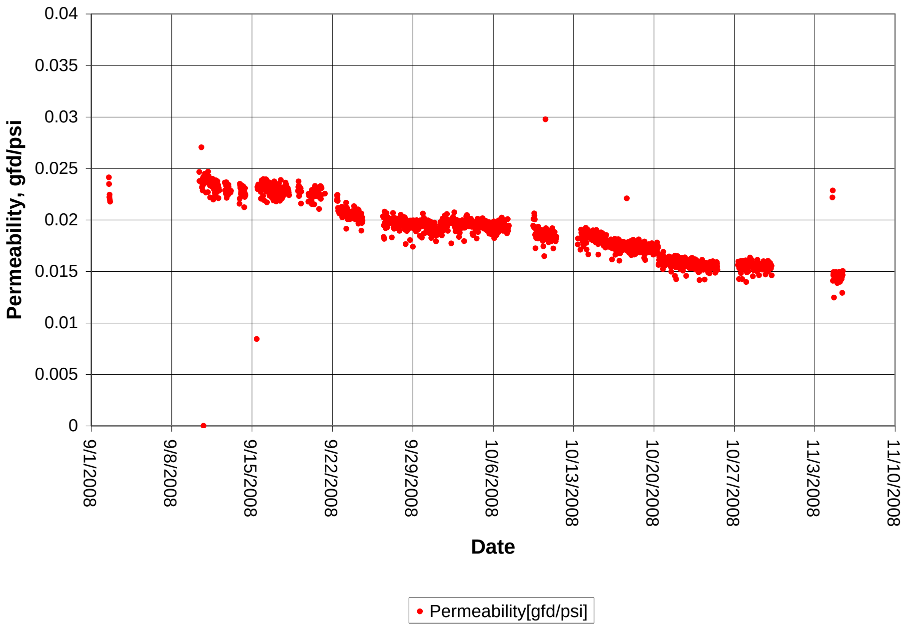


Figure 6-77 Toray TM810 Permeability September – November 2008

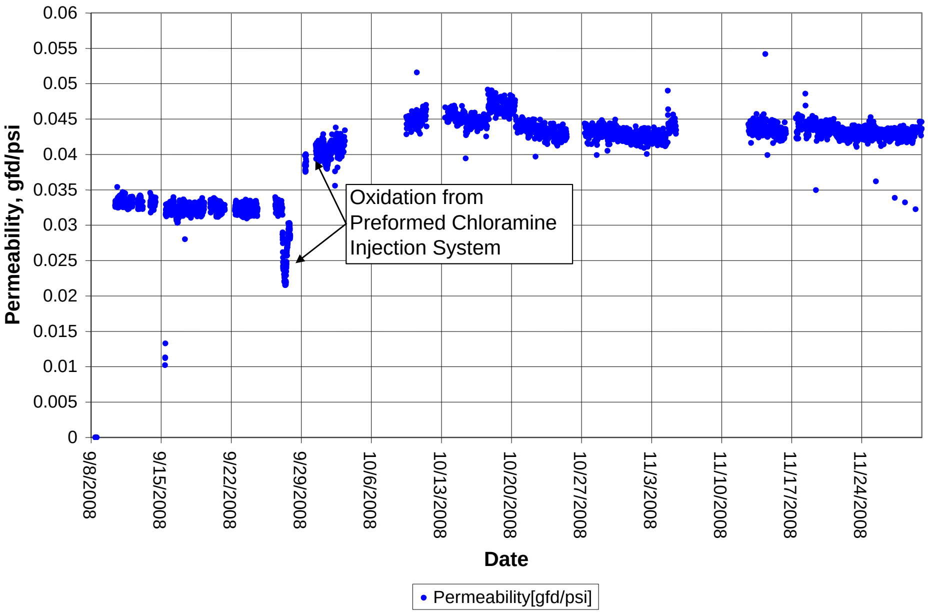


Figure 6-78 Saehan RE 4040-SHN Conductivity September – November 2008

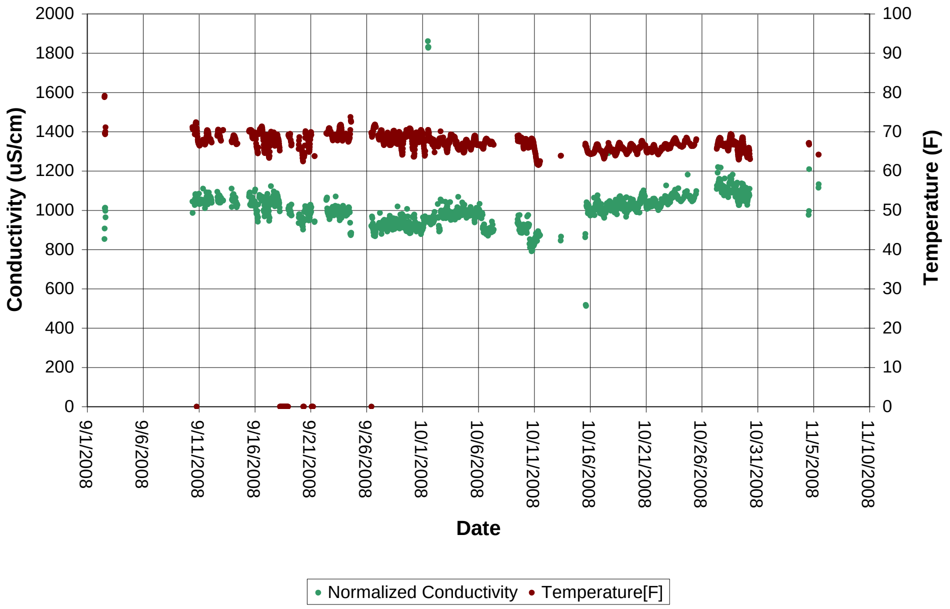
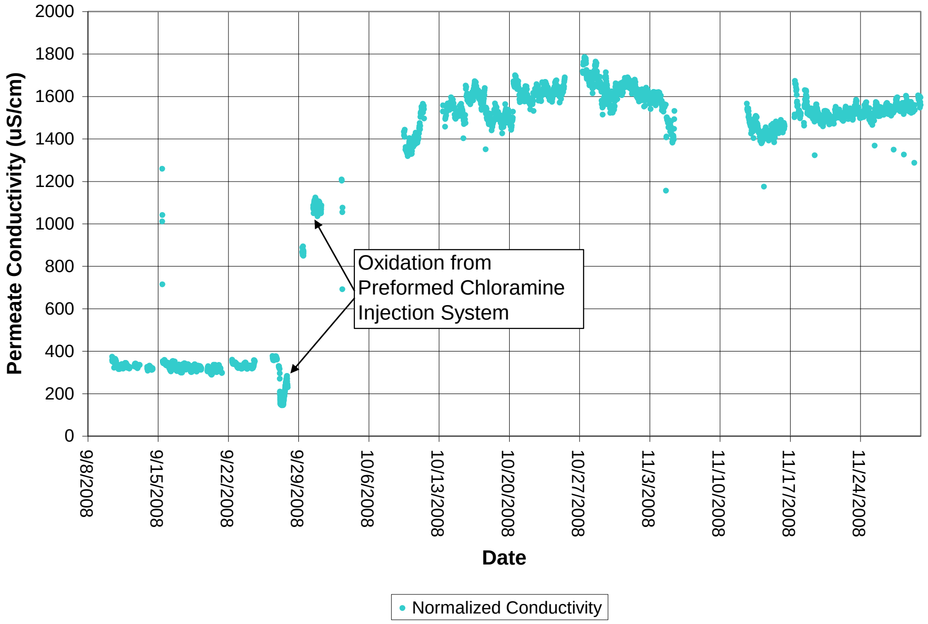


Figure 6-79 Toray TM810 Conductivity September – November 2008



On December 3rd, 2008 the Toray and Saehan membranes were removed from the trains and the new Hydranautics SWC5 SWRO membranes were loaded into both Trains 1 and 2.

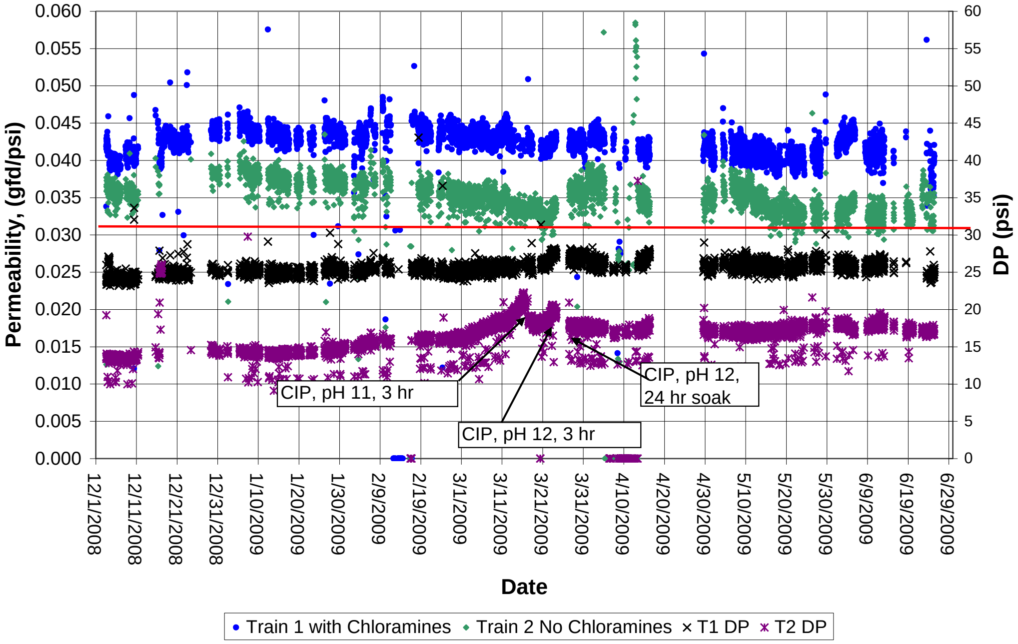
Upon loading the new membranes, the chloramine dosing system was started up and set to dose ~ 5-7 mg/l of chloramines into the feedwater of RO Train 1 only. An online ORP sensor had been previously installed in the feed line to RO Train 1, allowing for real time data to be collected to help monitor the performance of chloramine dosing system. Figure 6-80 shows the performance of the new SWC5 membranes with and without chloramine dosing.

The RO trains started up as expected during the first week of operation with no adverse effects from the chloramine dosing. However, it became evident as the month carried on that both sets of RO membranes were experiencing both an increase in permeability and conductivity. After much discussion the team came to the conclusion that the chloraminated RO permeate from Train 1 blended with the permeate from Train 2 to make up the RO flush water is the likely cause of oxidation. When the trains were to be shut down for a weekend or holiday, they were both flushed with RO permeate. Upon restarting the trains both the permeability and conductivity increased on more than one occasion. This is especially evident around the time of December 28th, where a large spike in the ORP was seen following a flush. This is discussed in further detail in Section 5.8, which details the chloramine trials.

It was decided that SBS was to be added to the flush tank prior to flushing the RO membranes during an extended shut down to neutralize any chloramine/chloramine byproducts in the flush water.

The most noteworthy trend seen in the permeability performance graph (Figure 112) is the fouling that occurred on Train 2 in March, and the lack of fouling of Train 1 during that same period. It is evident that the use of chloramines in Train 1 feedwater helped to prevent biofouling. Other than the initial increase in permeability witnessed at the beginning of the test, the permeability of Train 1 remained stable, compared to Train 2. It is also evident that the Hydranautics SWC5 membrane is tolerant to preformed chloramines present in the feedwater at 5-7 mg/l over the 6 month testing period.

Figure 6-80 Hydranautics SWC5 Train 1 and 2 Permeability December 2008 – June 2009



A decrease in permeability and increase in DP was seen for Train 2 in March 2009. Figure 114 details the CIP trials that were performed on Train 2 during this period. CIP 1 was performed on March 16th on Train 2 with a 2% solution of Avista P111 with a pH of 11.1 heated to 35ºC. The cleaning consisted of recirculation of the solution for 1 hour, followed by a 30 minute soak and then a 30 minute recirculation. The system was then flushed with permeate water to remove the cleaning solution, and then citric acid was added to the flush tank and the unit was flushed with low pH RO permeate water. A separate low pH cleaning step was not performed as biofouling is not typically removed from membranes with a low pH cleaning step. While the RO Trains were shut down for the CIP, the RO feed tank and feed piping were treated with a chlorine and caustic solution to kill and remove the biogrowth present in the feed piping.

After this high pH cleaning the RO system was started back up. Although there was some decrease in the high DP values in Train 2, the DP values did not return to startup values, so it was decided to try a more aggressive cleaning. Another high pH cleaning step, CIP 2 was performed on March 18th, but this time the 2% Avista P111 solution was adjusted to pH 12 by adding NaOH to the cleaning solution. This solution was heated to 30ºC per Hydranautics guidelines and then Train 2 was soaked for 3 hours in the cleaning solution. Train 2 was flushed as before and then started back up. There was very little improvement in performance after this cleaning.

The system ran for another week and then it was decided to try another high pH 12 soak, CIP 3, but this time for a 24 hour period. This was performed on March 25-26. This extended high pH 12 soak is considered an aggressive cleaning as the membranes are at risk of chemical attack. However, previous high pH cleanings of biofouled membranes at the pilot had proven successful, so it was decided this was a prudent step. After soaking for 24 hours, the system was brought back online and showed higher permeability and lower DP. The 24 hour soaking was more effective at restoring performance than the shorter 3 hour soak. Although there was some decline in permeability in May (Figure 6-81), there was not a similar drastic increase in DP that was seen previously in March, and the elements were not cleaned again during this study.

Figure 6-82 Hydranautics SWC5 Train 2 Permeability March 2009

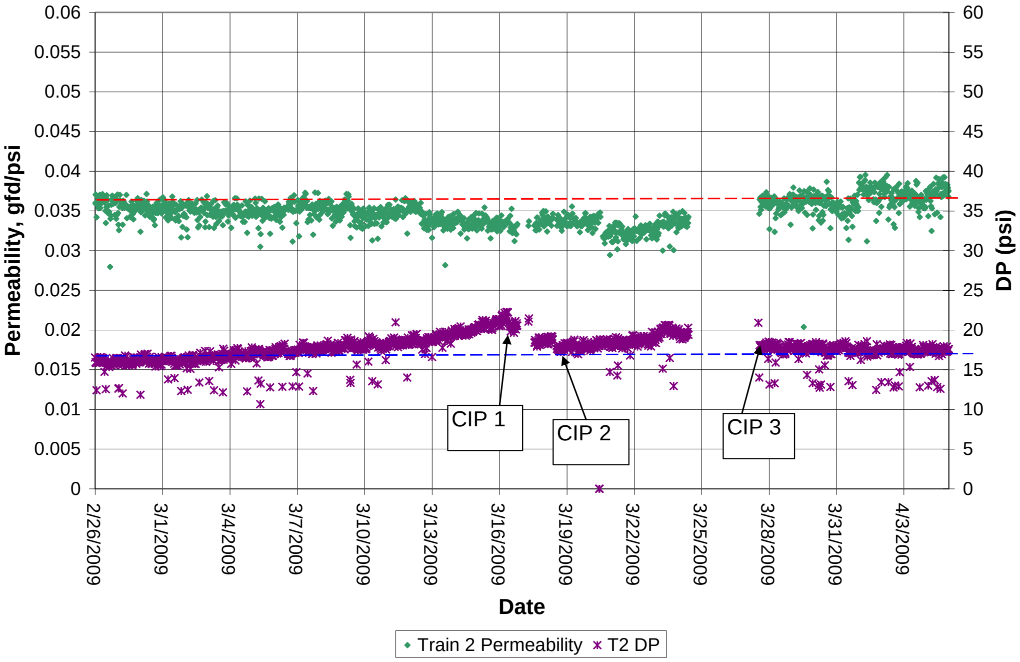
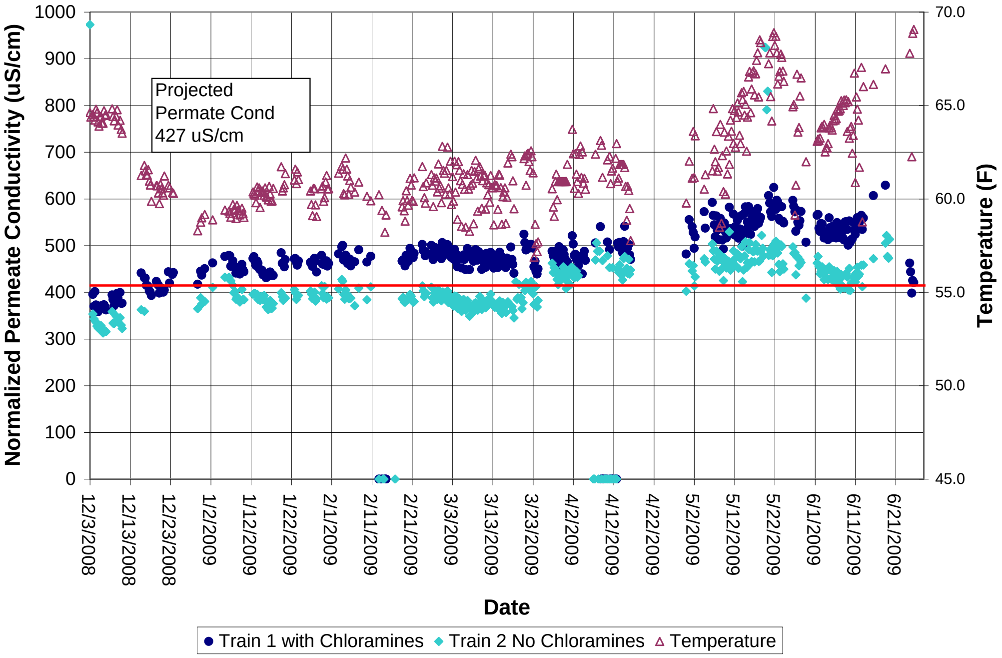


Figure 6-81 details the conductivity trends for both Trains 1 and 2. Trains 1 and 2 experienced an apparent increase in permeate conductivity in May. However, the system was shut down in mid June, and when the system was restarted on June 22nd the conductivity for Train 1 was lower and in line with previous values.

