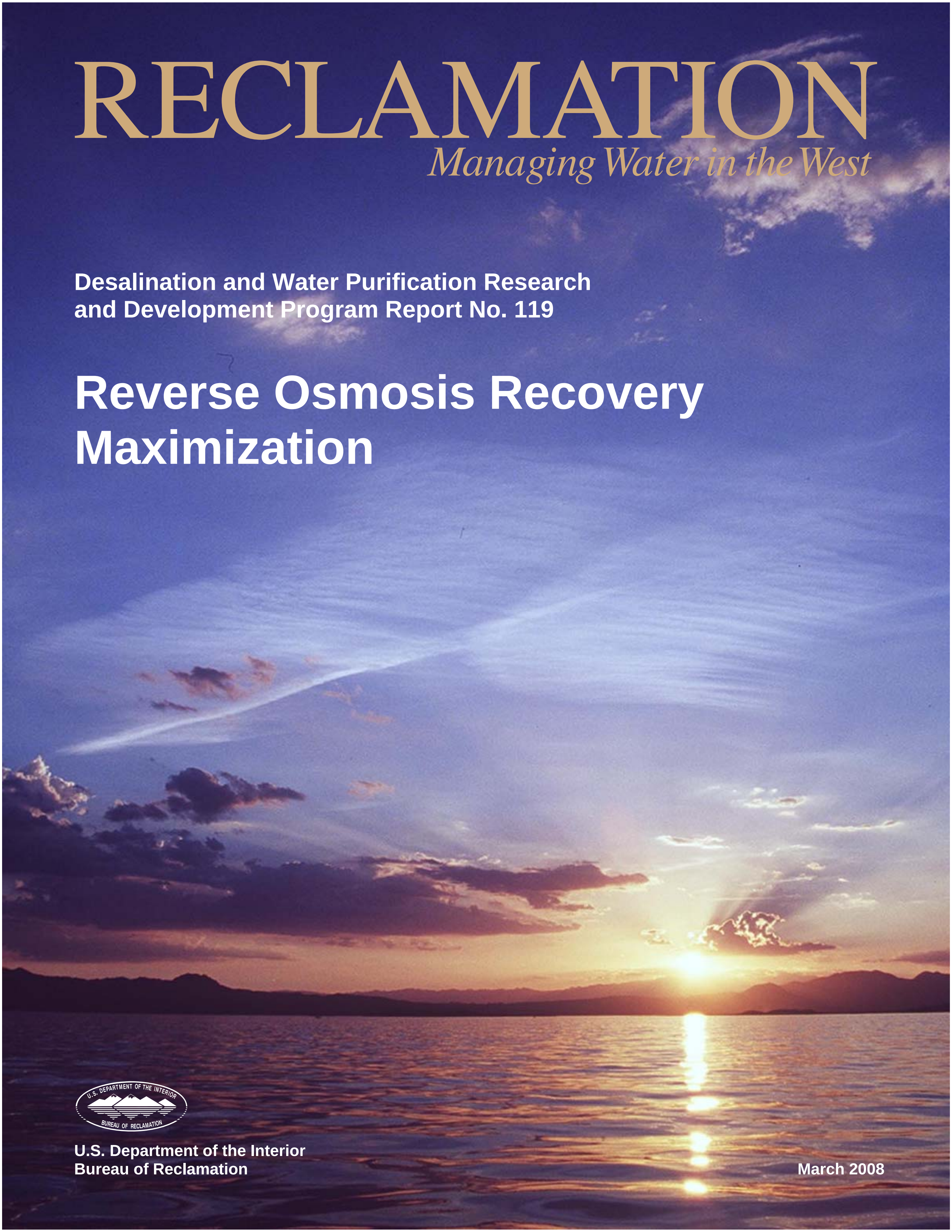

RECLAMATION

Managing Water in the West

Desalination and Water Purification Research
and Development Program Report No. 119

Reverse Osmosis Recovery Maximization

U.S. Department of the Interior
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14. ABSTRACT ***(Maximum 200 words)***

Two potential brackish potable water sources in the Phoenix area were tested at pilot scale with reverse osmosis (RO) to determine the maximum water recovery that could be obtained. A dendrimer-based scale inhibitor was used to try to enhance water recovery. One water source, with a largely surface water component from agricultural run-off (Western Canal water) was tested in Phase 1 of the project. Ultrafiltration (UF) was used as pretreatment to the RO during this phase, and the pilot system was operated for approximately 160 days between September 2004 and February 2005. In Phase 2 of the study a local ground water was tested with RO only, for approximately 130 days, between July 2005 and January 2006.

During Phase 1, the UF system performed well, but the RO process was not stable while operating at 90-percent recovery. There was a decrease in membrane performance after less than 30 days of operation. During Phase 2, the RO process showed better performance at 90-percent recovery. However, there was a decline in the system performance with time. A membrane autopsy confirmed the presence of high concentrations of silica, calcium, iron, and aluminum on the membrane surface. Future testing is recommended prior to designing a full-scale system.

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**Desalination and Water Purification Research
and Development Program Report No. 119**

Reverse Osmosis Recovery Maximization

Prepared for Reclamation Under Agreement No. 02-FC-81-0837

by

Dr. Graham Juby

**Carollo Engineers
Fountain Valley, California**

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
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MISSION STATEMENTS

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Disclaimer

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The Carollo team was lead by Graham Juby as the Partner in Charge and William Newhouse as the Project Manager. Jenna Manuszak and Martin Ramirez provided day-to-day pilot operations and monitoring functions. Tom Seacord, Sandeep Sethi, Susanna Li, Jerry Russell, Christian Tasser, Charlie He, and Mark Urban provided technical support.

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Abbreviations and Acronyms

µg/L	micrograms per liter
µS/cm	microsiemens per centimeter
CCPP	Calcium Carbonate Precipitation Potential
CEB	chemically enhanced backwash
CIP	clean-in-place
City	City of Phoenix
cm	centimeters
DOC	dissolved organic carbon
DWPR	Desalination and Water Purification Research
ft	feet
gal	gallon
GB	gigabytes
gfd	gallons per square foot per day
gph	gallons per hour
gpm	gallons per minute
ICPES	inductively coupled plasma emission spectroscopy
ICP-MS	inductively coupled plasma mass spectrometry
kPa	kilopascals
Lmh	liters per square meter per hour
L/s	liters per second
LSI	Langelier Saturation Index
m	meters
MF	microfiltration
mgd	million gallons per day
mg/L	milligrams per liter
NDP	net driving pressure
NPF	normalized permeate flow
NSP	normalized salt passage
NSR	normalized salt rejection
NTU	nephelometric turbidity unit
O&M	operation and maintenance
PLC	programmable logic controller

psi	pounds per square inch
psig	pound per square inch gauge
PWT	Professional Water Technologies
RO	reverse osmosis
ROSA	Reverse Osmosis System Analysis
scfm	standard cubic feet per minute
SDI	silt density index
SOC	synthetic organic compound
SRP	Salt River Project
SU	standard units
TDS	total dissolved solids
TMP	transmembrane pressure
TOC	total organic carbon
TSS	total suspended solids
TTHM	total trihalomethanes
UF	ultrafiltration
VFD	variable frequency drive

1. Executive Summary

The Bureau of Reclamation (Reclamation) awarded a project to Carollo Engineers for the study of wastewater desalination for ground water replenishment in the Las Vegas Valley. However, after the partnering organization withdrew from the project, funding was redirected to the Phoenix area for the study of recovery maximization of two water resources that would require desalination: Western Canal surface water and brackish ground water. The City of Phoenix (City) agreed to provide matching funds for the project.

This report presents the pilot test results obtained from two performance evaluations of a treatment train consisting of ultrafiltration (UF) and a three-stage reverse osmosis (RO) system to treat Western Canal surface water (Phase 1) and a three-stage RO system treating brackish ground water (Phase 2).

Historically, the Western Canal has not been used as a drinking water supply because it is relatively far from the population center of Phoenix. Also, it has water quality issues (large turbidity fluctuations; average salinity of about 800 milligrams per liter (mg/L); total hardness of 250 mg/L as $CaCO_3$; and total organic carbon (TOC) of 2.8 mg/L) from agricultural runoff and brackish ground water that is pumped into the Western Canal as a supplemental supply.

A second new source of drinking water for the Phoenix area that is currently unused is brackish ground water. This water has an average salinity of about 1,500 mg/L; total hardness of 120 mg/L as $CaCO_3$; and a TOC of 0.7 mg/L).

The management of concentrate disposal is a significant challenge to using either of these waters as a potable source. In fact, without a suitable means of concentrate disposal at this inland location, it would not be possible to reduce the salinity of these sources. Therefore, operating RO at the highest recovery possible would limit the volume of concentrate for disposal and increase the potential of a viable future desalination project.

Initially, this project had three main objectives:

- Examine alternative scale prediction models for predicting maximum RO recovery and the precipitation of calcium carbonate and other scale forming salts.
- Evaluate the use of a newly developed dendrimer scale inhibitor to maximize recovery and reduce the amount of concentrate for disposal.
- Examine the potential for beneficial reuse of the concentrate stream as a brine source in chlorine generation.

The last of these three objectives was initiated, but never completed due to budget limitations and the inability to find a suitable chlorine generator for the pilot test. Three vendors of onsite chlorine generators were contacted about participating in the project, but none agreed to do so. Therefore, the focus of the study was limited to the first two objectives.

2. Background

2.1 General

In order to meet rising water demands across the country, many communities have begun to investigate the feasibility of developing brackish ground water and seawater as supplemental sources of water supply. RO has rapidly emerged as the preferred method for desalination of these waters. However, RO is more expensive than conventional treatment techniques and generates a saline concentrate that ultimately requires disposal. Disposal of the concentrate can present serious challenges, especially at inland locations where ocean discharge is not available (Zacheis and Juby, 2002). In areas where water resources are scarce, there is also a strong desire to get the most product out of the source water used. Therefore, maximization of recovery (the ratio of treated water produced to source water used) has become an important challenge to make RO economically feasible for communities with few source water supplies and/or limited concentrate disposal resources.

In 2002, Reclamation advertised for proposals of research and pilot-scale system studies through the Desalination and Water Purification Research program. A project was awarded to Carollo Engineers for the study of wastewater desalination for ground water replenishment in the Las Vegas Valley. However, after the partnering organization withdrew from the project, funding was redirected to the Phoenix Area for the study of recovery maximization of two water resources that require desalination: Western Canal surface water and brackish ground water. This report presents the pilot test results obtained from treating these two brackish source waters.

2.2 Need for Research

2.2.1 City of Phoenix Water Supplies

Phoenix is our Nation's fifth largest city (based on population) and is located in the second fastest growing county (based on annual population increase). One of the most significant challenges that the City faces is the development of water resources to support this rapid growth phenomenon.

Historically, the Western Canal has not been used as a drinking water supply due to its geospatial location in relation to the population center of Phoenix. It also has water quality issues associated with agricultural runoff and the brackish ground water that is pumped into the Canal as a supplemental supply during high irrigation demand periods. Water from the Western Canal is also susceptible to turbidity fluctuations and requires pretreatment before it can be treated using RO. During this pilot study, a UF treatment system was selected for pretreatment of the RO feed water.

Associated with the desalination of the Western Canal, which inherently produces a concentrated waste stream, is the challenge of developing an economically and politically acceptable disposal management strategy.

Several of the typical disposal options for inland desalination plants may not be practical for Phoenix. Evaporation ponds, which are often a viable disposal option for arid climates, may be considered as a waste of a still valuable water source in this region of limited water resources and would not likely be supported by the general public. Deep-well injection may also be impractical due to the compact nature of the local geology and regulatory limitations.

Considering the difficulty and cost of concentrate disposal, as well as the limited supply of water resources in the Phoenix area and other inland desert communities, recovery maximization would be a key parameter in achieving a successful RO design. Further, implementation of concentrate reuse strategies would also support the City's overall philosophy of maximizing use of its water resources.

2.2.2 Basis for Reverse Osmosis Design Models

Typically, the design recovery for a new RO system is calculated using one of several modeling programs developed by the membrane manufacturers.
RO design models calculate the maximum design recovery that can be achieved based on salt saturation indices derived from the feed water quality. If recovery is pushed significantly beyond the design value, the RO concentrate will become saturated with salts and scale will begin to form on the membrane surfaces. Typical scale-forming salts include calcium carbonate, calcium sulfate, barium sulfate, strontium sulfate, calcium fluoride, and silica. Iron, manganese, and aluminum also become concentrated and can foul RO membranes and/or contribute to scale formation; for example, in the case of silica.

Traditionally, desalination engineers have used the Langelier Saturation Index (LSI) to assess the saturation limit of calcium carbonate, which can be the most scaling, and, therefore, most recovery-limiting, salt in the desalination of certain brackish water sources. Corrosion engineers, however, promote the use of an alternative scaling index, called the Calcium Carbonate Precipitation Potential (CCPP). While the LSI is a qualitative index of whether calcium carbonate will dissolve or precipitate, the CCPP is proportional to the kinetics of precipitation and thus considered to be a better estimate of the amount of calcium carbonate that will precipitate (Seacord and Zander, 2003). The use of the LSI in RO design modeling often results in a conservative design recovery, which can limit maximization of water resources.

2.2.3 Scale Inhibitor Development

Saturation limits can significantly hinder recovery maximization on more saline source waters. While effective pretreatment methods, such as softening or pH adjustment, can aid in controlling scale formation, most RO installations rely on chemical scale inhibitors to improve the solubility of important scaling salts.

Several types of scale inhibitor chemicals exist, including threshold inhibitors, distorting agents, and dispersants. Threshold inhibitors retard precipitation of salts by binding with ionic charges. Distorting agents alter crystal growth to make them weaker and more prone to fracture, which, in turn, makes the scale that does form easier to clean from the membrane surface. Polymer dispersants add charge to the crystals, causing them to repel one another and making it more difficult for scale buildup to form.

Dendrimers, one type of polymer dispersant, have gained attention in the RO market for their ability to be applied at higher concentrations without fouling the membrane, especially in water with high total dissolved solids concentration and containing iron and manganese (two chemicals that can cause interference with scale inhibitors). While conventional inhibitors begin to form a film on the membrane surface at accumulated levels over 50 mg/L in the RO concentrate, dendrimer limits may exceed 1,000 mg/L. As such, there is an opportunity to increase the application of these inhibitors in an attempt to reach higher RO recovery rates.

2.2.4 Hypochlorite Generation Technologies

In addition to recovery maximization, beneficial reuse of the RO concentrate has become an important aspect of desalination, especially in more economically challenged areas or inland regions with limited disposal options. Historically, the most widely used reuse technique has been land application for irrigation purposes (Kenna and Zander, 2000). However, dilution is usually required before application, and other reuse techniques warrant attention.

Conventional chlorine generators employed at many water and wastewater treatment facilities use electrolytic processes to convert high purity sodium chloride brine solutions into sodium hypochlorite for disinfection. Recent advances in generator technology were expected to allow the use of less pure brine sources, while still avoiding electrode fouling. RO concentrate contains a range of salts, including sodium chloride, present at levels directly proportional to their concentration in the feed stream and the performance characteristics of the membrane. However, limited testing has been done to analyze the feasibility of using RO concentrate as a brine source. Given the current prohibitive cost of most RO concentrate disposal options for inland communities, the additional concentration and/or purification that may be required to turn the RO concentrate into an acceptable brine feed solution for a chlorine generator may be less costly than the cost of conventional disposal. Furthermore, the chlorine generated from this process could be used for disinfection at existing or future water and wastewater treatment facilities.

Unfortunately, during the execution of this project, no commercial pilot system could be obtained to evaluate the technical feasibility of RO brine concentration and brine treatment for conversion to hypochlorite.

2.3 Economic Value

Concentrate disposal is a costly component of desalination treatment and presents challenges, especially for inland regions. A reduction in the concentrate volume resulting from process recovery maximization can result in significant capital and operating cost savings. Based on estimates of capital and operating costs for a 10-million-gallons-per-day (mgd) RO treatment plant, an increase in recovery from 70 to 90 percent can result in as much as $13 million in capital cost savings and $2 million annually in operation and maintenance costs savings (GE, 2003). Although increased recovery rates can sometimes require more frequent chemical cleaning of the membranes, the projected cost of increased chemical cleaning from once every 4 months to once per month is relatively insignificant when compared to the concentrate disposal savings of $1.5 million annually in chemical costs for a 10-mgd RO system.

2.4 Project Objectives

Based on the above research needs, three main project objectives emerged:

- Examine alternative scale prediction models for predicting maximum RO recovery and the precipitation of calcium carbonate and other scale forming salts.
- Evaluate the use of a newly developed dendrimer scale inhibitor chemical to maximize recovery and reduce the amount of concentrate requiring disposal.
- Examine the potential for beneficial reuse of the concentrate stream as a brine source in chlorine generation.

The technical approach sections provide further details on how the first two of these objectives were to be achieved. The third objective of examining the potential for beneficial reuse of the concentrate stream was initiated, but no pilot testing could be performed. Three vendors of onsite chlorine generators were contacted. However, in-kind contributions from the three vendors could not be obtained, and a pilot system for onsite chlorine generation could not be provided. Because of budget limitations, this task could not be completed.

2.5 Contributing Agencies

The costs for the preparation of the pilot site and the necessary infrastructure were paid for by the City. Carollo operated the pilot plant and collected the samples and delivered them to the City laboratory for analysis. The infrastructure provided by the City included sewer and potable water service, telephone service, raw feed water from the Western Canal, and ground water from a well near the Gila River. The City also purchased the RO cleaning unit and provided a trailer to house the RO unit.

3. Conclusions and Recommendations

The pilot plant equipment was operated for approximately 160 days during Phase 1 (between September 2004 and February 2005) and approximately 130 days during Phase 2 (between July 2005 and January 2006).

The UF pretreatment system used during Phase 1 demonstrated its ability to adequately remove suspended solids from the Western Canal water to a level suitable for RO treatment. Some insoluble iron was also removed from the water. A key finding of the investigation is that chemically enhanced backwashes were an effective way to maintain the membrane flux between full chemical cleaning events.

During Phase 1, RO test results showed that operating at 90-percent recovery was not feasible under the test conditions encountered. There was a decrease in membrane performance as indicated by a loss of permeate production and salt rejection after less than 30 days of operation at 90-percent recovery. Pilot testing did indicate stable operation at a recovery level of 85 percent, although this testing period was short (only 12 days).

During Phase 2, RO testing on local brackish ground water (without UF pretreatment) showed better performance at 90-percent recovery. However, there was a decline in system performance with time. A membrane autopsy confirmed the presence of high concentrations of silica, calcium, iron, and aluminum on the membrane surface. This confirmed that scale formation was occurring in the tail end membranes, resulting in the declining performance observed during the testing.

The study results show that the predictions for the performance of a newly developed dendrimer scale inhibitor for operating RO at 90-percent recovery and above could not be achieved under the dosages and system conditions encountered. This was the case for both water sources tested.

The study has provided valuable insight into the challenges associated with operating RO at high recovery levels on these source waters and also confirmed the value of such testing for evaluating model predictions. Future testing is recommended prior to designing a full-scale system, and such tests should include an extended period of operation to confirm stable performance at a recovery of 85 percent before testing at higher recovery levels. Future tests should also include periods of operation with different scale inhibitors to determine the optimum chemical and dose for each water source.

4. Technical Approach

4.1 General

Phase 1 focused on reverse osmosis (RO) recovery maximization when treating surface water from the Western Canal; Phase 2 focused on brackish ground water. The first step in the technical approach was to use modeling programs (Reverse Osmosis System Analysis [ROSA] Version 5 by Dow Chemical Company) to predict the RO performance. These modeling results were then compared with the performance of the pilot RO system. Furthermore, dendrimer antiscalants were used, which, compared to other antiscalants, appeared to offer the highest RO recovery. Manufacturer-recommended doses were used at the start of Phase 1 and were subsequently increased to higher concentrations in order to reach higher RO recovery rates.

In order to reach a steady RO performance, the surface water had to be pretreated. A hollow-fiber ultrafiltration (UF) system was run for a minimum of 30 days prior to the start of the RO system. Upon reaching stable feed water quality, the RO system was operated at a baseline recovery of 85 percent, which seemed to be a conservative operating condition based on the results of RO modeling projections (see Sections 4.2.4.2 and 4.3.4). The project test plan called for the system recovery to be increased to 90 percent after the baseline RO performance was stabilized and run accordingly for approximately 3 months in order to obtain long-term performance results and to establish the chemical cleaning frequency needed. After 3 months, the recovery was going to be further increased to 92 percent or more. The scale inhibitor dose was to be increased during this period, depending on RO performance and in accordance with manufacturer recommendations.

4.2 Surface Water Testing (Phase 1)

4.2.1 Scale Inhibitor Selection

Three vendors were contacted and asked to evaluate the given water quality and to propose the appropriate type and dosage of antiscalant. The names and dosages of the proposed antiscalants are presented in table 4.1.

Based on the vendors’ projections for the highest anticipated recovery, Professional Water Technologies’ SpectraGuard™ was chosen. SpectraGuard™ is a dendrimer-based scale inhibitor with a molecular geometry that was anticipated to result in enhanced solubility over conventional linear or cross-linked polymers. The dosage of the antiscalant was predetermined by the chemical antiscalant supplier and was based on the water quality of the canal water. The maximum water recovery with this antiscalant was expected to be 92 percent.

Table 4.1 Scale Inhibitor Applications for the Western Canal

Chemical Supplier	Scale Inhibitor Product	Suggested Dose	Anticipated Recovery
Professional Water Technologies	SpectraGuard™	4.2 mg/L	92%
King-Lee Technologies	Pretreat Plus™ 0100	3.0 mg/L	90%
Nalco	PermaTreat ® PC-510T	2.2 mg/L	91%

Note: mg/L = milligrams per liter.

4.2.2 Membrane Selection

4.2.2.1 UF Membrane Selection

The UF membrane chosen for pretreatment on the Western Canal was selected on a basis of availability, compatibility with Carollo's UF pilot skid, and cost. Under these criteria, the decision was made to use a Polymem™ UF membrane module from WesTech Engineering, Inc. As noted previously, the UF system was used solely for pretreatment for the RO testing. RO recovery maximization was the main focus of this project, not UF recovery.

Table 4.2 outlines the specifications of the UF pilot plant. Continuous fiber breakage resulted in a reduced permeate water quality, and the UF membrane module was replaced after 120 days of testing on January 6, 2005, with the same type of UF membrane.

Table 4.2 UF Pilot Plant Specifications

Parameter	Value
Dimensions	64 inches x 74 inches x 79 inches
Electrical requirement	3-phase, 480-volt, 40-ampere circuit breaker
Feed pump capacity	45 gpm
Backwash pump capacity	150 gpm at 55 psi
Backwash water tank	200 gal
Air scour pressure capacity	120 psi
Chemical dosing pump capacity	0.75 gph
Chemical cleaning pump capacity	Three 1.25-gph pumps
Chemical storage tanks	Three 10-gallon polyethylene tanks
Chemical cleaning solution heater	2-kW inline immersion heater
Recirculation pump capacity	10 gpm at 16 psig

Note: gpm = gallons per minute, gal = gallons, psi = pounds per square inch, gph = gallons per hour, kW = kilowatt, psig = pounds per square inch gauge.

4.2.2.2 RO Membrane Selection

As shown in table 4.3, the Dow FILMTEC™ BW30LE-4040 membranes were selected for RO Stages 1 and 2. This is a polyamide membrane configured in a 4-inch (10.16-centimeter [cm]) diameter and 4-foot (ft) (1.22-meter [m]) long spiral membrane element. For the third stage of the RO system, a Dow FILMTEC™ LP2540 was selected. This is a 2.5-inch (64-millimeter [mm]) diameter element with lower surface area. See Appendix A, "Filmtec RO Membranes," for complete membrane specifications. The RO array chosen for Phase 1 testing was 2:1:1. There were six 4-inch (102-mm) diameter elements per vessel in Stage 1, six elements in Stage 2, and six 2.5-inch (64-mm) diameter elements in Stage 3. During the testing, it was observed that the third stage elements did not have the required minimum feed flow rate; therefore, the RO array was modified during Phase 2 to address this issue.

Table 4.3 RO Membrane Selection for the Western Canal

Stage	Vessels/ Elements	Membrane Manufacturer	Product Name	Surface Area (ft^2)
1	1/6	Dow FILMTEC™	BW30LE-4040	82
2	1/6	Dow FILMTEC™	BW30LE-4040	82
3	1/6	Dow FILMTEC™	LP2540	28

4.2.3 Equipment Setup

The Western Canal test site is located at 1710 W. Dobbins Road in Phoenix (figure 4.1). The site is part of a larger property owned by the City of Phoenix (City) and intended for future construction of a Western Canal Water Treatment Plant. The UF and RO pilot equipment was installed in the southwestern portion of the property, adjacent to the Western Canal.

Raw water was taken directly from the Canal, using a centrifugal intake pump. Suspended material and algae were removed upstream of the UF unit using a 500-micron, automatic backwash in-line strainer. Water from the strainer was then collected in the UF feed tank that was mounted on the UF pilot skid. The permeate from the UF pilot system was collected in an intermediary 1,200-gal (4,500-liter) RO feed tank and then processed through the RO pilot system. The UF backwash water, RO concentrate, and RO permeate were combined and fed to a partially buried waste tank. A submersible pump transferred the combined water and wastewater streams to the sewer.

Figure 4.2 shows the Phase 1 process flow diagram, while figure 4.3 depicts the pilot plant site plan. Positioning of the pilots in this manner used minimal space and prevented the long side of the pilot trailers from exposure to the hot afternoon sun.

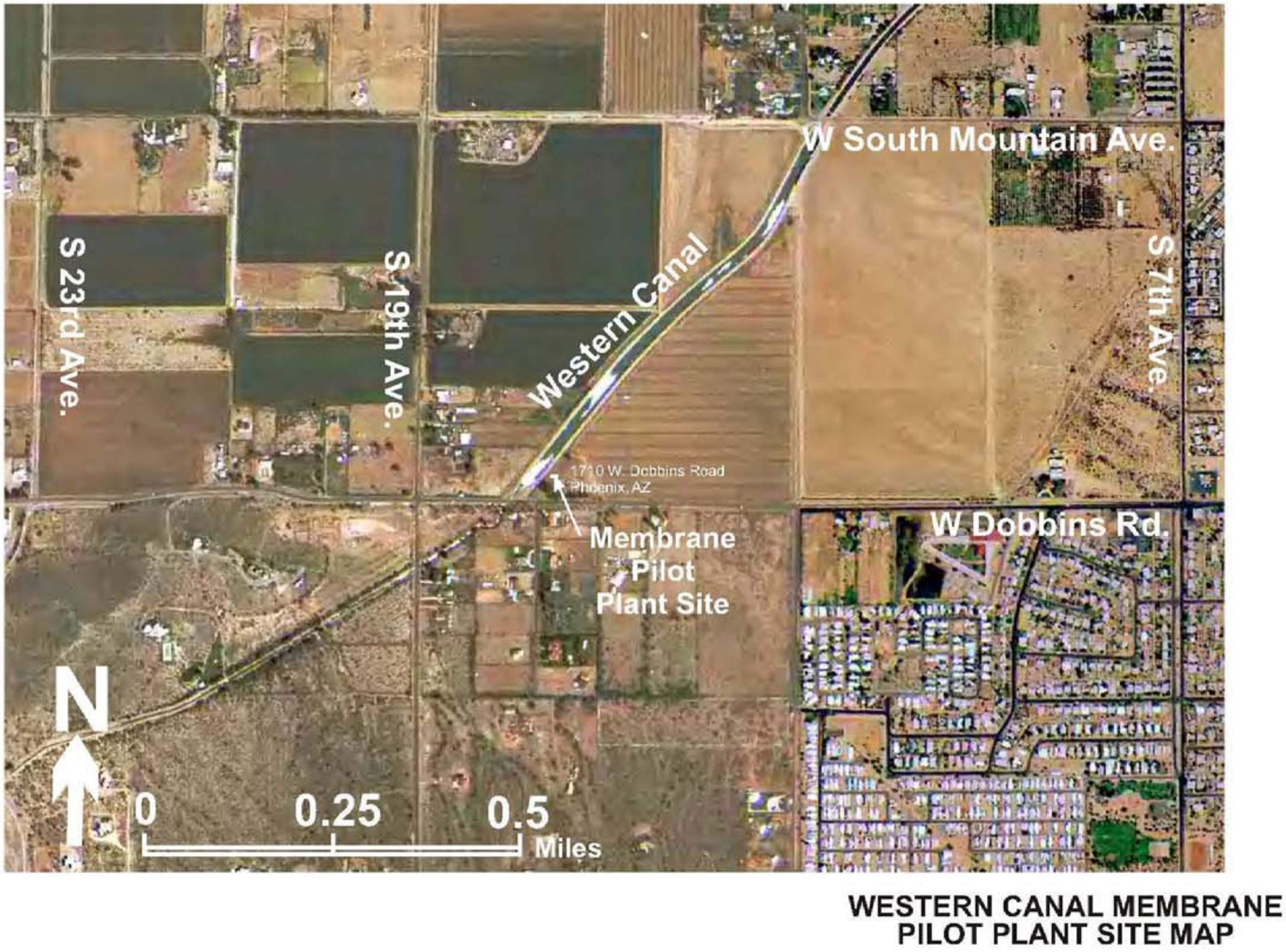

Figure 4.1 Western Canal Membrane Pilot Plant Site Map.

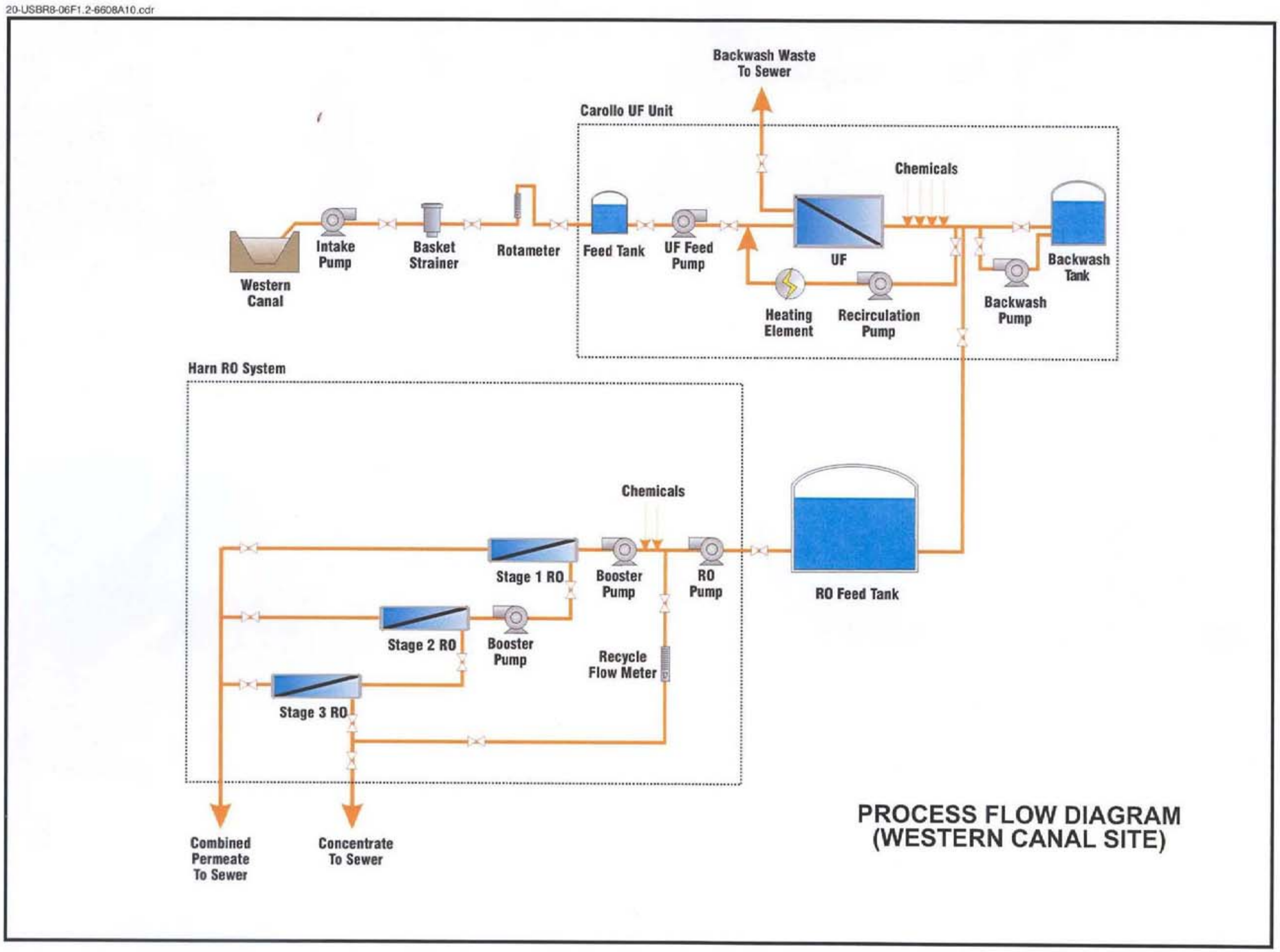

Figure 4.2 Process Flow Diagram (Western Canal Site).