Figure 6-81 Hydranautics SWC5 Train 1 and 2 Permeate Conductivity December 2008 – June 2009



An examination of conductivity values from each vessel indicates that the tail vessel did show an increase in conductivity in mid-May (Table 6-35), but it was not clear if this was from internal leaks, or actual membrane performance.

Table 6-35 Train 1 Conductivity Profiles

Date	Vessel 1 Conductivity (uS/cm)	Vessel 2 Conductivity (uS/cm)
3/30/2009	256	683
4/7/2009	271	746
4/8/2009	263	733
4/15/2009	244	635
5/6/2009	268	767
5/8/2009	276	797
5/15/2009	321	**934**
5/21/2009	330	**1071**
5/22/2009	310	**968**
5/26/2009	307	897
6/2/2009	278	808
6/9/2009	292	838
6/10/2009	274	746

At the conclusion of the testing, four elements were sent back to Hydranautics to undergo a retest of the flow and rejection parameters. Prior to leaving the Hydranautics factory the RO elements were initially "wet-tested", and the flow and rejection parameters were measured to make sure the elements were within specification. For the retest, the elements were subjected to the same test conditions as the original wet-test, and flow and rejection was measured again. The results of the original wet-test and the retest are shown in Table 6-36. The Train 1 elements, which had been subjected to chloramines, experienced a decrease in flow of 16% and 13%, but experienced an increase in salt rejection. This is a very strong indication that the SWC5 membrane is tolerant to the 5-7 mg/l of chloramine exposure over the course of 6 months (total exposure of approximately 2500 hours). The Train 2 elements experienced a loss in flow of 9% and 5%, but these elements had undergone extensive cleaning approximately halfway through the 6 months of operation, and were not cleaned after running for another 3 months. These elements also experienced an increase in salt rejection.

The results of the retest are very encouraging, as they indicate no major damage occurred to the either set of membrane elements that were subjected to chloramines (Train 1) and aggressive cleaning procedures (Train 2).

Table 6-36 Hydranautics SWC5 Element Retest Data

RO Element Serial #	RO Train / Element Position	Original Flow (gpd)	Retest Flow (gpd)	% Difference	Original % Rejection	Retest % Rejection
A1505602	Train 1 / # 2	1694	1428	-16%	99.6	99.86
A1505557	Train 1 / # 6	1594	1388	-13%	99.8	99.84
A1505520	Train 2 / # 2	1570	1423	-9%	99.8	99.89
A1505546	Train 2 / # 6	1547	1467	-5%	99.7	99.83

Table 6-37 shows the average water quality or the RO Feed, Concentrate and Permeate for Train 1 from December 2008-June 2009.

Table 6-37 Hydranautics SWC5 Average Water Quality (Train 1), Phase C December 2008 – June 2009

Parameter	RO Feed	RO Permeate	RO Concentrate	Units
TDS	36,010	192	69,000	mg/l
Alkalinity (as CaCO3)	111	<2	208	mg/l
Sulfate	2,595	<2	5,457	mg/l
Chloride	19,257	111	36,629	mg/l
Nitrate (as N)	<25	<0.1	<100	mg/l
Nitrite (as N)	<25	<0.1	<100	mg/l
Bromide	61	0.39	<200	mg/l
Calcium	394	0.38	755	mg/l
Magnesium	1,210	1.1	2,363	mg/l
Hardness (as CaCO3)	5,965	4.7	11,617	mg/l
Ca Hardness (as CaCO3)	983	0.95	1,885	mg/l
Sodium	10,195	68	19,587	mg/l
Potassium	367	2.7	697	mg/l
Boron	3.5	0.9	5.6	mg/l
Silica	<10	<1	<10	mg/l
TOC	0.7	0.1	1.7	mg/l
Color	4	<3	NA	color units

Average Flux: 9 GFD ***Average Temperature: 15.3°C***

6.6.6 Summary of SWRO Fouling

The following is a summary of the five distinct Reverse Osmosis fouling events experienced in Phase B and C, with the details of each occurrence below:

- Four distinct RO fouling events occurred during the 3+ years of Phase B testing, and one event occurred in Phase C.

- In Phase B, two of the events occurred during algae blooms, with one event on power plant influent water at a temperature of approximately 65ºF and the other on influent water with an average temperature range of 60-65ºF. The CIP procedure using a commercial membrane cleaner at pH 12 proved more effective at restoring permeability than using either a generic formulation of pH 11 or a commercial cleaner of pH 11.

- The third event was on power plant effluent water at 72-78ºF, with no algae bloom in effect but with biogrowth present in the break tank. The CIP utilizing the commercial cleaner at pH 10.5-11 proved to be effective at restoring permeability.

- The fourth event also occurred on power plant effluent water, with an elevated temperature range of 75-90ºF. There was a continuous presence of algae in the ocean during this time frame, and visual inspection of RO membranes indicated a biofouling layer was present in the RO membranes as well as throughout the RO system piping. The commercial membrane cleaner at an elevated pH of 12 was effective at restoring permeability to the Hydranautics membrane.

- The fifth fouling event occurred in Phase C, on Train 2, the Train with no chloramine dosing. This was on power plant influent water with a temperature between 60-63ºF. A commercial cleaner at pH of 12 with a 24 hour soak time was required to significantly restore performance.

The first fouling event occurred in late May and early June of 2005 on the Dow SW30HRLE and Hydranautics SWC4+ membrane. This fouling coincided with a severe algae bloom present in the ocean water where the pilot plant is located. The feed water source was influent water, with an average temperature of approximately 65ºF. A two step cleaning procedure was used for this first fouling event. Step 1 was a 2% citric acid (pH ~2) heated to 35 – 38ºC. Step 2 was a high pH with a generic formulation of:

- 1% sodium tripolyphosphate,
- 1% tetrasodium EDTA
- 1% trisodium phosphate
- The pH was adjusted to 11 and heated to 35 – 38ºC.

This generic formulation is commonly used for cleaning RO membrane; however, it had no effect on restoring permeability. No other formulations were evaluated at this time.

The second fouling event occurred in March of 2006 on the Toray TM810 and Koch 1820SS membranes. This fouling also coincided with an algae bloom that was verified by presence of domoic acid in the feedwater and by satellite imagery. The feed water source was influent water with an average temperature range of 60-65ºF. In anticipation of difficulty in cleaning these membranes, two Koch elements (Serial # 4010 and 4042) were sent to Avista Technologies for a cleaning study. The study consisted of using commercial membrane cleaners P111 (2% solution, pH 11) and P112 (1% solution, pH 12), both heated to 35ºC. The P111 cleaner improved #4042 permeability by 23%, and the P112 cleaner improved # 4010 permeability by 27% bringing the flow within 16% of its original factory flow data. This cleaning trial was very encouraging.

The third fouling event occurred in August and September of 2006 on new sets of Dow SW30HRLE and Toray TM810 membranes. This was a biofouling event, as green biogrowth was found in the break tank between the MF and RO units. The feedwater source was effluent water, and water temperature was elevated to an approximate range of 72-78ºF. Since there was no evidence of an algae bloom during this time frame, and biogrowth was found in the break tanks, a cleaning with 2% citric acid (pH ~2) and Avista P111 (pH~ 10.5), both heated to 35 – 38ºC, was performed on the Toray membrane. This cleaning proved to be successful in restoring permeability. This procedure was not able to be performed on the Dow membranes due to the timing of pilot plant relocation effort.

The fourth fouling event occurred in August and September of 2007 on the same set of Dow membranes mentioned in the above paragraph, and a new set of Hydranautics SWC4+ membranes. The feedwater source was effluent water, with an average temperature range of approximately 75-90ºF. The power plant was running consistently during the summer of 2007, and temperature spikes occasional reached 100ºF. There was also a persistent presence of algae in the ocean water during RO operation from June through September, and visual inspection of the RO membranes prior to cleaning revealed a layer of biofouling in the RO membranes and RO system piping. A cleaning with 2% citric acid (pH ~2) and Avista P111 (pH~ 10.5), both heated to 35 – 38ºC, was performed on the Hydranautics membrane with no effect on restoring performance. Biogrowth continued in the system until another CIP was implemented on the Hydranautics membrane approximately two weeks later. This CIP procedure utilized a 2% citric acid (pH ~2) heated to 35º C and 1% Avista P112 (pH 12) heated to only 30º C per Hydranautics specifications on operating limits at elevated pH. This cleaning proved to be successful at restoring permeability of the Hydranautics membrane back to startup values.

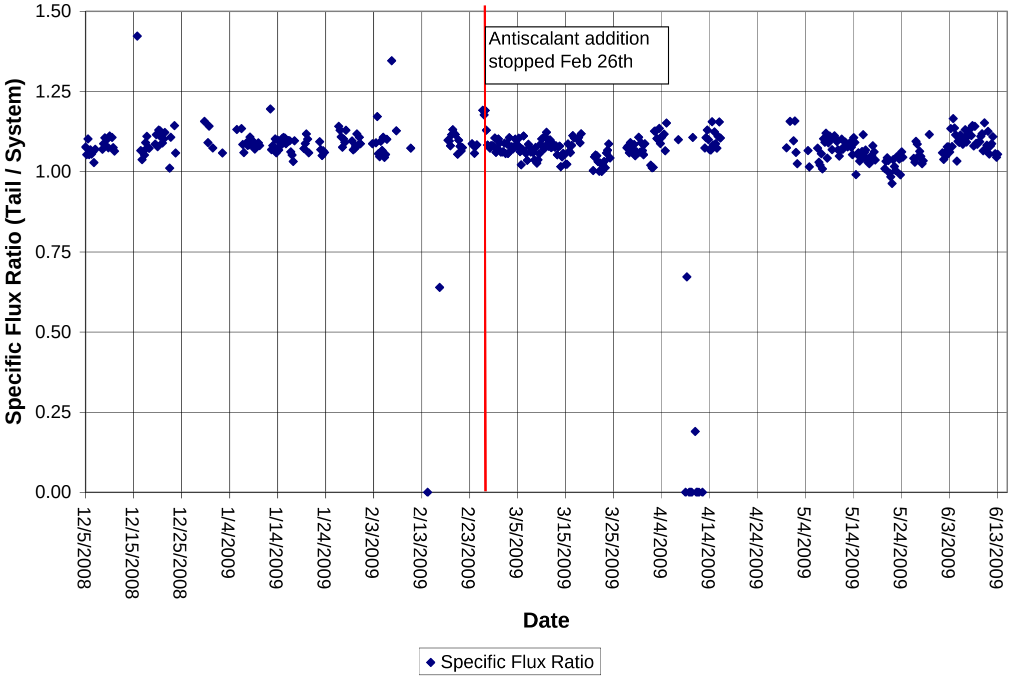
The same formulation was then utilized on the Dow membranes, with the only difference being heating the P112 solution to 35º C, per Dow specifications. This procedure did have some effect on restoring permeability, but the operating data after the cleaning suggests that more foulant may have been able to be removed.

The last fouling event occurred in Phase C in March of 2009 on intake water with a temperature of approximately 60ºF. The full details of the cleaning are described above in the Phase C RO performance section. An extended 24 hour soak with a pH 12 Avista P111 solution was required significantly restore performance from the biofouling.

6.6.7 Antiscalant Use in SWRO Train

Throughout Phase A and B of this study antiscalant was injected into the feed water to the SWRO system at ~3 mg/l to prevent scale formation from sparingly soluble salts in the seawater. In Phase C a trial was performed with no antiscalant addition at all to determine the effect of antiscalant on SWRO membrane performance. The specific flux ratio for Train 1 was used to monitor this performance. The specific flux ratio used was the average specific flux of the last four SWRO elements (vessel 2) divided by the average specific flux of all seven SWRO elements (vessel 1 and 2). If salts were to precipitate out of solution, this would occur in the tail end elements of the system, as the salts become more concentrated by the RO process. These precipitated salts then deposit onto the membrane surface of the tail elements, inhibiting permeate flow, and a decline in the specific flux ratio becomes evident. This data is shown in Figure 116. As seen in the data, there is no decline in the specific flux ratio. This data is encouraging, in that it shows that the use of antiscalant may not be necessary in a SWRO system operating at 50% recovery on Southern California Pacific Ocean water.

Figure 6-83 Hydranautics SWC5 Train 1 Specific Flux Ratio



6.6.8 Summary of SWRO Performance

Table 6-38 is a summary of the key parameters related to RO performance over the course of testing. This table shows that there are differences in membrane performance with regards to both permeability and rejection. Figures 115 and 116 display this information in graphical form, normalized to 9 GFD and 20°C.

Table 6-38 – Summary of SWRO Performance

Membrane	Average Permeability (GFD/PSI)	Average Permeate TDS (mg/l)	Average Permeate Chloride Concentration (mg/l)	Average Permeate Boron Concentration (mg/l)	Average Permeate Bromide Concentration (mg/l)
Filmtec SW30	0.024	166	89	0.75	<0.25
Hydranautics SWC1	0.025	174	94	1.03	<0.25
Filmtec SW30HRLE	0.025	80	45	0.45	<0.2
Hydranautics SWC4+	0.023	69	39	0.48	<0.2
Koch 1820SS	0.024	173	121	1.13	NA
Toray TM810	0.026	97	60	0.51	0.24
Saehan RE-4040SHN	0.022	245	150	1.26	0.64
Hydranautics SWC5	0.030	174	108	0.85	0.42

Data Normalized to 9 GFD and 20°C

A lower membrane permeability means that the feed pressure to that RO membrane will be higher in order to produce a certain amount of product water. Table 6-39 shows the equivalent RO feed pressure based on the above average permeability values from Table 6-38.

Table 6-39 – SWRO Equivalent Feed Pressures

Membrane	Equivalent RO Feed Pressure (psi)
Filmtec SW30	900
Hydranautics SWC1	895
Filmtec SW30HRLE	888
Hydranautics SWC4+	921
Koch 1820SS	907
Toray TM810	882
Saehan RE-4040SHN	943
Hydranautics SWC5	832

Data Normalized to 9 GFD and 20°C

Figure 6-84 summarizes the average permeability and average permeate TDS, normalized to 9 GFD and 20°C.

Figure 6-84 Summary of Permeability and Permeate TDS

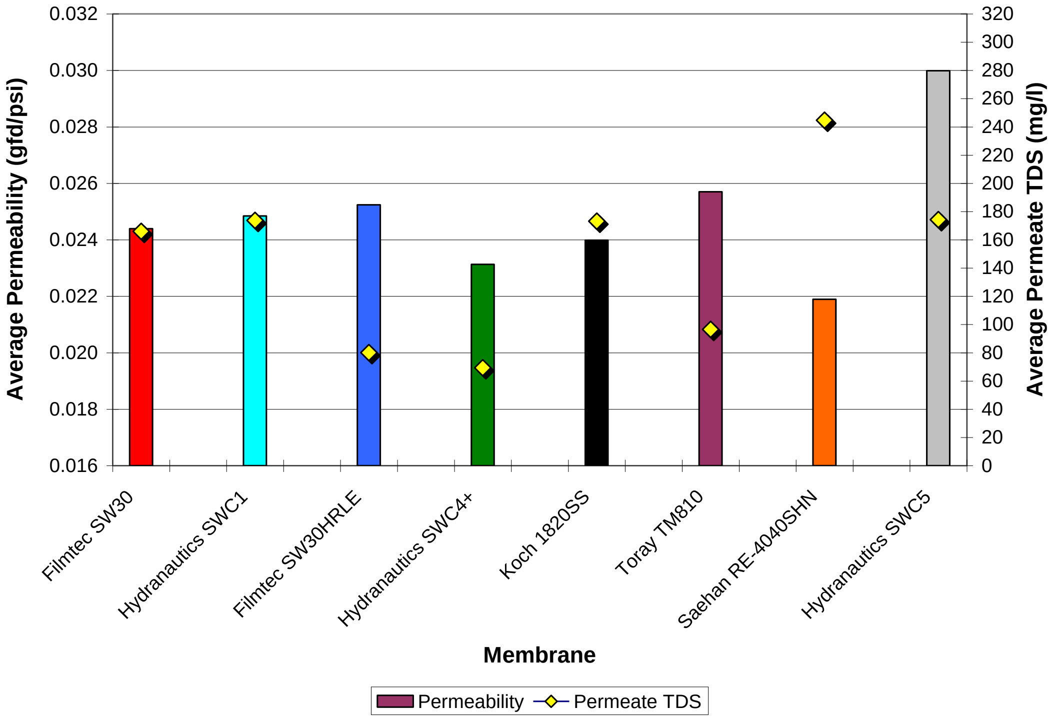
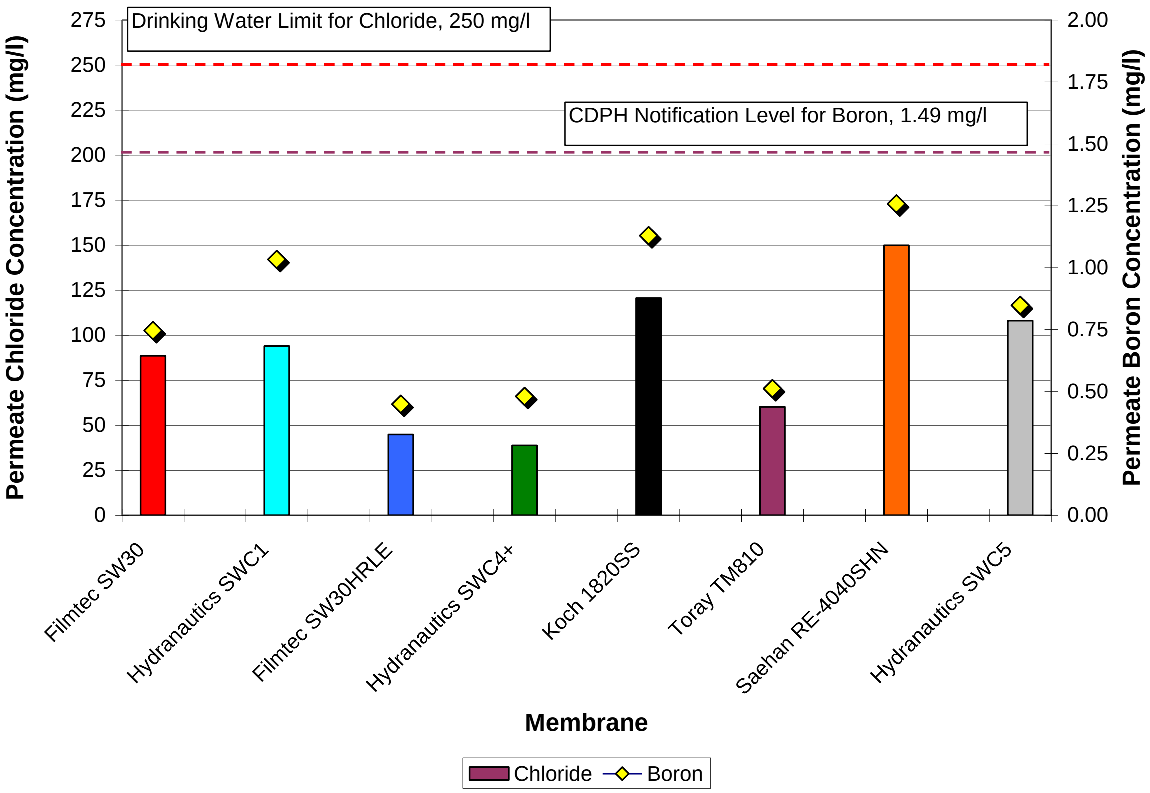


Figure 6-82 shows the average chloride and boron concentrations for each membrane tested, normalized to 9 GFD and 20°C, along with Drinking Water limits on Chloride and Boron.

Figure 6-85 Summary of Permeate Chloride and Boron Concentrations



6.7 Second Pass RO System

In order to achieve lower levels of boron in the finished water, a second pass RO system is needed to further treat the permeate from the SWRO unit. Depending on the final concentration of boron desired in the finished water, only a certain portion of the SWRO permeate needs to be further treated by the second pass RO unit, which is commonly referred to as a partial second pass process. Finished water quality targets for boron may be as low as 0.5 mg/l.

Boron is not very well rejected by reverse osmosis membrane in it's commonly found dissolved form of boric acid in ambient seawater. Typical boron concentrations in SWRO permeate ranged from 0.7-1.0 mg/l throughout the pilot study. In order to enhance the boron rejection by the second pass system, the pH of the second pass feed water (SWRO permeate) is increased by adding sodium hydroxide. Increasing the pH causes a shift in the equilibrium from the non-ionized (and poorly rejected) boric acid form to the ionized (and better rejected) borate form.

6.7.1 Performance at Various pH Levels

In order to assess permeability and rejection characteristics at various pH levels, the pH of the second pass RO feed water was increased by increments of 0.5, starting at a pH of 9. Figure 6-84 shows the permeability of the ESPA 2 BWRO membrane elements. The permeability was stable for the two months of testing at pH levels and 9 and 9.5, but showed an increasing trend when the pH was raised to 10 in late February/early March. Although run time was sporadic after March, there was no decline in permeability at pH of 10.5. System recovery was approximately 77-80%, and no antiscalant was used during this time frame for the second pass RO unit. Although the desired setpoint was 90% recovery, it was difficult to maintain those flow conditions at such low flow rates on the equipment.

Figure 6-84 Hydranautics ESPA Second Pass RO Permeability 2009

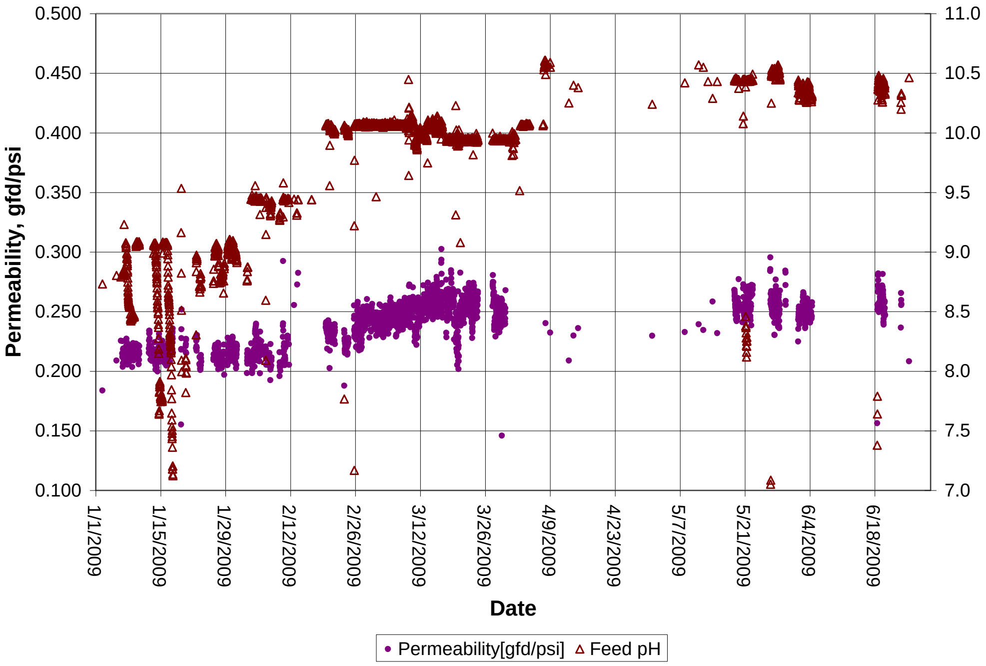
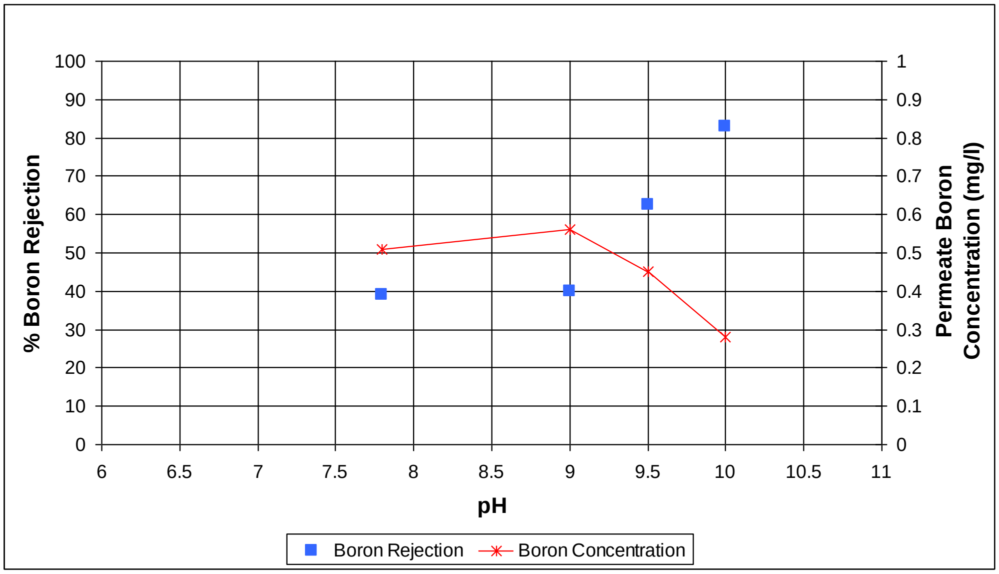


Figure 6-85 shows the boron rejection and permeate boron concentration at the varying pH levels between December and February. The samples analyzed were part of the weekly sampling events during this period, if the 2nd Pass unit was in operation. This data shows an increase in boron rejection (lower permeate boron concentrations) as the pH increases.

Figure 6-85 Long Term Operating Data, Boron Rejection vs pH



A test was performed on April 2, 2009 to gather more data at the different feed pH levels. During this test, the recovery was maintained at 90%, and the feed pH was increased from ambient levels up to 10.5, as shown in Figure 6-86. The trend of increasing boron rejection in this test follows the trend of the long term operating data, but the results differ a bit, in terms of boron permeate concentration at each pH level. The confirmation of the trend is encouraging, but the study of pH and final boron permeate concentration should continue.

Figure 6-86 Short Term Grab Sample Test, Boron Rejection vs pH

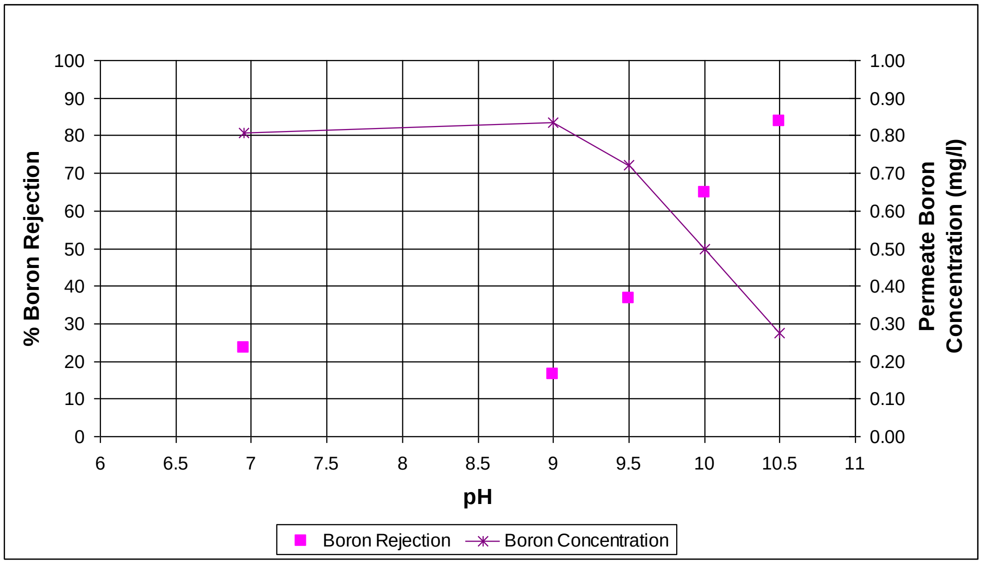


Table 6-87 shows the overall conductivity of the feed water as pH is increased, as well as the overall conductivity and boron concentration of the permeate during the April short term grab sample test. The addition of NaOH used to raise the pH also contributes to the increase in conductivity seen in both the feed and permeate.

Table 6-87 Conductivity and Boron Concentration at Various pH Levels

Feed pH	Feed Conductivity (uS/cm)	Permeate Conductivity (uS/cm)	Boron Concentration (mg/l)
6.95	360	9.4	0.81
9	351	11.2	0.83
9.5	359	15.3	0.72
10	372	22.3	0.50
10.5	406	50.2	0.28

6.8 Chloramines

6.8.1 Introduction

As mentioned previously, the use of chlorine and the formation of chloramines was trialed in an effort to reduce biofouling of both the MF treatment process and SWRO treatment process. Fouling, quite simply, is the loss of water permeability or throughput due to the accumulation of one or more foreign substance on the surface of the membrane. (American Water Works Assoc., 1999) As a result of the loss of permeability, fouled membranes require more pressure than clean membranes to produce an equivalent amount of product water. Fouling rates are typically the driving factor in the selection of the operating flux of a membrane system. Biofouling refers to biological growth that can occur on the membrane surface and acts as the fouling substance.