General

Fence: 48'X34', 6-foot w/ 3-strand barbed wire, 20-foot double gate.
Paving: Apply gravel to the entire fenced area and the primary access road (7032sf, or 0.16 AC).
Setbacks: Distances from property lines as shown.
Trailers: Non-occupied equipment trailers. See Site Layout For Details.
Access: Road work (earthmoving, gravel application, etc.) required at planned primary entrance. Secondary access from canal maintenance road (approved by SRP).
Canal Intake: Provide 3" PVC canal intake line. Provide cable across canal for intake pipe suspension (approved by SRP).
SRP Right of Way: Across traffic surface, contain intake pipe in 6" ductile iron pipe covered by dirt hump (approved by SRP).

Utilities

Potable Water Connection: Provide 3/4" potable water pipe (buried PVC, ~160' long, 12" deep minimum). City of Phoenix will provide standard potable water tap to property line.
Discharge To Sewer: Provide 3" sewer connection (buried PVC, ~300' long, 12" deep min). Provide clean-outs every 100 linear feet and at each turn. See City's standard details S-511 for manhole connection.
Electricity Meter: New service pole. Weather-head shall be 20'-0" AFG. Install per SRP requirements. Refer to A/E-2 for conduit and sweep info. Install meter per SRP requirements. Coordinate installation with SRP. Contact: Bruce Souder 602-236-0692.
Power Cable: Direct buried feeder (~160' long). Provide a minimum of 24" cover. Install electrical warning tape 18" above direct buried cable.

Note: Only buried sewer line, potable water line and SRP pole for power connection were left in place. Everything else was removed from site after completion of the study.

WESTERN CANAL MEMBRANE PILOT PLANT SITE PLAN

Figure 4.3 Western Canal Membrane Pilot Plant Site Plan.

4.2.3.1 UF Pilot

The UF system that operated at the Western Canal was a custom-built pilot plant owned by Carollo and designed to operate with a pressurized membrane module. The UF pilot operated using a programmable logic controller (PLC) and a human machine interface (figure 4.4). UF feed and backwash flows were controlled by variable frequency drives (VFD). Figure 4.5 presents the UF pilot process and instrumentation diagram. Table 4.4 outlines the technical specifications of the Polymem™ UF membrane module.

A chemically enhanced backwash (CEB) procedure was used at regular intervals to remove absorbed foulants. It was performed by dosing chemicals with a dosing pump during backwashing, followed by soaking the unit for a preset time and rinsing the unit by performing another backwash. The dosing chemicals included sodium hypochlorite (for removal of biological fouling) and hydrochloric acid (for removal of scaling). The chemical cleaning cycle consisted of a backwash combined with a chemical soak.

PROGRAMMABLE LOGIC
CONTROLLER (PLC) OF THE
UF PILOT SYSTEM

Figure 4.4 Programmable Logic Controller (PLC) of the UF Pilot System.

Table 4.4 UF Membrane Module Specifications

Parameter	Value
UF membrane	Polymem™ UF120S2 module
Membrane material	Polysulfone
Module diameter	12 inches
Module length	37.4 inches
Flow configuration	Hollow fiber outside-in, dead end
Fiber external diameter	0.028 inch (0.72 mm)
Fiber internal diameter	0.015 inch (0.38 mm)
Membrane surface area	1205.6 ft^2 (114 m^2)
Membrane cutoff	0.01 micron (nominal)
Operating temperature	32 to 95 ˚F (0 to 35 ˚C)
Operating pH	2 to 12

4.2.3.2 RO Pilot

The RO pilot plant was leased from Harn RO Systems, Inc. The pilot skid (figures 4.6 and 4.7) consisted of three stages of RO membranes, organized in a 2:1:1 array of three- and four-element pressure vessels operated in series. The RO pilot had a maximum feed capacity of 30 gpm (1.9 liters per second (L/s)). The unit measured approximately 60 inches (1.52 m) in width by 144 inches (3.66 m) in length by 72 inches (1.8 m) in height. Table 4.5 outlines the technical specifications of the Harn RO pilot plant.

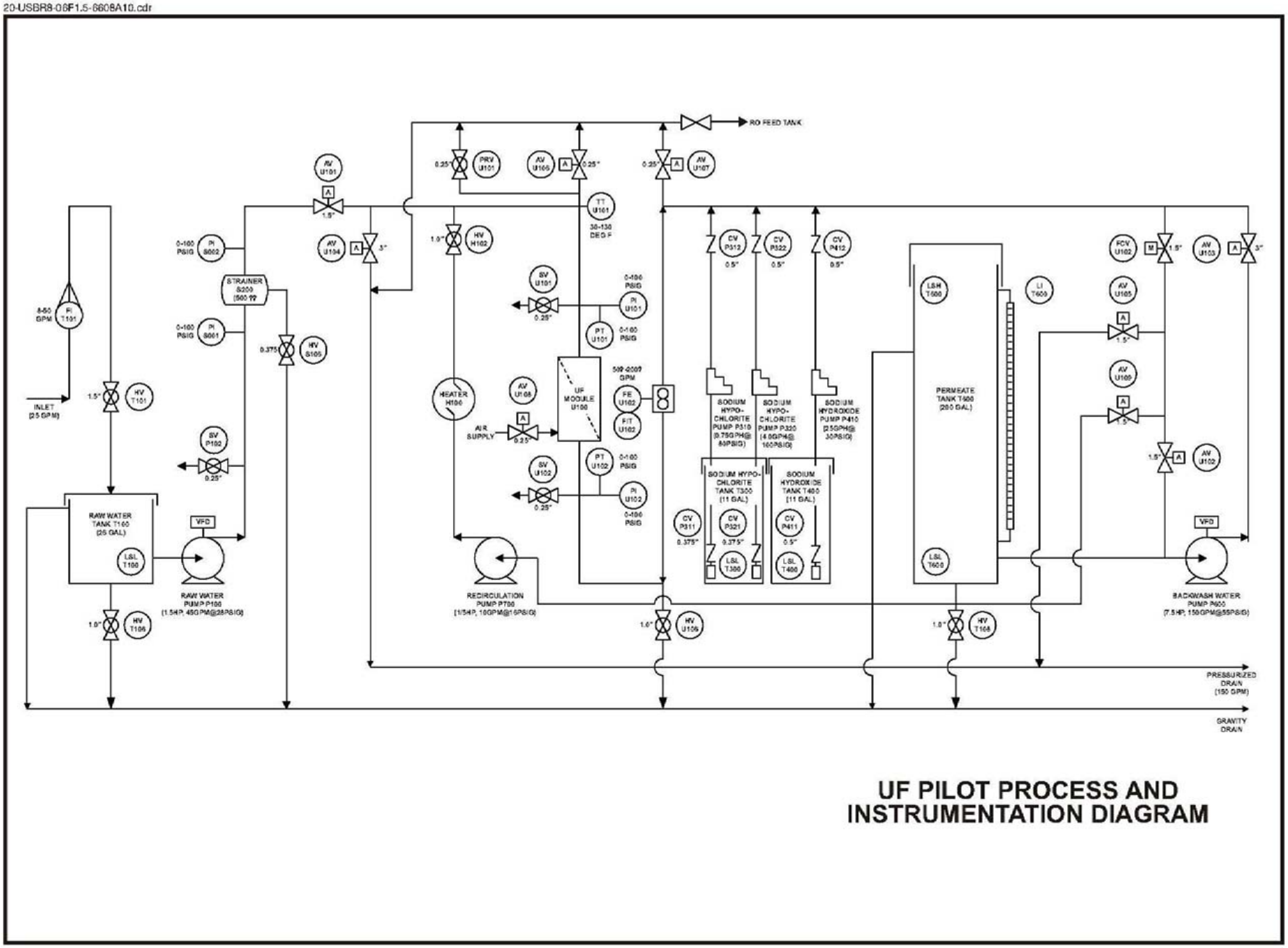

Figure 4.5 UF Pilot Process and Instrumentation Diagram.

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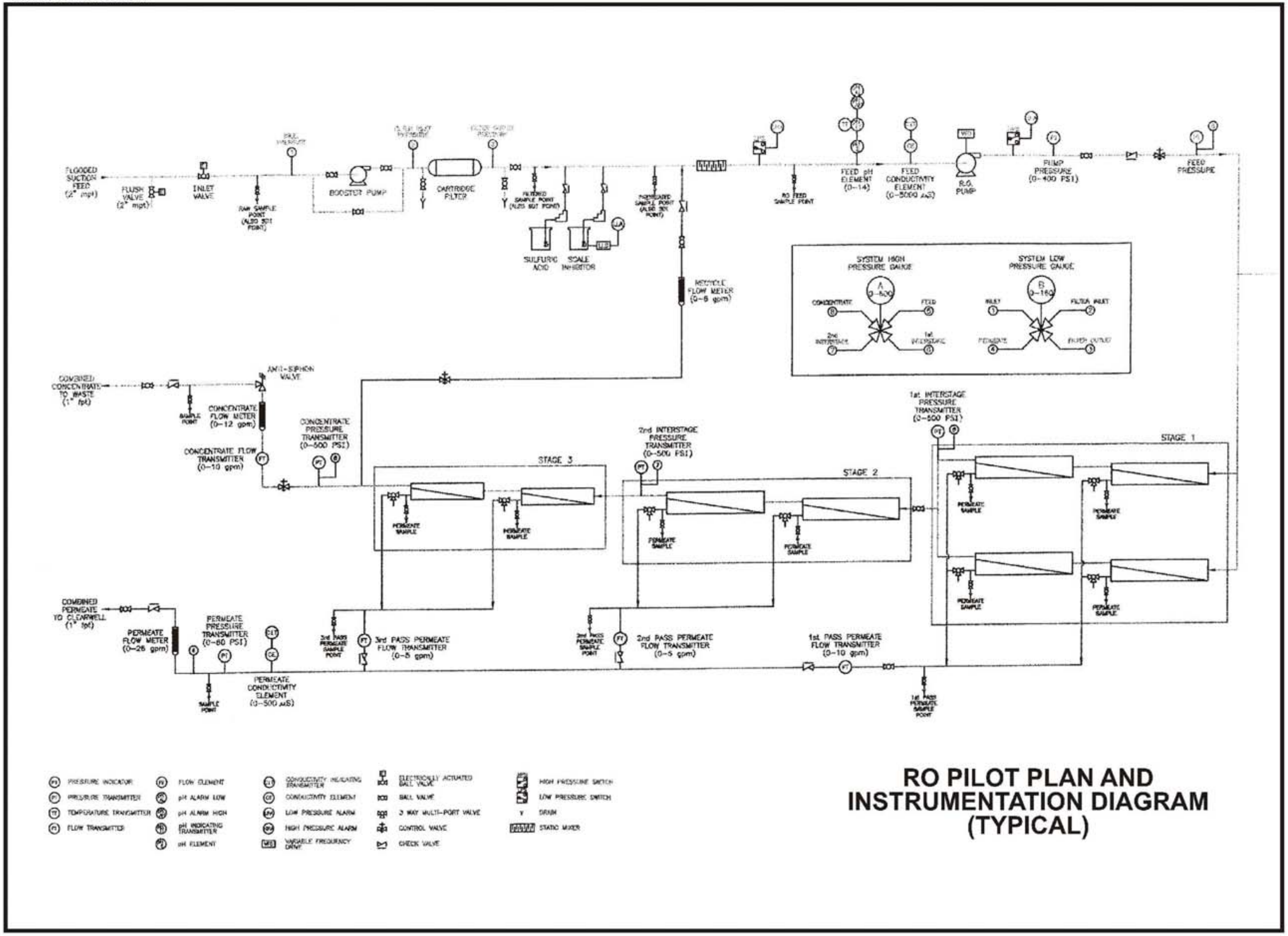


Figure 4.6 RO Pilot Plan and Instrumentation Diagram (Typical).

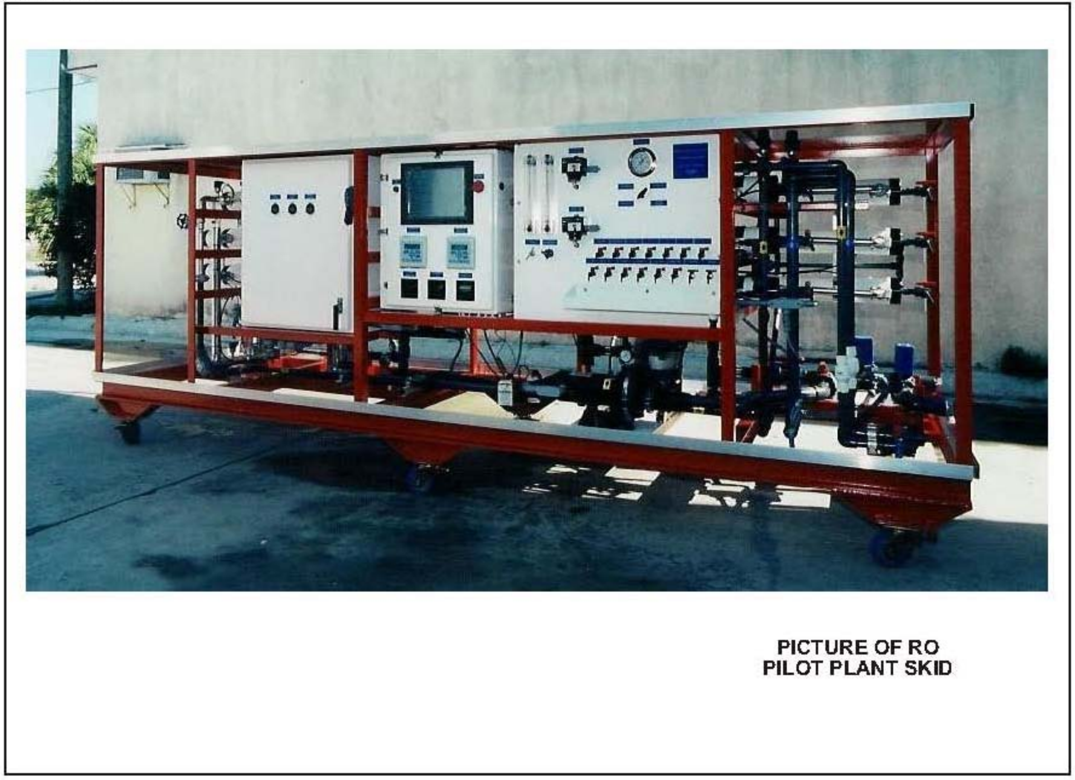


Figure 4.7 Picture of RO Pilot Plant Skid.

Table 4.5 RO Pilot Plant Specifications

Parameter	Value
Feed pump capacity	30 gpm
Chemical tanks	Two 30-gal tanks
Pretreatment chemicals	Acid and antiscalant
Scale inhibitor pump capacity	0.42 gph
Acid pump capacity	0.42 gph
Pressure vessels	Stage 1: (2) CodeLine 40A30-3, (2) Protec PRO-4-300
	Stage 2: (1) CodeLine 40A30-3, (1) Protec PRO-4-300
	Stage 3: (2) CodeLine 2.5B-3
Membrane element diameter	Stages 1 and 2: 4 inches
	Stage 3: 2.5 inches
Flow control	Booster pump between first and second stages; permeate throttling available on all stages

4.2.3.3 Site Layout

For security reasons and to protect the pilot equipment from extreme heat, the UF and RO pilots were housed within climate-controlled trailers. The UF system, including the UF product/RO feed tank, was housed in a 24-ft (7.32-m) by 8.75-ft

(2.67-m) by 9-ft (2.74-m) equipment trailer leased from Wastewater Resources, Inc. The RO pilot unit was housed in a 32-ft (9.75-m) by 8.5-ft (2.59-m) by 9-ft (2.74-m) custom trailer owned by the City. The City trailer had an attached work room, which was equipped with potable water and a sewer connection for performing simple onsite laboratory analyses. Both trailers were equipped with air conditioning to maintain temperatures below 100 °F (38 °C). Figure 4.8 provides a layout of the pilot equipment within the two trailers, figure 4.9 provides a photograph of the Western Canal pilot site, and figure 4.10 is a photograph of the raw water intake piping.

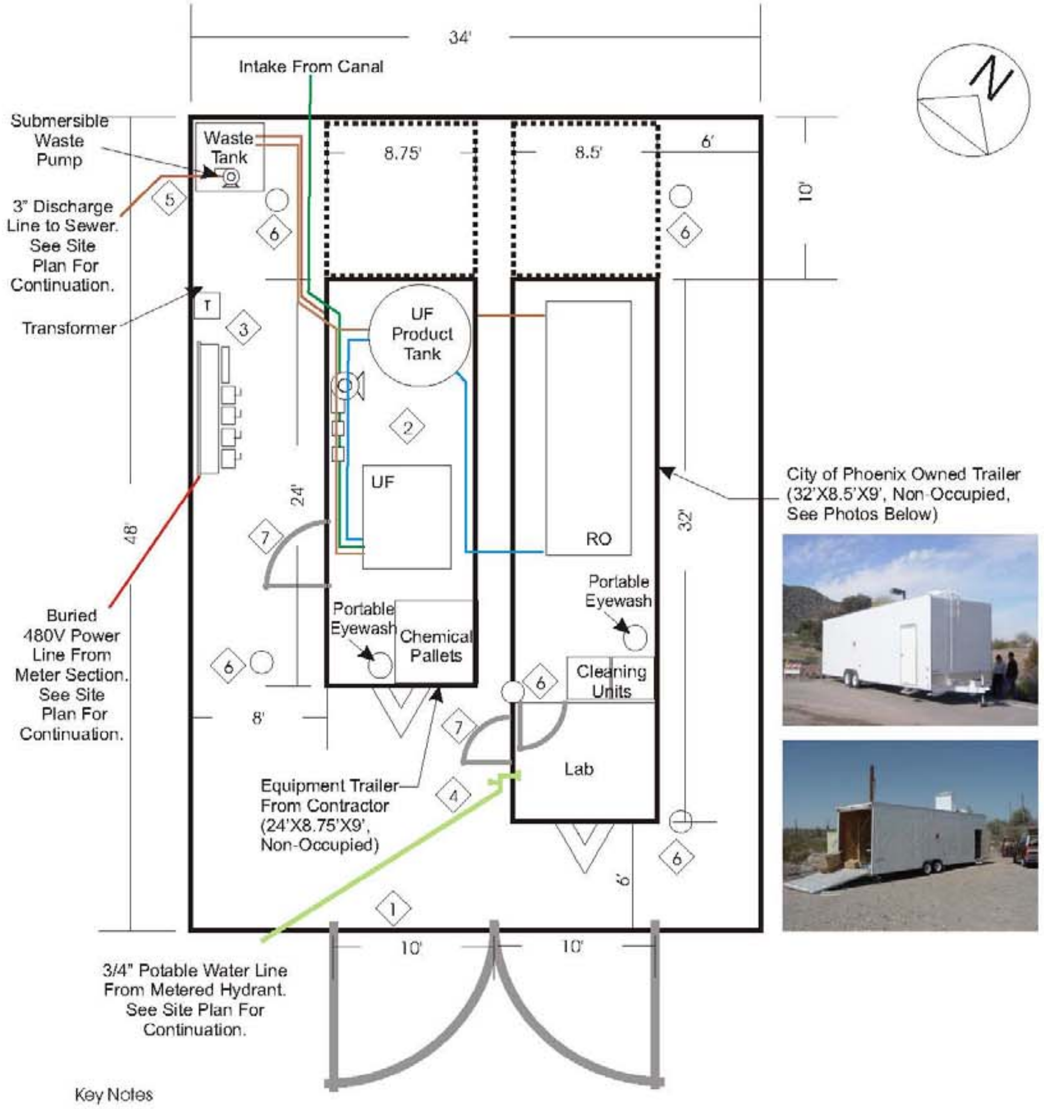
The Western Canal pilot site was equipped with multiple security measures, including security cameras, grills for the trailer doors, outdoor light fixtures, a motion detector, and screening for the roof-mounted air conditioning units. Figure 4.11 shows photographs of some of this equipment. All of the equipment, including the power transformers, pumps, waste tanks, and trailers, were enclosed within a 6-ft (1.83-m) construction fence with barbed wire. The fence had a 20-ft (6.1-m) double gate for access.

4.2.4 Normal Operation

In order to reach stable pretreatment conditions for the RO unit, the UF system was operated for 30 days at the start of the test program. During this time, the UF system was monitored for declining transmembrane pressure and adjusted to reach stabilized operation. Only after the UF unit had provided a continuously high-quality UF permeate was the RO system brought online. Chemical cleaning of the UF system and the recovery of the RO system were optimized to achieve the highest overall recovery.

4.2.4.1 UF for RO Pretreatment

Table 4.6 outlines the starting operating conditions for the UF pretreatment unit. The UF system was to be operated at a flux of approximately 47 gallons per square foot per day (gfd) (80 liters per square meter per hour [Lmh]). Feed flow was controlled using a VFD. Periodic backwashing with sodium hypochlorite was to be used to control membrane fouling. In addition to that, air scour was used during the backwash process to loosen the cake formed on the surface of the membranes. If the UF unit did not reach stable operation under the conditions shown in table 4.6, the flux was to be reduced and the backwash frequency and duration were to be increased.



Key Notes

1. Provide standard construction fence (6-foot with 3-strand barbed wire) and 20-foot double gate. Apply gravel for the entire fenced area.
2. Provide trailer (same type as existing City trailer) for the UF pilot skid, UF product tank, the canal intake pump, the raw water flow meter and the automatic strainer.
3. See electrical drawing for power system details.
4. Provide potable water connection (3/4" pipe buried) from metered hydrant. Provide hose bib connection in yard and connect water to trailer water tank.
5. Provide buried concrete or FRP waste tank (>200 gal). Maintain an air gap (min. double diameter of the discharge pipe) between the free flowing discharge to the tank and the water level in the tank. Lock hatch to secure pump. Provide waste line (3" PVC, buried) to sewer manhole. See City's standard details S-511 for manhole connection.
6. Provide four standard outdoor light fixtures and poles, one in each corner with photocell activator(s). Provide one security light with motion detector at the RO trailer personnel door.
7. Provide security grills for personnel doors.

* Other security measures include keeping the AC units and transformer out of sight by providing screening around them.

PILOT PLANT LAYOUT WITH THE TRAILERS

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Figure 4.8 Pilot Plant Layout with the Trailers.

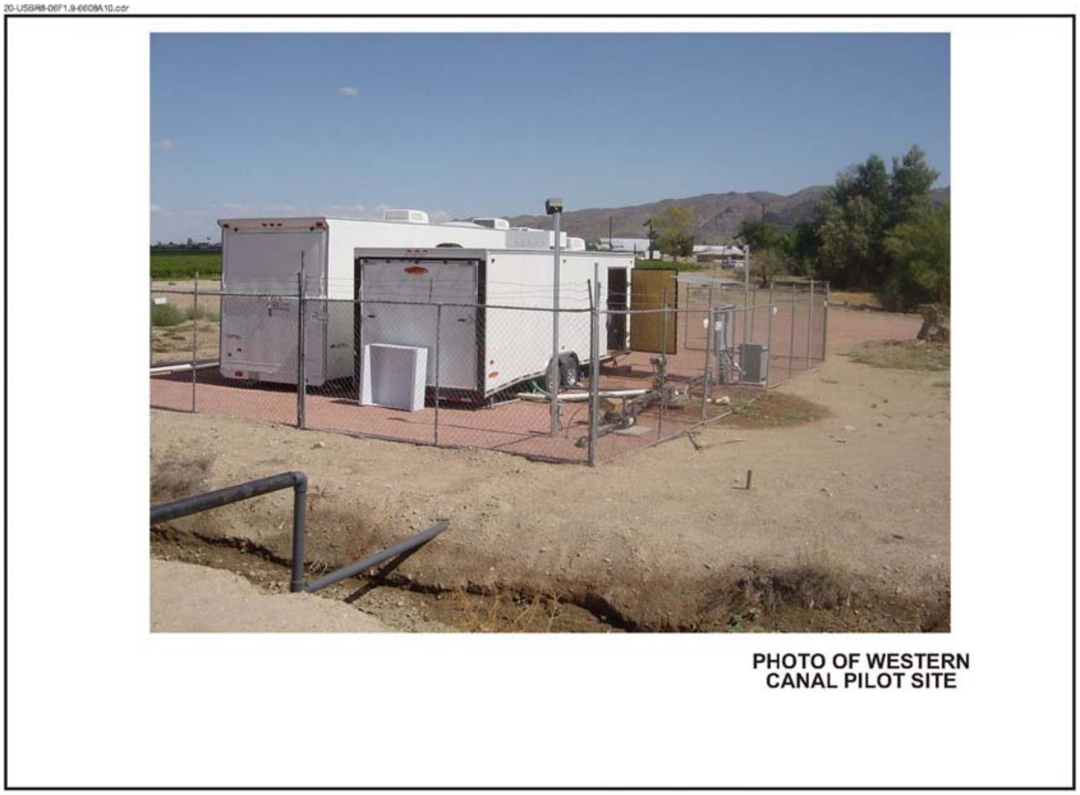

Figure 4.9 Photo of Western Canal Pilot Site.

Figure 4.10 Raw Water Intake Piping.

INSTALLATION OF SECURITY LIGHTING

INSTALLATION OF SECURITY CAMERAS

Figure 4.11 Site Security Equipment.

Table 4.6 UF Operating Conditions

Parameter	Value
System flux	47 gfd (80 Lmh)
Feed flow	40 gpm (219 m^3/d)
Maximum feed pressure	29 psi (2.0 bar)
Backwash frequency	30 minutes
Backwash duration	60 seconds
Maximum BW pressure	52.2 psi (3.6 bar)
Chemical addition	Sodium hypochlorite, 5 mg/L as Cl_2
BW Flow configuration	Reverse filtration, with air scour 1.5-3 scfm
Overall system recovery	90%

Notes: m^3/d = cubic meters per day, scfm = standard cubic feet per minute.

4.2.4.1.1 Air Integrity Testing

Air integrity testing was performed on a routine basis to detect any fiber breakage in the UF modules, which would lead to lower permeate water quality with higher turbidity and particle counts. An airflow test was used to determine the integrity of the membranes. The feed side was drained and pressurized as the filtrate side was left open to the atmosphere. Any broken fiber allowing a rapid escape of the pressurized air would result in an airflow rate higher than with an integral system. Broken fibers were identified and manually repaired.

4.2.4.1.2 Chemical Cleaning

The chemical cleaning sequence for the UF pilot was programmed in the PLC system, which controlled the three different chemical cleaning protocols: acid, bleach, and caustic. Cleaning was initiated based on time or after an increase in transmembrane pressure, declining flux, and reduced permeability. The sequence for cleaning of the UF was to first clean with hypochlorite and sodium hydroxide and then follow with citric acid. Raw water was used to make up the chemical cleaning solution.

The sodium hypochlorite cleaning backwash was set at 20 seconds. The cleaning solution was recirculated for 7,200 seconds. Thereafter, a sodium hypochlorite cleaning backwash was performed for 30 seconds (with recirculation for 7,200 seconds). The dosage of sodium hypochlorite was 200 mg/L.

4.2.4.2 RO Operation

Based on the test plan, the RO system was to be operated at a recovery of 85 percent and run at this condition for approximately 1 week. This startup period was chosen to allow time for the pilot operator to optimize operation without causing any irreversible damage or fouling to the new membranes. Only after successful results had been achieved within the first week was the recovery to be increased to 90 percent. Increasing the recovery further to 92 percent was also planned. The unit was to be operated at the higher recovery for approximately 3 months. During this longer testing period, more data were collected to evaluate the RO performance and the chemical cleaning requirements.

Table 4.7 outlines the overall RO system operating conditions at each recovery rate. Appendix B includes detailed results of the RO model projections for Phase 1 testing.

The RO modeling software predicts, as indicated in table 4.7 by the Langelier Saturation Index (LSI) and percent saturation values for $BaSO_4$, CaF_2, and SiO_2, that scaling conditions exist even at 85-percent recovery. As expected, the extent of the scaling potential increases as the recovery increases. The table also shows the dose of scale inhibitor predicted by the chemical manufacturer.

Table 4.7 RO Operating Conditions (Phase 1 – Surface Water)

Parameter	Value		
RO array	7:7:6:6		
Total number of elements	26		
Adjusted feed water pH	6.5		
Estimated acid dose (mg/L 100% H_2SO_4)	80.0		
RO system recovery[1]	85%	90%	92%
Scale inhibitor dose (mg/L SpectraGuard™)[2]	2.4	3.5	4.2
Raw water flow to RO system (gpm)	18.8	17.8	17.4
RO feed pressure (psi)	153	154	150
Permeate flow (gpm)	16.0	16.0	16.0
Average system flux (gfd)	14.0	14.0	14.0
Brine conditions[2]	85%	90%	92%
TDS (mg/L)	7,560	11,220	13,990
LSI	1.14	1.59	1.82
$BaSO_4$ (% saturation)	2,897	4,361	5,487
CaF_2 (% saturation)	332	1,090	2,113
SiO_2 (% saturation)	123	184	229
HCO_3 (mg/L)	1,166	1,720	2,134

Note: TDS = total dissolved solids.

[1] RO system modeled using ROSA Version 5.4 (The Dow Chemical Company).

[2] Scale inhibitor dose and recommended RO recovery modeled using PROdose32 Version 2.12.67 (Professional Water Technologies (PWT), Inc.).

4.2.4.2.1 Chemical Cleaning

Chemical cleaning of the RO system with low and high pH cleaners (Lavasol I™ and Lavasol II™) was to be performed when one or more of the following operational parameters had deviated:

- Normalized permeate flow dropped by 10 percent or more
- Normalized salt passage increased by 5 percent or more
- Normalized differential pressure increased by 15 percent or more

Table 4.8 summarizes the manufacturer-recommended chemicals for cleaning the FILMTEC™ membranes. Several cleanings are typically used in combination to remove the multiple layers of foulants from the membrane surface. One or more cycles of soaking and cleaning in recirculation may be required, depending on the nature of the foulant. Appendix C provides more detailed specifications for the commercial cleaning products.

The general sequence for cleaning was low pH cleaning to remove all inorganics, followed by high pH cleaning to remove organics. Starting with a high pH clean is generally not recommended because it can increase the severity of the scaling through the precipitation of calcium and magnesium hydroxides. Cleaning of the RO Stage 1 membranes was to be performed separately, followed by cleaning of Stages 2 and 3. All chemical cleaning wastes from the UF and RO cleanings were collected, diluted with RO permeate water, and fed slowly to the sewer system in accordance with local regulations.

Table 4.8 Recommended RO Cleaning Chemicals (Phase 1 – Surface Water)

Suspected Foulant	Cleaning Chemicals	Equivalent Commercial Product (PWT, Inc.)
Inorganic colloids (silt), silica, biofilms, organic fouling, and some sulfate scales	High pH cleaning, 0.1% sodium hydroxide, 0.25% sodium dodecylsufate, pH 12, 30 °C	Lavasol II™ - high pH and/or Lavasol V™ - for silica removal
Inorganic salts ($CaCO_3$)	Low pH cleaning, 0.2% hydrochloric acid, pH 2, 30-35 °C	Lavasol I™ - low pH
Metal oxides (i.e., iron)	1.0% sodium hydrosulfite	Lavasol I™ - low pH

4.2.5 Data Collection (Phase 1)

4.2.5.1 Manual Data Collection

UF and RO performance data were manually recorded into log books. The UF parameters included:

- Date, time, and operator initials
- Time to the next backwash cycle
- Pressure readings - feed, lower module, upper module, permeate, transmembrane, and backwash
- Flow readings - feed, permeate, and backwash

The following RO operational parameters were monitored and recorded daily:

- Date, time, and “run time” from the hour meter
- Pressure readings - cartridge filter inlet, cartridge filter outlet, system feed, system concentrate, system permeate, Stage 1 concentrate, Stage 2 feed, Stage 2 concentrate, Stage 2 permeate, Stage 3 feed, Stage 3 concentrate, and Stage 3 permeate
- Flow readings - system permeate, system concentrate, Stage 1 permeate, Stage 2 permeate
- Feed pump speed
- Scale inhibitor tank volume and flow rate

- Sulfuric acid tank volume and flow rate

4.2.5.2 Automatic Data Collection

The UF pilot system was equipped with automatic data collection for the following parameters:

- Date and time
- Feed temperature
- Feed pH
- Flow readings - feed, permeate, and backwash
- Pressure readings - feed, lower module, upper module, permeate, and backwash
- Flux
- Permeability

These data were downloaded and stored on floppy disks. A telephone line was also installed to allow remote access to the unit.