Phase A ocean water microfiltration testing demonstrated that the addition of chlorine to the feed water enhanced the microfiltration membrane performance. However, thin-film polyamide reverse osmosis membranes are damaged by strong oxidants such as free chlorine. In many past ocean water RO installations on open intakes with conventional filtration pretreatment, a reducing agent, such as sodium bisulfite is added after significant chlorine contact time to neutralize the oxidant before it contacts the RO membranes. However, this continuous chlorination/dechlorination process has been shown to actually enhance the tendency towards biological fouling of the RO. (Hamida and Moch, 1996)

Many MF/RO membrane facilities operating on wastewater use a different approach to control membrane fouling. In these facilities, chlorine is added to the feed water to enhance the membrane performance. Ammonia, naturally occurring or added to the wastewater, combines with the chlorine to form chloramines. The intent is to have a combined oxidant that would reduce the fouling rate of both the MF and RO processes. This chloramination→MF→RO process has been used successfully on many wastewater reclamation facilities including the 20 MGD West Basin Water Recycling Plant. The ammonia reacts with free chlorine or HOCl to form chloramines. The following reactions apply:

Reaction 1, Addition of sodium hypochlorite: $NaOCl + H_2O \rightarrow HOCl + NaOH$

Reaction 2, Formation of monochloramine $NH_4OH + HOCl \rightarrow NH_2Cl + 2H_2O$

Reaction 3, Formation of dichloramine $NH_2Cl + HOCl \rightarrow NHCl_2 + 2H_2O$

Reaction 4, Formation of trichloramine $NHCl_2 + HOCl \rightarrow NCl_3 + 2H_2O$

Chloramines are weaker oxidants than HOCl or OCl- (free chlorine), and RO membranes are tolerant of a few mg/L chloramines. Furthermore, it has been demonstrated in wastewater applications that the presence of chloramines in the water enhances the membrane performance by inhibiting membrane fouling.

This chloramination process was attempted on ocean water during this study. However, two items complicated the formation of chloramine on this water source. First, ammonia is not present is ocean water and thus must be added. Second, the presence of bromide (Br^-) in ocean water interferes with the reactions above. The Pacific Ocean water source used in this study has ~64 mg/L of Br^-. Br^- substitutes for Cl^- in reactions 1 - 4 listed above such that the chlorine addition to ocean water actually produces hypobromous acid (HOBr) instead of HOCl. Furthermore, subsequent ammonia addition creates bromamines instead of chloramines due to chemical kinetics. The following reactions apply:

Reaction 5, Addition of NaOCl to ocean water $NaOCl + Br- \rightarrow HOBr +Cl-$

Reaction 6, side reaction with chloramines $NH_2Cl +Br- + 2H_2O \rightarrow HOBr + NH_4OH + Cl-$

Reaction 7, subsequent Ammonia addition $NH_4OH + HOBr \rightarrow NH_2Br + 2H_2O$

Reaction 8, dibromamine formation $NH_2Br + HOBr \rightarrow NHBr_2 + H_2O$

(White, 1999)

6.8.2 Tests performed in Phase A

Tests were conducted in the early part of Phase A to use chorine/chloramines to prevent fouling of the MF and RO membranes. For the first tests, chlorine was injected into the MF feed line in an effort to prevent biogrowth on the MF membrane. The chlorine would then pass through the MF membrane into the MF filtrate. Ammonia was then injected into the MF filtrate in an effort to form chloramines, which would prevent biogrowth in the downstream RO membranes.

However, as mentioned above, the presence of Bromine complicates the formation of chloramines in seawater. As described earlier in Section 6.6 and shown below in Figure 6-88 and 6-89, this chlorination of MF feed water and subsequent ammonia addition in MF filtrate failed to protect the RO membranes from oxidation. Both the permeability and permeate conductivity of the Dow membranes increased steadily during the initial trial. In response to the RO deterioration, on October 3, the continuous chlorination in front of the MF was discontinued. Subsequently, attempts were made to run without any chlorine in the process and rapid MF fouling was observed (MF Trial II). An alternate attempt to use chlorinated MF backwashes was then trialed in an effort to reduce the fouling of the MF membrane only. Chlorine in the 20 - 40 mg/L range was utilized in the MF backwash, which is an intermittent operation. An additional "rinse" step was added to the MF backwash to ensure no chlorine carryover to the RO. This, combined with the addition of sodium bisulfite in front of the RO, was utilized in the remainder of the trials in Phase A and B. While this did not offer any residual biogrowth control for the downstream RO process, it proved to be a suitable method of operation for sustainable MF performance.

Figure 6-88 Permeability of Dow Membrane, Initial Chloramine Trial

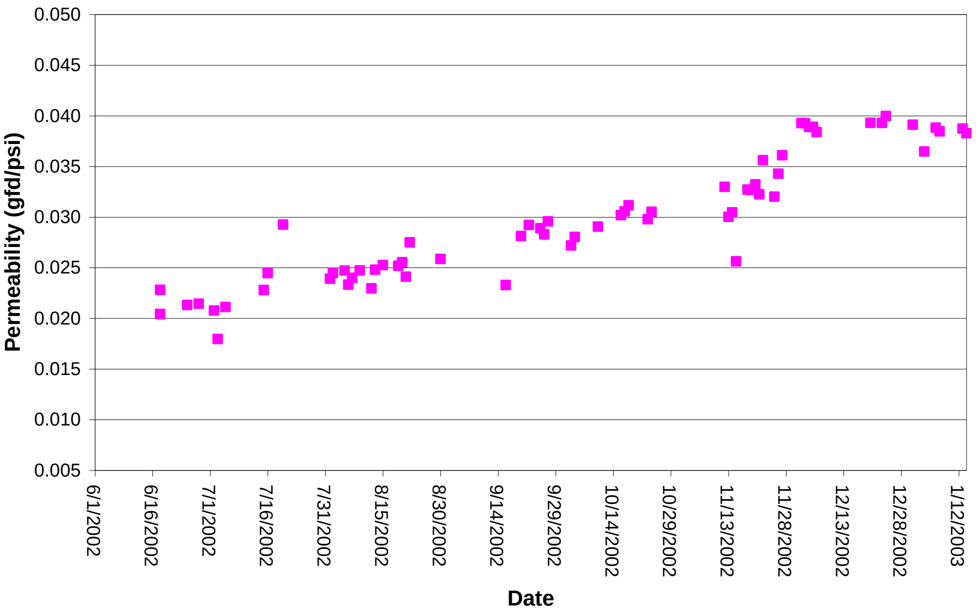
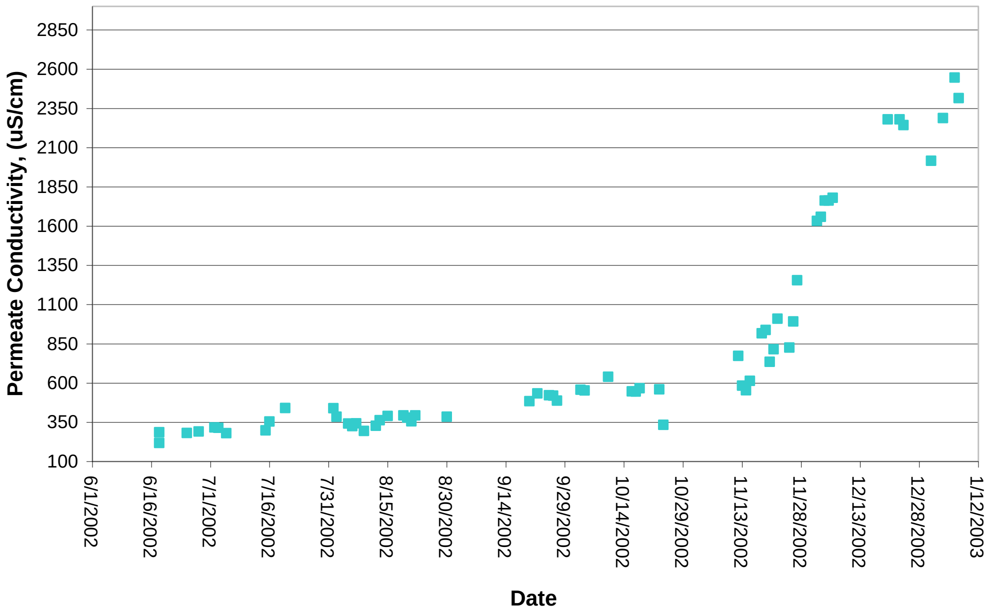


Figure 6-89 Permeate Conductivity of Dow Membrane, Initial Chloramine Trial



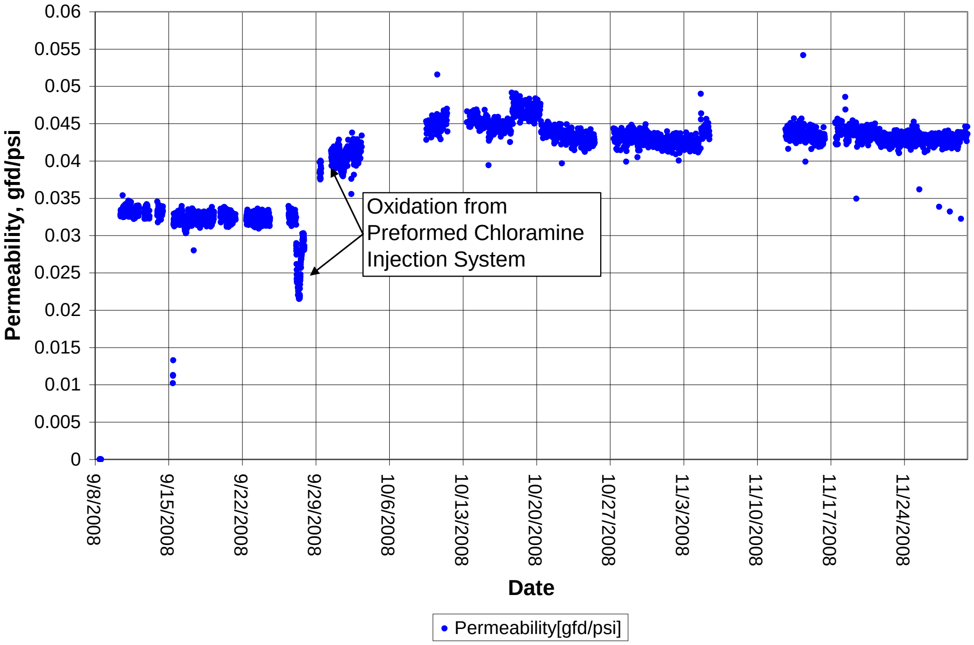
6.8.3 Tests performed in Phase C

After experiencing the problems associated with the presence of Bromine in seawater and formation of chloramines, another approach was attempted during Phase C. It was envisioned that if chloramines could be pre-formed prior to coming into contact with the seawater, then the presence of bromine would become less of an issue, and a chloramine residual could remain in the seawater long enough to have a beneficial effect in inhibiting biogrowth in RO treatment process. To test this approach, extensive bench scale work was performed for District by Trussell Technologies, Inc. Bench scale work provided promising results, showing that when pre-formed chloramines were added to seawater, the pre-formed chloramines react slowly enough with the bromide in seawater that significant bromamine formation does not occur in the time required to pass through the RO desalination process.

In order to introduce the pre-formed chloramines to the RO feed, it was envisioned that a small amount of RO permeate would be used a carrier water, and ammonium sulfate and sodium hypochlorite would be dosed at appropriate ratios into the carrier water line to make a chloramine solution with a 3:1 chlorine to ammonia ratio. This solution was added to the feed line of RO Train 1 at a concentration of 5-7 mg/l. RO Train 2 acted as a control, with no chloramine addition.

The original pilot equipment setup for manufacturing the inline, pre-formed chloramines utilized an LMI dosing pump to deliver RO permeate as the carrier water. Two additional LMI dosing pumps were used to inject the ammonium sulfate solution and sodium hypochlorite solution, respectively, along with inline static mixers. This process proved challenging, as the extremely low flow velocities and intermittent action of the dosing pumps made thorough mixing of the solution difficult. In late September, the SWRO membranes in Train 1 suffered from oxidation, which was believed to be caused by poor mixing in the small scale pilot equipment. This event is shown in Figures 6-90, where an increase in permeability is seen.

Figure 6-90 SWRO Permeability, Chloramine Trial

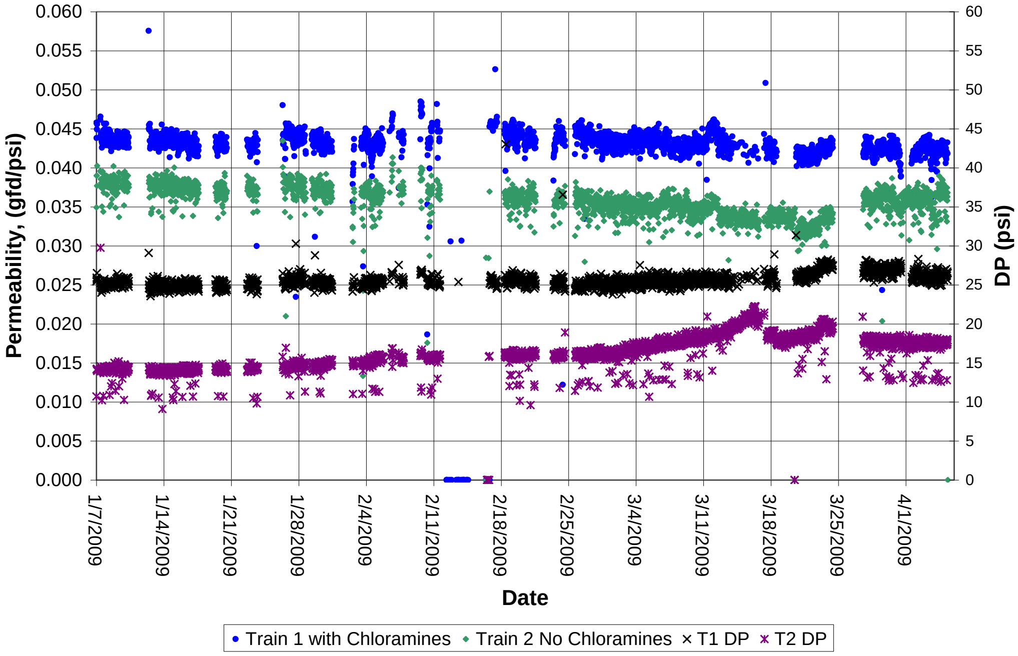


The team soon realized that while the in-line, pre-formed chloramine process was valid for larger scale applications, the process was too unstable with the limited small scale pilot equipment that was available at the site. It was decided that batches of pre-formed chloramines would be made on site, and dosed into the feedwater to Train 1 over the course of a day. Additional lab work was done to determine the maximum strength of chloramines that could be formed while maintaining stability. It was ultimately determined that a 1,000 mg/l chloramine solution could be manufactured at the pilot site in the available 90 gallons worth of storage tanks. Although some decay of the chloramine solution occurred over the course of 24 hours (about 15-20%), this setup ultimately proved acceptable to test the ability of pre-formed chloramines to control biogrowth in the RO Train.

Figure 6-91 shows both the permeability of, and differential pressure across RO Train 1 and 2. The benefit of chloramine dosing in Train 1 is evident in mid-March. The increase in DP and decrease in permeability for Train 2 can be attributed to biofouling. Train 1 did not experience these changes in operating parameters, indicating that the biofouling did not occur in Train 1 as a result of being dosed with chloramines.

It is important to note that personnel and equipment limitations did not allow for chloramine batching to be done seven days a week. Chloramines were only dosed Monday – Friday, which resulted in chloramines being present in the Train 1 feedwater approximately 60% of the time. Dosing chloramines into the feedwater even on a partial basis was beneficial in limiting biogrowth on the membrane.

Figure 6-91 SWRO Permeability, Chloramine Trial



One of the noteworthy observations from the chloramine dosing was the behavior of the feedwater ORP. The background ORP of ambient seawater was approximately 200 mV, and when chloramines were added, the ORP would increase. During extended shutdowns without a flush, the ORP of the feedwater would increase greatly over the course of 1 -2 days up to 900 mV. It is believed that bromamine formation was taking place over this extended shutdown time frame, and since bromamine is a stronger oxidant than chloramine, the ORP value would increase. It was believed during the period from January through the end of the testing in June that this increase in ORP may be causing oxidation damage to the membrane which resulted in the increase in conductivity and permeability seen in Train 1. However, as mentioned in Section 6.6.5, a factory retest of two of the elements from Train 1 showed no signs of membrane damage. Another possibility for the increase in permeate conductivity could be from o-ring damage from the high ORP feedwater, which can also contribute to an increase in permeate conductivity.

Figure 6-92 SWRO Permeability and ORP

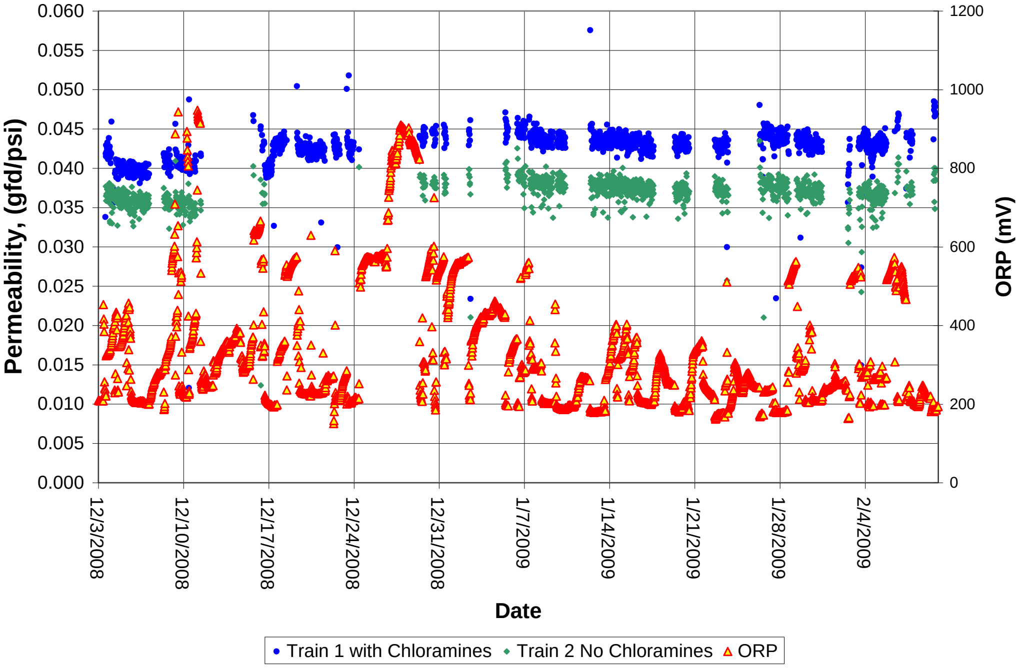
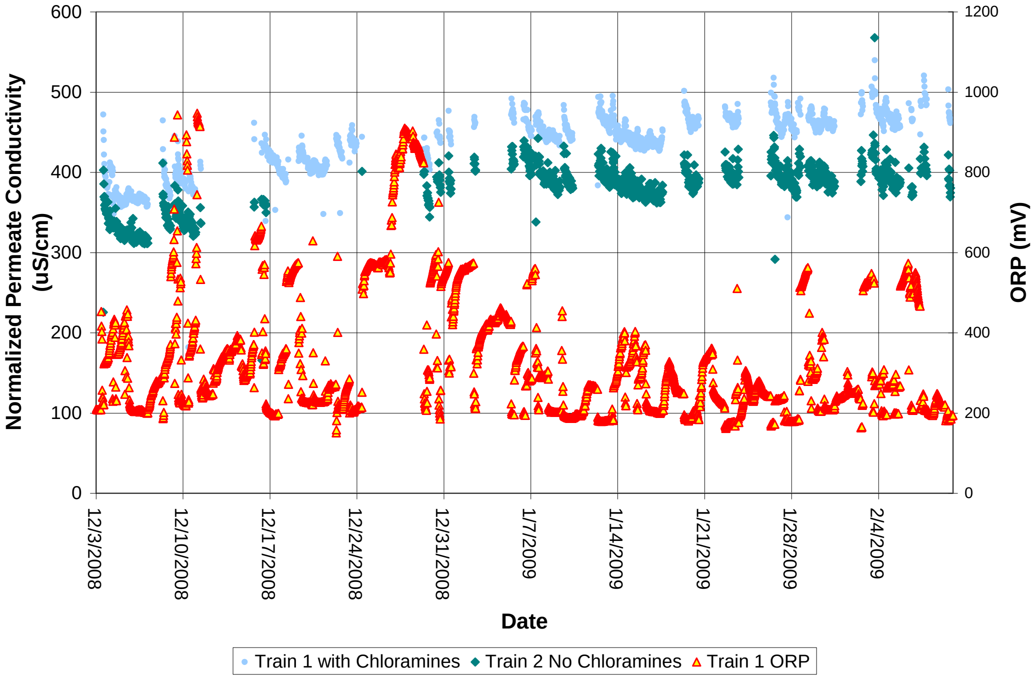
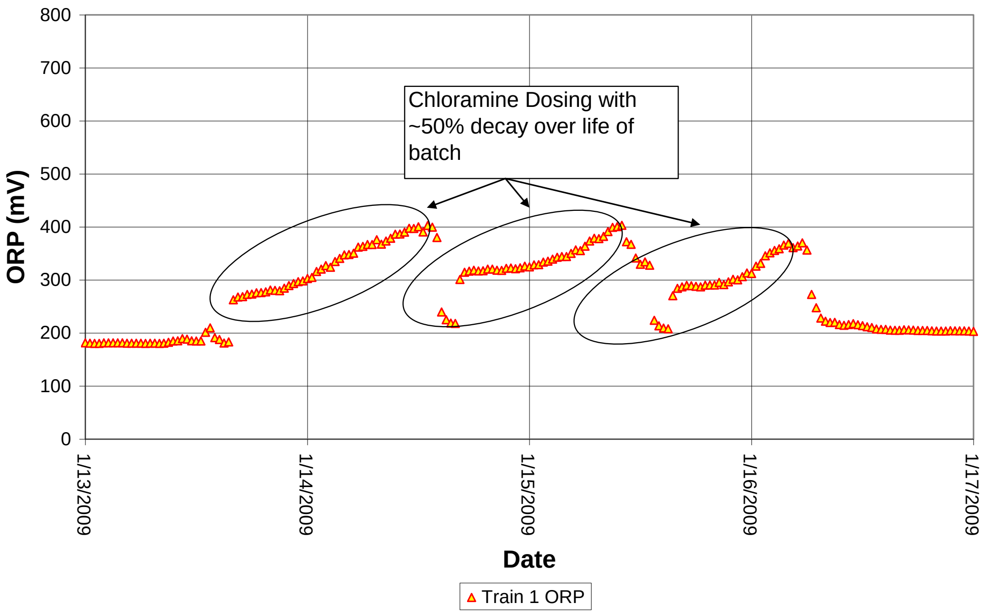


Figure 6-93 SWRO Permeate Conductivity and ORP



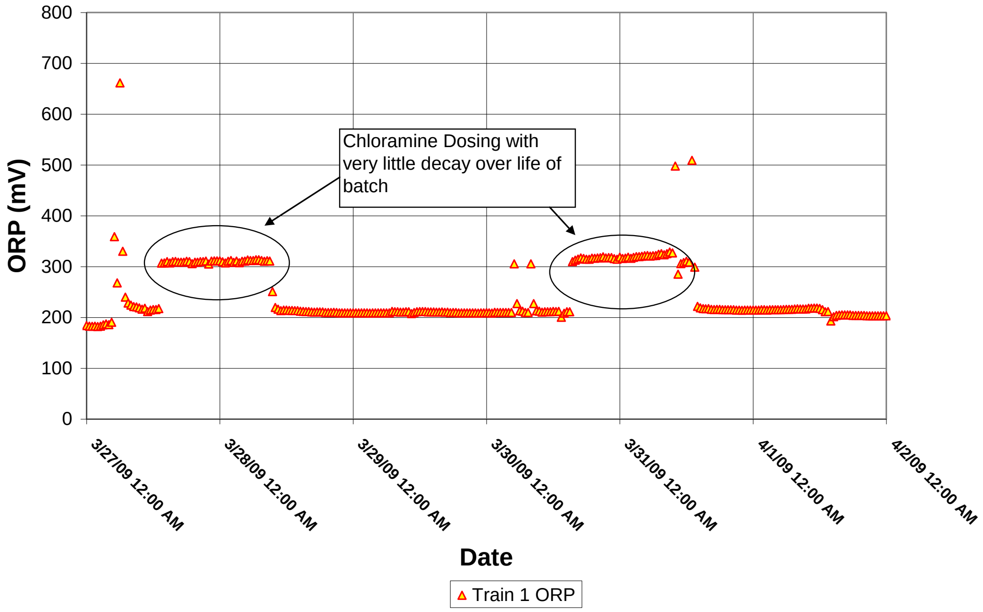
Another important observation of the chloramine dosing was that the ORP of the Train 1 feed water increased during the time that a batch was dosed into the feed water. Over the 18-20 hour time frame between when the chloramine batch was made and when almost the entire 90 gallons had been dosed into the feed, the chloramine solution experiences some decay in the batch tanks. It was evident that the decay byproducts of the chloramine solution cause the ORP values to change throughout the 24 hour time frame. Chloramine concentrations measured in December at the beginning and end of the 24 hour time frame indicated about a 50% decay as indicated in Figure 6-94.

Figure 6-94 Chloramine Batch Decay



It was believed that inadequate mixing was the cause for this instability. The team subsequently made equipment modifications to enhance the mixing during the batching process. Figure 6-95 shows the stable ORP feedwater values when better mixing was implemented. Chloramine concentrations measured at the beginning and end of these batches indicated only 15-20% decay over the 18-20 hour life of the batches. The problems associated with mixing should be minimized in larger scale applications where the in-line formation process would be used.

Figure 6-95 Stable Chloramine Batch



A more thorough and detailed description of the laboratory and pilot study work on the pre-formed chloramine testing has been prepared by Trussell Technologies, Inc. and is available to the reader for review.

6.8.4 Chloramines Summary

The following points summarize the use of chloramines in the pilot study:

- The presence of bromide ions naturally occurring in the ocean water hinders the formation of chloramines by simply adding ammonia and chlorine to the ocean water.
- Pre-forming chloramines, then adding the pre-formed chloramines to the ocean water resulted in prevention of biofouling on RO Train 1.
- This short term test indicates that the Hydranautics SWC5 SWRO membrane is tolerant of chloramine dosing at 5-7 mg/l over the course of 6 months for 60% of the time. This equates to approximately 13,000 ppm-hrs.
- The decay products of the chloramine batch solutions over the course of 20 hours caused the ORP of the feedwater to increase, which put the membranes at greater risk of oxidation. On a larger scale, it is envisioned that pre-formed chloramines can be formed in-line, eliminating the issue with long-term decay products, since the chloramines would only physically be in the system for a matter of minutes.

6.9 Sustainable Operating Criteria Summary for All Treatment Processes

The following tables summarize the sustainable operating criteria for all treatment processes tested during the pilot testing.

Table 6-88 – Sustainable Operating Criteria for Pre-Treatment and MF/UF

Treatment Process	Sustainable Operating Criteria
Arkal Disc Filter	▪ 70-100 micron rating ▪ Filtration Rate of 20 gpm per spine, but higher flow rates per spine are likely possible ▪ Liquid Backwash @ 35 gpm, 55 psi for 20 seconds per spine ▪ 100 mg/l Chlorine twice a week in backwash water
High Rate Granular Media Filter	▪ Filtration Rate of 40 gpm ▪ Surface Loading Rate of 24 gpm/sq ft ▪ Backwash every 48 hours ▪ Backwash flowrate 25 gpm ▪ Loading rates and backwash intervals reduced during Algal Blooms
Siemens CMF-S Microfiltration System	▪ Flux Rate: 34 GFD ▪ Filtration Time Interval : 20 minutes ▪ Recovery: 93% ▪ Chlorinated Backwash: Yes, 20 mg/l ▪ Daily Maintenance Clean: No ▪ Minimum CIP interval @ 34 GFD : 21 days
GE-Zenon ZW1000 Ultrafiltration System	▪ Flux Rate: 27.5 GFD ▪ Filtration Time Interval: 22 minutes ▪ Recovery: 93% ▪ Chlorinated Backwash: Yes, 2 mg/l ▪ Daily Maintenance Clean: Yes, 100 mg/l chlorine ▪ Minimum CIP interval @ 27.5 GFD : 21 days
Pall Microza Microfiltration System (MF Module:UNA-620A)	▪ Flux Rate: 70 GFD ▪ Filtration Time Interval: 20 minutes ▪ Recovery: 95% ▪ Chlorinated Backwash: No ▪ Daily Maintenance Clean (EFM): Yes, 350 mg/l chlorine, heated to 35°C ▪ Minimum CIP interval @ 70GFD : 30 days

Table 6-89 – Sustainable Operating Criteria for SWRO System

Treatment Process	Sustainable Operating Criteria
Seawater Reverse Osmosis System*	Operating Flux Rates from 8-12 GFD 9 GFD determined optimum for this source 50% Recovery
Filmtec SW30	Ave Permeability = 0.024 GFD/PSI Ave. Permeate TDS = 166 mg/l Ave. Permeate Chloride = 89 mg/l Ave. Permeate Boron = 0.75 mg/l Ave. Permeate Bromide = <0.25 mg/l
Filmtec SW30 HRLE	Ave. Permeability = 0.025 GFD/PSI Ave. Permeate TDS = 80 mg/l Ave. Permeate Chloride = 45 mg/l Ave. Permeate Boron = 0.45 mg/l Ave. Permeate Bromide = <0.2 mg/l
Toray TM810	Ave. Permeability = 0.026 GFD/PSI Ave. Permeate TDS = 97 mg/l Ave. Permeate Chloride = 60 mg/l Ave. Permeate Boron = 0.51 mg/l Ave. Permeate Bromide = 0.24 mg/l
Koch 1820 SS	Ave. Permeability = 0.024 GFD/PSI Ave. Permeate TDS = 173 mg/l Ave. Permeate Chloride = 121 mg/l Ave. Permeate Boron = 1.13 mg/l Ave. Permeate Bromide = NA
Saehan RE-4040SHN	Ave. Permeability = 0.022 GFD/ PSI Ave. Permeate TDS = 245 mg/l Ave. Permeate Chloride = 150 mg/l Ave. Permeate Boron = 1.26 mg/l Ave. Permeate Bromide = 0.64 mg/l
Hydranautics SWC4+	Ave. Permeability = 0.023 GFD/PSI Ave. Permeate TDS = 69 mg/l Ave. Permeate Chloride = 39 mg/l Ave. Permeate Boron = 0.48 mg/l Ave. Permeate Bromide = <0.2 mg/l
Hydranautics SWC5	Ave Permeability = 0.030 GFD/PSI Ave. Permeate TDS = 174 mg/l Ave. Permeate Chloride = 108 mg/l Ave. Permeate Boron = 0.85 mg/l Ave. Permeate Bromide = 0.42 mg/l

* SWRO Membrane Permeate TDS, Boron, Cl and Br values are normalized to 9 GFD and 20°C

Table 6-90 – Sustainable Operating Criteria for 2nd Pass RO System

Treatment Process	Sustainable Operating Criteria
2nd Pass Reverse Osmosis System	Operating Flux 20 GFD 90% Recovery
Hydranautics ESPA2	At feed pH 10, 20°C Ave Permeability = 0.25 GFD/PSI Ave. Permeate TDS = 15 mg/l Ave. Permeate Chloride = 5 mg/l Ave. Permeate Boron = 0.4 mg/l

Water Quality Assessment

7.0 Water Quality Assessment

The water quality data generated during the pilot test is necessary for future system designs and regulatory purposes. Analyses were performed that provide information related to treatment process performance, and also related to drinking water regulations and California Ocean Plan regulations.

7.1 Finished Water Quality

With respect to finished water quality, the data generated will help determine the treatment processes that are required to meet the ultimate finished water quality goals. Although the District has not determined finished water quality goals for a future full scale desalination facility at this time, a preliminary examination of possible water quality goals has been performed (Technical Memorandum 1 – Water Quality Assessment, for the West Basin MWD Temporary Ocean Water Desalination Demonstration Project, Phase A, written by Trussell Technologies and MWH, October 2006)

This preliminary examination looked at two aspects of finished water quality, one based on meeting drinking water quality strictly from a regulatory point of view, and another based on "ideal" water quality goals. The "ideal" water quality goals result from an analysis of consumer satisfaction with desalinated ocean water as a new water supply, and it is focused on water quality impacts on horticulture, corrosion concerns, and industrial standards. Boron and chloride were the focus of this investigation since if these two constituents are maintained below certain limits, then all other water quality constituents of concern should meet regulations. Table 7-1 shows the boron and chloride targets for the two cases.