The RO pilot system was equipped with automatic data collection for the following parameters:

- Pressure readings - system feed; Stage 1 permeate and concentrate; Stage 2 feed, permeate, and concentrate; Stage 3 feed, permeate, and concentrate
- Temperature
- System feed pH
- System feed and finished permeate conductivity
- Flow rates - Stages 1, 2, and 3 permeate and concentrate

4.2.5.3 Onsite Testing

Table 4.9 outlines the Phase 1 water quality analyses that were performed daily. The following equipment was used for performing these analyses at the site:

- Temperature and pH - HACH sensION1 portable pH meter and HACH Model 51910 platinum series pH electrode
- Alkalinity - HACH Digital Titrator Model 16900
- Conductivity - HACH sensION5 conductivity meter and HACH Model 51975-00 conductivity probe
- Turbidity - HACH 2100P portable turbidimeter

- Silt Density Index (SDI) - Applied Membranes' Direct SDITM with Millipore 0.45-micron nitrocellulose membranes
- Barium and silica - HACH DR2000 spectrophotometer

TDS was measured using dried weighing dishes, an analytical scale, and a commercial toaster oven.

Table 4.9 Onsite Water Quality Analyses (Phase 1- Surface Water)

Parameter	Raw Water	UF Permeate	RO Feed	RO Permeate	RO Byproduct
Temperature (°C)	✓				
pH (SU)	✓	✓	✓	✓	✓
Alkalinity (mg/L)	✓	✓	✓	✓	✓
Conductivity	✓	✓	✓	✓	✓
Turbidity (NTU)	✓	✓			
SDI	✓		✓		
TDS (mg/L)	✓	✓	✓	✓	✓
Barium	✓	✓	✓	✓	✓
Silica	✓	✓	✓	✓	✓

Notes: NTU = nephelometric turbidity units, SU = standard units.

4.2.5.4 Water Quality Laboratory Data

Table 4.10 outlines the weekly laboratory analyses that were performed and managed by the City. All water quality samples were collected by Carollo and delivered to the City on Monday of each week. A number of samples for the parameters noted in table 4.10 were forwarded to MWH Laboratories for analysis.

Table 4.10 Laboratory Analyses (Phase 1 - Surface Water) Performed by City of Phoenix

Parameter	Raw Water	UF Permeate	RO Feed	RO Permeate	RO Byproduct
pH (SU)	✓	✓	✓	✓	✓
Alkalinity (mg/L)	✓	✓	✓	✓	✓
Turbidity (NTU)	✓	✓			
TSS (mg/L)	✓	✓			
TDS (mg/L)	✓	✓	✓	✓	✓
TOC (mg/L)[1]	✓	✓			
DOC (mg/L)[1]	✓	✓			
THHM (µg/L)	✓	✓		✓	
Arsenic (mg/L)	✓			✓	✓

Table 4.10 Laboratory Analyses (Phase 1 - Surface Water) Performed by City of Phoenix (continued)

Parameter	Raw Water	UF Permeate	RO Feed	RO Permeate	RO Byproduct
Barium (mg/L)	✓	✓	✓	✓	✓
Calcium (mg/L)	✓	✓	✓	✓	✓
Magnesium (mg/L)	✓		✓		
Sodium (mg/L)	✓		✓		
Potassium (mg/L)	✓		✓		
Ammonia (mg/L)	✓		✓		
Barium (mg/L)	✓		✓		
Strontium (mg/L)	✓		✓		
Sulfate (mg/L)	✓		✓		
Chloride (mg/L)	✓		✓		
Fluoride (mg/L)	✓		✓		
Nitrate (mg/L)	✓		✓		
Silica (mg/L)	✓	✓	✓	✓	✓
SOCs (mg/L)[2]					

Note: TSS = total suspended solids, TOC = total organic carbon, DOC = dissolved organic carbon, TTHM = total trihalomethanes, SOC = synthetic organic compounds.

[1] Samples for these parameters were forwarded to MWH Laboratories for analysis.

[2] SOCs were performed monthly. All other parameters were monitored weekly.

4.3 Ground Water Testing (Phase 2)

Based on the RO recovery rates recommended by PWT, a series of RO projections were made using the ROSA modeling program (Dow Chemical Company, Version 6.0). The modeling results are presented in Appendix D, “RO Model Projections – Phase 2,” and summarized in table 4.11.

4.3.1 Scale Inhibitor Selection

Similar to Phase 1, the antiscalant used for Phase 2 was a dendrimer-based antiscalant supplied by PWT. PWT also predetermined the antiscalant dosages.

4.3.2 Membrane Selection

The FILMTEC™ low-pressure membranes used during Phase 1 were chemically cleaned and reused during Phase 2 (i.e., FILMTEC™ membranes BW30LE-4040 in RO Stages 1 and 2, and FILMTEC™ membranes LP2540 in Stage 3). Table 4.3, presented earlier, provides a summary of those membrane elements.

Table 4.11 RO Operating Conditions (Phase 2 – Brackish Ground Water)

Parameter	Value		
RO array	7:7:5:5		
Total number of elements	24		
RO system recovery[1]	85%	90%	94%
Scale inhibitor dose (mg/L)[2]	2.9	3.2	3.8
Raw water flow to RO system (gpm)	19.4	18.3	17.6
RO feed pressure (psi)	158	181	224
Permeate flow (gpm)	16.5	16.5	16.5
Concentrate recycle flow (gpm)	1.5	2.0	3.0
Average system flux (gfd)	14.0	14.0	14.0
Brine stream parameter	85%	90%	94%
TDS (mg/L)	9,993	14,603	23,050
LSI	1.93	2.23	2.57
$BaSO_4$ (% saturation)	1,855	2,816	4,835
CaF_2 (% saturation)	1,651	5,278	21,640
SiO_2 (% saturation)	151	229	385
HCO_3 (mg/L)	1,611	2,333	3,614

[1] RO system modeled using ROSA Version 6 (Dow Chemical Company).

[2] SpectraGuard™ scale inhibitor dose and recommended RO recovery modeled using PROdose32 Version 2.13.74 (PWT, Inc.).

In order to improve the RO performance, a different RO array design was chosen for Phase 2. The Stage 3 feed water flow rate was increased by reducing the number of elements from six to five.

4.3.3 Equipment Setup

The pilot site for Phase 2 remained at 1710 W. Dobbins Road in Phoenix (figure 4.1). The original proposal planned for testing ground water from an area west of downtown Phoenix, near the Gila River. However, extensive site development costs incurred during Phase 1 at the Western Canal made it advantageous to identify an alternative ground water source that could be pumped to the existing pilot site and eliminate the need to move the pilot equipment and develop a second site. An alternative well, owned by Salt River Project (SRP), was identified within a half mile (800 m) of the existing pilot site, which offered ground water of similar quality to that existing in the Gila River area.

SRP did not plan to use their well during the testing period; therefore, the project was responsible for the cost of pumping. To reduce electrical costs associated with continuous operation of SRP's existing well and to prevent the wasting of excess water not used by the pilot, a small submersible pump was installed to replace the SRP pump.

As in Phase 1, the RO concentrate and permeate streams were combined and fed to a partially buried waste tank. A submersible pump then transferred the waste to the sewer.

4.3.4 Normal RO Operation

Table 4.11 outlines the overall RO system operating conditions at each recovery rate for Phase 2 testing.

Appendix C includes detailed results of the RO model projections. Table 4.11 also presents a summary of the predicted concentrations of constituents in the brine stream when operating on the brackish ground water. Comparing these values with those predicted for Phase 1 (table 4.7), it can be seen that the Phase 2 brine TDS concentrations, as well as the LSI and CaF_2 and SiO_2 concentrations are higher. One difference is that the $BaSO_4$ concentrations were predicted to be lower for Phase 2. Pump limitations on the RO pilot required the use of partial concentrate recycling to reach certain recovery rates. While sulfuric acid was used in Phase 1 to lower the feed water pH and increase the solubility of certain scaling salts, the use of acid did not seem to improve system recovery and was, therefore, not used during Phase 2.

4.3.5 Data Collection (Phase 2)

Table 4.12 provides the water quality testing matrix showing the sampling frequency for parameters that were tested onsite. A list of the parameters and the frequency of laboratory testing is shown in table 4.13.

Table 4.12 Onsite Water Quality Testing (Phase 2 – Brackish Ground Water)

		Raw Water	RO Permeate	RO Concentrate
Temperature	˚C	1 per day		
pH	SU	1 per day	1 per day	1 per day
SDI		3 per week[1]		
Conductivity	µS/cm	3 per week	3 per week	3 per week
TDS	mg/L	3 per week	3 per week	3 per week
Turbidity	NTU	3 per week		
Silica	mg/L	3 per week[1]		

Note: µS/cm = microsiemens per centimeter.

[1] If raw water SDI and silica concentrations were stable, sampling frequency was reduced to once per week.

Table 4.13 Laboratory Analyses (Phase 2 - Brackish Ground Water) performed by City of Phoenix

Parameter	Raw Water	RO Permeate	RO Byproduct
Alkalinity (mg/L)	1 per week	1 per week	1 per week
Ammonia (mg/L)	1 per week	1 per week	
Arsenic (mg/L)	1 per week	1 per week	1 per week
Barium (mg/L)	1 per week	1 per week	
Boron (mg/L)	1 per week	1 per week	
Calcium (mg/L)	1 per week	1 per week	
Chloride (mg/L)	1 per week	1 per week	
DOC (mg/L)	1 per week	1 per week	
Fluoride (mg/L)	1 per week	1 per week	
Magnesium (mg/L)	1 per week	1 per week	
Nitrate (mg/L)	1 per month	1 per month	1 per month
pH	1 per week	1 per week	1 per week
Potassium (mg/L)	1 per week	1 per week	
Silica (mg/L)	1 per week	1 per week	1 per week
SOCs	1 per week	1 per week	1 per week
Sodium (mg/L)	1 per week	1 per week	
Strontium (mg/L)	1 per week	1 per week	
Sulfate (mg/L)	1 per week	1 per week	
TDS (mg/L)	1 per week	1 per week	1 per week
TOC (mg/L)	1 per week	1 per week	
TSS (mg/L)	1 per week	1 per week	
TTHM (µg/L)	1 per week	1 per month	1 per month
Turbidity (NTU)	1 per week	1 per week	

Notes: µg/L = micrograms per liter. RO permeate metals sampling frequency reduced after results confirmed that removal was consistent with system recovery rate.

4.3.6 Membrane Autopsies

At the end of the Phase 2, three elements were removed from the RO system and sent to the manufacturer for membrane testing. One element was a lead element in the third stage, and the other two elements were taken from the end of the third stage (tail elements). Standard performance tests were conducted on all the elements. A further test was carried out on one of the lead elements to determine whether the membrane could be cleaned by different cleaning solutions. A membrane autopsy was carried out on one of the tail-end elements, and an inductively coupled plasma emission spectroscopy (ICPES) was used to determine the nature of foulants/scalants on the membrane surface.

5. Test Results and Discussion

5.1 Surface Water Test Results (Phase 1)

5.1.1 Feed Water Quality (Phase 1)

The source water for Phase 1 testing was taken from the Western Canal. Selected constituents of that feed water with minimum, average, and maximum concentrations are presented in table 5.1. Appendix E presents a detailed table of all constituents that were analyzed. The raw water had relatively high concentrations of turbidity (around 50 NTU) and hardness (average around 270 mg/L as $CaCO_3$). During the first 3 months of UF operation, the raw water turbidity was mostly between 3 and 10 NTU, with a median turbidity of 4 NTU. However, by the end of November 2004, the feed water turbidity had increased significantly, reaching a peak of 50 NTU, and then gradually decreased over the ensuing months, reaching a low of 4 NTU in the middle of February 2005. Figure 5.1 shows the turbidity and particle counts of the raw water for the duration of the testing.

5.1.2 Ultrafiltration System Performance

The UF system performance was evaluated using data retrieved from the automatic data collection system and entries from the logbooks. The following performance indicators have been identified as the most critical ones to evaluate UF system performance:

- Transmembrane pressure (TMP)
- Flux
- Specific flux
- Normalized flux
- Feed and permeate water quality

Additionally, the backwash duration and frequency and the overall water recovery of the UF system were identified. Water quality is discussed later.

5.1.2.1 UF System Flux

The purpose of the UF system was to provide an adequate flow of high-quality permeate to the RO unit by removal of turbidity and particulate matter. Figure 5.2 shows the hydraulic performance of the UF system throughout Phase 1 testing.

After startup, the UF system flux was set at 60 Lmh, and the system was operated at this condition for 30 days. After 30 days, the transmembrane pressure had increased from 6 to 16.5 psig (41.37 to 113.76 kilopascals [kPa]), resulting in the normalized flux decreasing from 30 to 25.9 gfd (51 to 44 Lmh) and the specific flux declining from 4.14 to 1.8 gfd/psig (102 to 44 Lmh per bar).

Table 5.1 Raw Water Quality of the Western Canal (Phase 1)

Parameter	Units	Minimum	Average	Maximum
Temperature	° C	11.4	15	24.5
pH	SU	7.13	8.2	8.72
Alkalinity	mg/L as $CaCO_3$	112	197.8	257
Ammonia[1]	mg/L		0.2	
Barium - total	mg/L	0.05	0.068	0.09
Calcium - total	mg/L	37	63	95
Chloride	mg/L	43	264.3	426
DOC	mg/L	0.6	2.4	6.73
Fluoride	mg/L	0.21	0.38	0.81
Iron - dissolved	mg/L	0.02	0.0325	0.12
Iron - total	mg/L	0.1	0.63	2.6
Magnesium - total	mg/L	13	28	39
Manganese - total	mg/L	0.01	0.024	0.06
Nitrate-N	mg/L	0.3	3.82	9.8
Potassium - total	mg/L	2.6	5.30	7.3
Selenium - total	mg/L	0.005	1.00	2
Silica - total	mg/L as SiO_2	10.9	21.54	32.1
Silicon - total	mg/L	5.1	10.1	15
Sodium - total	mg/L	44	195	347
Strontium - total	mg/L	0.39	0.96	2.2
Sulfate	mg/L	29	111	168
TDS	mg/L	288	817	1,250
Total hardness	mg/L as $CaCO_3$	147	274	400
TOC	mg/L	0.8	2.78	7.48
Turbidity[1]	NTU		51.3	
UV254	cm^{-1}	0.01	0.089	0.179

Note: Samples taken between 8/10/2004 and 2/24/2005 (28 sampling events).
[1] Data for one sample only.

Between October 6 and October 8, 2004, the UF system was down, and after restart, the flux was reduced to 26 gfd (50 Lmh). Thereafter, the flux was stable until October 19, 2004. Between October 25 and November 11, 2004, the normalized flux was between 30 and 32.4 gfd (51 and 55 Lmh), while the transmembrane pressure increased from 7 to 12 psig (48.27 to 82.7 kPa).

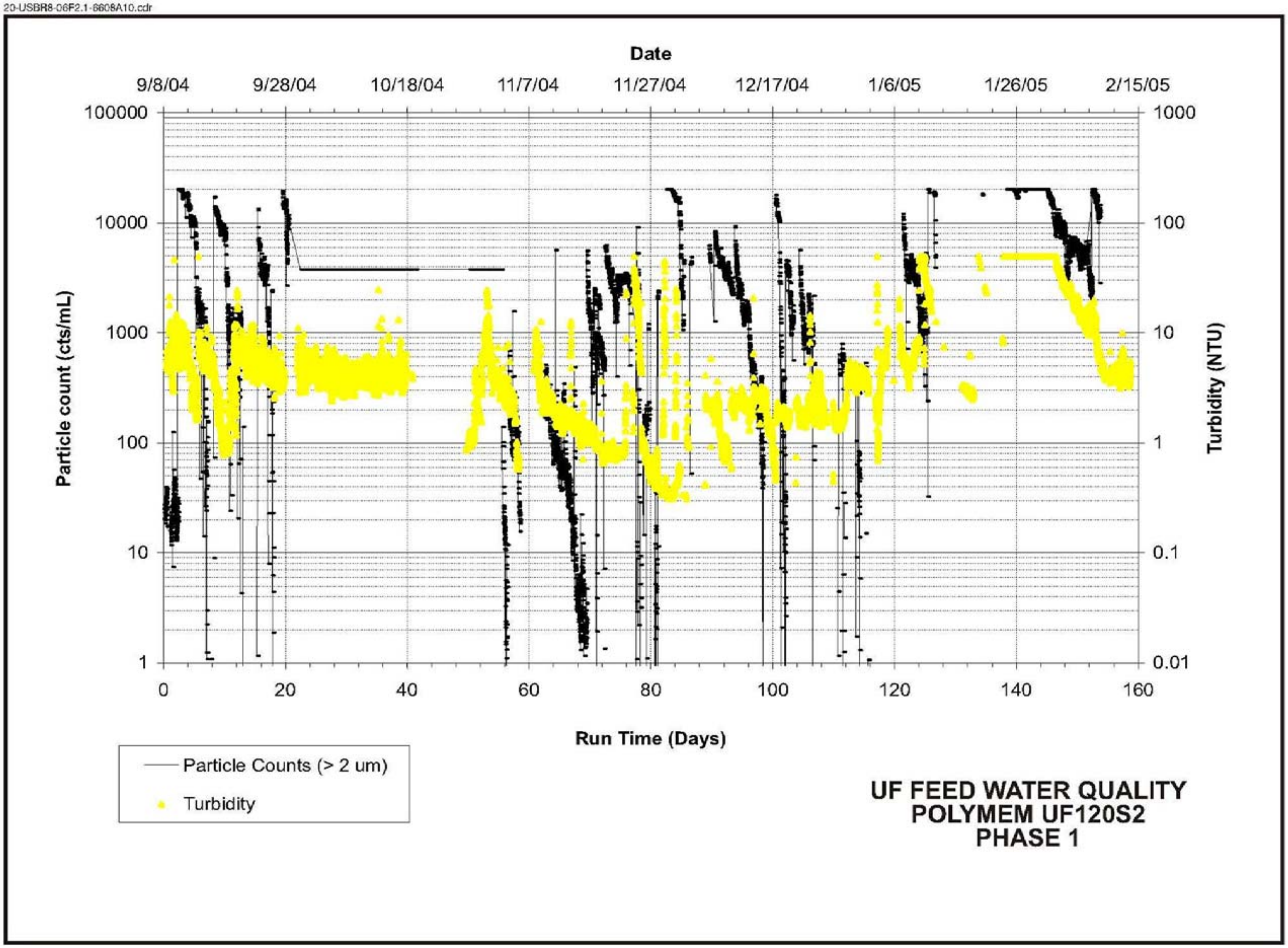

Figure 5.1 UF Feed Water Quality Polymem UF120S2 Phase 1.

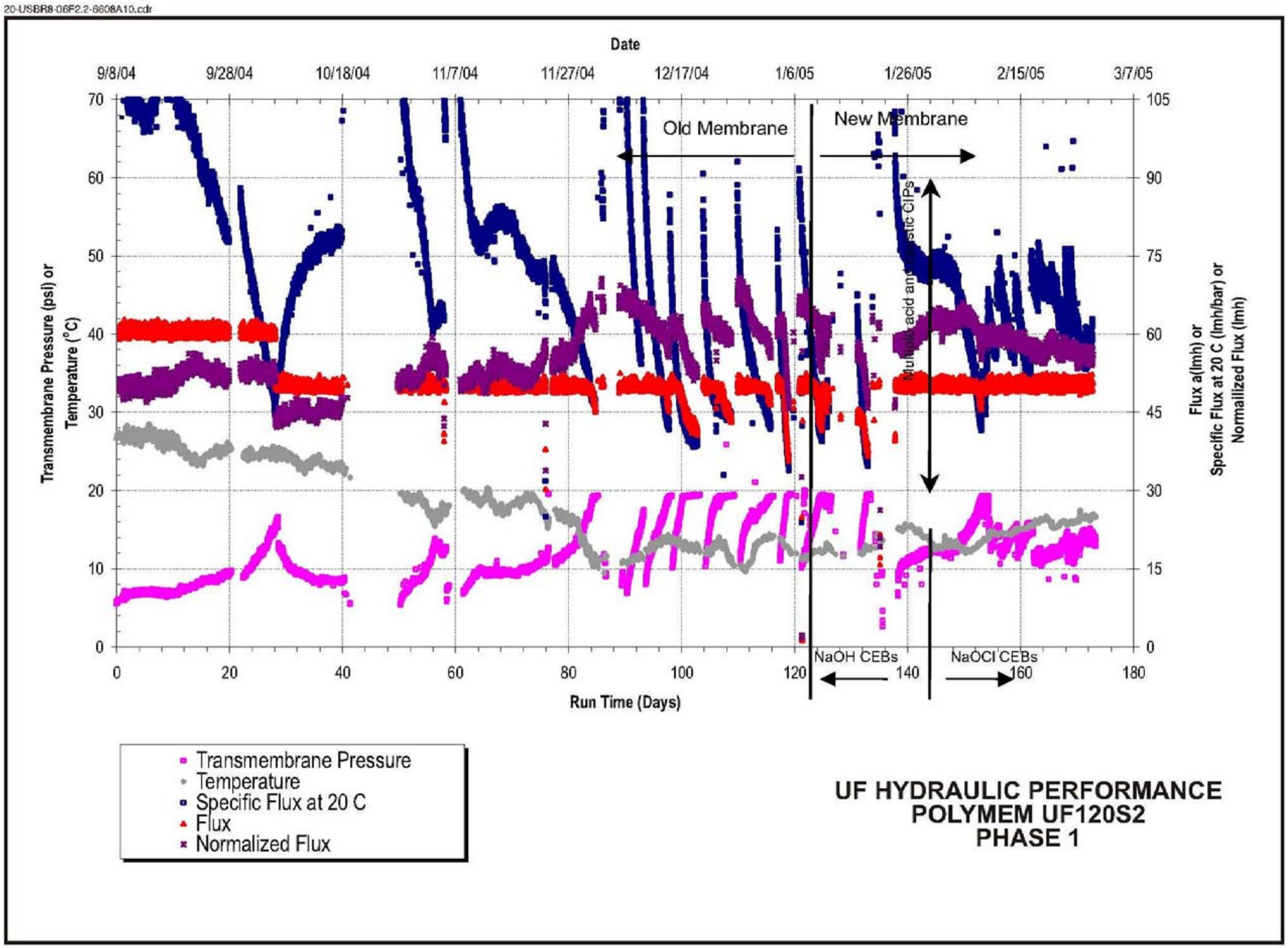

Figure 5.2 UF Feed Water Quality Polymem UF120S2 Phase 1.

During the next operating period between November 8 and December 3, 2004, the normalized flux rose between 30 and 37.7 gfd (50 and 64 Lmh), while the transmembrane pressure reached its first peak of 20 psig (137.9 kPa). The temperature was initially around 77 °F (25 °C) and, at this point, dropped to a minimum of 54 °F (12 °C).

From this point in time, the membrane system had to be cleaned more frequently to recover the flux. The membrane fibers had to be fixed every 4 days, which resulted in at least 1 or 2 days of downtime of the UF system. During every run, the normalized flux declined from 37.7 to 30 gfd (66 to 51 Lmh). The specific flux ranged between 1.4 and 3.7 gfd/psig (35 and 90 Lmh per bar). Finally, on January 11, 2005, the UF membrane module was replaced. With the new membrane, and after changing from NaOH CEBs to NaOCl CEBs, the flux was stable at 29.5 gfd (50 Lmh), and the specific flux ranged between 2.8 and 2.3 gfd/psig (70 and 57 Lmh per bar).

The recovery of membrane flux after chemical cleaning was measured based on permeability tests before and after the cleaning procedure. This procedure showed that a single cleaning, with both acid and caustic, was not as efficient as multiple clean in places (CIPs) with caustic alone. After February 9, 2005, the new NaOCl CEBs and the caustic cleaning enhanced and stabilized the flux of the UF system.

5.1.2.2 UF System Transmembrane Pressure

Transmembrane pressure, the pressure across the membrane, is the driving force needed to produce the desired UF permeate flow rate. Therefore, the transmembrane pressure increases to maintain the desired permeate flow as the membrane loses permeability due to membrane fouling.

As an example, between October 25 and November 5, 2004, the normalized flux was between 30 and 32.4 gfd (51 and 55 Lmh), while the transmembrane pressure increased from 7 to 12 psig (48.3 to 82.74 kPa) as shown in figure 5.2. During the period November 8 to December 3, 2004, the transmembrane pressure reached its first peak of 20 psig (137.9 kPa). A transmembrane pressure of 20 psig (137.9 kPa) was determined as a set point when the UF membrane cleaning cycle was to be initiated. The earlier sections dealing with the UF cleaning requirements (sections 4.2.3.1 and 4.2.4.1.2) contain more detailed information about the cleaning cycles.

5.1.2.3 Permeate Water Quality and UF Membrane Integrity

The turbidity of the UF permeate was consistently below 0.2 NTU; the median was 0.08 NTU, as shown in figure 5.3. Only during one episode on October 28, 2004, did the turbidity of the UF permeate increase to 3 NTU due to a membrane failure. During this episode, the particle count (for particles greater than 2 µm) increased from 15 to 500 counts. The median particle count in the permeate water was 130 counts.

After the UF membrane replacement, particle counts of less than 5 were consistently measured in the UF permeate, and the median particle count was only 1.

The SDI for 15 minutes (SDI15) was measured up to three times per week. The variations of the SDI15 in the UF permeate were between 0.5 and 1.82, which could be attributed to UF fiber breakages rather than to seasonal variations in raw water quality. The average SDI15 over the period October 6, 2004, to February 15, 2005, was 1.03. Based on the SDI values of the RO feed water, RO membrane fouling was not expected to be a problem.

Table 5.2 shows a summary of selected water quality parameters in the UF permeate stream for the period September 23, 2004, to February 25, 2005. Appendix F includes a table showing all constituents that were measured during this period.

Table 5.2 UF Permeate Water Quality - Western Canal Water (Phase 1)

Parameter	Units	Minimum	Average	Maximum
Temperature	˚C	9.4	15	27.5
Ph	SU	7.13	8.2	8.72
Alkalinity	mg/L as CaCO3	110	198.6	255
Total dissolved solids	mg/L	882	1,095	1,260
TOC	mg/L	0.7	2.4	6.23

Notes: Samples were taken between 8/10/2004 and 2/24/2005 (28 sampling events). Some of the parameters were analyzed only once.

5.1.2.4 UF Backwash Duration, Frequency, and Overall Recovery

The initial water recovery was around 90 percent but decreased to around 85 percent when more frequent backwashing was necessary. After replacement of the membrane module, the recovery was 83 percent. The backwash duration was between 235 and 280 seconds. The total backwash volume produced was between 78 and 205 gal (295 and 776 L). Backwash time 1 was set for 30 seconds, with 150 seconds rest time; backwash time 2 for 5 seconds on and 5 seconds off; and backwash time 3 for 40 seconds on and air purge of 10 seconds. A CEB was performed with NaOH until February 9, 2005. Thereafter, a combination of NaOCl CEBs and caustic cleaning helped enhance and stabilize the flux of the UF system.

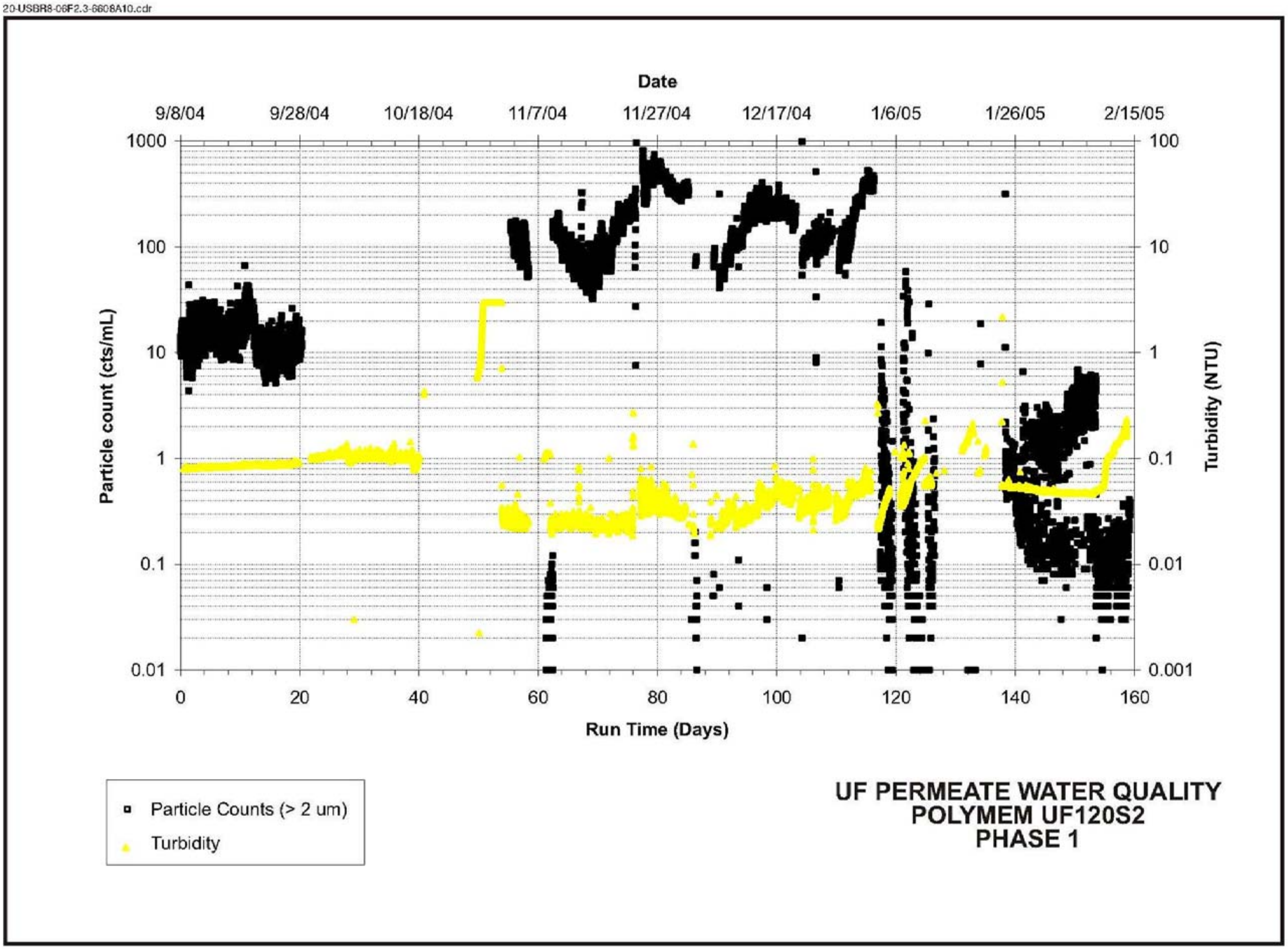

Figure 5.3 UF Permeate Water Quality Polymem UF120S2 Phase 1.

5.1.2.5 UF Membrane Cleaning Requirements

As mentioned earlier, more frequent and extended cleaning cycles of the UF membranes were required to sustain the desired permeate production. When the cleaning routine was optimized, the cleaning frequency was 2 to 3 days. The longest period of time during which no chemical cleaning was performed was 1 month, which was mostly due to intermediate pilot plant shutdowns. Figure 5.4 shows the cleaning frequencies and the effects on UF hydraulic performance.

Table 5.3 shows the cleaning requirements for the UF membranes. The efficiency of the cleaning procedures was determined by the decrease in transmembrane pressure.

Table 5.3 UF Membrane Cleaning Requirements - Western Canal Water (Phase 1)

Parameter	Unit	Value
NaOH dose	mg/L	7,500
NaOH pump capacity	gph	11.98
Loop volume	gal	70
Dosing time	minutes	10
NaOH strength (set point)	lb/gal	2.2
Chlorine strength	lb/gal	0.55
Chlorine dosing rate	gph	1.23
Dosing time	minutes	10
Target chlorine strength	mg/L	200
NaOH cleaning backwash	seconds	30
NaOH cleaning recirculation	seconds	3,600
NaOCl cleaning backwash	seconds	35
NaOCl cleaning recirculation	seconds	300
Before Cleaning Measurements:		
Flux	Lmh at 20 ˚C	62.15
TMP	psi	11.5
Permeability	Lmh per bar	78.4
After Cleaning Measurements:		
Flux	Lmh at 20 ˚C	62.15
TMP	Psi	9.5
Permeability	Lmh per bar	94.9

The relatively high hardness of the water used for the UF CIP resulted in a gray inorganic substance, which accumulated on the permeate side of the membrane as shown in figure 5.5. Softening of the make-up water for the cleaning solutions is recommended in the future because of the high calcium hardness in the Western Canal.