Table 7-1 Possible Finished Water Quality Goals

Constituent	Units	Drinking Water Regulations	Ideal Water Quality Goal
Boron	mg/l	≤ 1.49	≤ 0.5
Chloride	mg/l	≤ 250	≤ 100

When these ideal goals are compared with the average water quality from the various SWRO membranes tested, it is evident that further treatment of the single pass RO permeate is required. Table 7-2 shows the permeate boron and chloride concentrations for each SWRO membrane tested, normalized to two different conditions; 9 GFD and 20°C, and 9 GFD and 25°C, which represents the high end of the ambient water temperature range in this region.

Table 7-2 SWRO Permeate Quality Normalized to Different Temperatures

	Normalized to 20°C and 9 GFD		*Normalized to 25°C and 9 GFD*	
Membrane	**Ave. Permeate Chloride Concentration (mg/l)**	**Ave. Permeate Boron Concentration (mg/l)**	**Ave. Permeate Chloride Concentration (mg/l)**	**Ave. Permeate Boron Concentration (mg/l)**
Filmtec SW30	89	0.75	105	0.89
Hydranautics SWC1	94	1.03	110	1.21
Filmtec SW30HRLE	45	0.45	53	0.53
Hydranautics SWC4+	39	0.48	45	0.56
Koch 1820SS	121	1.13	141	1.32
Toray TM810	60	0.51	70	0.6
Saehan RE-4040SHN	150	1.26	171	1.44
Hydranautics SWC5	108	0.85	126	0.99

A common method of further treating the SWRO permeate is to treat all or a portion of this water with another reverse osmosis system, which is referred to as a 2nd Pass RO System. The feedwater to the 2nd Pass RO System is dosed with caustic to raise the feed pH which is necessary to enhance boron rejection. As mentioned in Section 6.7, increasing the pH causes a shift in the equilibrium from the non-ionized (and poorly rejected) boric acid form to the ionized (and better rejected) borate form. In order to determine how much SWRO permeate will require additional treatment with a 2nd Pass RO, mass balances and blending calculations are performed so that when the 2nd Pass RO permeate is blended back together with the remaining SWRO permeate, the final boron concentration is at or below the goal levels. An important design aspect that should be incorporated into the SWRO train is to allow for permeate to be collected from both the lead and tail end of the SWRO membrane pressure vessels. This allows for greater flexibility in the quantity of water that needs to be treated by the 2nd Pass RO system and can result in capital and operating cost savings.

Although this analysis is beyond the scope of this document, a detailed analysis of the use of a partial 2nd Pass RO incorporating this method should be performed for the ultimate full-scale seawater desalination facility.

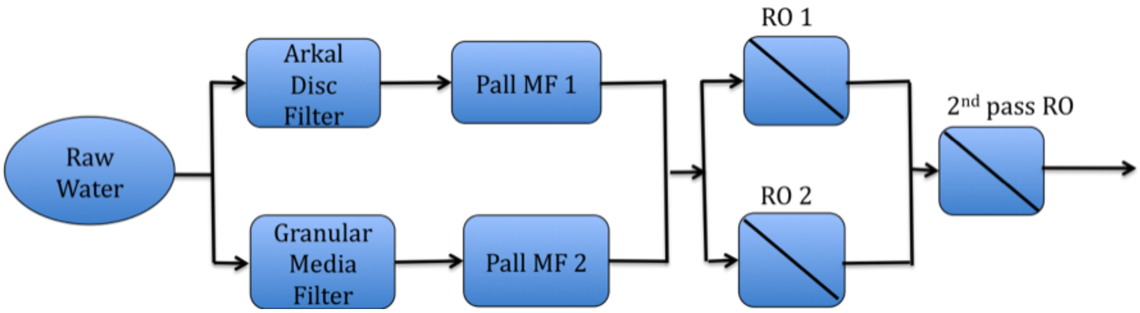
7.2 Water Quality Related to Regulations

This section provides a water assessment for the end of Phase B3 and Phase C testing of the West Basin Municipal Water District's Temporary Ocean Water Desalination Demonstration

Project over the period of 3/22/08 – 6/30/09. The water assessment defines the water quality requirements to meet both drinking water and Ocean Plan regulations.

The process schematic of the pilot plant during Phase C testing is shown in Figure 6-1.

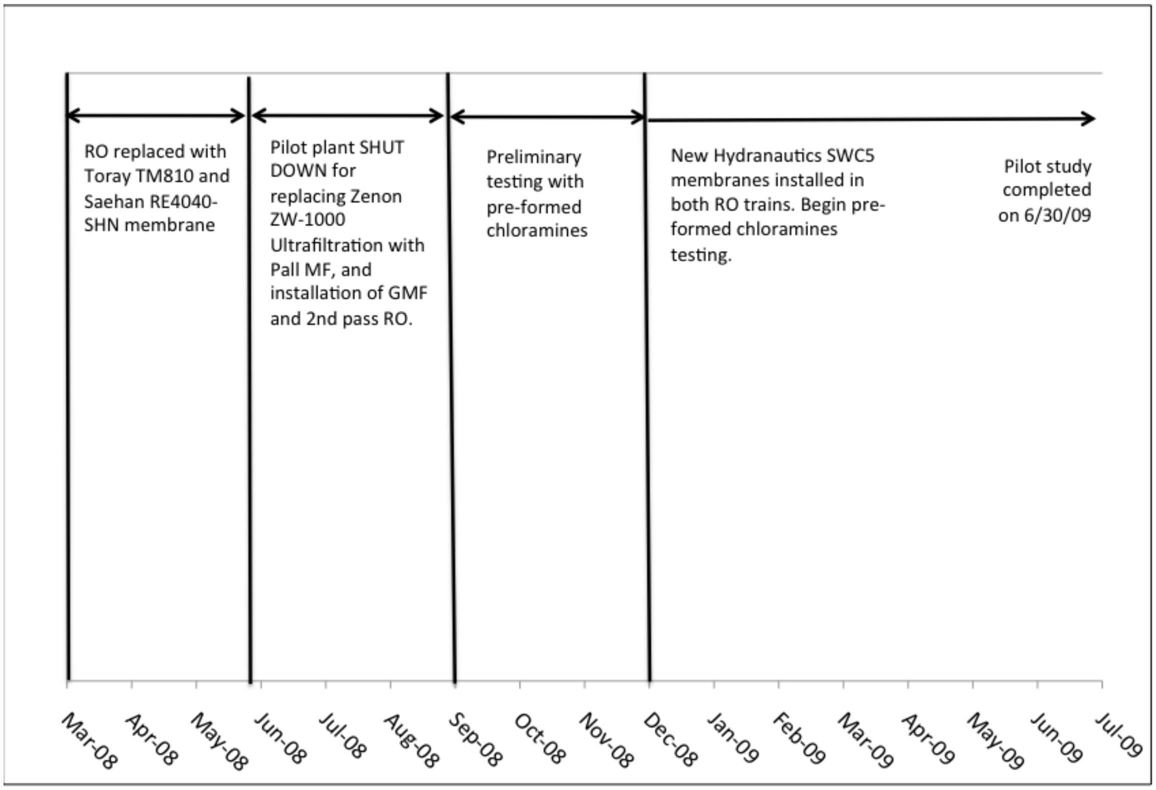
Figure 7-1 Phase C Flow Diagram of the Pilot Desalination Facility treatment process



Water samples were taken at each step of the process. Samples were analyzed to compare against drinking water standards for raw water and RO permeates, and Ocean Plan regulations for raw water and RO concentrates. Additionally, emerging contaminants were monitored for the raw water and RO permeates. Other key water quality parameters that are important for the overall plant design were also monitored on a routine basis in the raw water, the Arkal disc filter filtrate and backwash, granular media filter (GMF) filtrate and backwash, the Pall microfiltration (MF) filtrate and backwash, RO feed pre-disinfection and post-disinfection, RO 1 permeate and concentrate, RO 2 permeate and concentrate, and 2nd pass RO permeate. Samples were taken according to the sampling frequency recommended in TM-1 and outlined in Section 4.3.3 of this report.

Figure 7-2 presents the overall treatment activities during the last part of Phase B3 and Phase C testing periods. The pilot desalination facility was taken off-line between late May and Sept 2008 to install a high-rate granular media filter for pre-straining purpose, to replace the Zenon ZW-1000 UF with Pall MF, and to install a 2nd pass of RO into the treatment train.

Figure 7-2 Overall Treatment Activities Between Mar 08 and Jun 09



7.2.1 Compliance with Ocean Plan Regulations

Of the water quality data collected for the Ocean Plan constituents, Tables 7-3 to 7-5, respectively, summarize the constituents that exceeded the Ocean Plan limits at any time during Phase C testing for the raw water, for RO 1 concentrate, and for RO 2 concentrate, respectively. As shown in Table 7-3, four constituents in the raw water exceeded the Ocean Plan limits. One out of 6 samples exceeded the Cyanide limit, and 7 out of 14 samples exceeded the Beta/photon emitters (adjusted for K-40) limit. No constituents in the category, Protection of Human Health-Noncarcinogens, exceeded the Ocean Plan limits. PAHs and TCDD equivalents also exceeded the Ocean Plan limits.

The same constituents, with the addition of bis(2-ethylhexyl) phthalate, also exceeded the Ocean Plan limits in the RO 1 concentrate. It is possible that the bis(2-ethylhexyl) phthalate detection could be due to laboratory artifacts or sample contamination. Beta/photon emitters (adjusted for K-40) and PAHs exceed the Ocean Plan limits in the RO 2 concentrate. RO 2 concentrate was monitored only up to the sampling event in September 08. The appendix (Tables A1 to A3) provides a summary of each chemical constituent measured along with the reported value.

Table 7-3 Summary of Raw Water Quality Compared to Ocean Plan

Chemical with Limits in Ocean Plan		**Chemical with Exceedances of Limits in Ocean Plan**			
Name	***No. of Constituents***	***No. of Constituents***	***List of Constituents***	***No. of Obsevance***	***No. of Exceedance***
Protection of Marine Aquatic Life	27	2	Cyanide	6	1
			Beta/photon emitters (adjusted for K40)	14	7
Protection of Human Health-Noncarcinogens	20	0	None	NA	NA
Protection of Human Health-Carcinogens	41	2	PAHs	7	2
			TCDD equivalents	5	4

Table 7-4 Summary of RO 1 Concentrate Water Quality Compared to Ocean Plan

Chemical with Limits in Ocean Plan		**Chemical with Exceedances of Limits in Ocean Plan**			
Name	***No. of Constituents***	***No. of Constituents***	***List of Constituents***	***No. of Obsevance***	***No. of Exceedance***
Protection of Marine Aquatic Life	27	2	Cyanide	6	1
			Beta/photon emitters (adjusted for K40)	13	9
Protection of Human Health-Noncarcinogens	20	0	None	NA	NA
Protection of Human Health-Carcinogens	41	3	bis(2-ethylhexyl) phthalate	7	1
			PAHs	7	2
			TCDD equivalents	5	3

Table 7-5 Summary of RO 2 Concentrate Water Quality Compared to Ocean Plan

Chemical with Limits in Ocean Plan		**Chemical with Exceedances of Limits in Ocean Plan**			
Name	***No. of Constituents***	***No. of Constituents***	***List of Constituents***	***No. of Obsevance***	***No. of Exceedance***
Protection of Marine Aquatic Life	27	1	Beta/photon emitters (adjusted for K40)	3	2
Protection of Human Health-Noncarcinogens	20	0	None	NA	NA
Protection of Human Health-Carcinogens	41	1	PAHs	2	2

7.2.2 Compliance with Safe Drinking Water Act

Of the water quality data collected for the drinking water constituents, Tables 7-6 to 7-8 summarize the constituents that exceeded the Drinking Water limits (maximum contaminant levels, MCLs, and/or notification levels, NLs). There were 7 constituents in the raw water (Table 7-6), 3 constituents in the RO 1 permeate (Table 7-7), and 1 constituent in the RO 2 permeate (Table 7-8) that exceeded the drinking water limits. RO 2 permeate was only monitored until late May 08. The raw water quality exceeded the total dissolved solids (TDS), sulfate, chloride, boron, odor, and gross beta MCLs/NLs routinely, while NDMA was detected only once at a level exceeding its NL. The RO 1 permeate values met all drinking water regulations a majority of the time. However, odor-threshold readings exceeded the drinking water standards on a few occasions -- most likely an indication of re-growth on the permeate side or sample plumbing. Additionally, due to issues with membrane oxidation, the RO 1 permeate did exceed the recommended secondary MCL concentration of 250 mg/L for chloride on 8 occasions while boron concentrations exceeding the 1.49 mg/L CDPH Notification Level were measured on 11 occasions out of 45 observations as detailed in Table 7-7. The appendix (Tables A4 to A6) provides a summary of each chemical constituent measured along with the reported value.

Table 7-6 Summary of Raw Water Quality Compared to Drinking Water Limits

Chemical with Limits in Drinking Water Regulations			**Chemical with Exceedances of Limits in Drinking Water Regulations**			
Name	***Type***	***No. of Constituents***	***No. of Constituents***	***List of Constituents***	***No. of Obsevance***	***No. of Exceedance***
Inorganic Chemicals	Primary MCLs	17	0	None	NA	NA
Organis Chemicals	Primary MCLs	60	0	None	NA	NA
Various Types of Chemicals	Secondary MCLs	15	4	Odor-Threshold	13	13
				TDS	32	32
				Chloride	32	32
				Sulfate	32	32
Radionuclides	Primary MCLs	7	1	Beta/photon emitters (adjusted for K40)	14	7
Various Types of Chemicals	NLs	30	2	Boron	13	13
				N-Nitrosodimethylamine (NDMA)	3	1

Table 7-7 Summary of RO 1 Permeate Water Quality Compared to Drinking Water Limits

Chemical with Limits in Drinking Water Regulations			**Chemical with Exceedances of Limits in Drinking Water Regulations**			
Name	***Type***	***No. of Constituents***	***No. of Constituents***	***List of Constituents***	***No. of Obsevance***	***No. of Exceedance***
Inorganic Chemicals	Primary MCLs	17	0	None	NA	NA
Organis Chemicals	Primary MCLs	60	0	None	NA	NA
Various Types of Chemicals	Secondary MCLs	15	2	Odor-Threshold	13	4
				Chloride	45	8
Radionuclides	Primary MCLs	7	0	None	NA	NA
Various Types of Chemicals	NLs	30	1	Boron	45	11

Note: Chloride and Boron concentrations exceeding limits in RO permeate were due to membrane oxidation, and are not representative of typical RO permeate values.

Table 7-8 Summary of RO 2 permeate water quality compared to Drinking Water Limits

Chemical with Limits in Drinking Water Regulations			**Chemical with Exceedances of Limits in Drinking Water Regulations**			
Name	***Type***	***No. of Constituents***	***No. of Constituents***	***List of Constituents***	***No. of Obsevance***	***No. of Exceedance***
Inorganic Chemicals	Primary MCLs	17	0	None	NA	NA
Organis Chemicals	Primary MCLs	60	NA	NR	NA	NA
Various Types of Chemicals	Secondary MCLs	15	1	Odor-Threshold	2	1
Radionuclides	Primary MCLs	7	0	None	NA	NA
Various Types of Chemicals	NLs	30	0	None	NA	NA

NR=Not-Reported

7.2.3 Emerging Contaminants

Emerging contaminants were analyzed on a monthly basis and are summarized in Table 7-9 for the raw ocean water, RO 1 permeate, and RO 2 permeate. RO 2 permeate was monitored for only two sampling events. Because the list of emerging contaminants is so long, 15 were recommended for measurement as “Sentinels” in TM-1. However, from the list of Sentinels, Amoxicilin, EDTA, and Oxybenzone are not reported because the lab is not set up to perform those analyses.

As can be seen in Table 7-9, eight sentinels were detected in the raw ocean water and six were found in the RO 1 permeate, and one was found in the RO 2 permeate (only two sampling events reported). In the raw water samples, caffeine, carbamazepine, deet, estrone, and gemfibrozil were found on several occasions. Both caffeine and Gemfibrozil are common in wastewater discharges. Gemfibrozil is a drug used as a lipid regulator. Deet is the most common active ingredient in insect repellents. Carbamazepine is an anticonvulsant and mood stabilizing drug used primarily in the treatment of epilepsy and bipolar disorder.

In the RO 1 permeate sampling, ibuprofen was detected in the April 08 sample and 17 beta Estradiol was detected in the March 09 sample. However, neither was detected in the raw water sample at these times. These readings may be due to lab equipment contamination. The rest of the constituents detected in the RO 1 permeate were detected on a few occasions with very low concentration levels. The appendix (Table A7 to A9) provides a summary of each chemical constituent measured along with the reported value. In the RO 2 permeate samples, only bisphenol-a was detected in the May 08 sample, but it was not detected in the raw water sample. Again, this result might be due to lab equipment contamination.

Table 7-9 Summary of the Emerging Contaminants

Source Water	No. of Reported Consituents	No. of detected Consituents	List of the Constituents	No. of Observance	No. of detection
RAW Water	12	8	Bisphenol A	13	2
			Caffeine	13	6
			Carbamazepine	13	5
			DEET	13	5
			Estrone	13	4
			Gemfibrozil	13	9
			Ibuprofen	12	1
			Triclosan	8	1
RO 1 Permeate	12	7	17 beta Estradiol	13	1
			Bisphenol A	13	1
			Caffeine	13	1
			DEET	13	3
			Estrone	13	2
			Gemfibrozil	13	2
			Ibuprofen	12	1
RO 2 Permeate	12	1	Bisphenol A	2	1

7.2.4 Additional Routine Sampling Parameters

Besides the monitoring parameters presented above, some microbiological organisms and Chlorophyll-A were also analyzed for. Considering the large volume of water quality data that was generated as part of the WBMWD pilot study, probability plots were constructed to improve analysis of key water quality constituents. Probability plots for total coliform and fecal coliform are presented in Figures 7-7 and 7-8. These show that the raw water is of excellent water quality, with the median raw water total coliform concentration and fecal coliform concentration both less than 2 MPN/100 mL. The maximum concentration observed out of 201 samples showed that the total coliform concentrations were never greater than 500 MPN/100 mL, representing a level of source water quality that only requires a treatment train to provide 4 logs of virus removal per the established regulations. All results are summarized in Table 6.8 according to the treatment activity changes described in Figure 6.2 above.

Figure 7-7 Probability Plot of Raw Water Total Coliform Data

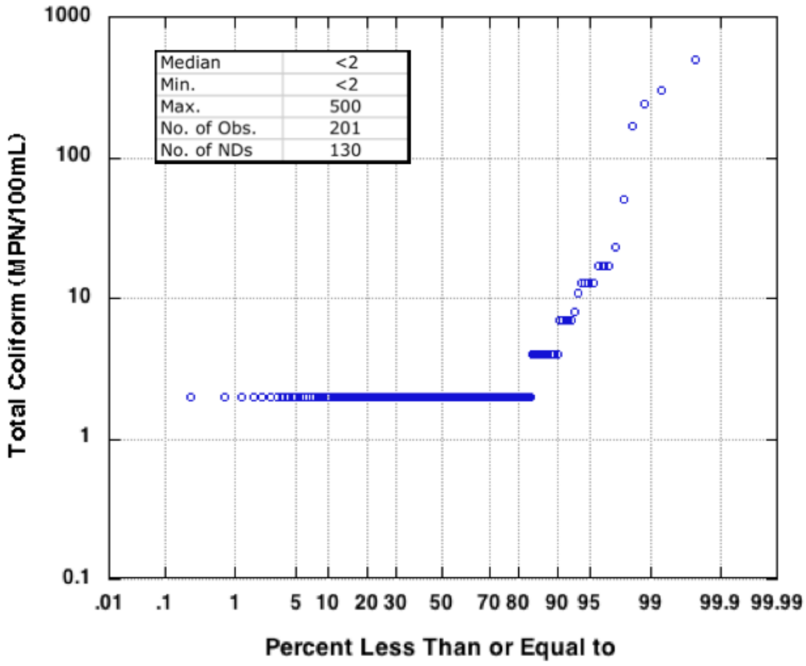


Figure 7-8 Probability Plot of Raw Water Fecal Coliform Data

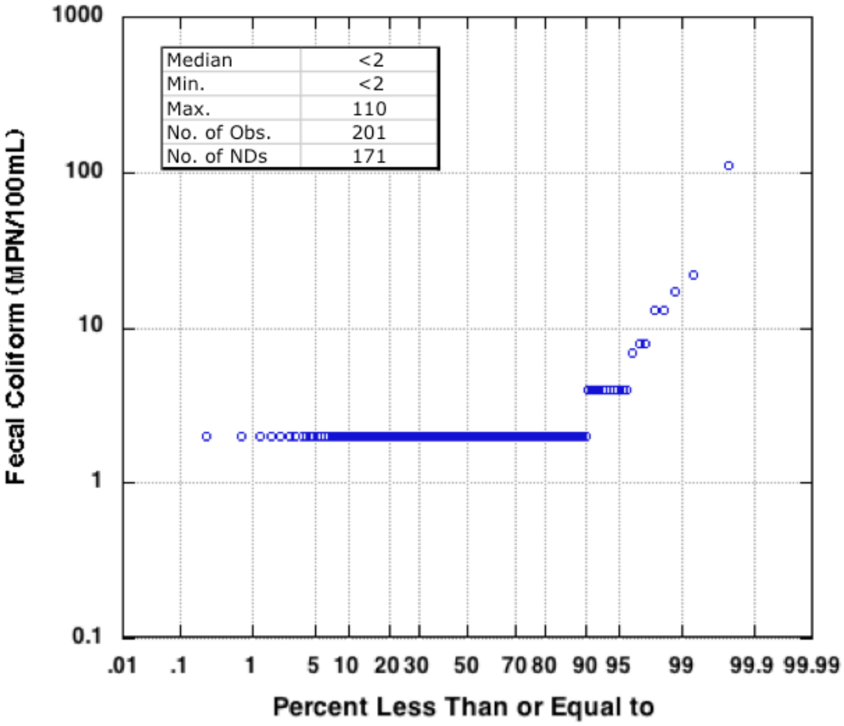


Table 7-10 Summary of Additional Routine Sampling Analyses

[a] The median and minimum values are reported as the detected values or < detection limit, which ever value is applied.

Microbiological Parameters	Method	Unit	March 08 to May 08						Sep 08 to Nov 08						Dec 08 to Jun 09					
			Median[a]	Minimum[a]	Maximum	No. of Observations	No. of Non-Detects	Reporting Limt	Median[a]	Minimum[a]	Maximum	No. of Observations	No. of Non-Detects	Reporting Limt	Median[a]	Minimum[a]	Maximum	No. of Observations	No. of Non-Detects	Reporting Limt
RAW																				
Total Coliform	SM 9221B	MPN/100ml	<2	<2	2	29	29	2	<2	<2	500	49	33	2	<2	<2	170	125	72	2
Fecal Coliform	SM 9221B	MPN/100ml	<2	<2	2	29	29	2	<2	<2	110	49	36	2	<2	<2	13	125	87	2
E. Coli	SM 9221B	MPN/100ml	<2	<2	<2	29	29	2	<2	<2	22	49	38	2	<2	<2	13	125	101	2
Enterococcus	Enterolert	MPN/100ml	<10	<1	<10	8	8	1,10	<10	<10	<10	9	9	10	<10	<1	20	29	24	1;10
HPC	SM 9215B	CFU/ml	63	5	1300	29	0	1	17.5	1	600	50	0	1	25	<1	1700	125	2	1
Chlorophyll-A	SM 10200H	ug/L	<10	<10	12	8	7	10	4	<2	<10	9	4	2,10	<2	<2	5.4	28	16	2
Arkal Dics Filtrate																				
E. coli	SM 9223 B	MPN/100ml	3.05	<1	22	4	1	1	180	130	210	3	0	1	<10	<1	260	7	6	1;10
HPC	SM 9215B	CFU/ml	87	4	440	11	0	1	12	2	920	19	0	1	21.5	<1	330	50	2	1
Enterococcus	Enterolert	MPN/100ml	7.5	2	7.5	3	3	1	<10	<10	13	3	2	1,10	<10	<10	<10	6	6	10
Arkal Dics Backwash																				
E. coli	SM 9223 B	MPN/100ml	5.3	2	61	4	0	1	170	140	500	3	0	1	<10	<10	1100	6	5	1;10
HPC	SM 9215B	CFU/ml	520	12	>/=5700	11	0	1	46	4	440	18	0	1	87	3	>/=5700	49	0	1
Enterococcus	Enterolert	MPN/100ml	14	13	50	3	3	1	<10	<10	23	3	2	1,10	10	<10	20	6	3	10
GMF Filtrate																				
E. coli	SM 9223 B	MPN/100ml	-	-	-	-	-	-	140	110	200	3	0	1	10	<10	10	6	3	10
HPC	SM 9215B	CFU/ml	-	-	-	-	-	-	58	4	1400	19	0	1	19.5	2	270	48	0	1
Enterococcus	Enterolert	MPN/100ml	-	-	-	-	-	-	<10	<10	52	3	2	1,10	<10	<10	43	6	5	10
GMF Backwash																				
E. coli	SM 9223 B	MPN/100ml	-	-	-	-	-	-	4	<1	2400	3	1	1,2	10	10	47	6	1	2;10
HPC	SM 9215B	CFU/ml	-	-	-	-	-	-	1800	2	>/=5700	15	0	1	1050	4	>/=5700	38	0	1
Enterococcus	Enterolert	MPN/100ml	-	-	-	-	-	-	<10	<10	<10	2	2	10	>2418.6	10	>2418.6	3	0	10
Pall 1 MF Filtrate																				
E. coli	SM 9223 B	MPN/100ml	<1	<1	<1	4	4	1	<1	<1	<1	3	3	1	<10	<1	<10	7	7	1;10
HPC	SM 9215B	CFU/ml	4	1	300	11	0	1	6	1	1600	18	0	1	4	<1	110	48	9	1
Enterococcus	Enterolert	MPN/100ml	<1	<1	<1	3	3	1	<10	<1	<10	3	3	1,10	<10	<10	<10	6	6	10
Pall 1 MF Backwash																				
E. coli	SM 9223 B	MPN/100ml	48	9.7	87	3	0	1	520	520	530	3	0	1	20	<10	160	7	3	1;10
HPC	SM 9215B	CFU/ml	1000	2	5000	9	0	1	1400	28	>/=5700	18	0	1	785	62	>/=5700	48	0	1
Enterococcus	Enterolert	MPN/100ml	46.5	24	69	2	0	1	10	<10	84	3	1	10	10	<10	10	6	4	10
Pall 2 MF Filtrate																				
E. coli	SM 9223 B	MPN/100ml	-	-	-	-	-	-	<1	<1	<1	3	3	1	<10	<1	<10	6	6	1;10
HPC	SM 9215B	CFU/ml	-	-	-	-	-	-	96	5	720	17	0	1	62.5	12	930	39	1	1
Enterococcus	Enterolert	MPN/100ml	-	-	-	-	-	-	<10	<1	<10	3	3	1,10	<10	<10	<10	5	5	10
Pall 2 MF Backwash																				
E. coli	SM 9223 B	MPN/100ml	-	-	-	-	-	-	510	90	830	3	0	1	30	<10	300	5	3	1;10
HPC	SM 9215B	CFU/ml	-	-	-	-	-	-	580	48	>/=5700	17	0	1	480	25	>/=5700	41	0	1
Enterococcus	Enterolert	MPN/100ml	-	-	-	-	-	-	10	<10	29	2	1	1;10	<10	<10	10	5	4	10
RO Feed - pre-disinfection																				
E. coli	SM 9223 B	MPN/100ml	-	-	-	-	-	-	<1	<1	<1	3	3	1	<10	<1	<10	7	7	1;10
HPC	SM 9215B	CFU/ml	-	-	-	-	-	-	21	2	600	18	0	1	11	1	1100	46	1	1
Enterococcus	Enterolert	MPN/100ml	-	-	-	-	-	-	<10	<1	<10	3	3	1;10	<10	<10	<10	6	6	10
RO Feed- post-disinfection																				
E. coli	SM 9223 B	MPN/100ml	-	-	-	-	-	-	-	-	-	-	-	-	<10	<10	<10	5	5	10
HPC	SM 9215B	CFU/ml	-	-	-	-	-	-	33	3	610	5	0	1	10	1	180	27	1	1
Enterococcus	Enterolert	MPN/100ml	-	-	-	-	-	-	-	-	-	-	-	-	<10	<10	<10	4	4	10
RO 1 Permeate																				
E. coli	SM 9223 B	MPN/100ml	<1	<1	<1	25	25	1	<1	<1	<1	43	43	1	<1	<1	<1	92	92	1
HPC	SM 9215B	CFU/ml	49	5	560	10	0	1	35	<1	1200	20	1	1	2	<1	190	46	13	1
Enterococcus	Enterolert	MPN/100ml	<1	<1	<1	3	3	1	<1	<1	<10	3	3	1;10	<1	<1	<1	7	7	1
RO 1 Concentrate																				
E. coli	SM 9223 B	MPN/100ml	<1	<1	<1	3	3	1	<1	<1	<1	2	2	1	<10	<1	<10	8	8	1;10
HPC	SM 9215B	CFU/ml	580	76	>/=5700	9	0	1	360	39	2200	16	0	1	155	<1	>/=5700	45	1	1
Enterococcus	Enterolert	MPN/100ml	<1	<1	<1	3	3	1	20	<1	40	2	1	1	<10	<10	10	7	6	10
RO 2 Permeate																				
E. coli	SM 9223 B	MPN/100ml	<1	<1	<1	25	25	1	<1	<1	<1	44	44	1	<1	<1	<1	95	95	1
HPC	SM 9215B	CFU/ml	170	15	980	11	0	1	75	13	1800	19	0	1	81	4	970	44	1	1
Enterococcus	Enterolert	MPN/100ml	<1	<1	<1	2	2	1	5	<1	<10	2	2	1;10	<1	<1	<1	7	7	1
RO 2 Concentrate																				
E. coli	SM 9223 B	MPN/100ml	<1	<1	<1	2	2	1	<1	<1	<1	3	3	1	<10	<1	<10	8	8	1;10
HPC	SM 9215B	CFU/ml	1600	98	>/=5700	10	0	1	330	43	2400	18	0	1	325	18	>/=5700	42	0	1
Enterococcus	Enterolert	MPN/100ml	1	<1	1	2	1	1	<10	<10	22	3	2	10	<10	<1	<10	6	6	1;10

As shown in Table 7-10, the results for E. Coli were problematic for Arkal filtrate and backwash, GMF filtrate and backwash, Pall 1 MF backwash, and Pall 2 MF backwash for the samples analyzed between Mar 08 to Nov 08. Those E. Coli levels were higher than the total coliform levels in raw water, which is not plausible because E. Coli levels at any stage in the treatment train should be lower than total coliform levels at that same stage, and be lower than total coliform levels at any earlier stage including the raw water feed. Our investigation revealed that incorrect application of the Colilert-18 method (also referred to as SM 9223B) for E. coli enumeration in those samples, specifically the use of an inappropriate dilution factor, was the cause of erroneous data. Previous research by Palmer and colleagues (1993) found that, at a minimum, a dilution factor of 10 is necessary to reduce the number of false positives resulting from the growth of Vibrio spp. using Colilert. Because Vibrio spp. thrive in saline waters, it is more competitive than coliform bacteria at high salinities. Utilization of the Colilert-18 method for the detection of *E. coli* requires a dilution of the salinity to provide a competitive advantage to the targeted *E. coli* bacteria. Results reported between Dec 08 and Jun 09 were analyzed with a dilution factor of 10, and they are more consistent with expected findings. No indicator bacteria passed through the microfiltration step in treatment. Pall 1 filtrate, Pall 2 filtrate, RO 1 permeate, and RO 2 permeate results were consistently less than the detection limits of 1 MPN/100mL or 10 MPN/100mL for the E. Coli and the Enterococcus counts.