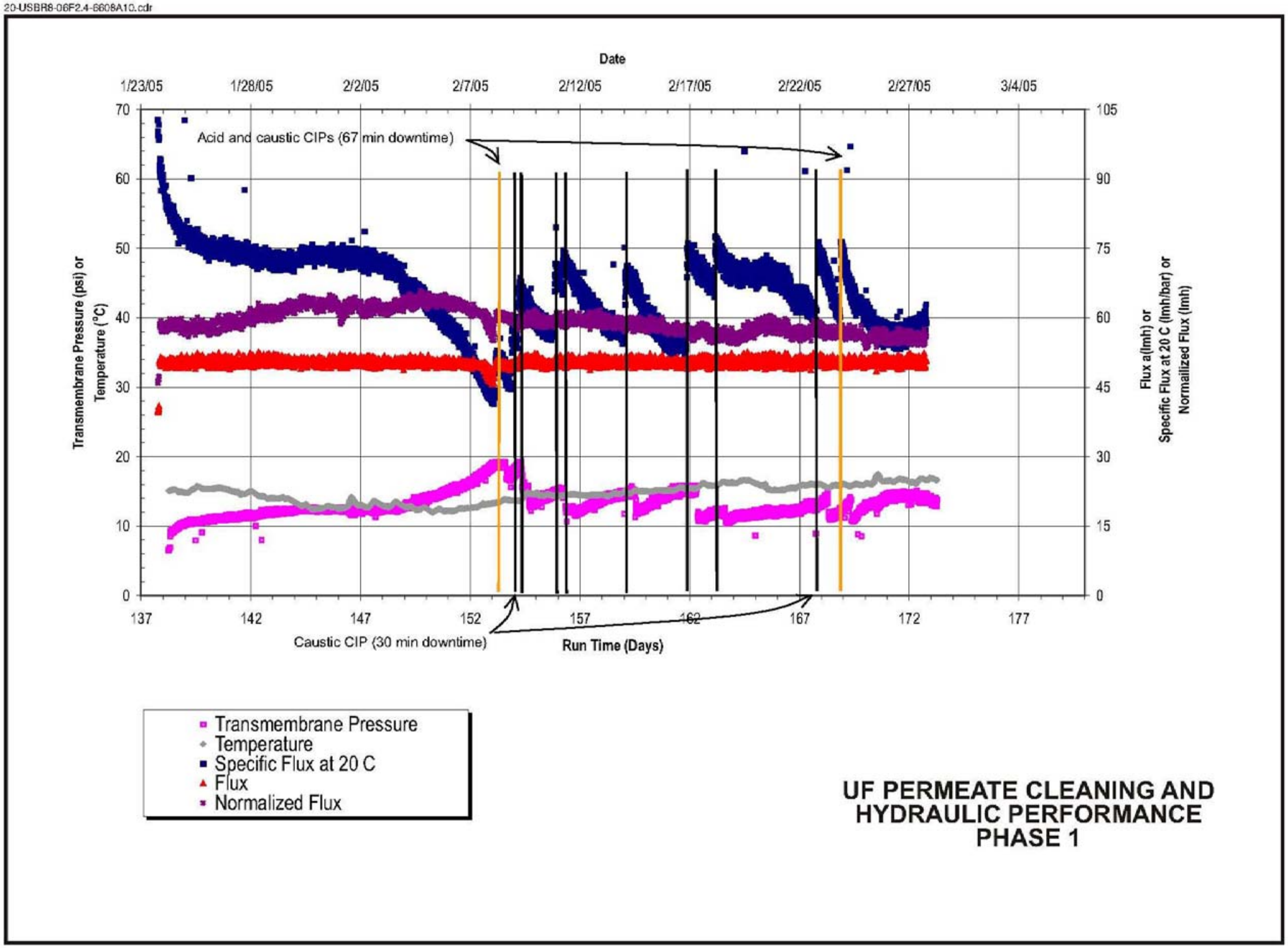

Figure 5.4 UF Permeate Cleaning and Hydraulic Performance Phase 1.

Figure 5.5 Close-Up of Silt and Mud Build-Up on UF Membrane Phase 1.

The cleaning requirements have been modified based on experience gained during the testing period. As shown in figure 5.4, a single cleaning with both acid and caustic solutions was not as efficient as multiple CIPs with caustic solution alone. Therefore, it is recommended that multiple CIPs be done within a short period of time using both acid and caustic cleaners.

5.1.3 Reverse Osmosis System Performance

5.1.3.1 Feed Water Quality

The feed water to the RO unit was the permeate from the UF system. The concentration of TDS is the parameter that determines the feed pressure and energy requirements of a RO system. The TDS concentration of the Western Canal water ranged between 300 and 1,290 mg/L; the average was 767 mg/L, as shown in table 5.4. The low calcium and magnesium concentrations and relatively low sulfate levels allowed for a relatively high water recovery in the RO system as indicated by the RO modeling results (Appendix B). Two other parameters that affect RO system performance are turbidity and SDI, which, after UF treatment, had readings below 0.2 NTU and 1.03 on average, respectively.

Table 5.4 RO Feed Water Quality – UF-Treated Surface Water (Phase 1)

Parameter	Units	Minimum	Maximum	Average[1]
Alkalinity	mg/L as CaCO3	61	196	130
Ammonia[2]	mg/L			0.2
Arsenic – total	μg/L	3.1	7.2	4.8
Barium – total	mg/L	0.04	0.08	0.06
Boron – total	mg/L	0.1	0.7	0.4
Calcium – total	mg/L	35	87	57
Chloride	mg/L	43	419	227
Fluoride	mg/L	0.29	0.79	0.43
Iron – total	mg/L	0.1	0.3	0.2
Magnesium – total	mg/L	13	36	26
Manganese – total	mg/L	0.01	0.03	0.02
Nitrate-N	mg/L	0.3	9.8	3.6
Nitrite-N[2]	mg/L			0.1
Potassium – total	mg/L	2.1	6.1	4.6
Selenium – total[2]	mg/L			0.025
Selenium – total[2]	μg/L			5
Silica[2]	mg/L as SiO_2		13.7	
Silica – total	mg/L as SiO_2	6.8	24.6	16.9
Silicon – total	mg/L	3.2	11.5	7.8
Sodium – total	mg/L	43	342	180
Strontium – total	mg/L	0.38	1.4	0.74
Sulfate	mg/L	32	285	156
TDS	mg/L	300	1290	767
Total hardness	mg/L as $CaCO_3$	142	368	248
Turbidity	NTU	0.15	0.3	0.19

Note: Samples taken between 9/12/2004 and 2/24/2005

[1] Average of 17 sampling events.

[2] Data for one sample only.

5.1.3.2 RO Hydraulic Performance

The performance of the RO system is influenced by feed water composition, temperature, and operating factors such as pressure and system recovery. In order to distinguish between variations over time in these feed and operating characteristics versus any performance changes due to fouling or scaling problems, the measured permeate flow and salt passage have to be normalized. Normalization allows a comparison of the actual performance to a given reference performance, while the influences of operating parameters are taken into account. The reference performance may be the designed performance or the measured initial performance. For this study, the first effective day of pilot operation was used as the reference point.

5.1.3.2.1 RO Performance Equations

Two parameters used to evaluate RO system performance are normalized permeate flow (NPF) and normalized salt passage (NSP). NPF is the permeate flow normalized for feed concentration, temperature, and applied transmembrane pressure. NSP is the salt passage normalized for feed concentration, transmembrane pressure, and the feed-brine salt concentration. The salt passage can also be expressed as a percent rejection; thus, normalized salt rejection (NSR) would be equal to 100 percent minus NSP. The respective equations are as follows:

Normalized Permeate Flow: $$NPF_t = \frac{NDP_i}{NDP_t} \text{ x } \frac{TCF_i}{TCF_t} \text{ x } Q_p$$

where: NPF_t = normalized permeate flow at time t (gpm)

NDP_i = net driving pressure at initial conditions of operation (psi)

NDP_t = net driving pressure calculated at time t (psi)

TCF_i = temperature correction factor based on temperature at initial conditions of operation

TCF_t = temperature correction factor based on temperature at time t

Qp = permeate flow (gpm)

Normalized Salt Passage: $$NSP_t = \frac{NDP_t}{NDP_i} \text{ x } \frac{Cfb_i}{Cfb_t} \text{ x } \frac{Cf_t}{Cf_i} \text{ x } SP$$

where: NSP_t = Normalized Salt Passage at time t (%)

NDP_i = Net Driving Pressure at initial conditions of operation (psi)

NDP_t = Net Driving Pressure calculated at time t (psi)

Cfb_i = Feed-brine salt concentration at initial conditions of operation (mg/L) (defined below)

Cfb_t = Feed-brine salt concentration at time t (mg/L) (defined below)

Cf_i = Feed salt concentration at initial conditions of operation (mg/L)

Cf_t = Feed salt concentration at time t (mg/L)

SP = Salt passage - the amount of salt that passes through the membrane into the permeate stream, expressed as a percentage

Feed-Brine Salt Concentration:

$$Cf_b = \frac{\ln\left(\frac{Cb}{Cf}\right)}{1-\left(\frac{Cf}{Cb}\right)}$$

where: Cfb = Feed-brine salt concentration

Cb = Brine (concentrate) salt concentration (mg/L)

Cf = Feed salt concentration (mg/L)

Normalized Salt Rejection: NSR = 100% - NSP

where: NSR = Normalized salt rejection (%)

NSP = Normalized salt passage (%)

Data obtained from the automated data collection systems and the log books were used to calculate the normalized parameters mentioned above. Conductivity data were not available due to mechanical problems with the conductivity probe for certain periods during testing. There were also missing pressure readings during certain periods. As a result, normalized data from these periods could not be calculated or used in the analyses. Furthermore, September 23, 2004, was used as the reference point due to insufficient data during the first week of testing that started on September 16, 2004.

5.1.3.2.2 Phase 1 Test Schedule

As discussed in Section 4.2.4.2, various test runs were scheduled to evaluate RO operation at three recoveries. These tests are summarized as:

Test 1: 85-percent recovery, 1 run:
Duration: September 23 to October 4, 2004 (12 days)

Test 2: 90-percent recovery, 3 runs:
Duration: Run 1 – October 4 to October 15, 2004 (12 days)
Run 2 – November 9 to December 2, 2004 (24 days)
Run 3 – December 10, 2004 to January 12, 2005 (34 days)

Test 3: 92-percent recovery, 1 run:
Duration: January 25 to February 25, 2005 (32 days)

Heavy rain began in early January 2005, which reduced the TDS of the water in the Western Canal significantly. As a result, the TDS levels during the third run of test 2 (at 90-percent recovery) and all of test 3 were lower than they were for the earlier runs. The decrease was more than 50 percent, from an average TDS level of 1,200 mg/L to about 500 mg/L. Consequently, although the results from these test runs are shown in the plots presented below, they are not included in the evaluation of the RO performance.

5.1.3.2.3 Normalized Permeate Flow

Figure 5.6 shows the NPF plots for the five tests. The 85-percent recovery test had the highest overall NPF, ranging from 14 to 16 gpm (0.88 to 1 liter per second (L/s). The NPF of the first run at 90-percent recovery ranged from 13 to 15 gpm (0.82 to 0.95 L/s), but there appeared to be a downward trend in the NPF. The rest of the runs ranged from 11 to 13 gpm (0.69 to 0.82 L/s), also with downward trends.

Overall, the system NPF for the 85-percent recovery test was relatively stable, with an average of 3-percent change in product flow over the duration of the test (12 days). The RO system was relatively stable at 85-percent recovery. The average system flux for this test run was 14 gfd (23.8 Lmh), similar to the target flux for the pilot test.

Higher degrees of NPF decline were observed for the rest of the test runs. As shown in figure 5.6, there was a gradual decline in the NPF in the RO system during the 3 months of testing at 90-percent recovery. The NPF decreased 13 percent during test 1 (12 days) and an additional 13 percent during test 3 (32 days). This gradual decline in NPF indicates that fouling or scaling of the membranes was occurring. More importantly, the system was chemically cleaned between each test run but was not able to return to the NPF at the beginning of the first run. This can be clearly seen in figure 5.6.

The first cleaning was carried out at the conclusion of the 85-percent recovery test run after 12 days of operation. The NPF at the start of the first run at 90-percent recovery was similar to that at the conclusion of the 85-percent recovery test run; it did not return to the NPF that existed at the beginning of the 85-percent test run. Furthermore, the NPF started to gradually decline soon after the operation at 90-percent recovery. The plant was operated for only 12 days before the second cleaning was carried out. The plant was restarted after the second cleaning at 90-percent recovery (Run No. 2), although the NPF at the start of the operation was a little bit higher than the NPF at the conclusion of the first 90-percent test run, it clearly was not restored to the NPF level at the beginning of the first test run at 90-percent recovery. After operation for 24 days, a third chemical cleaning was carried out, and again the system was operating at a lower NPF level than the

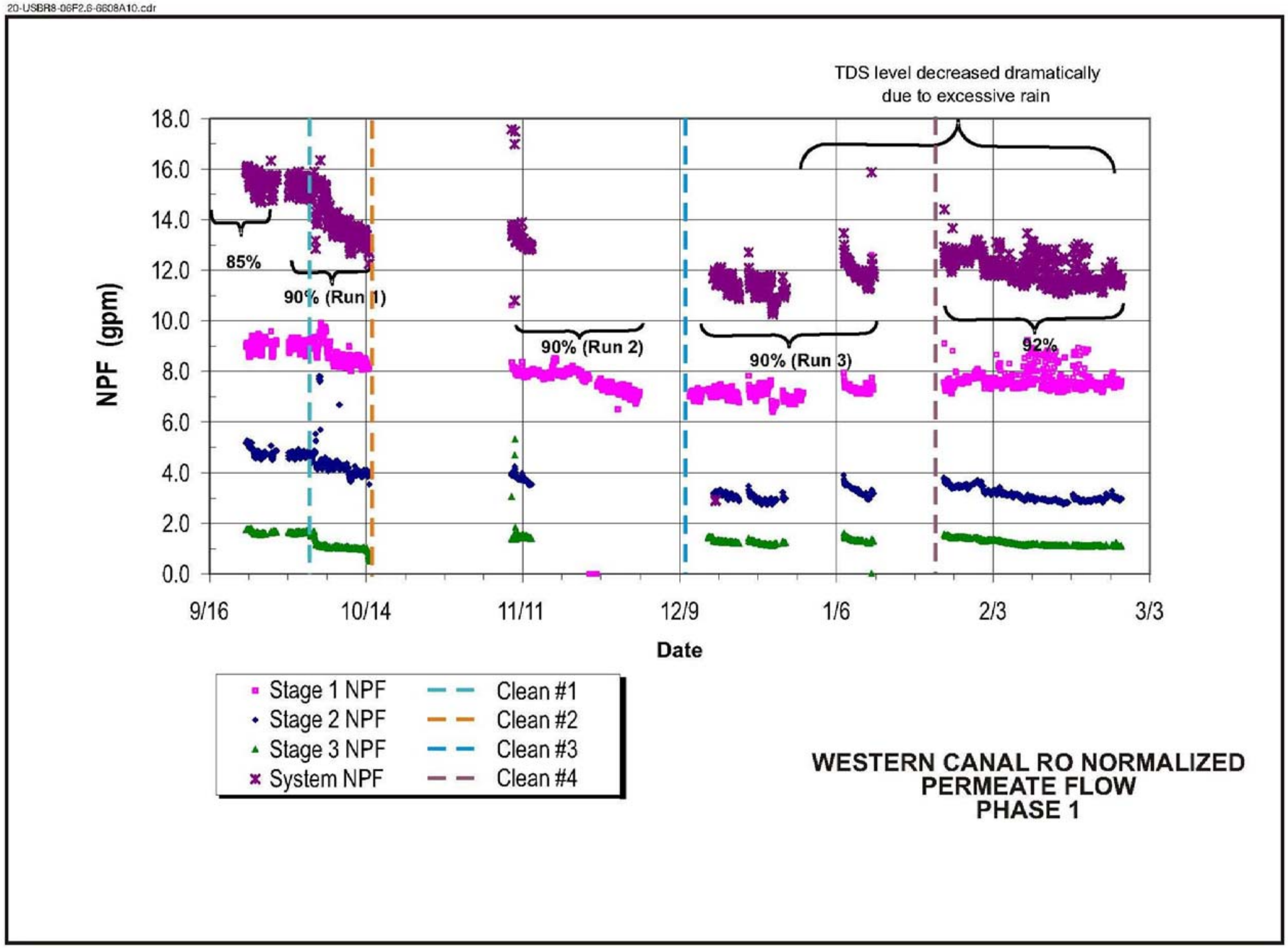

Figure 5.6 Western Canal RO Normalized Permeate Flow Phase 1.

beginning of the previous test run. This phenomenon indicates long-term fouling/scaling in the system. It also indicates that 90-percent recovery does not appear to be a feasible operating condition for the RO system on this feed water with the antiscalant used. Further, the results show that the cleaning method was not effective for this feed water.

As discussed earlier, since the heavy rains resulted in a decreased feed TDS, the results after early January 2006 are not pertinent to the current analysis. It is, however, observed that as expected, the much lower feed TDS results in a reduced decline in NPF at 92-percent recovery (compared to the test runs at 90-percent recovery and “normal” feed TDS). Nevertheless, a gradual decline in NPF is still clearly present, indicating continued membrane fouling despite the lower TDS. This may indicate organic, rather than inorganic, membrane fouling during this run.

Figure 5.7 shows the permeate fluxes across each stage, and it shows a similar trend to the NPF plots. The flux was relatively stable at 85-percent recovery but declines gradually for the 90-percent recovery tests.

5.1.3.2.4 Net Driving Pressure

The net driving pressure (NDP) measures the transmembrane pressure (the pressure available to drive water through the membrane). Significant or nonreversible increases (following chemical cleaning) in this parameter would indicate fouling or scaling on the membrane surface. Figure 5.8 shows the NDP of the different stages during Phase 1 testing. Looking at the NDP for the 85-percent recovery, the NDP curves of all three stages were relatively stable, indicating stable performance.

However, there were apparent increases in the NDP for all of the 90-percent test runs. These increases further support the occurrence of fouling/scaling in the RO system. Furthermore, the increases seem to be more prominent in the second and third stages of the RO train. This would indicate that it is likely that scaling is causing the drop in system permeate flow, and not fouling, as fouling tends to affect the performance at the first stage. Figure 5.9 shows the NDP for all test runs plotted on the same graph as the NPF. As shown, the NPF decreases as the NDP increases.

Results of the 92-percent recovery test run are also shown in figure 5.8. At the start of the run, the greatest increase in NDP was occurring in the third stage of the RO train, as before. The decrease in TDS appeared to stabilize the NDP, but there was no significant reduction in NDP, indicating that the scaling remained in place.

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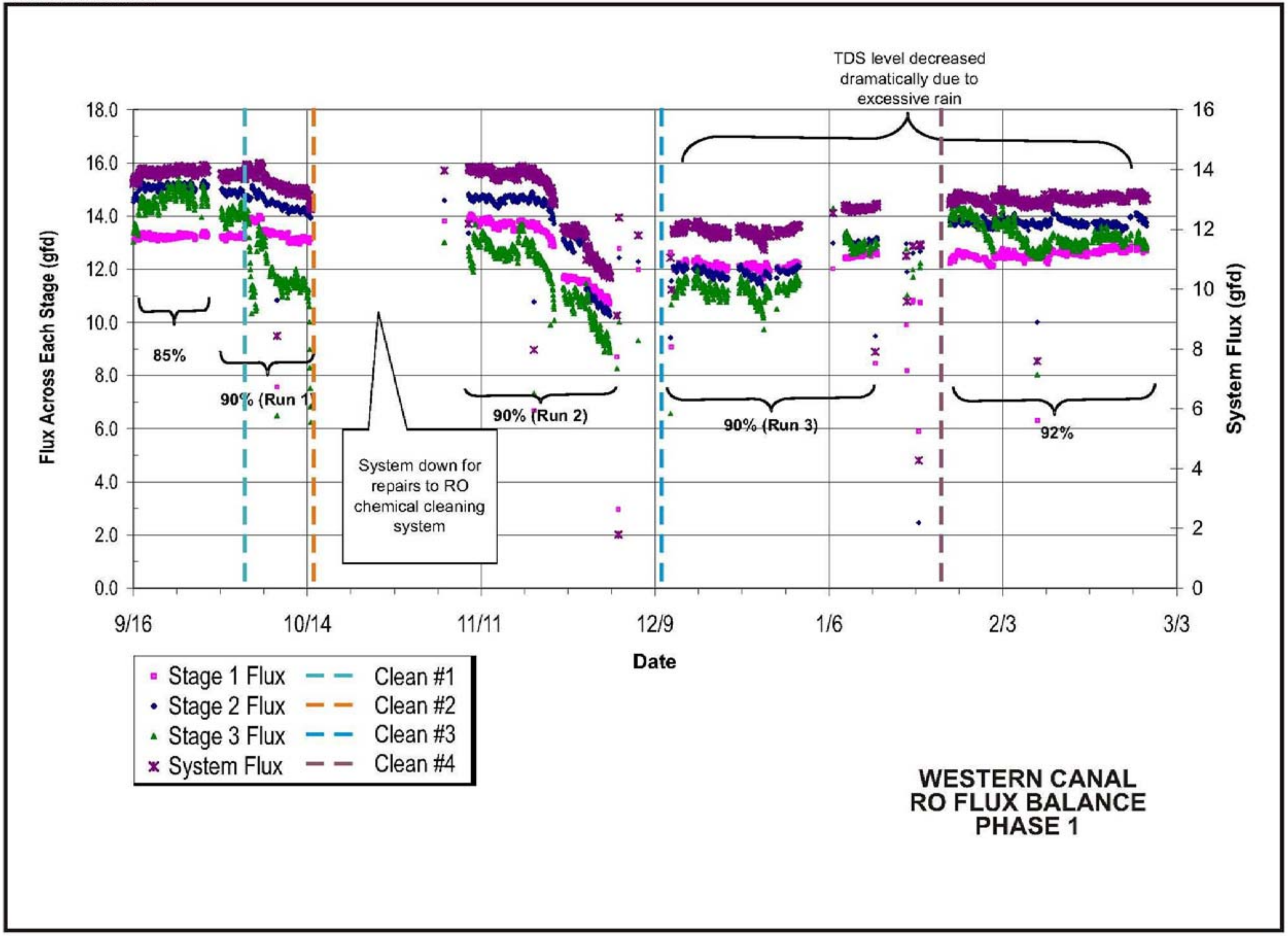

Figure 5.7 Western Canal RO Flux Balance Phase 1.

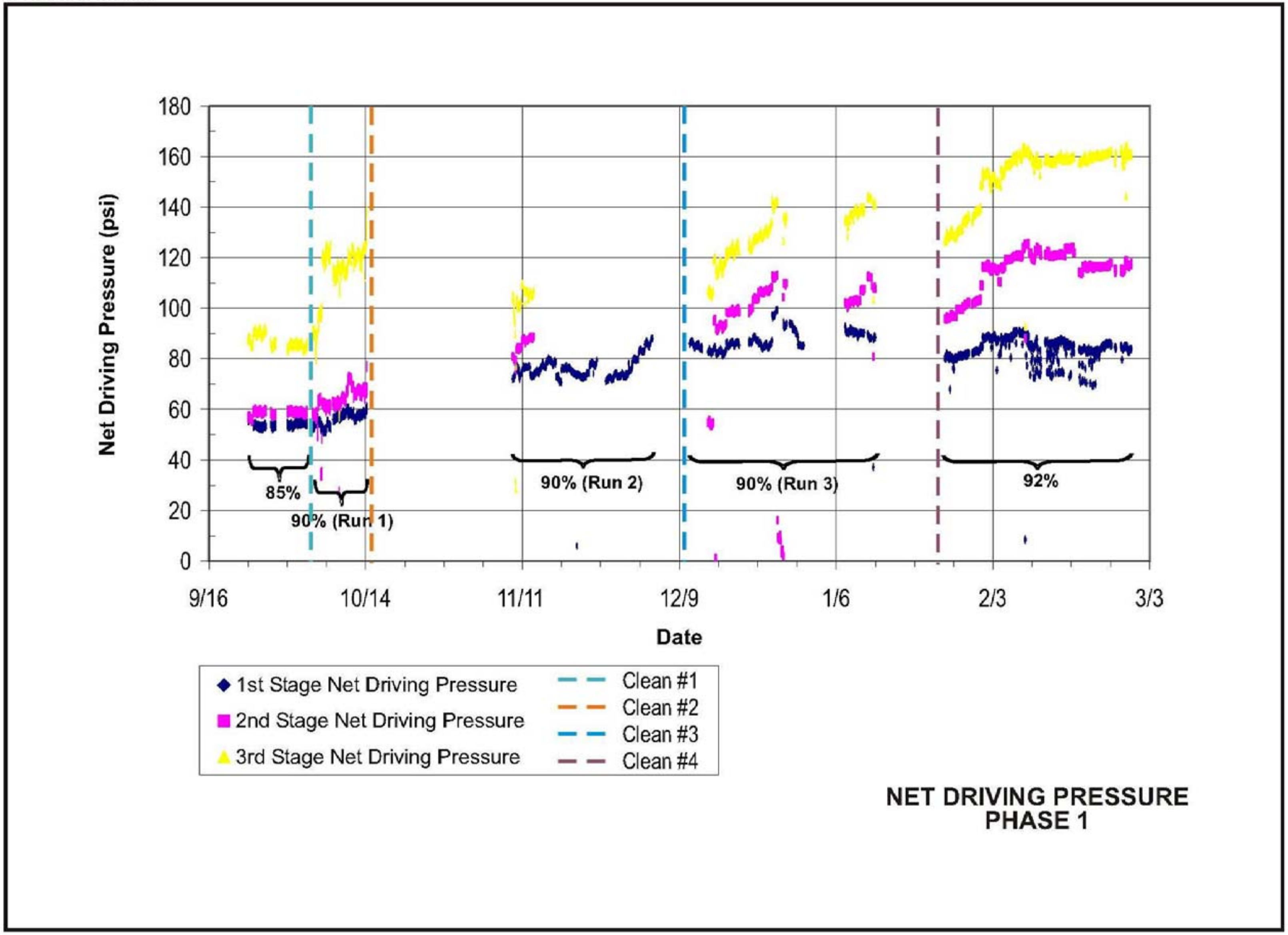

Figure 5.8 Net Driving Pressure Phase 1.

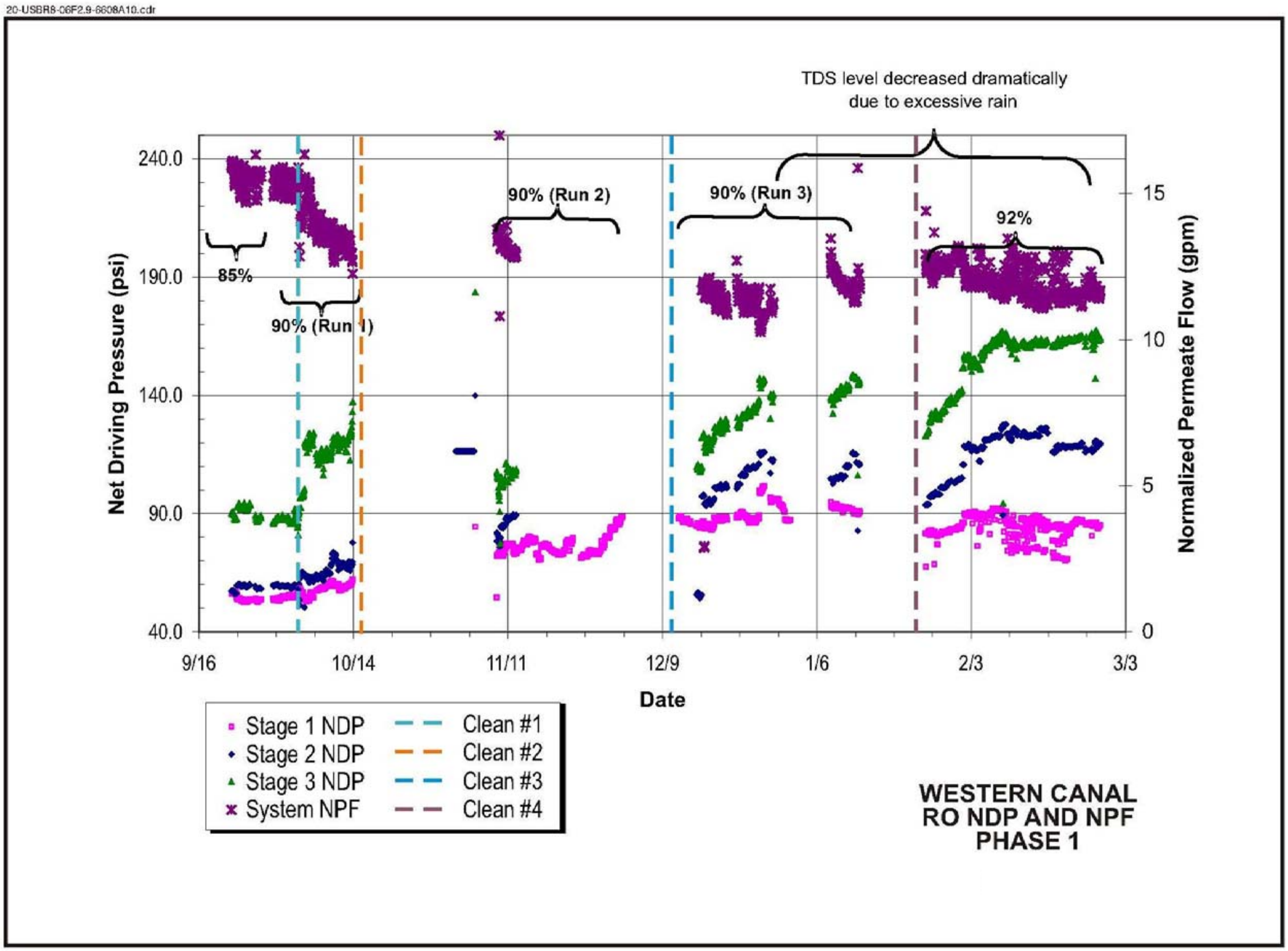

Figure 5.9 Western Canal RO NDP and NPF Phase 1.

5.1.3.3 Water Quality

5.1.3.3.1 Normalized Salt Rejection

Normalized salt rejection helps to evaluate changes in the passage of salt through the membrane, caused by membrane fouling and scaling, or changes in the permeability of the membrane itself, from exposure to feed water constituents. As shown on the NSR plot in figure 5.10, the NSR ranges between 95 and 99 percent. The NSR was relatively stable for the 85-percent recovery test run, ranging from 96 to 97 percent for Stage 1, 97 to 98 percent for Stage 2, and at 99 percent for Stage 3 over the duration of the run.

A similar trend can be seen for the first test run at 90-percent recovery. No conclusion can be drawn from the second test run at 90-percent recovery because only 4 days of effluent data were available for the analysis. However, there was some apparent decline in the NSR over the duration of the third test run at 90-percent recovery. This is consistent with the decline in NPF for the same period because as the permeate flow declines, the permeate TDS increases due to the more constant salt leakage across the membrane, lowering the overall salt rejection. Figure 5.10 also shows the NSR of the 92-percent recovery test run.

5.1.3.3.2 Permeate Water Quality

Table 5.5 shows the blended permeate water TDS (blended from the permeate of the three membrane stages). The average blended TDS level during the 85-percent recovery test was 65 mg/L, while the average TDS levels during the 90-percent test runs ranged from 49 to 68 mg/L. Lime addition to the permeate or filtration through $CaCO_3$ filters will be needed in a full-scale application in order to stabilize the water before distribution.

Table 5.5 RO Permeate Water Quality - Surface Water (Phase 1)

Parameter	Units	Minimum	Maximum	Average
Alkalinity	mg/L as $CaCO_3$	20	20	20
TDS	mg/L	10	72	35.3
TOC	mg/L	0.2	0.7	0.4
Turbidity	NTU	0.1	0.1	0.1

Notes: Samples taken between 9/12/2004 and 2/24/2005 (17 sampling events).

5.1.3.3.3 Concentrate Water Quality

The TDS of the RO concentrate, as shown in table 5.6, ranged between 6,500 and 9,800 mg/L. The average TDS level of the concentrate during the 85-percent recovery test was approximately 6,100 mg/L, while the average TDS during the 90-percent recovery test runs ranged from 7,300 to 8,200 mg/L. These values are somewhat lower than those predicted by the RO modeling software, presented earlier.

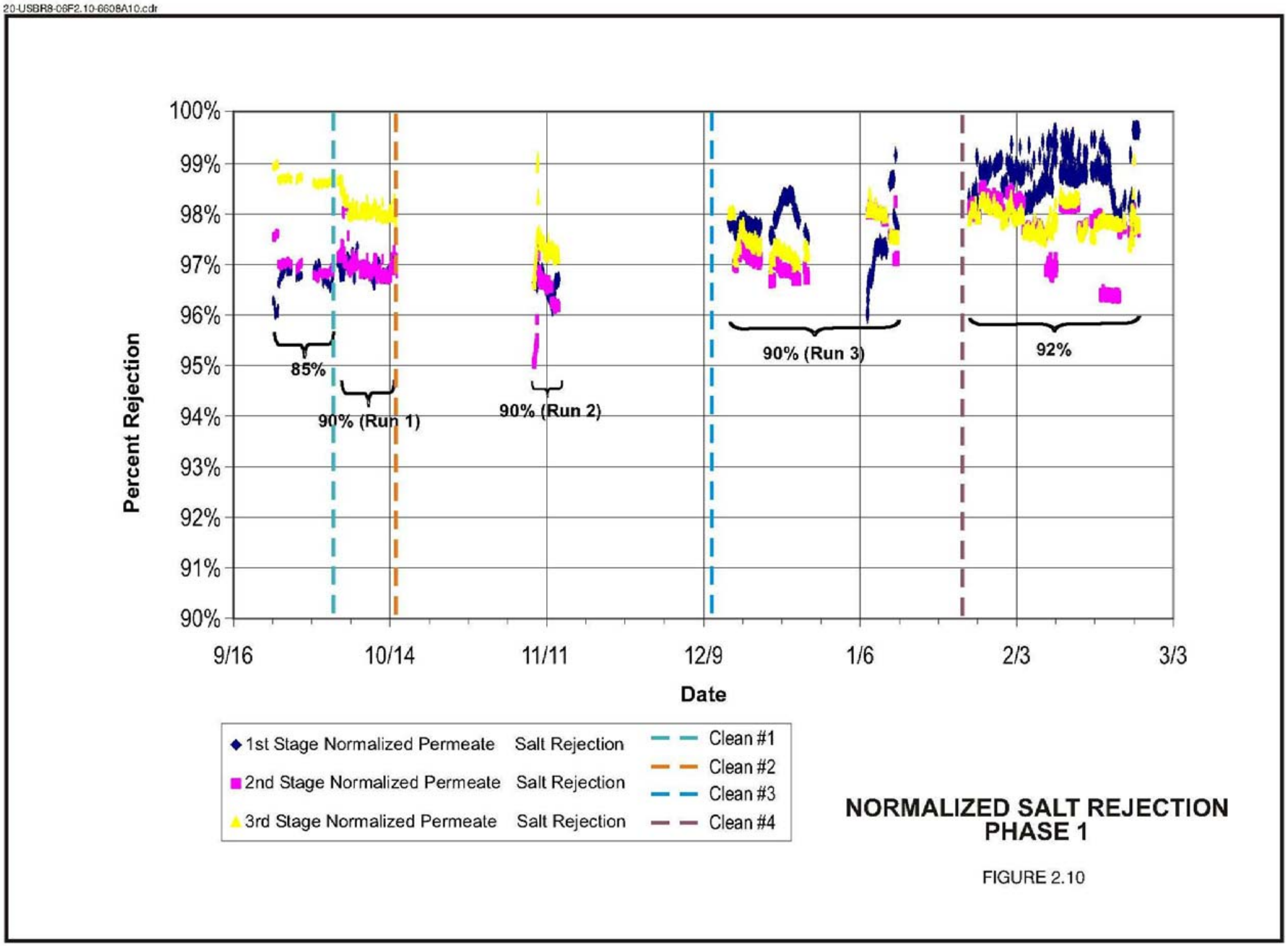

Figure 5.10 Normalized Salt Rejection Phase 1.

Table 5.6 RO Concentrate Water Quality - Surface Water (Phase 1)

Parameter	Units	Minimum	Maximum	Average
Alkalinity	mg/L as $CaCO_3$	20	1,590	935
Arsenic - total	µg/L	17	57	22.5
TDS	mg/L	6,540	9,840	7,901
Turbidity	NTU	1.2	1.3	1.25
Note: Samples taken between 9/12/2004 and 2/24/2005 (17 sampling events).				

5.1.4 Cleaning Requirements

In a typical RO operation, chemical cleaning of the membranes is performed on a monthly basis. The 85-percent recovery test was conducted over a duration of 12 days, and although the performance was relatively stable, the exact cleaning frequency cannot be determined due to the limited data and duration of the test.

The 90-percent test runs indicate that cleaning more frequently than once per month will be required. Furthermore, the cleaning in the 90-percent recovery runs did not restore the membranes to the initial performance. This would indicate that more frequent cleaning is required. Based on this result, a 90-percent recovery might not be operationally feasible for this water quality.

5.1.5 Summary of Phase 1 Testing Results

In terms of the UF pretreatment performance, the results clearly show the advantage of a membrane separation step upstream of the RO when treating surface water. The raw feed water turbidity to the UF plant varied significantly over the course of Phase 1, but the UF membrane was able to produce a consistently low turbidity feed water for the RO system with a correspondingly low SDI value. In addition, the UF membrane was able to reduce the iron concentration in the feed water to the RO system.

The results show that the RO system was relatively stable operating at 85-percent recovery; however, the test period was relatively short (less than 2 weeks). The water quality data presented earlier, together with the modeling results, showed that even at 85-percent recovery, the system would have to deal with potential scale formation from $CaCO_3$, $BaSO_4$, CaF_2 and silica. It is not possible to conclude if the system would maintain stable performance if it were operated for a longer period.

The results also suggest that operating the RO system at 90-percent recovery or higher is not feasible with this water under the operating conditions and with the antiscalant used in the tests. The NPF declined more than 10 percent after running for only 30 days or less. The decline in the NPF is attributed to possible scaling in the system.

5.2 Ground Water Test Results (Phase 2)

5.2.1 Feed Water Quality

The feed water for Phase 2 RO testing came from ground water in an area west of downtown Phoenix, near the Gila River. Table 5.7 shows water quality data from two samples taken by the SRP in 2003 and 2004. Table 5.8 shows the water quality measured during this study. As shown, the calcium and magnesium concentrations are relatively low compared to the Phase 1 feed water, resulting in a significantly lower total hardness of the water; average of 115 mg/L as $CaCO_3$ for Phase 2 compared with 248 mg/L as $CaCO_3$ for Phase 1. The water is brackish in quality with a TDS level in the range of 1,300 to 2,300 mg/L. The water also contains iron (0.24 mg/L), and the silica concentration is greater than that found in the Western Canal (Phase 1): 25 mg/L for the well water compared with about 14 mg/L for the Western Canal. The sulfate concentration in the well water is approximately double the concentration in the Western Canal water.

Table 5.7 Raw Water Quality of Well Utilized for Study (Phase 2)

Parameter	Units	4/22/03	9/28/04
Alkalinity	mg/L as $CaCO_3$	215	212
Aluminum	mg/L	<0.050	<0.050
Ammonia	mg/L	ND	ND
Arsenic	mg/L	0.012	0.012
Barium	mg/L	0.066	0.059
Bicarbonate	mg/L	262	259
Boron	mg/L	0.625	0.561
Bromide	mg/L	0.40	0.37
Calcium	mg/L	47.8	46.3
Carbonate	mg/L	< 1	< 1
Chloride	mg/L	525	434
Fluoride	mg/L	0.99	0.95
Iron	mg/L	< 0.010	< 0.010
Magnesium	mg/L	20.6	20.6
Manganese	mg/L	< 0.010	< 0.010
Nitrate	mg/L as NO_3	99.9	64.8
Noncarbonate hardness	mg/L as $CaCO_3$	0	0
Potassium	mg/L	3.1	3.5
pH	SU	7.7	7.6
Silica	mg/L as SiO_2	30.1	26.7
SDI	mg/L	ND	ND
Sodium	mg/L	406	411
Strontium	mg/L	ND	ND
Sulfate	mg/L	144	157

Table 5.7 Raw Water Quality of Well Utilized for Study (Phase 2) (continued)

Parameter	Units	4/22/03	9/28/04
TDS	mg/L	1,380	1,270
Temperature	˚C	23.9	24.6
Total hardness	mg/L as $CaCO_3$	204	201
Turbidity	NTU	ND	ND
UV254	m-1	ND	ND
Zinc	mg/L	< 0.010	< 0.010

Table 5.8 Water Quality of Ground Water near Gila River (Phase 2)

Parameter	Unit	Minimum	Maximum	Average[1]
Alkalinity	mg/L as $CaCO_3$	20	371	238
Arsenic - total	mg/L	0.0147	0.0177	0.016
Barium - total	mg/L	0.06	0.08	0.06
Calcium - total	mg/L	24	31	26
Chloride	mg/L	466	882	557
Dissolved organic carbon	mg/L	0.34	1.1	0.59
Fluoride	mg/L	1.6	2.8	1.9
Hardness - total	mg/L as $CaCO_3$	102	136	115
Iron - total	mg/L	0.1	0.6	0.2
Magnesium - total	mg/L	10	14	12
Manganese - total	mg/L	0.01	0.05	0.02
Nitrate-N	mg/L	13.5	26.4	17.5
Potassium - total	mg/L	3.1	8	4.8
Silica	mg/L as SiO_2	23.8	28.7	25.0
Silicon - total	mg/L	11.1	13.4	11.7
Sodium - total	mg/L	357	488	432
Strontium - total	mg/L	0.38	0.98	0.6
Sulfate	mg/L	165	313	198
TDS	mg/L	1,310	2,310	1,527
TOC	mg/L	0.35	1.47	0.66
Turbidity	NTU	0.1	0.1	0.1

Note: Samples taken between 7/18/2005 and 1/4/2006.

[1] Average of 17 sampling events.

5.2.2 Hydraulic Performance (Phase 2)

Note that the RO membranes used in Phase 2 were the same membranes used in Phase 1. The membranes were chemically cleaned at the end of Phase 1, and the number of elements in the third stage was reduced to increase the flow rate. Also, there was no pretreatment of the ground water by UF; the ground water was fed directly to the RO unit.

5.2.2.1 Performance Equations

The performance of the RO pilot system will again be compared by using normalized permeate flow and salt passage data. See Section 5.1.3.2.1 for the corresponding equations. Normalization allows a comparison of the actual performance to a given reference performance while the influences of operating parameters are taken into account. Data obtained from the automated data collector and from the daily manual data recording were used to calculate the normalized parameters mentioned before. For this study, the first effective day of pilot operation was used as the reference point.

5.2.2.2 Test Runs

During Phase 2 testing, the RO pilot system was operated at three recoveries to evaluate its performance using the ground water described above. These tests are summarized as:

Test 1: 80-percent recovery, 1 run:
Duration: July 18 to July 28, 2005 (11 days)

Test 2: 85-percent recovery, 1 run:
Duration: July 29 to August 25, 2005 (27 days)

Test 3: 90-percent recovery, 3 runs:
Duration: Run 1 – August 17 to October 6, 2005 (40 days)
Run 2 – October 14 to November 5, 2005 (22 days)
Run 3 – December 15, 2005 to January 6, 2006 (23 days)

No tests were conducted above 90-percent recovery during Phase 2 testing. The TDS of the feed water remained relatively constant at around 1,300 mg/L, except that it was higher towards the end of the third run at 90-percent recovery, when it averaged 2,200 mg/L.

These data also show that during the operation of the RO system at a recovery of 90 percent, the measured permeate pressures were 80 psig (3.83 kPa) in Stage 1 and 130 psig in Stage 2. The projected permeate back pressures used during the RO modeling were only 60 and 65 psig (414 and 448 kPa), respectively.

The discrepancy between projected and achieved maximum RO water recovery was evaluated by rerunning the RO model with the actual pressure data measured during the pilot testing and using the updated water quality data. Based on the new RO model results, the higher permeate back pressure would result in a flux of 13.5 gfd (22.9 Lmh) in Stage 1, 11.3 gfd (19.2 Lmh) in Stage 2, and 18.7 gfd (31.7 Lmh) in Stage 3.

The higher permeate back pressure in Stage 2 resulted in a lower permeate production in Stage 2 and, therefore, a lower overall system recovery. At the same time, the feed flow rate to the first element in Stage 3 and the permeate flow rates in Stage 3 were exceeded. The hydraulic imbalance could have resulted in excessive feed flow rates to Stage 3, higher flux in Stage 3, and, therefore, higher potential for fouling. By comparing the permeate quality of each stage, it could be determined if any membrane damage had occurred.

5.2.2.3 Normalized Permeate Flow

Figure 5.11 presents the NPF over the entire operating period of approximately 170 days (although there was a period of about 40 days starting in November 2005 when the system was offline).

The test run at 80-percent recovery was operated for 11 days, and the NPF was stable. The 85-percent recovery test run had the highest average system NPF: 18.5 gpm (1.17 L/s). As shown in figure 5.11, NPF was relatively stable throughout the 27-day test period, with virtually no decline in flow when the system was operating at 80 and 85-percent recovery. As shown in figure 5.11, the Stage 1 NPF was stable between 12 and 14 gpm (0.76 and 0.88 L/s), Stage 2 was stable around 4 gpm (0.25 L/s), and Stage 3 was stable around 1 gpm (0.06 L/s). These numbers should be compared with the values at which the membranes were operating at the end of Phase 1, namely: Stage 1 around 7.5 gpm (0.47 L/s), Stage 2 around 3 gpm (0.19 L/s), and Stage 3 around 1 gpm (0.06 L/s). There was a significant improvement in performance of Stage 1. Stages 2 and 3 performed about the same as before, but they certainly did not show a decline in performance with time during this period. During the first run at 90-percent recovery (Run 2), the NPF continued to be stable with no evidence of a decline in NPF.

The average system NPF of the first test run at 90-percent recovery was 17.9 gpm (1.13 L/s). This declined to 16.5 gpm (1.04 L/s) during the second run at 90-percent recovery and appears to have been due to a decline in NPF in the third stage. The average system NPF of the third test run at 90-percent recovery was 16.2 gpm (1.02 L/s); in this case, there does appear to be a gradual decline in the NPF with time in Stage 1.

Figure 5.11 also indicates when chemical cleaning of the membranes was carried out. A total of five cleans were required. The first cleaning was carried out at the conclusion of the run at 80 and 85-percent recovery, after almost 40 days of operation. The system was restarted at a recovery of 90 percent and operated for just over 40 days before the second membrane cleaning was carried out. The system was restarted after the second cleaning at a recovery of 90 percent once again (Run 2), and a slight drop in NPF can be seen between the conclusion of

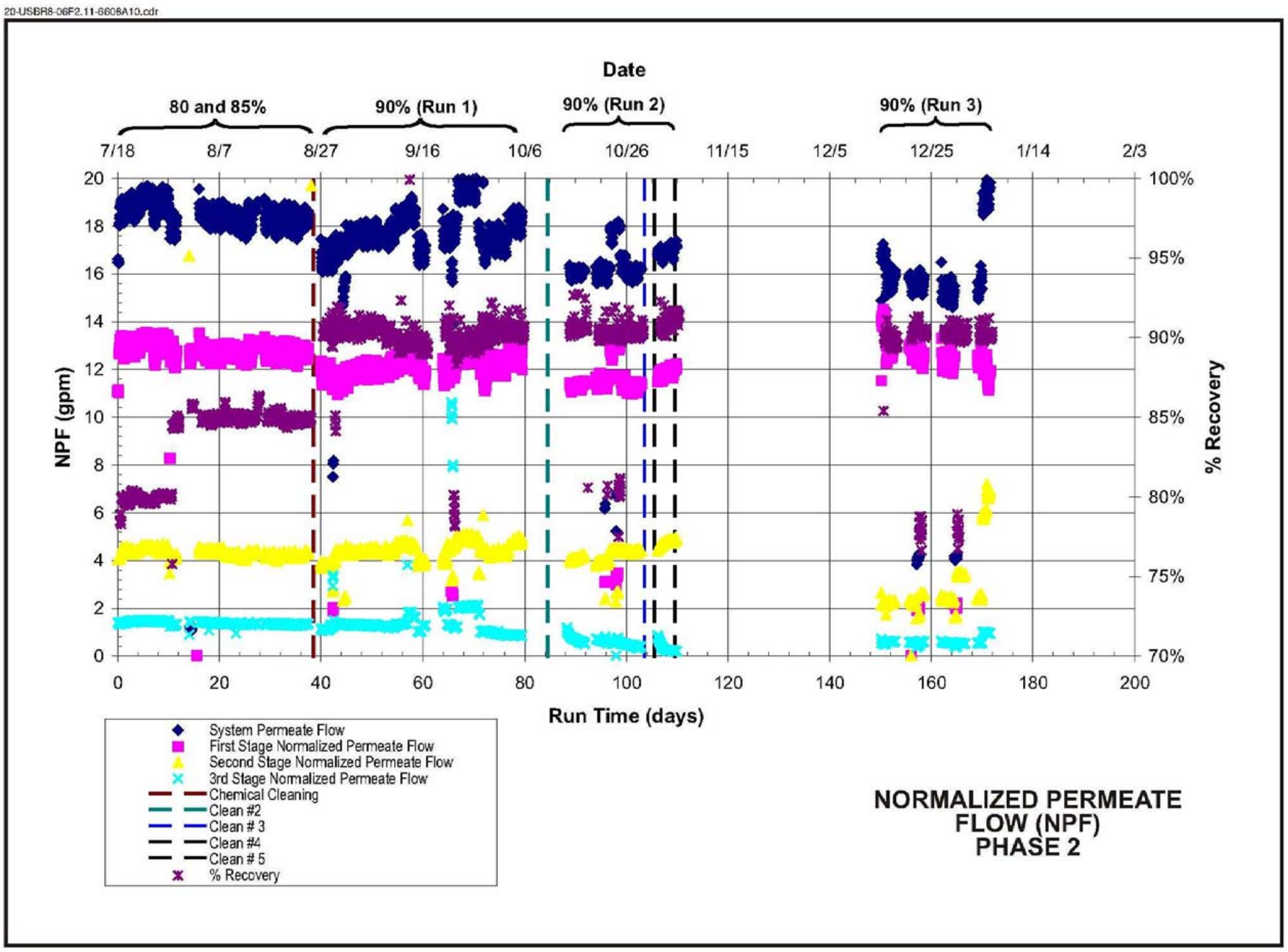

Figure 5.11 Normalized Permeate Flow (NPF) Phase 2.

Run 1 and the start of Run 2. A similar drop in NPF also occurred between the conclusion of the 85-percent recovery run and the start of the first 90-percent recovery run. After about 20 days of Run 2 at 90-percent recovery, the membranes were cleaned a third time, and then twice more within the following 10 days, and a decline in the NPF in the third stage is evident. The third 90-percent recovery run was more sporadic than the first two (between 150 and 170 days of operating time).

5.2.2.4 Net Driving Pressure

As stated earlier, the NDP measures the transmembrane pressure (the pressure available to drive water through the membrane). Any significant increase in this parameter would indicate fouling or scaling on the membrane surface. Figure 5.12 shows the NDP of the different stages during Phase 2 testing. As shown in the figure, the NDP curves of all three stages at the 85-percent recovery were relatively stable.

The NDP for all three stages of the first run at 90-percent recovery appeared to be relatively stable, except towards the end of the test. The NDP in the third stage increased from an average of 100 psi (689 kPa) to 130 psi (896 kPa) by the end of the test run. The third stage NDP for the two remaining test runs continued to increase and reached over 200 psi by the end of Run 3. This is consistent with the observations of the NPF in the third stage mentioned above.

An increase in NDP in the third stage indicates scaling, particularly as the increases were first observed in the third stage of membranes. The cause(s) of the drastic increase in NDP may be due to excessive permeate back pressure, which was applied at the second stage, causing an imbalance in flux across the three stages. The recommended permeate pressure by the manufacturer is 90 psi (621 kPa), while 130 psi (896 kPa) was accidentally applied periodically during Run 3.

5.2.3 Water Quality

5.2.3.1 Normalized Salt Rejection

As shown in figure 5.13, the NSR in Phase 2 testing ranges between 94 and 99 percent. The NSR was relatively stable for the 85-percent recovery test, ranging from 97 to 98 percent for Stage 1, 98 percent for Stage 2, and 97 to 99 percent for Stage 3, over the duration of the run.

The NSR plot seems to have similar trends to the NPF plot for the 90-percent test runs. Run 1 appeared to be relatively stable until September 15, 2005, when the system went down for about 4 days. Then, there was a drastic change in the third stage NSR. First, it increased for about 1 week, and then it decreased. Run 2 continued on October 14, and there was a decrease in the NSR in the first and third stages. There was no permeate TDS data available to determine the NSR for Run 3.

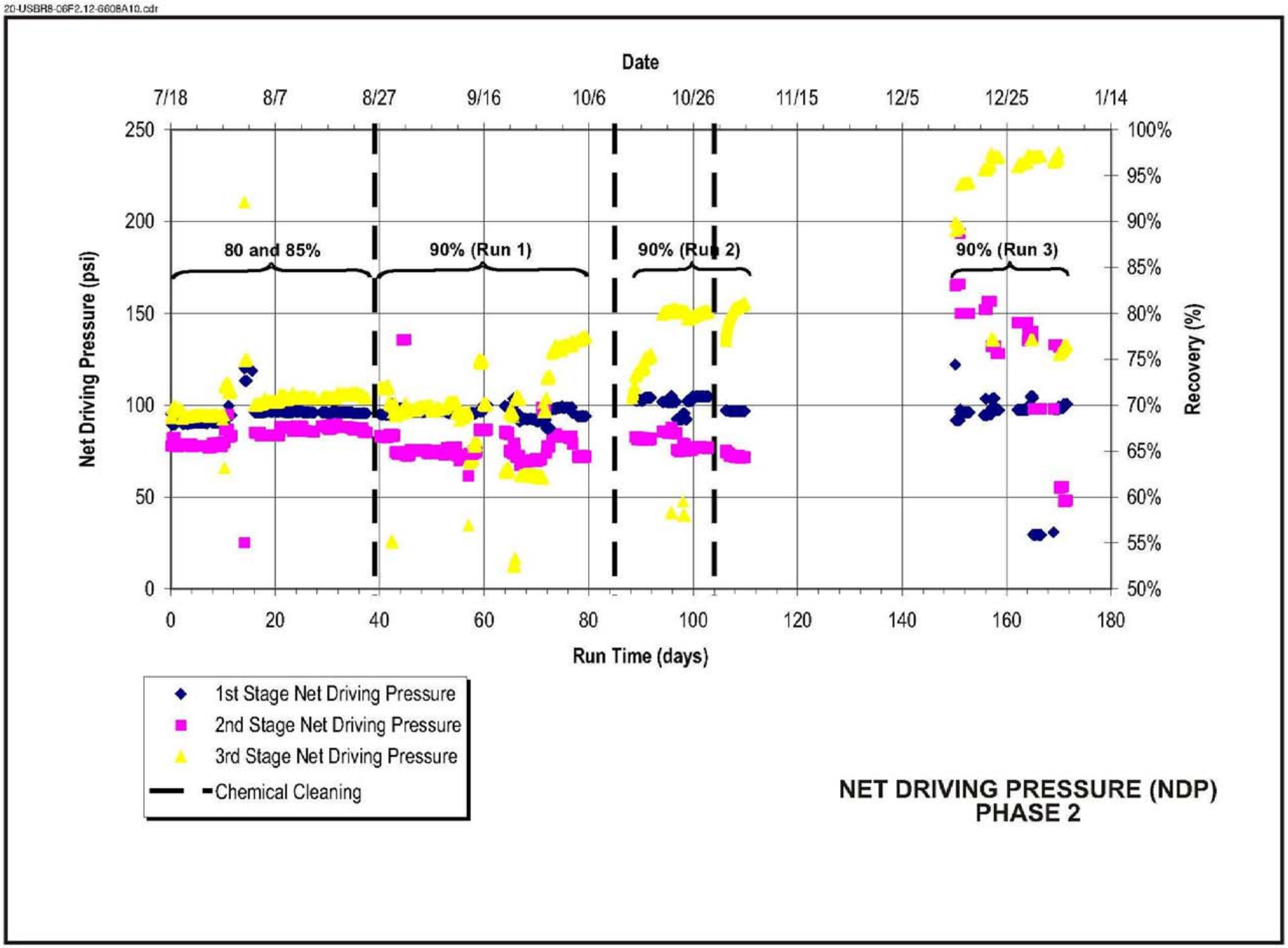

Figure 5.12 Net Driving Pressure (NDP) Phase 2.

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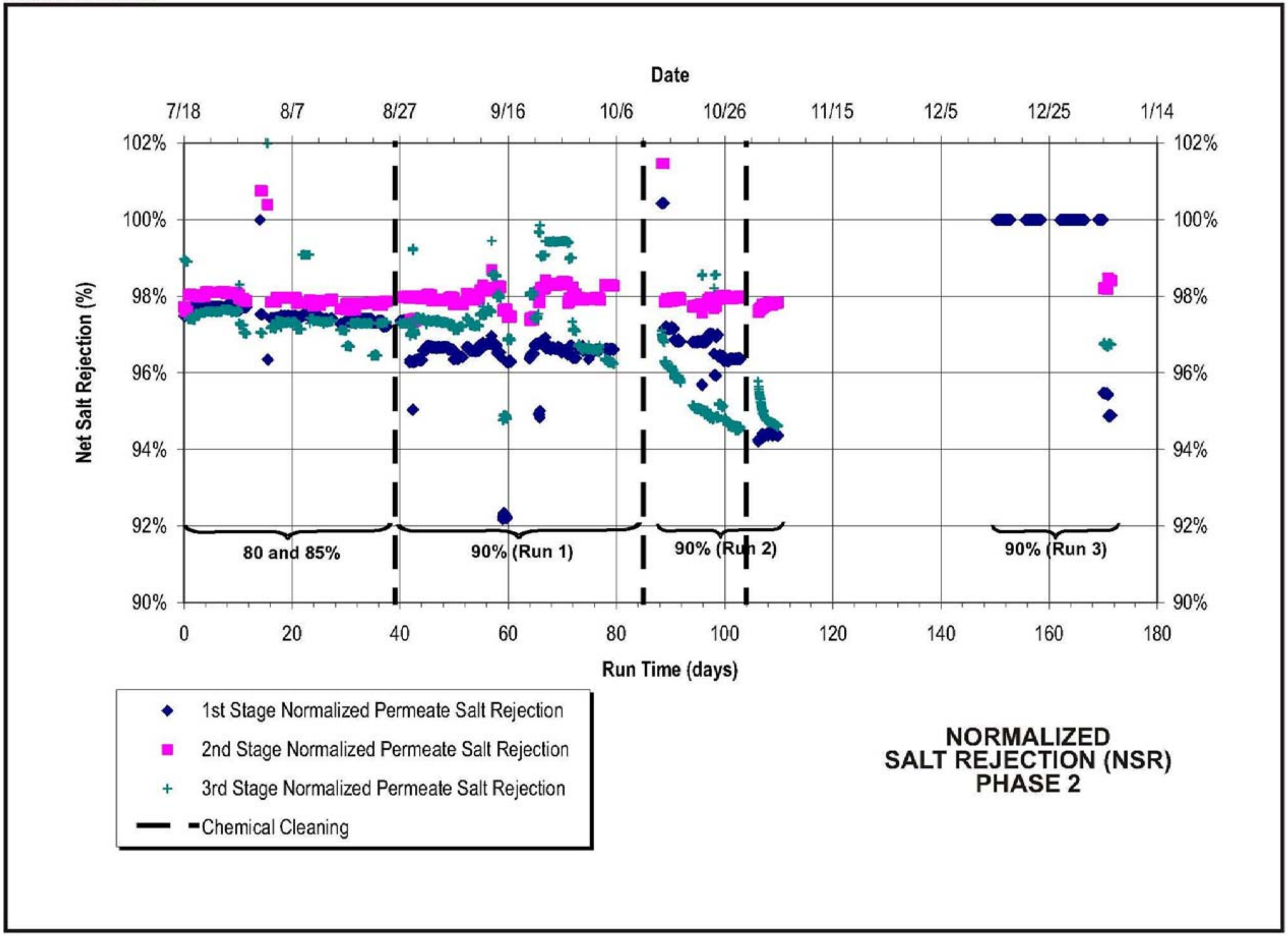

Figure 5.13 Normalized Salt Rejection (NSR) Phase 2.

The NSR plot seems to have similar trends to the NPF plot for the 90-percent test runs. Run 1 appeared to be relatively stable until September 15, 2005, when the system went down for about 4 days. Then, there was a drastic change in the third stage NSR. First, it increased for about a week, and then it decreased. Run 2 continued on October 14, and there was a decrease in the NSR in the first and third stages. There was no permeate TDS data available to determine the NSR for Run 3.

The decline in NSR observed in Stage 3 is consistent with the decline in NPF observed over the same period. It would appear that some scale or foulant on the surface was blocking the permeate passage.

The NSR data indicates that membrane scaling/fouling (likely scaling) began in the third stage during Run 2 at 90-percent recovery. The data for the NPF and NDP indicate a change between the end of Run 2 and the start of Run 3. This may have been a result of the system being off-line for about 40 days.

5.2.3.2 Permeate Water Quality

The average TDS of the blended permeate water ranged from 66 to 89 mg/L (figure 5.14). The blended TDS level during the 85-percent recovery test was the lowest, averaging 66 mg/L; while the average TDS levels during the 90-percent test runs averaged between 77 and 89 mg/L.

5.2.3.3 Concentrate Water Quality

The TDS of the concentrate averaged between 6,800 and 9,000 mg/L. The average TDS level of the concentrate during the 85-percent recovery test was approximately 6,800 mg/L, while the average TDS levels during the 90-percent recovery test runs ranged from 7,900 to 8,600 mg/L.

5.2.3.4 Cleaning Requirement

The performance was relatively stable during the 40 days of testing at 85 percent. Based on the performance and the typical RO operation, monthly chemical cleaning of the membranes may be adequate with this water.

The duration of the first run at 90-percent recovery was about 40 days. The NPF of this test was relatively stable as mentioned earlier; however, at around 20 days of operation, the NDP of the second and third stages started to destabilize. This would indicate more frequent cleaning is required. However, no conclusion can be made because the deterioration of performance might be caused, in part, by damage to the membrane resulting from excessive back pressure that was accidentally applied occasionally.

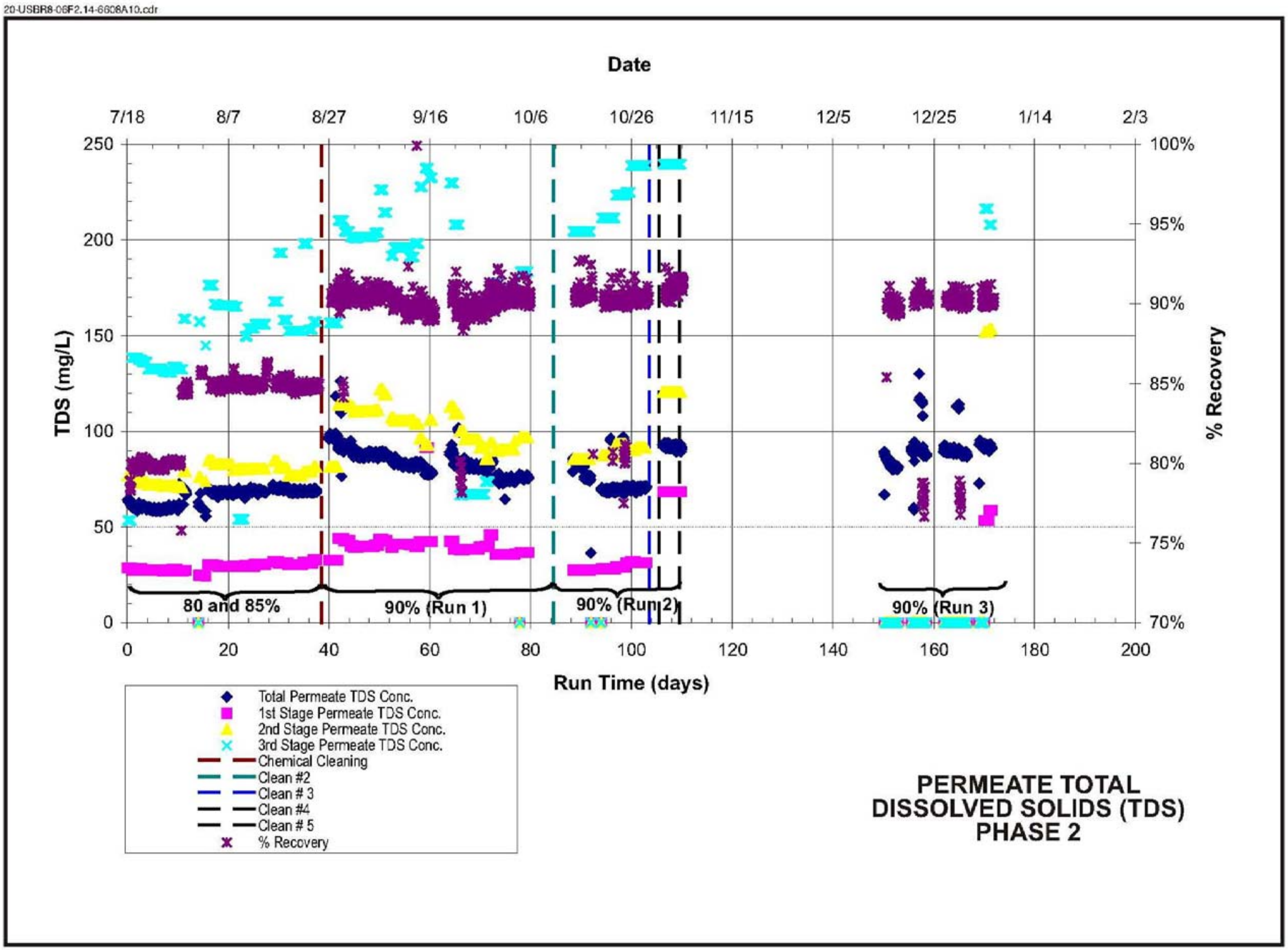

Figure 5.14 Permeate Total Dissolved Solids (TDS) Phase 2.