7.2.5 Summary of Regulatory Sampling

The sampling recommended in the water assessment TM-1 dated October 16, 2006 for the El Segundo pilot desalination facility was completed over the period March 2008 through June 2009. The data collected for the source water and for the various steps in the treatment train at the El Segundo pilot represent an important milestone toward establishing the “complete database” of water quality information required for permit applications with CDPH (drinking water) and the Los Angeles Regional Water Quality Control Board (concentrate discharge) for a desalination facility. Overall, the desalination treatment process was successful at removing contaminants to levels meeting the drinking water limits, as evident from comparing the raw and finished water qualities. In addition, the levels of constituents in the RO concentrate in most cases meet the requirements of the Ocean Plan.

Summary of Key Sampling Results:

<u>**Comparisons to Drinking Water Limits**</u>

- ***Raw Water.*** One of 84 inorganics, organics, and radionuclides with a primary MCL (the radionuclide beta/photon emitters); four of the 15 constituents with secondary MCLs; and two of the 30 constituents with NLs exceeded drinking water limits
- ***RO 1 Permeate***. Zero of 84 inorganics, organics, and radionuclides with primary MCLs; two (Chloride and odor) of the 15 constituents with secondary MCLs; and one (Boron) of the 30 constituents with NLs exceeded drinking water limits. However, Chloride and Boron exceedances are due to membrane oxidation, and are not representative of properly functioning RO membrane as shown in Section 6.12.5.
- ***RO 2 Permeate***. Zero of the 24 inorganics and radionuclides with primary MCLs measured (organics were not reported); one (odor) of the 15 constituents with secondary MCLs; and zero of the 30 constituents with NLs exceeded drinking water limits

Comparisons to Ocean Plan Limits

- ***Raw Water.*** Two of the 27 constituents in the *protection of marine aquatic life* category; zero of the 20 constituents in the *protection of human health-noncarcinogens* category; and two of the 41 constituents in the *protection of human health-carcinogens* category exceeded the Ocean Plan limit.
- ***RO 1 Concentrate***. Two of the 27 constituents in the *protection of marine aquatic life* category; zero of the 20 constituents in the *protection of human health-noncarcinogens* category; and three of the 41 constituents in the *protection of human health-carcinogens* category (with one likely due to laboratory error) exceeded the Ocean Plan limit.
- ***RO 2 Concentrate***. One of the 27 constituents in the *protection of marine aquatic life* category; zero of the 20 constituents in the *protection of human health-noncarcinogens* category; and one of the 41 constituents in the *protection of human health-carcinogens* category exceeded the Ocean Plan limit.

Observations of Microbiological Water Quality

- Raw water has excellent microbiological water quality in terms of low total coliform and fecal coliform levels.
- No indicator bacteria pass through the microfiltration step in treatment.

The complete water quality data for TM-1 sampling can be found in Appendix X.

Operational Challenges

8.0 Operational Challenges

This section covers the major operational challenges experienced at the pilot plant associated with three major areas:

- Power plant related
- Water quality related
- General mechanical issues

8.1 Power Plant Related

There are several operational challenges associated with operating a seawater desalination pilot in conjunction with a power plant. Coordination between power plant personnel and pilot plant operators is critical. Pilot plant operators must be aware of changes in power plant operating conditions, and must also work within existing power plant permits.

One of the major challenges associated with a power plant is the power plant's use of heat treatment cycles to control biogrowth in their cooling loop. As shown in the process flow diagrams, the feedwater to the desalination pilot was taken from the power plant's cooling water loop. Approximately every one to three months the power plant would perform a heat treatment cycle to their cooling loop, where ocean water heated to 105 – 120 °F is recirculated through the cooling loop to control biological growth and attachment. During the heat treatment, shell-life such as barnacles and mussels, and other biogrowth attached to the process piping are removed from the pipe walls. The pilot equipment was shut down during these heat treatment cycles to prevent the shells and particulate matter as well as the high temperature water from reaching the membrane systems and causing damage. However, there is a significant release period after the end of a heat treatment cycle where shells and other particulate matter continue to dislodge from the piping. This caused repeated clogging of the booster pump impeller and resulted in pilot plant shutdowns. To alleviate this problem, the basket strainer was moved ahead of the booster pump, but small particulate matter was still found downstream in the Siemens membrane tank. The eventual installation of the 100 micron Arkal filter and relocation of the intake pump to draw water directly from the open forebay helped deal with the increased solids from the heat treatment cycles. A full scale desalination facility operating in conjunction with a power plant that uses heat treatment cycles will need to coordinate and plan for these periods.

Another noteworthy operational challenge that requires coordination and attention is the use of power plant cooling water effluent as feedwater to the desalination facility. The NRG Power Plant in El Segundo where the pilot test took place is a peaking power plant and does not run continuously. As such, there is not a constant supply of power plant cooling water effluent at elevated temperatures. This made continuous testing on power plant effluent difficult, and it can be seen in Section 4 that the outfall water was at times the same temperature as the influent water. When the power plant was operational the cooling water outfall temperature reached a maximum of 36.8 °C (98 °F). A full-scale desalination facility operating on power plant effluent will need to pay close attention to the fluctuating feedwater temperature and the effects it has on finished water quality (i.e. increased concentrations of TDS, boron, chloride, etc.)

Coordination regarding the power plant's permits is also required. Pilot plant operating personnel coordinated with power plant operations to properly dispose of spent cleaning solutions in accordance with power plant permits. Careful monitoring of chemical addition to the process was also required to ensure compliance with the power plant's ocean water discharge permits.

8.2 Water Quality Related

Operational challenges at the pilot plant were also related to water quality.

As described in Section 5, there were MF fiber integrity challenges with the Siemens system, some of which can be attributed to water quality. Shell fragments in the ocean water were believed to cause some of the fiber breakage, which eventually led to the installation of the Arkal disc filter to provide further protection to the MF/UF systems.

The MF/UF systems were also affected by periodic algal blooms. The increase in biomass in the ocean water associated with periodic algal blooms caused rapid fouling of all three hollow fiber membrane systems tested. In order to maintain production the flux rate through the MF/UF systems had to be decreased, at one point up to 30%. A high-rate granular media filter (GMF) was installed in Phase C of the piloting to test the GMF as a pre-strainer (or roughing filter) against the Arkal disc filter ahead of the Pall Microfiltration system. During storm events and algal blooms the GMF pre-strainer provided better water quality to the Pall MF system compared to the 100 micron Arkal disc filter. Depending on full scale system cost analyses, the GMF may offer cost-effective protection against algal blooms.

RO fouling was another operational challenge encountered during pilot testing, as described in detail in Section 5.6. There were five distinct, well-documented RO fouling events that occurred in Phases B and C of testing. Three of the fouling events occurred on ambient intake water between March – June, and the other two events occurred on the warmer power plant outfall water in August – September. In all cases, a high pH cleaning step was more effective at restoring permeability and DP across the membranes than the low pH step, which is consistent with biofouling and fouling from organics versus scaling from precipitated salts. In certain cases, extended soaking for up to 24 hours at a pH of 12 was required to restore performance. In other cases, a 1 hour recirculation at pH 10.5 was sufficient to restore performance. Based on the trial and error that was sometimes required for a successful cleaning, a full-scale facility should be equipped with a small CIP trial system that can be used when a fouling event occurs to develop an effective cleaning formulation. A trial and error type approach on a full scale desalination facility is not acceptable in terms of cleaning chemical cost, system downtime, etc.

8.3 Mechanical Issues

There were several mechanical issues that were encountered over the period of testing that caused equipment downtime. These issues were related to equipment operation and design and to the more general aspect of the corrosive nature of a coastal oceanfront environment.

8.3.1 Vibration Issues Associated with Wanner Hydracell High Pressure RO Pumps

The RO System utilized for this study had two independent trains of 4 membranes, four-inch pressure vessels in a 1:1 array. To feed the seven 4” RO membranes in series, the RO pumps produce ~10 gpm at 1000 psig, and this flow/pressure combination was not readily available in a centrifugal pump. Wanner Engineering offered a positive displacement type pump with superaustinitic stainless steel wetted parts that withstand the corrosive ocean water environment. These Hydracell pumps have three pistons that are alternately moved by a wobble plate. The pistons are filled with oil on their return stroke. The oil balances the back side of the diaphragms causing them to flex forward and back as the wobble plate moves. This provides the pumping action.

These pumps were advertised as having smooth, low pulse output, and the original design of the RO skid had them placed on the frame with the other equipment. When put into operation, however, the pumps produced a great amount of vibration and caused damage to process piping and the pumps themselves. The system was able to operate under these challenging conditions, but eventually the pumps were replaced.

In August of 2006 one of the Hydracell Pumps was replaced with a relatively new pump on the market manufactured by Danfoss. The new pump, model number APP 2.2, is a positive displacement axial piston pump constructed of duplex stainless steel, making it corrosion resistant to ocean water. The pump is lubricated by the ocean water, not oil, so there is no possibility of oil leaking into the ocean water and fouling the RO membranes. The pump produces very little vibrations and does not require a pulsation dampener, and is controlled with a variable frequency drive. The second Hydracell pump was replaced with an additional APP 2.2 in May 2007 when the pilot equipment was relocated. The Danfoss pumps have proven much more reliable and user-friendly than the Hydracell pumps, and are recommended by the team for future seawater desalination pilot projects.

8.3.2 Corrosive Nature of a Coastal Oceanfront Environment

Other mechanical / electrical issues occurred throughout the course of pilot study that can be associated with the pilot plant’s proximity to the beach. Although the team was well aware of the corrosive nature of a coastal oceanfront environment, not all pilot equipment that was procured was specifically designed to withstand this type of location, as would be the case for a full scale desalination facility.

The salt air and general corrosive nature of the coastal environment caused several electrical failures of the Pall MF control panel. These control panels were Allen Bradley VersaView type touch screen computers, and although they are rated for outdoor duty, the units did not stand up well to this harsh environment. Other pilot units at the site used simpler Allen Bradley PanelView type controllers. These controllers were able to stand up to the environment, and were adequate to perform the necessary functions on the pilot equipment.

Other electrical failures occurred on several electrical outlets, and also on one of the air compressors, all of which were rated for outdoor use. Electrical panels constructed of 316SS and rated NEMA 4 suffered from minor corrosion, where lower grade coated steel panels experienced heavy corrosion. These pieces of equipment were rented from equipment vendors without the benefit of being specifically designed for this location.

Another consideration for this harsh environment is the selection of coatings and materials of construction used for equipment skids. Skids that used powder-coatings proved to be very durable, where simple painted coatings tended to chip and crack, subjecting the metal frames underneath the coatings to corrosion. Skids that were constructed of FRP material did not experience corrosion at all, as expected.

Conclusions

9.0 CONCLUSIONS

The West Basin Municipal Water District Pilot Program was a successful, multi-year ocean water desalination pilot program which developed a broad range of data, not previously available. Where operational or process challenges were encountered, they were addressed, supporting the development and planning of the demonstration and full-scale projects.

Specifically, the following conclusions can be drawn from this pilot study:

1. The study successfully established the feasibility of utilizing the membrane filtration pretreatment process for seawater reverse osmosis on an open intake. This was demonstrated on Pacific Ocean water taken from both a power plant intake and the warmer power plant post-condenser effluent sources.
2. The latest generation RO membranes demonstrated the capability of producing product water meeting drinking water regulations in a single-pass. The piloting also demonstrated the capabilities of a second-pass RO, should higher product quality standards be considered. Specifically the impact of pH adjustment on boron rejection was demonstrated.
3. Reverse Osmosis membranes operated effectively at 8 to 12 GFD flux on MF and UF filtrate.
4. Analyses for Domoic Acid in the RO permeate indicated non-detect (less than 0.002 µg/L) results, even when elevated concentrations (2-3 µg/L) existed in the raw feedwater due to substantial algae bloom events.
5. The Siemens CMF-S microfiltration system:
   a. Confirmed that a flux of 34 GFD was sustainable on the influent feed source (as established in Phase A) and established that this same operating condition was optimum for operation on the effluent source.
   b. Chlorine addition to the backwash was utilized and considered critical to performance achievement.
   c. Optimum MF operating conditions were determined to be:
      i. Flux = 34 GFD
      ii. Backwash Frequency = 20 minutes
      iii. Backwash with 20 mg/L NaOCl every backwash
      iv. CIP frequency of every 3 weeks
   d. Required a periodic heated clean-in-place (CIP) to restore membrane permeability. Non-heated CIP's proved to be inadequate to restore the membrane permeability to within 10% of its original level. Successful CIP protocol included:
      i. 2% citric acid recirculation/aeration at 36 - 38ºC followed by
      ii. 400 – 600 mg/L NaOCl recirculation at 20 - 22ºC
   e. Produced filtrate water with turbidity and SDI suitable for spiral RO membranes when the MF system maintained integrity.

   f. Fiber damage from shell fragments was prevented by use of an Arkal pre-filter of 70 micron or less.
   g. It was necessary to reduce MF capacity by 25-30% during the most severe algae bloom (Red Tide) events.

6. The Zenon ZW-1000 Ultrafiltration system:
   a. Established a flux of 27.5 GFD was sustainable on the effluent source. While this flux was not demonstrated on the influent source it is expected, based on similarities in UF performance between the two sources at other operating conditions.
   b. Chlorine in the backwash and maintenance clean was utilized and critical to performance achieved. Heating of the maintenance clean and CIP solutions was beneficial.
   c. Optimum UF operating conditions were determined to be:
      i. Flux = 27.5 GFD
      ii. Backwash Frequency = 22 minutes
      iii. Backwash with 4 mg/L NaOCl every backwash
      iv. CIP frequency of every 3 weeks
   d. Fiber damage from shell fragments was prevented by use of an Arkal pre-filter of 100 micron or less.
   e. It was necessary to reduce UF capacity by 25-30% during the most severe algae bloom (Red Tide) events.

7. The Pall Microza Microfiltration system:
   a. Established a flux of 70 GFD was sustainable on the influent source.
   b. Heating of the EFM maintenance clean was critical.
   c. Optimum UF operating conditions were determined to be:
      i. Flux = 70 GFD
      ii. Backwash Frequency = 20 minutes
      iii. EFM with 350 mg/L NaOCl daily
      iv. CIP frequency of every 30 days
   d. Fiber damage from shell fragments was prevented by use of an Arkal pre-filter of 100 micron or the high-rate granular media filter.
   e. It was necessary to reduce operating flux to 53 gfd during the most severe algae bloom (Red Tide) events.

8. No relationship was found between RO operating flux and fouling in the range tested, 8 to 12 GFD. RO operation at any flux within this range was found to be sustainable. The optimum RO flux for this study was found to be 9 GFD. However, this optimum is based upon site specific parameters such as water quality, energy cost, and capital expenses. Flux of 9 GFD may not be optimal for all ocean water desalination projects.

9. Operation on ocean water from the common power plant influent introduced additional challenges for the treatment process. The power plant heat treatment cycles, which clear the influent pipes of shellfish or other marine growth by recirculating ocean water at elevated temperature, result in a period of sluff-off of shells and other particulate matter.

A 100 micron Arkal disc filter was demonstrated to be effective removing these shell fragments.

10. A high-rate deep-bed granular media filter was demonstrated to enhance the performance of a Pall MF system during poor water quality conditions compared to an identical MF system operating with an Arkal disc filter.
11. Impacts of operation of the desalination process on a warm water (power plant effluent) source were documented relative to the ambient temperature feed source, including feed pressure, permeate quality and accelerated biofouling within the treatment process.
12. The viability of pre-formed chloramines as a biogrowth strategy for seawater RO was demonstrated.