5.2.3.5 Summary for Phase 2

The initial modeling of RO performance was carried out at 85, 90, and 94-percent recovery. Based on the test data, it was not possible to operate the system above 85-percent recovery. Three test runs were performed at 90 percent, but only the first two runs produced reasonable performance data.

The results indicated the following:

- Operation of the RO system at 85-percent recovery was stable.
- Chemical cleaning did not restore the RO system to original performance level.
- Operation of the RO system at 90-percent recovery does not seem feasible, although it is not clear whether the decline in system performance was due to the water quality alone or due to excessive back pressure applied at the second stage and hydraulic loading in the third stage.

5.2.3.6 Membrane Autopsy

At the end of the Phase 2 testing, three membrane elements (one from the front of the system (lead element) and two from the third stage (tail elements)) were sent to Dow/Filmtec Corporation for testing.

Standardized flow tests were carried out on all elements. These tests showed that the lead element permeate flow had declined by 34 percent. The permeate flow in one of the tail elements had declined by 53 percent, and the other is estimated to have declined by about 40 percent. The serial number of the latter element was removed during transport, so its initial conditions after manufacturing were not known.

Cleaning of the lead element showed an increase of about 10 percent in permeate flow after a NaOH (0.1 percent at pH 12) wash at 95 °F (35 °C) for 1 hour. A further 8-percent improvement in permeate flow was obtained after a second wash using 0.1 percent NaOH and 1 percent Na_4EDTA at 95 °F (35 °C) and pH 12 for 1 hour. Combined, the two standard washes were only able to recover the membrane to about 77 percent of its initial flow. The cleaning did not impact the salt rejection, which remained around 97.5 percent, down from its initial 98.1 percent when the element was new.

One of the tail elements was autopsied. The membrane surface was coated with a rust-colored foulant that felt “gritty” to the touch. The foulant was determined to contain iron. An inductively coupled plasma mass spectrometry (ICP-MS) analysis of the foulant material indicated very high concentrations of silica, calcium, iron, and aluminum. Details are provided in the autopsy report included in Appendix G.

It was mentioned earlier that the silica concentration in Phase 2 was higher than in Phase 1 (25 mg/L compared to 16.9 mg/L). The dose of antiscalant was 3.2 mg/L at 90-percent recovery. This was slightly lower than the dose recommended by the supplier for use during Phase 1 at the same recovery (3.5 mg/L).

The membrane autopsy confirms the presence of a silica scale in the tail-end membranes. Aluminum and iron are known to help facilitate the polymerization of reactive silica to form silica scale.

5.3 Comparison of LSI and CCPP Indices

The LSI is the standard measure of scaling potential. LSI is a qualitative assessment of the water's potential to precipitate calcium carbonate; it does not account for the amount of calcium carbonate that can precipitate. A negative LSI indicates that the water is undersaturated, while a positive LSI may indicate that the water is oversaturated.

Calcium Carbonate Precipitation Potential (CCPP) is an index that quantifies the amount of calcium carbonate that may dissolve or precipitate; it is a true indication of the water's potential to deposit calcium carbonate. A negative value denotes the amount of calcium carbonate that must dissolve to reach a saturated condition, while a positive value indicates the concentration of calcium carbonate that exceeds the saturated condition.

Table 5.9 summarizes the RO concentrate water quality data for both Phase 1 and Phase 2, including the respective LSI and CCPP indices for each. The Phase 1 feed water had a higher calcium concentration but an overall lower TDS. The alkalinity of the RO concentrate from the brackish ground water in Phase 2 was higher than that of the concentrate in Phase 1. With regard to the LSI index, the Phase 1 concentrate has a lower LSI than the Phase 2 concentrate, suggesting that the Phase 2 concentrate has a higher potential for calcium carbonate scale formation than the Phase 1 concentrate. However the CCPP indices suggest otherwise, in that the CCPP value for the Phase 1 concentrate is higher than that for Phase 2.

From this study, it was not possible to determine which index is more suitable, but the results do show that there is merit in evaluating both indices and using the values to assist in determining the antiscalant dosages. Certainly, one advantage the CCPP has over the LSI is that it gives an indication of the mass of precipitate that could form.

Table 5.9 Water Quality Data for RO Concentrate

Parameter	Surface Water (Phase 1)	Brackish Ground Water (Phase 2)
K	28.8 mg/L	17.2 mg/L
Na	2,466 mg/L	4,229 mg/L
Mg	321 mg/L	201 mg/L
Ca	734 mg/L	458 mg/L
CO_3	10 mg/L	76 mg/L
HCO_3	1,718 mg/L	2,314 mg/L
SiO_2	213 mg/L	290 mg/L
Cl	3,374 mg/L	4,902 mg/L
SO_4	2,128 mg/L	1,621 mg/L
TDS	11,180 mg/L	14,804 mg/L
pH	7.25	7.88
LSI	1.73	2.3
CCPP	944	858

Note: Samples taken between 7/18/2005 and 1/4/2006.

6. Summary and Conclusions

6.1 Ultrafiltration Pretreatment System

Ultrafiltration was selected as the pretreatment process upstream of the RO pilot plant while treating surface water from the Western Canal during Phase 1 of the project. A Polymem™ UF membrane was selected for this application based on good experience on a previous pilot-scale project. These hollow fiber membranes also provided the large surface area needed to produce enough UF permeate to feed to the RO unit.

There was significant variability of the raw water turbidity withdrawn from the Western Canal, ranging from less than 1 NTU at times to greater than 50 NTU. The UF membrane was able to produce a product stream that had a turbidity consistently less than 1 NTU (apart from one isolated incident) and generally less than 0.1 NTU for the entire 160-day Phase 1 operating period. SDI measurements of the UF permeate showed values that were generally around 1.0. This is well below the generally accepted SDI values of 2 to 3 considered suitable for RO feed water.

Operation of the UF system indicated that the cleaning frequency of once every 30 days was not sufficient to sustain the permeate production at a fixed rate. This indicates that the water had fouling tendencies and that, in practice, a lower flux rate would likely be required for long-term operation. A CEB, using chlorine in the form of sodium hypochlorite, was shown to improve the membrane performance in terms of maintaining flux.

The hardness of the water used to prepare the high pH wash solution for the UF CIP operation is thought to have resulted in the formation of a gray inorganic substance, which accumulated on the permeate side of the membrane (probably calcium carbonate). Tests were not done to confirm the nature of this material, and it did not appear to impact the performance of the membrane, but softening of the make-up water for the cleaning solutions would be recommended for a full-scale application. The RO permeate can also be used as cleaning make-up water.

The UF system demonstrated its ability to adequately remove suspended solids from the Western Canal water to a level suitable for RO treatment. The membrane was also able to remove some insoluble iron from the water, which is an important advantage of the process when coupled with RO, due to the potential fouling issues associated with iron and silica on RO membranes. A key finding of the investigation is that CEBs proved to be an effective way to maintain the membrane flux between full chemical cleaning events.

6.2 Reverse Osmosis System

The RO pilot plant was operated in both phases of the project. During Phase 1, the RO system operated on UF-pretreated Western Canal surface water; during Phase 2, the RO system operated directly on brackish ground water.

The main objective of the RO portion of the study was to maximize the RO system recovery with the use of a newly developed dendrimer antiscalant. The goal was to achieve a recovery of 90 percent or more, which was based on the results of computer modeling and recommendations from the antiscalant manufacturer.

During Phase 1, the RO system was operated on UF-pretreated water from the Western Canal, with an average TDS of 767 mg/L. Test results showed that operating at 90-percent recovery was not feasible under the test conditions encountered. The results showed that there was a decrease in membrane performance as indicated by a loss of permeate production and salt rejection after less than 30 days of operation at 90-percent recovery. The cleaning methods that were used were not effective at restoring membrane performance for this water source, and permeate production continued to decline as the operation continued. A more frequent cleaning schedule or a different cleaning procedure needs to be evaluated. The pilot testing did indicate stable operation at a recovery level of 85 percent, although this testing period was short – only 12 days.

During Phase 2, testing on brackish ground water (average TDS of 1,526 mg/L – roughly twice that of the surface water) showed better RO system performance at 90-percent recovery. The membranes used in the approximately 130-day operating period were the same as those used during Phase 1, with one new element installed in the first membrane stage and a modification made to the second and third stages to improve the hydraulics. However, despite the improved performance relative to Phase 1, there was a decline in system performance during each of the test runs, and a gradual decline in performance occurred over the entire 3-month test period while operating at 90-percent recovery. It is unclear from the data whether the decline in performance was due to scale formation on the membranes due to Phase 2 operation alone, contributions from Phase 1 operation, and/or due to acceleration of scale formation attributable to excessive permeate back pressure applied accidentally in the second stage of the RO system to maintain adequate flow to the third stage. An operational challenge associated with the three-stage RO pilot plant was the requirement to meet the minimum/maximum feed flow rates to the third stage membranes.

A membrane autopsy (carried out on an element taken from the third stage of the pilot plant at the end of Phase 2 operation) confirmed a drop in membrane permeate flow and salt rejection. Analysis of scale on the membrane surface showed the presence of high concentrations of silica, calcium, iron, and aluminum. This result confirmed that scale formation was occurring in the tail-end membranes, resulting in the declining performance observed during the testing. The presence of silica suggests that this resulted from the Phase 2 operation, since the silica concentration in the raw water was higher in Phase 2 than in Phase 1. The iron concentration in the raw water was also higher in Phase 2 than in Phase 1 (where some of the ambient iron concentration was removed by the UF process). Iron removal should be considered for future pretreatment of this water.

6.3 Overall Conclusions

The testing conducted in Phases 1 and 2 on Western Canal surface water and brackish ground water, respectively, has provided a good insight into the different issues associated with each of these water sources.

In the case of the Western Canal surface water, pretreatment using UF appeared to provide a good quality of water (in terms of turbidity and SDI value) for RO treatment. Nevertheless, scaling and/or fouling of the RO membranes was observed when a dose of 3.5 mg/L of scale inhibitor was used. In addition, there were challenges with cleaning the RO membranes.

During testing on the brackish ground water, which had a higher average TDS concentration than the surface water, pretreatment with UF was not used. The RO system performed a lot better initially, but then showed scaling/fouling in the RO membranes too when operating at 90-percent recovery and a scale inhibitor dose of 3.2 mg/L. Once again, periodic membrane cleaning was not able to sustain permeate production. A membrane autopsy showed the presence of scale containing silica, iron, calcium, and aluminum in the tail end membrane element.

The CCPP index proved to be a better tool than the LSI in predicting scaling potential, based on the actual mass of calcium carbonate that has potential to deposit on the membrane. However, for this study, neither index proved to be more valuable than the other. Both indices should be used to predict the potential for calcium carbonate scale formation and assist with setting scale inhibitor dosages.

This study has indicated that the predictions for the performance of a newly developed dendrimer scale inhibitor for operating RO at 90-percent recovery and above could not be achieved during this pilot test under the dosages and system conditions encountered. This was the case for both water sources tested.

The results from this study provide a good starting point for the additional testing that would be necessary before starting to design an RO treatment plant to demineralize one or both of these water sources. Such testing would need to include an extended period of operation to confirm stable performance at a recovery of 85 percent. Future testing should also include the evaluation of different scale inhibitors to determine which one works best for these source waters.

7. References

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Appendix A
Filmtec RO Membranes

FILMTEC Membranes

FILMTEC Fiberglassed Elements for Light Industrial Systems

Features

FILMTEC™ brackish water reverse osmosis membrane elements provide consistent, outstanding system performance in light industrial applications.

- FILMTEC BW30LE-4040 delivers highest performance at lowest pressure resulting in less energy usage and lower costs.
- FILMTEC BW30-4040 is the industry standard for reliable operation and production of the highest quality water.
- FILMTEC BW30-2540 elements are designed for systems smaller than 1 gpm (0.2 m^3/h) offering a hard shell exterior for extra strength.

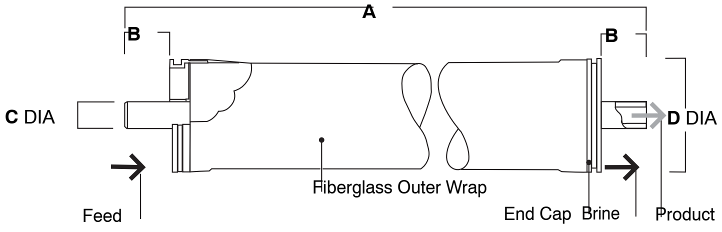
Elements with a hard shell exterior are recommended for systems with multiple-element housings containing three or more membranes, as they are designed to withstand higher pressure drops.

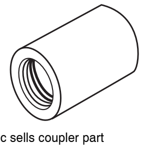
Product Specifications

Product	Part Number	Active Area ft^2 (m^2)	Applied Pressure psig (bar)	Permeate Flow Rate gpd (m^3/d)	Stabilized Salt Rejection (%)
BW30LE-4040	80604	82 (7.6)	150 (10.3)	2,300 (8.7)	99.0
BW30-4040	80783	82 (7.6)	225 (15.5)	2,400 (9.1)	99.5
BW30-2540	80766	28 (2.6)	225 (15.5)	850 (3.2)	99.5

1. Permeate flow and salt rejection based on the following test conditions: 2,000 ppm NaCl, pressure specified above, 77°F (25°C) and 15% recovery.
2. Permeate flows for individual elements may vary +/-20%.
3. For the purpose of improvement, specifications may be updated periodically.
4. BW30LE-4040 was previously named BW30HP-4040.

Figure 1





FilmTec sells coupler part number 89055 for use in multiple element housings. Each coupler includes two 2-210 EPR o-rings, FilmTec part number 89255.

Product	Dimensions – Inches (mm) A	B	C	D
BW30LE-4040	40.0 (1,016)	1.05 (26.7)	0.75 (19)	3.9 (99)
BW30-4040	40.0 (1,016)	1.05 (26.7)	0.75 (19)	3.9 (99)
BW30-2540	40.0 (1,016)	1.19 (30.2)	0.75 (19)	2.4 (61)

1. Refer to FilmTec Design Guidelines for multiple-element systems.

1 inch = 25.4 mm

2. BW30-2540 elements fit nominal 2.5-inch I.D. pressure vessel. BW30LE-4040 and BW30-4040 elements fit nominal 4-inch I.D. pressure vessel.

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* Trademark of The Dow Chemical Company

Operating Limits

Membrane Type	Polyamide Thin-Film Composite
Maximum Operating Temperature[a]	113°F (45°C)
Maximum Operating Pressure	600 psi (41 bar)
Maximum Feed Flow Rate - 4040 elements	16 gpm (3.6 m^3/h)
- 2540 elements	6 gpm (1.4 m^3/h)
Maximum Pressure Drop	15 psig (1.0 bar)
pH Range, Continuous Operation[a]	2 – 11
pH Range, Short-Term Cleaning[b]	1 – 12
Maximum Feed Silt Density Index	SDI 5
Free Chlorine Tolerance[c]	<0.1 ppm

[a] Maximum temperature for continuous operation above pH 10 is 95°F (35°C).

[b] Refer to Cleaning Guidelines in specification sheet 609-23010.

[c] Under certain conditions, the presence of free chlorine and other oxidizing agents will cause premature membrane failure. Since oxidation damage is not covered under warranty, FilmTec recommends removing residual free chlorine by pretreatment prior to membrane exposure. Please refer to technical bulletin 609-22010 for more information.

Important Information

Proper start-up of reverse osmosis water treatment systems is essential to prepare the membranes for operating service and to prevent membrane damage due to overfeeding or hydraulic shock. Following the proper start-up sequence also helps ensure that system operating parameters conform to design specifications so that system water quality and productivity goals can be achieved.

Before initiating system start-up procedures, membrane pretreatment, loading of the membrane elements, instrument calibration and other system checks should be completed.

Please refer to the application information literature entitled "Start-Up Sequence" (Form No. 609-00298) for more information.

Operation Guidelines

Avoid any abrupt pressure or cross-flow variations on the spiral elements during start-up, shutdown, cleaning or other sequences to prevent possible membrane damage. During start-up, a gradual change from a standstill to operating state is recommended as follows:

- Feed pressure should be increased gradually over a 30-60 second time frame.
- Cross-flow velocity at set operating point should be achieved gradually over 15-20 seconds.
- Permeate obtained from first hour of operation should be discarded.

General Information

- Keep elements moist at all times after initial wetting.
- If operating limits and guidelines given in this bulletin are not strictly followed, the limited warranty will be null and void.
- To prevent biological growth during prolonged system shutdowns, it is recommended that membrane elements be immersed in a preservative solution.
- The customer is fully responsible for the effects of incompatible chemicals and lubricants on elements.
- Maximum pressure drop across an entire pressure vessel (housing) is 50 psi (3.4 bar).
- Avoid static permeate-side backpressure at all times.

FILMTEC Membranes

For more information about FILMTEC membranes, call the Dow Liquid Separations business:

North America:	1-800-447-4369
Latin America:	(+55) 11-5188-9222
Europe:	(+32) 3-450-2240
Pacific (ex. China):	+800-7776-7776
China:	+10-800-600-0015

http://www.filmtec.com

Notice: The use of this product in and of itself does not necessarily guarantee the removal of cysts and pathogens from water. Effective cyst and pathogen reduction is dependent on the complete system design and on the operation and maintenance of the system.

Appendix B
RO Model Projections - Phase 1

Reverse Osmosis System Analysis for FILMTEC(TM) Membranes ROSA v5.4
Project: Phoenix Area Membrane Pilot Study Case: 1
Jenna Worley, Carollo Engineers 5/25/2004

System Summary

Feed Flow to Stage 1	18.80 gpm	Permeate Flow	15.98 gpm
Raw Water Flow to System	18.80 gpm	Recovery	85.00 %
Feed Pressure	152.62 psig	Feed Temperature	20.50 C
Fouling Factor	0.95	Feed TDS	1168.77 mg/l
Chem. Dose (100% H2SO4)	79.99 mg/l	Number of Elements	24
Total Active Area	1644.00 ft2	Average System Flux	14.00 gfd
Water Classification	Surface Supply SDI < 3		

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	BW30LE-4040	2	6	18.80	147.62	0.00	9.56	127.69	9.24	13.52	50.00	0.00	23.24
2	BW30LE-4040	1	6	9.56	172.69	0.00	4.47	153.21	5.09	14.89	50.00	50.00	43.14
3	LP-2540	1	6	4.47	148.21	0.00	2.82	113.26	1.65	14.18	0.00	0.00	130.71

(mg/l, except pH)	Raw Water	Adj Feed	Permeate	Concentrate
NH4	0.20	0.20	0.10	0.74
K	4.20	4.20	0.87	23.06
Na	249.00	258.67	9.85	1668.67
Mg	32.70	32.70	0.52	215.07
Ca	74.80	74.80	1.16	492.11
Sr	0.00	0.00	0.00	0.00
Ba	0.06	0.06	0.00	0.39
CO3	3.21	0.05	0.00	4.01
HCO3	275.00	181.91	7.25	1166.11
NO3	23.60	23.60	3.65	136.64
Cl	351.00	351.09	11.61	2274.84
F	0.35	0.35	0.01	2.25
SO4	138.00	216.36	2.71	1427.04
Boron	0.52	0.52	0.43	1.05
SiO2	21.80	21.80	0.43	142.90
CO2	2.70	70.71	69.49	71.30
TDS	1176.90	1168.77	40.59	7559.84
pH	8.10	6.50	5.23	7.15

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Design Warnings

-None-

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100 %
CaF2 (% Saturation) > 100 %
SiO2 (% Saturation) > 100 %
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Scaling Calculations

	Raw Water	Adj Feed	Concentrate
pH	8.10	6.50	7.15
Langelier Saturation Index	0.70	-1.08	1.14
Stiff & Davis Stability Index	1.04	-0.76	0.77
Ionic Strength (Molal)	0.02	0.02	0.15
TDS (mg/l)	1176.90	1139.96	7559.84
HCO3	275.00	181.91	1166.11
CO2	2.74	71.86	72.46
CO3	3.21	0.05	4.01
CaSO4 (% Saturation)	0.49	0.76	22.08
BaSO4 (% Saturation)	268.49	420.94	2897.50
SrSO4 (% Saturation)	0.00	0.00	0.00
CaF2 (% Saturation)	1.22	1.22	332.59
SiO2 (% Saturation)	16.18	17.69	123.19

To balance: 9.67 mg/l Na added to feed.

Array Details

Stage 1 Element	Recov.	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.10	0.91	15.92	9.40	1168.77	147.62
2	0.10	0.85	18.22	8.50	1291.68	142.90
3	0.10	0.79	21.08	7.65	1432.78	138.83
4	0.11	0.74	24.66	6.86	1596.09	135.33
5	0.11	0.69	29.17	6.12	1786.55	132.35
6	0.12	0.64	34.97	5.42	2010.56	129.81

Stage 2 Element	Recov.	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.11	1.03	26.46	9.56	2275.95	172.69
2	0.11	0.96	31.60	8.54	2547.08	167.90
3	0.12	0.88	38.14	7.58	2864.30	163.83
4	0.12	0.81	46.55	6.69	3237.65	160.41
5	0.13	0.74	57.56	5.88	3678.92	157.55
6	0.13	0.67	72.18	5.14	4200.72	155.17

Stage 3 Element	Recov.	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.08	0.36	86.48	4.47	4814.77	148.21
2	0.08	0.32	102.38	4.11	5228.61	140.64
3	0.08	0.29	121.46	3.79	5666.28	133.90
4	0.07	0.26	144.45	3.50	6124.17	127.89
5	0.07	0.23	172.22	3.24	6597.12	122.50
6	0.07	0.20	205.91	3.02	7078.39	117.65

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Reverse Osmosis System Analysis for FILMTEC(TM) Membranes ROSA v5.4
Project: Phoenix Area Membrane Pilot Study Case: 2
Jenna Worley, Carollo Engineers 5/25/2004

System Summary

Feed Flow to Stage 1	17.76 gpm	Permeate Flow	15.98 gpm
Raw Water Flow to System	17.76 gpm	Recovery	89.99 %
Feed Pressure	153.81 psig	Feed Temperature	20.50 C
Fouling Factor	0.95	Feed TDS	1168.77 mg/l
Chem. Dose (100% H2SO4)	79.99 mg/l	Number of Elements	24
Total Active Area	1644.00 ft2	Average System Flux	14.00 gfd
Water Classification	Surface Supply SDI < 3		

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	BW30LE-4040	2	6	17.76	148.81	0.00	8.33	131.11	9.43	13.80	50.00	0.00	23.88
2	BW30LE-4040	1	6	8.33	176.11	0.00	3.29	161.36	5.05	14.77	50.00	50.00	52.01
3	LP-2540	1	6	3.29	156.36	0.00	1.78	135.83	1.51	12.92	0.00	0.00	196.92

(mg/l, except pH)	Raw Water	Adj Feed	Permeate	Concentrate
NH4	0.20	0.20	0.12	0.96
K	4.20	4.20	1.03	32.70
Na	249.00	258.67	12.03	2475.23
Mg	32.70	32.70	0.64	320.85
Ca	74.80	74.80	1.43	734.22
Sr	0.00	0.00	0.00	0.00
Ba	0.06	0.06	0.00	0.58
CO3	3.21	0.05	0.00	10.34
HCO3	275.00	181.91	8.75	1720.62
NO3	23.60	23.60	4.33	196.74
Cl	351.00	351.09	14.20	3378.80
F	0.35	0.35	0.02	3.34
SO4	138.00	216.36	3.35	2130.69
Boron	0.52	0.52	0.45	1.19
SiO2	21.80	21.80	0.51	213.14
CO2	2.70	70.71	69.65	74.10
TDS	1176.89	1168.77	48.95	11224.97
pH	8.10	6.50	5.31	7.26

Design Warnings

CAUTION: The concentrate flow rate is less than the recommended minimum flow. Please change your system design to increase concentrate flow rates. (Product: BW30LE-4040, Limit: 4.00 gpm)

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100 %
CaF2 (% Saturation) > 100 %
SiO2 (% Saturation) > 100 %
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Scaling Calculations

	Raw Water	Adj Feed	Concentrate
pH	8.10	6.50	7.26
Langelier Saturation Index	0.70	-1.08	1.59
Stiff & Davis Stability Index	1.04	-0.76	1.05
Ionic Strength (Molal)	0.02	0.02	0.23
TDS (mg/l)	1176.89	1139.96	11224.97
HCO3	275.00	181.91	1720.62
CO2	2.74	71.86	75.31
CO3	3.21	0.05	10.34
CaSO4 (% Saturation)	0.49	0.76	41.45
BaSO4 (% Saturation)	268.49	420.94	4361.23
SrSO4 (% Saturation)	0.00	0.00	0.00
CaF2 (% Saturation)	1.22	1.22	1090.71
SiO2 (% Saturation)	16.18	17.69	183.74

To balance: 9.67 mg/l Na added to feed.

Reverse Osmosis System Analysis for FILMTEC(TM) Membranes ROSA v5.4
Project: Phoenix Area Membrane Pilot Study Case: 2
Jenna Worley, Carollo Engineers 5/25/2004

Array Details

Stage 1 Element	Recov.	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.10	0.92	15.90	8.88	1168.77	148.81
2	0.11	0.86	18.28	7.96	1301.78	144.49
3	0.11	0.81	21.33	7.10	1457.73	140.80
4	0.12	0.76	25.23	6.29	1642.72	137.67
5	0.13	0.71	30.34	5.53	1864.63	135.05
6	0.14	0.66	37.18	4.82	2134.12	132.88

Stage 2 Element	Recov.	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.12	1.04	29.05	8.33	2464.99	176.11
2	0.13	0.97	35.56	7.29	2812.16	172.22
3	0.14	0.89	44.28	6.33	3235.78	169.01
4	0.15	0.81	56.24	5.44	3757.40	166.41
5	0.16	0.72	73.04	4.63	4402.95	164.32
6	0.16	0.62	97.32	3.91	5199.76	162.66

Stage 3 Element	Recov.	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.10	0.34	119.47	3.29	6168.58	156.36
2	0.10	0.30	145.61	2.95	6865.30	151.55
3	0.10	0.27	178.81	2.64	7634.48	147.42
4	0.10	0.23	221.41	2.38	8471.06	143.87
5	0.09	0.20	276.37	2.14	9362.68	140.81
6	0.09	0.17	347.39	1.95	10289.34	138.15

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Reverse Osmosis System Analysis for FILMTEC(TM) Membranes	ROSA v5.4
Project: Phoenix Area Membrane Pilot Study	Case: 3
Jenna Worley, Carollo Engineers	5/25/2004

System Summary

Feed Flow to Stage 1	17.37 gpm	Permeate Flow	15.98 gpm
Raw Water Flow to System	17.37 gpm	Recovery	91.99 %
Feed Pressure	149.64 psig	Feed Temperature	20.50 C
Fouling Factor	0.95	Feed TDS	1168.76 mg/l
Chem. Dose (100% H2SO4)	79.98 mg/l	Number of Elements	24
Total Active Area	1644.00 ft2	Average System Flux	14.00 gfd
Water Classification	Surface Supply SDI < 3		

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	BW30LE-4040	2	6	17.37	144.64	0.00	8.95	126.73	8.42	12.33	55.00	0.00	24.85
2	BW30LE-4040	1	6	8.95	196.73	0.00	3.04	181.32	5.91	17.30	55.00	75.00	45.20
3	LP-2540	1	6	3.04	176.32	0.00	1.39	159.65	1.65	14.12	0.00	0.00	213.34

(mg/l, except pH)	Raw Water	Adj Feed	Permeate	Concentrate
NH4	0.20	0.20	0.12	1.13
K	4.20	4.20	1.08	40.09
Na	249.00	258.66	12.73	3084.50
Mg	32.70	32.70	0.68	400.61
Ca	74.80	74.80	1.52	916.81
Sr	0.00	0.00	0.00	0.00
Ba	0.06	0.06	0.00	0.72
CO3	3.21	0.05	0.00	17.45
HCO3	275.00	181.91	9.26	2134.42
NO3	23.60	23.60	4.55	242.48
Cl	351.00	351.09	15.01	4212.68
F	0.35	0.35	0.02	4.16
SO4	138.00	216.35	3.57	2661.19
Boron	0.52	0.52	0.45	1.31
SiO2	21.80	21.80	0.54	266.10
CO2	2.70	70.71	69.76	77.29
TDS	1176.89	1168.76	51.66	13989.81
pH	8.10	6.50	5.33	7.31

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Design Warnings

WARNING: Maximum element recovery has been exceeded. Please change your system design to reduce the element recoveries. (Product: BW30LE-4040, Limit: 17.00)

CAUTION: The concentrate flow rate is less than the recommended minimum flow. Please change your system design to increase concentrate flow rates. (Product: BW30LE-4040, Limit: 4.00 gpm)

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100 %
CaF2 (% Saturation) > 100 %
SiO2 (% Saturation) > 100 %
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Scaling Calculations

	Raw Water	Adj Feed	Concentrate
pH	8.10	6.50	7.31
Langelier Saturation Index	0.70	-1.08	1.82
Stiff & Davis Stability Index	1.04	-0.76	1.20
Ionic Strength (Molal)	0.02	0.02	0.29
TDS (mg/l)	1176.89	1139.94	13989.81
HCO3	275.00	181.91	2134.42
CO2	2.74	71.86	78.56
CO3	3.21	0.05	17.45
CaSO4 (% Saturation)	0.49	0.76	57.90
BaSO4 (% Saturation)	268.49	420.93	5487.70
SrSO4 (% Saturation)	0.00	0.00	0.00
CaF2 (% Saturation)	1.22	1.22	2113.87
SiO2 (% Saturation)	16.18	17.69	229.40

To balance: 9.66 mg/l Na added to feed.

Array Details

Stage 1 Element	Recov.	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.10	0.83	17.04	8.69	1168.76	144.64
2	0.10	0.77	19.50	7.86	1290.10	140.43
3	0.10	0.72	22.57	7.09	1428.93	136.78
4	0.11	0.68	26.40	6.36	1588.94	133.63
5	0.11	0.63	31.21	5.69	1774.54	130.94
6	0.12	0.58	37.36	5.06	1991.36	128.66

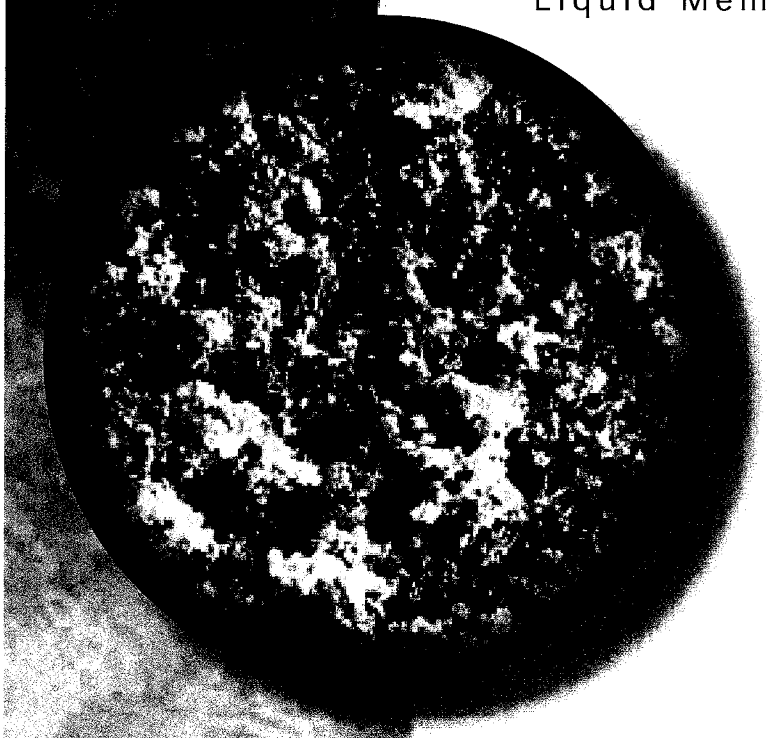
Stage 2 Element	Recov.	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.13	1.20	23.86	8.95	2246.06	196.73
2	0.15	1.13	29.43	7.74	2591.76	192.45
3	0.16	1.04	37.14	6.62	3027.85	189.00
4	0.17	0.95	48.21	5.57	3588.07	186.26
5	0.18	0.85	64.63	4.62	4318.56	184.14
6	0.19	0.73	90.04	3.77	5277.92	182.52

Stage 3 Element	Recov.	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.13	0.38	117.72	3.04	6526.08	176.32
2	0.13	0.34	147.82	2.65	7450.70	172.08
3	0.13	0.30	188.43	2.31	8522.44	168.58
4	0.12	0.25	244.03	2.02	9742.12	165.70
5	0.12	0.21	321.10	1.77	11092.03	163.32
6	0.11	0.17	428.34	1.56	12529.54	161.33

Appendix C
RO Cleaning Products and Procedures

Lavasol™

Liquid Membrane Cleaners



Lavasol™ liquid membrane cleaners effectively remove inorganic scale, metals, colloids, biological growth, and organic foulants from RO membranes

Lavasol™ liquid membrane cleaners effectively remove a wide variety of foulants from polyamide thin-film composite and cellulose acetate membranes. Each cleaner dilutes quickly and easily to form a solution that vigorously removes membrane foulants without harming the membrane surface. A regular maintenance program including Lavasol™ membrane cleaners ensures optimum system performance and maximum element life.

Lavasol I™ - Low pH Cleaner For Removing Inorganic Scale and Metals from Polyamide Thin-Film Composite and CA Membranes. Foulants effectively removed by Lavasol I™ include:

- Calcium Carbonate
- Calcium Sulfate
- Barium Sulfate
- Strontium Sulfate
- Iron
- Metal Oxides

Lavasol II™ - High pH Cleaner For Removing Acid Insoluble Foulants from Polyamide Thin-Film Composite Membranes. Foulants effectively removed by Lavasol II™ include:

- Silt
- Colloids
- Organics
- Microbiological
- Acid Insoluble
- Mucilaginous Material

Lavasol III™ - Medium pH Cleaner For Removing Acid Insoluble Foulants from CA Membranes. Foulants effectively removed by Lavasol III™ include:

- Silt
- Colloids
- Organics
- Microbiological
- Acid Insoluble
- Mucilaginous Material

Lavasol IV™ - Medium pH Cleaner For Removing Organics from Polyamide Thin-Film Composite, CA, UF, and NF Membranes. Foulants effectively removed by Lavasol IV™ include:

- Organic Acids
- Proteinase Foulants
- Cellulosic Foulants
- Oils
- Waxes
- Paraffins

Lavasol V™ - For Removing Silica from Polyamide Thin-Film Composite, CA, and UF Membranes

Mixing and Application Instructions for Lavasol™ Cleaners

- ***Prepare system for cleaning.***
- ***Fill cleaning tank with good quality water, preferably RO permeate water.***
- ***Mix 1 gallon of Lavasol™ for each 40 gallons of water in the cleaning tank.***
- ***Recirculate solution for at least 1 hour.***
- ***Static soaking heavily fouled elements is recommended.***
- ***Rinse system at low pressure prior to system start-up.***
- ***Discard system product water 15-30 minutes after system start up.***

Pressure and Element Flows:

- Pressure: 60 psi
- 4" Element Flow: 7 GPM
- 8" Element Flow: 35 GPM

PROFESSIONAL WATER TECHNOLOGIES, Inc.
High Performance Reverse Osmosis Chemicals

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FILMTEC Membranes

Cleaning Procedures for FILMTEC FT30 Elements

The following are general recommendations for cleaning FILMTEC™ FT30 elements. More detailed procedures for cleaning a reverse osmosis (RO) system are typically included in the operating manual provided by the system supplier. It should be emphasized that frequent cleaning is not required for a properly designed and properly operated RO system, however because of the FT30 membrane's unique combination of pH range and temperature resistance, cleaning may be accomplished very effectively.

Cleaning Requirements

In normal operation, the membrane in reverse osmosis elements can become fouled by mineral scale, biological matter, colloidal particles and insoluble organic constituents. Deposits build up on the membrane surfaces during operation until they cause loss in normalized permeate flow, loss of normalized salt rejection, or both.

Elements should be cleaned when one or more of the below mentioned parameters are applicable:

- The normalized permeate flow drops 10%
- The normalized salt passage increases 5 - 10%
- The normalized pressure drop (feed pressure minus concentrate pressure) increases 10 - 15%

If you wait too long, cleaning may not restore the membrane element performance successfully. In addition, the time between cleanings becomes shorter as the membrane elements will foul or scale more rapidly.

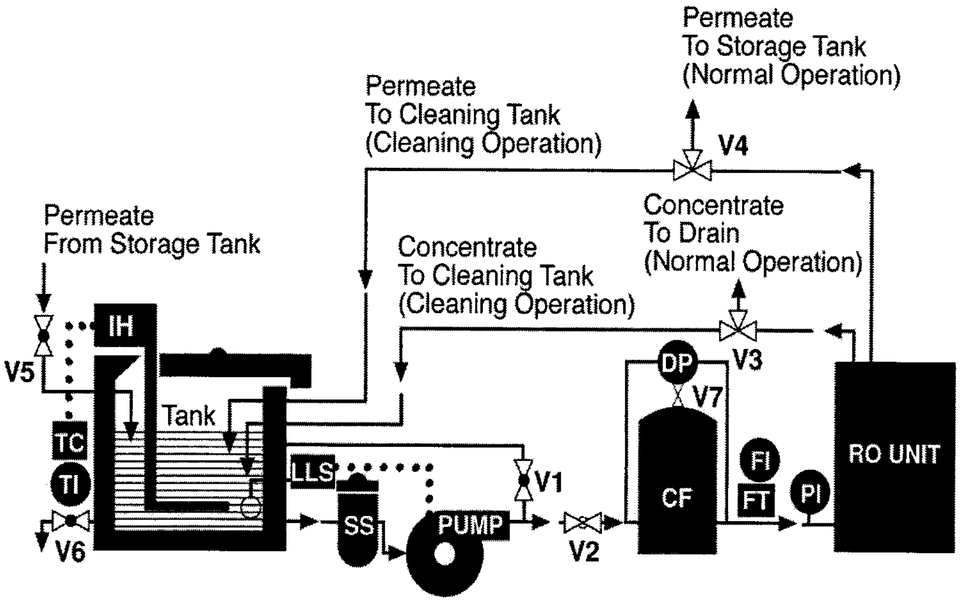
Differential Pressure (ΔP) should be measured and recorded across each stage of the array of pressure vessels. If the feed channels within the element become plugged, the ΔP will increase. It should be noted that the permeate flux will drop if feedwater temperature decreases. This is normal and does not indicate membrane fouling.

A malfunction in the pretreatment, pressure control, or increase in recovery can result in reduced product water output or an increase in salt passage. If a problem is observed, these causes should be considered first. The element(s) may not require cleaning. A computer program called FTNORM is available from FilmTec for normalizing performance data of FILMTEC RO membranes. This program can be used to assist in determining when to clean and can be downloaded from our web site (www.filmtec.com).

Safety Precautions

1. When using any chemical indicated here in subsequent sections, follow accepted safety practices. Consult the chemical manufacturer for detailed information about safety, handling and disposal.
2. When preparing cleaning solutions, ensure that all chemicals are dissolved and well mixed before circulating the solutions through the elements.
3. It is recommended the elements be flushed with good-quality chlorine-free water (20°C minimum temperature) after cleaning. Permeate water or deionized water are recommended. Care should be taken to operate initially at reduced flow and pressure to flush the bulk of the cleaning solution from the elements before resuming normal operating pressures and flows. Despite this precaution, cleaning chemicals will be present on the permeate side following cleaning. Therefore, the permeate must be diverted to drain for at least 30 minutes or until the water is clear when starting up after cleaning.
4. During recirculation of cleaning solutions, the maximum temperature must not be exceeded. The maximum allowed temperature is dependent on pH and membrane type. Table 1 contains information on the maximum allowed temperatures.
5. For elements greater than six inches in diameter, the flow direction during cleaning must be the same as during normal operation to prevent element telescoping, because the vessel thrust ring is installed only on the reject end of the vessel. This is also recommended for smaller elements. Equipment for cleaning is illustrated below.

Cleaning System Flow Diagram



TANK	Chemical Mixing Tank, polypropylene or FRP
IH	Immersion Heater (may be replaced by cooling coil for some site locations)
TI	Temperature Indicator
TC	Temperature Control
LLS	Lower Level Switch to shut off pump
SS	Security Screen–100 mesh
PUMP	Low-Pressure Pump, 316 SS or non-metallic composite
CF	Cartridge Filter, 5-10 micron polypropylene with PVC, FRP, or SS housing
DP	Differential Pressure Gauge
FI	Flow Indicator
FT	Flow Transmitter (optional)
PI	Pressure Indicator
V1	Pump Recirculation Valve, CPVC
V2	Flow Control Valve, CPVC
V3	Concentrate Valve, CPVC 3-way valve
V4	Permeate Valve, CPVC 3-way valve
V5	Permeate Inlet Valve, CPVC
V6	Tank Drain Valve, PVC, or CPVC
V7	Purge Valve, SS, PVC, or CPVC

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Suggested Equipment

The equipment for cleaning is shown in the Cleaning System Flow Diagram. The pH of cleaning solutions used with FILMTEC elements can be in the range of 1 to 13 (see Table 1), and therefore non-corroding materials should be used in the cleaning system.

1. The mixing tank should be constructed of polypropylene or fiberglass-reinforced plastic (FRP). The tank should be provided with a removable cover and a temperature gauge. The cleaning procedure is more effective when performed at a warm temperature, and it is recommended that the solution be maintained according to the pH and temperature guidelines listed in Table 1. It is not recommended to use a cleaning temperature below 20°C because of the very slow chemical kinetics at low temperatures. In addition, chemicals such as sodium lauryl sulfate might precipitate at low temperatures. Cooling may also be required in certain geographic regions, so both heating/cooling requirements must be considered during the design. A rough rule of thumb in sizing a cleaning tank is to use approximately the empty pressure vessels volume and then add the volume of the feed and return hoses or pipes. For example, to clean ten 8-inch diameter pressure vessels with six elements per vessel, the following calculations would apply:

   A. Volume in Vessels

   $V1 = \pi r^2 L$

   $= 3.14\ (4\ \text{in})^2\ (20\ \text{ft})\ (7.48\ \text{gal/ft}^3)\ /\ (144\ \text{in}^2/\text{ft}^2)$

   $V1 = 52\ \text{gal/vessel}\ (0.2\ \text{m}^3)$

   $V10 = 52 \times 10 = 520\ \text{gal}\ (1.97\ \text{m}^3)$

   B. Volume in Pipes, assume 50 ft. length total 4" Sch 80 pipe

   $Vp = \pi r^2 L$

   $= 3.14\ (1.91\ \text{in})^2\ (50\ \text{ft})\ (7.48\ \text{gal/ft}^3)\ /\ (144\ \text{in}^2/\text{ft}^2)$

   $= 30\ \text{gals}\ (0.11\ \text{m}^3)$

   $Vct = V_{10} + Vp = 520 + 30 = 550\ \text{gal.}$

Therefore, the cleaning tank should be about 550 gals (2.1 m^3).

2. The cleaning pump should be sized for the flows and pressures given in Table 2, making allowances for pressure loss in the piping and across the cartridge filter. The pump should be constructed of 316 SS or nonmetallic composite polyesters.
3. Appropriate valves, flow meters, and pressure gauges should be installed to adequately control the flow. Service lines may be either hard piped or hoses. In either case, the flow rate should be a moderate 10 ft/sec (3 m/sec) or less.

Cleaning Elements In Situ

There are six steps in the cleaning of elements:

1. Make up cleaning solution.
2. Low-flow pumping. Pump mixed, preheated cleaning solution to the vessel at conditions of low flow rate (about half of that shown in Table 2) and low pressure to displace the process water. Use only enough pressure to compensate for the pressure drop from feed to concentrate. The pressure should be low enough that essentially no or little permeate is produced. A low pressure minimizes redeposition of dirt on the membrane. Dump the concentrate, as necessary, to prevent dilution of the cleaning solution.
3. Recycle. After the process water is displaced, cleaning solution will be present in the concentrate stream. Then recycle the concentrate and permeate to the cleaning solution tank and allow the temperature to stabilize. Measure the pH of the solution and adjust the pH if needed.

Table 1. pH range and temperature limits during cleaning

Element type	Max Temp 50°C (122°F) pH range	Max Temp 45°C (113°F) pH range	Max Temp 35°C(95 °F) pH range	Max Temp 25°C (77°F) pH range
BW30, BW30LE, LE, XLE, TW30, TW30HP, NF90	Please contact Dow for assistance	1 - 10.5	1 - 12	1 - 13
SW30HR, SW30HR LE, SW30XLE, SW30	Please contact Dow for assistance	1 - 10.5	1 - 12	1 - 13
NF200, NF270	Not allowed	3 - 10	1 - 11	1 - 12
SR90	Not allowed	3 - 10	1 - 11	1 - 12

Table 2. Recommended feed flow rate per pressure vessel during high flow rate recirculation

Feed Pressure[1]		Element Diameter	Feed Flow Rate per Pressure Vessel	
(psig)	(bar)	(inches)	(gpm)	(m3/hr)
20-60	1.5-4.0	2.5	3-5	0.7-1.2
20-60	1.5-4.0	4[2]	8-10	1.8-2.3
20-60	1.5-4.0	6	16-20	3.6-4.5
20-60	1.5-4.0	8	30-40	6.-9.1
20-60	1.5-4.0	8[3]	35-45	8.0-10.2

1. Dependent on number of elements in pressure vessel.
2. 4-inch full-fit elements should be cleaned at 12-14 gpm (2.7-3.2 m^3/hr).
3. For full-fit and 440 sq. ft. area elements.

4. Soak. Turn the pump off and allow the elements to soak. Sometimes a soak period of about 1 hour is sufficient. For difficult fouling an extended soak period is beneficial; soak the elements overnight for 10-15 hours. To maintain a high temperature during an extended soak period, use a slow recirculation rate (about 10 percent of that shown in Table 2).
5. High-flow pumping. Feed the cleaning solution at the rates shown in Table 2 for 30-60 minutes. The high flow rate flushes out the foulants removed from the membrane surface by the cleaning. If the elements are heavily fouled, a flow rate which is 50 percent higher than shown in Table 2 may aid cleaning. At higher flow rates, excessive pressure drop may be a problem. The maximum recommended pressure drops are 15 psi per element or 50 psi per multi-element vessel, whichever value is more limiting. Please note that the 15 psi per element or the 50 psi per multi-element vessel should NOT be used as a cleaning criteria. Cleaning is recommended when the pressure drop increases 15%. Pressure drop above 50 psi in a single stage may cause significant membrane damage.
6. Flush out. RO permeate or deionized water is recommended for flushing out the cleaning solution. Prefiltered raw water or feed water should be avoided as its components may react with the cleaning solution: precipitation of foulants may occur in the membrane elements. The minimum flush out temperature is 20°C.

Cleaning Tips

1. It is strongly recommended to clean the stages of the RO or NF system separately. This is to avoid having the removed foulant from stage 1 pushed into the 2nd stage resulting in minimal performance improvement from the cleaning. If the system consists of 3 stages, stage 2 and stage 3 should also be cleaned separately.
   For multi-stage systems, while each stage should be cleaned separately, the flushing and soaking operations may be done simultaneously in all stages. Fresh cleaning solution needs to be prepared when the cleaning solution becomes turbid and/or discolored. High-flow recirculation, however, should be carried out separately for each stage, so the flow rate is not too low in the first stage or too high in the last. This can be accomplished either by using one cleaning pump and operating one stage at a time, or by using a separate cleaning pump for each stage.

2. The fouling or scaling of elements typically consists of a combination of foulants and scalants, for instance a mixture of organic fouling, colloidal fouling and biofouling. Therefore, it is very critical that the first cleaning step is wisely chosen. FilmTec strongly recommends alkaline cleaning as the first cleaning step. Acid cleaning should only be applied as the first cleaning step if it is known that only calcium carbonate or iron oxide/hydroxide is present on the membrane elements.

   Acid cleaners typically react with silica, organics (for instance humic acids) and biofilm present on the membrane surface which may cause a further decline of the membrane performance. Sometimes, an alkaline cleaning may restore this decline that was caused by the acid cleaner, but often an extreme cleaning will be necessary. An extreme cleaning is carried out at pH and temperature conditions that are outside the membrane manufacturer's guidelines or by using cleaning chemicals that are not compatible with the membrane elements. An extreme cleaning should only be carried out as a last resort as it can result in membrane damage.

   If the RO system suffers from colloidal, organic fouling or biofouling in combination with calcium carbonate, then a two- step cleaning program will be needed: alkaline cleaning followed by an acid cleaning. The acid cleaning may be performed when the alkaline cleaning has effectively removed the organic fouling, colloidal fouling and biofouling.

3. Always measure the pH during cleaning. If the pH increases more than 0.5 pH units during acid cleaning, more acid needs to be added. If the pH decreases more than 0.5 pH units during alkaline cleaning, more caustic needs to be added.

4. Long soak times. It is possible for the solution to be fully saturated and the foulants can precipitate back onto the membrane surface. In addition, the temperature will drop during this period, therefore the soaking becomes less effective. It is recommended to circulate the solution regularly in order to maintain the temperature (temperature should not drop more than 5°C) and add chemicals if the pH needs to be adjusted.

5. Turbid or strong colored cleaning solutions should be replaced. The cleaning is repeated with a fresh cleaning solution.

6. If the system has to be shutdown for more than 24 hours, the elements should be stored in 1% w/w sodium metabisulfite solution.

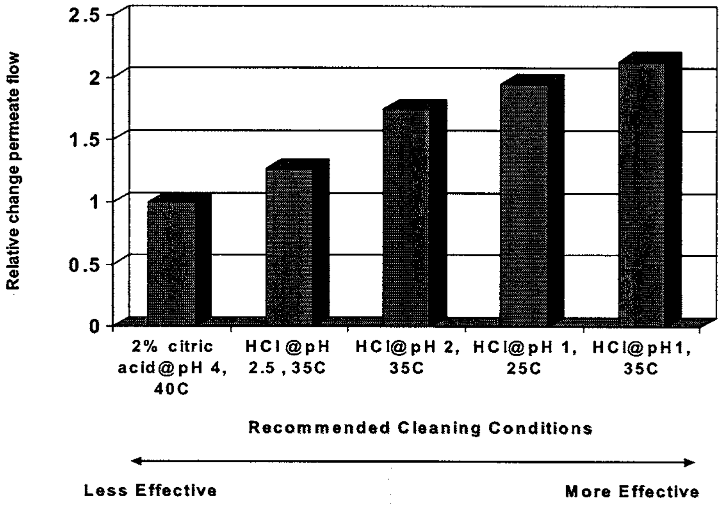
Effect of pH on foulant removal

In addition to applying the correct cleaning sequence (alkaline cleaning step first), selecting the correct pH is very critical for optimum foulant removal. If foulant is not successfully removed, the membrane system performance will decline faster as it is easier for the foulant to deposit on the membrane surface area. The time between cleanings will become shorter, resulting in shorter membrane element life and higher operating and maintenance costs.

Most effective cleaning allows longer system operating time between cleanings and results in the lowest operating costs.

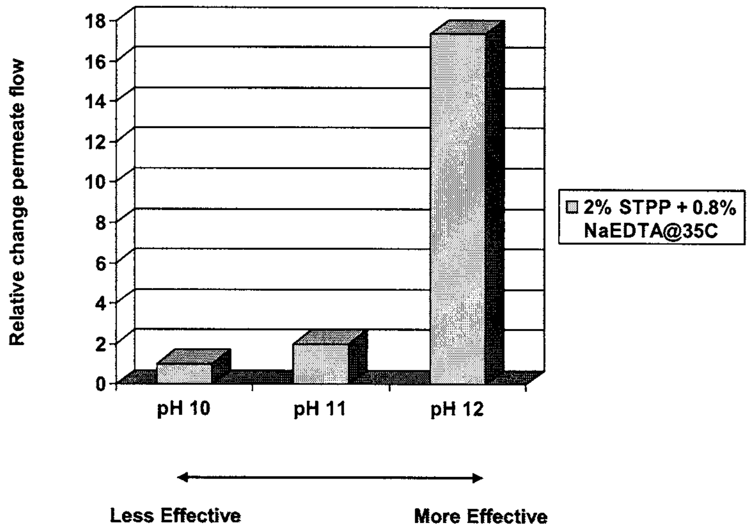
Figure 1 and 2 below show the importance of the selecting the right pH for successful cleaning.

Figure 1. Effect of pH on the removal of calcium carbonate



Calcium carbonate is best removed by cleaning with hydrochloric acid at pH 1-2.

Figure 2. Effect of pH on the removal of biofouling



Biofouling is best removed by cleaning at pH 12.

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Cleaning Chemicals

Table 3 lists suitable cleaning chemicals. Acid cleaners and alkaline cleaners are the standard cleaning chemicals. The acid cleaners are used to remove inorganic precipitates including iron, while the alkaline cleaners are used to remove organic fouling including biological matter. Sulfuric acid should never used for cleaning because of the risk of calcium sulfate precipitation. Reverse osmosis permeate or deionized water should be used for the preparation of cleaning solutions.

Table 3. Simple cleaning solutions for FT30 membrane

Cleaner Foulant	0.1% (W) NaOH and pH 12, 35°C max. or 1.0% (W) Na_4EDTA and pH 12, 35°C max.	0.1% (W) NaOH and pH 12, 35°C max. or 0.025% (W) Na-DSS and pH 12, 35°C max.	0.2% (W) HCl, 25°C and pH 1 - 2	1.0% (W) $Na_2S_2O_4$, 25°C and pH 5	0.5% (W) H_3PO_4, 25 °C and pH 1 - 2	1.0% (W) NH_2SO_3H, 25°C and pH 3 - 4
Inorganic Salts (for example, $CaCO_3$)			Preferred	Alternative	Alternative	
Sulfate Scales ($CaSO_4$, $BaSO_4$)	OK					
Metal Oxides (for example, iron)				Preferred	Alternative	Alternative
Inorganic Colloids (silt)		Preferred				
Silica	Alternative	Preferred				
Biofilms	Alternative	Preferred				
Organic	Alternative	Preferred				

The temperatures and pH listed in table 3 are applicable for BW30, BW30LE, LE, XLE, TW30, TW30HP, SW30HR, SW30HR LE , SW30XLE, SW30 and NF90 membrane elements. For more information regarding the allowed temperatures and pH for cleaning, please refer to table 1.

Notes:

1. (W) denotes weight percent of active ingredient.
2. Foulant chemical symbols in order used: $CaCO_3$ is calcium carbonate; $CaSO_4$ is calcium sulfate; $BaSO_4$ is barium sulfate.
3. Cleaning chemical symbols in order used: NaOH is sodium hydroxide; Na_4EDTA is the tetra-sodium salt of ethylene diamine tetraacetic acid and is available from The Dow Chemical Company under the trademark VERSENE* 100 and VERSENE 220 crystals; Na-DSS is sodium salt of dodecylsulfate; Sodium Laurel Sulfate; HCl is hydrochloric acid (Muratic Acid); H_3PO_4 is phosphoric acid; NH_2SO_3H is sulfamic acid; $Na_2S_2O_4$ is sodium hydrosulfite.
4. For effective sulfate scale cleaning, the condition must be caught and treated early. Adding NaCl to the cleaning solution of NaOH and Na_4EDTA may help as sulfate solubility increases with increasing salinity. Successful cleaning of sulfate scales older than 1 week is doubtful.
5. Citric Acid is another cleaning alternative for metal oxides and calcium carbonate scale. It is less effective (see also figure 1 of this document). It may contribute to biofouling especially when it is not properly rinsed out.

FILMTEC Membranes
For more information about FILMTEC membranes, call the Dow Liquid Separations business:

North America:	1-800-447-4369
Latin America:	(+55) 11-5188-9222
Europe:	(+32) 3-450-2240
Pacific:	+60 3 7958 3392
Japan:	+813 5460 2100
China:	+86 21 2301 9000

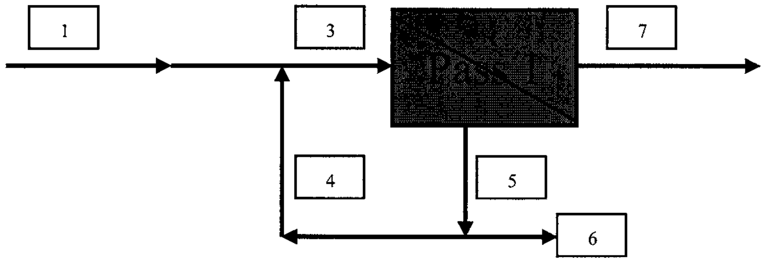
http://www.filmtec.com

Appendix D
RO Model Projections - Phase 2

Project: Western Canal - Phase 2
Prepared By: Jenna Manuszak
Carollo Engineers

ROSA v6.0 ConfigDB 35240039
Case: 1
6/28/2005

System Design Overview



Raw Water TDS	1590.10 mg/l	% System Recovery (7/1)	94.00 %
Water Classification	Well Water SDI < 3	Fouling Factor (Pass 1)	0.95
Feed Temperature	25.0 C		

Pass #	**Pass 1**		
Stage #	**1**	**2**	**3**
Element Type	BW30LE-4040	BW30LE-4040	LP-2540
Pressure Vessels per Stage	2	1	1
Elements per Pressure Vessel	7	5	5
Total Number of Elements	14	5	5
Pass Average Flux	14.00 gfd		
Stage Average Flux	14.40 gfd	13.89 gfd	11.03 gfd
Permeate Back Pressure	70.00 psig	70.00 psig	0.00 psig
Booster Pressure	0.00 psig	95.00 psig	0.00 psig
Chemical Dose	-		
Energy Consumption	3.06 kWh/kgal		

Pass 1			
Stream #	**Flow (gpm)**	**Pressure (psig)**	**TDS (mg/l)**
1	17.56	0.00	1590.10
3	20.56	228.92	4737.84
4	3.00	233.60	23046.29
5	4.05	233.60	23046.29
6	1.05	233.60	23046.29
7	16.51	-	225.22
7/1	**% Recovery**	94.00	

Project Information:

Design Warnings:

-None-

Solubility Warnings:

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
CaF2 (% Saturation) > 100%
SiO2 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Reverse Osmosis System Analysis for FILMTEC™ Membranes
Project: Western Canal - Phase 2
Jenna Manuszak, Carollo Engineers

ROSA v6.0 ConfigDB 35240039
Case: 1
6/28/2005

Project Information:

System Details

Feed Flow to Stage 1	20.56 gpm	Pass 1 Permeate Flow	16.51 gpm	Osmotic Pressure:	
Raw Water Flow to System	17.56 gpm	Pass 1 Recovery	94.00 %	Feed	14.94 psig
Feed Pressure	228.92 psig	Feed Temperature	25.0 C	Concentrate	204.68 psig
Fouling Factor	0.95	Feed TDS	1590.50 mg/l	Average	109.81 psig
Chem. Dose (100% H2SO4)	0.00 mg/l	Number of Elements	24	Average NDP	130.80 psig
Total Active Area	1698.00 ft2	Average Pass 1 Flux	14.00 gfd	Power	3.03 kW
Water Classification: Well Water SDI < 3				Specific Energy	3.06 kWh/kgal

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	BW30LE-4040	2	7	20.56	223.92	3.00	9.08	202.08	11.48	14.40	70.00	0.00	153.35
2	BW30LE-4040	1	5	9.08	292.08	0.00	5.13	276.99	3.96	13.89	70.00	95.00	306.62
3	LP-2540	1	5	5.13	271.99	0.00	4.05	233.60	1.07	11.03	0.00	0.00	694.57

Pass Streams
(mg/l as Ion)

Name	Feed	Adjusted Feed		Concentrate			Permeate			
		Initial	After Recycles	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Total
NH4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	3.10	3.10	5.92	11.63	18.61	22.25	1.41	2.58	4.86	1.91
Na	451.52	451.91	1344.84	2988.18	5223.72	6549.76	45.05	91.15	210.06	66.81
Mg	20.60	20.60	65.52	147.46	260.13	328.04	0.70	1.46	3.39	1.06
Ca	47.80	47.80	152.13	342.44	604.13	761.85	1.60	3.31	7.78	2.41
Sr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ba	0.07	0.07	0.21	0.47	0.83	1.05	0.00	0.00	0.01	0.00
CO3	1.45	1.45	18.50	55.37	118.84	163.18	0.01	0.01	0.04	0.01
HCO3	262.00	262.00	765.86	1679.88	2900.42	3614.38	21.69	44.12	102.42	32.30
NO3	99.90	99.90	224.23	465.14	774.04	943.57	33.69	64.83	133.06	47.60
Cl	525.00	525.00	1598.52	3568.24	6257.21	7859.07	40.57	83.62	200.65	61.28
F	0.99	0.99	2.99	6.65	11.65	14.62	0.09	0.18	0.42	0.13
SO4	144.00	144.00	460.35	1037.10	1830.74	2309.59	4.17	8.63	20.23	6.28
Boron	0.63	0.63	0.71	0.95	1.16	1.24	0.52	0.69	0.88	0.59
SiO2	30.10	30.10	94.67	212.63	374.54	471.85	1.38	2.80	6.63	2.06
CO2	5.99	5.99	5.54	12.75	25.27	34.20	7.33	15.80	26.81	10.62
TDS	1590.10	1590.50	4737.84	10520.65	18381.53	23046.29	153.35	306.62	694.57	225.22
pH	7.70	7.70	8.12	8.02	7.88	7.82	6.63	6.59	6.69	6.64

Reverse Osmosis System Analysis for FILMTEC™ Membranes
Project: Western Canal - Phase 2
Jenna Manuszak, Carollo Engineers

ROSA v6.0 ConfigDB 35240039
Case: 1
6/28/2005

Design Warnings

-None-

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
CaF2 (% Saturation) > 100%
SiO2 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Stage Details

Stage 1	Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
	1	0.12	1.21	76.85	10.28	4737.84	223.92
	2	0.12	1.07	96.32	9.07	5357.67	218.97
	3	0.12	0.94	121.82	8.00	6063.61	214.83
	4	0.11	0.81	155.71	7.06	6855.76	211.37
	5	0.11	0.68	201.13	6.25	7724.49	208.46
	6	0.10	0.56	262.41	5.56	8648.45	206.00
	7	0.09	0.46	344.88	5.00	9594.00	203.90
Stage 2	Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
	1	0.13	1.15	177.30	9.08	10520.65	292.08
	2	0.12	0.96	235.25	7.93	12022.05	287.94
	3	0.11	0.77	317.31	6.97	13635.52	284.51
	4	0.10	0.61	432.25	6.20	15290.25	281.62
	5	0.08	0.47	591.09	5.59	16898.98	279.15
Stage 3	Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
	1	0.06	0.31	463.98	5.13	18381.53	271.99
	2	0.05	0.25	578.09	4.82	19526.71	263.18
	3	0.05	0.21	723.11	4.56	20582.51	255.05
	4	0.04	0.17	906.92	4.35	21527.49	247.49
	5	0.03	0.13	1139.38	4.19	22349.71	240.37

Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	7.70	7.70	7.82
Langelier Saturation Index	0.17	0.17	2.57
Stiff & Davis Stability Index	0.43	0.43	1.79
Ionic Strength (Molal)	0.03	0.03	0.42
TDS (mg/l)	1590.10	1590.50	23046.29
HCO3	262.00	262.00	3614.38
CO2	5.99	5.99	34.19
CO3	1.45	1.45	163.18
CaSO4 (% Saturation)	1.28	1.28	49.05
BaSO4 (% Saturation)	297.05	296.95	4835.68
SrSO4 (% Saturation)	0.00	0.00	0.00
CaF2 (% Saturation)	6.23	6.23	21639.38
SiO2 (% Saturation)	24.08	24.08	385.84
Mg(OH)2 (% Saturation)	0.00	0.00	0.05

To balance: 0.39 mg/l Na added to feed.

Reverse Osmosis System Analysis for FILMTEC™ Membranes
Project: Western Canal - Phase 2
Jenna Manuszak, Carollo Engineers

ROSA v6.0 ConfigDB 35240039
Case: 2
6/28/2005

Project Information:

System Details

Feed Flow to Stage 1	20.34 gpm	Pass 1 Permeate Flow	16.51 gpm	Osmotic Pressure:	
Raw Water Flow to System	18.34 gpm	Pass 1 Recovery	90.00 %	Feed	14.94 psig
Feed Pressure	186.34 psig	Feed Temperature	25.0 C	Concentrate	130.42 psig
Fouling Factor	0.95	Feed TDS	1590.50 mg/l	Average	72.68 psig
Chem. Dose (100% H2SO4)	0.00 mg/l	Number of Elements	24	Average NDP	118.17 psig
Total Active Area	1698.00 ft2	Average Pass 1 Flux	14.00 gfd	Power	2.40 kW
Water Classification: Well Water SDI < 3				Specific Energy	2.43 kWh/kgal

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	BW30LE-4040	2	7	20.34	181.34	2.00	8.97	159.41	11.37	14.26	60.00	0.00	96.69
2	BW30LE-4040	1	5	8.97	224.41	0.00	5.07	209.40	3.90	13.70	65.00	70.00	196.89
3	LP-2540	1	5	5.07	204.40	0.00	3.83	167.84	1.24	12.74	0.00	0.00	396.88

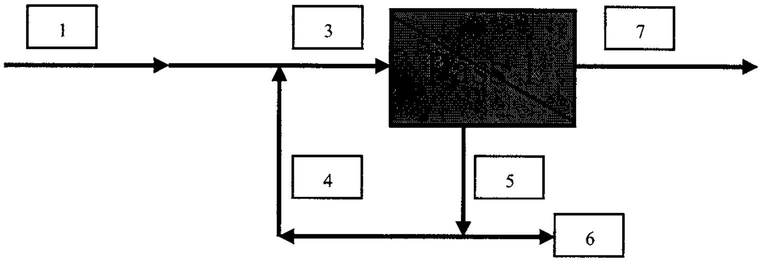
Pass Streams
(mg/l as Ion)

Name	Feed	Adjusted Feed		Concentrate			Permeate			
		Initial	After Recycles	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Total
NH4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	3.10	3.10	4.58	9.03	14.42	17.96	1.07	2.02	3.47	1.48
Na	451.52	451.91	817.37	1817.97	3171.67	4158.22	27.77	57.57	118.22	41.60
Mg	20.60	20.60	38.32	86.36	152.11	200.67	0.40	0.86	1.79	0.62
Ca	47.80	47.80	88.93	200.46	353.11	465.87	0.92	1.95	4.10	1.40
Sr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ba	0.07	0.07	0.12	0.28	0.49	0.64	0.00	0.00	0.01	0.00
CO3	1.45	1.45	5.75	21.07	48.82	73.10	0.00	0.01	0.02	0.00
HCO3	262.00	262.00	471.62	1036.83	1790.16	2333.29	12.93	26.99	56.11	19.49
NO3	99.90	99.90	159.83	332.39	552.10	702.42	23.65	46.68	86.82	33.83
Cl	525.00	525.00	959.72	2145.80	3757.19	4936.41	23.75	50.29	107.44	36.30
F	0.99	0.99	1.80	4.02	7.03	9.23	0.05	0.11	0.23	0.08
SO4	144.00	144.00	268.39	605.50	1067.23	1408.62	2.37	5.05	10.60	3.62
Boron	0.63	0.63	0.68	0.89	1.07	1.16	0.51	0.65	0.80	0.57
SiO2	30.10	30.10	55.71	125.27	220.32	290.37	0.83	1.66	3.51	1.22
CO2	5.99	5.99	5.71	10.00	16.88	22.57	6.83	11.79	18.23	8.85
TDS	1590.10	1590.50	2876.05	6390.07	11140.79	14603.46	96.69	196.89	396.88	142.88
pH	7.70	7.70	7.94	7.97	7.92	7.87	6.45	6.52	6.62	6.51

Project: Western Canal - Phase 2
Prepared By: Jenna Manuszak
Carollo Engineers

ROSA v6.0 ConfigDB 35240039
Case: 2
6/28/2005

System Design Overview



Raw Water TDS	1590.10 mg/l	% System Recovery (7/1)	90.00 %
Water Classification	Well Water SDI < 3	Fouling Factor (Pass 1)	0.95
Feed Temperature	25.0 C		

Pass #	**Pass 1**		
Stage #	**1**	**2**	**3**
Element Type	BW30LE-4040	BW30LE-4040	LP-2540
Pressure Vessels per Stage	2	1	1
Elements per Pressure Vessel	7	5	5
Total Number of Elements	14	5	5
Pass Average Flux	14.00 gfd		
Stage Average Flux	14.26 gfd	13.70 gfd	12.74 gfd
Permeate Back Pressure	60.00 psig	65.00 psig	0.00 psig
Booster Pressure	0.00 psig	70.00 psig	0.00 psig
Chemical Dose	-		
Energy Consumption	2.43 kWh/kgal		

Permeate Flux reported by ROSA is calculated based on ACTIVE membrane area.

Pass 1			
Stream #	**Flow (gpm)**	**Pressure (psig)**	**TDS (mg/l)**
1	18.34	0.00	1590.10
3	20.34	186.34	2876.05
4	2.00	167.84	14603.46
5	3.83	167.84	14603.46
6	1.83	167.84	14603.46
7	16.51	-	142.88
7/1	**% Recovery**	90.00	

Project Information:

Design Warnings:

-None-

Solubility Warnings:

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
CaF2 (% Saturation) > 100%
SiO2 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Design Warnings

-None-

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
CaF2 (% Saturation) > 100%
SiO2 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Stage Details

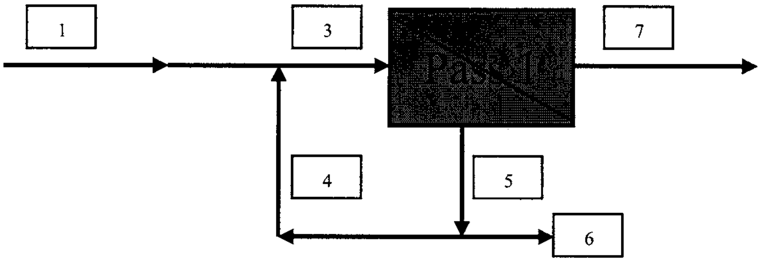
Stage 1	Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
	1	0.11	1.11	50.57	10.17	2876.05	181.34
	2	0.11	1.01	62.27	9.06	3221.61	176.45
	3	0.11	0.91	77.12	8.05	3616.25	172.30
	4	0.11	0.81	96.20	7.15	4065.05	168.79
	5	0.11	0.71	120.93	6.34	4570.86	165.83
	6	0.11	0.62	153.27	5.63	5132.80	163.33
	7	0.10	0.52	195.91	5.01	5743.98	161.21
Stage 2	Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
	1	0.12	1.05	121.81	8.97	6390.07	224.41
	2	0.12	0.91	155.06	7.92	7222.06	220.33
	3	0.11	0.77	199.57	7.01	8138.88	216.90
	4	0.10	0.64	259.60	6.24	9120.98	214.00
	5	0.09	0.52	340.38	5.59	10135.37	211.53
Stage 3	Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
	1	0.07	0.34	271.40	5.07	11140.79	204.40
	2	0.06	0.29	332.21	4.73	11923.92	195.80
	3	0.05	0.24	408.30	4.44	12678.33	187.98
	4	0.05	0.20	503.95	4.20	13386.04	180.78
	5	0.04	0.16	624.58	4.00	14031.49	174.11

Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	7.70	7.70	7.87
Langelier Saturation Index	0.17	0.17	2.23
Stiff & Davis Stability Index	0.43	0.43	1.63
Ionic Strength (Molal)	0.03	0.03	0.26
TDS (mg/l)	1590.10	1590.50	14603.46
HCO3	262.00	262.00	2333.29
CO2	5.99	5.99	22.56
CO3	1.45	1.45	73.10
CaSO4 (% Saturation)	1.28	1.28	27.23
BaSO4 (% Saturation)	297.05	296.95	2816.39
SrSO4 (% Saturation)	0.00	0.00	0.00
CaF2 (% Saturation)	6.23	6.23	5278.89
SiO2 (% Saturation)	24.08	24.08	229.71
Mg(OH)2 (% Saturation)	0.00	0.00	0.04

To balance: 0.39 mg/l Na added to feed.

System Design Overview



Raw Water TDS	1590.10 mg/l	% System Recovery (7/1)	85.00 %
Water Classification	Well Water SDI < 3	Fouling Factor (Pass 1)	0.95
Feed Temperature	25.0 C		

Pass #	**Pass 1**		
Stage #	**1**	**2**	**3**
Element Type	BW30LE-4040	BW30LE-4040	LP-2540
Pressure Vessels per Stage	2	1	1
Elements per Pressure Vessel	7	5	5
Total Number of Elements	14	5	5
Pass Average Flux	14.00 gfd		
Stage Average Flux	14.03 gfd	14.04 gfd	13.63 gfd
Permeate Back Pressure	50.00 psig	60.00 psig	0.00 psig
Booster Pressure	0.00 psig	65.00 psig	0.00 psig
Chemical Dose	-		
Energy Consumption	2.22 kWh/kgal		

Permeate Flux reported by ROSA is calculated based on ACTIVE membrane area. DISCLAIMER: NO WARRANTY, EXPRESSED OR IMPLIED,AND NO WARRANTY OF MERCHANTABILITY OR FITNESS, IS GIVEN. Neither FilmTec Corporation nor The Dow Chemical Company assume liability for results obtained or damages incurred from the application of this information. FilmTec Corporation and The Dow Chemical Company assume no liability, if, as a result of customer's use of the ROSA membrane design software, the customer should be sued for alleged infringement of any patent not owned or controlled by the FilmTec Corporation nor The Dow Chemical Company.

Reverse Osmosis System Analysis for FILMTEC™ Membranes
Project: Western Canal - Phase 2
Jenna Manuszak, Carollo Engineers

ROSA v6.0 ConfigDB 35240039
Case: 3
6/28/2005

Project Information:

System Details

Feed Flow to Stage 1	20.92 gpm	Pass 1 Permeate Flow	16.51 gpm	Osmotic Pressure:	
Raw Water Flow to System	19.42 gpm	Pass 1 Recovery	85.00 %	Feed	14.94 psig
Feed Pressure	163.40 psig	Feed Temperature	25.0 C	Concentrate	89.90 psig
Fouling Factor	0.95	Feed TDS	1590.50 mg/l	Average	52.42 psig
Chem. Dose (100% H2SO4)	0.00 mg/l	Number of Elements	24	Average NDP	108.87 psig
Total Active Area	1698.00 ft2	Average Pass 1 Flux	14.00 gfd	Power	2.20 kW
Water Classification: Well Water SDI < 3				Specific Energy	2.22 kWh/kgal

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	BW30LE-4040	2	7	20.92	158.40	1.50	9.74	134.77	11.19	14.03	50.00	0.00	73.07
2	BW30LE-4040	1	5	9.74	194.77	0.00	5.74	177.38	4.00	14.04	60.00	65.00	139.01
3	LP-2540	1	5	5.74	172.38	0.00	4.41	128.38	1.32	13.63	0.00	0.00	262.77

Pass Streams
(mg/l as Ion)

Name	Feed	Adjusted Feed		Concentrate			Permeate			
		Initial	After Recycles	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Total
NH4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	3.10	3.10	3.89	7.36	11.38	14.03	0.88	1.58	2.58	1.19
Na	451.52	451.91	624.01	1317.28	2207.09	2846.31	20.66	40.15	77.45	29.94
Mg	20.60	20.60	28.80	61.57	104.06	134.96	0.29	0.58	1.13	0.43
Ca	47.80	47.80	66.85	142.89	241.54	313.26	0.66	1.31	2.59	0.97
Sr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ba	0.07	0.07	0.09	0.20	0.33	0.43	0.00	0.00	0.00	0.00
CO3	1.45	1.45	3.01	11.40	26.25	39.06	0.00	0.00	0.01	0.00
HCO3	262.00	262.00	361.18	755.46	1255.05	1611.00	9.45	18.49	36.14	13.78
NO3	99.90	99.90	130.44	258.92	415.17	521.45	18.62	34.66	61.09	25.91
Cl	525.00	525.00	728.56	1545.87	2599.10	3358.66	17.26	34.18	68.54	25.47
F	0.99	0.99	1.37	2.90	4.88	6.30	0.04	0.07	0.14	0.05
SO4	144.00	144.00	201.54	431.15	729.19	946.05	1.70	3.39	6.68	2.51
Boron	0.63	0.63	0.66	0.84	1.00	1.08	0.50	0.61	0.73	0.55
SiO2	30.10	30.10	41.98	89.48	151.05	195.72	0.65	1.12	2.23	0.89
CO2	5.99	5.99	5.93	8.64	12.80	16.09	6.63	9.75	13.62	7.95
TDS	1590.10	1590.50	2195.50	4629.29	7750.81	9993.39	73.07	139.01	262.77	104.25
pH	7.70	7.70	7.82	7.92	7.92	7.90	6.34	6.44	6.57	6.41

Pass 1			
Stream #	**Flow (gpm)**	**Pressure (psig)**	**TDS (mg/l)**
1	19.42	0.00	1590.10
3	20.92	163.40	2195.50
4	1.50	128.38	9993.39
5	4.41	128.38	9993.39
6	2.91	128.38	9993.39
7	16.51	-	104.25
7/1	**% Recovery**	85.00	

Project Information:

Design Warnings:

-None-

Solubility Warnings:

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
CaF2 (% Saturation) > 100%
SiO2 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Reverse Osmosis System Analysis for FILMTEC™ Membranes
Project: Western Canal - Phase 2
Jenna Manuszak, Carollo Engineers

ROSA v6.0 ConfigDB 35240039
Case: 3
6/28/2005

Design Warnings

-None-

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
CaF2 (% Saturation) > 100%
SiO2 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Stage Details

Stage 1	Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
	1	0.10	1.06	39.90	10.46	2195.50	158.40
	2	0.10	0.97	48.50	9.40	2437.87	153.28
	3	0.10	0.88	59.20	8.44	2711.32	148.89
	4	0.11	0.79	72.58	7.56	3019.33	145.12
	5	0.11	0.71	89.45	6.76	3364.89	141.90
	6	0.10	0.63	110.85	6.05	3749.47	139.15
	7	0.10	0.55	138.20	5.42	4172.31	136.79
Stage 2	Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
	1	0.11	1.03	91.08	9.74	4629.29	194.77
	2	0.10	0.91	112.53	8.71	5162.82	190.16
	3	0.10	0.80	139.93	7.80	5750.00	186.21
	4	0.10	0.69	175.19	7.01	6385.54	182.82
	5	0.09	0.58	220.88	6.32	7058.26	179.91
Stage 3	Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
	1	0.06	0.36	183.25	5.74	7750.81	172.38
	2	0.06	0.31	221.49	5.38	8257.74	162.13
	3	0.05	0.26	269.10	5.07	8746.22	152.75
	4	0.05	0.22	329.14	4.81	9204.97	144.08
	5	0.04	0.18	405.90	4.59	9623.53	135.99

Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	7.70	7.70	7.90
Langelier Saturation Index	0.17	0.17	1.93
Stiff & Davis Stability Index	0.43	0.43	1.49
Ionic Strength (Molal)	0.03	0.03	0.18
TDS (mg/l)	1590.10	1590.50	9993.39
HCO3	262.00	262.00	1611.00
CO2	5.99	5.99	16.08
CO3	1.45	1.45	39.06
CaSO4 (% Saturation)	1.28	1.28	16.89
BaSO4 (% Saturation)	297.05	296.95	1855.32
SrSO4 (% Saturation)	0.00	0.00	0.00
CaF2 (% Saturation)	6.23	6.23	1651.93
SiO2 (% Saturation)	24.08	24.08	151.83
Mg(OH)2 (% Saturation)	0.00	0.00	0.03

To balance: 0.39 mg/l Na added to feed.

Appendix E
Raw Water Quality - Phase 1

Table E.1 Raw Water Quality of the Western Canal - Phoenix Area Membrane Pilot Study - Phase 1

Parameter	Units	Minimum	Maximum	Average	MCL/NL
Temperature	ºC	11.4	24.5	15	
pH	S.U.	7.13	8.72	8.2	
Alkalinity	mg/L as $CaCO_3$	112	257	197.8	
Ammonia*	mg/L			0.2	
Arsenic - total	µg/L	3.6	8.1	5.6	10
Atrazine*	µg/L			0.05	1
Barium - total	mg/L	0.05	0.09	0.068	1
Bentazon*	µg/L			0.5	18
Benzene*	µg/L			0.5	
Benzo(a)pyrene*	µg/L			0.02	0.2
Boron - total	mg/L	0.1	0.7	0.4	1
Bromodichloromethane*	µg/L			0.5	5
Bromoform*	µg/L			0.5	
Calcium - total	mg/L	37	95	63	
Carbofuran (Furadan)*	µg/L			1	
Carbon tetrachloride*	µg/L			0.5	0.5
Chlordane*	µg/L			0.1	
Chloride	mg/L	43	426	264.3	250
Chloroform	µg/L	0.5	2	0.8	
Dalapon*	µg/L			1	200
Di-(2-Ethylhexyl)adipate*	µg/L			0.6	400
Di(2-Ethylhexyl)phthalate*	µg/L			0.6	4
Dibromochloromethane*	µg/L			0.5	5
Dibromochloropropane (DBCP)*	µg/L			0.01	0.2
Dicamba*	µg/L			0.08	
Dichlorprop*	µg/L			0.5	
Dieldrin*	µg/L			0.01	0.002
Dinoseb*	µg/L			0.2	7
Diquat*	µg/L			0.4	20
Dissolved organic carbon	mg/L	0.6	6.73	2.4	
Endothall*	µg/L			5	100
Endrin	µg/L	0.01	0.1	0.055	2
Ethylene Dibromide (EDB)*	µg/L			0.01	
Fluoride	mg/L	0.21	0.81	0.38	
Glyphosate*	µg/L			5	700
Heptachlor	µg/L	0.01	0.04	0.025	0.01
Heptachlor epoxide	µg/L	0.01	0.02	0.015	0.01
Heptachlor epoxide (isomer B)*	µg/L			0.02	0.01
Hexachlorobenzene*	µg/L			0.05	1
Hexachlorocyclopentadiene*	µg/L			0.05	50
Iron - dissolved	mg/L	0.02	0.12	0.0325	
Iron – total	mg/L	0.1	2.6	0.63	0.3
Lindane*	µg/L			0.02	0.2
Lindane (gamma-BHC)*	µg/L			0.01	

Table E.1 Raw Water Quality of the Western Canal - Phoenix Area Membrane Pilot Study - Phase 1

Parameter	Units	Minimum	Maximum	Average	MCL/NL
Magnesium - total	mg/L	13	39	28	
Manganese - total	mg/L	0.01	0.06	0.024	0.05
Mercury - total*	mg/L			0.0002	0.002
Methiocarb*	µg/L			0.5	
Methoxychlor	µg/L	0.05	0.1	0.075	30
Nitrate-N	mg/L	0.3	9.8	3.82	45 (as NO_3)
Nitrite-N*	mg/L			0.1	1
Oxamyl (Vydate) *	µg/L			0.5	1
Paraquat*	µg/L			2	
PCB 1016 Arochlor*	µg/L			0.07	
PCB 1221 Arochlor*	µg/L			0.1	
PCB 1232 Arochlor*	µg/L			0.1	
PCB 1242 Arochlor*	µg/L			0.1	
PCB 1248 Arochlor*	µg/L			0.1	
PCB 1254 Arochlor*	µg/L			0.1	
PCB 1260 Arochlor*	µg/L			0.1	
Pentachlorophenol*	µg/L			0.04	1
Picloram*	µg/L			0.1	500
Potassium - total	mg/L	2.6	7.3	5.30	
Propoxur (Baygon)*	µg/L			1	30
Selenium - total	mg/L	0.005	2	1.00	50
Silica – total	mg/L as SiO_2	10.9	32.1	21.54	
Silicon - total	mg/L	5.1	15	10.1	
Simazine*	µg/L			0.05	4
Sodium - total	mg/L	44	347	195	
Strontium - total	mg/L	0.39	2.2	0.96	
Sulfate	mg/L	29	168	111	250
Total DCPA mono- and di-acid degradates*	µg/L			1	
Total dissolved solids	mg/L	288	1,250	817	500
Total organic carbon	mg/L	0.8	7.48	2.78	
Total PCBs*	µg/L			0.07	0.5
Total TTHM	µg/L	0.5	2	0.8	100
Toxaphene*	µg/L			0.5	3
Trichloroethylene*	µg/L			0.5	5
Turbidity*	NTU			51.3	5
UV254	cm^{-1}	0.01	0.179	0.089	

* Sampled and analyzed one time only
MCL = Maximum Contaminant Level (NL = Notification Level)

Appendix F
UF Permeate Water Quality - Phase 1

Table F.1 UF Permeate Water Quality Western Canal Water - Phoenix Area Membrane Pilot Study – Phase 1

Parameter	Units	Minimum	Maximum	Average	MCL/NL
Temperature	ºC	9.4	27.5	15	
pH	SU	7.13	8.72	8.2	
1,1,1-Trichloroethane*	µg/L			0.5	200
1,1-Dichloroethylene*	µg/L			0.5	6
1,2-Dichloroethane*	µg/L			0.5	0.5
1,4-Dichlorobenzene*	µg/L			0.5	5
2,3,7,8-Tcdd 1613 drinking water*	µg/L			5	
2,4,5-T*	µg/L			0.2	
2,4,5-TP (Silvex)*	µg/L			0.2	50
2,4-D*	µg/L			0.1	100
2,4-DB*	µg/L			2	
3,5-Dichlorobenzoic acid*	µg/L			0.5	
1,1,1-Trichloroethane*	µg/L			0.5	200
1,1-Dichloroethylene*	µg/L			0.5	6
1,2-Dichloroethane*	µg/L			0.5	0.5
1,4-Dichlorobenzene*	µg/L			0.5	5
Acifluorfen*	µg/L			0.2	
Alachlor (alanex)*	µg/L			0.05	2
Alacor*	µg/L			0.05	
Aldrin*	µg/L			0.01	0.002
Alkalinity	mg/L as $CaCO_3$	110	255	198.6	
Atrazine*	µg/L			0.05	1
Bentazon*	µg/L			0.5	18
Benzene*	µg/L			0.5	
Benzo(a)pyrene*	µg/L			0.02	0.2
Bromodichloromethane*	µg/L			0.5	5
Bromoform*	µg/L			0.5	
Carbofuran (Furadan)*	µg/L			1	
Carbon tetrachloride*	µg/L			0.5	0.5
Chlordane*	µg/L			0.1	
Chloroform	µg/L	0.5	3.6	1.33	
Dalapon*	µg/L			1	200
Di-(2-Ethylhexyl)adipate*	µg/L			0.6	400
Di(2-Ethylhexyl)phthalate*	µg/L			0.6	4
Dibromochloromethane*	µg/L			0.5	5
Dibromochloropropane* (DBCP)*	µg/L			0.01	0.2
Dicamba*	µg/L			0.08	
Dichlorprop*	µg/L			0.5	
Dieldrin*	µg/L			0.01	0.002
Dinoseb*	µg/L			0.2	7
Diquat*	µg/L			0.4	20
Endothall*	µg/L			5	100

Table F.1 UF Permeate Water Quality Western Canal Water - Phoenix Area Membrane Pilot Study – Phase 1

Parameter	Units	Minimum	Maximum	Average	MCL/NL
Endrin	µg/L	0.01	0.1	0.06	2
Ethylene Dibromide (EDB)*	µg/L			0.01	
Glyphosate*	µg/L			5	700
Heptachlor	µg/L	0.01	0.04	0.025	0.01
Heptachlor epoxide	µg/L	0.01	0.02	0.015	0.01
Heptachlor epoxide (isomer B)*	µg/L			0.02	0.01
Hexachlorobenzene*	µg/L			0.05	1
Hexachlorocyclopentadiene*	µg/L			0.05	50
Lindane*	µg/L			0.02	0.2
Lindane (gamma-BHC)*	µg/L			0.01	
Methiocarb*	µg/L			0.5	
Methoxychlor	µg/L	0.05	0.1	0.08	30
Oxamyl (Vydate)*	µg/L			0.5	1
Paraquat*	µg/L			2	
PCB 1016 Arochlor*	µg/L			0.07	
PCB 1221 Arochlor*	µg/L			0.1	
PCB 1232 Arochlor*	µg/L			0.1	
PCB 1242 Arochlor*	µg/L			0.1	
PCB 1248 Arochlor*	µg/L			0.1	
PCB 1254 Arochlor*	µg/L			0.1	
PCB 1260 Arochlor*	µg/L			0.1	
Pentachlorophenol*	µg/L			0.04	1
Picloram*	µg/L			0.1	500
Propoxur (Baygon)*	µg/L			1	30
Simazine*	µg/L			0.05	4
Total DCPA mono- and di-acid degradates*	µg/L			1	
Total dissolved solids	mg/L	882	1,260	1,095	500
Total organic carbon	mg/L	0.7	6.23	2.4	
Total PCBs*	µg/L			0.07	0.5
Total TTHM	µg/L	0.5	3.6	1.33	
Toxaphene*	µg/L			0.5	3
Trichloroethylene*	µg/L			0.5	5
Vinyl chloride*	µg/L			0.5	0.5

* Sampled and analyzed one time only
MCL = Maximum Contaminant Level (NL = Notification Level)

Appendix G
Membrane Autopsy

May 3, 2006

FilmTec Corporation
5230 West 73rd Street
Edina MN55439
USA

DIRECTOR* Services
Membrane Test Report

Carollo Engineers
Western Canal Pilot Study

RA # 106060DS

Membrane Sample Background

Three FILMTEC™ LP-2540 elements were received at our Minneapolis, MN site on April 7, 2006 under Return Authorization # 106060DS. The element's serial numbers were A9908201, A9908247, and unknown serial number. The elements originally shipped from FilmTec on July 19, 2004.

The purpose of the element return was to determine an effective cleaning protocol to remove the foulant from the membrane surface and to identify the cause of the performance decline.

Summary Of Tests Performed:

The following tests were performed on the returned element:

- **Physical Inspection of Element:**

A non-destructive test for an observation of physical integrity of the element and visual identification of potential foulants.

All elements are visually inspected noting any differences from new product.
(Examples would be: cracked endcaps, discolored scrolls, fiberglass discoloration, etc.)

- **Performance Testing:**

Determination of element operating performance, with a comparison to typical properties and original production test data (when available, not applicable to dry product). This is also a non-destructive test, used to determine how the element is performing at standard test conditions.

- **Cleaning Recommendations:**

Evaluation of the visual inspection as well as the performance test indicates to the technician what type of cleaning is likely to be most effective. If the first cleaning is unsuccessful, further cleanings can be instituted using different chemicals to improve performance. A performance test should be run after each cleaning to evaluate the degree of success.

- **Element Autopsy:**

A destructive test, the element is cut lengthwise to allow the membrane to be unrolled. Two cuts must be made, on opposite sides, just deep enough to penetrate the element casing. The element should be unrolled carefully so as to not damage the membrane surface. The surface is fully examined and sprayed with cleaning chemicals to check for reaction.

- **Analytical Testing:**

Inorganic, such as Inductively Coupled Plasma Emission Spectroscopy (ICP) to help in determining specific metals on the membrane surface, as well as silica.

Physical Inspection of Element:

The elements were received in Minneapolis on April 7, 2006. They were inspected on arrival.

Unknown S/N (tail element):
- Tape wrinkled and came loose near feed end (photo 1)
- The end cap and permeate tube on concentrate end are dirty (photo 2).

S/N A9908247 (lead element):
- Tape wrinkled and came loose near feed end (photo 3)
- Damaged end cap on feed end (photo 4)

S/N A9908201 (tail element):
- Tape and label came loose (photo 5)
- Tape wrinkled near feed end

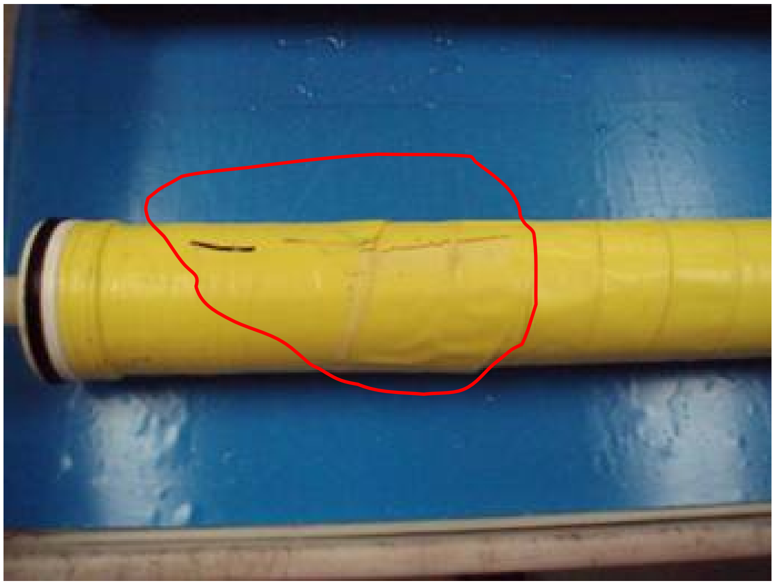


Photo 1: tape wrinkled and came loose

Photo 2: end cap and permeate tube on concentrate end are dirty

Photo 3: tape wrinkled and came loose

Photo 4: damaged end cap on feed end

Photo 5: tape and label came loose

Performance Testing:

The elements were subjected to the FilmTec brackish water baseline test. This test uses a 2,000-ppm NaCl solution at 77° F with an applied pressure of 150 psi.

The test results are reported below:

Serial #	Date shipped	Production / normal element			Return element		
		Flow (GPD)	Rejection (%)	Delta P (psig)	Flow (GPD)	Rejection (%)	Delta P (psig)
Unknown	NA	NA	NA	NA	479	99.1	NA
A9908201	7/19/2004	843	98.7	NA	393	98.4	NA
A9908247	7/19/2004	805	98.1	NA	525	97.5	NA

The test results indicate that rejection has declined and flow has decreased in comparison to the FilmTec production quality control test data.

Cleaning Recommendations:

S/N A9908247:
In an attempt to improve performance, the element was put through a standard cleaning cycle. The detail cleaning and the effectiveness are shown on table below:

Serial No. A9908247	**Before**			**After**				
Cleaning	**Flow (gpd)**	**Salt Rej. (%)**	**Δ P psi**	**Flow (gpd)**	**Salt Rej. (%)**	**Δ P psi**	**Delta Flow (%)**	**Cleaned Solution**
1. 0.1% (w) NaOH, pH12, 35ºC for 1 hour	525	97.5	NA	577	97.7	NA	9.9%	Clear
2. 0.1% (w) NaOH, pH12, 35ºC, SLS, 1% (w) NaEDTA for 1 hour	577	97.7	NA	622	97.4	NA	7.8%	Clear

Autopsy Summary:

S/N A9908201:
The outer tape wrap was removed from the element and the brine channel spacer and membrane surfaces were inspected.

- The membrane surface was coated with rusted color foulant and it feels gritty to the touch (photo 6).
- Pressure ridges and cracks along the inside bottom glue line (top leaf) on every membrane leaf (photo 7).
- Brine feed spacer imprinted on membrane surface (photo 7).

- Both acid and caustic were applied to the foulant in order to determine whether it could be removed. The acid turned yellow indicating the presence of iron. Both acid and caustic appeared to remove some foulant from a visual perspective.
- Glue adhesion of the membrane was in good order, indicating that no leaks had occurred between membrane edges.

Photo 6: rusted color foulant covers on membrane surface

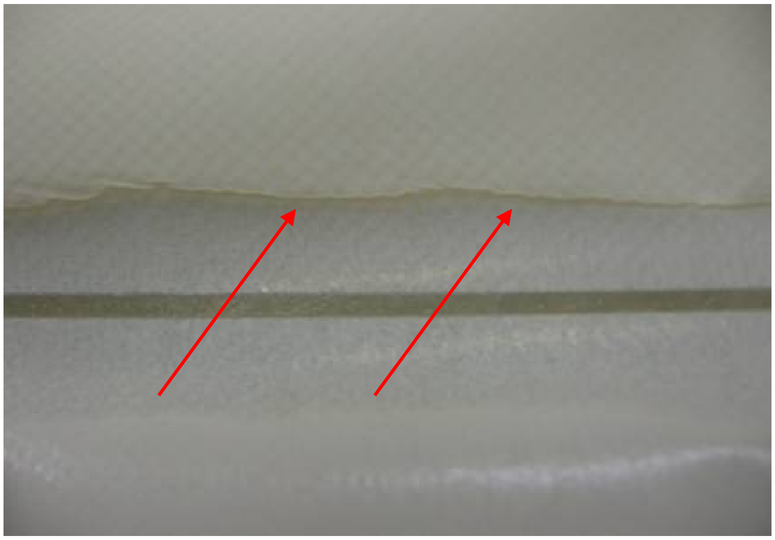


Photo 7: pressure ridges and cracks along inside the bottom glue line

Analytical Testing:

ICP:
Testing was done on the surface of the membrane to detect what types of metals, as well as the amount of organics present.

Element A9908201 (tail element) was analyzed for metals by ICP (Inductive Coupled Plasma Emission Spectroscopy).

**All metals reported in mg/m^2

Al	Ba	Ca	Cu	Fe	Mg	Mn	Ni	P	K	Na	Sr	Zn	Si
30.7	0.48	158.9	0.17	78.12	11.76	2.26	0.05	1.46	2.90	73.30	1.30	2.93	1095

Conclusions:

Based on the test results:
S/N unknown: the permeate flow decreased 44% in comparison to a typical element.
S/N A9908021: the permeate flow decreased 53% and the salt rejection decreased from 98.7% to 98.4% in comparison to FilmTec quality control test data.
S/N A9908247: the permeate flow decreased 35% and salt rejection decreased from 98.1% to 97.5% in comparison to FilmTec quality control test data.

The outer tape wrap wrinkles and the brine feed spacer imprints on the membrane surface are the indication for high pressure operation. High pressure operation will result in a mechanical damage of the membrane: low flow and subsequently salt passage will be worse if operating at high feed pressure continued.

The ICP analysis of element S/N A9908201 (tail element) indicates very high concentration of silica followed by calcium, iron, and aluminum.

Alkaline cleanings indicate some improvement in flow and salt rejection. The membrane is severely fouled and the performance decline may be irreversible.

Recommendations:

The pilot RO system information is not available from the customer and therefore, it is not possible to identify the source of silica and metals. However, the common source of the silica and metals are in the feed water. It is recommended to check and optimize the pre-treatment system and piping prior to membrane RO unit to prevent fouling the membrane.

The majority of the fouling is thought to be related to high recovery operation. Careful control of sparingly soluble salts is necessary for successful high recovery operation of membrane systems.